Texte zu den geplanten neuen EU-Regelungen zur umweltgerechten Produktgestaltung und zur Energieverbrauchskennzeichnung in der Beleuchtung – Zusammenstellung [1] des Umweltbundesamtes (UBA), Deutschland

Studien der EU-Kommission

Anträge auf Erneuerung verschiedener Ausnahmeregelungen nach Richtlinie 2011/65/EU [2]:

Studie, erstellt durch Öko-Institut e.V. [3] und Fraunhofer-Institut IZM [3], 6. Juni 2016

Hinweis: Bitte beachten Sie, daß der angehängte Text nur in Englisch verfaßt ist.

EN: Information on the coming EU Lighting Regulations – Ecodesign and Energy Labelling – Compilation [1] of the Federal Environment Agency (UBA), Germany

Studies of the EU Commission

Requests for renewal of various exemptions under Directive 2011/65/EU [2]

– Study, prepared by Oeko-Institut e.V. [3] and Fraunhofer-Institut IZM [3], 6. June 2016 –

FR: Informations sur les futures réglementations de l'UE concernant l'éclairage – l'écoconception et l'étiquetage énergétique – Compilation [1] de l'Agence Fédérale de l'Environnement (UBA), Allemagne

Études de la Commission européenne

Demandes de renouvellement pour diverses exemptions pertinentes accordées par la directive 2011/65/UE [2]

– Ètude préparée par l'Oeko-Institut [3] et l'Institut Fraunhofer IZM [3], 6 juin 2016 –

Indication : Veuillez noter que le présent texte n'est disponible qu'en anglais.

[1] https://www.eup-network.de/de/eup-netzwerk-deutschland/offenes-forum-eu-regelungen-beleuchtung/dokumente/texte/

[2] https://www.eup-network.de/fileadmin/user_upload/lichtquellen_RL_2011_65_DE.pdf; *EN.pdf; …

[3] https://www.oeko.de/; https://www.fraunhofer.de/

DE: ↓ **EN:** → page III **FR :** → page IV

Texte im Offenen Forum (**abc** = vorliegender Text)

- **Bestehende EG- und EU-Regelungen**
- **Studien der EU-Kommission**
  - Produktgestaltung und -information
  - **Verwendung gefährlicher Stoffe (2011/65/EU (RoHS))**
    - **Anträge auf Erneuerung verschiedener Ausnahmeregelungen – Studie 6. Juni 2016**
    - Anträge auf Erneuerung verschiedener Ausnahmeregelungen – Studie 29. Juli 2019
- **Regelungsentwürfe**
- **Öffentliche Konsultationen auf EU-Ebene**
- **Diskussion im Offenen Forum**
- **Weitere Dokumente**

Abkürzungen: ● EG = Europäische Gemeinschaft ● EU = Europäische Union ● RoHS = Restriction of hazardous substances in electrical and electronic equipments (Beschränkung gefährlicher Stoffe in elektrischen und elektronischen Geräten)

EN

Documents in the Open Forum

(**abc** = text at hand)

- **Existing EC and EU Regulations**
- **Studies of the European Commission**
  - Product design and information
  - **Use of hazardous substances (2011/65/EU (RoHS))**
    - **Requests for renewal of various exemptions – Study 6 June 2016**
    - Requests for renewal of various exemptions – Study 29 July 2019
- **Draft regulations**
- **Public Consultations at EU level**
- **Discussion in the Open Forum**
- **Further documents**

Abbreviations: ● EC = European Communities ● EU = European Union ● RoHS = Restriction of hazardous substances in electrical and electronic equipments

FR

Documents dans le forum ouvert (**abc** = présent document)

- **Règlements existants de la CE et de l’EU**
- **Études de la Commission européenne**
  - Conception des produits et information relative au produit
  - **L’utilisation de substances dangereuses (2011/65/UE (LdSD))**
    - **Demandes de renouvellement pour diverses exemptions – Étude 6 juin 2016**
    - Demandes de renouvellement pour diverses exemptions – Étude 29 juillet 2019
- **Projets de règlements**
- **Consultations publiques au niveau de l'UE**
- **Discussion dans le Forum Ouvert**
- **Autres documents**

Abréviations : ● CE = Communauté européenne ● LdSD = Limitation de l'utilisation de certaines substances dangereuses dans les équipements électriques et électroniques ● UE = Union européenne

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Es folgt ein unveränderter Originaltext.

EN: The following is an unmodified original text.

FR: Ce qui suit est un texte original.

Assistance to the Commission on Technologica Socio-Economic and Cost-Benefit Assessment Related to Exemptions from the Substance Restrictions in Electrical and Electronic Equipment:

Study to assess renewal requests for 29 RoHS 2 Annex III exemptions [no. l(a to e -lighting purpose), no. l(f - special purpose), no. 2(a), no. 2(b)(3), no. 2(b)(4), no. 3, no. 4(a), no. 4(b), no. 4(c), no. 4(e), no. 4(f), no. 5(b), no. 6(a), no. 6(b), no. 6(c), no. 7(a), no. 7(c) - I, no. 7(c) - II, no. 7(c) - IV, no. 8(b), no. 9, no. 15, no. 18b, no. 21, no. 24, no. 29, no. 32, no. 34, no. 37]

Final report

June 2016

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Assistance to the Commission on Technological Socio-Economic and Cost-Benefit Assessment Related to Exemptions from the Substance Restrictions in Electrical and Electronic Equipment:

Study to assess renewal requests for 29 RoHS 2 Annex III exemptions [no. I(a to e -lighting purpose), no. I(f - special purpose), no. 2(a), no. 2(b)(3), no. 2(b)(4), no. 3, no. 4(a), no. 4(b), no. 4(c), no. 4(e), no. 4(f), no. 5(b), no. 6(a), no. 6(b), no. 6(c), no. 7(a), no. 7(c) - I, no. 7(c) - II, no. 7(c) - IV, no. 8(b), no. 9, no. 15, no. 18b, no. 21, no. 24, no. 29, no. 32, no. 34, no. 37]

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07 June 2016

Report for The European Commission

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Executive Summary

Under Framework Contract no. ENV.C.2/FRA/2011/0020, a consortium led by Eunomia Research & Consulting was requested by DG Environment of the European Commission to provide technical and scientific support for the evaluation of exemption requests under the new RoHS 2 regime. The work has been undertaken by Oeko-Institut and Fraunhofer Institute IZM, and has been peer reviewed by Eunomia Research & Consulting.

E.1.0 Background and Objectives

The RoHS Directive 2011/65/EU entered into force on 21 July 2011 and led to the repeal of Directive 2002/95/EC on 3 January 2013. The Directive can be considered to have provided for two regimes under which exemptions could be considered, RoHS 1 (the former Directive 2002/95/EC) and RoHS 2 (the current Directive 2011/65/EU).

- The scope covered by the Directive is now broader as it covers all EEE (as referred to in Articles 2(1) and 3(1));
- The former list of exemptions has been transformed in to Annex III and may be valid for all product categories according to the limitations listed in Article 5(2) of the Directive. Annex IV has been added and lists exemptions specific to categories 8 and 9;
- The RoHS 2 Directive includes the provision that applications for exemptions have to be made in accordance with Annex V. However, even if a number of points are already listed therein, Article 5(8) provides that a harmonised format, as well as comprehensive guidance – taking the situation of SMEs into account – shall be adopted by the Commission; and
- The procedure and criteria for the adaptation to scientific and technical progress have changed and now include some additional conditions and points to be considered. These are detailed below.

The new Directive details the various criteria for the adaptation of its Annexes to scientific and technical progress. Article 5(1)(a) details the various criteria and issues that must be considered for justifying the addition of an exemption to Annexes III and IV:

- The first criterion may be seen as a threshold criterion and cross-refers to the REACH Regulation (1907/2006/EC). An exemption may only be granted if it does not weaken the environmental and health protection afforded by REACH;
- Furthermore, a request for exemption must be found justifiable according to one of the following three conditions:

- Substitution is scientifically or technically impracticable, meaning that a substitute material, or a substitute for the application in which the restricted substance is used, is yet to be discovered, developed and, in some cases, approved for use in the specific application;
- The reliability of a substitute is not ensured, meaning that the probability that EEE using the substitute will perform the required function without failure for a period of time comparable to that of the application in which the original substance is included, is lower than for the application itself;
- The negative environmental, health and consumer safety impacts of substitution outweigh the benefits thereof.

- Once one of these conditions is fulfilled, the evaluation of exemptions, including an assessment of the duration needed, shall consider the availability of substitutes and the socio-economic impact of substitution, as well as adverse impacts on innovation, and life cycle analysis concerning the overall impacts of the exemption; and
- A new aspect is that all exemptions now need to have an expiry date and that they can only be renewed upon submission of a new application.

The current study presented here, evaluates a total of 29 exemption renewal requests for existing exemptions approaching their expiry date.

E.2.0 Key Findings – Overview of the Evaluation Results

The exemption requests covered in this project and the applicants concerned, as well as the final recommendations and proposed expiry dates are summarised in Table 1-1. The reader is referred to the corresponding section of this report for more details on the evaluation results.

The – not legally binding – recommendations for the requests for the renewal of exemptions (29 RoHS 2 Annex III exemptions: no. I(a to e - lighting purpose), no. I(f - special purpose), no. 2(a), no. 2(b)(3), no. 2(b)(4), no. 3, no. 4(a), no. 4(b), no. 4(c), no. 4(e), no. 4(f), no. 5(b), no. 6(a), no. 6(b), no. 6(c), no. 7(a), no. 7(c) - I, no. 7(c) - II, no. 7(c) - IV, no. 8(b), no. 9, no. 15, no. 18b, no. 21, no. 24, no. 29, no. 32, no. 34, no. 37) were submitted to the EU Commission by Oeko-Institut and have already been published at the EU CIRCA website on 27 June 2016. So far, the Commission has not adopted any revision of the Annex to Directive 2011/65/EU based on these recommendations.

Table 1-1: Overview of the exemption requests, associated recommendations and expiry dates

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n. 1	Mercury in single-capped (compact) fluorescent lamps not exceeding (per burner):			Mercury in single-capped (compact) fluorescent lamps not exceeding (per burner)		
a to e (lighting)		1(a) For general lighting purposes < 30 W: 5 mg 1(b) For general lighting purposes ≥ 30 W and < 50 W: 5 mg 1(c) For general lighting purposes ≥ 50 W and < 150 W: 5 mg 1(d) For general lighting purposes ≥ 150 W: 15 mg 1(e) For general lighting purposes with circular or square structural shape and tube diameter ≤ 17 mm: 7 mg	NARVA Lichtquellen GmbH + Co. KG LightingEurope	(a) For general lighting purposes < 30 W: 2.5 mg (b) For general lighting purposes ≥ 30 W and < 50 W: 3.5 mg	For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. industrial: 21 July 2024	The maximum transition period should be granted to other categories (18 months); The COM should consider adopting measures to limit product availability to B2B transactions.
				(c) For general lighting purposes ≥ 50 W and < 150 W: 5 mg (d) For general lighting purposes ≥ 150 W: 15 mg	For Cat. 5: 21 July 2019; For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
				(e) For general lighting purposes with circular or square structural shape and tube diameter ≤ 17 mm	7 mg may be used per burner until 31.12.2019, 5 mg may be used per burner after 31.12.2019 For Cat. 5: 21 July 2019 For Cat. 8 and Cat. 9: 21 July 2021 For Sub-Cat. 8 in-vitro: 21 July 2023 For Sub-Cat. 9 industrial: 21 July 2024	
f (special purpose)		1(f) For special purposes: 5 mg	NARVA Lichtquellen GmbH + Co. KG LightingEurope	**Mercury in single-capped (compact) fluorescent lamps not exceeding (per burner)**		
				(f)-I For lamps designed to emit light in the ultra-violet spectrum: 5 mg	For Cat. 5: 21 July 2021	The maximum transition period should be granted for other applications and other categories (18 months); Integrating this entry into a UV lamp exemption should be considered.

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
				(f)-II For special purposes: 5 mg	For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	The COM should consider adopting measures to limit product availability to B2B transactions.
n. 2 (a)	Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp):		NARVA Lichtquellen GmbH + Co. KG LightingEurope	**Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp)**		
(1-5)		(1) Tri-band phosphor with normal lifetime and a tube diameter < 9 mm (e.g. T2): 5 mg		1) Tri-band phosphor with normal lifetime and a tube diameter < 9 mm (e.g. T2): 4 mg	For Cat. 5, 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
		(2) Tri-band phosphor with normal lifetime and a tube diameter ≥ 9 mm and ≤ 17 mm (e.g. T5): 5 mg (3) Tri-band phosphor with normal lifetime and a tube diameter > 17 mm and ≤ 28 mm (e.g. T8): 5 mg (4) Tri-band phosphor with normal lifetime		(2) Tri-band phosphor with normal lifetime and a tube diameter ≥ 9 mm and ≤ 17 mm (e.g. T5): 3 mg (3) Tri-band phosphor with normal lifetime and a tube diameter > 17 mm and ≤ 28 mm (e.g. T8): 3.5 mg (4) Tri-band phosphor with normal lifetime and a tube diameter > 28 mm (e.g. T12): 3.5 mg	For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	The maximum transition period should be granted for other applications and other categories (18 months);

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
		and a tube diameter > 28 mm (e.g. T12): 5 mg (5) Tri-band phosphor with long lifetime (≥ 25 000 h): 8 mg		(5) Tri-band phosphor with long lifetime (≥ 25 000 h): 5 mg	For Cat. 5, 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n. 2 (b) (3)		(3) Non-linear tri-band phosphor lamps with tube diameter > 15 mm (e.g. T9)	NARVA Lichtquellen GmbH + Co. KG LightingEurope	2(b) Mercury in other fluorescent lamps not exceeding (per lamp) (3) Non-linear tri-band phosphor lamps with tube diameter > 17 mm (e.g. T9)	For Cat. 5: 21 July 2019; For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n. 2 (b) (4)		(4) Lamps for other general lighting and special purposes (e.g. induction lamps): 15 mg per lamp	LightingEurope	(I) Lamps for other general lighting and special purposes (e.g. induction lamps); 15 mg may be used per lamp after 31 December 2011	For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
				(II) Lamps emitting light in the non-visible spectrum: 15 mg per lamp	For Cat. 5: 21 July 2021	Integrating this entry into a UV lamp exemption should be considered.
				(III) Emergency lamps: 15 mg per lamp	For Cat. 5: 21 July 2021	
				(IV) Mercury in other fluorescent special purpose lamps not specifically mentioned in this Annex: 15mg per lamp	For Cat. 5: 21 January 2019	
n.3	Mercury in cold cathode fluorescent lamps and external electrode fluorescent lamps (CCFL and EEFL) for special purposes not exceeding (per lamp):		LightingEurope	Mercury in cold cathode fluorescent lamps and external electrode fluorescent lamps (CCFL and EEFL) for special purposes not exceeding (per lamp):		
		(a) Short length (≤ 500 mm): 3.5 mg per lamp (b) Medium length (> 500 mm and ≤ 1 500 mm): 5 mg per lamp (c) Long length (> 1 500 mm): 13 mg per lamp		(a) Short length (≤ 500 mm), 3,5 mg may be used per lamp; (b) Medium length (> 500 mm and ≤ 1 500 mm), 5 mg may be used per lamp; (c) Long length (> 1 500 mm) 13 mg may be used per lamp	For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
				(d) Short length (≤ 500 mm), 3,5 mg may be used per lamp in EEE placed on the market before 22 July 2016* (e) Medium length (> 500 mm and ≤ 1 500 mm), 5 mg may be used per lamp in EEE placed on the market before 22 July 2016* (f) Long length (> 1 500 mm) 13 mg may be used per lamp in EEE placed on the market before 22 July 2016*	For Cat. 5: 21 July 2021	*Or before the EC's decision date on this exemptions renewal
				(g) For back-lighting liquid crystal displays, not exceeding 5 mg per lamp, used in industrial monitoring and control instruments placed on the market before 22 July 2017	Alternative a: For Cat. 5: 21 July 2021; or Alternative b: For Sub-Cat. industrial: 21 July 2024	To be considered should Ex. 35 of Annex IV be transferred to Annex III
n.4 (a)	Mercury in other low pressure discharge lamps (per lamp): 15 mg per lamp		NARVA Lichtquellen GmbH + Co. KG LightingEurope	4(a)-I: Mercury in low pressure non-phosphor coated discharge lamps, where the application requires the main range of the lamp-spectral output to be in the UV spectrum; up to 15 mg mercury may be used per lamp.	For Cat. 5: 21 July 2021	The maximum transition period should be granted for other applications and other categories (18 months);

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
				4(a)-II: Mercury in other low pressure discharge lamps (15 mg may be used per lamp)	For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n.4 (b)	Mercury in High Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner) in lamps with improved colour rendering index Ra > 60:		LightingEurope	Mercury in High Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner) in lamps with improved colour rendering index Ra > 60:		
		I) P ≤ 155 W: 30 mg per burner II) 155 W < P ≤ 405 W: 40 mg per burner III) P > 405 W: 40 mg per burner		(I) P ≤ 155 W; 30 mg may be used per burner (II) 155 W < P ≤ 405 W; 40 mg may be used per burner	For Cat. 5, 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. industrial: 21 July 2024	
				(III) P > 405 W; 40 mg may be used per burner	For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	It is understood that these lamps are no longer placed on the market. Thus the exemption appears to have become obsolete, however is specified for Cat. 8 and Cat. 9 in light of Article 5(2).

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.4 (c)	Mercury in other High Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner)			Mercury in other High Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner):		
		I) P ≤ 155 W: 25 mg per burner II) 155 W < P ≤ 405 W: 30 mg per burner III) P > 405 W: 40 mg per burner	LightingEurope	(I) P ≤ 155 W; 25 mg may be used per burner after 31 December 2011 (II) 155 W < P ≤ 405 W; 30 mg may be used per burner after 31 December 2011 (III) P > 405 W; 40 mg may be used per burner after 31 December 2011	For Cat. 5: 31 August 2018; For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
				(IV) P ≤ 405 W; 20 mg may be used per burner (V) P > 405 W; 25 mg may be used per burner	For Cat. 5: from 1 September 2018 until 21 July 2021	
n.4(e)	Mercury in metal halide lamps (MH)		LightingEurope	Mercury in metal halide lamps (MH)	For Cat. 5, 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.4(f)	Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex	VskE Lighting Europe VDMA	(I) Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex	For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. industrial: 21 July 2024	
			(II) Mercury in high pressure mercury vapour lamps used in projectors where an output ≥2000 lumen ANSI is required	For Cat. 5: 21 July 2021	
			(III) Mercury in high pressure sodium vapour lamps used for horticulture lighting	For Cat. 5: 21 July 2021	
			(IV) Mercury in lamps emitting light in the ultraviolet spectrum for curing and disinfection	For Cat. 5: 21 July 2021	
n.5(b)	Lead in glass of fluorescent tubes not exceeding 0,2 % by weight	LightingEurope	Lead in glass of fluorescent tubes not exceeding 0,2 % by weight	For Cat. 5: 21 July 2021; For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.6(a)	Lead as an alloying element in steel for machining purposes and in galvanised steel containing up to 0,35 % lead by weight	Dunkermotoren; The European Steel Association (EUROFER) and European General Galvanizers Association (EGGA) Sensata Technologies	I) Lead as an alloying element in steel for machining purposes containing up to 0,35 % lead by weight	For Cat. 1-7 and 10 and 11: 21 July 2019	
			II) Lead in batch hot dip galvanized steel components containing up to 0.2% lead by weight	For Cat. 1-7 and 10 and 11: 21 July 2021	
			III) Lead as an alloying element in steel for machining purposes and in galvanized steel containing up to 0,35 % lead by weight	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n.6(b)	Lead as an alloying element in aluminium containing up to 0,4 % lead by weight	AISBL - EAA Sensata Technologies Dunkermotoren	Lead as an alloying element in aluminium		
			I) with a lead content up to 0.4 % by weight, used for the production of parts not machined with shape cutting chipping technologies	For Cat. 1-7 and 10 and 11: 21 July 2021	
			II) for machining purposes with a lead content up to 0.4 % by weight	For Cat. 1-11: 21 July 2021	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
			III) Lead as an alloying element in aluminium containing up to 0,4 % lead by weight	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n.6(c)	Copper alloy containing up to 4 % lead by weight	Bourns Inc. Dunkermotoren Framo Morat Group Sensata Technologies Phoenix Contact GmbH &Co KG; Harting KGaA Lighting Europe	Copper alloy containing up to 4% lead by weight	For Cat. 1-7 and 10 and 11: 21 July 2019; For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n.7(a)	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)	Bourns Inc. IXYS Semiconductor GmbH Chenmko Enterprise Co., Ltd Yeashin Technology Co., Ltd Freescale Semiconductor Formosa Microsemi Co., Ltd.	I) Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
			Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)		
			II) in all applications not addressed in items III and IV,	For categories 1 to 7 and 10: 21 July 2021	See exemption report for alternative

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
			but excluding applications in the scope of exemption 24		wording proposal for 7(a)(II-IV).
			III) for die attach	For categories 1 to 7 and 10: 21 July 2019	
			IV) for electrical connections on or near the voice coil in power transducers		
n.7(c)-I	Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound	Bourns Inc. Sensata Technologies YAGEO Corporation RALEC TECHNOLOGY (KUNSHAN) CO. BANDELN electronic GmbH&Co.KG RALEC TECHNOLOGY (KUNSHAN) CO. Japan Electronics & Information Technology Industries Association Murata Elektronik GmbH EPCOS AG VISHAY BC	7(c)-I: Electrical and electronic components containing lead in a ceramic other than dielectric ceramic in discrete capacitor components, e.g. piezoelectronic devices	For categories 1-7 and 10: 21 July 2019	See exemption report for alternative wording proposal for 7(c)-I
			7(c)-V: Electrical and electronic components containing lead in a glass or in a glass or ceramic matrix compound. This exemption does not cover the use of lead in the scope of exemption 34 (cermet-based trimmer potentiometers).	For categories 1-7 and 10: 21 July 2021	See exemption report for alternative wording proposal for 7(c)-I

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
		components BEYSCHLAG GmbH SCHOTT AG	7(d): Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	See exemption report for alternative wording proposal for 7(c)-I
n.7(c)-II	Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher	Murata Elektronik GmbH EPCOS AG VISHAY BC components BEYSCHLAG GmbH JEITA(Japan Electronics & Information Technology Industries Association)	Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
			Lead in dielectric ceramic in discrete capacitor components for a rated voltage of 125 V AC or higher, or for a rated voltage of 250 V DC or higher	For Cat. 1-7 and 10: 21 July 2019	
n.7(c)-III	Recommended modified wording		Lead in dielectric ceramic in discrete capacitor components for a rated voltage of less than 125 V AC, or for a rated voltage of less than 250 V DC	1 January 2013 and after that date may be used in spare parts for EEE placed on the market before 1 January 2013	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.7(c)-IV	Lead in PZT-based dielectric ceramic materials for capacitors which are part of integrated circuits or discrete semiconductors	ST Microelectronics	Lead in PZT-based dielectric ceramic materials of capacitors being part of integrated circuits or discrete semiconductors	For Cat. 1-7 and 10: 21 July 2019; For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n.8(b)	Cadmium and its compounds in electrical contacts	Sensata Technologies National Electrical Manufacturers Association	8(b) Cadmium and its compounds in electrical contacts	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
			8(c): Cadmium and its compounds in electrical contacts of (I) circuit breakers (II) thermal motor protectors excluding hermetically sealed thermal motor protectors	For Cat. 1-7 and 10: 21 July 2021	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
			(III) thermal sensing controls	For Cat. 1-7 and 10: 21 July 2019	
			(IV) AC switches rated at 6 A and more in combination with 250 V AC and more (V) AC switches rated at 12 A and more in combination with 125 V AC and more	Applies to *EEE* in Cat. 1 to 5, 7 and 10 For Cat. 1 to 5, 7 and 10: 21 July 2019	
			(VI) AC switches for corded tools rated at 6 A and more in combination with 250 V AC and more (VII) AC switches for corded tools rated at 12 A and more in combination with 125 V AC and more (VIII) DC switches for cordless tools with a rated current of 20 A and more in combination with at a rated voltage of 18 V DC and more (IX) switches for tools conceived to be used with power supplies of 200 Hz and more	Applies to Cat. 6 EEE: 21 July 2021	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.9	Hexavalent chromium as an anticorrosion agent of the carbon steel cooling system in absorption refrigerators up to 0,75 % by weight in the cooling solution	Dometic	Hexavalent chromium as an anticorrosion agent applied in carbon steel cooling systems of absorption refrigerators of applications: (I) designed to operate with electrical heater only, with up to 0,75 % by weight in the cooling solution		
			(II) designed to operate with variable energy sources (III) designed to operate with other than an electrical heater	For Cat. 1: 21.7.2019 (three years)	
n.15	Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages	Intel Corporation	I) Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
			II) Lead in solders to complete a viable electrical connection between semiconductor die and the carrier within integrated circuit flip chip packages where one of the below criteria applies:		
			a) A semiconductor technology node of 90 nm or larger	For categories 1-7 and 10: 21 July 2019	
			b) A single die of 300 mm^2 or larger in any semiconductor technology node	For categories 1-7 and 10: 21 July 2021	
			c) Stacked die packages with dies of 300 mm^2 or larger, or silicon interposers of 300 mm^2 or larger	For categories 1-7 and 10: 21 July 2021	
			d) Flip chip on lead frame (FCOL) packages with a rated current of 3 A or higher and dies smaller than 300 mm^2		The exemption cannot be recommended but is added here in case the Commission would decide that it should be granted

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.18(b)	Lead as activator in the fluorescent powder (1 % lead by weight or less) of discharge lamps when used as sun tanning lamps containing phosphors such as BSP (BaSi 2 O 5 :Pb)	NARVA Lichtquellen GmbH + Co. KG Lighting Europe	Lead as activator in the fluorescent powder (1 % lead by weight or less) of discharge lamps containing phosphors such as BSP (BaSi2O5 :Pb), when used: I. in tanning equipment; or II. in Annex I category 8 medical phototherapy equipment - excluding applications falling under point 34 of Annex IV	For Cat. 5: 21 July 2021	
n.21	Lead and cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses	Lighting Europe	I. Cd when used in colour printed glass to provide filtering functions, used as a component in lighting applications installed in displays and control panels of EEE	For Cat. 1-7 and 10: 21 July 2021	The EU Commission should consider if it would not be more beneficial to add this entry to Ex. 13b.
			II. **Alternative A:** Cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses, when used to comply with harmonised standards specifying the use of	For Cat. 1-7 and 10: 21 July 2021	The EU Commission could consider providing a shorter validity period so as to promote the supply chain to develop a strategy for research and

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
			particular hues for safety applications. **Alternative B:** Cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses, excluding Cd used in colour printed glass to provide filtering functions.		development of alternatives for Cd-based inks.
			III. Lead in printing inks for the application of enamels on other than borosilicate glasses.	For Cat. 1-4, 6,7 and 10: 21 July 2019	The recommended period should suffice to establish the reliability of Pb-free substitutes in other than borosilicate glasses.

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
			IV. Lead and cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses	For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024;	As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.
n.24	Lead in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors	Knowles	Lead in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors	For Cat. 1-7 and 10: 21 January 2019; For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024;	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.29	Lead bound in crystal glass as defined in Annex I (Categories 1, 2, 3 and 4) of Council Directive 69/493/EEC (1)	EUROPEAN DOMESTIC GLASS and LightingEurope	Lead bound in crystal glass as defined in Directive 69/493/EEC	For Cat. 1-10: 21 July 2021 For Sub-Cat. 8 in-vitro: 21 July 2023 For Sub-Cat. industrial: 21 July 2024	
n.32	Lead oxide in seal frit used for making window assemblies for Argon and Krypton laser tubes	Coherent Inc. JDSU	Lead oxide in seal frit used for making window assemblies for Argon and Krypton laser tubes	For Cat. 1-10: 21 July 2021 For Sub-Cat. 8 in-vitro: 21 July 2023 For Sub-Cat. industrial: 21 July 2024	
n.34	Lead in cermet-based trimmer potentiometer elements	General Electric	Lead in cermet-based trimmer potentiometers	For Cat. 1-7 and 10: 21 July 2019; For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024;	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.37	Lead in the plating layer of high voltage diodes on the basis of a zinc borate glass body	IXYS Semiconductor GmbH General Electric	Lead in the plating layer of high voltage diodes on the basis of a zinc borate glass body	For categories 1-7 and 10: 21 July 2019; For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

The report includes the following sections:

Section 1.0: Project Set-up

Section 2.0: Scope

Section 3.0: Links from the Directive to the REACH Regulation

Sections 4.0 through 34.0: Evaluation of the requested exemptions handled in the course of this project.

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List of Tables and Figures

1.0 Project Set-up

Assignment of project tasks to Oeko-Institut, started 29 December 2014. The overall project has been led by Carl-Otto Gensch. At Fraunhofer IZM the contact person is Otmar Deubzer. The project team at Oeko-Institut consists of the technical experts Yifaat Baron and Katja Moch. Eunomia, represented by Adrian Gibbs, have the role of ensuring quality management.

2.0 Scope

The scope of the project covers the evaluation of twenty-nine exemptions for which requests for renewal have been submitted to the European Commission. An overview of the exemption requests is given in Table 1-1 below.

In the course of the project, a stakeholder consultation was conducted. The stakeholder consultation was launched on 21 August 2015 and held for a period of 8 weeks, thus concluding on 16 October 2015.

The specific project website was used in order to keep stakeholders informed on the progress of work: http://rohs.exemptions.oeko.info. The consultation held during the project was carried out according to the principles and requirements of the European Commission. Stakeholders who had registered at the website were informed through email notifications about new steps within the project.

Information concerning the consultation was provided on the project website, including a general guidance document, the applicants' documents for each of the exemption requests, results of earlier evaluations where relevant, a specific questionnaire and a link to the EU CIRCA website. All non-confidential stakeholder comments, submitted during the consultation, were made available on the RoHS Evaluation website and on the EU CIRCABC website (Communication and Information Resource Centre for Administrations, Businesses and Citizens).[1]

The evaluation of the stakeholder contributions led to further consultation including, inter alia, engaging with stakeholders in further discussion, further exchanges in order to clarify remaining questions, cross-checking with regard to the accuracy of technical arguments, and checks in respect of confidentiality issues. Meetings held in the context of the exemptions are detailed in the specific exemption reports.

[1] EU CIRCABC website: https://circabc.europa.eu (Browse categories > European Commission > Environment > RoHS 2014 Evaluations Review, at top left, click on "Library")

The exemptions requested for renewal were evaluated according to the various criteria (Cf. Section E.1.0 for details). The evaluations of each exemption appear in the following chapters. The information provided by the applicants and by stakeholders is summarised in the first sections. This includes a general description of the application and requested exemption (requested renewal or proposed amendment), a summary of the arguments made for justifying the exemption, information provided concerning possible alternatives and additional aspects raised by the applicants and other stakeholders. In some cases, reference is also made to information submitted by applicants and stakeholders in previous evaluations, in cases where a similar request has been reviewed or where a renewal has been requested of a request reviewed in the past. The Critical Review follows these sections, in which the submitted information is discussed, to clarify how the consultants evaluate the various information and what conclusions and recommendations have been made. For more detail, the general requirements for the evaluation of exemption requests may be found in the technical specifications of the project.[2]

[2] Cf. under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_8/RoHS_Pack8_Technical_specifications.pdf

3.0 Links from the Directive to the REACH Regulation

Article 5 of the RoHS 2 Directive 2011/65/EU on “Adaptation of the Annexes to scientific and technical progress” provides for the:

> “*inclusion of materials and components of EEE for specific applications in the lists in Annexes III and IV, provided that such inclusion does not weaken the environmental and health protection afforded by Regulation (EC) No 1907/2006*”.

RoHS 2 does not further elaborate the meaning of this clause.

Regulation (EC) No 1907/2006 regulates the safe use of chemical substances, and is commonly referred to as the REACH Regulation since it deals with **R**egistration, **E**valuation, **A**uthorisation and Restriction of **Ch**emical substances. REACH, for its part, addresses substances of concern through processes of authorisation and restriction:

- Substances that may have serious and often irreversible effects on human health and the environment can be added to the candidate list to be identified as Substances of Very High Concern (SVHCs). Following the identification as SVHC, a substance may be included in the Authorisation list, available under Annex XIV of the REACH Regulation: “List of Substances Subject to Authorisation”. If a SVHC is placed on the Authorisation list, companies (manufacturers and importers) that wish to continue using it, or continue placing it on the market, must apply for an authorisation for a specified use. Article 22 of the REACH Regulation states that: *“Authorisations for the placing on the market and use should be granted by the Commission only if the risks arising from their use are adequately controlled, where this is possible, or the use can be justified for socio-economic reasons and no suitable alternatives are available, which are economically and technically viable.”*
- If the use of a substance (or compound) in specific articles, or its placement on the market in a certain form, poses an unacceptable risk to human health and/or to the environment that is not adequately controlled, the European Chemical Agency (ECHA) may restrict its use, or placement on the market. These restrictions are laid down in Annex XVII of the REACH Regulation: “Restrictions on the Manufacture, Placing on the Market and Use of Certain Dangerous Substances, Mixtures and Articles”. The provisions of the restriction may be made subject to total or partial bans, or other restrictions, based on an assessment of those risks.

The approach adopted in this report is that once a substance has been included into the regulation related to authorization or restriction of substances and articles under REACH,

the environmental and health protection afforded by REACH may be weakened in cases where, an exemption would be granted for these uses under the provisions of RoHS. This is essentially the same approach as has already been adopted for the re-evaluation of some existing RoHS exemptions 7(c)-IV, 30, 31 and 40,[3] as well as for the evaluation of a range of requests assessed through previous projects in respect of RoHS 2.[4] Furthermore, substances for which an authorisation or restriction process is already underway are also reviewed, so that future developments may be considered where relevant.

When evaluating the exemption requests, with regard to REACH compliance, we have checked whether the substance / or its substitutes are:

- on the list of substances proposed for the adoption to the Candidate List (the Registry of Intentions);
- on the list of substances of very high concern (SVHCs- the Candidate List);
- in the recommendations of substances for Annex XIV (recommended to be added to the Authorisation List);
- listed in REACH Annex XIV itself (The Authorization List); or
- listed in REACH Annex XVII (the List of Restrictions).

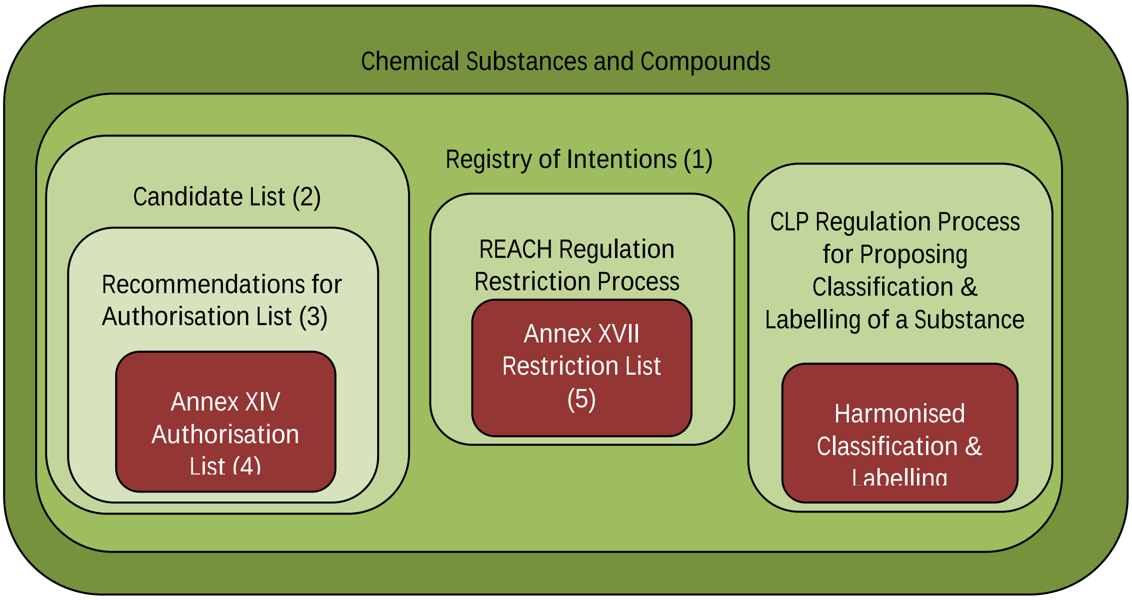
As the European Chemicals Agency (ECHA) is the driving force among regulatory authorities in implementing the EU's chemicals legislation, the ECHA website has been used as the reference point for the aforementioned lists, as well as for the exhaustive register of the Amendments to the REACH Legal Text.

Figure 3-1 shows the relationship between the two processes and categories. Substances included in the red areas may only be used when certain specifications and or conditions are fulfilled.

[3] See Zangl, S.; Blepp, M.; Deubzer, O. (2012) Adaptation to Scientific and Technical Progress under Directive 2011/65/EU - Transferability of previously reviewed exemptions to Annex III of Directive 2011/65/EU, Final Report, Oeko-Institut e. V. and Fraunhofer IZM, February 17, 2012, http://rohs.exemptions.oeko.info/fileadmin/user_upload/Rohs_V/Re-evaluations_transfer_RoHS_I_RoHS_II_final.pdf

[4] Gensch, C., Baron, Y., Blepp, M., Deubzer, O., Manhart, A. & Moch, K. (2012) Assistance to the Commission on technological, socio-economic and cost-benefit assessment related to exemptions from the substance restrictions in electrical and electronic equipment (RoHS Directive), Final Report, Oeko-Institut e. V. and Fraunhofer IZM, 21.12.2012 http://rohs.exemptions.oeko.info/fileadmin/user_upload/Rohs_V/RoHS_V_Final_report_12_Dec_2012_final.pdf

Figure 3-1: Relation of REACH categories and lists to other chemical substances



The following bullet points explain in detail the above mentioned lists and where they can be accessed:

- Member States Competent Authorities (MSCAs) / the European Chemicals Agency (ECHA), on request by the Commission, may prepare Annex XV dossiers for identification of Substances of Very High Concern (SVHC), Annex XV dossiers for proposing a harmonised Classification and Labelling, or Annex XV dossiers proposing restrictions. The aim of the public Registry of Intentions is to allow interested parties to be aware of the substances for which the authorities intend to submit Annex XV dossiers and, therefore, facilitates timely preparation of the interested parties for commenting later in the process. It is also important to avoid duplication of work and encourage co-operation between Member States when preparing dossiers. Note that the Registry of Intentions is divided into three separate sections: listing new intentions; intentions still subject to the decision making process; and withdrawn intentions. The registry of intentions is available at the ECHA website at: http://echa.europa.eu/web/guest/addressing-chemicals-of-concern/registry-of-intentions;
- The identification of a substance as a Substance of Very High Concern and its inclusion in the Candidate List is the first step in the authorisation procedure. The Candidate List is available at the ECHA website at http://echa.europa.eu/web/guest/candidate-list-table;
- The last step of the procedure, prior to inclusion of a substance into Annex XIV (the Authorisation list), involves ECHA issuing a Recommendation of substances for Annex XIV. The ECHA recommendations for inclusion in the Authorisation List are available at the ECHA website at

http://echa.europa.eu/web/guest/addressing-chemicals-of-concern/authorisation/recommendation-for-inclusion-in-the-authorisation-list/authorisation-list;

- Once a decision is made, substances may be added to the Authorisation List available under Annex XIV of the REACH Regulation. The use of substances appearing on this list is prohibited unless an Authorisation for use in a specific application has been approved. The Annex can be found in the consolidated version of the REACH Legal Text (see below);
- In parallel, if a decision is made concerning the Restriction on the use of a substance in a specific article, or concerning the restriction of its provision on the European market, then a restriction is formulated to address the specific terms, and this shall be added to Annex XVII of the REACH Regulation. The Annex can be found in the consolidated version of the REACH Legal Text (see below); and
- As of the 28 of September, 2015, the last amendment of the REACH Legal Text was dated from 28 May 2015 (Commission Regulation (EU) No 2015/830) and so the updated consolidated version of the REACH Legal Text, dated 01.06.2015, was used to check Annex XIV and XVII: The consolidated version is presented at the ECHA website: http://echa.europa.eu/web/guest/regulations/reach/legislation.

Relevant annexes and processes related to the REACH Regulation have been cross-checked to clarify:

- In what cases granting an exemption could "weaken the environmental and health protection afforded by Regulation (EC) No 1907/2006" (Article 5(1)(a), pg.1)
- Where processes related to the REACH regulation should be followed to understand where such cases may become relevant in the future;

In this respect, restrictions and authorisations as well as processes that may lead to their initiation, have been reviewed, in respect of where RoHS Annex II substances are mentioned (i.e. lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE).[5]

Compiled information in this respect has been included, with short clarifications where relevant, in Tables A.1-5, which appear in Appendix A.1.0.

The information has further been cross-checked in relation to the various exemptions evaluated in the course of this project. This has been done to clarify that the Article 5(1)(a) pg.1 threshold-criteria quoted above is complied with in cases where an

[5] This review currently does not address the 4 phthalates, DEHP, BBP, DBP and DIBP, which according to Commission Delegated Directive (EU) 2015/863 of 31 March 2015, have been added to the Annex. Information regarding these substances shall be added in future reviews.

exemption is to be granted / its duration renewed/ its formulation amended/ or where it is to be revoked and subsequently to expire as an exemption. The considerations in this regard are addressed in each of the separate chapters in which the exemption evaluations are documented (Chapters 4.0 through 34.0) under the relevant section titled "*REACH Compliance – Relation to the REACH Regulation*" (Sections 4.5.1 through 34.4.1).

4.0 Exemptions 1-4 Regarding the Use of Mercury in Lamps – General Aspects

Declaration

In the sections that precede the "Critical Review" the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

CFL	Compact fluorescent lamps
Danish EPA	The Ministry of Environment and Food of the Danish Environmental Protection Agency
EEE	Electrical and electronic equipment
EEB	European Environmental Bureau
Health FGOV	Belgish Federal Public Services for Health, Food Chain Safety and Environment
Hg	Mercury
EoL	Early end of life
Lm/W	Lumen per watt
LEU	LightingEurope
MPP	The Mercury Policy Project
NARVA	NARVA Lichtquellen GmbH + Co. KG
PZPO	The Polish Association of Lighting Industry
RPN	The Responsible Purchasing Network
WEEE	Waste EEE

LightingEurope (LEU), a lighting industry association and NARVA Lichtquellen GmbH + Co. KG (NARVA)[6], a manufacturer, each submitted multiple applications requesting the renewal of some of the exemptions related to mercury in lamps listed in Annex III of RoHS (exemptions 1-4, for further details see Section E.2.0 as well as Chapters 5.0 through 16.0 to see what exemptions are being evaluated in the course of this project). Though there may be some differences in their individual requests, many aspects raised in their documentation and in the documents provided by stakeholders throughout the consultation are of general relevance to the Hg lamp exemptions. For this reason, the following chapter summarises general aspects in respect to the Hg lamp exemptions. Where possible, first conclusions and recommendations are made, that shall be referenced where relevant, in the evaluation of the specific exemptions under review (to follow in the next chapters).

4.1 Background

Exemptions 1-4 of Annex III of the RoHS Directive permit the use of mercury in various types of discharge lamps. In general, gas discharge lamps are a family of artificial light sources that generate light by sending an electrical discharge through an ionized gas. LightingEurope[7] explains that a small amount of mercury (Hg) is intentionally dosed in such lamps in order to create the gas discharge. When electric current flows through the lamp bulb (=burner), the mercury atoms inside are excited and produce UV radiation. For example, in fluorescent discharge lamps this UV light passes through a fluorescent coating on the interior of the lamp bulb glass and is thus converted into the required spectra of light (mostly into visible light) emitted from the lamp.

The exemptions for Hg in discharge lamps, listed in Annex III of the RoHS Directive and under review in the context of this evaluation process explicitly name the following technologies and families (only technologies falling in the scope of exemptions for which a renewal has been requested by LEU and/or by NARVA are named below):

- Fluorescent:
  - Compact fluorescent lamps (Ex. 1(a)-1(f));
  - Linear triband phosphor lamps for general lighting (Ex. 2(a)(1-5));
  - Nonlinear triband phosphor lamps (Ex. 2(b)(3));
  - Induction lamps (Ex. 2(b)(4));
  - Cold cathode fluorescent lamps (Ex. 3((a) – 3(c)).

[6] NARVA (2014a), NARVA Lichtquellen GmbH + Co. KG , Exemption request for using of mercury in fluorescent lamps, submitted 19.12.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/NARVA/01_02_a__2b3_4a.pdf

[7] LEU Ex. 1a (2015a), Lighting Europe, Request to Renew Exemption 1(a) under the RoHS Directive 2011/65/EU Mercury in Single-Capped (Compact) Fluorescent Lamps Below 30 W, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Lighting_Europe/1a_LE_RoHS_Exemption_Req_Final.pdf

- Non-Fluorescent:
  - Low pressure discharge lamps (Ex. 4(a))
  - High pressure sodium (vapour) lamps (Ex. 4(b)(I-III) and Ex. 4(c)(I-III))
  - Metal halide lamps (HPMV – Exemptions 4(e))

4.2 Annex I Category Covered by this Exemption

LightingEurope[8] is of the opinion that lamps in general are category 5 because the most are used for general illumination. However, they have some of the characteristics of components (used in luminaires), consumables (finite lifetime and regularly replaced) and spare parts, lamps in luminaires have to be replaced when they cease functioning). Some manufacturers of electrical equipment in other RoHS categories may install fluorescent lamps into their equipment for general illumination purposes and so they will need to use lamps that comply with the RoHS Directive, however the products that they place on the market are not category 5 but may be household appliances, medical devices or potentially any RoHS category 1 - 11.

LightingEurope[9] is aware of the difficulty to unambiguously classify certain lamps in the category set out by RoHS legislation. For lamp manufacturers it is essential to have legal certainty regarding the possibility to put the products on the market irrespective of the planned application as manufacturers are not able to control the use of the lamps in products falling in other categories in or out of the RoHS scope. In practice, most lamps are installed in buildings for lighting applications (category 5) but some are used in other types of equipment, potentially, in all other RoHS categories. The way that lamps are used has no effect on lamp design so will not affect the exemption requests.

Therefore lamp manufacturers consider the lamps in scope of this document to belong exclusively to category 5 as individual products.

The Test and Measurement Coalition (TMC)[10] includes the seven leading companies in the sector representing roughly 60% of the global production of industrial test and measurement products. It is TMC's understanding that, according to the RoHS Directive, the exemptions listed in Annex III and Annex IV for which no expiry date has been specified, apply to sub-category 9 industrial with a validity period of 7 years, starting from 22 July 2017. This is also said to be explained in the RoHS FAQ, p. 26 http://ec.europa.eu/environment/waste/rohs_eee/pdf/faq.pdf. TMC, thus does not interpret the current exemption evaluation related to package 9 to concern category 9 industrial equipment, for which the exemptions evaluated in pack 9 are understood to remain valid, and has not provided exemption specific information.

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[8] Op. cit. Lighting Europe, Ex. 1a (2014a)
[9] Op. cit. Lighting Europe, Ex. 1a (2014a)
[10] TMC (2015), Test & Measurement Coalition, General comments related to RoHS exemption package 9, submitted 16.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/General_Contribution_Test___Measurement_Coalition_package_9_exemptions_20151016.pdf

Though similar contributions have not been made by other sectors, the aspect raised is understood to be of relevance to all products of categories, which first came into scope under RoHS 2 and for which Article 5(2) specifies durations different from those relevant to categories 1-7 and 10, namely Cat. 8 (medical devices) and Cat. 9 (monitoring and control instruments).

4.3 Justification for the Exemption Renewals

For many of the exemptions for Hg-based lamps, the main argumentation revolves around a few main points that shall be detailed shortly below:

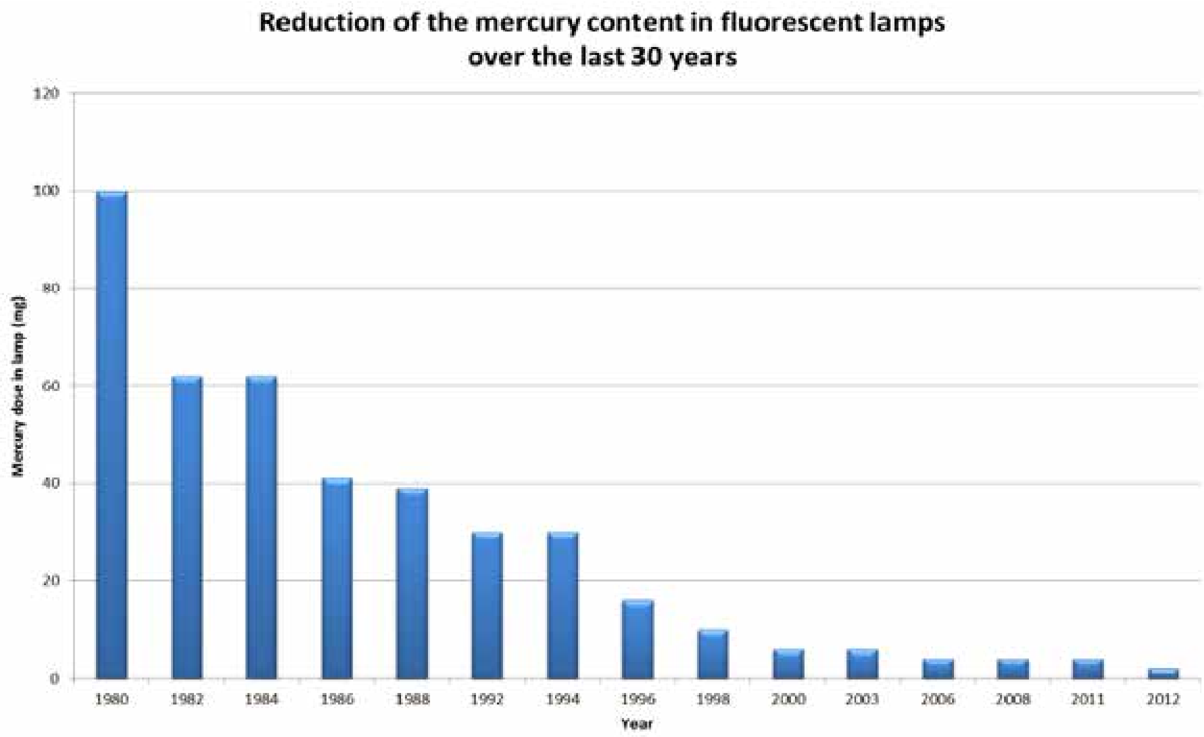
- The limited potential for reducing the amount of Hg dosed in lamps;
- The lack of substitutes for Hg in lamps covered by Ex. 1-4 (substance substitute);
- The limited applicability and product range of Hg-free lamps that may allow eliminating the use of Hg associated with Ex. 1-4, as well as possible restrictions to their use as replacements;
- Possible environmental costs and benefits related to the use of Hg-based lamps and to their possible early phase-out.

Though some of these points require a detailed discussion in the context of the specific exemption, many general aspects are common aspects that have been addressed and evaluated in the following sections. These aspects shall only be further detailed in the exemption specific chapters where detailed information is relevant for the exemption at hand. The critical review of each exemption shall otherwise make reference to this section and only shortly summarise the main conclusions of relevance, where this serves the purpose of supporting exemption-specific conclusions and recommendations.

4.3.1 Amount of Mercury Used under the Exemptions

LEU explains that the level of mercury dosed in fluorescent lamps has decreased considerably during the last years. Examples of this decrease are given in the various requests for exemption renewal. Likewise, LEU has provided Figure 4-1, to show the achieved mercury reduction of the total fluorescent family.

Figure 4-1: Mercury content of fluorescent lamps



Source: Lighting Europe, Ex. 1a (2014a)

LEU[11] states that mercury is dosed in the burner during lamp manufacturing as a homogeneous material (pill, capsule or as amalgam). This technology enables dosing of the small and accurate amount of mercury that is needed, without unintended losses. The amount of mercury dosed per lamp depends on aspects like lamp power, optical performance and anticipated lamp life. In some of the Annex III exemptions, this is reflected through the specification of a maximum allowance of mercury permitted per burner. During lamp life, apparent consumption of mercury takes place inside the burner itself. Throughout operation Hg bonds to the glass and in some lamps to the phosphor layer, after which, it is no longer available to emit ultraviolet light. LEU provides further indication of aspects that may influence the availability of Hg during lamp life and thus of considerations for determining the optimal Hg dose of a specific lamp, among others mentioning:

- Lamp dimensions – “*higher lamp wattage involves more glass and phosphor surface, thus more mercury consumption during lamp life and therefore a higher initial mercury dose*”;
- Lamp life time;

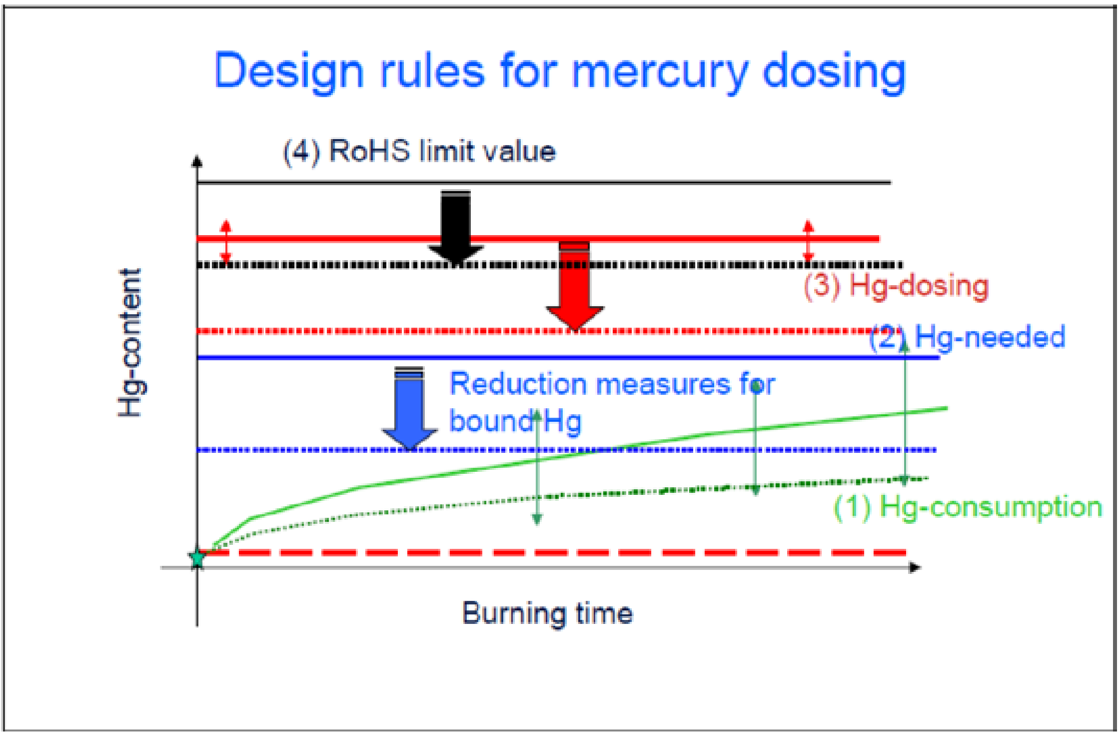
[11] Op. cit. LEU Ex. 1a (2015a)

- *"Coating of phosphors and glass can give a reduction of the Hg 'consumption' over lamp life"*;
- Lamp processing during manufacturing – "*actual dose per lamp scatters around the nominal dose, while the threshold value as set by RoHS directive sets a maximum limit*"
- Mercury 'consumption' – *"processes within the burner, which make a large part of the mercury unavailable for the discharge over lifetime. This is the reason why more mercury has to be dosed to make sure the intended lifetime is not shortened due to too little available mercury"*, e.g. lamp-ballast interaction during operation and interaction with gasses and impurities.

LEU goes on to explain – "*Therefore a balance has to be found between mercury needed over lifetime, mercury variance per dosing unit but also the measurement accuracy when estimating the amount of mercury in a lamp for market surveillance. The lowest (red dashed) line in* Figure 4-2 *gives the ideal situation for a low pressure mercury discharge: there is just enough mercury for the discharge to properly function... However, because of the mercury consumption mechanisms a significantly higher amount must be dosed... In practice, mercury from the discharge is consumed over lamp life. The mercury is mostly deposited and effectively bonded to the glass and the phosphor layer. This is reflected by the full green curve (1) in* Figure 4-2*, which represents more or less a square root relationship with lamp life. The longer the burning time, the higher the amount of mercury needed. The variance in this mercury consumption, as depicted by the green arrows, is considerable and depends on many factors (see below for counteracting measures). To obtain the designed lamp life, the right amount of mercury has to be dosed, taking into account the consumption during lamp lifetime and the variance. The solid blue line 2 in* Figure 4-2 *represents the typical amount that is needed and the solid red line 3 is the amount that also incorporates the variance. Alternatively, this target value is called nominal or average value, and can be listed in catalogues. This average value is lower than the threshold value so the actual amount per lamp is lower than the limit set by the Directive. The solid black line 4 in* Figure 4-2 *is the line representing the RoHS limit (expressed as mg per lamp), the value of which, as explained before, has to take into account both variances of mercury consumption and of mercury dosing. On the one hand, we would like to have this value as low as possible, but on the other hand, it should be safely chosen to (1) eliminate the customer risk of a non-performing product over the designed lamp life and (2) to be able to demonstrate in internal manufacturer's tests and in market surveillance tests that products comply with the RoHS Directive. This leads to a built-in safety margin on top of the target mercury dose, finally leading to RoHS content limit*."[12]

[12] Op. cit. LEU Ex. 1a (2015a)

Figure 4-2: Design rules for mercury dosing in fluorescent lamps, schematically showing the process of setting RoHS limit values based on insights in mercury consumption and mercury dosing.



Source: Lighting Europe, Ex. 1a (2014a)

4.3.1.1 Overview of Mercury in Lamps

Where available, information is detailed in the various exemption evaluation reports as to the amounts of mercury brought on the European market through discharge lamps of various types. Table 4-1 provides an overview of this information in order to provide context for the individual figures and to allow an indicative understanding of the total amount of mercury placed on the market through lamps. Unless otherwise stated, data originates from the documents provided by LightingEurope and is referenced in the separate chapters where the amounts are discussed.

Table 4-1: Overview of Hg amounts brought on the market through discharge lamps

Ex. (entry)	Hg dose per lamp general comments	2013 unless otherwise stated				Comments
		Number of lamps	Average Hg per lamp	Hg	Share of total	
1	**Various CFL lamps**			**947 kg**	**33.01 %**	**Calculated total**
1(a)		291 million	2.5 mg	727 kg	25.34 %	
1(b)		34 million	3.5 mg	120 kg	4.16 %	
1(c)		10 million	5 mg	51 kg	1.78%	
1(d)		2 million	15 mg	26 kg	0.91 %	
1(e)		3 million	7 mg	21 kg	0.73 %	
1(f)	Up to 5 mg per lamp	400	Not	2 kg	0.07%	

Ex. (entry)	Hg dose per lamp general comments	2013 unless otherwise stated				Comments
		Number of lamps	Average Hg per lamp	Hg	Share of total	
	(exemption limit)	thousand	detailed			
2(a)	**Various tri-band phosphor LFL lamps**			**982 kg**	**34.23 %**	**Calculated total**
2(a)(1)		400 thousand	2.5-5 mg	1-1.2 kg	0.03 % (calculated for 1 kg)	
2(a)(2)		76 million	2.5 mg	190 kg	6.62 %	
2(a)(3)		247 million	3 mg	751 kg	26.18 %	
2(a)(4)	-	-	-	-	-	Entry not applied for by LEU. Data not provided by NARVA
2(a)(5)		8-10 million in 2014	4 mg in 2014	40 kg in 2014	1.39 %	
2(b)(3)	Up to 15 mg lamp (exemption limit)	18.6 million*	10 mg*	188 kg*	6.55 %*	*Data provided for exemptions 1(e), 2(b)(2), 2(b)(3), 2(b)(4) and 4(a) – Ex. 1(e) figures have been subtracted. Ex. 2(b)(2) share assumed negligible as it expires in April 2015
2(b)(4)	8 mg average; Up to 15 mg lamp (exemption limit)	18.6 million*	10 mg*	188 kg*	6.55 %*	*Data provided for exemptions 1(e), 2(b)(2), 2(b)(3), 2(b)(4) and 4(a) – Ex. 1(e) figures have been subtracted. Ex. 2(b)(2) share assumed negligible as it expires in April 2015
3	3.5-13 mg per lamp (exemption limit)	Not detailed	Not detailed	Less than 2 kg	< 0.07 %	
4(a)	Hg content from < 4 mg - 15 mg	18.6 million*	10 mg*	188 kg*	6.55 %*	*Data provided for exemptions 1(e), 2(b)(2), 2(b)(3), 2(b)(4) and 4(a) – Ex. 1(e) figures have been subtracted. Ex.

Ex. (entry)	Hg dose per lamp general comments	2013 unless otherwise stated				Comments
		Number of lamps	Average Hg per lamp	Hg	Share of total	
						2(b)(2) share assumed negligible as it expires in April 2015
4(b), 4(c), 4(e)	**Various high intensity discharge lamps (HID)**			**528.5 kg**	**18.42 %**	**Calculated total**
4(b)	Up to 30 mg for entry (I) and up to 40 mg for entries (II and III)	Not detailed	Not detailed	5-10 kg	0.26 % (calculated for 7.5 kg)	
4(c)	Hg amounts vary between 1 - 40 mg	23 million	15 mg	345 kg	12.03 %	
4(e)	In most lamps 3-30 mg, but higher power lamps 200mg is more common and up to 2 gram can be dosed in a small share of lamps	16 million	11 mg (mean)	176 kg	6.14 %	
4(f)	**Various lamps**			**211 kg**	**7.7 %**	**Calculated total**
4(f) Projection lamps	10-40 mg	3 million	15 mg	45 kg	1.57 %	
4(f) UV short arc mercury	up to 100 g per lamp	Not detailed	1 g	20 Kg	0.7 %	
4(f) UV curing lamps	10-3000 mg	132 thousand lamps in 2012[13]	Not specified	75 kg in 2014	2.61 %	Market increase of 6% was applied to 2012 data
4(f) UV Disinfection lamps		178 thousand in 2012[13]		81 kg	2.82 %	Data mentioned in VDMA application for exemption.
Calculated Total				**2868 kg**	**100%**	LEU estimates that 45.7% of lamps are collected for recycling (see Figure 4-3).

Source: Compiled from Information Available from Applicants, see references in individual exemption evaluation reports

[13] Referenced as "UV LED Market" report from Yole Dveloppement, 2012

4.3.2 Alternatives to Hg-based Discharge Lamps

4.3.2.1 Possible Alternatives for Substituting RoHS Substances

Regarding the possible substance substitution of Hg in lamps NARVA[14] states that low pressure discharge lamps do not work without mercury.

LEU[15] agrees with this point, explaining that the mercury discharge is highly efficient in transforming electrical energy into light. The technology has only two drawbacks: first that the generated UV radiation needs to be transformed into visible light, a process from which large energy losses occur due to the Stokes shift[16] and secondly that the discharge inherently contains Hg as the source to create the UV photons. Attempts to generate UV with noble gases have succeeded partially. However the plasma radiates in the deep UV and at such wavelengths that the Stokes shift is even larger causing lower energy efficiency. Some alternatives were developed on the basis of research, however the energy efficiency in prototype lamps is said to be significantly reduced (40 lm/W or below)[17]. In light of the progress of developing alternatives to the discharge lamp (e.g. LEDs) research of substance alternative gas discharges has stopped at most companies and universities. Some additional examples are detailed in the application dossiers; however, none are explained to have resulted in a substance-substitute for Hg in discharge lamps.

4.3.2.2 Possible Alternatives for Eliminating RoHS Substances

Regarding possible technological substitutes for mercury-based discharge lamps, the main mercury free alternatives that have been (or that are becoming) available on the market are incandescent lamps, halogen lamps and light emitting diodes (LEDs).

The well-known conventional incandescent lamps and halogen lamps are less efficient in terms of lm/W and in this respect exhibit negative environmental impacts related to energy and energy related environmental impacts. These would need to be considered under the Article 5(1)(a) criteria related to environmental and health impacts of substitutes. However, both lamp types are subjected to various restrictions through the EcoDesign Directive under which the placing on the EU market of lamps with an energy class lower than B shall be forbidden from 2018. This is expected to effectively ban most incandescent and halogen lamps, and in any case those used for general lighting. Such

[14] Op. cit. NARVA (2014a)

[15] LEU Ex. 2(a)(1)(2015a), Lighting Europe, Request to Renew Exemption 2(a) under the RoHS Directive 2011/65/EU 2(a) Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp): 2(a)(1) Tri-band phosphor with normal lifetime and a tube diameter < 9 mm (e.g. T2): 4 mg may be used per lamp after 31 December 2011, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/Lighting_Europe/2a1_LE_RoHS_Exemption__Req_Final.pdf

[16] LEU explains that an energetic UV photon generates a visible photon which has a much lower energy.

[17] Such values differ depending on technology; however for comparison CFL lamps currently available on the market often have energy efficiencies of 50-65 lm/w, LFLs exhibit energy efficiencies of 80-100 lm/w.

lamps would thus not comprise a practical alternative and shall therefore not be discussed further in detail, unless relevant to the discussion on a specific exemption.

The quickly developing LED technology offers a wide range of Hg-free alternatives that could serve to substitute fluorescent lamps in many cases, thus eliminating the need to use Hg-based technologies. Various stakeholders, including LEU[18] and NARVA[19], claim that the discussion on the suitability of LEDs as technological substitutes for discharge lamps needs to distinguish between two cases:

- Use **as replacement lamps** in existing installations; and
- Use in new installations and **in replacement installations -** new luminaires used to replace luminaires compatible with discharge lamps with ones compatible with LEDs (in some cases luminaires with integrated LED).

LEU[20] explains that new luminaires and lighting systems are now frequently based on LED technology. However, it is claimed that for the current installed base of luminaires and lighting systems operating with discharge lamps, LEDs may in some cases not be suitable drop-in replacements. Towards the development of possible alternatives, the LED technology developments are also addressing one-on-one replacements, but this will not result in a situation which would allow for full replacement of the current discharge lamps portfolio within the timeframe of the exemptions. On this basis it is argued that the availability of suitable discharge lamps needs to be secured to prevent a forced, early refurbishment of installations resulting in extra costs and environmental burden.

Related to lamp replacement, LEU describes three replacement strategies:

- **Retrofit route**: a discharge lamp is substituted by a Hg-free lamp (e.g., LED). The luminaire itself is not rebuilt. Where relevant, the control gear remains in the installation. Driver compatibility is assumed in such cases.
- **Conversion route**: the discharge lamp is replaced, and technical changes also need to be made to the luminaire: ballasts and/or internal wiring may need to be replaced or altered – it is explained that this shifts the responsibility for the technical and the safety consequences of the conversion to the party carrying out the conversion.
- **Rewiring route** – replacing the discharge lamp with an Hg free alternative requires removing the control gear (CG) from the existing installation to establish driver compatibility.[21]

[18] Op. cit. LEU Ex. 2(a)(1) (2015a)
[19] Op. cit. NARVA (2014a)
[20] Op. cit. LEU Ex. 2(a)(1) (2015a)
[21] The exact difference between rewiring and conversion is not clear from the available information, however it can be understood that the scope of changes to the equipment in conversion is wider than in rewiring. A conversion can include rewiring adjustment, but also replacement of drivers, dimmers, etc.

In the exemption renewal documents, LEU[22] describes various aspects that may limit the applicability of LED substitutes as replacements for the full range of discharge lamps covered by the exemptions. Among others the following points are raised:

- Limited variety in terms of shape, sizes, wattage, colour;
- Lacking suitability of LED replacements in light of thermal performance or electric compatibility when used in discharge luminaires;
- Lacking comparability in light output (luminous flux; light pattern and distribution);
- Lack of standards to support product safety certification and to assist in identifying compatible replacement lamps;

4.3.3 Environmental Arguments

4.3.3.1 Life Cycle Aspects

According to LEU[23] several external life-cycle-analysis' (LCA) have been performed regarding lighting. LEU explains that there is general agreement, that the main environmental impact is created during the use phase, meaning through electricity consumption when burning the lamp. This means that currently the energy efficiency (i.e. during the use phase) of the lamp is the determining parameter for almost all environmental impacts throughout the life cycle of a lamp. Specifically regarding mercury, the biggest amount is released to the environment by power plants when generating energy (especially when fossil fuel is the primary power source).

A summary and critical review of the more recent LCA studies cited is presented in Section 5.5.2.2 of the review on Ex. 1(a-e). The location of this information has been determined in light of most of the comparative LCAs to have been performed between LED lamps, incandescent and compact fluorescent lamps. Though the general statements are assumed to be indicative of performance in comparison to other discharge technologies, results of available studies do not address this in detail and are therefore not discussed in depth in this chapter.

4.3.3.2 Use of Materials and Hazardous Substances

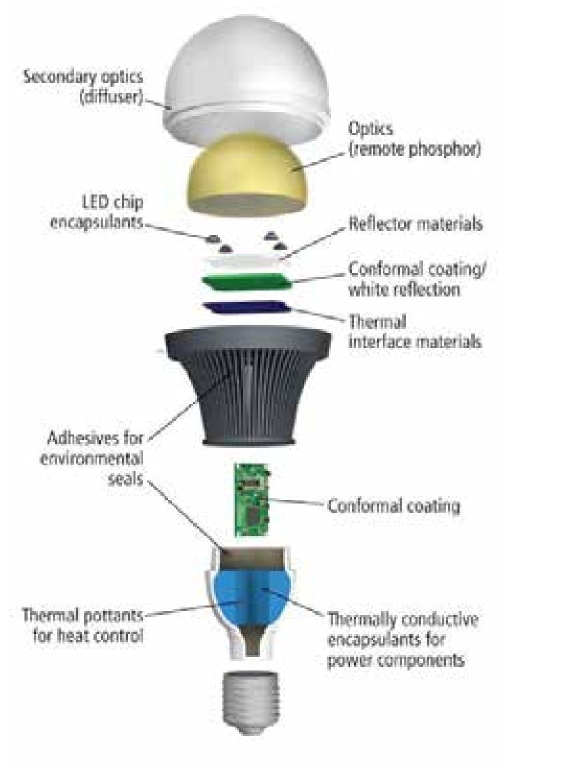
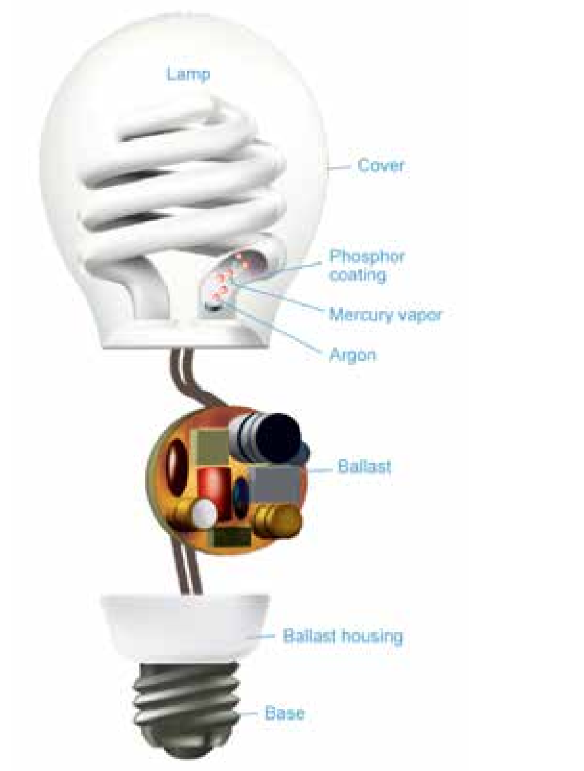
LEU[24] claims that concerning material composition it is also necessary to have a case by case view. Fluorescent lamps contain glass, metals, phosphors and mercury. These components can be effectively recycled. LED based alternatives contain electrical and electronic components such as a control gear and a light engine with mounted LEDs. Like in most other electrical and electronic equipment electronic LED luminaires contain components and other materials using substances regulated in RoHS but exempted in certain exempted applications (e.g. lead in high melting temperature type solders in

[22] Op. cit. LEU Ex. 2(a)(1) (2015a)
[23] Op. cit. LEU Ex. 1a (2015a)
[24] Op. cit. LEU Ex. 2(1)(a) (2015a)

diodes, lead in glass or ceramic in electronic components, lead in aluminium alloys used for the heatsink, lead in copper alloys etc.).

LEU was asked to further substantiate statements related to the use of materials and hazardous substances in discharge lamps and in LEDs. In this regard LEU[25] answered that both lamp technologies use similar electronic circuits and similar components. The lamps as well as luminaires might use exemptions 5(b), 6(a, b, c), 7(a), 7(c)(I, II, IV) or 15, all permitting the use of the element lead. No differentiation between lamps covered by different exemptions is observed. Examples provided can be observed in Table 4-2 (general examples of lamp composition) and Table 4-3 (real examples of electronics used in LED retrofit and compact fluorescent lamps).

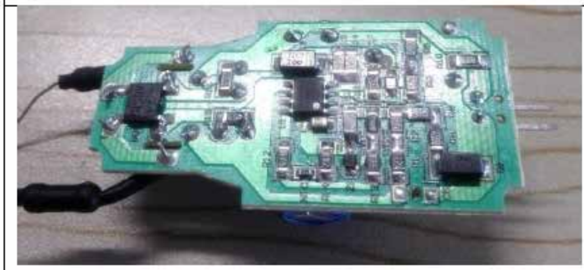
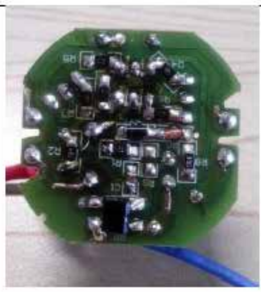
Table 4-2: General composition of LED and CFLi lamps

Example of a LED lamp composition	Example of a compact fluorescent (with integrated ballast) lamp composition
	

Source: Sources provided in LEU (Ex. 1-4) (2015a) by LEU as follows: Left image: http://www.ledsmagazine.com/content/dam/leds/migrated/objects/features/9/10/14/MoldableFig3.jpg Right image: Source: U.S. EPA/ DOE Energy Star Program. "Learn About Compact Fluorescent Light Bulbs" http://www.energystar.gov/index.cfm?c=cfls.pr_cfls_about

[25] LEU Ex. 1-4 (2015a), LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 1-4 (renewal requests) General Questions for Lamp Exemptions Related to Mercury, submitted 25.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/LE_Ex_1-4_LightingEurope_General_Clarification-Questions_Final.pdf

Table 4-3: Example of electronics used in LED and CFLi lamps

Example of a LED electronic driver	Example of a compact fluorescent driver (lamp with integrated ballast)
	
	

Source: Source provided in LEU (Ex. 1-4) (2015a) as LightingEurope

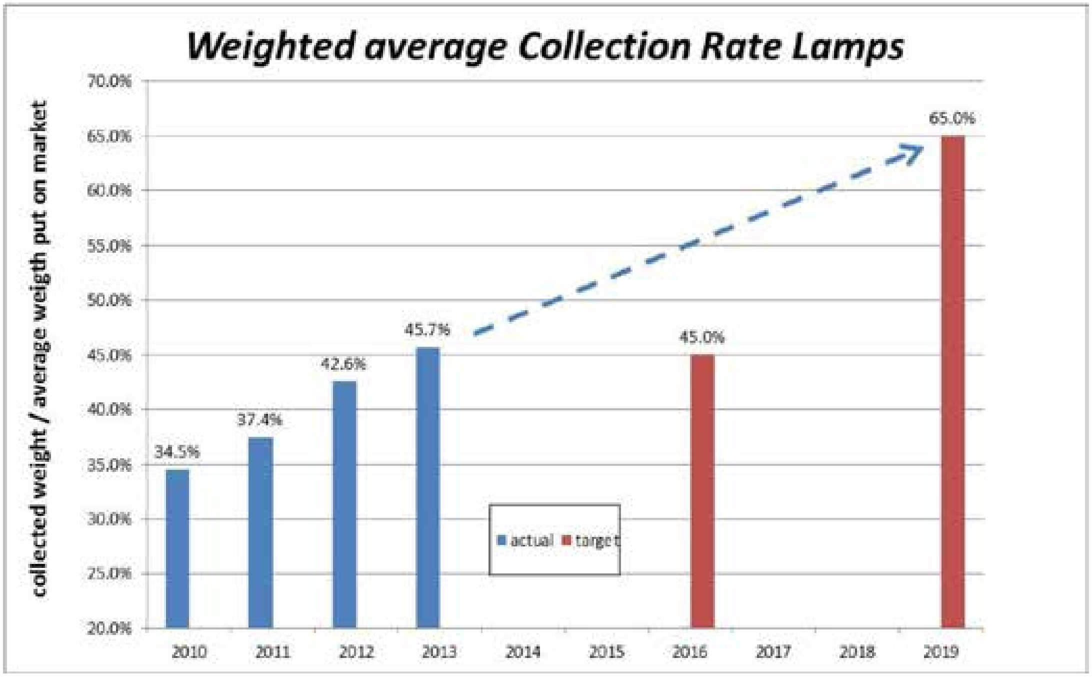
4.3.3.3 Waste management

Information in many of the LEU exemption requests regarding waste streams and recycling is very similar and based on the general approach of industry in the EU towards recycling as a result of the WEEE Directive. LEU[26] states that lamps are in the scope of EU Directives 2002/96/EC (WEEE) and 2012/19/EU (WEEE Recast). The WEEE European legislation stipulates that producers are responsible for end of life products within this category as from August 13th, 2005. Target setting as consequence of the present legislation is 45%/annum of EEE placed on the market by 2016, rising to 65%/annum in 2020. The European Lamp Companies are explained to have founded ‘Collection & Recycling Organisations’ in the EU Member-States, with the objective to organise the collection and recycling of gas discharge lamps. The goal is to comply with present and probable future EU legislation and to meet or exceed national targets. “*Take back systems are installed in all EU Member States: end users and most commercial customers have to bring back the lamps free of charge... are collected separately from general household waste and separately from other WEEE waste. Also a dedicated recycling process exists for lamps because, according to legislation, the mercury shall be removed from the gas discharge lamps. Mercury is recovered in specialised facilities by distillation.*”

[26] Op. cit. LEU Ex. 1a (2015a)

LEU[27] provides Figure 4-3 showing the collection rate of lamps in Europe compared to the average amount of lamps put on the market during 2010 – 2013. The figure is based on Collection & Recycling Service Organization (CRSO) data for all lamp types, consolidated by Philips Lighting and includes the targets set for 2016 and 2019.

Figure 4-3: Collection rate of lamps in Europe compared to the average amount of lamps placed on the market between 2010 and 2019



Source: LEU Ex. 1a (2015a)

4.3.4 Socio-economic Impact of Substitution

Regarding the costs of substitution, LEU[28] claims that for many applications the prices of LED-based alternatives for discharge lamps (especially for increased wattages) are still significantly higher while the system energy efficiency and lifetime in principle are comparable. This means higher investments and a longer payback time are to be expected. This statement is referenced to a McKinsey Report[29] from 2011.

LEU expects a premature phase out of discharge lamps to result in (amongst others):

- Increase in fixed costs;
- Possible social impacts within the EU;
- Possible social impacts external to the EU;

[27] Op. cit. LEU Ex. 1a (2015a)
[28] Op. cit. LEU Ex. 2(1)(a)(2015a)
[29] Quoted as: McKinsey, Lighting the way : Perspectives on the global lighting market, July 2011

- "…*an increased spend of EU consumers due to enforced usage of more expensive LED lamps (no cheaper alternative yet) and pre-mature refurbishment in professional applications*" [quote unchanged from the LEU text to avoid any unintended shift in the interpretation];
- Banning mercury shall result not only in a reduction of product choice in general but particularly in relation to energy efficient lighting solutions.
- Some discharge lamp families are manufactured in Europe. Not granting the exemptions will lead to the closing of such factories in the EU, and to subsequent loss of jobs.
- "*RoHS is copied by many countries in the world (e.g. Asia, Middle East, the America's). Ending the exemption would have as consequence that also people in other countries would not be able to buy energy efficient and affordable CFL lamps and will go back to using incandescent lamps. This has a very negative impact on the environment*."
- An extension of the exemptions will have a positive effect on the efforts to further innovate in LED technologies, as CFL is the benchmark to be outperformed by LED.

Further information substantiating and quantifying the magnitude of the possible impacts mentioned was not detailed.

4.3.5 Road Map to Substitution

In its various exemption renewal application documents LEU[30] explains that further extension of the various exemptions shall not affect innovation into new LED technologies. It further clarifies that innovative R&D related to discharge lamps has already ceased as LEDs are seen as the future substitute.

4.3.6 The Minamata Convention

The Minamata Convention on Mercury is a global treaty to protect human health and the environment from the adverse effects of mercury. It was agreed at the fifth session of the Intergovernmental Negotiating Committee in Geneva, Switzerland on 19 January 2013. The Convention draws attention to a global and ubiquitous metal that, while naturally occurring, has broad uses in everyday objects and is released to the atmosphere, soil and water from a variety of sources. Controlling the anthropogenic releases of mercury throughout its lifecycle has been a key factor in shaping the obligations under the convention. [31]

Among others the convention requires that:

[30] See for example LEU Ex. 2(1)(a) (2015a)
[31] UNEP, 2016, Minamata Convention on Mercury Website, http://www.mercuryconvention.org/Convention last accessed 4.3.2016

"Article 4(1): Each Party shall not allow, by taking appropriate measures, the manufacture, import or export of mercury-added products listed in Part I of Annex A after the phase-out date specified for those products, except where an exclusion is specified in Annex A or the Party has a registered exemption pursuant to Article 6…"

Annex A specifies the following products relevant to the Hg discharge lamp exemptions dealt with in this report:

"*Mercury-added products*

The following products are excluded from this Annex:

… (c) Where no feasible mercury-free alternative for replacement is available, switches and relays, cold cathode fluorescent lamps and external electrode fluorescent lamps (CCFL and EEFL) for electronic displays, and measuring devices;

Part I: Products subject to Article 4, paragraph 1

Mercury-added products	***Date after which the manufacture, import or export of the product shall not be allowed (phase-out date)***	**Consultants comments**
Compact fluorescent lamps (CFLs) for general lighting purposes that are ≤ 30 watts with a mercury content exceeding 5 mg per lamp burner	*2020*	Covers lamps falling under Ex. 1(a)
Linear fluorescent lamps (LFLs) for general lighting purposes: *(a) Triband phosphor < 60 watts with a mercury content exceeding 5 mg per lamp;* *(b) Halophosphate phosphor ≤ 40 watts with a mercury content exceeding 10 mg per lamp*	*2020*	Covers lamps falling under Ex. Covers lamps falling under Ex. 2a
High pressure mercury vapour lamps (HPMV) for general lighting purposes	*2020*	Covers lamps falling under Ex. 4(d), which has expired
Mercury in cold cathode fluorescent lamps and external electrode fluorescent lamps (CCFL and EEFL) for electronic displays: *(a) short length (≤ 500 mm) with mercury content exceeding 3.5 mg per lamp* *(b) medium length (> 500 mm and ≤ 1 500 mm) with mercury content exceeding 5 mg per lamp* *(c) long length (> 1 500 mm) with mercury content exceeding 13 mg per lamp*	*2020*	Covers lamps falling under Ex. 3(a-c)

The restrictions above apply to all countries who have signed the convention, however it is also mentioned that "*nothing in this Convention prevents a Party from taking additional domestic measures consistent with the provisions of this Convention in an effort to protect human health and the environment from exposure to mercury in accordance with that Party's other obligations under applicable international law.*"

4.4 Stakeholder Contributions

A number of contributions have been made by stakeholders with general comments regarding the lamp exemption (Annex III Ex. 1-4) as well as with comments specific to a certain exemption. The latter shall be discussed in the exemption specific chapters to follow, whereas the former are summarised below.

Ministry of Environment and Food of the Danish Environmental Protection Agency (DEPA)

DEPA[32] has sent a few documents as reference to the lamp exemptions. Though some of these documents were in Danish, a summary in English was provided:

- The first reference provides results of a web based survey performed in October 2014 with 1152 consumers (age 18 years or above).
- The second reference regards data on LED and Hg containing lamps (Baggrundspapir, kviksølv og sparepærer ...) with relevant references in English that could be consulted. Furthermore, a first calculation of the possible energy, CO_2 and Hg saved if all energy saving lamps in Denmark are replaced with LEDs is made. The calculation is made on the assumption that the LED lamps use approx. 25% less energy compared to CFLs. For Denmark the result is 46.8 GWh, 16983 tons CO_2 and 0.4 kg Hg. This corresponds all in all to approximately €15 million.

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[32] Danish EPA (2015a), Ministry of Environment and Food of the Danish Environmental Protection Agency, Contribution to RoHS Stakeholder Consultation Regarding 29 Exemptions, submitted 8.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/Stakeholder_consultation_RoHS_-_29_exemption_in_Annex_III.pdf, links to referenced document: Tabbelraport in Danish:
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/Tabelrapport_med_kryds_-_Kampagneevaluering_elsparepaerekampagne_-_Praetest.pdf
Baggrundspapir vedr. kampagne om sparepærer og kviksølv in Danish:
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/Baggrundspapir__kviksoelv_og_sparepaerer_5.2.12_GODKENDT.pdf
Survey and health assessment of mercury in compact fluorescent lamps and straight fluorescent lamps:
http://mst.dk/service/publikationer/publikationsarkiv/2010/jul/survey-and-health-assessment-of-mercury-in-compact-fluorescent-lamps-and-straight-fluorescent-lamps/
Commission Regulation implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for nondirectional household lamps:
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/sec_2009_327_impact_assesment_en.pdf

- The third reference is to a Danish survey and health assessment of mercury in compact fluorescent lamps and straight fluorescent lamps. The report presents methodology and results of an assessment of the health risk associated with breakage of these kinds of lamps in a private home.
- A last reference is to a Commission impact assessment regarding possible measures considered for implementation under the EcoDesign Directive. DEPA explains that in this assessment from 2009, a large share of the energy consumption was from fossil fuels. DEPA requests that the validity of this argumentation be revised, as it is understood that the share of energy produced from alternative energy sources (e.g. windmills) in the EU has increased. Thus the balance between Hg used in lamps to reduce energy consumption and Hg emissions associated with energy production is expected to have changed and this argumentation may no longer be valid.

In later correspondence DEPA[33] submitted the following revised table from the EPINION survey with data as to how Danish people have disposed of lamps in the past, highlighting which methods are understood to be correct (marked in yellow) and which are not (marked in red).

Table 4-4: Survey of Danish households on bulb disposal

Responses of Danish households to the question *"Think of the last time you had to discard one of the following worn out bulbs. How did you discard the bulb?"*	**Energy saving bulb (i.e. CFLs)**	**LED bulb**	**Fluorescent tube**	**Special bulb (halogens or incandescent bulbs)**
I delivered it at the recycling station	38%	26%	39%	31%
I delivered it as bulky waste	4%	3%	4%	3%
I put it into the bin for domestic waste	18%	10%	6%	19%
I delivered it as hazardous waste	11%	6%	9%	8%
I delivered it as small electronic waste	9%	7%	7%	8%
I delivered it as glass	3%	2%	3%	4%
Other	2%	2%	2%	2%
I never put a bulb like that to waste	5%	36%	15%	7%
I do not remember/I do not know	10%	17%	15%	17%
Correct disposal behavior total	**38%**	**33%**	**39%**	
Incorrect disposal behavior total	**30%**	**10%**	**16%**	

Source: Provided by DEPA (2016a), referencing data from the EPINION 2014 survey.
Note: In the table the clearly correct and incorrect way of discarding worn out bulbs is marked with yellow and red respectively. For special bulbs it is not possible to indicate correct way of discarding them since this headline covers different bulbs. In some area a special box for collecting bulbs is put up in the bulky waste area. It is therefore not possible to say if this way of discarding the lamps is correct or incorrect, unless the numbers are crossed with the municipalities and their collection system is checked. Bulbs can be delivered as hazardous waste, then the staff will always make sure the lamp is handled correctly, however this is not always the recommendation by the local authorities.

[33] Danish EPA (2016a), Ministry of Environment and Food of the Danish Environmental Protection Agency, Answers to Clarification Questions as to Contributed Documents, Prepared Towards Meeting at Oeko-Institut e.V., Berlin, Friday 5th February 2016, submitted per email 4.2.2016

Further information regarded the amount of light bulbs placed on the market in various years and collected through the various collection mechanisms:[34]

- "In Denmark DPA-system administers the mandatory producer responsibility system. According to the **2014 statistics of the DPA-system** 1547 tons of bulbs (the various types of bulbs are not specified) were put on the market for consumers and 199 tons for professionals, for a total of 1746 tons of bulbs[35]. Concerning collection 765 tons of bulbs were collected from consumers and 12 tons from professionals, amounting to 777 tons and corresponding to a collection percentage of 45%. [36]. According to **statistical data from the DPA system for 2006,** in 2006 Denmark achieved an overall collection rate of 36%[37]. Data from 2010 shows an overall collection rate of 43%.
- In a Ph.D.-thesis from 2014 based on waste composition analysis, it has been estimated that every household in Denmark delivers 1 gram of energy saving bulbs (containing mercury)/week as domestic waste. This number is based on statistics from 3129 households[38]. 1 gram/week corresponds to approximately 50 gram/year[39]. Having 2.775 million households this corresponds to ca. 140 tons of bulbs/year.

DEPA[40] refers to an assessment made in 2015 by FORCE Technology commissioned by the Danish EPA, which among others looked into the influence of the mixture of bulbs and the influence on energy consumption using numbers from the Danish Energy Agency[41].

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[34] Op. cit. DEPA (2016a)
[35] DEPA (2016a) refers to DPA system (Danish Producer responsibility), WEEE, BAT og ELV Statistik 2014 (https://www.dpa-system.dk/da/DPA/Dokumenter?id=7854eb59-7b8d-4fcc-b58a-221f6d0b9ad5 - available in English for 2013 file:///C:/Users/doble/Downloads/UK_WEEE%20%20BAT%20og%20ELV%20Statistik%202013.pdf)
[36] Ibid.
[37] DEPA (2016a) refers to DPA system (Danish Producer responsibility), Data og statistik for 2006 (file:///C:/Users/doble/Downloads/WEEE-Statistik%202006.pdf)
[38] DEPA (2016a) refers to Bigum 2014, Life cycle assessment of special waste types: WEEE and batteries, Ph.D. Thesis, Danish Technical University
[39] Ibid.
[40] Op. cit. DEPA (2016a)
[41] DEPA (2016a) refers to Danish Energy Agency, ELMODELBOLIG Statistik, http://statistic.electric-demand.dk/TekniskRap/Resultater?AppGrTek=60&AppTek=61&SpmTek=1&SubSpmTek=1&disp=1&res1ser=4&App=61&ExtraDevice=0&CheckExtradevice=False&Spm=1&Sub=0&QuestId=0

Table 4-5: Energy consumption totals by bulbs type in 1998 and 2012

Bulbs	1998 (GWh)	2012 (GWh)
Incandescent bulbs	1200.5	236.2
Energy Saving bulbs	50.1	197.8
Fluorescent tubes	155.5	148.8
Halogen bulbs	112.4	382.5
Total consumption for lighting	**1518.5**	**963.3**

Source: DEPA (2016a) refers to Danish Energy Agency, ELMODELBOLIG Statistik, See footnote 41

Polish Association of Lighting Industry

The Polish Association of Lighting Industry (PZPO)[42] have submitted general comments concerning the lamp exemptions.

- PZPO reiterates the impracticability of reducing Hg quantities besides a certain point, in light of the negative impacts that this could have on lamp life and subsequently increasing the replacement frequency and waste generation: "*Although technological advances facilitated reduction in the quantity of mercury in fluorescent light sources, there is a certain threshold value responsible for a significant drop in lamp's lifespan*."
- PZPO further raises concern as to the possible influence that fluorescent light source availability could have on the further development of LEDs: *"This is due mainly to the possibility of changing one lighting system to another as well as to the possibility to increase the energy savings... The demand for higher energy savings triggered the development of LED sources, with fluorescent lamps continuing to be the main points of reference. Imposing restrictions on fluorescent sources may lead to a halt in the development of LED sources."*

Belgian Federal Public Services for Health, Food Chain Safety and Environment

The Belgian Federal Public Services for Health, Food Chain Safety and Environment (Health FGOV)[43], submitted comments regarding Hg in lamps, explained to specifically target lamps falling under Ex. 1 (compact fluorescent lamps). However the points raised are of a general nature and may thus be of relevance to Hg lamps in general. In this respect, a main concern regards the collection and treatment of lamps at EoL. The lack of

[42] PZPO (2015a), Polish Association of Lighting Industry, Comments to Annexes III and IV Directive 2011/65/EU (RoHS), submitted 5.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Directive_RoHs_-_PZPO_comments_05_10_15_eng.pdf

[43] Health FGOV (2015a), The Belgish Federal Public Services for Health, Food Chain Safety and Environment, Belgian communication for the public consultation on the renewal of the ROHS exemptions on the Mercury containing lamps, submitted 16.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/Ex_1-4_FPS_Health__Food_chain_safety_and_Environment_Be_position_Hg_lamps_20151016.pdf

information as to the actual collection and treatment rates throughout Europe does not allow understanding the efficacy of the mechanism in place to handle this type of WEEE. Two concerns are mentioned in this respect, the one related to the possible need to evaluate the loss of mercury where lamps are not collected and treated properly (i.e. potentially emitted to the environment). The other questions the fate of Hg in the short and medium term, explaining that there are decreasing options for future use of recycled Hg. This could result in the long term in environmental impacts which should be assessed, related to the continued marketing of Hg lamps and their EoL.

European Environmental Bureau (EEB) the Mercury Policy Project, and the Responsible Purchasing Network

The European Environmental Bureau (EEB), the Mercury Policy Project, and the Responsible Purchasing Network[44] submitted general comments while also including specific conclusions and recommendations for some of the specific exemptions, to be detailed in chapters to follow. EEB et al. are concerned about LEU's request to renew several RoHS exemptions for continued use of mercury for the maximum validity period and with the present maximum mercury limits. This concern is mainly associated with their understanding that equivalent products with no or less mercury are widely available. Some of which (LEDs), are also more energy-efficient and have a longer rated life than Compact Fluorescent Lamps (CFLs). Such alternatives are expected to rapidly become more cost competitive, especially when their long life and ability to cut energy, replacement, and waste disposal costs are considered. EEB et al. do not favour the length of many of the requested mercury exemptions mainly based on the statement that equivalent LED lamps are not a practical replacement today for every application. They request definite, near-term expiry dates in certain categories of lamps on the basis that LEDs are environmentally preferable and practical for most applications. To support this opinion they support this view with various sources – including the EC and its consultants – that are predicting the availability, performance and price of LED lamps to continue to quickly improve. In some other lamp categories[45], they propose lower Hg limits, that they expect can be achieved when the present expiry dates go into effect – or shortly thereafter (within the next 2 years).

KEMI Kemikalieinspektionen, Swedish Chemicals Agency

KEMI Kemikalieinspektionen, Swedish Chemicals Agency (KEMI)[46], submitted comments for two exemptions[47], explaining that the comments are the same in nature. Aspects of

[44] EEB et al. (2015a),The European Environmental Bureau, the Mercury Policy Project, and the Responsible Purchasing Network, Environmental NGOs Response to Stakeholder consultation 2015 #2 on mercury-containing lamps – Exemption 1-4 (Review of Annex to the RoHS directive), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1-4_EEP-RPN-MPP_Comments_on_RoHS_Request-final_20151016.pdf

[45] EEB et al. have suggested reductions in the thresholds set for Ex. 1(b), Ex. 1(d), 2(b)(3) and 4(c). Recommendations are also made for Ex. 1(a); Ex. 2(a)(2-5), Ex. 4(b), Ex. 4(e).

[46] KEMI (2015a), Kemikalieinspektionen, Swedish Chemicals Agency, Contribution to Stakeholder

general relevance to all Hg exemptions are shortly summarised here. KEMI mention voluntary business initiatives such as that of IKEA who has communicated that it shall switch to selling only LED lamps in various EU countries throughout 2015 and 2016[48]. Further reference is made to an effective phase-out of mercury vapour lamps in the US mentioned in a study for the update of Ecodesign requirements for light sources prepared by VHK, in cooperation with VITO and JeffCott Associates[49]. The study is cited as follows (pg. 131): "*There is value in highlighting the mechanism used by the US to phase-out mercury vapour lamps, i.e. through prohibiting sale of the ballast rather than the lamp itself*." KEMI conclude that a phase-out of mercury in lamps is possible, even if the mechanism to achieve it may vary.

4.5 Critical Review

General note: Lamps are generally understood to be a product, which undergoes relatively short design cycles (in comparison with for example medical devices (average design cycles of 7 years). Currently the lamp sector is in the midst of a transformation from conventional technologies such as incandescent, halogen and discharge lamps towards LED technologies. Within this transition, development is understood to be quick, with some products coming onto the market only for short periods. VHK & VITO for example write in this regard "*The technology is still evolving rapidly and therefore the methods and materials used today could be outdated and outperformed in the (nearby) future*."[50]

Against this background, the study team has consciously attempted to limit the review of existing literature (studies forecasting developments of the lighting sector, available reports of comparative studies, etc.) to more recent reports, where such documents were available. In this respect, it should also be kept in mind that such studies are usually based in the best case on data collected at least half a year before the study was published and in some cases on data collected a year or two prior to publication. Thus where more recent literature was available, studies published before 2013 have not been revisited, with the understanding that results based on earlier data shall be limited in their applicability to products available on the market in 2016.

Consultation 2015-2 Request for extension of exemption 1(a-e), submitted 19.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1a-e_KEMI_Answer_to_SC_RoHS_20151016.pdf

[47] Ex. 1(a-e) and Ex. 2(a)(1-5)

[48] See provided reference http://www.ikea.com/gb/en/catalog/categories/departments/lighting/

[49] Reference provided by KEMI: Reference: http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources%20Task1_Main%20Final%2020151031.pdf See page 140 as report version has been updated.

[50] VITO & VHK (2015), Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'), Final report, Task 4, Technologies, Prepared for the European Commission, DG ENER.C.3, pg. 26, available under http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources%20Task4%20Final%2020151031.pdf

4.5.1 REACH Compliance – Relation to the REACH Regulation

Appendix A.1.0 of this report lists Entry 18 of Annex XVII of the REACH Regulation, which restricts the use of mercury. According to this entry, mercury and its compounds shall not be placed on the market or used as substances or in mixtures where the substance or mixture is intended for use:

- to prevent fouling;
- in the preservation of wood;
- in the impregnation of heavy-duty industrial textiles and yarn; and
- in the treatment of industrial waters.

Entry 18a is also listed, not allowing mercury to be placed on the market:

- In fever thermometers;
- In other measurement devices intended for sale to the general public;
- In specified measuring devices intended for industrial and professional uses;

None of the above restrictions apply to the use of mercury in CFL lamps falling under the scope of Ex. 1(a-e).

Annex XVII of the REACH Regulation also lists Entry 30 in Annex XVII of the REACH Regulation, stipulating that Hg and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public.

In the consultants' understanding, the restriction for substances under entry 30 of Annex XVII does not apply to the use of mercury in this application. Hg is used in lamps, which in the consultants' opinion is not a supply of mercury as a substance, mixture or constituent of other mixtures to the general public. Hg is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

No other entries, relevant for the use of mercury in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2015).

Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

4.5.2 Scientific and Technical Practicability of Substitution

From the information available it can be followed that substance substitutes for Hg in discharge lamps have not become available in products on the market. Various research of such alternatives have not resulted in technologies with comparable performance to that of the various discharge lamps to be discussed in the next chapters and research has been discontinued.

Regarding mercury reduction, as shall be presented in some of the chapters to follow, it is observed that progress has been made in the reduction of the amounts of Hg used in various lamps. Though it is possible that in some cases further reductions are possible, it

can be followed that this could require further research into dosing optimisation technologies and use of various materials and components that affect the "consumption" of mercury throughout lamp life and thus the need to preserve a minimal presence of mercury. As it is understood that for some discharge lamp types, a technology alternative in the form of LED is either in development or to some degree already available, it can be followed that the industry is focusing research efforts in this direction. However, as the development stage of LED alternatives differs between technologies, abandoning the reduction strategy shall need to be discussed in the context of specific technologies and sub-groups of exemptions in the following chapters. These discussions relate to the expected availability of LED alternatives and how this could affect the need for exemptions for Hg in discharge lamps in the decades to come. If exemptions are to be considered relevant despite the availability of LED substitutes (i.e. for replacement lamps) over the next few decades, the consultants cannot follow that abandoning further research in to Hg reductions is to be accepted as justified. In this respect, the consultants differentiate between the following cases:

- Cases where it is observed that implementation of LED substitutes is already widespread (or could be widespread, where obstacles such as conformity with standards or price based competition with conventional technologies could be removed). Here achieving further reductions of mercury should be dismissed in favour of adapting measures that shall facilitate the shift to LED, such as limiting exemption validity and exemption revoke.
- Cases where substitutes are still scarce and/or where available retrofit-lamps still provide inferior performance (e.g. in relation to light quality, energy efficiency, electrical compatibility, compatibility with existing luminaires in terms of dimensions, etc.). In such cases it may be relevant to further require a reduction strategy:
    - In some cases this could be accomplished through a shift to long-life lamps, for which it can be followed that in total, a lower Hg amount shall be needed to establish a certain functional life time, as compared to "normal life" lamps.
    - In other cases, though reduction should be promoted, this reduction strategy should not go so far as to create a situation in which the lack of mercury affects the functionality of the lamps (i.e., resulting in premature failures, shifts in spectral output, etc.).

Though in some cases, other Hg-free alternatives may exist, it can be understood that for the most part industry is focusing on LED technologies to deliver alternatives for the various Hg-based discharge lamp technologies. LEU mentions various aspects that need to be considered when evaluating the applicability of LED alternatives, however the relevance of such aspects is case specific and is thus discussed in relation to the various exemptions.

4.5.3 Environmental Arguments

4.5.3.1 Use of Materials and Hazardous Substances

From the information provided it can be understood that both types of lamps use similar electrical components, including the RoHS restricted substance lead, permitted in certain applications through various exemptions. Though differences may be of relevance, available information does not allow a comprehensive comparison in this respect and it can be expected that such a comparison would in any case be case specific. Where information is available to allow a more detailed discussion in relation to specific technologies, it is detailed in the chapters of relevance.

4.5.3.2 Early End of Life and Waste Management

LEU's main concern in relation to LED replacement lamps is that where they are not fully compatible as substitutes, that the early phase-out of Hg-based discharge lamps could cause an early end-of-life of installations, as once a lamp shall malfunction the luminaire shall be useless. The consultants can understand that this aspect is of concern, in light of luminaires which would need to be scrapped early, meaning that the resources used in their making shall have not served their planned product-life potential. However, this aspect needs to be observed against the types of waste that shall be created under different scenarios.

To begin with, as long as discharge lamps containing mercury are to be placed on the market, mercury shall be an aspect of concern in the waste stream, only to be resolved years after the last lamp has been placed on the market. As shortly shown in information provided by stakeholders, and as discussed below and in Section 4.5.6, it is apparent that less than the half of lamps put on the market are properly collected and subsequently disposed of and it is thus to be concluded that possible mercury emissions from such lamps are to some degree not sufficiently controlled. Regardless of the compliance of collection and recycling mechanisms with WEEE targets, the understanding that many lamps are not collected separately raises concern as to the fate of such lamps and the potential for Hg emissions. Where collection is not carried out properly, it is assumed that at least part of the mercury available in such lamps shall end up as diffuse emissions in the environment.

As for the possible early EoL of luminaires, for which replacement lamps shall not be available and the waste resulting in such cases, this argumentation should be observed with caution. To begin with, as shall be discussed in some of the exemptions, it is observed that when carried out by trained personnel, in many cases luminaires can be converted so that LED replacements can be used once modifications are applied. In such cases, though certain components may become waste (for example drivers, dimmers and reflectors) this would not apply to the whole luminaire. In a similar fashion, it can also be expected that conversion-kits shall become quickly available on the market for some luminaires, as is already the case in the USA, where conversion-kits for linear

fluorescent luminaires are addressed in studies dealing with the comparability of LFL and LED technologies[51]. Where such conversions support a shift towards more efficient and Hg-free lamps, such waste would be acceptable as it allows for other environmental benefits. It should be noted in this respect that as compact discharge lamps came onto the market, similar problems occurred as to their incompatibility with luminaires of other technologies (incandescent, halogen) in terms of weight and dimensions. This incompatibility was however accepted, as it was understood that the shift would create environmental benefits in terms of energy savings. In the shift from discharge technologies to LED technologies, in some cases energy savings can also already be observed, whereas in others they are expected in the future under the assumption of further developments of LED technologies. Furthermore, LED technology enables the elimination of mercury, which also needs to be considered as an environmental benefit to be weighed against environmental impacts of early-end-of-life of luminaires (further discussed below). It also needs to be kept in mind that early EoL of luminaires shall in any case be expected to some degree, as consumers decide to change their installations as a result of changing fashion and as a result of additional technical capabilities of new luminaires (for example in the case of LED applications: adjustable colour, or smart applications that can be controlled through the internet and through cellular applications etc.).

A further point of importance in this respect is that the RoHS Directive and its substance restrictions have been in force since 2002. The lighting industry members, which manufacture discharge lamps and, which are in many cases already shifting towards LED technologies, have been aware of these regulations for over a decade as all lamps using mercury needed an exemption from the RoHS restrictions to allow their placement on the market. In this sense, this industry who is leading the development of LED technologies has been aware for many years that a time would come where exemptions for Hg in lamps would expire in light of the development of LED alternatives. Especially as this industry faced similar problems when discharge lamps first came on the market, it is expected that the development of LED technologies be carried out so as to facilitate their uptake on the market and so as to avoid incompatibility of new lamps with old luminaires.

LEU argues that waste from EoL of luminaires is a concern, should exemptions be revoked. However, new luminaires designed for discharge lamps, explained to have life expectancies of 15-20 years or more are continuously placed on the market. The RoHS Directive restricts the use of certain substances, among others mercury, and requires products with such substances to be removed from the market where substitutes available. As lamps and luminaires are usually sold separately, the Directive cannot restrict the further sales of new luminaires designed for discharge lamps. Thus as long as luminaires can be placed on the market, the relevance of the early end-of-life argument is extended indefinitely. If the exemptions should remain available in the long term to

[51] See for example CALiPER studies, some of which are quoted in Section 8.0 of this report.

ensure the availability of replacement lamps for existing luminaires, this could prolong the use of mercury lamps indefinitely. Though one may argue that the market should be allowed to evolve naturally, this argument, principally related to environmental impacts, needs to be seen in context of other environmental aspects of the various lamp technologies, such as energy efficiency and the phase-out of mercury. Against this background, the consultants believe that should exemptions duration be extended, measures beyond the RoHS Directive should be devised to promote the uptake of Hg-free LED technologies, and subsequently the reduction of mercury and the phase-out of mercury using products.

In relation to waste, it can be followed that a recycling mechanism has been developed and is functioning towards the targets for collecting and proper treatment of Hg-based discharge lamps. Though the consultants can follow that these arguments are made to clarify that industry is in compliance with the obligations regarding the end-of life of their products, in lack of specific data relevant for each of the exemptions at hand, this information does not provide a basis for concluding as to the collection rates and the achieved recycling rates of lamps in the EU, neither in general nor in regard to a particular sort of lamp discussed in the requests at hand. Though in some cases argumentation is made against the early application of substitutes, in light of the lack of a developed collection and recycling mechanism for the newer lamp types, the information presented above only clarifies that it is in any case the obligation of industry to elaborate existing mechanisms and to provide for the collection and recycling of new types and models once these are placed on the market.

Information regarding the recycling rates of various lamp types at present is only partially available and does not allow understanding the full effectiveness of such systems. Nonetheless, from other available information it can be understood that the collection and recycling rates are still not as high as is required in general for EEE under the WEEE Directive in all Member States.[52] This, in itself, is of concern in light of the mercury contained in such lamps and the uncertainties as to the fate of such lamps at EoL.

In light of this information the consultants can follow that a further effort is still required to improve the various mechanisms, among others in light of the difficulty to promote consumers to participate in the separate collection of lamps. In any case it is assumed that should new types of lamps come onto the market in the coming years in larger quantities, that industry would be required to further develop existing mechanisms so as to also handle such items at end-of-life to enhance collection and to improve recycling techniques.

[52] For example, information provided by DEPA and by Health FGOV for example cites collection rates below those provided by LEU in relation to specific countries.

The Fate of the RoHS Exemptions for Mercury in Lamps and Subsequent Impacts on the Environment

In general, for a specific application, the provision of an exemption means that RoHS restricted substances are brought on to the European market through that application, while once an exemption expires, the environmental impact related to that substance is avoided. Each of these scenarios, however, results in additional impacts on the environment, related to the use of resources of the application or its substitutes, impacts related to their end-of-life, etc. For the lamp this suggests that it would be necessary to evaluate the two following scenarios in the context of the RoHS Directive and its criteria for exemptions:

- Prolongation of existing exemptions for Hg lamps, resulting in diffuse Hg emissions in the environment in the magnitude of half of the amount of Hg applied in lamp production (i.e. assuming the other half is collected and recycled).
- Revoke of existing exemptions for Hg-lamps, resulting in less diffuse Hg emissions in the environment but additional emissions from waste management procedures due to the early end-of-life of existing installations / luminaires.

Information by LEU in this respect however remains general in nature and does not allow understanding the range of possible impacts nor the various factors that would need to be considered to understand the volume of such impacts. In this respect it is worth noting some of the factors of relevance.

On the component level, various LCAs have been performed (see further details in Section 4.3.3.1 and also Section 5.5.2.2 for the review of such information) between certain discharge technologies and their respective LED alternatives. The most common focus of such studies has been the comparison of CFLs with incandescent lamps and LED alternatives therefor. However, some LCA data or other types of comparative comparisons are also available for example for LFLs as well as for high intensity discharge (HID) lamps. LCA comparisons of single products are complex and do not provide a basis for clear conclusions as to other technologies. However, LEU itself states that "*There is general agreement, that the main environmental impact is created during the use phase, meaning through electricity consumption when burning the lamp. This means that currently the efficacy of the lamp is the determining parameter. Specifically regarding mercury, the biggest amount is released to the environment by power plants when generating energy (especially when coal is the primary power source)*."[53] In this sense it can be concluded that if the efficacy of LED alternatives is comparable to the discharge technology that it is replacing, that from a component perspective that LEDs could be considered at least similar in terms of their environmental impact. The "components" for which this statement needs to be scrutinized more carefully are on the one side the Hg

[53] This statement appears in many of the applications. See for example LEU Ex. 2(b)(3)(2015a)

containing component of discharge lamps (dosed for example as amalgam pills in some cases) and on the other the heat sink of LEDs when it is based on aluminium. During use, however once efficacy is comparable, LEDs would be understood to have an advantage as the Hg emission related to energy consumption would be similar and LEDs do not contain mercury.

If to go a step further, on the system level, the potential for early-end-of life of luminaires needs to be weighed against the actual waste produced and how it is handled. As explained above, even were an exemption for a certain technology to be revoked, it should not be assumed that the respective luminaire stock would be scrapped as a result thereof.

- In some cases luminaires would have been scrapped anyway, in light of natural end-of-life or decisions of consumers to replace luminaires in light of new technological advantages, changing fashions, renovation of buildings, etc. Some of the existing luminaires may indeed be scrapped gradually as last lamps burn-out. For such installations it can be understood that the luminaires would be collected and handled along with other electronic waste. As a large share of such articles is expected to be various metals such as iron, copper and aluminium, it can be expected that such materials would be recycled and would return to the market as secondary materials.
- In others it can be expected that consumers would be able to use available LED alternatives in existing discharge luminaires to enable their further use, even if these would require conversions in some cases. In other words for some of these luminaires early EoL is not expected, while for other early EoL is only relevant for the parts scrapped through conversion (for example electric components such as ballasts). Here too a share of such components can be expected to be recycled and returned to the market as secondary material.

The share of luminaires scrapped as detailed above can be expected to vary for different technologies, depending on the availability of different types of alternatives as well as on the age distribution within the luminaire stock and its respective lifetime. Materials to be recycled would reduce to some degree the expected “cost” of early EoL. In parallel, these impacts would also need to be weighed against the potential of new technologies (such as LED) to save energy and of course to eliminate mercury. On the one side, LED luminaires may in some cases be more resource intensive than discharge ones, for example, where they require measures for dissipating heat such as in lamps with higher lumen output. On the other side, in technologies where larger amounts of mercury need to be dosed, the elimination of Hg from the lamp may balance out the Hg related to energy consumption of luminaire production.

This discussion is only indicative; however it should serve to show the larger context in which the argumentation of early EoL of lamps should be observed.

4.5.4 Safety Aspects

LEU raises concern related to the possible revocation of the exemptions for Hg in discharge lamps, on the basis that where replacement lamps are not available as drop-in substitutes, that adaptation of the installations to accept available alternatives may affect the warranty as well resulting in possible safety impacts. In the consultants view, it needs to be assumed that where such changes should be needed, that they would be carried out (at least for the most part) by technical professionals. Such professionals are expected to have the capability to perform rewiring and conversions without resulting in safety related consequences and in this sense this argumentation cannot be understood to justify an exemption in light of possible future safety issues. Furthermore neither type, nor probability, of the safety issues are described sufficiently in order to assess whether these issues outweigh the benefits from substitution.

4.5.5 Road Map to Substitution

LEU explains that research and development efforts into substitutes for Hg in discharge lamps have ceased, and that all present efforts are directed at the further development of LED technologies. The consultants understand the reference to such research to relate to the possibility of enabling further reductions of Hg doses in discharge lamps as well as to research into possible substance alternatives for Hg in such lamps. There have been cases in the past where exemptions were extended as it became clear that alternatives needed a few more years of development to ensure the applicability of substitutes and their reliability for the respective product range or to ensure the availability of a suitable volume of products on the market. However in contrast to such cases, the case of discharge lamp technology as presented by LEU is not understood to require a grace period of another few years but of a much longer period.

In parallel LEU explains that a full transition to LED in some product groups should only be considered after sufficient time has been provided to resolve the technical issues described and to allow EU users time to make changes without negative safety or socio-economic impacts. The consultants understand from these statements that where LED alternatives shall not enable substitution of discharge lamps within existing installations, that there is no intention of developing other alternatives. LEU, further explains in their documents, that Hg-based discharge lamps could be needed in some cases for over 25 years to avoid possible environmental costs of early EoL of luminaires. LEU was thus asked to clarify if the renewal for some exemptions could be limited to the application of Hg in lamps to be used in installations placed on the market in the past.

LEU explains:

> "*at the moment mercury containing lamps are still used in new installations… Luminaires for general lighting are usually marketed without the lamp. There is no legal ground within the RoHS Directive to prohibit a luminaire or fixture if prohibited substances are not contained exceeding the threshold of RoHS. This would also be very difficult to survey. In every exemption there are many applications where no alternative technology is available, that is fully suitable for the customers' purpose and has comparable or better technical, environmental or*

safety characteristics. Customers must have the option to buy a new luminaire fitting to their existing installation e.g. additional luminaires of exactly the same type to be able to realize the desired solution...".

Though such argumentation may be relevant for phasing out of certain technologies, the consultants are of the opinion that a situation in which a new product using a certain component is still placed on the market cannot be considered a near phase-out situation. This is particularly so given that LEU argues that availability of lamps (i.e. the component) in such products could be relevant for over 25 years in some cases. It also needs to be noted in respect with the last part of the above statement that customers may not always have the chance of purchasing a *"new luminaire fitting to their existing installation"*, regardless of the fate of the discharge lamps, because luminaire models are changed and adapted with time and as a reaction to fashion. In this sense, this argumentation cannot be followed as a justification for extending the Hg exemptions, according to the applicants' requests, for what could be a cumulative period of 15 to 20 years.

4.5.6 The Minamata Convention

LEU rightly claims that lamps allowed on the market through the current exemptions comply with the restrictions of the Minamata convention. However, it is noted that:

> "*nothing in this Convention [i.e. Minamata – consultants addition] prevents a Party from taking additional domestic measures consistent with the provisions of this Convention in an effort to protect human health and the environment from exposure to mercury in accordance with that Party's other obligations under applicable international law*".[54]

The restrictions specified in the Minamata Convention are understood to aim at a global mercury reduction. This is to be accomplished by, inter alia, ensuring that countries where legislation for regulating the use and the emissions of Hg are not as developed or are lacking, are required to apply minimum requirements, which have evolved in some of the other countries.

RoHS restricts the use of mercury in general, and only in some cases are exemptions for further use provided. The fact that products made available on the EU comply with the Minamata restrictions is not understood to contribute to the discussion on the renewal of the remaining exemptions for Hg in lamps. This aspect does not relate to the Article 5(a) criteria for justifying an exemption and is thus not a relevant argument for this purpose.

[54] Op. cit. UNEP, 2016

4.5.7 Stakeholder Contributions

DEPA provides estimations as to the risks associated with lamp breakage, as well as presenting results of surveys where private consumers were asked if they had had to deal with breakage of an Hg lamp in the past and how this was done.

The consultants agree that the information presented justifies concern that emissions of Hg during the use phase of lamps are of relevance and thus cannot be considered to be sufficiently controlled at present.

LEU mentions the mechanism for the collection and recycling of discharge lamps and provides general data as to the collection rates estimated for all discharge lamps. Though the consultants do not disregard the effort made to develop this mechanism, information provided by different stakeholders show that its achievements need to be observed in perspective:

- Health FGOV raises concern as to the number of lamps not collected by the mechanism and as to their fate and that of the mercury contained in their burners. It explains that there are indications that less than 50% of CFL lamps have been collected through the mechanism in 2014 in Belgium. It also points out that the WEEE Directive does not require 100% collection, but that industry is merely required to meet certain targets. Concern is also raised as to future uses for recycled mercury from lamps, which can be expected to still enter the waste stream for many years, even after the Hg-lamp exemptions are to expire.
- DEPA raises concern as to the fate of lamps which are not recycled properly and provide information from consumer surveys as to lamp disposal. A study estimating the amount of mercury present in Danish municipal waste is also provided, raising concern as to the possible emissions related to such lamps when not disposed of properly.

As for the contributions of KEMI and EEB et al., the main aspects arising from these documents are discussed in the context of the specific exemptions to which they are related. The reference of KEMI to the possibility of prohibiting the sale of ballasts rather than prohibiting the sales of lamps is an interesting approach. However, developing such a measure under RoHs could only be relevant as long as the RoHS substance, in this case mercury, is present in the component. Ballasts for example can be regulated through the EcoDesign Directive to ensure energy efficiency and this could also be done to promote the uptake of LED alternatives where they provide higher energy efficiency. Nonetheless, under RoHS this proposal would not be feasible as ballasts for example do not contain mercury and can thus not be denied market access as a way of eliminating this RoHS restricted substance.

The consultants can follow that the risk of emissions from Hg lamps during the end-of-life phase are of concern, despite the collection rates stated by LEU. Despite the efforts made and the first achievements, which should not be disregarded, the consultants' are of the opinion that Hg emissions in the end-of-life phase cannot be considered to be sufficiently controlled in light of improper lamp disposal by consumers.

The contribution submitted by TMC raises a legal question as to the availability of the current exemption to category 9 equipment. Regardless of TMCs claims as to the availability of Annex III exemptions to sub-category 9 industrial for 7 years starting in 22.7.2017, in the case of the lamp exemptions the wording formulation limits their applicability to lamps. Though in theory, such lamps could be used in Cat. 9 products, this aspect has not been raised by the applicant or other stakeholders to be an area of application. Furthermore, should such a lamp be used as a component in EEE of Cat. 9, it would still benefit from the exemption as long as it is valid and as long as the wording remains unchanged. Should substitutes become available however, it would be of importance to evaluate their applicability in all possible applications at the same time. In this sense, in the consultants opinion, though some Cat. 9 products could enjoy a validity period of the current exemption up till 2024 (Cat- 9 industrial), it would still be considered beneficial to align the exemption validity of all categories. In contrast, should certain entries of the exemption change, or be revoked, the current formulation would need to remain available to Cat. 9 Articles, which at least from a legal perspective are entitled to benefit from the current exemption for a longer period (until 2021 or 2023, depending on sub-category). This logic is also understood to apply to CFL lamps used in devices falling under Cat. 8.

4.5.8 The Scope of the Exemption

A further aspect that should be considered is the availability of lamps falling under Exemptions 1-4 to EEE in other categories. In general, a lamp is understood to be a component, either used in light equipment that would fall under Cat. 5, or used in other equipment of other categories. As long as an exemption is available, the use of lamps covered by such exemptions as a component in equipment is understood to be possible in equipment of all categories. In this respect, the consultants would generally recommend limiting the exemption entries to category 5.

That said, in the case of Cat. 8 (medical devices) and Cat. 9 (monitoring and control devices) this aspect may need to be handled differently. Only for a few of the entries covered by Exemptions 1-4 is there information that allows concluding that EEE falling under these categories actually makes use of lamps covered by the various entries as components. For example, some of the lamps falling under Ex. 1(f) are used in medical equipment. However where such information is not available, the opposite (i.e. that the exemption is not relevant for such equipment) cannot be concluded at present. In light of Article 5(2), from a legal perspective, excluding EEE falling under Cat. 8 and 9 from the scope of these exemptions may not be possible; however the consultants' are also concerned that extended availability of such lamps for these categories may create a loophole for consumers seeking lamp replacements covered by entries that are due to expire. If possible, the Commission should investigate limiting the sales of such lamps to a business-to-business basis to avoid such misuse.

4.6 References Exemptions 1-4 – General Aspects

Danish EPA (2015a) Ministry of Environment and Food of the Danish Environmental Protection Agency, Contribution to RoHS Stakeholder Consultation Regarding 29 Exemptions, submitted 8.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/Stakeholder_consultation_RoHS_-_29_exemption_in_Annex_III.pdf,

Danish EPA (2016a) Ministry of Environment and Food of the Danish Environmental Protection Agency, Answers to Clarification Questions as to Contributed Documents, Prepared Towards Meeting at Oeko-Institut e.V., Berlin, Friday 5th February 2016, submitted per email 4.2.2016

EEB et al. (2015a) The European Environmental Bureau, the Mercury Policy Project, and the Responsible Purchasing Network, Environmental NGOs Response to Stakeholder consultation 2015 #2 on mercury-containing lamps – Exemption 1-4 (Review of Annex to the RoHS directive), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1-4_EEP-RPN-MPP_Comments_on_RoHS_Request-final_20151016.pdf

Health FGOV (2015a) The Belgish Federal Public Services for Health, Food Chain Safety and Environment, Belgian communication for the public consultation on the renewal of the ROHS exemptions on the Mercury containing lamps, submitted 16.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/Ex_1-4_FPS_Health__Food_chain_safety_and_Environment_Be_position_Hg_lamps_20151016.pdf

KEMI (2015a) Kemikalieinspektionen, Swedish Chemicals Agency, Contribution to Stakeholder Consultation 2015-2 Request for extension of exemption 1(a-e), submitted 19.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1a-e_KEMI_Answer_to_SC_RoHS_20151016.pdf

LEU Ex. 1-4 (2015a) LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 1-4 (renewal requests) General Questions for Lamp Exemptions Related to Mercury, submitted 25.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/LE_Ex_1-4_LightingEurope_General_Clarification-Questions_Final.pdf

LEU Ex. 1a (2015a) Lighting Europe, Request to Renew Exemption 1(a) under the RoHS Directive 2011/65/EU Mercury in Single-Capped (Compact) Fluorescent Lamps Below 30 W, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Lighting_Europe/1a_LE_RoHS_Exemption_Req_Final.pdf

LEU Ex. 2(a)(1)(2015a) Lighting Europe, Request to Renew Exemption 2(a) under the RoHS Directive 2011/65/EU 2(a) Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp): 2(a)(1) Tri-band phosphor with normal lifetime and a tube diameter < 9 mm (e.g. T2): 4 mg may be used per lamp after 31 December 2011, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/Lighting_Europe/2a1_LE_RoHS_Exemption__Req_Final.pdf

NARVA (2014a) NARVA Lichtquellen GmbH + Co. KG, Exemption request for using of mercury in fluorescent lamps, submitted 19.12.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/NARVA/01_02_a__2b3_4a.pdf

PZPO (2015a) Polish Association of Lighting Industry, Comments to Annexes III and IV Directive 2011/65/EU (RoHS), submitted 5.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Directive_RoHs_-_PZPO_comments_05_10_15_eng.pdf

TMC (2015) Test & Measurement Coalition, General comments related to RoHS exemption package 9, submitted 16.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/General_Contribution_Test___Measurement_Coalition_package_9_exemptions_20151016.pdf

UNEP (2016) Minamata Convention on Mercury Website, http://www.mercuryconvention.org/Convention last accessed 4.3.2016

VITO & VHK (2015) Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements (‘Lot 8/9/19’), Final report, Task 4, Technologies, Prepared for the European Commission, DG ENER.C.3, pg. 26, available under http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources%20Task4%20Final%2020151031.pdf

5.0 Exemption 1(a-e): "Mercury in single capped (compact) fluorescent lamps not exceeding (per burner)”

This review of Annex III exemption 1 covers the following exemption entries:

(a) For general lighting purposes < 30 W: 5 mg

(b) For general lighting purposes ≥ 30 W and < 50 W: 5 mg

(c) For general lighting purposes ≥ 50 W and < 150 W: 5 mg

(d) For general lighting purposes ≥ 150 W: 15 mg

(e) For general lighting purposes with circular or square structural shape and tube diameter ≤ 17 mm

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

B2B	Business to business
CFL	Compact fluorescent lamp
CFLi	CFL with integrated ballast
CFLni	CFL with non-integrated ballast
EEE	Electrical and Electronic Equipment
EM	Electromagnetic: lamp control gear based on a magnetic coil (= CCG)
HF	High frequency: lamp control gear based on high frequency (= ECG)
Hg	Mercury
LEU	LightingEurope
NARVA	NARVA Lichtquellen GmbH + Co. KG
EoL	End-of-life

5.1 Background

LightingEurope (LEU) and NARVA Lichtquellen GmbH + Co. KG (NARVA) have both applied for the renewal of Ex. 1, items a-e, of Annex III of the RoHS Directive. This exemption covers single capped (compact) fluorescent lamps.[55]

NARVA[56] explains that lamps falling under these exemptions are discharge lamps, which use mercury for the discharge process, arguing that there are no substitutes for Hg in discharge lamps.

In relation to substitutes, LEU[57] mentions that though more and more LED solutions come to the market, they cannot always serve as a fully compatible replacement for the huge variety of CFL lamps for consumers and professional end users.

Both applicants apply for the renewal of Ex. 1 entries a-e, with the current wording formulations listed in Annex III of the RoHS Directive and requesting the maximum available duration allowed (based on Art. 5(2) of the Directive).

5.1.1 Amount of Lead Used under the Exemption

To provide an estimation of the amount of Hg entering the EU through CFLs per annum, LEU[58] refers to the VHK report "Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling, Requirements ('Lot 8/9/19'), Draft Interim Report, Task 2" [59] prepared for the EC. This report indicates a total volume of CFL lamps in EU 28 of 342 Mpcs in 2013, a volume, which includes all wattages. An external report indicating the exact wattage split is not available, however based on experience of the LEU members, an estimation is made as to the break-down of this number to various wattages. The assumption along with the estimated respective amounts of Hg to come on the EU market through the applications covered by each exemption entry is detailed in

Table 5-1.

[55] LEU Ex. 1a(2015a), LightingEurope, Request to renew Exemption 1(a) under the RoHS Directive 2011/65/EU Mercury in single-capped (compact) fluorescent lamps below 30 W, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Lighting_Europe/1a_LE_RoHS_Exemption_Req_Final.pdf

[56] NARVA (2014a), NARVA Lichtquellen GmbH + Co. KG , Exemption request for using of mercury in fluorescent lamps, submitted 19.12.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/NARVA/01_02_a__2b3_4a.pdf

[57] Op. cit. LEU Ex. 1a(2015a)

[58] Op. cit. LEU Ex. 1a(2015a)

[59] Quoted in LEU Ex. 1a(2015a) as: Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'). Draft Interim Report, Task 2 by Prepared by VHK, in cooperation with VITO and JeffCott Associates Date: 19 November 2014, Table 1.

Table 5-1: Breakdown of total CFL market share according to wattages (RoHS exemption item) and respective Hg amounts

CFL Type[2]	EU market share of CFL	Calculated EU market volume in 2013[1]	Maximum allowed Hg	Hg brought on the market through application - worst case[4]
All	100 %[3]	342 Mpcs	-	945 Kg (100%)
Ex. 1(a): < 30 W	85 %	291 Mpcs	2.5 mg	727 kg (77%)
Ex. 1(b): ≥ 30 W and < 50 W	10%	34 Mpcs	3.5 mg	120 kg (13%)
Ex. 1(c): ≥ 50 W and < 150 W	3%	10 Mpcs	5 mg	51 kg (5%)
Ex. 1(d): >150 W	0.5%	2 Mpcs	15 mg	26 kg (3%)
Ex. 1(e): circular or square structural shape	0.5%	3 Mpcs	7 mg	21 kg (2%)

[1] Total sum according to LEU Ex. 1a(2015a), based on total market volume in pieces taken from VHK report for EU; exemption item specific data is calculated on that basis.
[2] Source for all other data is taken from LEU Ex. 1a(2015a), LEU Ex. 1b(2015a), LEU Ex. 1c(2015a), LEU Ex. 1d(2015a) and LEU Ex. 1a(2015a), respective to the relevant exemption item.
[3] According to LEU Ex. 1(2015b), 1% of this quantity is associated with lamps falling under Ex. 1(f).
[4] Shares are calculated and do not appear in source.

LEU further uses information from a McKinsey study quoted in the VHK report to forecast how the amount of Hg should change until 2020. The main reason for the reduction is explained to be the increased penetration of LED alternatives due to their expected decreasing price, improved availability and better suitability as replacements for the different CFL lamp types. LEU emphasizes that this is an estimation of the upper limit based on the threshold value of the Directive. In reality the amount entering the market is expected to be lower, as the average dose per lamp is most often below this threshold value (see Figure 4-2 in general chapter). LEU estimates that the average value is roughly 20% below the threshold value. This exercise is carried out for each of the Ex. 1 items and is summarised in

Table 5-2.

Table 5-2: Evolvement of Hg amounts to be placed on the EU market through exemption 1(a-e) between 2013 and 2020

Ex. 1 item	Share of all CFL lamps	Hg placed on EU market per annum						Comments
		2013		2016		2020		
All	100%	945 kg	342 Mpcs	615,5 kg	222 Mpcs	262,5 kg	93 Mpcs	All CFLs on the market - reference
a)	85%	727 kg	291 Mpcs	472 kg	189 Mpcs	198 kg	79 Mpcs	
b)	10%	120 kg	34 Mpcs	78 kg	22 Mpcs	33 kg	9 Mpcs	
c)	3%	51 kg	10 Mpcs	33 kg	7 Mpcs	14 kg	3 Mpcs	
d)	0.5%	27 kg	2 Mpcs	17 kg	1 Mpcs	7 kg	0.5 Mpcs	
e)	0.5%	21 kg	3 Mpcs	15.5 kg	1 Mpcs	10.5 kg	0.5 Mpcs	

Source of data is taken from LEU Ex. 1a(2015), LEU Ex. 1b(2015), LEU Ex. 1c(2015), LEU Ex. 1d(2015) and LEU Ex. 1a(2015), respective to the relevant exemption item. Lamp volumes for individual entries are calculated based on total and share data from source.

5.2 Description of Requested Exemption

Compact fluorescent lamps come in a wide variety of shapes, sizes and wattages. A few examples are given in Table 5-3. CFLs can have the electronic control gear integrated in the product (internal ballast/self-ballasted CFLs or CFLi's) or their control gear is separated from the lamp (external ballast / plug-in CFLs or CFLni's).

Table 5-3: Examples of CFL lamps

Source: Left image: Typical shapes and forms, taken from LEU Ex. 1a (2015a); Right image: Comparison of lamps of smaller wattages with lamps of higher wattages, taken from LEU Ex. 1(d)(2015a); Bottom image: examples of lamps falling under Ex. 1(e), taken from LEU Ex. 1d (2015a).

According to LEU[60], compact fluorescent lamps used in residential environments can be found in applications where they act as an energy saving solution for the now banned incandescent lamps. CFL lamps in professional applications are used as energy saving

[60] Op. cit. LEU Ex. 1(a)(2015a)

solutions and are found in many down-lighters providing general lighting in for example shops, banks, schools, malls, hotels (reception, restaurants, bars, lobby, corridors, rest areas, conference rooms), galleries, offices (reception, lobby, meeting rooms, corridors, rest areas) and sporting facilities (gyms). Many luminaires have been specifically designed for the use of the CFL lamps.

Compact fluorescent lamps in category 1(a)(< 30 W) include lamps for residential and professional use.[61] Typical applications of the category 1(b)(≥ 30 W and < 50 W) are offices, public buildings, shops supermarkets and department stores, hotels, restaurants, industry, outdoors in residential areas and parks[62]. CFLs of categories 1(c and d)(≥ 50 W and < 150 W; >150 W) are mostly lamps for professional use.[63], [64] CFLs in category 1(e) (circular or square structural shape) include lamps for specific applications in residential and professional use.[65]

LEU[66] explains that for the current installed base of luminaires and lighting systems employing discharge lamps, replacement light sources based on discharge lamp technology will be needed for a long time. A typical refurbishment cycle in shops and offices is on average 7 and 12 years respectively and for street lighting it is even up to 30 years.[67]

Data are provided as to the various characteristics of CFL lamps falling under the various entries, as compiled in Table 5-4 below:

Table 5-4: Characteristics of CFL lamps falling under ex. 1(a-e)

CFL Type[1]	CRI	Colour temperature range	Light output range	Energy efficiency range	Lifetime range
Ex. 1(a): < 30 W	Above 80	warm white (2200K) to cool daylight (6500K)	150-2500 lm	50-80 lm/W	6000-20000 hours
Ex. 1(b): ≥ 30 W and < 50 W	Above 80	warm white (2700K) to cool daylight (6500K)	2000-4000 lm	70-80 lm/W	10000-20000 hours
Ex. 1(c): (≥ 50 W and < 150 W	Above 80	warm white (2700K) to cool daylight (6500K)	4000-12000 lm	70-80 lm/W	10000-20000 hours
Ex. 1(d): ≥ 150 W	Above 80	warm white (2700K) to cool daylight (6500K)	Typically above 12000 lm	70-80 lm/W	10000-20000 hours
Ex. 1(e):	80	warm white (2700K) to cool daylight (6500K)	Not specified	50-80 lm/W	6000-20000 h

[1] Source for further data is taken from LEU Ex. 1a(2015), LEU Ex. 1b(2015), LEU Ex. 1c(2015), LEU Ex. 1d(2015) and LEU Ex. 1a(2015), respective to the relevant exemption item.

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[61] Op. cit. LEU Ex. 1(a)(2015a)
[62] Op. cit. LEU Ex. 1(b)(2015a)
[63] Op. cit. LEU Ex. 1(c)(2015a)
[64] Op. cit. LEU Ex. 1(d)(2015a)
[65] Op. cit. LEU Ex. 1(e)(2015a)
[66] Op. cit. LEU Ex. 1(a)(2015a)
[67] Op. cit. LEU Ex. 1(a)(2015a) and LEU Ex. 1(e)(2015a) – do not mention street lighting; LEU Ex. 1(b)(2015a); LEU Ex. 1(c)(2015a); LEU Ex. 1(d)(2015a)

LEU[68] refers to data from the VHK report[69] indicating a split between residential and non-residential used lamps in 2013 and a split into CFL integrated (CFLi) and non-integrated (CFLni) versions. These data indicate the following for the total CFL range in 2013 (all exemptions)[70]:

- **Residential:** 184 Mpcs (54%) of which 162Mpcs CFLi (~88% thereof) and 22 Mpcs CFLni (~12% thereof);
- **Non-Residential (Professional):** 158 Mpcs (46%) of which 108 Mpcs CFLi (~68% thereof) and 50Mpcs CFLni (~32% thereof).

The VHK[71] report provides an overview of 'stock', being the installed base of CFL lamps in 2013. This shows that in residential areas 2580 million CFL lamps are installed, of which 2296 million units are CFLi lamps (~89% thereof) and 283 million are CFLni versions (~11% thereof). The non-residential (professional) area consisted in 2013 of an installed park of 1881 million CFL lamps of which 1531 million pieces were CFLi (~81% thereof) and 350 million pieces CFLni (~19% thereof).

LEU[72] further explains that from a lamp-technical point of view CFLni's and CFLi's are not so different, except that the first use external ballasts (EM or HF) and have different caps. However, from a driver-technical point of view, the two groups (CFLni's and CFLi's) are quite different, i.e. in respect of the presence of a driver in CFLi's. CFLni's cannot be tuned for optimal cathode operation with a specific driver as it happens for CFLi's, which have specific ballasts for the lamp. The "ni" versions need to be designed for a variety of drivers available on the market which causes a lot of spread on the cathode condition. This is to a certain extent solved by using specific lamp bases (examples are provided in LEU Ex. 1(2015b)). Both lamp versions can be dimmable when specific designed ballasts are used. Inherent for the CFLi lamps is that lamps and ballasts are tuned to each other, whereas for the ni lamps again a range of ballast versions is available complicating the diversity even further. For both CFLi as well as CFLni types there are specific lamp-luminaire combinations. CFLni's in many cases are installed in luminaires containing 2-4 lamps, which implicates higher temperature of the lamp during burning. Typical examples of products are given in LEU's application document for Ex. 1c in Section 4.1.1., referenced as LEU Ex. 1(c)(2015a).

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68 LEU Ex. 1(2015b), Lighting Europe, Answers to 1st Questionnaire Exemption Request No. 1(a-e), submitted 15.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Lighting_Europe/Ex_1_a_e__LightingEurope_1st_Clarification-Questions_final.pdf

69 See footnote 59 for LEU reference of VHK study, Table 3 and Table 4.

70 Data is udnerstood to represent new lamps placed on the market in 2013.

71 VITO & VHK (2015), Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'), Final report, Task 4, Technologies, Prepared for the European Commission, DG ENER.C.3

72 Op. cit. LEU Ex. 1(2015b)

5.3 Applicant's Justification for Exemption

LEU explains that manufacturers offer a wide variety of energy efficient lighting products in their portfolio, providing customer choice for professional and residential use. LEU warns that banning mercury or setting very strict limits on its use will eventually prohibit the use of fluorescent technology for lighting. This means a serious reduction of customer choice for energy efficient lighting solutions.

5.3.1 Possible Alternatives for Substituting RoHS Substances

LEU details some of the efforts in seeking an alternative for mercury in the discharge lamps, concluding that substitutes for Hg in the discharge technology are not available. Details can be found in the application documents as well as in part in Section 4.3.2.1 of this report.

5.3.2 Possible Alternatives for Eliminating RoHS Substances

In relation to the CFL lamps, LEU[73] mentions that a mercury free available technology is halogen. Halogen lamps can be a retrofit solution for some of the applications, but not for all. LEU[74] later refers to the stage 6 requirements of Commission Regulation EC/ 244/2009, which bans halogen bulb solutions and is to come into force in Sept 2018. Taking this ban into consideration, the estimated share of LED lamps sold from January 1 2019 is 100% if only Hg free technologies shall remain available on the market.

LEU[75] further provides detail about LED technologies which are rapidly developing and are considered an important alternative to discharge technology. It is explained that the lighting market is rapidly changing from discharge lamp technology to LED technology; however the change is explained mainly to be occurring in the new installation share of the market (new luminaires). Details can be found in the application documents and in Section 4.3.2.2 in general chapter. LEU reminds that CFL lamps are installed in a huge variety of types, shapes, sizes, wattages and colours, and claims that LED retrofit solutions are entering the market for just a few of these types. It is questionable if LED retrofit solutions will be developed for the total of this complex and scattered landscape with often small series per type. In relation to lamps of the specific entries, LEU also mentions the following points:

- More and more LED solutions come to the market; however they cannot always serve as a fully compatible replacement for the huge variety of CFL lamps falling under Ex. 1(a) (< 30 W) for consumers and professional end users.[76]

[73] Op. cit. LEU Ex. 1(a)(2015a)
[74] Op. cit. LEU Ex. 1(2015b)
[75] Op. cit. LEU Ex. 1(a)(2015a)
[76] Op. cit. LEU Ex. 1(a)(2015a)

- The main characteristics of lamps falling under Ex. 1(b) (≥ 30 W and < 50 W) is that they emit high lumen packages (2000 – 4000 lumen). Lamps falling under Ex. 1(c) (≥ 50 W and < 150 W) and lamps falling under Ex. 1(d)(≥ 150 W) are also explained to emit high lumen packages (4000 – 12000 lumen[77] and 12000 lumen[78] and more respectively). LEU explains that the development of LEDs with higher lumen packages (above 1500 lumen) is focussing on new luminaire solutions instead of retrofit CFL substitution. As a result, not many replacement solutions for this specific category in LED are available on the market.[79]
- Furthermore, most of the lamps falling under Ex. 1(d)(≥ 150 W) are self-ballasted, though both CFLi and CFLni versions are available. For CFLi (self-ballasted) lamps in high wattages (>150 W) no retrofit LED replacements are available on the market reaching the same lumen output.[80]
- Lamps in exemption 1(e) are clearly a different group of lamps than in the other exemption requests under exemption 1 because of their different shape and specific application. Lamps in this category can be with integrated driver (CFLi) or without (CFLni). The relative small volume of this application and the higher cost of a real replacement lamp (giving the same light characteristics) limit the number of alternative LED lamps offered on the market. LED technology developments are addressing one-on-one replacements for this segment (some examples are provided), but this will not result in a situation which would allow for full replacement of the current discharge lamps portfolio within the timeframe of the exemption. [81]

In this respect a few points are raised specifically related to the shortcomings of LEDs as replacements for CFL discharge lamps, including:

- CFL lamps are more of omnidirectional nature, while LEDs by nature emit their light more directionally, making one to one replacement difficult. [82]
- Luminaires are often dedicatedly designed for use of a high lumen CFL lamp. The size and shape of the reflector of the luminaire is fitted with the so-called Light centre length of the lamp to get the desired light distribution. Substitution of the lamp in such a luminaire by LED or HID is problematic as the Light centre and/or the direction of the light can differ significantly from the CFL lamp. Replacing an omnidirectional fluorescent lamp with a (bigger) directional LED lamp can result in reduced illuminance at the work place, changed uniformity ratios on floor and surroundings and even in unwanted

[77] Op. cit. LEU Ex. 1(c)(2015a)
[78] Op. cit. LEU Ex. 1(d)(2015a)
[79] Op. cit. LEU Ex. 1(b)(2015a)
[80] Op. cit. LEU Ex. 1(d)(2015a)
[81] Op. cit. LEU Ex. 1(e) (2015a)
[82] Op. cit. LEU Ex. 1(a)(2015a)

glare, sometimes requiring a new light plan design (renovation; installation of new luminaires). In street lighting the light distribution is bound by legal requirements, which can be a problem when installing a LED alternative in a CFL luminaire. On the right a 32 W CFL is shown next to a 25W LED bulb giving the same lumen output. The difference in size shows obvious problems when fitting in the CFL down light luminaires. [83]

Figure 5-1: Demonstrative comparisons of CFL lamps and LED alternative lamps

Referred Source in LEU Ex. 1a(2015a): http://www.energystar.gov/index.cfm?c=lighting.pr_what_are

CFL 32W and LED 25W with same lumen package from LEU Ex. 1b(2015a)

CFL and LED in the same 6' and 10' down light fixture, from LEU Ex. 1b(2015a)

- Where reflectors are used in installations, they are designed for the shape, dimensions and burning position of a CFL lamp to generate the desired light distribution. The more directional light of an LED will give a different light distribution in a CFL luminaire with reflector. This can result in reduced illuminance at the work place, changed uniformity ratios on floor and surroundings, unwanted glare and possibly require a new light plan design. [84]
- Some CFL luminaires are designed for 2 lamps. Differences in size of the LED alternatives can cause problems in fitting both lamps in the luminaire. [85]

[83] Op. cit. LEU Ex. 1(b)(2015a)
[84] Op. cit. LEU Ex. 1(a)(2015a)
[85] Op. cit. LEU Ex. 1(a)(2015a)

Figure 5-2: Demonstration of incompatibility of LED alternative lamps with luminaires designed for multiple lamps

Source: LEU Ex. 1a(2015a)

- The current lamp holders are designed to carry the weight of the existing CFL lamps. Safety standard for CFL lamps (EN60968) prescribes a maximum weight and bending moment to prevent a too high loading of the lamp holder. LED lamps can have a higher weight and bending moment than CFL lamps due to the necessary heat sink which needs to be close to the LEDs to remove the heat from the diodes. The weight of the LED solution often exceeds the values for CFL. [86]
- Luminaires for CFL are designed for the thermal properties of a CFL lamp and not to control the heat as required for dedicated LED fixtures. Direct application of LED replacement lamps instead of CFL can cause thermal problems in closed and/or narrow CFL luminaires. [87]
- The external lamp driver can be a conventional ballast or an electronic control gear. The market for new installations is moving toward electronic control gear due to new functionality (e.g. dimmability) and upcoming energy efficient legislation for the driver. Many CFL lamps used by professional end users are designed to be dimmable. Several modes of dimming (e.g. phase cutting) are present in the market. All modes of operation (EM, HF current controlled, power controlled, voltage controlled, preheat, non-preheat) have in common that the light source is expected to behave electrically as a standardised CFL lamp. The large diversity of drivers is not meant for an

[86] Op. cit. LEU Ex. 1(a)(2015a)
[87] Op. cit. LEU Ex. 1(a)(2015a)

electronically ballasted LED lamp. This makes it very difficult for a customer to know which ballast is used and which LED lamp to apply as a retrofit. [88]

- For many applications the prices of LED-based alternatives for CFL lamps (especially for increased wattages) are still significantly higher while the system energy efficiency and lifetime in principle are comparable. This means higher investments and a longer payback time. [89]
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LEU[90] continues, that based on above arguments LightingEurope is of the opinion that suitable LED replacement lamps are not available for many CFL lamp types in many applications. Removing CFL lamps from the market would therefore force early refurbishment of the lighting systems or even new luminaire investments, which would unnecessarily and dramatically increase the waste. Furthermore, in the residential area, due to the higher product price of the LED alternative, giving the same energy efficiency, the consumer has to invest more to achieve the same amount of energy savings.

LEU[91] adds that aside from integrated LED solutions, the focus in the LED development is on reaching certain price points in the significant volume type of lamps and less on completing the total variety of lamp types available in conventional lamps. LEU also states that there is a focus on interesting high volume lamp types, ignoring many parts of the fragmented market. LEU expects the renewal of the exemption to have a positive effect on the efforts to further innovate in LED, as CFL is the benchmark to be outperformed by LED. It is explained that

> "*in the lighting industry a big fight for market share is ongoing in the LED arena. This fight is played along the price axis where performance is sacrificed to come to a lower price point (e.g. lifetime, efficacy, light output, size, lumen maintenance, colour quality). As long as there are alternative products on the market there is a 'threat', that users will buy the alternative when too much of the performance is sacrificed. So CFL will be the backstop for LED quality*."

5.3.3 The Minamata Convention

LEU states that during the 2013 UNEP Minamata Convention on Mercury in Japan agreements were made to limit mercury in various products, including compact fluorescent lamps. This treaty has been agreed upon and signed by 94 countries around the globe. The agreed mercury level for CFLs ≤ 30W is 5 mg, and is to be adapted until 2020 in countries that have signed the convention.

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[88] Op. cit. LEU Ex. 1(a)(2015a)
[89] Op. cit. LEU Ex. 1(a)(2015a)
[90] Op. cit. LEU Ex. 1(a)(2015)
[91] Op. cit. LEU Ex. 1(2015b), also referring to VHK study referenced in footnote 59

5.3.4 Roadmap to Substitution

It can be understood that all efforts towards development of further substitutes are focused on LED technologies. LEU does not provide a roadmap related to efforts for further improvement of CFL technology and it can be understood that such research is no longer being performed.

In a later communication, LEU[92] states that there is no general roadmap to develop LED replacements for all existing CFL lamp types in the market (LEU is not entitled to share individual roadmaps of its member companies in relation to LEDs). McKinsey indicates in its report[93] that by 2020 still 48% of total general lighting will be in conventional technology. In relation to the breakdown of lamp sales to different technologies, data is provided from the VHK report as reproduced in Table 5-5, with shows CFL and LED sales in the context of other technologies.

Table 5-5: Technology breakdown of lamp sales, 2013

Lamp type	2013 sales in millions of units					
	Total		Residential		Non-residential	
	Mpcs	**%**	**Mpcs**	**%**	**Mpcs**	**%**
LFL	**344**	**20%**	**22**	**2%**	**322**	**45%**
CFL	**342**	**20%**	**184**	**18%**	**158**	**22%**
· **Retrofit CFLi**	271	16%	162	16%	108	15%
· **Non-Retrofit CFLni**	72	4%	22	2%	50	7%
Tungsten (HL)	**772**	**45%**	**617**	**61%**	**154**	**22%**
GSL	**159**	**9%**	**127**	**12%**	**32**	**4%**
HID	**33**	**2%**	**0**	**0%**	**33**	**5%**
LED	**82**	**5%**	**68**	**7%**	**14**	**2%**

Source: VHK study, see footnote 59 for reference, Compiled from Tables 1-4

5.4 Stakeholder Contributions

A number of contributions have been made by stakeholders. Comments of general nature have been summarised in Section 4.4 in the chapter regarding lamps in general. Comments regarding the lamp exemption Ex. 1(a-e) are summarised below:

The Belgian Federal Public Services for Health, Food Chain Safety and Environment (Health FGOV)[94], submitted comments regarding Hg in lamps, explained to specifically

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[92] Op. cit. LEU Ex. 1(2015b)

[93] Quoted in LEU Ex. 1(2015b) as Lighting the way: Perspectives on the global lighting market – Second edition August 2012 by McKinsey & Company - Exhibit 27, page 52

[94] Health FGOV (2015a), The Belgish Federal Public Services for Health, Food Chain Safety and Environment, Belgian communication for the public consultation on the renewal of the ROHS exemptions on the Mercury containing lamps, submitted 16.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/Ex_1-4_FPS_Health__Food_chain_safety_and_Environment_Be_position_Hg_lamps_20151016.pdf

target lamps falling under Ex. 1 (compact fluorescent lamps). Points raised regarding the fate of lamps and Hg and EoL are summarised in Section 4.4 above. Health FGOV recognize that alternative technologies to CFLs are already on the market and recommend an evaluation on the potential for substitution by these alternatives, relaying available data as to their possible limitations or deficiencies (including from a health perspective).

The Ministry of Environment and Food of the Danish Environmental Protection Agency (DEPA) [95] contributed a number of documents to the stakeholder consultation, which have been discussed in Section 4.4. In later correspondence additional detail was provided with specific relevance to Ex. 1(a-e) as follows[96]:

DEPA provides data from various surveys where consumers were asked to detail how many and what type of lamps they have in their homes. Results are compiled in Table 5-6 below. Though a general increase in the number of bulbs per household from 2010 to 2014 is observed in the data, during a discussion with DEPA it was explained that this change is probably explained in the different approaches of the surveys to data acquisition. It is thus assumed that total numbers have either remained similar of have changed less significantly.

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[95] Danish EPA (2015a), Ministry of Environment and Food of the Danish Environmental Protection Agency, Contribution to RoHS Stakeholder Consultation Regarding 29 Exemptions, submitted 8.9.2015, available under:
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/Stakeholder_consultation_RoHS_-_29_exemption_in_Annex_III.pdf, links to referenced document:
Tabbelraport in Danish:
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/Tabelrapport_med_kryds_-_Kampagneevaluering_elsparepaerekampagne_-_Praetest.pdf
Baggrundspapir vedr. kampagne om sparepærer og kviksølv in Danish:
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/Baggrundspapir__kviksoelv_og_sparepaerer_5.2.12_GODKENDT.pdf
Survey and health assessment of mercury in compact fluorescent lamps and straight fluorescent lamps:
http://mst.dk/service/publikationer/publikationsarkiv/2010/jul/survey-and-health-assessment-of-mercury-in-compact-fluorescent-lamps-and-straight-fluorescent-lamps/
Commission Regulation implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for nondirectional household lamps:
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/sec_2009_327_impact_assesment_en.pdf

[96] Danish EPA (2016a), Ministry of Environment and Food of the Danish Environmental Protection Agency, Answers to Clarification Questions as to Contributed Documents, Prepared Towards Meeting at Oeko-Institut e.V., Berlin, Friday 5th February 2016, submitted per email 4.2.2016

Table 5-6: The number of the various bulb types in Danish households

	EPINION 2014 survey[1]		Danish Energy Agency 2010 Data[2]		Danish Energy Agency 2006 Data[3]	
	Average	%	Average	%	Average	%
Special bulbs (halogens or incandescent bulbs)	10.73	32%	10.2 (5.9+4.3)	50.6% (29.6%+21%)	15.13 (6.13+9)	68.25% (27.65%+40.6%)
Energy saving bulbs	9.72	29%	8.2	41%	4.64	20.93%
LED bulbs	8.84	26%	0.95	4.7%	0.44	1.98%
Fluorescent tube	4.4	13%	1.4	7%	1.96	8.84%
Crystal bulbs	-	-	0.25	1.2%	-	-
Total	**33.69**	**100%**	**19.91**	**100%**	**22.17**	**100.00%**

Source: 1 - EPINION, 2014, Kampagneevaluering elsparepærekampagne, Miljøstyrelsen (http://mst.dk/media/130867/forundersoegelse_sparepaerer.pdf)
2 - Danish Energy Agency, 2011, ELMODEL-domestic (http://statistic.electric-demand.dk/Files/2010_questionnaire_res.pdf)
3- Danish Energy Agency, ELMODELBOLIG Statistik, http://statistic.electric-demand.dk/TekniskRap/Resultater?AppGrTek=60&AppTek=61&SpmTek=1&SubSpmTek=1&disp=1&res1ser=4&App=61&ExtraDevice=0&CheckExtradevice=False&Spm=1&Sub=0&QuestId=0

DEPA[97] refers to the EPINION survey of 2014, where consumers were asked as to their priorities when choosing lightbulbs for household use. The three most common aspects named were “saving energy and use as little current as possible” (53%); that lamps “have a long lifetime” (14%) the “Low price” (12%).

DEPA[98] refers to an assessment made in 2015 by FORCE Technology commissioned by the Danish EPA, in which a comparison of lumen/Watt for three randomly chosen LED bulbs and three energy saving bulbs was made. The result was that the LED lamps gave 24% more lumen for the same wattage. In Table 5-7 below a similar random comparison is made with 11 LED and 8 energy saving bulbs. Here the LED bulbs provide 26 % more lumen for the same wattage. DEPA states that these type of assessments are uncertain, however they are estimated to be in a realistic range, thus for further calculation the number was rounded to 25%.

[97] Op. cit. DEPA (2016a)
[98] Op. cit. DEPA (2016a)

Table 5-7: Lumen/Watt for randomly chosen bulbs

LED bulb			**Brand**	**Energy saving bulbs**			**Brand**
lumen	Watt	Lumen/Watt		Lumen	Watt	Lumen/Watt	
400	6,3	63	IKEA	550	11	50	Frostlight
600	10	60	IKEA	300	7	42	Frostlight
1000	13	77	IKEA	680	11	62	Frostlight
1000	14,2	70	IKEA	235	6	39	Osram
200	3,5	57	IKEA	430	9	48	Osram
200	3,0	66	IKEA	740	14	53	Osram
280	4	70	LED JemogFix	480	8	60	Phillips
290	4,2	69	LED JemogFix	425	8	53	Phillips
400	6	67	IKEA				
420	5	85	Opus				
2452	33	74	LG				
Average		69				51	

Source: DEPA (2016a)

DEPA[99] states that where omnidirectional light is required, many LED lamps are now available on the market which meet the requirements. DEPA provides a few examples in table form as presented below.

Figure 5-3: Examples of omnidirectional LED lamps

				
SunFlux krone LED E14 (greenline.dk)	SunFlux kultråds krone LED pære (greenline.dk)	Sunflux Kerte LED pære (greenline.dk)	Philips Inca LED Standard - E27 6w (Silvan.dk)	LED-PÆRE 6W E27 A60 KLAR (Harald-Nyborg.dk)

Source: DEPA (2016a)

Comments of the European Environmental Bureau (EEB), the Mercury Policy Project, and the Responsible Purchasing Network[100] are also summarised in part in Section 4.4 above. Regarding the Ex. 1 entries (a-e) EEB et al. explains that equivalent light emitting diode (LED) mercury-free products are not only widely available but are also more energy-

[99] Op. cit. DEPA (2016a)

[100] EEB et al. (2015a),The European Environmental Bureau, the Mercury Policy Project, and the Responsible Purchasing Network, Environmental NGOs Response to Stakeholder consultation 2015 #2 on mercury-containing lamps – Exemption 1-4 (Review of Annex to the RoHS directive), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1-4_EEP-RPN-MPP_Comments_on_RoHS_Request-final_20151016.pdf

efficient and have a longer rated life than CFLs. Such alternatives are rapidly becoming more cost competitive, especially when their long life and ability to cut energy, replacement, and waste disposal costs are considered. EEB et al. contest:

> "*LightingEurope's primary arguments against LEDs serving as a practical replacement to CFLs are based on their contention that LEDs cannot always serve as a fully compatible replacement for CFLs needed by consumers and professional users. LightingEurope presents this as their "opinion"*[101] *and has failed to substantiate the extent of this potential problem – if any. The crux of their argument lies in their contention that "LEDs in* ***many*** *[emphasis added] cases are not suitable drop-in replacements…so the availability of suitable discharge lamps needs to be secured to prevent a forced, early refurbishment resulting in extra costs and environmental burden."*[102] *While the issues they raised were a problem in the past, these concerns have largely been overcome by improved designs*."

EEB et al. further make recommendations regarding Ex. 1(a, b and e). In relation to CFLs, EEB et al. state that LEDs are a practical replacement that are more energy-efficient, more easily dimmable, and more cost-effective on a lifecycle basis (with a short payback of one year or less for most models).

- In particular, LEDs are explained to be a practical replacement for CFLs <30 Watts, where EEB et al.'s market survey shows a sufficient variety of both omni-directional LEDs and directional LEDs. "*Because a wide array of non-directional and directional LED lamps are available as practical and cost-effective replacements to CFLs <30 watts, we urge the EC to issue an expiry date on this exemption that is consistent with the phase out of inefficient halogen lamps: 1 September 2018*."
- Nonetheless EEB et al. state that "*according to our market research, most LED lamps are low-wattage models and could replace CFLs <30 watts*" (i.e., lamps falling under Ex. 1(a)). Though it is stated in relation to Ex. 1(b) that it is understood that the CFL variety in this category is much lower than in the *<30 watts* category, EEB et al. also state that they "*were able to identify far fewer LED lamps that appear to be direct replacements for CFLs in this category*". In this respect they propose reducing the threshold of Hg allowed for use in lamps falling under this exemption from 3.5 to 2.5 mg per burner. However, as their market survey revealed a few lamps with longer service lives with more than 2 mg of Hg, it is also recommended to consider adding new categories to the exemption for long-life CFLs.

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[101] Refered to in EEB et. al (2015) as: See page 6 of 35 of LightingEurope's exemption request.

[102] Refered to in EEB et. al (2015) as: 26LightingEurope, Request to Renew Exemption 1(a) under the RoHS Directive 2011/65/EU: Mercury in Single-Capped (Compact) Fluorescent Lamps Below 30W, January 15, 2015.

- In relation to Ex. 1(e), their position is similar. CFLs they have found on the market in this category show lower quantities of Hg, and on this basis EEB et al. proposes to lower the threshold in this category from 7 mg to 4 mg.

KEMI Kemikalieinspektionen, Swedish Chemicals Agency (KEMI)[103] mentions that new standards developed in the context of ecolabelling and public procurement criteria are based on the real market situation. KEMI concludes that the allowances permitted for Hg in lamps in most recent publications of this kind, for the Ex. 1(a-e) exemptions, show that it is possible to find low-energy light bulbs on the EU market with lower Hg-content than the current limit values prescribed in these RoHS exemptions. The following table is provided in this respect.

Table 5-8: Limit values for some light sources in RoHS compared with recommended mercury levels in EU GPP criteria for indoor lighting

	RoHS exemption request	Public procurement core criteria	Public procurement comprehensive criteria
Exemption 1(a-e) "Mercury in single capped (compact) fluorescent lamps not exceeding (per burner)":			
(a) For general lighting purposes < 30 W:	5 mg	2.5 mg	1.5 mg
(b) For general lighting purposes ≥ 30 W and < 50 W:	5 mg	3 mg	1.5 mg
(c) For general lighting purposes ≥ 50 W and < 150 W:	5 mg	3 mg	1.5 mg
(d) For general lighting purposes ≥ 150 W:	15 mg	3 mg	1.5 mg
(e) For general lighting purposes with circular or square structural shape and tube diameter ≤ 17 mm	7 mg		

Consultants Note: The Hg thresholds specified for Ex. 1(a-b) detailed above represent the levels allowed when the exemption was approved. The exemption however specified lower levels to come into force in 2011 and 2012 with the current allowances being as follows: 1(a): 2.5 mg; 1(b) 3.5 mg
Source: KEMI (2015a)

[103] KEMI (2015a), Kemikalieinspektionen, Swedish Chemicals Agency, Contribution to Stakeholder Consultation 2015-2 Request for extension of exemption 1(a-e), submitted 19.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1a-e_KEMI_Answer_to_SC_RoHS_20151016.pdf

In respect with fluorescent lighting, the Polish Association of Lighting Industry (PZPO)[104] claim that fluorescent and LED lighting systems are not inter-compatible. "*Changing the fluorescent lamp-based systems to LED-based systems is associated with the need to replace the entire electrical system (power balance issues)... change the fixtures... number of lighting points... facility ceilings, as well as redesign the entire system and employ a sufficient number of designers and engineers*". This is also expected to generate WEEE.

5.5 Critical Review

5.5.1 Scientific and Technical Practicability of Substitution

LEU and NARVA request the renewal of Exemption 1, entries a-e, explaining that there are no substitutes on the market on the substance level, despite various research in this direction in the past. It is also explained that following the last review of Exemption 1 and its recommendations, industry has made an effort to reduce the levels of Hg in various lamps in this product range. This effort towards reduction among others allowed complying with the decreasing Hg allowances specified in Annex III for exemption 1(a, b and e).

The applicants argue that on the technical level, though Hg-free lamps are available, these also would not allow a phase-out of CFL lamps at present for various reasons. In theory these include incandescent light bulbs, halogens and LEDs, however as explained below, in some cases the availability of such alternatives is short-termed and in others the range of available products needs to be investigated (i.e. in the context of the various exemptions).

Halogens and incandescent lamps are explained to be a non-practical alternative as they consume significantly more energy during their use. The consultants agree with this point, which is also reflected in the European Commission's policy to phase out these lamps (based on non-compliance with minimum energy efficiency criteria of the EcoDesign Regulation).

As for LEDs, it is explained that the variety of CFLs on the market in relation to dimensions, wattages, luminous flux, efficacy etc. is very wide and that the parallel variety of LEDs is understood not to provide drop-in replacements for many of these lamps. LEU[105] quotes from the VITO & VHK study (Task 4) that

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[104] PZPO (2015a), Polish Association of Lighting Industry, Comments to Annexes III and IV Directive 2011/65/EU (RoHS), submitted 5.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Directive_RoHs_-_PZPO_comments_05_10_15_eng.pdf

[105] Op. cit. LEU Ex. 1(2015b)

"in recent years, CFLi sales are decreasing, and the impression is that this regards in particular the sales in the low wattage range, where LED lamps are increasingly used."

"CFLi's are available up to 320 W (23000 lm) in cap E40 and 100 W (6365 lm) in cap E27. The maximum lumen output of LED retrofit lamps with integrated control gear is limited and high lumen output LED retrofit lamps are relatively more expensive. Consequently, direct LED retrofit solutions for high-capacity CFLi's are expected to be scarce."

"No LED retrofit lamps for CFLni have been found in the catalogues of major lighting manufacturers as Philips, Osram, General Electric, Havells Sylvania and Megaman. This is interpreted as a sign that this market is not sufficiently interesting, and that for many consumers the substitution of CFLni's by LED retrofits may not be an attractive option."

LEU contends that for an LED to be a retrofit solution for the total variety of CFL lamps, all the varieties have to be taken into account.

The VITO & VHK Task 4 report also states that for CFLni:

"...*there is a ballast problem: in most cases the existing ballast has to be removed or by-passed and a new LED control gear has to be installed (if not integrated in the lamp). The associated costs and luminaire safety certification problems might induce many consumers to stick with CFLni or to substitute the entire luminaire. However, technically there are no obstructions, because several smaller manufacturers are offering LED retrofit lamps for CFLni... Some are plug-and-play versions that can operate on existing ballast. However, when the ballast is not removed, their losses remain and these can be significant*."[106]

In contrast to LEU, the consultants do not believe that LED substitutes need to be available for "the total variety of CFL lamps", i.e., for each and every type of lamp. In the consultants' view a substitute needs to provide the same function, in this case light with similar quality and in parallel a substitute should not create significant negative environmental or health related impacts, such as significant additional energy consumption or hazardous waste. In this respect the consultants contend that if the provision of light shows a high degree of similarity (e.g. above 90% in relation to for example luminous flux, light distribution) that this should be sufficient as long as from an environmental and health perspective the substitutes are at least comparable. Where substitutes show superiority in relation to environmental and health impacts, a larger difference in terms of light quality could also be considered. The consultants find this strategy is reflected in the various decisions of the EcoDesign Directive in relation to the banning of incandescent lamps and halogen lamps, which are understood to provide light of higher quality (e.g., "warm" light and higher colour rendering properties) but to

[106] Op. cit. VITO & VHK (2015)

have significantly higher energy consumption. In relation to CFLni the ECs decision in this respect can also be used as a basis to decide as to the applicability of substitutes. In the case of substitutes for halogen directional and non-directional lamps, exemptions from the phase-out of such lamps, were considered where the lamp fixture did not allow using alternatives within the same luminaires. In this sense, as long as plug-and-play alternatives are available, it can be understood that phase-out would be possible, with the provision of a sufficient transition periods. In the case of LEDs and CFLs, a further aspect that needs to be considered is the phase-out of mercury which goes hand in hand with the transition to LEDs.

In the consultants view, the information provided by LEU as to possible LED substitutes is very general in its nature. Many of the specific LED design limitations, raised as problems of LED technologies in the past review, are understood to now have been resolved, at least in many cases:

- As pointed out by some of the stakeholders who have made contributions[107] a growing variety of omni-directional LED lamps has become available.
- Furthermore, though indeed in the past the form and size of LED alternatives were problematic due to the use of large heat sinks, in recent years a decrease in the size of these components, as well as in the dimensions of LED lamps in general, is observed.[108] This is apparent from the amount of substitutes available for private consumers on the open market, which would clearly fit into standard installations. This trend towards a decrease in the size of heat sinks is also communicated for example in the DOE LCA[109], as early as 2012 as a trend expected to continue (see also Section 5.5.2 below). VHK & VITO[110] also state that in the small wattage range, lamps are available without a heat sink as other thermal dissipation techniques can be used. Impacts of heat sinks on weight are also understood to have decreased respectively and will not be relevant in the full wattage range. The evolving of heat sinks, in LED alternatives thus changes the significance of raised thermal incompatibility issues.
- LEU explains that some installations are particularly designed with reflectors to create a certain light distribution. Though it can be followed that in some cases LED lamps may not provide identical light distribution when used as substitutes, the consultants cannot follow that this aspect would result in insufficient light in most cases, particularly not in the lower wattage groups. In other words the consultants do not agree that light distribution is required to be identical, but only that a degree of similarity would be required.

[107] For example EEB et al. (2015a) and (DEPA 2016a)
[108] See for example EEB et al. (2015a)
[109] See DOE (2012a), DOE (2012b), DOE (2013a) and DOE (2013b) below.
[110] Op. cit. VHK & VITO (2015)

- LEU claims that LED alternatives are often not compatible with dimmers; however, as is also mentioned by some of the stakeholders[111], this claim was identified in the past as a problem of CFLs. LEU states in this respect that both CFLi and CFLni can be dimmable when specifically designed ballasts are used, however the consultants understand this to mean that this is not always the case. In other words, though information suggests that LEDs may not be compatible with all dimmers, information also suggests the same of CFLs. In the consultants' opinion, as seems to have been the case with CFLs, it can be expected that if LEDs are not compatible with all dimmers, that this would further develop in the coming years. Furthermore, at least some manufacturers are making information as to dimmer compatibility accessible to users on the internet. Information from Philips for example suggests that various LED models are compatible with a large variety of dimmers.[112] In contrast, from information on a Philips website for CFLs, only 5 CFLs out of 21 lamps can be dimmed.[113]
- LEU also raises concern as to the prices of LED alternatives, which are said in many cases to still be higher than the prices of CFLs. This aspect is particularly raised in relation to models of increased wattages, further stating that system energy efficiency and lifetime are in principal comparable. First of all, the consultants do not agree with the general statements as to energy efficiency and lifetime, as detailed in Section 5.5.2 below. The DOE LCA for example identified comparability in relation to the total life-cycle energy efficiency as early as 2012 and assumed that LEDs would significantly surpass their CFL counterparts in 2015. Other studies have also concluded that the longer-life and improved energy consumption of LEDs show that from a life-cycle-cost perspective, LEDs have a better "return on investment" due to reduced electricity costs. In relation to price, although cost aspects do not suffice to justify an exemption, in the consultants view, this aspect would possibly even justify revoking the exemption to some degree. Should LEDs indeed be more expensive than CFLs (with a sometimes more and sometimes less significant difference) the consultants assume that for some users the price at the time of purchase would actually delay the uptake of LEDs, despite the availability

[111] For example see EEB et al. (2015a)
[112] See for example Philips dimmer compatability data from November 2015 for various LEDs, "KEY Consumer LED Mains Voltage range Recommended dimmer compatibility list for Mains Voltage Lamps", available under:
http://download.p4c.philips.com/files/8/8718696481240/8718696481240_dmc_enggb.pdf
[113] See www.usa.philips.com/c-m-li/choose-a-bulb/latest#filters=STANDARD_BULB_SU%2CCANDLE_BULB_SU%2CSPOT_BULB_SU%2CREFLECTOR_BULB_SU%2CMINIREFLECTOR_BULB_SU%2CLUSTER_BULB_SU%2CGLOBE_BULB_SU%2CSPIRAL_BULB_SU%2CCAPSULE_BULB_SU%2CLINEAR_BULB_SU%2CCIRCULAR_BULB_SU%2CTUBULAR_BULB_SU%2CUBENT_BULB_SU%2CSPECIALTY_BULB_SU%2CFK_BULBS_COMPACT_FLUORESCENT&sliders=&support=&price=&priceBoxes=&page=&layout=36.subcategory.p-grid-icon

of plug-and-play substitutes. This is particularly of concern in respect of older technologies, which are being phased out (for example halogens to phase out by September 2018) in light of their low energy efficiency. The consultants assume that users who have chosen CFLs in the past over the cheaper halogens (and incandescent) may be more aware to energy saving aspects and may thus also shift to LED when confronted with the purchase of a replacement lamp. However, for users who have retained the less efficient bulbs, despite the related costs of energy consumption, the availability of less expensive CFLs could create a shift towards these lamps when replacements are needed. This would not only reduce the potential for energy savings, but may also create a rebound effect in the trend away from Hg lamps explained to be underway relating to LED technology. This is understood to be particularly of importance in the residential market share, in which halogens still represented 61% in 2013, according to VHK & VITO data (See Table 5-5).

The consultants find it difficult to conclude as to two aspects raised by LEU as limitations of LED technology – the lack of plug-and-play substitutes for lamps with high lumen packages and the limited availability of plug-and-play substitutes for CFL with non-integrated ballasts (ni).

Regarding lumen packages, LEU states that the variety of LED alternatives for higher lumen packages is limited, of particular concern for exemption entries 1(b) through 1(d), which are specified with lumen packages between 2000 and 12000 lumen and above (see Table 5-4). This is also raised in the VHK & VITO study, though it also needs to be noted that in light of the generally lower variety of lamps placed on the market in these categories (particularly entry c and d) it is to be expected that the variety of CFLs shall also be smaller.[114] The consultants find it difficult to conclude as to the applicability of the range of available LEDs for the full range of higher lumen package CFLs. However, in contrast to LEU the consultants do not agree that in the case of lighting that substitutes need to be available for each and every lamp model. In the consultants' opinion, having alternatives that would be in the range of lumen output should be sufficient. Solutions need to be similar but not identical and a LED lamp providing a certain lumen flux can be expected to cover various CFLs exhibiting a range of luminous flux.

As regards CFLni, the consultants understand from the available information that there is limited availability of lamp replacement alternatives, particularly where plug-and-play substitutes are concerned, meaning that replacing a CFL could require conversion of installations due to driver incompatibility. LEU explains that 32% of lamps used for professional uses and 11% of lamps used for residential uses have non-integrated ballasts. When put into perspective of the breakdown of lamp sales according to different technologies (see Table 5-5) however, 11% of residential CFLs translates into 2% of all residential lamps, and 32% of non-residential (i.e. professional) ones into 7%. It

[114] Also stated in EEB et al. (2015a)

is thus observed that this aspect is of higher relevance for professional uses. Of further importance is that the ni lamps are often used in office lighting in arrays of luminaires, meaning that a lack of replacement lamps could have a more significant impact if replacements are not available for professional consumers as it may affect an array of luminaires and not a single installation. In such luminaires it is understood that lamps are often installed in twos and fours, meaning that where concern is raised as to early end-of-life (EoL) of luminaires, these numbers would actually be half or maybe even one third of lamp numbers (i.e., in reference to stock and not annual sales). In this respect, though the consultants can follow that the availability of LED substitutes for CFLni may be more limited (particularly where plug-and-play substitutes are concerned), this aspect is more of a concern for lamps used for professional uses. Though CFLni lamps may cover only 7% of the professional sector uses, it is possible that such uses are not distributed evenly between users; i.e. office lighting users may be affected to a higher degree than 7% of their lamps should the exemption be revoked. In this respect it should however also be noted that where (multiple) arrays exist within the same location (building), this will make the professional rewiring / conversion option more practical and shall increase the economic feasibility. The reason for this being, that for the conversion of a single lamp, technicians may charge a larger sum to include e.g., travel costs, etc. or the work may be refused completely. But as the number of lamps to be rewired or converted grows, the marginal cost for the repair of each additional one can be expected to decrease.

5.5.2 Environmental Arguments

5.5.2.1 Energy Savings

LEU[115] was asked to estimate the impacts to arise from a possible phase-out of the exemption over the next 10 years and explained that in relation to energy, the expected effect is minimal, because the efficacy of CFL is just a bit lower than LED. An impact such as that of the shift from incandescent lamps to CFLs (80% energy saving) is not anticipated as CFLs themselves are very energy efficient. In contrast, LEU says that energy savings can also be achieved through smart solutions with conventional lighting (e.g. dimming, presence detection, daylight link, etc.). It is further explained that lamps covered by the exemption for professional use are subject to application specific norms and requirements e.g. building norms for offices EN 12464-1. Replacing lamps in such installations so that they adhere to such norms may require a new lighting plan because e.g. the required illuminance levels can't be reached with the same number of light points. This could influence the total energy use negatively.

In the consultants' view it seems that statements raised by LEU in relation with energy savings overlook the fact that halogen lamps are to be phased out by September 2018 and, according to data from 2013 that such lamps still represent up to 45% of the total sales on the market. Even if LED energy efficiencies are only slightly superior to CFLs, the shift from halogens to LEDs could still be expected to result in a large energy savings with

[115] Op. cit. LEU Ex. 1(2015b)

the added values of the elimination of mercury. Furthermore, despite LEU's claims, at least in the lower wattages (Ex. 1(a)), comparisons of LEDs and CFLs currently on the market show that "the LED bulbs give 26 % more lumen for the same watt"[116]. Thus this argumentation cannot be followed and the consultants believe that significant energy savings could still to be expected, especially as further developments in the efficiencies of LEDs are expected, whereas for CFLs it is understood from LEU that industry is no longer focusing on further developments. Smart solutions raised by LEU are also relevant for LEDs and thus should not be understood to support further potential for energy savings through CFLs.

Even if LEDs and CFLS were still to be considered comparable in relation to energy savings, the fact that LEDs allow avoiding the use of mercury, which is a substance restricted not only under RoHS but also by the Minamata convention and other legislations, is of importance. As shall be raised in Section 5.5.3 despite the general reduction in the mercury quantities in CFLs, this substance is still of high concern, particularly where there is a risk of emissions to the environment. Thus promoting the shift from all conventional lamps to LEDs (and avoiding for example a shift from halogen to CFLs) is also understood to be of importance for reducing possible risks associated with mercury releases in various life cycle phases of lamps.

5.5.2.2 Life Cycle Aspects

Several stakeholders (e.g., LEU, EEB et al.) refer in their contributions to a study published in 2012 and 2013 by the U.S. Department of Energy. In the following this study will be summarised briefly against the background of the exemption evaluation at hand.

The U.S. Department of Energy (DOE) conducted a three-part study to assess the total life-cycle impact of LED screw-based replacement lamps in relation to two comparable lighting technologies used in residential homes: incandescent lamps and compact fluorescent lamps (CFLs). Taking this into account the scope that the study reflects is relevant to a large extent to exemption 1(a-e), with the exception of CFLs with an external ballast (CFLni). According to the principles of LCA, the DOE study regards not only use, but also manufacturing, transport, and disposal of the products under consideration. The DOE considers the LCA to be the most comprehensive study of its kind for LED products, breaking new ground in their understanding of how lighting affects the environment. In addition, it was the first public study to consider the LED manufacturing process in depth. The comparison looked at the LED lamp technology as available in 2012 and also projected what it might be in 2017, taking into account some of the anticipated improvements in LED manufacturing, performance, and driver electronics[117]. Part 1 of the study mainly includes an in-depth review of 10 existing LCAs on lighting products from various sources. As this review led to the conclusion, that most

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[116] Op. cit. DEPA (2016a)

[117] DOE (2013a), U.S. Department of Energy, Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products. Factsheet, April 2013

of the uncertainty concerning the life-cycle energy consumption of an LED lamp was found to be related to the manufacturing of the LED package, part 2 of the study focused specifically on this issue. Part 3 of the study takes the end-of-life disposal into consideration and presents a worst-case scenario regarding potentially toxic elements in hazardous waste from disassembly of lamps.

In respect to the exemption at hand the main findings of the study can be summarised as follows[118,119,120,121]:

- The “use” phase of all three types of lamps accounted for 90 percent of total life-cycle energy, on average, followed by manufacturing and transport.
- The average life-cycle energy consumption of LED lamps and CFLs was similar, and was about one-fourth the consumption of incandescent lamps.
- The efforts to further enhance the efficacy of LED are still ongoing. If LED lamps meet their performance targets by 2015, their life-cycle energy is expected to decrease by approximately one-half, whereas CFLs are not likely to improve nearly as much.
- Taking the environmental impacts into consideration, the LED lamp had a significantly lower environmental impact than the incandescent, and a slight edge over the CFL.
- The CFL was found to be slightly more harmful than today’s[122] LED lamp in relation to all impact measures except hazardous waste landfill, because of the LED lamp’s large aluminium heat sink. The heat sink is the main reason the LED currently exceeds the CFL in the category of hazardous waste to landfill, which is driven by the upstream energy and environmental impacts from manufacturing the aluminium from raw materials.
- As the efficacy of LED lamps continues to increase, aluminium heat sinks are expected to shrink in size—and recycling efforts could reduce their impact even further.
- The light source that performed the best was the LED lamp projected for 2017, whose impacts are expected to be about 50 percent lower than the 2012 LED lamp and 70 percent lower than the CFL.

Taking these results in to consideration in the context of exemption group 1, it can be concluded, that the environmental impacts caused by a substitution of CFL with LED

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[118] Op. cit. DOE (2013a)

[119] DOE (2013b), Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products. Part 3: LED Environmental Testing. March 2013

[120] DOE (2012a), U.S. Department of Energy, Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products. Part 1: Review of the Life-Cycle Energy Consumption of Incandescent, Compact Fluorescent, and LED Lamps. Updated version August 2012

[121] DOE (2012b), U.S. Department of Energy, Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products. Part 2: LED Manufacturing and Performance. June 2012

[122] The study estimated LED developments and thus the reference to today’s LED technology is relevant for lamps assumed to be available by 2015 and thus also in 2016 – consultants note.

would not outweigh the total environmental benefits in relation to technologies on the market in 2012. Taking into account the increasing efficacy of LED, this conclusion can be expected to have increased in relevance; more than three years after the DoE published its results. Though from the total impact point of view equivalency and possibly superiority of LEDs is expected at present, for the heat sink factor the LEDs may have an environmental disadvantage where heat sinks are still used. Some LEDs, particularly in the low wattage range, shall no longer have an aluminium heat sink, removing the related environmental impact. VHK & VITO[123] state in this regard "*Efficacy improvements have a double positive effect: they also reduce the amount of heat produced. Some years ago, relatively low lumen LED bulbs (500-800 lm) had efficacies of 60-80 lm/W and a heavy and bulky heat sink, while recent LED filament lamps reach efficacies of 100-120 lm/W and are without heat sink*". This is explained not only to be due to efficacy improvements, but also to other dissipation methods, i.e. gas filling of the lamps. In other lamps, the heatsink may have already decreased in size and weight in comparison to what was common at the time of the DoE study, providing for a reduced environmental impact. In such cases, where the lamp is disposed of properly, the heat sink is expected to be recycled, alleviating the environmental disadvantage. Furthermore, the possible environmental impact related to the heat sink is one of 15 environmental indicators investigated and does not render the total environmental performance as inferior to CFLs. LEDs are still expected to show better performance when all indicators are considered.

5.5.3 Stakeholder Contributions

Various contributions have been made as specified in Section 5.4 and some of the aspects raised are already discussed in the sections above and thus not raised here again, however in the following some additional arguments raised by stakeholders are discussed.

As already mentioned in the general chapter, the consultants can follow concern raised by stakeholders that the risks of Hg emissions during the use phase (result of lamp breakage) and during the end-of-life phase (improper disposal, e.g. as municipal waste) may not be sufficiently controlled. Such risks shall prevail to some degree, despite the successful efforts of industry to communicate the risks of lamp breakage and how to handle such situations and despite the organisation, collection and recycling mechanisms as well as the communication of their availability to consumers. These concerns are of particular relevance to Ex. 1(a-e), as lamps covered by these exemptions are often used in households, where infants and elderly may be exposed in cases of breakage, and where behavioural habits concerning disposal can be more difficult to change.

DEPA provides results of a survey as to the total number of lamps in Danish households and the average shares for the various lighting technologies. The data is of particular

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[123] Op. cit. VITO & VHK (2015)

interest to Ex. 1(a-e) as it shows that the number of CFLs has increased in the period between 2006 and 2014, whereas the number of halogens and incandescent lamps has decreased. Though the differences in the total number of lamps between the 2006/2010 data and the 2014 data suggest inconsistencies in the method of data collection, the consultants assume that these inconsistencies do not contradict this trend, though they may affect its intensity. In the consultants view this trend further supports concern as to the possible shift of consumers from halogens to CFLs, once the former are to be phased out in 2018. Additional data as to the average number of light sources per household and their breakdown across various technologies is presented in Appendix A.2.0.

DEPA also provides results of a survey, where Danish consumers were asked as to the main motivation for purchasing a lamp of a specific technology. Though results show that over 60% would buy a lamp because of its energy savings or its service life, for 12% the most important aspect is still price. If as LEU claims, the energy savings of CFL and LEDs are similar, than the fact that price still plays a role in consumer choice could mean that some consumers would prefer CFL over LED when replacing a halogen bulb.

EEB et al. criticizes LightingEuropes' argumentation, regarding the insufficient availability of LEDs as substitutes for CFLs, explaining that LEU fails to substantiate the extent and the potential of this problem and mainly raises issues that were a problem in the past, but that have for the most part been overcome with improved designs.

The consultants can follow the proposal of EEB et al. to specify an expiration date for Ex. 1(a), however do not agree with the proposed date, 1.9.2018. The consultants assume that EEB et al. are concerned that earlier expiration of this exemption could create a rebound effect of consumers purchasing halogens with higher energy consumption. However, should the exemption be revoked, a transition period of up to 18 months could be granted, at the earliest starting in 22.7.2016 and thus ending in 21.1.2018. Though a rebound affect may possibly occur in the time between January and September 2018, it is expected to be short termed, whereas as renewing the exemption with the expiration date of 1.9.2018 would enable stakeholders to request a renewal, at minimum resulting in an additional transitional period of 12 months.

EEB et al. further propose to reduce the Hg threshold allowances provided for Ex. 1(b) and for Ex. 1(e). The consultants do not disagree that some and possibly most CFLs available on the market could already be applying lower quantities of Hg. However, in the consultants' opinion, it can be followed that as claimed by the lighting industry, all current development efforts are directed towards LED solutions, which can be assumed to become the leading technology within the next few years. In this sense, it is clear that a reduction of thresholds shall not motivate manufacturers to change the application of Hg in their lamps, all the more so as it can be understood that the levels proposed by EEB are already applied in most lamps on the market. Though a reduction might "banish" models with more Hg from the market, the consultants assume that this shall not result

in a significant change, while communicating to industry that as long as lamps comply with the new threshold, market entry shall be allowed.

KEMI presents requirements of green public procurement initiatives, and proposes to align exemption Hg threshold allowances with the specified levels. LEU[124] responded to this proposal, explaining that the RoHS thresholds specified by KEMI have in some cases already decreased, as mentioned in the consultants note to Table 5-8. LEU further explains that for this reason the differences between the RoHS thresholds and the public procurement thresholds are not as significant and that it needs to be kept in mind that these are average levels, whereas there is a need to retain a margin above the average for the RoHS Directive thresholds. From the consultants experience with Green Public Procurement, threshold criteria are usually developed to create a preference for products that have a higher level of performance. Where such criteria have been developed, restricting the presence of hazardous substances, this is only done when the specified limits outperform restrictions already specified in legislation (e.g. in RoHS). Otherwise, there would be no need to specify the limit as all products are required to comply with legislation. With the current development strategy of the lighting industry, the consultants do not perceive a strategy of reducing Hg thresholds as preferable to other strategies in terms of the potential for creating environmental benefit.

5.5.4 The Scope of the Exemption

The exemption entries address CFLs, differentiating between lamp groups based on wattage groups and in the case of Ex. 1e based on shape and dimensions (e.g., tube diameter). In contrast, from the information provided by LightingEurope and the discussion of alternatives in the VHK & VITO report, different aspects appear to be of relevance in relation to the question of substitute compatibility.

A first differentiation regards the lumen packages of lamps. LEU explains that the development of LEDs with higher lumen packages (above 1500 lumen) is focussing on new luminaire solutions instead of retrofit CFL substitution. As a result, not many replacement solutions for this specific category in LED are available on the market. [125]

From independent market surveys, the consultants' are aware that the variety of available LED substitutes indeed decreases as lumen package increases. Nonetheless, the variety of CFLs in this area is also significantly lower than in lower lumen packages, and thus it follows that a lower variety of LED substitutes would also be expected. Though in theory it could be considered if future exemptions could be limited to lamps with higher lumen packages, available information to support the determination of a lumen threshold is not available in the public realm in a compiled form that would allow supporting a knowledgeable proposal.

[124] LEU (2015c), LightingEurope, Summary of critical observations to stakeholder submissions , Submitted per email on 18.12.2015

[125] Op. cit. LEU Ex. 1b(2015a)

A second aspect where a differentiation in the availability of substitutes is observed concerns the location of the ballast. In luminaires devised for CFLni's, the ballast is part of the luminaire and as such substitutes will either need to be plug and play for a consumer to be able to simply replace a lamp, or the ballast will need to be removed and the luminaire rewired. Though a lack of substitutes is observed in the product portfolios of major lighting manufacturers, it is also understood that several smaller manufacturers are offering LED retrofit lamps for CFLni, some being plug-and-play versions that can operate on existing ballast. This may make replacement less straightforward for consumers; however, on this basis the consultants find it difficult to follow LEU's general argumentation that there is a lack of alternatives.

In this sense, both of the aspects above do not assist in making a clearer demarcation as to the availability of LED substitutes for CFL lamps. The current differentiation, based on wattage and form, is also not optimal for such a demarcation. However, as shall be discussed below, against the background of market data and the knowledge of available LED substitutes, using this scope differentiation is understood to allow a gradual phase-out of CFL technologies and thus to still be useful.

5.5.5 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

The applicants put forward information that clearly shows that substitution on the substance level is not practical and that further reducing Hg amounts per burner is also not expected to result in significant environmental benefits.

The consultants can follow these points. A reduction has indeed taken place in the general Hg amounts. Though further reductions may be possible to some degree, the consultants also agree that the potential for this strategy has been realised to a large degree. As a shift towards LED technologies has become clear, the consultants further do not believe that a change in the Hg levels shall motivate manufacturers towards further reductions in actual lamps placed on the market. Though a decrease in levels could be proposed to allow the exemption to reflect the actual lamps on the market (or for example the best 80%), the consultants do not assume this to create a significant environmental benefit in comparison to scenarios where CFLs are substituted with LEDs, eliminating Hg completely.

In contrast, the statements made by the applicants regarding the availability of **LED substitutes** cannot be followed comprehensively. Statements are very general in nature

and the applicants do not provide data to substantiate various claims. Particularly for lamps of lower wattages such as those falling under Ex. 1(a), the various claims are also not supported by the range of LEDs available on the market that suggests that many of the problems raised were relevant in the past, but have been handled in newer products on the market.

Though for lamps of higher lumen packages there might be a lack of suitable alternatives, or a decreased variety thereof, the consultants are of the opinion that the general argumentation only holds true for some of the product range.

For lamps of lower wattages, there appears to be a large variety of substitutes of various sizes and various lumen packages. Such alternatives are understood to provide comparable performance in terms of energy efficiency and are in many cases understood to be more efficient than CFL counterparts on a lumen/watt basis, as well as having longer service lives. Many of the LED alternatives presented by the larger manufacturers (see footnote 112 as to dimmer compatibility of the Philips LED product range) are also understood to be compatible with a large variety of dimmers and information as to dimmer compatibility is provided by manufacturers for specific lamps and should sufficiently facilitate the correct choice of replacements. Even if the light distribution may differ, such lamps are understood to be sufficiently compatible in terms of light-output, with LEDs available in both direct versions (spot-lamp and omni-directional lamps). Arguments raised in relation to the size and weight of heat-sinks and possible thermal incompatibility are understood to have been of high concern in the past, but to have lost their relevance, at least in the lower wattage categories. The consultants also do not agree that the price of LED substitutes should be of concern in relation to the validity of the exemption – economical aspects do not suffice to justify an exemption from the RoHS Directive. Furthermore, though LEDs may be more expensive at the time of initial investment, the savings related to energy consumption are understood to return this investment quickly (lower life-cycle-costs) as compared with other lamp technologies.

For the higher lumen package categories, data suggests that the variety of substitutes in this area is more limited (as is also the variety of CFLs) and does not allow concluding whether the range of products sufficiently covers the CFL product range.

In this sense, the consultants conclude that there is a sufficient availability of substitutes for lamps of lower wattages, whereas in the higher wattage area, available data does not allow concluding whether the range of LED alternatives sufficiently covers the range of available CFLs.

To summarize, where substitutes exist, they are understood to have sufficient reliability and compatibility with **CFLi** installations (CFLni are discussed separately below), while also exhibiting superiority in terms of service life. The LED product range is developing considerably, with manufacturers quickly developing their product portfolios to expand the range of applicability. Though in areas of small market share, manufacturers can be expected to allocate lower priority to the development of a large variety of substitutes, in areas of larger market share the opposite is the case, as is clear from the larger variety of substitutes for Ex. 1(a).

Though LEU raises general argumentation as to the risk of negative environmental impacts related to early end-of-life of luminaire installations, the consultants do not agree that this argumentation is valid for CFLi lamps. For such lamps, a large variety of LED alternatives are available, which can be used as one-to-one, plug and play replacements, without a need for installation conversion. Though as explained above, for higher lumen packages (understood to fall under the higher wattage sub-categories) substitutes may not be available at present, it is understood that once they become available they also would be one-to-one / plug and play replacements. In this sense the consultants conclude that the only possible justification for an exemption for CFLi lamps is related to the lack of substitutes and this argumentation is only relevant for CFLi lamps of higher lumen packages, which also have higher wattages.

In contrast, there is concern as to the suitability of LED alternatives for substituting **CFLni**, where the ballast is not integrated in the lamp but rather part of the installation. Available information suggests, however, that smaller enterprises have brought LED alternatives to the market, which are compatible with installations. Compatibility in this case is either as plug-and-play substitutes or as substitutes requiring a conversion of the luminaire (rewiring of the ballast, etc.). The consultants can follow that such substitutes may be less straightforward for consumers as one-to-one replacements, since a larger effort shall be required to find a suitable substitute, possibly also requiring the conversion of the installation. However, from a technical perspective, the consultants do not agree that this can be understood as a lack of sufficient substitute availability. As is the case for CFLi, substitutes may be less available for lamps with higher lumen packages; however, in the lower lumen package categories in the consultants' opinion, from a technical point of view substitutes are available and when installed properly they are also expected to be reliable. In the case of retrofit lamps, when driver compatibility is assured, LED substitutes are expected to have higher energy efficiency. Though in some cases incompatibility with drivers may reduce the lamp efficiency, it is also expected that proper rewiring or conversion (performed by skilled personnel) shall prevent such decreases and that here too LED lamps shall be more efficient than CFLni's.

An important point raised by LEU in this respect regards the compatibility of installations with safety requirements and warranty conditions. Once a CFLni installation is rewired or converted to allow the use of an LED replacement, the responsibility for such aspects is said to shift from the manufacturer to the individual performing the conversion. Though this aspect does not necessarily change the actual safety of the installation, it is possible that it shall be more difficult to find professionals who are willing to perform such changes – this relating to the possible responsibility to faults in comparison to the possible profit from such conversions. Nonetheless in the consultants view, though this could make substitution more challenging in CFLni installations, it cannot be said that there is a lack of substitutes in this area. It can also not be said that such substitutes show lacking reliability, though it is possible that there is a lack in standardisation and in skilled employees willing to perform such conversions while ensuring sufficient reliability of installations. In such cases, early phase-out of CFLni's may result in early replacement of installations / luminaires, where the costs of conversion or the lacking guarantee of minimum reliability shall push consumers to replace CFLni installations with LED ones.

This could mean that some CFLni installations would reach end-of-life early, however a quantification of the actual environmental costs that could incur is not straightforward as installations will be in different life phases, and lamps still in use can also be expected to remain functional until they reach the end of their expected service life. To try to shed some light on the possible range of impacts that could be expected, it is important to note the share of CFLni's from the total CFL market, which is relatively small (~12% for residential uses and ~32% for non-residential). Put into the context of the total market share of lamps these numbers become even less significant (CFLni is 2% of residential uses and 7% of non-residential uses). LEU has further stated that some CFLni's are used in installations with 2 or 4 lamps. In this respect the stock of CFLni installations can be assumed to be smaller than the stock of CFLni lamps, meaning that impacts of early-end-of-life of installations would affect a smaller number of luminaires. As CFLni's are often used in arrays, for example in office lighting, it is assumed that costs related to installation replacement shall, however not be spread evenly across consumers, or at least not across non-residential consumers. Based on the available information it cannot be concluded how significant the described impacts could be. It is also not possible on the basis of the available information to conclude as to the actual relevance of CFLni's for the various Exemption 1 entries. Two strategies related to exemptions could be considered:

- The first following the logic of availability of LEDs for lower wattage categories, as from a technical perspective they can be used as replacements. In this case, CFLni's would be covered as was the case until now through exemption entries that are to remain valid, with the understanding that should certain entries not be renewed, that possible costs related to EoL of CFLni luminaires are acceptable.
- A second strategy would be based on an understanding that possible environmental impacts of EoL are of a range which would not be acceptable. In this case an exemption could be formulated specifically for CFLni lamps. Though the argumentation for this alternative is supported by the potential for environmental costs, the consultants' would like to note that such costs need to be observed in perspective. The fact that substituting a CFL with an LED eliminates the use of mercury in the product and thus also problems related to emissions of mercury at EoL shall to some degree off-set any environmental problems related to the early scrapping of luminaires. This is particularly relevant when one observes the current collection rates, which may comply with WEEE targets but are still below 50% (see further details below). It would also be false to expect the whole luminaire stock to be scrapped. Some plug-and-play substitutes are already available. Luminaire conversion is also possible, and when done properly results in reliable and more efficient lighting solutions. At least some luminaires are expected to be retrofitted or converted, with a rising trend in this direction as LED conversion kits could become more common and particularly in office lighting arrays, the larger number of luminaires to be converted shall affect the willingness of consumers to make an investment in conversion. Furthermore, some

luminaires are expected to be scrapped anyway due to age and also changing fashion trends. Against this background it is not to be expected that the total luminaire stock shall be scrapped subsequent to termination of the associated RoHS exemption, but only a certain percentage thereof. Finally, CFL luminaires, and with them also CFLni luminaires can still and are still placed on the market as new EEE. LEU states in this respect that "*luminaires for professional applications can exist for up to 30 years… it must also be clarified that it is allowed in the EU to sell and install new luminaires based on conventional technology*".[126] So any possible environmental impacts are not related solely to the current stock of luminaires, but rather to a stock that is still in growth. Due to the obvious lack of a clear roadmap towards phase-out of CFL lamps, the consultants believe that the continuous growth of the CFL luminaire stock needs to be considered in this context.

As shortly referred to above, despite the elaborate collection mechanism that has been established for lamps containing mercury, the actual estimated collection rates are still below 50%. The sound recycling of lamps not collected through this mechanism is not ensured and thus raises high concern related to possible mercury emissions associated with such lamps.

To summarize the above, the consultants believe that alternatives are sufficiently available for lower lumen packages. This includes lamps falling under Ex. 1(a), which are understood to have lumen packages up to 2500 lm. From surveys of various LED types it is also assumed that LEDs are available at lumen packages that would cover Ex. 1(b). For example, products presented on the German Eco-top-ten website[127] include two lamps (27 W) of 2800 lumen, one lamp (35 W) of 4000 lumen and one lamp (35 W) of 4160 lumen. Though the LED replacement variety in this category is not as large, the consultants believe that a long transition period (18 months) would suffice in this case for industry to develop further LED replacements to sufficiently cover the product range of both of these entries. As these two entries also cover the larger shares of the total CFL market (Ex. 1(a): 85% and Ex. 1(b): 10%), it can also be followed that industry is focusing on these areas in the current development of LED substitutes. As apparent from Table 5-1, this shall allow eliminating 90% of the mercury placed on the market through CFL applications. In the other three entries it is difficult to clarify the variety of LED

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[126] Op. cit. LEU (2015b), Following this statement, LEU provides the following examples of luminaires based on conventional technologies:
(1) http://www.ecat.lighting.philips.nl/l/buitenverlichting/stads-en-straatverlichting/stads-en-straatverlichtingsarmaturen/metronomis/metronomis-torino-cds530-531/910502146918_eu/
(2) http://www.ecat.lighting.philips.nl/l/buitenverlichting/stads-en-straatverlichting/stads-en-straatverlichtingsarmaturen/iris/912300025697_eu/
(3) http://www.ecat.lighting.philips.nl/l/armaturen-binnenverlichting/downlights/fugato/fugato-performance-algemene-verlichting/910502488515_eu/

[127] See following link: http://www.ecotopten.de/beleuchtung/led-lampen?&&&field_10102_tid[0]=3850&&page=1

substitutes currently available. Though it can be assumed that some alternatives may be available, it cannot be dismissed that availability is not yet sufficient. As these three entries also cover relatively small shares of the total CFL market (Ex. 1(c): 3%; Ex. 1(d) and Ex. 1(e): 0.5%;), it is further assumed that developing a larger variety of substitutes in these categories is not a first priority for industry, and shall also have a much smaller contribution to the total amount of Hg placed on the market through lamps. Based on Table 5-1, this represents 10% of the Hg placed on the market through CFLs (excluding Ex. 1(f) CFLs). Renewing these three entries at present shall allow industry to focus its development efforts on then completing the substitute range for the other two entries, where environmental benefits of phase-out are expected to be more significant.

A three year exemption could allow evaluating the changed availability of substitutes in these three sub-categories in the short term, however assuming industry is to focus throughout the transition period on developing substitutes for the other two entries, it is possible that this period would not allow for a substantial change in substitute availability. In contrast, should a rebound effect of lamps falling under Ex. 1(c) and 1(d) being used to substitute lamps falling under Ex. 1(b)[128] become apparent (i.e. an increase in sales) a shorter transition period would allow identifying this trend earlier. Thus, though a longer period would support industry in terms of prioritisation of the development of LEDs, in the consultants' opinion a short termed exemption prior to next review would provide improved monitoring of changes within market trends, and thus is advised to be the preferable option.

5.6 Recommendation

Taking into account the availability of LED alternatives as explained in the conclusions the consultants recommend discontinuing exemptions for lower lumen packages covered by Ex. 1(a) and 1(b), while renewing Ex. 1(c), Ex. 1(d) and Ex. 1(e). The renewal is recommended for a period of three years, to allow following the development of substitutes more carefully, while also monitoring possible negative rebound affects. Should exemption 1(e) be renewed again after this period, the Hg threshold should be decreased to 5 mg, as specified in the Minamata Convention. For exemptions that are not to be renewed, a long transition period of 18 months should be granted, to allow industry additional time to further establish the availability of substitutes in relevant product categories.

For CFLni lamps it is possible that replacement of lamps with LEDs might be more complex and in some cases result in consumers deciding to replace luminaires in order to avoid such complications. Though this is understood to create an environmental impact, where lamps reach EoL early, prolonging exemptions for such lamps is not expected to allow reducing the impacts, as CFLni luminaires are still available on the market and have

[128] The availability of LED substitutes for CFLs under Ex. 1(a) is understood to suffice in terms of variety and prices are also lower than for higher lumen packages, so that a rebound trend would not be expected for this category.

in some cases expected service lives of up to 30 years. Such impacts also need to be observed in perspective of the relatively small share of the CFLni lamps in relation to the total CFL market and to the total lamp market. They shall further be off-set through the elimination of Hg and through application of retrofit and conversion substitution routes where this is possible. Thus, the consultants recommend not to provide an exemption specifically for CFLni lamps.

In light of Article 5(2), from a legal perspective, excluding EEE falling under Cat. 8 and 9 from the scope of this exemption may not be possible; however the consultants' are also concerned that extended availability of such lamps for these categories may create a loophole for consumers seeking CFL replacements covered by entries to expire. If possible, the Commission should investigate limiting the sales of such lamps to a business-to-business basis to avoid such misuse.

Exemption 1	**Scope and dates of applicability ***	**Comments**
Mercury in single capped (compact) fluorescent lamps not exceeding (per burner)		
(a) For general lighting purposes < 30 W: 2.5 mg	*For Cat. 8 and Cat. 9: 21 July 2021* *For Sub-Cat. 8 in-vitro: 21 July 2023* *For Sub-Cat. 9 industrial: 21 July 2024*	The maximum transition period should be granted to other categories (18 months); The COM should consider adopting measures to limit product availability to B2B transactions.
(b) For general lighting purposes ≥ 30 W and < 50 W: 3.5 mg		
(c) For general lighting purposes ≥ 50 W and < 150 W: 5 mg	*For Cat. 5: 21 July 2019* *For Cat. 8 and Cat. 9: 21 July 2021* *For Sub-Cat. 8 in-vitro: 21 July 2023* *For Sub-Cat. 9 industrial: 21 July 2024*	
(d) For general lighting purposes ≥ 150 W: 15 mg		
(e) For general lighting purposes with circular or square structural shape and tube diameter ≤ 17 mm	*7 mg may be used per burner until 31.12.2019, 5 mg may be used per burner after 31.12.2019* *For Cat. 5: 21 July 2019* *For Cat. 8 and Cat. 9: 21 July 2021* *For Sub-Cat. 8 in-vitro: 21 July 2023* *For Sub-Cat. 9 industrial: 21 July 2024*	

Note: As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

5.7 References Exemption 1(a-e)

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Tabbelraport in Danish: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/Tabelrapport_med_kryds_-_Kampagneevaluering_elsparepaerekampagne_-_Praetest.pdf

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6.0 General Recommendation Regarding Exemptions for Special Purpose Lamps

The current review has investigated four exemptions which permit the use of mercury in special purpose lamps. Through the review of the available information, an attempt was made to clarify differences in applications and in technologies falling under these exemptions, and to understand if overlapping's exist between these exemptions and other exemptions that needed to be considered in the reformulation of certain exemptions.

- **Ex. 1(f)**: "1: Mercury in single capped (compact) fluorescent lamps not exceeding (per burner):
  (f) For special purposes: 5 mg"
- **Ex. 2(b)(4)**: "*Lamps for other general lighting and special purposes (e.g. induction lamps): 15 mg may be used per lamp after 31 December 2011"*
- **Ex. 4(a)**: "*Mercury in other low pressure discharge lamps (per lamp: No limitation of use until 31 December 2011; 15 mg may be used per lamp after 31 December 2011*"
- **Ex. 4(f)**: "*Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex*"

Such differences have been discussed in the various chapters reporting on the evaluation of these exemptions, and taken into consideration in the recommendations therein as far as possible. See Chapters 7.0, 10.0, 12.0 and 16.0 for the individual review reports.

Generally, the consultants view the term "special purposes" as very broad and open to false interpretations, possibly making market surveillance complex and ineffective. In the past, exemptions were provided for Hg for a large range of technologies in light of the absence of sufficient substitutes. At that time, the use of such a general term in the formulation of exemptions could be considered acceptable, as the respective discharge lamps were to come onto the market through one exemption or through another. Possible overlaps could have still been perceived as unconcise regulation; however, the outcome in terms of products that could be placed on the market would have been the same. However, at present it is observed that for many lamp applications alternatives are coming on the market or are already available, usually in the form of light emitting diode (LED) technologies. In light of these developments, recommendations have been made in the course of this evaluation to restrict the scope of some exemptions as far as reasonable. Against this background, it is apparent that avoiding the use of general formulations is pertinent, as these may leave loopholes that could be misinterpreted or misused, leading to restricted articles, containing Hg, being placed on the market.

Towards this purpose an effort has been made to clarify the term “special purposes”. Among others, in each of these exemptions, attempts have been made to understand what types of lamps (applications or technologies) are considered to fall under the specific exemption. As a second stage, other exemptions were reviewed to ensure if certain lamps might be covered by multiple exemptions. Finally, where possible recommendations were developed, proposing adjustments in exemption formulations so as to clearly demarcate technologies and/or applications included in the scope of a particular exemption. In some cases, where available information did not support this exercise, short termed exemptions have been provided to allow industry to provide further clarification before the possible revoke of the exemption for some technologies.

This process has allowed identifying two cases, where exemptions are currently considered justified (see details in respective evaluation reports in Chapters XXXX), and where the consultants believe that further separating these cases from the current exemptions could be beneficial:

- UV Lamps – The justification for the further use of Hg in discharge lamps that emit in the UV range is two-fold. Current substitutes are understood to be limited in terms of their spectral output and thus do not provide a comparable performance in this respect. Furthermore, where alternatives are available that do emit in a limited range of the UV spectrum, their wall-plug-efficiency is currently significantly lower than that of discharge lamps. The early phase-in of such lamps would result in an increase in energy consumption and in other words in a negative environmental impact. Against this background, for all UV lamps it can currently be followed that exemptions are currently justified on the basis of Article 5(1)(a). In parallel however, once substitutes are to become available, their applicability to the full range of UV lamps should be investigated. In this sense, merging all special lamps which emit in the UV range into a separate exemption would be beneficial as it would ensure that future evaluations for such technologies would be carried out at the same time and focussing on comparable technical questions. To this end, and to address the various differences addressed in the various special purpose exemptions for such lamps, the following wording has been suggested as an exemption alternative for UV lamps, and should be considered as an alternative to the separate entries recommended for such lamps in each of the respective exemptions:

  “*Mercury in discharge lamps, emitting mainly in the ultra-violet (UV) spectrum:*

  (I) in single capped (compact) fluorescent lamps, not exceeding 5 mg per burner;
  (II) in other than single capped (compact) fluorescent lamps, not exceeding 15 mg per burner;
  (III) in low pressure non-phosphor coated lamps, not exceeding 15 mg per burner;
  (IV) in medium and high pressure lamps used for curing and disinfection applications;

Valid for Cat. 5 until 21 July 2021"

Entry (II) could alternatively be formulated as "*in fluorescent lamps not covered by entry (I) not exceeding 15 mg per burner*;". However, this would create a dependency between exemption entries (I) and (II), which may lead to legal uncertainties should the entry formulations be adapted with time, without proper consideration of the dependency.

- Emergency lamps – In the application for Ex. 2(b)4, the necessity of retaining an exemption for Hg used in lamps used for emergency lighting was communicated. The given justification was that for emergency lighting, safety regulation and standards specify what lamps can be used as replacement lamps in respective luminaires. Assuming that at least in some cases, such regulation and standards do not specify Hg-free lamps that can be used to replace lamps that have malfunctioned, the consultants agree that an exemption would need to be retained. Though relevant regulation and standards may be updated with time to allow the use of Hg-free lamps (where relevant specifying if and how luminaires must be converted to ensure safety), the consultants can follow that an exemption could be restricted to cases where this is still forthcoming through the following formulation:

  "*Mercury in discharge lamps used in emergency lighting applications, where safety regulation and standards do not permit the use of mercury-free replacement lamps;*

  Valid for Cat. 5 until 21 July 2021"

Should the European Commission choose to follow this recommendation, the suggested entries proposed for UV lamps and emergency lighting lamps under Ex. 1(f), Ex.2(b)(4), Ex. 4(a) and Ex. 4(f) should be omitted.

7.0 Exemption 1(f): Mercury in single capped (compact) fluorescent lamps not exceeding (per burner) For Special purposes: 5 mg

Acronyms and Definitions

AlGaN	Aluminium gallium nitride
CFL	Compact fluorescent lamp
CRI	Colour Rendering Index
DBD	Dielectric barrier discharge
EEE	Electrical and Electronic Equipment
EoL	End of Life
LED	Light Emitting Diode
LEU	LightingEurope
NARVA	NARVA Lichtquellen GmbH + Co. KG
OLED	Organic Light-Emitting Diode
UV	Ultraviolet (subtypes UVA, UVB, UVC)

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

7.1 Background

LightingEurope (LEU)[129] and NARVA Lichtquellen GmbH + Co. KG (NARVA)[130] submitted requests for the renewal of exemption 1(f) of Annex III of the RoHS Directive.

Lamps in Exemption 1(f) can be used both in professional and consumer applications. They differ in construction from general lighting lamps by the use of different glass and phosphors (for some no phosphor is applied), typically emitting in UV or blue wavelength bands. These lamps are used for several areas in medical, disinfection and other applications, where an efficient source for UV light is needed. The power of compact fluorescent lamps (CFL) for special purposes ranges from 5W – 110W. Typical life cycle of equipment in disinfection, medical and insect trap applications is 20-50 years.

Based on experience of LEU, single ended CFLs for special purpose lamps covered by Ex.1(f) count for 0,1% of the total CFL market share in Europe, which means approximately 400.000 special purpose lamps and a maximum of 2 kg of mercury entering the EU. These numbers are expected to remain stable.

LEU explains that substitutes are currently not available to allow a phase-out of lamps covered by this exemption. A further reduction of the current mercury threshold specified in the exemption is also explained not to be practical.

Against this background, LEU and NARVA do not expect the availability of LED alternatives to allow for a full phase-out of Ex. 1(f) lamps within the coming 5 years[131], and thus requests a renewal of the exemption with following wording:

Annex III:

> *"1: Mercury in single capped (compact) fluorescent lamps not exceeding (per burner):*
>
> *(f) For special purposes: 5 mg"*

7.2 Applicant's Justification for Exemption

The applications under the special purpose exemption are in majority applications that are not used for general illumination. LEU[132] claims that Ex. 1(f) lamps can be applied

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[129] LEU Ex. 1f (2015a), LightingEurope, Request to renew Exemption 1(f) under Annex III of the RoHS Directive 2011/65/EU Mercury in single capped (compact) fluorescent lamps not exceeding (per burner) for Special purposes: 5 mg, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_f/Lighting_Europe/1f_LE_RoHS_Exemption_Req_Final.pdf

[130] NARVA (2014a), NARVA Lichtquellen GmbH + Co. KG , Exemption request for using of mercury in fluorescent lamps, submitted 19.12.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/NARVA/01_02_a__2b3_4a.pdf

[131] A maximum validity period, expiry date not required

[132] Op. cit. LEU Ex. 1f (2015a)

both in professional and consumer applications and generates for the most part UV light. Such lamps are used in various application areas where an efficient source for UV light or blue wavelength bands is needed. They differ in construction from general lighting lamps by the use of different technology, wattage, size and compactness, life time, glass and phosphor coating (for some no phosphor is used). Special purposes are explained to include:[133]

- Disinfection of air, water or surfaces;
- Skin treatment (medical), including:
  - Tanning;
  - Narrowband and Broadband UVB phototherapy;
  - PUVA phototherapy; and
  - UVA-1 phototherapy;
- Treatment of neonatal jaundice;
- Insect attraction in insect traps;
- Photo-polymerization of plastics (nail curing, contact lens manufacturing, etc.);
- Counterfeit detection (money checkers);
- Forensic investigation (UV light to detect organic material);
- Enhancing colours of fish in aquaria;
- Fluorescence by black lights in disco's; and
- Many other applications;

Examples of CFL lamps falling under Ex. 1(f) are presented in Figure **7-1**.

LEU further explains[134] that for some of these applications dedicated lamps are marketed, like medical reprography and insect traps, but other lamps are sold in general with a special spectral characteristic and it is unknown which lamp types are used for which applications.

Only a small number of special purpose lamps generate visible light. These have special applications like colour comparison, lamps with high CRI> 90, or lamps with special spectra for poultry farms. However, LEU states[135] that requirements for specifying terms besides the spectral sensitivity are very challenging and mostly depend on the application. Most of the special purpose radiation is dose related. This means that the applied energy during a certain period of time leads to the desired effect but also that undesired side-effects might occur. The dose is a combination of output and time, where time is completely determined by the application and output is the irradiance which

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[133] Op. cit. LEU Ex. 1f (2015a)
[134] LEU Ex. 1f (2015b), Lighting Europe, Response to Oeko-Institut regarding the 1st Questionnaire, Exemption Request No. 1(f) (renewal request, submitted 15.9.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_f/Lighting_Europe/Ex_1_f__LightingEurope_1st_Clarification-Questions_final.pdf
[135] Op. cit. LEU Ex. 1f (2015b)

depends on the distance, the amount of lamps in the appliance and the used drivers to provide the electrical power. Thus the lamp manufacturers have only control on the nominal output measured under standardized circumstances and the spectral shape.

Figure 7-1: Examples of CFL 1(f) lamps and applications

Source: Top image: Typical shapes and forms, taken from LEU Ex. 1f (2015a); Bottom image: examples of lamps applications falling under Ex. 1(f), taken from LEU (2015a).

7.2.1 Possible Alternatives for Substituting RoHS Substances

LEU details some of the efforts in seeking an alternative for mercury in the discharge lamps, concluding that substitutes for Hg in the discharge technology are not available. Details can be found in the application documents as well as in part in Section 4.3.2.1 of this report (the general lamp chapter).

LEU also explains that the amount of mercury used in compact fluorescent lamps has decreased considerably during the last years, but that the technology needs the maximum dosed mercury amount, which is set at 5 mg, in order to function properly throughout the full indicated lifetime.

7.2.2 Possible Alternatives for Eliminating RoHS Substances

According to the applicant more and more LED solutions for general lighting are coming on to the market, while special purpose lamps are a niche market where the development of LED alternatives is slower. LEU[136] states further that only LED and DBD (dielectric barrier discharge) can be considered at present as substitution candidates. Whereas other lighting technologies i.e. halogen and OLED lamps, are not taken into account as substitutes because they cannot produce radiation in the range that is required for applications of Ex. 1(f) lamps.

However, LEU explains that LED and DBD are not considered to allow a proper replacement of the full range of CFL lamps for the various special purposes. LED based light sources are not a viable alternative, as the correct light spectrum is currently not reproduced in lamps available on the market. There are differences in wall plug efficiency, effectiveness, regulation / approbation and in the compatibility with all varieties of ballasts used in relevant equipment. Thus it can be difficult for a customer to choose between LED alternatives and to know when technical "*conversion*" changes are needed to ensure the compatibility of the LED with the existing installation.

LEU reminds that special purpose lamps are installed in a huge variety of types, shapes, sizes, wattages and colours, and explains that LED retrofit solutions and new LED equipment currently cannot be used as replacements (retrofit) for the full range of applications. It is questionable if LED retrofit solutions will be developed for the total range of applications, which is characterised as a scattered landscape with often small series per type. LEU supports its argument regarding the lack of alternatives for a proper full compatible replacement of Ex. 1(f) CFL lamps with specific retrofit criteria. The criteria to determine whether a new technology can replace existing fluorescent lamps using mercury in existing equipment are[137]:

- Similar spectral power distribution;
- Safety and reliability must be assured;

[136] Op. cit. LEU Ex. 1f (2015a)
[137] Op. cit. LEU Ex. 1f (2015a)

- Compatibility must be assured (electrical and mechanical specification);
- Effectiveness to reach the desired effect (tanning result, phototherapeutic effect, insect attraction rate, etc.) must be met;
- Compliance with CE regulations / approbation;
- No (negative) side effects;
- Economically feasible (cost of replacement technology);
- UVA and UVB output must be similar [important only for new technology – consultants comment];
- Similar radiation output [important only for retrofit solutions – consultants comment];

The criteria must be fulfilled both for lamp replacement and for placing new LED equipment on the market. The main difference whether a new technology can replace existing fluorescent lamps using mercury in existing equipment is explained to be justified as all technologies cannot produce radiation output in the range that is required for applications considered to be special purpose CFLs. In a similar fashion, this argument applies also to new LED-based equipment, as the UVA and UVB output must be similar.

LEU demonstrates as an example an alternative technology[138] for the use in water dispensers without mercury. However these lamps cannot replace the current installed base of CFLs, since the electrical and mechanical interface is completely different.

Consideration needs to be given to the following three criteria:

- Comparability of 'Wall Plug Efficiency' to fluorescent lamps;
- Comparability of effectiveness to fluorescent lamps (i.e. same tanning effect, photo-therapeutic effect, insect attraction rate etc.); and
- Regulation/approbation for replacement lamps/alternative equipment is approved.

Wall plug efficiency describes the useful UV power divided by the power used by the whole lighting device (including control gear) from the mains power supply.

On a technical basis the applicant states that achieving the required spectral output is only possible when converting from shorter wavelengths to longer. CFL emit radiation in the non-visible UV spectra and LED primarily emit only in the visible light spectra, of higher wavelengths. It's therefore impossible to create UV light with materials currently used to produce visible light LEDs.

Where it is possible to produce LEDs with non-visible UV light spectra (through AlGaN-LED) the efficiency is still very low. For e.g. according to the applicant[139] studies on insect

[138] A disinfection lamp system for water dispensers, based on a dielectric barrier discharge. Op. cit. LEU Ex. 1f (2015a)
[139] Op. cit. LEU Ex. 1f (2015a)

trap applications (not yet published) looking into LEDs currently show negative results with respect to their ability to attract insects as compared to CFL lamps.

Therefore, according to the applicant[140], LED is not expected any time soon to be suitable as a practical alternative for:

- Disinfection/purification of air/water/surfaces;
- Broadband and Narrowband UVB Phototherapy;
- PUVA phototherapy; and
- Tanning

Regarding the **effectiveness**, for most special purposes, no test results are available yet from studies comparing CFL-based equipment with LED-based equipment, to allow evaluating the effectiveness of new technologies to reach the desired effect. For some applications, for which LED-based equipment is on the market (e.g. nail curing equipment using LEDs) it turns out to be less effective and longer curing/treatment times are necessary. For some other curing applications new photo-initiators have been developed to be able to cure at wavelengths where LEDs are available at a reasonable price. Nonetheless, retrofit LED lamps cannot be used as replacements, due to approbation requirements. Renewal of [medical device – consultants comment] approbation with retrofit LED lamps is not endorsed by equipment companies.

Another example provided by the applicant regards black lights and aquarium lamps. In these applications the visual effects of single CFLs and LEDs are not comparable and therefore LED alternatives cannot be considered compatible.

Regulation (with respect to safety and system responsibility) such as CE[141] conformity and other European directives for special purpose applications (like for instance approbation of medical devices for phototherapy) is based on fluorescent lamps. If the intent is to convert existing equipment to LED alternatives, as most alternative lamps will in practice require a replacement of the equipment ballast to ensure their compatibility, this would be imply that the complete equipment needs to be replaced resulting in an increase of waste. LEU thus claims[142] that spare part replacement of compact fluorescent lamps with LED based lamps is therefore generally not practical.

Thermal Aspects: Current equipment using compact fluorescent lamps is not designed to take care of the heat generated by LEDs. Where in CFL-type lamps the generated heat is mostly radiated away, with LEDs the heat has to be transported away by conduction. Furthermore CFLs for special purpose are designed to have a very homogenous spatial radiation distribution compared to LED retrofit lamps. The more directional light of an LED will give a different radiation distribution in the same equipment.

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[140] Op. cit. LEU Ex. 1f (2015a)
[141] CE marking is a mandatory conformity marking for certain products sold within the European Economic Area (EEA)
[142] Op. cit. LEU Ex. 1f (2015a)

Electrical Configuration: LEU [143] further explains that luminaires can use conventional electromagnetic ballasts or high frequency electronic drivers. The market for new installations is moving towards electronic drivers due to new functionality (e.g. dimmability) and upcoming legislation for drivers related to energy efficiency. Professional CFL lamps are designed to be dimmable. Several modes of dimming (e.g. phase cutting) are present on the market. All modes of operation (EM, HF current controlled, power controlled, voltage controlled, preheat, non-preheat) have in common that the light source is expected to behave electrically as a standardised CFL lamp. The large diversity of drivers is not intended for an electronically ballasted LED lamp and there is no interface description for LED lamps yet. Thus, in the case of existing installations where the life of the lamp is shorter than that of the luminaire, a customer does not know which ballast is used and which LED lamp to apply as retrofit. A wrong combination can lead to instable lamp power for the LED and to safety consequences. Ballasts for professional CFL lamps are designed to be used with several subsequent lamps (at least 3-4 lamps before the ballast itself has to be replaced). So if the combination of the ballast with the LED lamp is not working or not available, the ballast needs to be changed earlier.

It is understood that the argumentation made regarding ballasts compatibility could only be a concern for lamps with external ballasts, as from the fixtures observed in figure Figure **7-1** not all lamps falling under Ex. 1(f) shall have an external ballast.

LEU concludes[144] that LEDs currently do not provide a viable alternative for replacing single capped fluorescent lamps for special purposes based on the following results:

- For UV-C and UV-B: higher energy consumption (see example in report of Ex. 18b, Chapter 27.0) due to low efficiency of currently available UV-C and UV-B LEDs;
- For UV-A: For applications with a spectral output below 380 nm, energy consumption will also go up due to low efficiency of UV-A LEDs in that wavelength region;
- Applicable for all applications: In practice, most alternative lamps need replacement of the equipment ballast. Effectively, this would imply that the complete equipment needs to be replaced, which produces additional waste when still properly operating components need to be disposed.

7.2.3 Environmental Arguments

In addition to the overall environmental arguments detailed in Section 4.3.3 of the general chapter, the applicant further argues that although the LED technology doesn't contain mercury, it may contain other sorts of substances as lead and plastics. The applicant advocates to first carry-out further research into the overall substance effect

[143] Op. cit. LEU Ex. 1f (2015a)
[144] Op. cit. LEU Ex. 1f (2015a)

of LED lamps in comparison with CFL lamps. LEU later substantiated such statements revealing that discharge lamps and LED alternatives may have similar electronic components and thus may contain similar hazardous materials (see Section 4.3.3.2 of the general chapter). However, should new materials need to be developed to allow for LED substitutes to improve in spectra and in energy wall efficiency, this statement may be observed differently.

Argumentation related to lower wall-plug efficiency is also of environmental relevance, but is not presented here again as it appears in the sections above.

7.2.4 Road Map to Substitution

With regards to Ex. 1(f)-lamps, the applicant states (since special purpose lamps are a niche market) that LED development is slower in comparison to the general lighting application range. LED technology performance is developing and some UV-LEDs are available from several suppliers. However the balance between cost price, differences in wall plug efficiency, effectiveness, the difficulties in regulation/approbation and the time needed to approve approbation is not yet clear. The most difficult of these issues to overcome is likely to be the differences in spectral output. For different applications the time needed for implementing development efforts to allow releasing equipment to the market may differ significantly for various applications. For example for medical treatment applications, with the risk of side effects, equipment releases could be extremely costly, time consuming and difficult.

According to the applicant an extension of the exemption will have no negative effect on the efforts to further innovate in LED, because the future focus of the lighting industry is already on the further development of such technologies.

7.3 Stakeholder Contributions

Five contributions were submitted during the stakeholder consultation, however none of these provide specific information related to Ex. 1f –lamps. General aspects raised can be viewed in Section 4.4 of the general chapter.

7.4 Critical Review

7.4.1 Scientific and Technical Practicability of Substitution

LEU does not provide a roadmap related to efforts for further improvement of CFL technology and it can be understood that such research is no longer being performed. It can be concluded that all efforts towards development of alternatives are focused on LED technologies. Moreover the amount of mercury has been drastically reduced in the last decades in mercury-based lamp applications. Thus it is uncertain if the amount of mercury of 5mg currently permitted through Ex. 1(f) can be reduced while ensuring comparable performance in terms of lifetime, optical performance and energy efficiency.

Halogens lamps are explained to be a non-practical alternative as they consume significantly more energy during their use. The consultants agree with this point and thus they are not further discussed in this respect.

The applicant mentions that organic light-emitting diode (OLED) lamps cannot produce radiation in the range that is required for applications of lamps for special purposes. In a first clarification round[145] the applicant described these alternatives as not suitable for special purpose lamps. OLEDs are similar to LEDs in the sense that both use solid-state semiconductor materials that emit light from a p-n-junction. They are different in the sense that LEDs use inorganic materials while OLEDs use organic (carbon based) materials. OLED material is designed to function in the visible light range and is used for display or general illumination purposes. In order to create UV light (radiation) other materials need to be tested. Furthermore, most of the organic materials are very unstable under UV conditions and rapidly degrade. This argument however, can only support that OLEDs are not a practical substitute for special purpose lamps with a spectral output in the non-visible range.

LEU explains that there are UV LEDs, which in principle could be used for special purposes, available from several suppliers. However such alternatives cannot produce radiation in the spectral range required for various applications of special purpose CFLs. In the consultants view this argumentation is only substantiated for applications for which the main function of the lamp is to provide spectral output in the non-visible light range, for instance tanning lamps, broadband and narrowband UVB phototherapy; PUVA phototherapy or disinfection/purification applications, and black light referred to as a UV-A light that emits long wave (UV-A) ultraviolet light and not much visible light. For such applications, it can be followed that current alternatives do not provide a comparable spectral output (UVB/UVC), and/or that wall plug efficiency of the applications effectiveness are lower.

It is further explained that lamps covered by the exemption for professional use are subject to application specific EU regulations or CE marking. Replacing lamps in such installations so that they adhere to such norms may require a new lighting plan because, for example, the required illuminance levels can't be reached with the same number of light points. This can influence the total energy use negatively.

LEU did not provide any roadmap that predicts when UV LEDs with acceptable spectral output and efficiency shall become available. According to the applicant the presence of mercury in such special purpose Ex. 1(f) – UV lamps is understood to still be necessary as performance of alternatives is still not comparable to CFLs (spectral output, efficiency, etc.). This argumentation can be followed.

In contrast, for special purpose lamps where the main function is understood to be in the visible spectral output range, the provided argumentation does not explain why substitution is currently not possible. Arguments are similar to those provided for Exemption entries 1(a-e) and it is not sufficiently explained why such applications are to be understood to be special purposes and not general lighting and why possible alternatives cannot achieve comparable performance (such as higher CRI's). Lighting

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145 Op. cit. LEU Ex. 1f (2015b)

Europe further does not confirm that detailed applications are exhaustive (i.e., special purposes cannot be defined comprehensively), and thus additional applications could be placed on the market through this exemption if its wording remains unchanged.

Argumentation related to the availability of substitutes for lamps operating in the visible light spectrum are discussed in the chapter regarding Exemption 1a-e (See Chapter 5.0). In the consultants view, the information provided by LEU as to possible LED substitutes is very general in its nature. Many of the specific design limitations raised as problems of LED technologies have been communicated in the past reviews and are understood to have been resolved in applications on the market. As LEU does not provide specific information to substantiate its claims in relation to Ex. 1(f) lamps operating in the visible-light range, it cannot be concluded if such developments have also been implemented in LED alternatives on the market that are relevant for this exemption.

In contrast, the consultants can follow the argumentation that despite development efforts, that LED alternatives for UV sources do not provide comparable performance related to application effectiveness and lifetime. As the UV lamp area is a niche application are, it can also be followed that such developments shall be slower than for other lamp applications with larger market shares.

7.4.2 Environmental Arguments

Regarding the environmental arguments made by LEU, most of these are not specific for lamps falling under Ex. 1(f) and are discussed in the general chapter (see Section 4.5.3).

As for aspects raised regarding possible reduced wall plug efficiency of current candidate alternatives, these are discussed in Section 7.4.1 and can be followed.

7.4.3 The Scope of the Exemption

LEU was asked to clarify exhaustively the scope of exemption 1(f) in terms of lamp type sub-groups, in order to determine what applications fall under the term “special purposes” and what the respective characterisations of lamps are. LEU explains that the majority of the applications are not in the visible output range. There are only a small number of special purpose lamps that generate visible light. According to the applicant these lamps differ in their colour, with high colour rendering >CRI 90. However LEU delivers no further arguments and data as to such applications and states that lighting manufacturers do not know exactly which lamp types are used in which applications. The applicant thus argues that it is difficult to classify certain lamp types.

According to the applicant the power rating of CFL for special purposes ranges from 5W – 110W. Fluorescent lamps can be distinguished into general lighting purpose lamps and special purpose lamps as well as single-capped (CFL), and double-capped (LFL) linear lamps. Ex. 1(f) covers CFLs with the same range of wattages also addressed under the existing exemption entries 1(a-c). The use of the undefined term “special purposes” is thus understood to potentially create loopholes, under which lamps falling under the scope of Ex. 1(a-c) could be placed on the market through Ex. 1(f), should the term not be clearly defined. Such loopholes have also been discussed among others, in the preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements

('Lot 8/9/19') prepared by VHK & VITO and in the Omnibus study[146]. There is a need to clearly define what technologies are to be considered to fall under "special purpose uses" so as to eliminate such loopholes in exemptions where this term is referred to, particularly at a time where it is expected that some exemptions may be revoked. However, LightingEurope and other studies do not provide an exhaustive definition at present and arriving at such a definition is also not possible on the basis of the information provided by the applicants, where detailed applications are specified as not exhaustive. Information provided by LEU clarifies that lights emitting in the UV spectrum would fall under this exemption. Though additional applications are named, the only parameter mentioned as characteristic of such lamps is colour rendering index (CRI) values of above 90. However information is not provided to explain why alternatives do not provide comparable performance, nor is it clear why such applications would be considered to fall under special purposes, particularly as LEU could not provide information as to the range of relevant applications. As long as the lighting industry cannot provide information clearly demonstrating what applications and respectively what performance aspects would be relevant for special purpose, the only way to avoid loop-holes is to limit the scope of the exemption. Such a limitation can only consider articles clearly understood to be of relevance, not to be covered by other exemptions and for which argumentation is provided to justify the applicability according to Article 5(1)(a).

LEU explains that the lamp manufacturers only control the nominal spectral output measured under standardized circumstances. Though it can be followed that in some cases manufacturers do not know for what purposes their lamps are used in practice[147], the consultants cannot follow LEU's general argumentation that it is not possible to exhaustively define what lamps are covered under this exemption (for example through specifying typical spectral output specifications and colour performance aspects). This is further an issue of concern as without such specifications it cannot be determined if certain lamps placed on the market through Exemption 1(f) would not also fall under the scope of Ex. 1(a-c). In the consultants view it is essential to distinguish between visible (to most human eyes) and non-visible light in order to allow differentiating between applications for which argumentation justifies the renewal of the exemption and applications for which this is not understood to be the case.

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[146] Op. cit. Omnibus (2014)

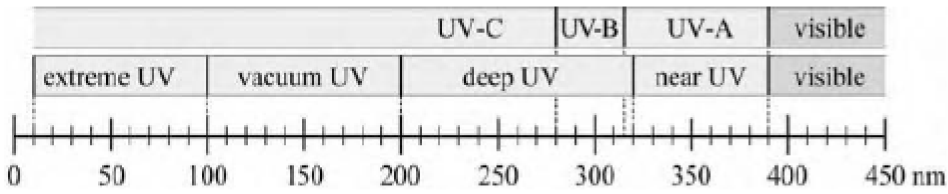
[147] When a lamp is placed on the open market, the manufacture cannot guarantee that it shall only be installed in equipment for which it was designed. Nonetheless, the consultants expect that the lighting industry be able to detail the range of lamps covered by a certain exemption as they are aware of what is manufactured (dimensions, technical parameters, etc.) and for which applications it is designed (i.e. what functions the lamp needs to fulfil).

7.4.3.1 Lamps Designed for Emitting Light in the Non-Visible Spectrum

Ultraviolet (UV) light is that part of electromagnetic radiation between the lower wavelength extreme of the visible spectrum and the X-ray radiation band, which is commonly used in medicine. The spectral range of UV light is between 100 and 400 nm (1 nm=10-9m) and is invisible to human eyes[148]. The spectral range can be produced by light of a narrow band of wavelengths. The spectrum is continuous, with no clear boundaries between one colour and the next classification. Using the CIE classification[149] the UV spectrum is subdivided into three subtype bands UVA, UVB, UVC. Each has different penetration properties and potential for damage to human health.

In order to discuss the issue of the wavelengths it is useful to illustrate the Wavelength (nm) for the UV spectrum, as shown in Figure 7-2.

Figure 7-2: Classification of UV radiation



Source: https://www.fh-muenster.de/fb1/downloads/personal/juestel/juestel/AlGaN______UV-LEDs_MatthiasMueller_.pdf

In general, the following types of UV light are distinguished:

- UVA (long-wave) / near UV-Black Light 315-400 nm[150];
- UVB (medium-wave) 280-315 nm;
- UVC UV C (short-wave) / far UV-Germicidal 100-280 nm.

The most important application of UV lamps is probably in tanning devices (e.g. solariums). It is estimated that there are around 50.000 tanning facilities (salons, beauty parlours, hot baths and spas)[151]. However there is a huge variety of lamps used for additional applications, i.e., medical, disinfection, etc. (see detail in Section 7.2).

There are other types of non-visible light e.g. infrared light, X-Rays, microwaves etc. some of which may also be relevant for special purposes lamps (e.g. infrared). The consultants assume that special purpose lamps emitting infrared wavelength are not

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[148] Visible light lies in the wavelength range around 400 to around 700nm
[149] http://www.cie.co.at/index.php/Technical+Committees
[150] (in DIN only defined to 380 nm, in practice often down to 400 nm)
[151] VHK (2015b): Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'). Final report, Task 1, Annexes, Standards, Legislation, by Prepared by VHK, in cooperation with VITO and JeffCott Associates, 31 October 2015; Prepared for the European Commission, DG ENER.C.3

part of the requested exemption at hand as the applicant did not detail any applications related to that spectra.

7.4.4 Exemption Wording Formulation

The applicant has requested the renewal of the exemption with the following wording formulation.

> *"1: Mercury in single capped (compact) fluorescent lamps not exceeding (per burner):*
>
> *(f) For special purposes: 5 mg"*

The analysis of the term special purpose lamps under the current lighting regulations (RoHS and Ecodesign) and the information highlighted by LEU does not allow specifying an exhaustive definition for this term.

As argumentation for justifying the exemption only supports the lack of substitutes for applications in the non-visible range, the consultant recommends a distinction between visible and non-visible light. The consultants note that distinctions between visible and non-visible have been made before; for instance, the definition for the initial scope in legislation drafted for the Commission consequence to the Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19') refers to visible light as "mainly visible optical radiation in a wavelength of 380-780 nm".

7.4.5 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof

In the consultants' opinion, lamps for special purposes are needed where application specific characteristics are prescribed. They generally have the following characteristics:

- Special purpose lamps are generally manufactured on the basis of general purpose lamp production technologies.
- The use of special design, materials and process steps provides their special features and CFLs for special purposes cover a very broad range of different lamps with different characteristics.
- Special purpose lamps covered by Ex. 1(f) are estimated to have relevance very small market share (most of them are not supported by market data) in comparison to other CFL lamps discussed above.

The applicant puts forward information that clearly shows that substitution on the substance level is not practical and it can also be followed that further reducing Hg amounts per burner may not result in significant environmental benefits. All efforts towards development of further substitutes are understood to be focused on LED technologies.

Based on the available information the consultants conclude that most of the applications operate mainly in the non-visible radiation range such as UV lamps. For such lamps, the argumentation that substitutes do not provide comparable performance as a consequence of insufficient wall-plug efficiency, non-comparable spectral output and lacking application effectiveness. Application approbation shall only be possible after resolving these issues. The consultants' can follow that the last stages of substitution may thus require more time.

- LEU explains that some CFL-lamps operate in the visible radiation range; however, justification for the exemption is only presented for lamps operating in the non-visible range (i.e. where the main function of the application requires the spectral output to be in the non-visible range). This does not allow understanding whether the exemption renewal would be justifiable for lamps operating in the visible range. Further argumentation to support the lack of substitutes for such lamps does not allow concluding that such lamps would not fall under Ex. 1(a-c) and to what degree LED substitutes are available or not. Whether these lamps are indeed to be considered as special purpose applications can also not be derived from the available information. For example, Ex. 4(b) also concerns lamps with special colour performance and relevant applications are addressed in the exemption as "general purposes". Specific information as to alternatives for Ex. 1(f) lamps operating in the visible light range are not provided. Though some alternatives may be available for such applications, it cannot be dismissed that availability may still be insufficient.

Since most of LEU's examples for lamps that are "Ex. 1(f) special purpose lamps" are in the non-visible light spectrum and since for such lamps the argumentation can be followed, it would be practical to renew the exemption for such types. Thus splitting the exemption to address lamps designed for emitting light in the visible spectrum and in the non-visible spectrum would be practical. However, in the visible radiation range sufficient justification is not provided and the application list is not exhaustive, nor is other specification data available to allow a clear demarcation of lamps covered under the exemption. For such lamps manufacturers should be required to specify what types of lamps would fall under the exemption and why, based on the Article 5(1)(a) criteria to show the exemption is still justified. Manufacturers could be required to identify such lamps when placed on the market as "for special purpose" in order to allow collecting more specific information for future revisions of the Directive.

7.5 Recommendation

The consultants recommend granting an exemption as follows:

For lamps designed to emit light in the visible spectrum, technical justification has not been provided. The consultants can neither conclude that an exemption is justified nor that it is not, as specific information as to the application range and as to available substitutes are lacking. The consultants recommend revoking the exemption for such applications or allowing a short termed exemption so that industry can request new exemptions where data and information show justification on the basis of Article 5(1)(a). The consultants believe the definition of exemptions and of special purpose lamps should be application specific and based on technical parameters for all applications (sub-groups) of relevance.

For the special purpose lamps with UV radiation it is recommended to grant the exemption with the maximum available duration.

In light of Article 5(2), from a legal perspective, excluding EEE falling under Cat. 8 and 9 from the scope of this exemption may not be possible; however the consultants' are also concerned that extended availability of such lamps for these categories may create a loop hole for consumers seeking CFL replacements covered by entries due to expire. If possible, the EU Commission should investigate limiting the sales of such lamps to a business to business basis to avoid such misuse.

Exemption 1	**Duration***	**Comments**
Mercury in single capped (compact) fluorescent lamps not exceeding (per burner),		
(f)-I For lamps designed to emit light in the ultra-violet spectrum: 5 mg	*For Cat. 5: 21 July 2021*	The maximum transition period should be granted for other applications and other categories (18 months); Integrating this entry into a UV lamp exemption should be considered.
(f)-II For special purposes: 5 mg	*For Cat. 8 and Cat. 9: 21 July 2021* *For Sub-Cat. 8 in-vitro: 21 July 2023* *For Sub-Cat. 9 industrial: 21 July 2024*	The COM should consider adopting measures to limit product availability to B2B transactions.

7.6 References Exemption (1f)

LEU Ex. 1f (2015a) LightingEurope, Request to renew Exemption 1(f) under Annex III of the RoHS Directive 2011/65/EU Mercury in single capped (compact) fluorescent lamps not exceeding (per burner) for Special purposes: 5 mg, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_f/Lighting_Europe/1f_LE_RoHS_Exemption_Req_Final.pdf

LEU Ex. 1f (2015b) Lighting Europe, Response to Oeko-Institut regarding the 1st Questionnaire, Exemption Request No. 1(f) (renewal request, submitted 15.9.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_f/Lighting_Europe/Ex_1_f__LightingEurope_1st_Clarification-Questions_final.pdf

NARVA (2014a) NARVA Lichtquellen GmbH + Co. KG , Exemption request for using of mercury in fluorescent lamps, submitted 19.12.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/NARVA/01_02_a__2b3_4a.pdf

VHK (2015b) Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements (‘Lot 8/9/19’). Final report, Task 1, Annexes, Standards, Legislation, by Prepared by VHK, in cooperation with VITO and JeffCott Associates, 31 October 2015; Prepared for the European Commission, DG ENER.C.3

8.0 Exemption 2(a)(1-5): " Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp):" [various entries]"

This review of Annex III exemption 2(a) covers the following exemption entries:

(1) Tri-band phosphor with normal lifetime and a tube diameter < 9 mm (e.g. T2): 5 mg

(2) Tri-band phosphor with normal lifetime and a tube diameter ≥ 9 mm and ≤ 17 mm (e.g. T5): 5 mg

(3) Tri-band phosphor with normal lifetime and a tube diameter > 17 mm and ≤ 28 mm (e.g. T8): 5 mg

(4) Tri-band phosphor with normal lifetime and a tube diameter > 28 mm (e.g. T12): 5 mg

(5) Tri-band phosphor with long lifetime (≥ 25 000 h): 8 mg

Declaration

In the sections that precede the "Critical Review" the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

CCG	Conventional control gear
CRI	Colour rendering index
ECG	Electric control gear
EEE	Electrical and Electronic Equipment
EoL	End-of-life
Hg	Mercury

LED	Light emitting diode
LEU	LightingEurope
LFL	Linear fluorescent lamps
NARVA	NARVA Lichtquellen GmbH + Co. KG

8.1 Background

LightingEurope (LEU) and NARVA Lichtquellen GmbH + Co. KG (NARVA) have both applied for the renewal of Ex 2(a) of Annex III of the RoHS Directive. LightingEurope[152] has applied for the renewal of items 1, 2, 3 and 5. NARVA[153] have applied for the renewal of items 1 through 5. This exemption covers double capped linear fluorescent lamps for general lighting purposes using tri-band phosphors as the fluorescing material.[154]

NARVA[155] explains that lamps falling under these exemptions are discharge lamps, which use mercury for the discharge process, arguing that no substitutes for the mercury are available. In relation to substitutes, LEU[156] mentions that though more and more LED solutions are coming onto the market, they cannot always serve as a fully compatible replacement for the huge variety of linear fluorescent lamps (LFLs) for consumers and professional end users.

Both applicants apply for the renewal of Ex. 2(a), entries (1, 2, 3 and 5), with the current wording formulations listed in Annex III of the RoHS Directive and requesting the maximum available duration allowed (based on Art. 5(2) of the Directive). NARVA also applies for entry 4, with the current wording formulation and requesting the maximum validity period, however did not provide specific information to justify this request.

[152] LEU Ex. 2(a)(1)(2015a), LightingEurope, Request to renew Exemption 2(a)(1) Under Annex III of the RoHS Directive 2011/65/EU 2(a) Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp): 2(a)(1) Tri-band phosphor with normal lifetime and a tube diameter < 9 mm (e.g. T2): 4 mg may be used per lamp after 31 December 2011, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/Lighting_Europe/2a1_LE_RoHS_Exemption__Req_Final.pdf

[153] NARVA (2014a), NARVA Lichtquellen GmbH + Co. KG , Exemption request for using of mercury in fluorescent lamps, submitted 19.12.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/NARVA/01_02_a__2b3_4a.pdf

[154] Op. cit. LEU Ex. 2(a)(1)(2015a)

[155] Op. cit. NARVA (2014a)

[156] Op. cit. LEU Ex. 2(a)(1)(2015a)

8.2 Description of Requested Exemption

According to LEU, all lamps falling under Ex. 2(a)(1-3) are very economical and offer a good quality of light and excellent luminous flux. They are slim and compact with good average lifetime (entries 1, 2 and 3) or with long-lifetime (entry 5[157]) with suitable electronic control gear. Employing only limited componentry, fluorescent tubes are explained to be very resource efficient.[158]

The introduction of electronic ballasts for fluorescent lamps was important for improving lighting quality, especially regarding flicker. Today, most fluorescent lamps operate on either instant-start or rapid-start electronic ballasts, with the former using shunted lampholders (sockets) and the latter using unshunted lampholders - meaning there is no connection between the terminals. There is also still a substantial installed base of lamps operating on magnetic ballasts, which typically connect to unshunted sockets. Shunted sockets are usually recognizable because they have a connection terminal on only one side of the lampholder. When changing lamps - or retrofitting an existing luminaire with LED lamps - it is important to know the type of lampholder used, because the electrical paths are different. In general, there has been a shift to using linear fluorescent lamps with a colour rendering index (CRI) of at least 80 in typical applications, as opposed to a CRI of at least 70 in earlier LFL applications.[159]

For lamps covered by Ex. 2(a)(1) the maximum allowed mercury dose is currently 4 mg per lamp. T2 linear fluorescent lamps (LFL) [where the 'T' designates a tubular lamp and the numerical identifier represents the diameter in eights of an inch] are a small segment of energy efficient lamps required on the market. They are used in professional areas as well as in private homes (e.g. as furniture background lighting). According to LEU such lamps have a diameter of ca. 7 mm and different lengths. Due to the very wide range of applications LEU believes that there is still a market need for lamps covered by this exemption for 15-20 years for the existing applications, fixtures and equipment.[160]

For lamps falling under the scope of Ex. 2(a)(2) the maximum allowed mercury dose is currently 3 mg per lamp. Such lamps placed on the EU market have a diameter of ca. 16 mm and different lengths. The lamps are in use mainly in professional areas, such as offices, schools and industrial buildings, but also in residential homes. T5 are among the

[157] In later communication LEU states that some T8 lamps operating on conventional control gear (CCG) are also covered by this exemption. The consultants thus assume that this statement is made as lamps are understood to have a longer service life when operated on electric control gear (ECG) as compared to CCG.
[158] Op. cit. LEU Ex. 2(a)(1)(2015a); LEU Ex. 2(a)(2)(2015a); LEU Ex. 2(a)(3)(2015a); LEU Ex. 2(a)(5)(2015a)
[159] CALiPER (2014a), Pacific Northwest National Laboratory, Application Summary Report 21: Linear (T8) LED Lamps, Solid-State Lighting Program Building Technologies Offi ce Office of Energy Effi ciency and Renewable Energy U.S. Department of Energy, available under: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_21_t8.pdf
[160] Op. cit. LEU Ex. 2(a)(1)(2015a)

most energy efficient lamps, reaching levels up to 115 lumens per watt and a lifetime of 20,000 hours for the regular lamps.[161]

In relation to T5 lamps, LEU further states that luminaire service lifetime can be estimated on different levels depending on the application, e.g. approximately 20 years for industry installations, 10-14 years for offices, 15-30 for outdoor. LEU notes that lamp service life is significantly lower than 20 yrs. So during these 20 years the luminaire has had several lamp replacements.[162]

T2 and T5 luminaires are operated nearly exclusively with electronic control gears (ECG) which have advantages over conventional control gears (CCG) regarding power consumption, lifetime, maintenance costs, temperature behaviour, switching, flicker, dimming etc.[163]

In lamps covered by Ex. 2(a)(3) the maximum allowed mercury dose is currently 3.5 mg per lamp. T8 lamps currently placed on the EU market usually have a diameter of ca. 26 mm and come in 16 different lengths. Linear T8 lamps for general lighting as covered by exemption 2(a)3 is a very big segment of all linear fluorescent lamps. They are among the most energy efficient lamps, reaching levels up to 100 lumens per watt and a lifetime of 20,000 hours for the regular lamps. LEU roughly estimates that ca. 60% of the installed T8 luminaires are using a CCG, elaborating that there are no statistical data available. [164] In contrast, the VHK & VITO[165] study states that available data are confusing, but the share of electronic ballasts in 2014 is expected to be around 75-80%.

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[161] LEU Ex. 2(a)(2)(2015a), LightingEurope, Request to renew Exemption 2(a)(1) Under Annex III of the RoHS Directive 2011/65/EU 2(a) 2(a)Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp): 2(a)(2) Tri-band phosphor with normal lifetime and a tube diameter ≥ 9 mm and ≤ 17 mm (e.g. T5): 3 mg may be used per lamp after 31 December 2011, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/Lighting_Europe/2a2_LE_RoHS_Exemption__Req_Final.pdf

[162] LEU Ex. 2(a)(2015b), LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 2(a)(1-5) (renewal request), submitted 15.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/Lighting_Europe/Ex_2a_1-5__LightingEurope_Clarifications_1st_round_final.pdf

[163] Op. cit. LEU Ex. 2(a)(1)(2015a) and LEU Ex. 2(a)(2)(2015a)

[164] LEU Ex. 2(a)(3)(2015a), LightingEurope, Request to renew Exemption 2(a)(3) under Annex III of the RoHS Directive 2011/65/EU, 2(a) Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp): 2(a)(3) Tri-band phosphor with normal lifetime and a tube diameter > 17 mm and ≤ 28 mm (e.g. T8): 3.5 mg may be used per lamp after 31 December 2011, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/Lighting_Europe/2a3_LE_RoHS_Exemption__Req_Final.pdf

[165] VITO & VHK (2015), Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements (‘Lot 8/9/19’), Final report, Task 4, Technologies, Prepared for the European Commission, DG ENER.C.3

Both T5 and T8 lamps are said to be used in hundreds of millions of installed light points in many configurations. [166]

Notably, T8 lamps have supplanted T12 lamps - which have now been phased out of production - and offer substantially improved performance. T5 fluorescent lamps are not a direct replacement for either T12 or T8 lamps.[167]

Ex. 2(a)(5) covers long-life linear T5 (16 mm diameter) and T8 (27 mm) tri-band phosphor lamps with standardised dimensions and base. The maximum allowed mercury dose is currently 5 mg per lamp. Electrical characteristics of long life lamps are compatible to normal life lamps. LEU explains that lamps with long life time need more Hg compared to normal life time, but have environmental advantages compared to the standard types. The main reason for this is the relationship between Hg consumption and lamp life span. It is of course to be expected that lamps with a longer life span will mean fewer lamps throughout the life of a luminaire. So long-life lamps need less materials and the waste at end-of-life is reduced accordingly. Regarding mercury, the quantity required per 10,000 hours life span is significantly lower in long life lamps compared to the alternative. So a T8 with a 90,000 hour life span needs < 30% of the mercury per hour of life span compared to a 20,000 hour life span lamp. Examples as listed in Table 8-1 below show 46% reductions for a T5 HE 35W, and at least 11% reduction for a T5 HO lamp.[168]

[166] LEU Ex. 2(a)(2)(2015a); Ex. 2(a)(3)(2015a)
[167] Op. cit. CALiPER (2014a)
[168] LEU Ex. 2(a)(5)(2015a), LightingEurope, Request to renew Exemption 2(a)(5) under the RoHS Directive 2011/65/EU 2(a) Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp): 2(a)(5) Tri-band phosphor with long lifetime (≥ 25.000): 5 mg may be used per lamp after 31 December 2011, submitted 55.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/Lighting_Europe/2a5_LE_RoHS_Exemption__Req_Final.pdf

Table 8-1: Comparison of resource efficiency and mercury content per 10.000 hours lifespan show significant advantages of linear T5 and T8 lamps with long life time compared to lamps with normal lifetime (examples)

Lamp type	T8 36W/840	T8 XT 36W/840	T8 XXT 36W/840	T5 HE 35W/840	T5 XT HE 35W/840	T5 HO 49W/840	T5 XT HO 49W/840
Length	1200 mm	1200 mm	1200 mm	1449 mm	1449 mm	1449 mm	1449 mm
Life span (B50)	20.000	50.000	90.000	24.000	45.000	24.000	45.000
Service life	18.000	42.000	75.000	19.000	30.000	19.000	30.000
Average mercury	2.5 mg	3.3 mg	3.3 mg	2.5 mg	2.5 mg	1.5 mg	2.6 mg
Mercury per 10.000 h life span (Hg/Life span*10.000) [mg]	1.25	0.66	0.37	1.04	0.56	0.63	0.56
Lamps required for 100.000 h life span	5,00	2,00	1,11	4,17	2,22	4,17	2,22

Note: In a later communication LEU[169] explains that:
Average rated lamp life (here referred to as Lifespan)(B50) is the average value of the life values of individual lamps operated under standardized conditions (50 % failure). In other words, this is the operation time at which for a standardized 3-hour switching cycle (165 minutes on/15 minutes off in accordance with IEC 60081 and IEC 60901) 50 % of a sample population of lamps have failed. See Fig. 27, Fig. 28, Fig. 29 and Fig. 30.
Service life time is the mathematical life time (maintenance multiplied with the % of failed lamps e.g. B10) for lamps in an installation after which the installation luminous flux (100 h value) decreased with 20 % (decrease in luminous flux and failed lamps) for indoor lighting.
See Fig. 27, Fig. 28, Fig. 29 and Fig. 30.
For further information, please consult http://catalog.myosram.com.
Source: LEU Ex. 2(a)(5)(2015a)

LEU[170] explains that for the purpose of Ex. 2(a)(5), long lifetime has been defined as *"≥ 25.000 hours where the installed luminous flux (lamp survival in % times lamp luminous flux in % or service life) is higher than 80% at 25.000 hours with an electronic ballast using the standardised 3 hour cycle"*.[171] This definition is different to the widely used average (=median) life time, which is defined as the average value of the life values of individual lamps operated under standardized conditions (50% failure): i.e. the operation time at which for a standardized 3-hour switching cycle (165 minutes on/15 minutes off

[169] LEU (2016c) LightingEurope, Response to Clarifiction Questions Regarding Ex. 2(a)(5)", submitted 9.3.2016 per email
[170] Op. cit. LEU Ex. 2(a)(5)(2015a)
[171] Referenced in LEU Ex. 2(a)(5)(2015a) as: Final Report "The Adaptation to scientific and technical progress under Directive 2002/95/EC, Oeko-Institut, 20 Feb. 2009, http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf

in accordance with IEC 60081) 50% of a sample population of lamps have failed. According to these definitions service life as used for the purpose of this exemption is much more demanding than average or median life time as it also takes the luminous flux into account. Life time values of fluorescent lamps are different, depending on whether lamps are operated with magnetic ballast and starter (i.e. CCG) or with ECG.[172]

Long-life lamps are used in areas where lamp replacement is difficult and expensive due to high ceilings, when special luminaire design for critical application is required or when too much disturbance of running processes would occur during long operating hours. There is more Hg in the lamp since the process "consuming" mercury in the lamps is taking place for a longer time (see Section 4.3.1 in general chapter regarding Hg "consumption"). The product is different and more expensive to produce since for instance more rare earths are used in the phosphor to produce the lamps. In long life lamps, the corresponding mercury amount per lumen hour of operation is lower compared to lamps with lower lifetime. For example, one lamp with 50,000 hour lifespan and 4.5mg Hg can replace 2.5 lamps with 20,000 hour lifespan each containing 3mg (i.e. 2.5 × 3mg = 7.5 mg Hg).[173]

LEU provides typical parameters for each entry to further describe the range of lamps available on the market and covered by this exemption. The data is summarised in Table 8-2.

[172] Op. cit. LEU Ex. 2(a)(5)(2015a)

[173] LEU Ex. 1-4 (2015a), LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 1-4 (renewal requests) General Questions for Lamp Exemptions Related to Mercury, submitted 25.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/LE_Ex_1-4_LightingEurope_General_Clarification-Questions_Final.pdf

Table 8-2: Typical parameters of lamps falling under Ex. 2(a)(1,2,3, and 5)

	Ex. 2(a)(1)	Ex. 2(a)(2)	Ex. 2(a)(3)	Ex. 2(a)(5)
Available Wattages (main types used in EU)	6 Watt, 8 Watt, 11 Watt, 13 Watt	4 - 80 W	10 - 70 W	10 - 70 Watt (W)
Typical lengths in mm		136; 212; 288; 517; 550; 850; 1150; 1.450;	330; 361; 438; 470; 691; 590; 720;742; 818; 895; 970; 1047; 1200; 1500; 1764;	
Available Colour Temperatures	2.700K up to > 6.500 Kelvin (K)	2.700K up to > 6.500K	2.700K up to > 6.500K	2.700 up to >6.500 K
Typical Colour Rendering Index (Ra)	70-79	80 - >90	80 - >90	80 - >90
Average Lifetime	8.000hrs (with preheat electronic control gear)*	Typically ca. 20.000hrs on an electronic control gear*	Typically 15.000 - 20.000hrs on an electronic control gear*	Typically 40.000 – 90.000 hrs (B50): Corresponding service life time: 30.000 h (T5 on ECG), up to 75.000 (T8 on ECG);
Base (standard designation)	W4.3 x 8.5d (IEC/EN60061)	G5 (bi-pin), (acc IEC/EN60061):	G13 (bi-pin), IEC/EN60061),	
Additional aspects mentioned:		Dimmable	Dimmable (with special electronic control gear)	Dimmable;

* Explained by LEU as: Average rated lamp life (B50) which is the average value of the life values of individual lamps operated under standardized conditions (50 % failure). In other words, this is the operation time at which for a standardized 3-hour switching cycle (165 minutes on/15 minutes off in accordance with IEC 60081 and IEC 60901) 50 % of a sample population of lamps have failed.

Source: Op. cit. LEU Ex. 2(a)(1)(2015a), LEU Ex. 2(a)(2)(2015a), LEU Ex. 2(a)(3)(2015a); LEU Ex. 2(a)(5)(2015a)

8.2.1 Amount of Mercury Used under the Exemption

LightingEurope explains that there are no specific sales data available for EU-28. However, it provides estimated data based on a rough estimation of the world market performed by a LightingEurope member. The various data are summarised in Table 8-3.

8.3 Applicant's Justification for Exemption

LightingEurope claims that the replacement of mercury in LFLs is scientifically and technically impracticable. Currently there are no significant T2, T5 LED lamps available on the market, whereas the availability of T8 retrofit replacements is limited as shall be explained below. Argumentation is also raised as to the comparability of LED alternatives

in terms of efficacy and light distribution. Alternatively, installed luminaires can be replaced with very high socioeconomic impact by mercury-free fixtures. [174]

Table 8-3: Data regarding lamp sales and respective Hg quantities placed on the market

Entry		Lamp sales, million lamps unless otherwise noted					
		2009	2010	2011	2012	2013	2014
Ex. 2(a)(1) (T2 lamps) – global data.	Lamp sales - thousand	*n.s*	*n.s*	*n.s*	*n.s*	400	250–300
	Hg placed on market (kg)	*n.s*	*n.s*	*n.s*	*n.s*	1-1.2	0.75-0.9
	Average Hg per lamp (mg)	*n.s*	*n.s*	*n.s*	*n.s*	2.5-3	*n.s*
Ex. 2(a)(2) (T5 lamps) – EU 28 data.	Lamp sales - millions	57	68	76	81	76	*n.s*
	Hg placed on market (kg)	228	272	228	203	190	*n.s*
	Average Hg per lamp (mg)	4	4	3	2.5	2.5	*n.s*
Ex. 2(a)(3) (T8 lamps Tri-band) – EU 28 data.	Lamp sales - millions	175	216	254	261	247	*n.s*
	Hg placed on market (kg)	1604	1408	1097	815	751	*n.s*
	Average Hg per lamp (mg)	4	4	3.5	3	3	*n.s*
Ex. 2(a)(5) (Long-life lamps, T5, T8) – EU 28 data.	Lamp sales - millions	Statistic data is not collected separately for long-life T5 and T8 lamps, but included in data for normal lamps above.					8 – 10 Mio. T5 and T8 lamps
	Hg placed on market (kg)	*n.s*	*n.s*	*n.s*	*n.s*	*n.s*	40 Kg
	Average Hg per lamp (mg)	*n.s*	*n.s*	*n.s*	*n.s*	*n.s*	4 mg

Note: n.s = not specified

Source: LEU Ex. 2(a)(1)(2015a), LEU Ex. 2(a)(2)(2015a), LEU Ex. 2(a)(3)(2015a), LEU Ex. 2(a)(5)(2015a)

8.3.1 Possible Alternatives for Substituting RoHS Substances

LightingEurope explains that during the last decades several approaches have been made to design low pressure discharge lamps where the light producing element Hg is replaced by a less hazardous material. So far no approach yielded a result with comparable luminous efficacy, product cost and product availability as the (still state of the art) Hg low pressure discharge lamps. However, it is said that with the arrival of equally efficient LED light sources, research into alternative discharges has stopped at most companies and universities. Further details of such research efforts can be viewed in LEU's applications. Information is also provided as to the accomplishments in terms of Hg reduction, however it can be understood that the potential for this strategy has been implemented for the most part and that further research is focusing on the development of LED alternatives and not on Hg reduction.[175]

8.3.2 Possible Alternatives for Eliminating RoHS Substances

LEU states that lamps and luminaires based on LED technology show much more opportunities as substitutes and are rapidly entering the market. Correctly installed LED

[174] Op. cit. LEU Ex. 2(a)(1)(2015a); LEU Ex. 2(a)(2)(2015a); LEU Ex. 2(a)(3)(2015a); LEU Ex. 2(a)(5)(2015a)
[175] Op. cit. LEU Ex. 2(a)(1)(2015a); LEU Ex. 2(a)(2)(2015a); LEU Ex. 2(a)(3)(2015a); LEU Ex. 2(a)(5)(2015a)

based luminaires are considered to be reliable; however, they have specific technical and performance characteristics that need to be considered and that prevent immediate change-over. Those will be discussed in this chapter in detail. It is explained that there are two key ways to use LED technology in order to substitute fluorescent lamps: (1) replacement lamps, (2) new installation (either in new buildings or refurbished areas).[176]

8.3.2.1 LED Replacement Lamps

LEU describes two routes for achieving replacement of an LFL with a LED tube:

- **Retrofit route:** A fluorescent lamp is substituted by a LED tube. The luminaire itself is not rebuilt and the control gear remains in the installation. Driver compatibility is assumed here. Such replacement is also called plug-and-play.
- **Conversion route:** Conversion route: the fluorescent lamp is replaced, and technical changes also need to be made to the luminaire: ballasts and/or internal wiring may need to be replaced or altered.

Though various types of LED tubes are becoming available, LEU explains that such alternatives still show limitations as substitutes, both in terms of the range of products available (i.e. its coverage of the LFL product range) and in terms of the technical comparability. Safety aspects and lack of standards for using such lamps to replace LFLs is also explained to be a limiting factor.

In relation to product range, LEU explains that on the European market there are nearly no **T2** products available based on LED technology that allow a direct replacement of T2 lamps in existing applications.[177] There are also relatively few **T5** products available based on LED technology. Developing LED alternatives in this area requires efforts in electronics miniaturization and heat management, while meeting T5 energy efficiency standards at reasonable costs. According to LEU members this has not been broadly solved yet, and from the limited examples of such lamps available on the EU market, none can be considered fully compatible with existing applications.[178] According to LEU for T2 and T5, all alternatives require refurbishment (rewiring or complete luminaire replacement) of the existing fixture and the involvement of professional expertise.

In contrast **T8** LED based lamps, are available in both retrofit and conversion route options, however, in this area, LEU[179] explains that there are limitations in the technical compatibility. Currently the majority of T8 LED tube replacements are designed for CCG systems. T8 LED tube replacements for ECG systems require different technology to ensure electrical compatibility and are rare on the market (LEU members claim that only one of the key market players offers LED tubes for ECG). Typically CCG compatible lamps have single-ended electrical supply, where ECG compatible LED replacements require double ended electrical supply from the outside. Though the CCG systems can be

[176] Op. cit. LEU Ex. 2(a)(1)(2015a); LEU Ex. 2(a)(2)(2015a); LEU Ex. 2(a)(3)(2015a); LEU Ex. 2(a)(5)(2015a)
[177] Op. cit. LEU Ex. 2(a)(1)(2015a
[178] Op. cit. LEU Ex. 2(a)(2)(2015a
[179] Op. cit. LEU Ex. 2(a)(5)(2015a)

recognized by the existence of a starter in the luminaire, it is not easy for a non-skilled customer to recognize the exact installation he has, without a broader technical knowledge. The starter is often not visible from the outside and the installation looks the same as an ECG system. In this respect, LEU further explains that the market is still in transition from CCG to ECG. The share of installations with ECG, from the total stock of LFL installations, is growing and they currently represent around 30% of the market. Furthermore, from April 2017, CCGs shall no longer be permitted on the EU market in light of Regulation 245/2009/EC (Ecodesign requirements for fluorescent lamps), so ECG market share shall grow. LEU explains that the average lifetime of an installed luminaire in office or industrial areas is typically 15 years[180], so it is expected that the replacement market will be completely ECG by 2035-2040. LEU contends that with the present installed base complexity, it is impossible to guarantee a full 100% coverage for both CCG and ECG systems compatibility. This could lead to situations where a customer opting for a retrofit lamp (assuming driver compatibility) is forced to use the conversion route in light of drivers not supported by retrofit alternatives. Furthermore, LEU explains that available LED retrofit tubes still do not cover the full product range of T8 lamps. LED retrofits are mainly available on the market in 3 lengths (600, 1200, 1500 mm) and only in the most common colour temperatures (not available in very cool (12000K) and warm (2700K) colours). In comparison, conventional T8 lamps offer more than 10 different lengths and even more wattage equivalents.[181]

As for the LFL long-life lamps, LEU states that T5 and T8 linear fluorescent lamps with long lifetime have advantages compared to LED retrofit and conversion lamps as well as LED based luminaires. Resource efficiency of fluorescent lamps is better due to comparable or longer lifetime (40,000 – 90,000 hours life span B50) compared to LED lamps (30,000 – 50,000 hours B50). Where LED retrofits are preferred, instead of only a lamp being replaced, the complete luminaire or set of luminaires has to be replaced at end of life creating more waste and resulting in higher costs.

On the technical level, LEU further explains that there are differences between LFLs and LED retrofits regarding light distribution and lumen output. LFLs are omnidirectional in light distribution, whereas LED packages emit light directionally. In an LED, it is difficult to achieve an omnidirectional luminous intensity distribution, while also meeting needs for thermal management and electrical regulation. As a result the emitting surface of linear LED lamps often covers only half of the surface area.[182]

Finally, LEU raises concern as to the problematic conformity of LED retrofits to safety certification requirements, of relevance to the conversion route:

[180] Referenced in LEU Ex. 2(a)(5)(2015a) as McKinsey – Lighting the way, http://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/automotive%20and%20assembly/lighting_the_way_perspectives_on_global_lighting_market_2012.ashx
[181] Op. cit. LEU Ex. 2(a)(5)(2015a)
[182] Op. cit. LEU Ex. 2(a)(1)(2015a); LEU Ex. 2(a)(2)(2015a); LEU Ex. 2(a)(3)(2015a); LEU Ex. 2(a)(5)(2015a)

> "*Conversion of the luminaire shifts the responsibility for the technical and the safety consequences of the conversion to the party carrying out the conversion. There is no separate safety standard for the conversion of lamps. Converted luminaires must conform to the basic requirements of the Low Voltage Directive and the Electromagnetic Compatibility directive. A new conformity assessment is required for rebuilt luminaires used with conversion lamps, which needs to be carried on case-by-case basis.*"[183]

When a conversion is performed, legal and compliance requirements like conformity assessments, declaration, and labelling of the changed luminaire are necessary to establish the conformity of the changed installation with safety requirements. For conversion lamps there is no own safety standard available so far:

> "*For a modified luminaire, the manufacturer of the original luminaire will generally no longer be seen as responsible for the safety of the product. Any modifications made to the original luminaire may alter the characteristics of the original product e.g. safety aspects of the original luminaire, and hence risk assessment of hazards posed by the original luminaire may no longer be applicable to the modified luminaire. In this case, the modified luminaire would be considered as a new product.*"[184]

Although a standard covering double capped linear retrofit LED tube is in preparation (EN62776), until its approval manufacturers are recommended to use draft standard 34A/1642/CDV (ZVEI, 2014). For the electromagnetic compatibility of LED retrofit lamps an electromagnetic compatibility assessment is in preparation at IEC/CISPR (current draft CISPR/F/628/CDV). Requirements of the lamp components must be met, e.g. EN61347-2-13 for the control gear, etc. This aspect is understood to apply to any conversion, making the process more complicated and more costly.[185] However, in the case of emergency lighting applications, LEU states that no dedicated replacement solutions are available. Given that standards (of LFL emergency lighting applications) specify lamps that can be used as replacements, and that currently LED retrofit lamps are not specified, such replacements would currently be understood not to be permitted.[186]

8.3.2.2 LED New Instalations

According to LEU[187], Linear LED luminaires are providing a viable alternative to the traditional fluorescent tube with such features as: efficacy, energy efficiency, and design

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[183] Referenced in LEU Ex. 2(a)(1)(2015a) as ZVEI and VDE document LA-T 2012-025: "LED lamps as substitutes for fluorescent lamps", 2012 http://www.zvei.org/Publikationen/LED%20tubes%20-%202012-01-26%20english.pdf

[184] Referenced in LEU Ex. 2(a)(1)(2015a) as LVD ADCO Recommendation on "Safety of LED T-type replacement tubes and modified luminaires" http://ec.europa.eu/enterprise/sectors/electrical/files/lvd-adco/recomm-led-replac-tubes_en.pdf

[185] Op. cit. LEU Ex. 2(a)(1)(2015a); LEU Ex. 2(a)(2)(2015a); LEU Ex. 2(a)(3)(2015a); LEU Ex. 2(a)(5)(2015a)

[186] Op. cit. LEU Ex. 2(a)(5)(2015a)

[187] Op. cit. LEU Ex. 2(a)(1)(2015a); LEU Ex. 2(a)(2)(2015a); LEU Ex. 2(a)(3)(2015a); LEU Ex. 2(a)(5)(2015a)

flexibility and appearance. But the quality and performance of LED products varies among manufacturers. Many conformity and performance related issues are solved. Dedicated designed luminaires directly comply; a system with all safety and standardization legislations is tested and confirmed by the luminaire manufacturer. LED based luminaires so far do not reveal a clear general environmental benefit, e.g. energy efficiency is not higher than in conventional luminaires based on LFL lamps.

However, LEU argues that LED luminaires may have limitations in some cases, i.e. when a single luminaire in an array of luminaires malfunctions and needs to be replaced: If a luminaire is broken in an existing installation or a customer wants to refurbish an existing installation with built in, recessed luminaires in the ceiling, the replacement LED luminaire should be able to fit in the existing space and give the same light distribution. Described earlier challenges that customers might be confronted with (e.g. illuminance), will not be solved in many cases with one-to-one luminaire replacement. A customer will be forced to refurbish his ceiling and/or building, make a new lighting design and replace all existing luminaires, while many of them still operating properly.[188]

A growing market approach is the use of integrated LED luminaires requiring full luminaire replacement. This would lead to high investment and negative environmental impact, especially when the T2 luminaire is installed in furniture, vehicles, installations or other electrical and electronic equipment. There is a clear development in the lighting market for new installations towards LED technology, such as LED stripes in furniture. Correctly installed LED based luminaires are considered to be reliable.[189]

8.3.3 Environmental Arguments

LEU states that various LCA's show different results and are as such inconclusive regarding the comparison of LED technology versus conventional linear fluorescent technology on their total environmental impact. Non-renewal of this exemption will lead to unnecessary waste of luminaires that cannot be used, due to lack of a replacement lamps (premature refurbishment).[190]

The consultants would like to note in this respect that, though some information on LCA studies is provided in the Exemption 2 applications, comparative LCA studies relate to CFLs and LEDs and show equivalency as early as 2012. The consultants are not aware of comparative LCA studies of LFLs with LED alternatives.

Referring to various studies, LEU[191] explains that LED lamp product manufacturing uses considerably more energy than does the manufacturing of a T8 with comparable light

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[188] Op. cit. LEU Ex. 2(a)(1)(2015a); LEU Ex. 2(a)(2)(2015a); LEU Ex. 2(a)(3)(2015a); LEU Ex. 2(a)(5)(2015a)
[189] Referenced in LEU Ex. 2(a)(1)(2015a) as CALiPER, "Application Summary Report 21: Linear (T8) LED Lamps", p.6
[190] Op. cit. LEU Ex. 2(a)(2015b)
[191] LEU Ex. 2(a)(5)(2015a) refers to http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_21-4_t8.pdf

output[192]. However one must consider the improving LED alternative in the right perspective: according to reference[193] the LED sources are expected to have a real advantage in the total life cycle over time, at least if efficiency keeps improving at the same rate and given their relatively long life. Recent DoE research[194] illustrated that luminaires retrofitted with LED lamps performed in the same efficacy range as the fluorescent benchmarks, so it is not clear that they offer guaranteed energy savings when compared to fluorescent troffers (rectangular light fixtures) equipped with 25 or 28 W high-performance lamps and electronic dimming ballasts. Energy efficiency, or more specifically the total luminaire efficacy and lighting power density of a typical installation, is an important criterion for choosing a proper LED replacement in existing installations. In this regard, LEU states in a particular consultation submission the following, referring to a US DOE study:[195]

> "In 2013 the US Department of Energy analysed LED retrofit lamps and came to the conclusion: "*This report focused on the bare-lamp performance of 31 linear LED lamps intended as alternatives to T8 fluorescent lamps. Data obtained in accordance with IES LM-79-08 indicated that the mean efficacy of the group was slightly higher than that of fluorescent lamps (with ballast), but that lumen output was often lower. Along with a range of colour quality attributes, the luminous intensity distributions of the linear LED lamps varied substantially, with none truly comparable to a linear fluorescent lamp. (March 2014)*"."

In case T2 fluorescent lamps would no longer be available for existing installed lighting solutions, the impact would be significant. The need to replace or technically change the luminaires, control gears, equipment etc. results in high investments for private, commercial or public customers.

The lamps concerned in this exemption request are mainly for professional use (where certain application norms and requirements are in place), one-to-one (i.e., retrofitting) replacement should not always be taken into account. As explained in the exemption requests, change of a conventional application may require a new lighting plan adjusted to the need of the space, hence can influence the total energy use. The overall energy use will remain at a comparable level as today. Additionally it should be noted, that

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[192] LEU Ex. 2(a)(5)(2015a) refers to U.S. Department of Energy. (2012). Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products. Retrieved March 10, 2012 from – Study not found. It is possible that one of the CALiPER studies prepared for the DoE is meant.
[193] LEU Ex. 2(a)(5)(2015a) refers to Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products, The U.S. Department of Energy (DOE) building technologies office – report found under the following link http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/lca_factsheet_apr2013.pdf, however, with direct comparison of LEDs and LFLs.
[194] LEU Ex. 2(a)(5)(2015a) refers to http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_recessed-troffer_2013.pdf
[195] LEU Ex. 2(a)(5)(2015a) refers to http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_21-4_t8.pdf

energy savings can also be achieved through smart solutions with conventional lighting (e.g. dimming, presence detection, daylight link, etc.).[196]

8.3.4 The Minamata Convention

LEU states that during the 2013 UNEP Minamata Convention on Mercury in Japan, agreements were made to limit mercury in various products including linear fluorescent lamps. This treaty has been agreed upon and signed by 94 countries around the globe. The agreed mercury level for linear fluorescent is 5 mg and is to be adapted until 2020 in countries that have signed the convention. [197]

8.3.5 Road Map to Substitution

LightingEurope[198] is not able to share the individual road maps the member companies have planned for their LED portfolio. There is no general roadmap to develop LED replacements for all existing linear fluorescent lamp types in the market. McKinsey indicates in its report that by 2020 it shall still make up for 48% of total general lighting. Specific data per application is given, e.g. in Industry Lighting 75% and in Office Lighting 71% of the light sources will still be of conventional technology.

8.4 Stakeholder Contributions

A number of contributions have been made by stakeholders. Comments of general nature have been summarised in Section 4.4 in the Chapter regarding lamps in general. Comments regarding the lamp exemption Ex. 1(a-e) are summarised below:

Comments of the European Environmental Bureau (EEB), the Mercury Policy Project, and the Responsible Purchasing Network[199] are also summarised in part in Section 4.4 above. Regarding the Ex. 2(a) entries (a-e) EEB et al. explains that one area where there has been tremendous innovation over the past several years is in the development of LED tube lamps. According to a 2014 report by the International Energy Agency (IEA), LED tube lamps now have equivalent performance to even the most energy-efficient fluorescent tubes: T5s. EEB et al. quotes this report:

> "*In the domain of professional lighting, the T5 linear fluorescent lamp luminaire was the best rated product in 2009. In studies published in 2013, the T5 lamp*

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[196] Op. cit. LEU Ex. 2(a)(2015b)
[197] Op. cit. LEU Ex. 2(a)(1)(2015a)
[198] Op. cit. LEU Ex. 2(a)(2015b)

[199] EEB et al. (2015a),The European Environmental Bureau, the Mercury Policy Project, and the Responsible Purchasing Network, Environmental NGOs Response to Stakeholder consultation 2015 #2 on mercury-containing lamps – Exemption 1-4 (Review of Annex to the RoHS directive), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1-4_EEP-RPN-MPP_Comments_on_RoHS_Request-final_20151016.pdf

remains the product with the lowest environmental impacts, but thanks to the advances of LED technology, LED tubes are nearly at the same level of performance."[200]

EEB et al. recommend removing the words 'normal lifetime' from Ex. 2(a)(2) since from their research all T5s (covered by this exemption), meet the threshold of 3 mg, regardless of their lifetime. EEB et al. also recommend monitoring improvements in the performance of LED T5 tubes and their life-cycle price to allow understanding their practicability as substitutes in the future and subsequently the further need for the exemption.

In relation to T8 lamps, EEB et al. state that many European lamp manufacturers are now offering LED linear T8 lamps that are drop-in replacements for linear fluorescent T12 and T8 lamps, claiming that they are more energy efficient. Some of these products include an internal driver so that no additional wiring is required. Other products are compatible with either electronic or magnetic ballasts, or both. Some examples are given for T8 substitutes showing comparable lumen per watt performance and service lives of 40-50 thousand hours as well as plug-and-play alternatives for both magnetic and electric ballasts. EEB et al. expect LED tube lights to continue to improve over the next several years, and urges the European Commission to continue to monitor their advancements for performance and lifecycle costs and consider them for phase-out in the next review. The words 'normal lifetime' are proposed to be removed since T8s, no matter their lifetime, already meet these limits.

EEB et al. make recommendations regarding entry 4, which concerns T12 lamps, however as LEU has not requested the renewal of this lamp, it is assumed to have been phased out for the most part in light of availability of alternatives and is not discussed further.

Regarding the exemption entry for long-life lamps (Ex.2(a)(5)) EEB et al. recommends that this exemption be eliminated and that all T5 linear fluorescent lamps be included under Exemption 2(a)(2), which currently has a mercury limit of 3 mg, and that all T8 lamps be included under Exemption 2(a)(3), which currently has a mercury limit of 3.5 mg. In their research, long-life T2 and T12s were not found, e.g. in the GE and OSRAM catalogues. In case such types of lamps exist, the exemption should be rephrased accordingly to cover only those; the T5 and T8s should all meet 3 mg and 3.5 mg respectively, no matter the lifetime, as many already do. Examples are provided to demonstrate this.

KEMI Kemikalieinspektionen, the Swedish Chemicals Agency (KEMI)[201] mentions that new standards developed in the context of ecolabelling and public procurement criteria

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[200] Quoted as International Energy Agency, *Solid State Lighting Annex: Life Cycle Assessment of Solid State Lighting: Final Report*, 17 September 2014, http://ssl.iea-4e.org/files/otherfiles/0000/0068/IEA_4E_SSL_Report_on_LCA.pdf

are based on the real market situation. KEMI concludes that the allowances permitted for Hg in lamps in most recent publications of this kind, for the Ex. 2(a) exemption entries, show that it is possible to find LFLs on the EU market with lower Hg-content than the current limit values prescribed in these RoHS exemption entries. Table 8-4 is provided in this respect.

Table 8-4: Limit values for some light sources in RoHS compared with recommended mercury levels in EU GPP criteria for indoor lighting

	RoHS exemption request	**Public procurement core criteria**	**Public procurement comprehensive criteria**
Exemption 2(a)(1-5) "Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp):			
(1) Tri-band phosphor with normal lifetime and a tube diameter < 9 mm (e.g. T2):	5 mg		
(2) Tri-band phosphor with normal lifetime and a tube diameter ≥ 9 mm and ≤ 17 mm (e.g. T5):	5 mg	2.5 mg	2 mg
(3) Tri-band phosphor with normal lifetime and a tube diameter > 17 mm and ≤ 28 mm (e.g. T8):	5 mg	3.5 mg	4.5 mg
(4) Tri-band phosphor with normal lifetime and a tube diameter > 28 mm (e.g. T12):	5 mg		
(5) Tri-band phosphor with long lifetime (≥ 25 000 h):	8 mg		

Note: The RoHs Hg allowances for Exemption 2(a) entries decreased in December 2011 and are as currently follows: Ex. 2(a)(1) – 4mg; Ex. 2(a)(2) – 3mg; Ex. 2(a)(3) – 3.5mg; Ex. 2(a)(4) – 3.5mg; Ex. 2(a)(5) – 5mg;
Source: KEMI (2015)

In respect with fluorescent lighting, the Polish Association of Lighting Industry (PZPO)[202] claim that fluorescent and LED lighting systems are not inter-compatible. "*Changing the*

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[201] KEMI (2015), Kemikalieinspektionen, Swedish Chemicals Agency, Contribution to Stakeholder Consultation 2015-2 Request for extension of exemption 1(a-e), submitted 19.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1a-e_KEMI_Answer_to_SC_RoHS_20151016.pdf

[202] PZPO (2015a), Polish Association of Lighting Industry, Comments to Annexes III and IV Directive 2011/65/EU (RoHS), submitted 5.10.2015, available under:

fluorescent lamp-based systems to LED-based systems is associated with the need to replace the entire electrical system (power balance issues)… change the fixtures… number of lighting points… facility ceilings, as well as redesign the entire system and employ a sufficient number of designers and engineers". This is also expected to generate WEEE.

8.5 Critical Review

8.5.1 Scientific and Technical Practicability of Substitution

LEU explains that substitutes are not sufficiently available for LFLs. In terms of substance substitutes the consultants can follow that despite various research initiatives, results have not led to the development of Hg-free LFLs. As for the reduction of Hg in LFLs, it is also apparent that the potential for such benefits has been realised to a large extent. In light of the development of LED technologies, further potential for these strategies is understood to no longer be in the focus of development efforts. As for LED substitutes, LEU claims that at present, replacement products are lacking and that available substitutes often do not provide comparable performance. General statements are made, however, data as to availability of substitutes and their comparability has been found in various studies performed over the last few years.

The VHK & VITO[203] study states that for T8 LFLs, a broad range of LED retrofit tubes is available on the market from all major lighting manufacturers and many new companies entered this market. According to the results of their study, the majority of the LED retrofit tubes found on the market today require a rewiring of the existing luminaire to by-pass the existing ballast. However, it is also mentioned that recently so called plug-and-play lamps have come to the market that can directly replace an LFL T8 in the existing configuration without any further action. Some of these LED lamps have control gears that will automatically detect the type of ballast installed and shall "behave" accordingly. These lamps can operate on a wide range of existing ballasts, including magnetic and electronic ballasts. Other plug-and-play lamps have been specifically designed for operation on instant-start electronic ballasts, for example. The plug-and-play lamps have the control gear integrated in the tube. This implies that a small part of the tube length is occupied by the control electronics and hence may not be available for light emission. The integrated solution is also more challenging when additional functions have to be integrated in the control gear, such as 0-10 V dimming, a DALI interface, or a wireless receiver. In addition the location of the control gear inside the tube can pose specific thermal management problems. External control gears offer

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http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Directive_RoHs_-_PZPO_comments_05_10_15_eng.pdf

[203] Op. cit. VITO & VHK (2015)

advantages from these points of view.[204] The study lists some of the variety of LED T8 alternatives and it is observed that in this category most alternatives are for lamp lengths of 120 or 150 cm, with few alternatives for other lengths. Only a few models are said to be dimmable, though LEU reported that this aspect is not a concern. Furthermore, VHK & VITO states that many of the listed tubes have a tested CRI below 80 (usually between 70 and 80), implying that they do not meet the requirements from regulation 1194/2012. The VHK & VITO study states that, some manufacturers offer T5 (16 mm) LED tubes with G13 cap and efficiencies up to 141 lm/W[205] (G13 is typical for T8 as opposed to T5 usually equipped with a G5 base). LED luminaires for upgrading the efficiency of existing installations are also available and offer similar efficacies as retrofit tubes (100-143 lm/W) 177, though VHK & VITO identify various reasons for favouring luminaire replacement with LED over lamp replacement (required electrical modifications of luminaire, change on lighting plan, etc.). VHK & VITO list the following as shortcomings of LED retrofits: relatively low lumen output, low CRI, not suitable for direct-indirect lighting applications, and potential dimming problems, however expect shortcomings to be resolved within 2 to 3 years.

In contrast to the T8 lamps, the VHK & VITO study states LED retrofit tubes for substitution of LFL T5 are available on the market, but the choice is limited as compared to LED retrofit tubes for LFL T8. In addition, major (LED) lighting manufacturers as Philips, Osram, General Electric, Havells-Sylvania, Megaman and CREE, do not have LED tubes with G5 cap in their catalogues. This is explained in part by the number of T5 lamps being replaced per annum to be is considerably smaller than the number of T8 lamps being replaced (market is less interesting). The improvement potential of LED tubes with respect to LFL T5 is also said to still be too small, also considering the price difference. The study further refers to alternatives to T12 lamps, however as LEU did not request the renewal of that exemption these are not mentioned here. As for further types (including for example T2), the VHK & VITO study did not specifically research the availability of such types, however it is assumed that such retrofits will generally not exist.

A factsheet published by the US DoE[206] with the purpose of providing guidance when deciding on an LED upgrade for a fluorescent system confirms some of the arguments made by LEU. It is understood that the conclusions are based on studies of alternatives for T8 LFLs. The US DoE states that most products marketed as retrofit lamps require further modifications to the luminaire, and will have labour costs similar to products marketed as retrofit kits (upgrade expected to require electrical modifications). For

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[204] Op. cit. VITO & VHK (2015)
[205] Referenced in VITO & VHK (2015) as http://www.narvabel.de/clicksystem/csdata/download/1/de/leaflet_sl_t5_linear_lens_technology__spt_narva_en_1436.pdf
[206] DoE (2014), US Department of Energy – Building Technologies Office, Solid State Lighting Technology Fact Sheet, Published Jnauary 2014, avaialbe under http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led_troffer-upgrades_fs.pdf

retrofit projects that retain the existing number of luminaires and control scheme, energy costs depend on the wattage of the luminaire with the new components installed relative to the existing luminaire. In some cases, the retrofit products offering the greatest wattage reductions also deliver much less light than the existing system. A recent CALiPER[207] project found that some LED replacement lamp products provided little to no reduction in wattage; in one case also increasing the system wattage. Based on efficacy data from CALiPER, LED Lighting Facts[208], and other programs, new LED luminaires are said to generally provide the greatest energy savings for equal luminaire output, followed by LED retrofit kits. Many of the LED options produce different distribution characteristics than typical fluorescent troffers. In addition to increasing the chance for glare from the luminaire, this altered distribution also may result in uneven light levels in task areas and reduced light on the walls. LED options are available for lighting systems requiring dimming capability, although dimmable products in the replacement lamp category were very rare at the time of publication. Some combinations of LEDs, drivers, and dimmers can produce noticeable flicker. All of the LED categories offer products with a selection of correlated colour temperatures (CCT), and all offer products with colour rendering index (CRI) values in the 80s and higher, though LED products with poor colour quality are also available, often at low cost.

The CALiPER[209] study on recessed troffer lighting (recessed luminaires) procured and tested twenty-four pairs of 2×2 and 2×4 troffers for photometric and electrical performance, including installation in a mock-up space for testing. Three of the pairs were T8 fluorescent benchmark products, 12 were dedicated LED troffers, five were fluorescent troffers modified for LED lamps (sometimes referred to as “tubes”), and another four troffers were modified with LED retrofit kits. Summarised findings include:

- **LED luminaire replacements:** Dedicated LED troffers are ready to compete with fluorescent troffers in terms of efficacy (lumens per watt [lm/W]), and also in terms of many lighting quality issues such as glare, light distribution, visual appearance, and colour quality. That is not to say that each one is stellar, but each one tested in this CALiPER study bested the fluorescent benchmarks in terms of efficacy, and almost all were rated highly in several categories—only one luminaire of twelve performed consistently poorly. One area of concern is that one third of the dedicated LED troffers were equipped with 0-10V dimming drivers that caused the LEDs to exhibit flicker when dimmed. It is important for the lighting industry to develop, adopt, and apply

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207 Referenced in DoE (2014) as: Exploratory Study on Recessed Troffer Lighting", March 2013 (revised June 2013), http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_recessed-troffer_2013.pdf.

208 Referenced in DoE (2014) as: http://www.lightingfacts.com/

209 CALiPER (2013), Exploratory Study on Recessed Troffer Lighting", March 2013 (revised June 2013), available under: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_recessed-troffer_2013.pdf

standards to limit flicker that may contribute to health concerns and reduced task performance.

- **LED lamp replacements:** Luminaires retrofitted with LED lamps performed in the same efficacy range as the fluorescent benchmarks, so it is not clear that they offer guaranteed energy savings when compared to fluorescent troffers equipped with 25 or 28 W high-performance lamps and electronic dimming ballasts. The colour quality from these LED lamps ranged widely from very poor (CRI in the 60s) to very good (CRI in the upper 80s, which is slightly higher than typical high-performance T8 fluorescent lamps), so specifiers need to exercise care to ensure the new lamps are not reducing colour quality compared to the incumbent fluorescent. LED lamps that have exposed rows of bright LEDs are more likely to produce objectionable stripes and patterns in existing troffers than LED lamps that have a diffuse finish on the luminous half of the tube. Even diffuse LED lamps produced a more "stripey" troffer appearance and increased perceived glare, compared to fluorescent lamping. This was true whether K12 lensed troffers or parabolic louvered troffers were retrofitted.
- **LED kit replacements:** LED retrofit kits hold some promise, but also face challenges. Each one of the four kits in this CALiPER study had issues:
    - different colours delivered from the same fixture specification,
    - odd or distracting brightness patterns produced on the lens,
    - a poor-quality appearance,
    - greater glare, and/or
    - flicker when dimmed.

  However, these are engineering issues that can be solved by manufacturers, and a retrofit kit avoids some of the safety concerns associated with LED lamps. Kits also offer the chance to provide a fresh appearance to the luminaire, rather than retaining the original lens or louver.

Though this information is understood to sufficiently portray the status of LED substitutes for lamps with normal service-life, there is no specific information for alternatives for long-life LFLs. In general, the consultants can follow that alternatives for T5 lamps falling under this category shall also not be available. As for T8 lamps, though availability may be larger, it can be understood that such lamps shall be comparable with lamps of normal service life, and thus it is assumed that they shall not perform as well when compared to long life lamps. As such lamps are understood to be a potential substitute for T5 and T8 lamps, additional information as to such lamps follows:

When asked about the types of long-life lamps which are covered by Ex. 2(a)(5), LEU[210] confirmed that the following three types exist:

- T5 lamps with electronic control gear (ECG) and a lifetime of 30,000h;

[210] Op. cit. LEU Ex. 2(a)(2015b)

- T8 lamps with ECG and a lifetime up to 75,000h; and
- T8 Long Life lamps that can be operated with a conventional gear (CCG) – these are understood to comply with the lifetime threshold of the exemption of 25,000h.

LEU[211] further explains that, at present, the lifetime of T8 lamps has been standardised only for the use on a conventional control gear (magnetic ballast, IEC60081). A large variation on lifetime will exist depending on the operating conditions of the ECG driver (e.g. cold start versus warm start, see manufacturers' product pages for reference). These lifetimes are usually significantly higher. Therefore, the preferred definition for lifetime of the lamps is the one according to IEC60081. This means lifetime evaluation for T8 lamps is recommended to be made for 50% point at a standardized 3-hours cycle on a CCG (not like suggested on ECG one). In that case for certain long-life lamp types the lifetime will be still below 30,000h. Hence proposal is to keep the defined lifetime target at ≥ 25,000h. LEU recommends referencing EN60081 for the measurements of lifetime and lumen maintenance, which are the basis for the service life, in the wording of the exemption:

> *"Tri-band phosphor with long lifetime (≥25,000h service life, EN60081) and a tube diameter ≥9 mm: 5 mg"*

8.5.2 Environmental Arguments

Though LEU provides information as to LCA studies to show that there are uncertainties in the comparison of LFLs and LED replacements, most of their references regard LCAs comparing other fluorescent technologies (e.g. CFLs) with LEDs, results of which are discussed in the review of Ex. 1(a-e) in Section 5.5.2.2. Despite an effort to identify LCA studies comparing LFLs with their LED replacements, there is little information available of such studies in the public realm.

A study from 2014 prepared by Tähkämö et al.[212], and published by "International Energy Agency 4E Solid State Lighting Annex", states the following:

> "*In the domain of professional lighting, the T5 linear fluorescent lamp luminaire was the best-rated product in 2009. In studies published in 2013, the T5 lamp remains the product with the lowest environmental impacts, but thanks to the advances of LED technology, LED tubes are nearly at the same level of performance… It should be noted that the comparison of LED-based products with conventional lighting technologies is not always in favour of solid-state lighting.*

[211] Op. cit. LEU Ex. 2(a)(2015b)

[212] Tähkämö et al. (2014), Tähkämö, L., Martinsons, C., Ravel, P., Grannec, F., and Zissis, G., Life Cycle Assessment of Solid State Lighting, Final Report, International Energy Agency 4E Solid State Lighting Annex (4E), pg. 2, pg. 31, available under http://ssl.iea-4e.org/files/otherfiles/0000/0068/IEA_4E_SSL_Report_on_LCA.pdf

> *In professional indoor lighting (tertiary, offices, etc.), the T5 linear fluorescent lamp luminaire was the best-rated product (DEFRA 2009)*".

However Tähkämö et al. also note that:

> "*this is one of the first studies for this technology area. We need to remind readers that performance has changed much since*".

In this sense, the consultants conclude that though studies performed in the past may have shown superiority of LFLs, at least for T5, such analysis has been carried out a few years ago and is assumed to be based on older data sets. Though 5 years may not be a long time for some technologies, in the case of LEDs it is understood to be substantial due to rapid developments in this market, and in this respect it can currently not be concluded whether LFLs still retain their advantage or whether this has changed.

8.5.3 Stakeholder Contributions

Various contributions have been made as specified in Section 8.4.

EEB et al. argue that substitutes for LFLs are available for T2, T5 and T8. However examples with actual specifications are only provided for substitutes available for T8 models and no evaluation is made as to their actual comparability when used as a retrofit substitute. On the basis of the data provided, EEB et al. urge the Commission to continue monitoring the comparability of substitutes, which can be understood to mean that EEB et al. are not yet confident if the product range of LFLs is sufficiently covered for various lamp types. EEB et al. further proposes to merge long-life and normal life lamps for T5 and T8, prescribing the Ex. 2(a)(2 and 3) Hg thresholds for each lamp type. In the situation where long-life lamps now fulfil normal life Hg restrictions, omitting this distinction seems plausible. However, the consultants cannot agree to this proposal. For these lamp types it is understood that the lamps are similar in terms of the use of resources, and that the amount of Hg and phosphor used may differ. However this small difference provides service lives that are significantly longer than the normal life counterparts, particularly against the background of how long-life is defined for this exemption (see Section 8.2). LEU has been asked about the differences and whether the Hg allowance could be lowered, and responded "*In order to achieve higher lifetimes different design changes are required. One of them is an up to 3 times higher amount of phosphor containing in addition a higher amount of rare earth metals. Further measures are optimized electrode and emitter design, higher filling pressure to extend lifetime of the electrode. The higher amount of phosphor is needed in order to compensate lower efficiency of this design. Mercury is consumed over lifetime. This consumption is also dependant on the nature and amount of materials in the discharge tube… The RoHS value is a maximum value every single lamp has to meet. Published values are average values where the dosing units can have variances of +/-10-20%... A limit value of 3.5 mg would definitively be the end of certain lamp types, especially those with the highest lifetimes and best mercury per lifetime ratio leading to higher mercury usage and lower*

resource efficiency."[213] On this basis it would thus appear not possible to lower the RoHS limit threshold. As the lamps are otherwise very similar, the consultants believe that it would be preferable from a resource efficiency perspective to require all lamps to be long-life, according to the more stringent definition:

> *"≥ 25,000 hours where the installed luminous flux (lamp survival in % times lamp luminous flux in % or service life) is higher than 80% at 25,000 hours with an electronic ballast using the standardised 3 hour cycle*".[214]

KEMI presents requirements of green public procurement initiatives, and proposes to align exemption Hg threshold allowances with the specified levels. LEU[215] responded to this proposal, explaining that the RoHS thresholds specified by KEMI have in some cases already decreased, as also noted. LightingEurope further explains that for this reason the differences between the RoHS thresholds and the public procurement thresholds are not as significant and that it needs to be kept in mind that these are average levels, whereas there is a need to retain a margin above the average for the RoHS Directive thresholds.

As explained in Section 4.5.7, differences between RoHS thresholds and public procurement ones are generally acceptable. All the more so, as in light of the valid RoHS thresholds, the only difference is in this case of Ex. 2(a)(2), which is not as far from the public procurement levels.

8.5.4 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

As explained above, it can be followed that Hg-free LFL substitutes are not available and that the potential for further Hg reductions has been realised to a large degree.
In contrast, LED alternatives are understood to be developing rapidly, both as retrofit lamp replacements and as luminaire replacements. Information is available from various

[213] LEU (2016b), LightingEurope, Response to Clarifiction Questions Regarding Ex. 2(a)(5)", submitted 7.3.2016 per email

[214] Referenced in LEU Ex. 2(a)(5)(2015a) as: Final Report The Adaptation to scientific and technical progress under Directive 2002/95/EC, Oeko-Institut Freiburg, Feb. 19, 2009, http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf

[215] LEU (2015c), LightingEurope, Summary of critical observations to stakeholder submissions , Submitted per email on 18.12.2015

studies performed in the past, however only a few are more recent (2013 and on) and have been presented above. On the basis of these studies, it can be concluded that LED replacements are available for T8 LFLs, however their comparability on the component level (lamp) and the system level (after installed in LFL luminaire as replacement) can have various shortcomings, expected to be resolved within a few years. Furthermore it appears that most alternatives are sufficient for a few of the LFL length range, while for other lengths only few or no alternatives were reported. For other LFL types (T2, T5), the availability of LED replacement lamps is understood to be very limited and where existing, performance advantages are currently not observed.

It is understood that most of the studies have compared LFLs with "normal" lifetimes to LED alternative options, and it is thus expected that where long-life LFLs are available, that such lamps might still have advantages over LED alternatives, in light of their extended performance time. Though LED alternatives are understood to have longer lives in comparison with "normal" LFLs, it can be expected that service-lives shall be comparable with long-life LFLs (particularly in lamps operating on electric ballast which are understood to have longer service lives). Where it can be understood that LED replacement tubes are starting to be comparable with LFLs with "normal" service lives, it can be expected that "long-life" LFLs shall still show a higher comprehensive performance. In this sense, despite a possible availability of LED replacements with long-life, these are still not assumed to have larger benefits in terms of environmental and health impacts, in light of some of the limitations mentioned above.

There is understood not to be a reliability problem with LED alternatives where these are properly installed, however LightingEurope raises concern that a lack of sufficient LED retrofit substitutes shall push consumers to replace lamps prior to actual end of life (EoL). In light of the current limitations related to LED replacement lamps, the consultants can follow that this concern may be justified for T2 and T5 lamps and to some degree also for T8 lamps. The concern of possible significant environmental costs of early EoL of LFL luminaires, may justify a slower shift towards LED alternatives, however the consultants observe that "substitutes" in the form of long-life LFLs would have environmental benefits in comparison with normal LFLs and should be considered in relation to the justification of the exemptions.

Long-life LFL models are available for T5 and T8 lamp types and are understood to be a preferable substitute in light of the clear environmental benefit over normal life lamps in the form of resource savings. The still very high sales volumes of such lamps, as well as continued sales of new LFL designed luminaires, plus statements (from LightingEurope) that such replacements could be needed for many years to come, further support a shift from normal life to long life. Such a shift shall reduce sales, and in this sense also the use of resources needed for manufacturing new lamps, while also preventing accelerated waste of luminaires. This shall also allow industry to further develop LEDs to their full potential and compatibility over the next few years. In contrast, since both types of substitutes are understood not to exist for T2 models, the renewal of the exemption for these lamps could be justified. This is further supported by the understanding that the sales of such lamps have significantly decreased. In both cases, although LightingEurope

states that replacement lamps shall be needed for many years (10-20 and longer), the consultants do not agree that this should justify continuation of exemptions for many years. This statement is understood in part to be related to the fact that new LFL luminaires are still coming onto the market; in this sense, extending the exemptions shall mainly delay the point in time at which such luminaires and lamps are to be phased out.

8.6 Recommendation

The consultants recommend granting a renewal for the specific exemption for T2 lamps. Alternatives are understood not to be available as replacement lamps and replacement luminaires would cause environmental costs in the form of luminaires reaching EoL early (waste). Sales of such lamps also suggest that this technology is rapidly headed towards phase-out, but shall still be needed where luminaires are still in use.

The consultants recommend revoking specific exemptions for T5 and T8 lamps as substitutes, either in the form of long-life lamps or in the form of LEDs are available. A longer transition period could be granted, as manufacturers may need to establish long-life alternatives for some specific models (combinations of wattages, lengths and diameters).

As an exemption was not requested for entry 4 (T12 lamps) by LightingEurope, it is assumed that such lamps have phased out. It is thus also recommended that this exemption be revoked. In light of the expected phase-out, a short termed transition period is expected to suffice.

As LED alternatives are not understood to be preferable to long life LFL lamps (possibly also exhibiting environmental or performance disadvantages for T8 models and not available for T5 models), it is recommended to extend the exemption for long-life lamps.

Exemption 2(a)	Duration*
Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp)	
1) Tri-band phosphor with normal lifetime and a tube diameter < 9 mm (e.g. T2): 4 mg	For Cat. 5, 8 & 9: 21 July 2021
	For Sub-Cat. 8 in-vitro: 21 July 2023
	For Sub-Cat. 9 industrial: 21 July 2024
(2) Tri-band phosphor with normal lifetime and a tube diameter ≥ 9 mm and ≤ 17 mm (e.g. T5): 3 mg ***(3) Tri-band phosphor with normal lifetime and a tube diameter > 17 mm and ≤ 28 mm (e.g. T8): 3.5 mg*** ***(4) Tri-band phosphor with normal lifetime and a tube diameter > 28 mm (e.g. T12): 3.5 mg***	For Cat. 8 & 9: 21 July 2021
	For Sub-Cat. 8 in-vitro: 21 July 2023
	For Sub-Cat. 9 industrial: 21 July 2024
(5) Tri-band phosphor with long lifetime (≥ 25 000 h): 5 mg	For Cat. 5, 8 & 9: 21 July 2021
	For Sub-Cat. 8 in-vitro: 21 July 2023
	For Sub-Cat. 9 industrial: 21 July 2024

Note: As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

8.7 References Exemption 2(a)(1-5)

CALiPER (2013) Exploratory Study on Recessed Troffer Lighting", March 2013 (revised June 2013), available under: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_recessed-troffer_2013.pdf

CALiPER (2014a) Pacific Northwest National Laboratory, Application Summary Report 21: Linear (T8) LED Lamps, Solid-State Lighting Program Building Technologies Offi ce Office of Energy Effi ciency and Renewable Energy U.S. Department of Energy, available under: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_21_t8.pdf

DoE (2014) US Department of Energy – Building Technologies Office, Solid State Lighting Technology Fact Sheet, Published Jnauary 2014, available under http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led_troffer-upgrades_fs.pdf

EEB et al. (2015a) The European Environmental Bureau, the Mercury Policy Project, and the Responsible Purchasing Network, Environmental NGOs Response to Stakeholder consultation 2015 #2 on mercury-containing lamps – Exemption 1-4 (Review of Annex to the RoHS directive), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1-4_EEP-RPN-MPP_Comments_on_RoHS_Request-final_20151016.pdf

KEMI (2015) Kemikalieinspektionen, Swedish Chemicals Agency, Contribution to Stakeholder Consultation 2015-2 Request for extension of exemption 1(a-e), submitted 19.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1a-e_KEMI_Answer_to_SC_RoHS_20151016.pdf

LEU Ex. 2(a)(1)(2015a) LightingEurope, Request to renew Exemption 2(a)(1) Under Annex III of the RoHS Directive 2011/65/EU 2(a) Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp): 2(a)(1) Tri-band phosphor with normal lifetime and a tube diameter < 9 mm (e.g. T2): 4 mg may be used per lamp after 31 December 2011, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/Lighting_Europe/2a1_LE_RoHS_Exemption__Req_Final.pdf

LEU Ex. 2(a)(2)(2015a) LightingEurope, Request to renew Exemption 2(a)(1) Under Annex III of the RoHS Directive 2011/65/EU 2(a) 2(a)Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp): 2(a)(2) Tri-band phosphor with normal lifetime and a tube diameter ≥ 9 mm and ≤ 17 mm (e.g. T5): 3 mg may be used per lamp after 31 December 2011, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/Lighting_Europe/2a2_LE_RoHS_Exemption__Req_Final.pdf

LEU Ex. 2(a)(3)(2015a) LightingEurope, Request to renew Exemption 2(a)(3) under Annex III of the RoHS Directive 2011/65/EU, 2(a) Mercury in double-capped linear

fluorescent lamps for general lighting purposes not exceeding (per lamp): 2(a)(3) Tri-band phosphor with normal lifetime and a tube diameter > 17 mm and ≤ 28 mm (e.g. T8): 3.5 mg may be used per lamp after 31 December 2011, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/Lighting_Europe/2a3_LE_RoHS_Exemption__Req_Final.pdf

LEU Ex. 2(a)(5)(2015a) LightingEurope, Request to renew Exemption 2(a)(5) under the RoHS Directive 2011/65/EU 2(a) Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp): 2(a)(5) Tri-band phosphor with long lifetime (≥ 25.000): 5 mg may be used per lamp after 31 December 2011, submitted 55.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/Lighting_Europe/2a5_LE_RoHS_Exemption__Req_Final.pdf

LEU Ex. 1-4 (2015a) LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 1-4 (renewal requests) General Questions for Lamp Exemptions Related to Mercury, submitted 25.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Contribution_Exemption_1-4/LE_Ex_1-4_LightingEurope_General_Clarification-Questions_Final.pdf

LEU Ex. 2(a)(2015b) LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 2(a)(1-5) (renewal request), submitted 15.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/Lighting_Europe/Ex_2a_1-5__LightingEurope_Clarifications_1st_round_final.pdf

LEU (2015c) LightingEurope, Summary of critical observations to stakeholder submissions, submitted per email on 18.12.2015

LEU (2016b) LightingEurope, Response to Clarifiction Questions Regarding Ex. 2(a)(5)“, submitted 7.3.2016 per email

LEU (2016c) LightingEurope, Response to Clarifiction Questions Regarding Ex. 2(a)(5)“, submitted 9.3.2016 per email

NARVA (2014a) NARVA Lichtquellen GmbH + Co. KG, Exemption request for using of mercury in fluorescent lamps, submitted 19.12.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/NARVA/01_02_a__2b3_4a.pdf

PZPO (2015a), Polish Association of Lighting Industry, Comments to Annexes III and IV Directive 2011/65/EU (RoHS), submitted 5.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Directive_RoHs_-_PZPO_comments_05_10_15_eng.pdf

Tähkämö et al. (2014) Tähkämö, L., Martinsons, C., Ravel, P., Grannec, F., and Zissis, G., Life Cycle Assessment of Solid State Lighting, Final Report, International Energy

Agency 4E Solid State Lighting Annex (4E), pg. 2, pg. 31, available under http://ssl.iea-4e.org/files/otherfiles/0000/0068/IEA_4E_SSL_Report_on_LCA.pdf

VITO & VHK (2015) Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'), Final report, Task 4, Technologies, Prepared for the European Commission, DG ENER.C.3

9.0 Exemption 2(b)(3): "Mercury in other fluorescent lamps not exceeding (per lamp): (3) Non-linear tri-band phosphor lamps with tube diameter > 17 mm (e.g. T9)”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

CCG	Conventional control gear
ECG	Electric control gear
EEE	Electrical and Electronic Equipment
EoL	End-of-life
Hg	Mercury
LED	Light emitting diode
LEU	LightingEurope
LFL	Linear fluorescent lamps
NARVA	NARVA Lichtquellen GmbH + Co. KG

9.1 Background

LightingEurope (LEU)[216] and NARVA Lichtquellen GmbH + Co. KG (NARVA) [217] have both applied for the renewal of Ex 2(b)(3) of Annex III of the RoHS Directive. This exemption covers non-linear triband phosphor fluorescent lamps for general lighting, explained to be a small group of energy- and resource-efficient lamps required in the EU market.[218]

NARVA[219] explains that lamps falling under this exemption are discharge lamps, which use mercury for the discharge process, arguing that no substitutes for the mercury are available. In relation to substitutes, LEU[220] also states that the replacement of mercury in non-linear fluorescent lamps is scientifically and technically impracticable. Currently there are no significant LED retrofit lamps available in the market. Alternatively installed luminaires can be replaced with very high socioeconomic impact by installations using mercury-free lamps.

Both applicants apply for the renewal of the exemption, requesting the current wording formulation as listed in Annex III of the RoHS Directive and the maximum available duration allowed (based on Art. 5(2) of the Directive).

9.2 Description of Requested Exemption

LEU explains that Exemption 2(b)(3) covers mercury in non-linear fluorescent tri-band phosphor lamps for general lighting purposes with normal lifetime and a tube diameter > 17 mm (e.g. circular T9 or T12 lamps or U-shaped T8 lamps, see Figure 9-1. The maximum allowed mercury dose is currently 15 mg per lamp. Non-linear fluorescent lamps always need more mercury compared to linear lamps. The main reason for this effect lies in the production process. Lamp production starts with a linear glass tube, to which coatings on glass are applied as well as the phosphor layer. After these processes the tube is brought in a circular, U-form or other non-linear structural shape. This process has influence on the coating and phosphor layers as small cracks are created where the glass is bent. For that reason more mercury diffuses into the glass tube during

[216] LEU Ex. 2(a)(1)(2015a), LightingEurope, Request to renew Exemption 2(b)(3) Under Annex III of the RoHS Directive 2011/65/EU 2(b) Mercury in other fluorescent lamps not exceeding: 2(b)(3) Non-linear tri-band phosphor lamps with tube diameter > 17 mm (e.g. T9): 15 mg may be used per lamp after 31 December 2011, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_b__3-4_/Lighting_Europe/2b3_LE_RoHS_Exemption__Req_Final.pdf

[217] NARVA (2014a), NARVA Lichtquellen GmbH + Co. KG , Exemption request for using of mercury in fluorescent lamps, submitted 19.12.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/NARVA/01_02_a__2b3_4a.pdf

[218] Op. cit. LEU Ex. 2(b)(3)(2015a)

[219] Op. cit. NARVA (2014a)

[220] Op. cit. LEU Ex. 2(b)(3)(2015a)

operational lamp life meaning more mercury is necessary in order to provide the functionality of these lamps over the lamp lifetime. [221]

The majority of lamps falling under this exemption currently put on the EU market by LEU members are T9 circular or T8 U-shaped lamps with standardised dimensions and base. These lamps with a diameter of ca. 26 mm (T8) or 29 mm (T9) are very economical, offer a good quality of light having a very good luminous flux. They are compact with good average lifetime and have suitable electronic control gear. In contrast, in other parts of the application, LEU states that non-linear tri-band phosphor lamps with tube diameter > 17 mm can be used with conventional control gear (CCG) as well as with electronic control gear (ECG). Lamps are in use mainly in professional areas (public buildings, restaurants, industry, shops, supermarkets; department stores, street and city lighting), but sometimes also in private homes. [222]

Figure 9-1: Drawings/pictures of T9 circular and T8 U-shaped lamps

Source: LEU Ex. 2(b)(3)(2015a)

[221] Op. cit. LEU Ex. 2(b)(3)(2015a)
[222] Op. cit. LEU Ex. 2(b)(3)(2015a)

LEU provides typical parameters for each entry to further describe the range of lamps available on the market and covered by this exemption. The data is summarised in Table 9-1.

Table 9-1: Typical parameters of lamps falling under Ex. 2(b)(3)

	U-shaped T8	Circular T9
Available types and wattages (main types used in EU):	18, 36, 58 Watt	22, 32, 40 Watt
Available Colour Temperatures: 2.700K up to 6.500K	2.700 - 6.500K	
Typical Colour Rendering Index (Ra):	80- >90	
Base (standard designation): G13 (bi-pin), IEC/EN60061),	2G13	G10q
Typical average Lifetime[2]	13.000h	7.500h
Dimmable	yes	

*

Source: Op. cit. LEU Ex. 2(b)(3)(2015a)

9.2.1 Amount of Mercury Used under the Exemption

There are limited statistical data available for non-linear T8 or T9 lamps. T12 lamps are considered to have a niche market only. Specific market data is not available for the lamps covered by this exemption. As an indication, LEU explains that data for the EU-28 of lamps covered by the exemptions 1(e), 2(b)(2), 2(b3), 2(b)(4) and 4(a), show a decrease in market sales from 2009 to 2013. For lamps under all of these exemptions, in 2013 ca. 19 Mio. pcs. non-linear and special purpose lamps were marketed[223]. The overall roughly estimated annual mercury input decreased between 2009 and 2013 from circa 510 kg to 190 kg (total decrease of -63%, average decrease per lamp of -33%). Data for the various years can be viewed in Table 9-2.[224]

Table 9-2: Market and mercury content of lamps covered by the Exemptions 1(e), 2(b)(2), 2(b)(3), 2(b)(4) and 4(a) of RoHS Annex III

EU28	2009	2010	2011	2012	2013
Other FL [Mio pcs.]	34	32	27	23	19
Mercury [kg]	510	480	324	230	190
Average Hg content of lamps [mg]	15,0	15,0	12,0	10,0	10,0

Note: Data represent sales in EU-2814. Mercury content has been estimated by LightingEurope.
Source: Op. cit. LEU Ex. 2(b)(3)(2015a)

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[223] Referenced in LEU Ex. 2(b)(3)(2015a) as Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19) Draft Interim Report, Task 2, Nov.2014, VITO, VHK

[224] Op. cit. LEU Ex. 2(b)(3)(2015a)

9.3 Applicant's Justification for Exemption

LEU claims that the replacement of mercury in non-linear fluorescents is scientifically and technically impracticable. Currently there are no significant non-linear LED lamps available on the market. Argumentation is also raised as to the comparability of LED alternatives in terms of efficacy and light distribution. The alternative of a continuation of this exemption would be to bring about replacement of installed non-linear fluorescent luminaires with LED luminaires. [225]

9.3.1 Possible Alternatives for Substituting RoHS Substances

LEU explains that during the last decades several approaches have been made to design low pressure discharge lamps where the light producing element Hg is replaced by a less hazardous material. So far no approach yielded a result with comparable luminous efficacy, product cost and product availability as the (still state of the art) Hg low pressure discharge lamps. However, it is said that with the arrival of equally efficient LED light sources, research into alternative discharges has stopped at most companies and universities. Further details of such research efforts can be viewed in LEU's applications.[226]

Information is also provided as to the accomplishments in terms of Hg reduction, however it is explained that the potential for this strategy has been implemented for the most part and that further research is focusing on the development of LED alternatives and not on Hg reduction.[227]

LEU members producing these lamps have reduced the mercury content within most lamp models in the past years. The point is made that there is not an "average lamp", but that they take all manner of different wattages, phosphors, sizes and forms. LEU emphasizes that some lamps on the market have a value exceeding the 10 mg average and that the current limit should thus not be changed. Publicly available data only reveals the mercury content of lamps for general lighting. But exemption 2(b)(3) also covers special purpose lamps. Therefore LEU recommends not changing the limit as it would in practise only have impact in very small amounts, but probably with the consequence that for some lighting or non-lighting[228] applications, lamps would no longer be available.[229]

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[225] Op. cit. LEU Ex. 2(b)(3)(2015a)
[226] Op. cit. LEU Ex. 2(b)(3)(2015a)
[227] Op. cit. LEU Ex. 2(b)(3)(2015a)
[228] The consultants understand this to mean EEE of other categories (not Cat. 5) in which an Ex. 2(b)(3) lamp is integrated, where the main purpose of the equipment is not lighting. For example furniture with lighting would be considered a non-lighting application.
[229] LEU Ex. 2(b)(3)(2015b), LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 2(b)(3) (renewal request), submitted 15.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_b__3-4_/Lighting_Europe/Ex_2b3_LightingEurope_1st_Clarification-Questions_final.pdf

9.3.2 Possible Alternatives for Eliminating RoHS Substances

LED lighting is understood to comprise the candidate substitutes for non-linear fluorescent lamps. LED lighting is a very innovative technology offering a high variety of new functionalities, high and still increasing energy efficiency and overall performance in nearly all areas. However, at present no significant trend for nonlinear LED based replacement lamps is visible. They have a relatively small market, with diverse portfolio, hence LED penetration might be slower (on lamp level). [230]

LEU states that there are two key ways to use LED technology in order to substitute fluorescent lamps: 1) replacement lamps (retrofit/ conversion), or 2) new installations (for example in new buildings or in refurbished areas). Currently LightingEurope is not aware of any relevant nonlinear T8 or T9 LED replacement lamps being available on the EU market. However, in other parts of the application document, LEU states that the non-linear LED replacement market is in its very initial stage. To the best knowledge of LEU members, only limited examples of such lamps can be found on the European market and none of them can be considered as fully compatible with existing applications.[231]

New circular or U-bent LED lamps would have to be developed. So far there is no market justifying the effort to develop these lamps and make them available for the EU market. It is also much easier to produce different fluorescent lamp types and wattages due to the big similarity of phosphors and components compared to development and production of the full range of lamps in LED technology.[232]

Installation of replacements mostly requires involvement of people with professional expertise due to the following issues: [233]

- Electrical compatibility: A LED tube has to operate on the installed control gear without any problems. It can require technical changes to the luminaire (rewiring), especially in luminaires equipped with electronic control gears.
- Applicable legal and compliance requirements like conformity assessments, declaration, and labelling of the changed luminaire are needed.
- Different light distribution: LED has typically unidirectional optical characteristics vs. more omnidirectional distribution from fluorescent lamps[234].
- LED lamps do contain electronic components as well as materials which like nearly all other electronic equipment use the RoHS regulated substance lead in applications exempted by Annex III of the Directive.

[230] Op. cit. LEU Ex. 2(b)(3)(2015a)
[231] Op. cit. LEU Ex. 2(b)(3)(2015a)
[232] Op. cit. LEU Ex. 2(b)(3)(2015b)
[233] Op. cit. LEU Ex. 2(b)(3)(2015a)
[234] The consultants interpret this statement to be in relation to the different light distribution, where LED is typically non-directional vs. fluorescent lamps which are typically of an omnidirectional nature.

Further detail as to these aspects is available in the application document and can also be observed in Section 8.3.2 related to substitutes for LFLs, in light of the similarities.

LEU summarises that only few nonlinear LED replacements are available, hence reliability cannot judged. However, correctly installed LED based luminaires are considered to be reliable.

Another growing market approach is the use of integrated LED luminaires, but this requires full luminaire replacement including the additional high investment and negative environmental impact. There are no data available about number of luminaires, equipment and fixtures using non-linear lamps. With a conservative assumption 500€ per luminaire including installation would be needed for replacement creating 5-10 kg WEEE for each still functional and energy efficient equipment. LEU further contends that LED based luminaires so far do not reveal a clear general environmental benefit, for example due to higher energy efficiency during the use phase. [235]

LEU summarised that for non-linear T8, T9 and T12 lamps no significant LED retrofit solutions are currently available on the EU market, which can be used in respective fluorescent lamp luminaires. Those lamps which are available often need technical changes in the luminaire. Instead new LED solutions are replacing non-linear fluorescent lamps in new products, such as LED street lighting systems.

9.3.3 Environmental Arguments

LEU explains that there are several external [understood to mean independent – consultant's comment] LCA's performed regarding lighting. There is general agreement, that the main environmental impact is created during the use phase, meaning through electricity consumption when burning the lamp[236]. This means that currently the efficacy of the lamp is the determining parameter. The environmental and economic performance comparison of various lamp types is difficult, due to lack of established rules for the LCA of light sources. As a result, it creates distortion and makes it difficult to numerically compare the results of the LCAs. LEU explains that comparing non-linear fluorescent lamps and LED lamps with LCA is even more challenging due to the various-shaped LED light sources. LED technology provides new possibilities for manufacturers to design luminaires, lamps, components and packages containing LED chips, thus the question on which basis those should be compared remains.[237, 238]

[235] Op. cit. LEU Ex. 2(b)(3)(2015a)
[236] Referenced in LEU Ex. 2(b)(3)(2015a) as Enlighten report, Section 5, Ch. 3 fig. 4 & 5
[237] Referenced in LEU Ex. 2(b)(3)(2015a) as Life cycle assessment of light sources – Case studies and review of the analyses Leena Tähkämö, Aalto University publication series DOCTORAL DISSERTATIONS 111/2013, p. 17-18
[238] Op. cit. LEU Ex. 2(b)(3)(2015a)

9.3.4 Road Map to Substitution

Lamps covered by exemption 2(b)(3) cover a small market segment. Developing retrofit or conversion lamps takes as much time as other comparable electrical and electronic equipment. A prerequisite for the development of such products is market demand. This market demand could only be sufficient for a positive marketing decision for the lamp types with the highest volume. Currently for lamps under this exemption, LEU states that there is no positive business case. This is said to remain valid even if the lamps would be prohibited in certain cases. [239]

9.4 Stakeholder Contributions

A number of contributions have been made by stakeholders raising general points in relation to discharge lamps. Such contributions are summarised in Section 4.5.7 of the general lamp chapter.

The European Environmental Bureau (EEB), the Mercury Policy Project and the Responsible Purchasing Network[240], submitted comments specifically in relation to Ex. 2(b)(3). They argue that "*the example of T9 lamps may not be correct. T9s are halophosphate. Even ELC[241] at the 2009 submission was talking about halophosphate lamps in relation to the T9s. Therefore the example there should rather be T8 and the limit should be reduced since U-shaped T8s can meet this lower limit… The mercury limit for non-linear tri-band phosphor lamps with tube diameter > 17 mm, including the U-bent T8s, should be lowered to 8 mg from the current limit of 15 mg.*"

9.5 Critical Review

9.5.1 Scientific and Technical Practicability of Substitution

LEU explains that substitutes are not sufficiently available for non-linear fluorescent lamps. In terms of substance substitutes the consultants can follow that despite various research initiatives, results have not led to the development of Hg-free LFLs. As for the reduction of Hg in LFLs, it is also apparent that the potential for such benefits has been realised to a large extent. Though LEU admits that many lamps covered by this exemption use less than 10 mg, they also explain that some lamps with special purposes

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[239] Op. cit. LEU Ex. 2(b)(3)(2015b)

[240] EEB et al. (2015a),The European Environmental Bureau, the Mercury Policy Project, and the Responsible Purchasing Network, Environmental NGOs Response to Stakeholder consultation 2015 #2 on mercury- containing lamps – Exemption 1-4 (Review of Annex to the RoHS directive), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1-4_EEP-RPN-MPP_Comments_on_RoHS_Request-final_20151016.pdf

[241] ELC is the European Lamp Companies Federation, who participated in the 2008/2009 review of the exemption – consultants comment.

require more mercury. Due to the development of LED technologies, further potential for these strategies is understood to no longer be in the focus of development efforts.

As for LED substitutes, LEU claims that at present, replacement products are lacking and that available substitutes often do not provide comparable performance. In general it is explained that the small market segment of Ex. 2(b)(3) lamps means that that very few replacement LEDs are available, and that they would all require conversion of existing luminaires. LED luminaires are available, however LEU is neither aware of their market uptake, nor whether their efficiency can be considered comparable to non-linear fluorescent lamps or not. LEU states that new installations can be applied in new buildings or in refurbished areas of buildings, however in the consultants view this limitation would only be relevant to luminaires applied in arrays such as in office lighting. However, from the examples provided by LEU (see Figure 9-1) it seems that lamps relevant for this exemption are used in "stand-alone" luminaires as well as luminaires used for street lighting. It cannot be assumed from this information that such lamps are applied as luminaire arrays for office lighting and thus this limitation could only be relevant for some luminaires if at all.

To support statements related to LED alternatives, LEU does not submit any data and it is difficult to estimate to what degree these statements are correct.

The VHK & VITO[242] study also does not address such lamps specifically. Circular (T9 or T12) lamps are explained to be covered in the information provided for T5 LFL lamps, from which it can be understood that there is a lack in replacement substitutes. Though VHK & VITO explain some replacements to be available from the smaller manufacturers for T5 lamps, the variety is said to be small among others as "*The number of T5 lamps being replaced in a year is considerably smaller than the number of T8 lamps being replaced, so the market is less interesting*". This statement is assumed to be of higher relevance for circular lamps, which are understood to have a much smaller market share. U-shaped T-8 lamps are assumed to be addressed by VHK & VITO under "*LFLs, other types*", specifically said to include for example "*special fluorescent lamps, e.g. circular T9*" as well as other T-classifications. It is explained that "*No specific research on the availability of LED retrofit lamps was performed, but considering the situation for the LFL T5 base case discussed…, it is assumed that such retrofits will generally not exist*." As for how the market is expected to develop, the study states "*In the residential sector it is expected that most people will switch to dedicated LED luminaires, in particular for portable applications. In the tertiary sector, strict safety regulations apply for emergency lighting and exit signs, which might induce a choice for the lamps with exactly the same specifications as those issued with the luminaire. In general a natural phase-out of LFL X lamps is expected, in favour of LED solutions*".

Where LED luminaires shall be chosen as replacements, it is understood that they would be reliable. Though there is no information as to their efficiency, the consultants assume

[242] Op. cit. VITO & VHK (2015a)

that as with any type of technology, that some would be more efficient than others. LED solutions are however generally understood to provide good efficiencies as well as a large flexibility in terms of producing lighting solutions in a variety of shapes and sizes.

9.5.2 Environmental Arguments

Though LEU provides information as to LCA studies to show that there are uncertainties in the comparison of LFLs and LED replacements, most of their references regard LCAs comparing other fluorescent technologies (e.g. CFLs) with LEDs, results of which are discussed in the review of Ex. 1(a-e) in Section 5.5.2.2.

The consultants are not aware of comparative LCAs in the public realm of relevance to non-linear fluorescents and their LED replacements. However it is considered plausible that comparisons of non-linear fluorescents and possible LED replacements may be more challenging in this case due to a lack of products which are sufficiently comparable (dimensions, wattage, luminous flux etc.).

9.5.3 Stakeholder Contributions

For the discussion of general aspects raised by stakeholders, please see Section 4.5.7 of the general chapter.

As for the specific aspects raised by EEB et al., the consultants do not recommend following the approach proposed by the applicants. To begin with, assuming that T9 circular lamps are only produced with halo-phosphate phosphors, they would not benefit from the current exemption wording, which limits its applicability to tri-band phosphors.

Furthermore, if indeed T9 circular lamps are not produced with tri-band phosphors, lowering the current mercury limit may be possible, however as EEB et al. states, U-shaped T8 lamps already comply with the proposed lower limit. This strategy is thus not assumed to result in a change in articles on the market and thus also not in respective environmental benefits. In contrast, should T9 circular lamps produced with tri-band phosphors be marketed, it cannot be concluded that such lamps would not need the current mercury limit. The consultants further believe that enforcing a mercury reduction at this point of development of LED technologies would give an unhelpful signal to industry on where R&D efforts are best spent, which might delay further developments of substitutes.

9.5.4 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;

- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

As explained above, it can be followed that Hg-free LFL substitutes are not available and that the potential for further Hg reductions has been realised to a certain degree.

LED alternatives are understood to be developing rapidly, however from available information it still seems that LED replacements are limited in their variety and possibly also in their compatibility as retrofit replacements. It is apparent that LED luminaires are available and that this technology opens a large degree of flexibility in terms of creating various shapes and sizes. VHK & VITO estimate that private consumers shall shift towards LED luminaires and this is understood as a natural phase-out, which is possibly already underway to some degree. In contrast, the same study assumes that in the tertiary sector, stricter regulations may hinder such a phase-in, particularly should emergency lighting and exit signs be relevant for this exemption. However, LEU has not specified such examples to be relevant to the scope of this exemption. As the conclusions of the VHK & VITO study apply to a wider range of lamps, and not just to non-linear lamps, it is possible that this aspect is not relevant to this exemption.

A further aspect of interest in this regard is the possible size of this exemptions' market segment. LEU specifies sales of 19 million lamps for the following exemptions: 1(e), 2(b)(2), 2(b3), 2(b)(4) and 4(a). This information is said to originate in the VHK & VITO szudy. It is assumed that this data is taken from the first version of the Task 2 report[243], however in the final version from May 2015 according to Table 1, 19 million lamps were placed on the market for all other LFLs (including T5 old types 4 -13 Watt and special FL), excluding T2, T5 and T8 types for which specific data is provided. This would mean that lamps for Ex. 1(e) and Ex. 4(a) are not included in this count. Furthermore, Ex. 2(b)(1) expired in 2012 and Ex. 2(b)(2) is to expire on 13 April 2016, and it is thus assumed that the sales of such lamps in 2013 would have been negligible. It is not clear how 19 million lamps would be distributed between Ex. 2(b)(3) and Ex. 2(b)(4), however it is possible that the number of lamps related to Ex. 2(b)(3) is not negligible.

Despite LEU explaining that there is a wide variety of lamps that require substitutes, it appears that the factor that is of the largest importance for substitutes is dimensions. LEU has specified that all lamps are either T8 (U-shaped) or T9 (circular), meaning that the diameter is standardized. In parallel, it can be understood that other dimensions may vary. From manufacturer catalogues it is observed that U-shaped lamps come in a relatively small variety of overall lengths: 310; 601-607; 570; 765[244]. It is possible that a

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[243] VHK & VITO (2015b), Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19') - Draft Interim Report, Task 2 (revision 1): Markets, Prepared for the European Commission, DG ENER.C.3, pg. 2-15, Table 1.

[244] Based on Data from Osram: http://www.osram.de/appsinfo/pdc/pdf.do?cid=GPS01_1027909&vid=PP_EUROPE_DE_eCat&lid=DE

few further lengths exist, however the consultants assume that most further variance is in terms of the lumen package and the wattage. According to one internet supplier[245], 48 different lamps were available from 6 suppliers, in 6 different lumen groups and 12 different wattage types. The consultants believe that as long as substitutes would be available for each of the different dimension groups, that a forced phase-out, leading to early end-of-life (EoL) of luminaires would be avoidable, possibly requiring luminaire conversions in order to "accept LED replacements".

As for circular lamps, from data available from the same supplier[246], 50 lamps are available from 6 manufacturers in 6 lumen groups and in 4 different watt types. According to one source[247] for such T9 tubes, outside diameters of 6½", 8", 12", or 16" are available. In this sense, here too, the dimension variety and the wattage variety clarify that were a small number of alternatives available in terms of dimensions, that these should suffice to enable substitution.

As it is understood form the applicant that lamps have different types of drivers, it is possible that at present alternatives do not provide sufficient compatibility on this respect. However data to substantiate such claims has not been provided.

Against this background, it is difficult to determine the availability of substitutes in terms of their coverage of non-linear lamp dimensions and their electric compatibility with existing luminaries. In parallel it can be understood that substitutes on the system level (luminaires) are available and phase-out is assumed to have begun in this direction.

Because of the lacking data related to replacement lamp availability, the consultants would recommend a short term renewal. This period should allow industry to bring a few LED substitutes on to the EU market[248] and to compile data so as to clarify if indeed a substitution problem exists that could create substantial waste from early EoL of luminaires should this exemption be allowed to expire.

9.6 Recommendation

As explained above, it seems that substitutes are available on the system level (LED luminaires). However the range of substitutes on the component level (replacement LEDs) and their compatibility with existing installations is yet to be verified in terms of dimensions and electric compatibility. Only with this information would it be possible to understand the range of potential environmental costs of early EoL of luminaires and subsequently their acceptability in comparison to the potential for Hg saving. The

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[245] http://www.mercateo.com/kw/leuchtstofflampe%2820%29u%282d%29form/leuchtstofflampe_u_form.html

[246] http://www.mercateo.com/kw/leuchtstofflampe%2820%29ringform/leuchtstofflampe_ringform.html?ViewName=live&wortFilter=G10Q

[247] https://sizes.com/home/fluorescents.htm

[248] It can be understood that a few substitutes are available on non-EU markets such as the US market, however from an initial survey similar lamps were not found on the EU market.

consultants thus recommend a short (three year) exemption to allow for the bringing of substitutes onto the market and for data to be compiled regarding LED coverage of the non-linear product range.

Exemption 2(b)(3)	**Duration***
2(b) Mercury in other fluorescent lamps not exceeding (per lamp)	
(3) Non-linear tri-band phosphor lamps with tube diameter > 17 mm (e.g. T9)"	For Cat. 5: 21 July 2019
	For Cat. 8 & 9: 21 July 2021
	For Sub-Cat. 8 in-vitro: 21 July 2023
	For Sub-Cat. 9 industrial: 21 July 2024

Note: As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

9.7 References Exemption 2(b)(3)

EEB et al. (2015a) The European Environmental Bureau, the Mercury Policy Project, and the Responsible Purchasing Network, Environmental NGOs Response to Stakeholder consultation 2015 #2 on mercury- containing lamps – Exemption 1-4 (Review of Annex to the RoHS directive), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1-4_EEP-RPN-MPP_Comments_on_RoHS_Request-final_20151016.pdf

LEU Ex. 2(a)(1)(2015a) LightingEurope, Request to renew Exemption 2(b)(3) Under Annex III of the RoHS Directive 2011/65/EU 2(b) Mercury in other fluorescent lamps not exceeding: 2(b)(3) Non-linear tri-band phosphor lamps with tube diameter > 17 mm (e.g. T9): 15 mg may be used per lamp after 31 December 2011, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_b__3-4_/Lighting_Europe/2b3_LE_RoHS_Exemption__Req_Final.pdf

LEU Ex. 2(b)(3)(2015b) LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 2(b)(3) (renewal request), submitted 15.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_b__3-4_/Lighting_Europe/Ex_2b3_LightingEurope_1st_Clarification-Questions_final.pdf

NARVA (2014a) NARVA Lichtquellen GmbH + Co. KG, Exemption request for using of mercury in fluorescent lamps, submitted 19.12.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_a__1-5_/NARVA/01_02_a__2b3_4a.pdf

VHK & VITO (2015b) Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19') – Draft Interim Report, Task 2 (revision 1): Markets, Prepared for the European Commission, DG ENER.C.3, pg. 2-15, Table 1.

10.0 Exemption 2(b)4: Lamps for other general lighting and special purposes (e.g. induction lamps): 15 mg may be used per lamp after 31 December 2011

Declaration

In the sections that precede the "Critical Review" the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

CCG	Conventional control gears
CFL	Compact fluorescent lamp
CRI	Colour Rendering Index
DBD	Dielectric barrier discharge
ECG	Electronic control gears
EEE	Electrical and Electronic Equipment
EoL	End of Life
LED	Light Emitting Diode
LEU	LightingEurope
R&D	Research and Development
UV	Ultraviolet (subtypes UVA, UVB, UVC)

10.1 Background

LightingEurope (LEU)[249] has submitted a request for the renewal of the above mentioned exemption.

LEU states that due to a vast variety of parameters relevant for lamps falling under Ex. 2(b)(4), such lamps cannot be easily replaced with LED alternatives (e.g. form factor, length, spectrum etc.).

The applicant applies for the renewal of Ex. 2(b)(4), with the current wording formulation listed in Annex III of the RoHS Directive and requesting the maximum available duration allowed.

10.2 Description of Requested Exemption

According to LEU[250], lamps in the scope of Ex. 2(b)(4) are in a wide variety of different lamp families with mercury content from < 2 mg and up to 15 mg. They are mainly niche products with low market shares compared to the other fluorescent lamps, and have a vast variety of parameters (form, factor, length, spectrum, colours, and technologies – e.g. induction, external ignition etc.). [251] Specific market data is not available for the lamps covered by this exemption.

In general, LEU explains that fluorescent lamps are very energy- and resource efficient lamps. They contain a small amount of intentionally added mercury in the discharge tube, which is essential to convert electrical energy into light. There are no specific market data and mercury content available for the lamps covered by this exemption.

There is a growing market for mercury-free lamps based on LED technology with features such as energy efficiency and design flexibility. At present to the best knowledge of LEU none of the key players on the market offer LED-based alternative solutions for most of the lamps covered by Ex. 2(b)(4).

For most of the lamps covered by this exemption there is currently no significant availability of LED retrofit or conversion lamps.

Against this background, LEU does not expect LED alternatives to allow for a full phase-out of Ex. 2(b)4 lamps within the coming 5 years, and thus requests a renewal of the exemption with the following wording:

> *"2(b)(4) Lamps for other general lighting and special purposes (e.g. induction lamps): 15 mg may be used per lamp after 31 December 2011"*

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[249] LEU Ex. 2(b)(4) (2015a), LightingEurope, Request to renew Exemption 2b(4) under Annex III of the RoHS Directive 2011/65/EU Lamps for other general lighting and special purposes (e.g. induction lamps): 15 mg may be used per lamp after 31 December 2011, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_b__3-4_/Lighting_Europe/2b4_LE_RoHS_Exemption__Req_Final.pdf

[250] Op. cit. LEU 2(b)(4)- (2015a)

[251] Op. cit. LEU 2(b)(4)- (2015a)

10.1 Applicant's Justification for Exemption

LEU[252] explains that the scope of exemption 2(b)(4) includes all other fluorescent lamps for general lighting and special purposes, which do not belong to any other exemptions in Annex III:

- Compact fluorescent lamps (Exemptions 1(a)-1(f));
- Double-capped linear triband phosphor lamps for general lighting (2(a)(1) – 2(a)(5));
- Linear and non-linear halophosphate lamps (2(b)(1) – 2(b)(2));
- Non-linear triband phosphor lamps (2(b)(3));
- Cold cathode fluorescent lamps (3(a) – 3(c)).

Fluorescent lamps are low-pressure discharge lamps containing a phosphor coating. Low- pressure discharge lamps without a fluorescent phosphor layer (e.g. UV-lamps) as well as medium and high pressure discharge lamps are covered by exemptions 4(a) – 4(f). Thus exemption 2(b)(4) includes an inhomogeneous group of lamps with amongst others different:[253]

- Form factors and bases, e.g. linear, circular, square shape;
- Technologies e.g. induction, external ignition;
- Colours, e.g. white, coloured, black light; blue light; and
- Applications and purposes, e.g. general lighting, colour, explosion protection, tanning, horticultural lighting, colour comparison, medical use;

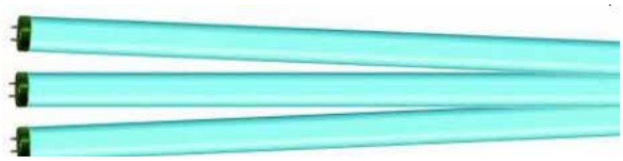
A non-exhaustive selection of lamps falling under 2(b)(4) is listed in Table 10-1.

Table 10-1 Non-exhaustive list of fluorescent lamps falling under Ex. 2(b)(4)

Lamps and applications	Example
Chip control **Lamps without UV- and blue spectrum (below 500 nm) through special coating, yellow light Applications: semiconductor industry (wafer), printing industry, (lithography);**	 
Colour proof lamps Printing industry, graphic workshops, photographic laboratories, industrial inspection and colour	[No visual example provided]

[252] Op. cit. LEU 2(b)(4)- (2015a)
[253] Op. cit. LEU 2(b)(4) (2015a)

Lamps and applications	Example
matching facilities, **industry**, shops, incoming goods inspection;	
High colour rendering index lamps **Very good colour rendering group: 1A (Ra: ≥ 90);**	[No visual example provided]
High colour temperature lamps **Colour temperatures > 6500K range;**	[No visual example provided]
T12 lamps with external ignition strip improved ignition at low ambient temperatures **Applications: street lighting, industry, outdoor applications (only in suitable luminaires);**	 **T12 lamps for explosion proof luminaires** Applications: Industry, places with a heightened risk of fire or explosions, oil rigs; Product features Fa6 base for explosion-proof fixtures; Operation without starter; 
Coloured lamps **Cost-effective creative illumination and decoration, uniform light along the entire length of the lamp;** **Areas of application: Decorative applications: shops supermarkets and department stores, restaurants, hotels, accent lighting;**	
Blacklight & Blue fluorescent lamps **Lamps that emit long wave (UV-A) ultraviolet light and not much visible light.** **Applications: Curing large areas of plastic, hardening paints, lacquers and modern adhesives, artificial, material aging, exposure of diazo film material and print masters, fluorescence excitation (with black glass filters);**	

Lamps and applications	Example	
Tanning lamps **Cost-effective creative illumination and decoration[254], uniform light along the entire length of the lamp;**		
Induction lamps **Electrodeless lamps, very long life time (ca. 100.000hours), 70 – 150 Watt) Wherever relamping is expensive;** **- Outdoor lighting, tunnel lighting and factory lighting** **- Street and city lighting** **- Sports grounds and outdoor facilities** **- Marine lighting** **- Outdoor applications only in suitable luminaires**		**Medical, Therapy lamps** Special spectra for medical applications 

Source: taken from LEU Ex. 2(b)4 (2015a)

Moreover, LEU states[255] that some of the 2(b)(4)- lamps can be used with conventional control gears (CCG) as well as with electronic control gears (ECG). There are numerous different control gears available on the market offering various functionalities. For more details in this regard, see also Section 8.2. They are used depending on customer requirements, such as dimming or temperature range. LEU highlights that due to international safety standards, it is essential that only suitable combinations of lamps and luminaires are installed and maintained. These lamps can operate on a wide range of existing ballasts, including magnetic and electronic ballasts. For further information on ballasts in fluorescent lamps please refer to Section 8.3.2.1.

10.1.1 Possible Alternatives for Substituting RoHS Substances

LEU[256] explains that during the last decades several approaches have been made to design low pressure discharge lamps where the light producing element Hg is replaced by a less hazardous material. So far no approach yielded a result with comparable

[254] The consultants would like to note that tanning lamps are not understood to be used for decorative purposes, however the text is copied from LEU's application as is. It is assumed that this aspect could be a result of a typing mistake.
[255] Op. cit. LEU 2(b)(4)- (2015a)
[256] Op. cit. LEU 2(b)(4)- (2015a)

luminous efficacy, product cost and product availability similar to that of the still state of the art Hg low pressure discharge lamps. However, it is said that with the arrival of equally efficient LED light sources, research into alternative discharges has stopped at most companies and universities.

LEU claims[257] that non-linear fluorescent lamps always need more mercury compared to linear lamps. The average amount of mercury in lamps falling under Ex. 2(b)(4) on the market is about 8.0 mg Hg. Higher mercury consumption of Ex. 2(b)(4) fluorescent lamps as compared to normal linear fluorescent lamps is mainly caused by special phosphors and additives in the fluorescent powder and their life expectancy. Many of the lamps are produced on the same production lines as general lighting. The difference in Hg content between linear and non-linear lamps in many cases is quite small. Furthermore, in most cases, significant reductions of mercury content have already been realised, likely of a similar order to the mercury reductions implemented in linear fluorescent lamps for general lighting (as presented in 8.2.1). However, the current 15 mg limit is said to be needed due to the large variety of different lamps and functions, and their high variance in relation to different factors. Thus according to the applicant Ex. 2(b)(4) should still be specified with a maximum limit of 15 mg.

Further reduction of mercury might technically be possible with high economic effort and research and development (R&D) resources. But these would require financial and human resources, which are needed for the investments in the production process and transfer to LED technology. Moreover it is explained that the potential for Hg reduction has been implemented for the most part and that further research is focusing on the development of LED alternatives and not on Hg reduction

10.1.2 Possible Alternatives for Eliminating RoHS Substances

According to the applicant[258] there is a growing market for mercury-free lamps based on LED technology with features such as energy efficiency and design flexibility.

At present, to the best knowledge of LEU, there is no manufacture of LED based alternative solutions for most of the lamps covered by Ex. 2(b)(4). The Ex. 2(b)(4) lamp portfolio addresses fragmented, specialized applications. LEU states that these applications cannot be easily replaced by LED in all situations, since in some cases the functional objective of the special lighting application might not be met in terms of technical comparability. It must be decided case by case, if the LED based solution can be an effective replacement for the existing fixture and situation. It mostly requires involvement of people with professional expertise due to the following issues (see also the general chapter, Section 4.3.2.2.

1) Electrical compatibility: LED tube has to operate on the installed control gear without any problems. It is essential to know what kind of control gear is present

[257] Op. cit. LEU 2(b)(4)- (2015a)
[258] Op. cit. LEU 2(b)(4)- (2015a)

in the luminaire. It can require technical changes to the luminaire (rewiring), especially in luminaires equipped with an electronic control gear. Full compatibility with all installed conventional or electronic control gears is not possible.

2) Applicable legal and compliance requirements like conformity assessments, declaration, and labelling of the changed luminaire, fixture or other electrical or electronic equipment are needed. Safety aspects and lack of standards for using such lamps to replace LFLs is also explained to be a limiting factor.
3) Different light distribution: due to the LED tubes, changed optical characteristics vs. the existing lamp, the light plan can no longer be optimized for the application.
4) Restricted choice in the LED based lamps, only a fraction of the existing lengths are available, not all colours are available, for example no direct replacements are available for emergency lighting.

When asked for clarification as to lamps covered by this exemption and their availability of substitutes, LEU explained[259] that it is currently not possible to demonstrate an overview of lamps being easily replaced with LED alternatives. Only within the group of coloured lamps for non-professional purposes may LED T8 retrofit lamps be available.

10.1.3 Environmental Arguments

LEU explains[260] that comparing non-linear fluorescent lamps and LED lamps (regarding the specific characteristics and requirements) with LCA is especially challenging due to the various-shaped LED light sources for lamps falling under Ex. 2b(4). The applicant advocates carrying out further research into the overall substance effect of LED lamps in comparison with fluorescent lamps. LEU is not aware of such LCAs[261]

Other environmental arguments are general in nature. Please refer in this respect to Section 4.3.3 of the general chapter.

10.1.4 Socio-economic Impact of Substitution

A growing market approach is the use of integrated LED luminaires, but this requires sufficient time for a full luminaire replacement including an additional high investment (in the luminaire) for private, commercial or public customers. It is also said to lead to

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[259] LEU Ex. 2(b)4 (2015b), LightingEurope, Response to Oeko-Institut regarding the 1st Questionnaire Exemption No. 2(b)4 (renewal requests) Mercury in other fluorescent lamps not exceeding (per lamp): (4) Lamps for other general lighting and special purposes (e.g. induction lamps): 15 mg per lamp", submitted 25.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_b__3-4_/Lighting_Europe/Ex_2b4_LightingEurope_1st_Clarification-Questions_final.pdf

[260] Op. cit. LEU 2(b)(4)- (2015a)

[261] Op. cit. LEU 2(b)(4)- (2015a)

potential increased environmental impact (assuming the original installation is not yet at end-of-life), without a mitigating improvement in safety or socio-economic factors.

According to the applicant[262] a conservative assumption is that 500€ per luminaire including installation would be needed for replacement, creating 5-10 kg of WEEE for each still functional and energy efficient installation. For special EEE using lamps covered by this exemption, figures are assumed to be much higher.

10.1.5 Road Map to Substitution

LEU[263] is not able to share the individual road maps that its member companies have planned for their LED portfolio. There is no general roadmap to develop LED replacements for all existing linear fluorescent lamp types on the market (see also Section 4.3.5 in the general chapter. Regarding lamps covered by Ex. 2(b)(4) the applicant further emphasizes the market segment of lamps covered by this exemption, with a vast variety of parameters and small market shares for lamp types of relevance.

According to the applicant, currently the market demand for the development of substitutes for specific lamp types is low[264], so the efforts would result in higher costs for the manufactures. LEU[265] states in this respect that it is much easier to produce different fluorescent lamp types and wattages compared to development and production of the full range of lamps in LED technology.

10.2 Stakeholder Contributions

A number of contributions have been made by stakeholders, all of a general nature. Such aspects are summarised in Section 4.4 of the general chapter.

10.3 Critical Review

10.3.1 Scientific and Technical Practicability of Substitution

LEU explains that several approaches have been investigated to design fluorescent lamps where the light producing element Hg is replaced by a less hazardous material. So far no approach yielded a result with comparable luminous efficacy, product cost and product availability to that of the still state-of-the-art Hg low pressure discharge lamps. With the arrival of equally efficient LED light sources, research into alternative discharges has been discontinued. Further details of such research efforts can be viewed in LEU's application document. Information is also provided as to the accomplishments in terms of Hg reduction; however, it can be understood that the potential for this strategy has

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262 Op. cit. LEU 2(b)(4)- (2015a)
263 Op. cit. LEU 2(b)(4)- (2015a)
264 The consultants interpret this to mean that the general market demand for lamps covered by this exemption is low and thus there is no motivation to develop substitutes.
265 Op. cit. LEU 2(b)(4)- (2015a)

been implemented for the most part. Further research is focusing on the development of LED alternatives and not on Hg reduction.

The current threshold specified in the exemption in the form of a 15 mg limit, leaves a wide range allowance for using Hg. Examples of lamps falling under this exemption show that in some cases the limit is needed but that in other cases a far lower threshold could be applied. But according to the applicant it is not practical to address certain sub-groups of lamps in relation to the actual use of Hg applied.

Based on the latter point, it becomes obvious that where no sub-groups can be specified, it is difficult to propose a new threshold lower than 15mg. The consultants however assume that a reduction could be specified if sub-groups could be identified. Without further information and data as to the parameters, market sales and possible overlaps with other exemptions listed in Annex III, such a specification is difficult.

LED is a very innovative technology offering a high variety of new functionalities, high and still increasing energy efficiency, and overall high performance in nearly all areas relating to light sources emitting in the wavelength of visible light. However, at present to the best knowledge of the applicant there is no manufacture of LED based alternative solutions for most of the lamps covered by Ex. 2(b)(4). Moreover, Ex. 2(b)4 applications have a relatively small market, with diverse portfolio; hence LED penetration might be slower compared to general lighting applications. LEU states that there are two key ways to use LED technology in order to substitute fluorescent lamps:

- Replacement lamps (retrofit/ conversion); or
- New installations.

LEU claims that "*Even if retrofit solutions would be developed it must be verified case by case for every application whether the lamp can technically replace the fluorescent lamp with all required specified parameters. Therefore LEU is not able at the moment to give a detailed overview".* Only for T8-lamps are there LED retrofit tubes available. The VHK & VITO[266] study also supports this statement.

The consultants understand from these statements that where LED alternatives shall not enable substitution within existing installations, there is no intention of developing other alternatives. This is further supported by the applicants' statement that it is much easier to produce different fluorescent lamp types and wattages compared to development and production of the full range of lamps in LED technology. The consultants interpret this to mean that currently, very limited development of alternatives is being undertaken, and it seems that there is no roadmap towards substitution of Ex. 2(b)4 applications, or at least not one which is in the public realm.

The statements made by the applicant regarding the availability of LED substitutes cannot be followed comprehensively, because the applicant did not provide specific information in relation to all sub-groups of this exemption to justify its request. Such

[266] Op. cit. VITO & VHK (2015)

information is not provided, neither in relation to the availability of existing LED substitutes for specific applications, nor in relation to the difficulty or limitations of developing such substitutes.

In the consultants view, the information provided by LEU as to possible LED substitutes is very general in its nature. Such arguments are discussed in the chapter regarding Exemption 1a-e or 2a (see Section 5.5.1and 8.5.1). Many of the specific design limitations raised as problems of LED technologies have been communicated in the past reviews and are understood to have been resolved in applications on the market. As LEU does not provide specific information to substantiate its claims in relation to Ex. 2(b)4 lamps operating in the visible-light range, it cannot be concluded if such developments have also been implemented in LED alternatives on the market that are relevant for this exemption, or why they could not be implemented for such applications.

In the following, the various sub-groups understood to fall under Ex. 2(b)(4) are discussed.

T12 lamps with external ignition, with improved ignition and for explosion proof luminaires: LEU mentions certain T12 lamps that are explained to be covered by Ex. 2(b)(4), e.g. T12 lamps with external ignition strip and improved ignition at low ambient temperatures and T12 lamps for explosion proof luminaires that operate without a starter. Though it can be followed that such lamps may have different electrical characteristics, it has also been explained for lamps used for general purposes that they have a wide variety of electrical configurations. It is not explained why the light produced by such lamps would be understood to be relevant for special purpose applications and why it would not be covered by general purpose exemptions. In this respect it is not sufficiently clear why such lamps would not fall under the exemptions specified for T12 lamps in Annex III, namely 2(a)(4) and Ex. 2(b)(1). As applications for the renewal of these exemptions were not submitted, it is understood that such lamps have been phased out for general purposes. Thus without a comprehensive explanation why remaining T12 lamps would be considered as special purpose lamps, it cannot be established whether they would indeed be covered by Ex. 2(b)(4) and why an exemption for their further use is to be understood as justified. In this respect it should also be mentioned that T12 lamps are understood to have been phased out, as they were not efficient and thus do not comply with the Ecodesign Regulation for lamps. Understanding why such lamps could still be placed on the EU market thus needs to be clarified from a technical perspective in relation to the Ecodesign limitations.

Lamps with high colour rendering, with high colour temperature and coloured lamps: The consultants regard colour lamps mentioned in relation to this exemption similarly; these being lamps with high colour rendering (Ra: ≥ 90), lamps with high colour temperature > 6500K, and coloured lamps for creative illumination and decoration. LEU does not provide specific information or data to explain why such lamps would fall under Ex. 2(b)4. It is not explained why such lamps would not fall under exemptions for lamps used for general purposes, which do not limit the colour of lamps, their colour temperature or their colour rendering. Such lamps are understood to be of use for general purposes and it thus cannot be understood why they would fall under Ex.

2(b)(4). For example, coloured lamps can be applied for decorative purposes by residential consumers, lamps with CRI above 90 are considered as general purpose lamps under Ex. 4(b), etc. There are LEDs available in many colours such as red, green, yellow or blue[267]. LEU states only that due to the fact of restricted choice in the LED based lamps, only a fraction of the existing lengths are available, not all colours and for example no direct replacement in emergency lighting. However no details are provided to substantiate this claim and detail is not provided as to for what type of applications available substitutes are relevant. On the basis of the provided information it is thus not possible to conclude neither whether such lamps would fall under this exemption nor what the status of available substitutes is in this respect.

Induction lamps are also mentioned and explained to have a long lifetime. It is understood that most of the studies that have compared fluorescent lamps and LED lamps have investigated fluorescents with "normal" lifetimes. Thus it is expected that where long-life fluorescent lamps are available, that such lamps could still have advantages, or at least be comparable to LED alternatives, due to their extended performance time. However, LEU does not provide information to substantiate its statement or to allow an understanding as to how such lamps compare with possible LED alternatives. It can thus not be concluded neither if LED substitutes are sufficiently available nor if they are comparable in their performance or not.

Lamps for emergency lighting: LEU mentions that lamps for emergency lighting applications in the application for this request, but does not provide any detail as to such lamps and whether they would indeed fall under this exemption in terms of their characteristics. It is thus possible that lamps used for emergency lighting are covered by other exemptions, particularly where lamp output and dimensions could be provided by other lamps, for example, by the use of linear fluorescent lamps (LFL). In relation to lamp replacement, the consultants agree that there may be limitations as to lamps that could be used for this purpose. Where addressing substitutes for LFLs, VHK & VITO state in this respect "In the tertiary sector, strict safety regulations apply for emergency lighting and exit signs, which might induce a choice for the lamps with exactly the same specifications as those issued with the luminaire."[268] The consultants can thus follow that for existing luminaires, that safety regulations and standards might restrict the use of lamps in such installations to discharge lamps for which the luminaire was originally designed. In contrast, a lack of LED alternatives on the system level cannot be followed without a better understanding of the type of light that such lamps would need to provide.

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[267] http://www.osram.com/osram_com/news-and-knowledge/led-home/professional-knowledge/led-basics/light-colors/index.jsp

[268] VHK & VITO (2015), VITO in cooperation with VHK, Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'). Final report, Task 4 – Technologies, Prepared for the European Commission, DG ENER.C.3, available under http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources%20Task4%20Final%2020151031.pdf

UV lamps: The consultants can follow the argumentation that despite development efforts, that LED alternatives for UV sources do not provide comparable performance related to application effectiveness and lifetime. As the UV lamp area is a niche application, it can also be followed that such developments shall be slower than for other lamp applications with larger market shares. As detailed in Section 7.4.1 of the report for Ex. 1(f) LED alternatives currently do not provide sufficient performance in terms of spectral output and in terms of wall-plug efficiency and can thus not be viewed as a practical substitute for UV lamps falling under Ex. 2(b)(4).

10.3.2 Environmental Arguments

The environmental performance comparison of various lamp types is difficult, due to lack of established rules for the LCA of light sources. Though LEU provides information as to LCA studies to show that there are uncertainties in the comparison of fluorescent lamps and LED replacements, their references regard LCAs comparing other fluorescent technologies with LEDs, results of which are discussed in the review of Ex. 1(a-e) in Section 5.5.2.2

Regarding other environmental arguments (inter alia: the use of materials and hazardous substances; the health and safety impact of substitutes; aspects related to the waste stream and recycling) please also refer to section 4.5.3 of this report.

10.3.3 Stakeholder Contributions

There were no specific contributions submitted regarding the exemption at hand, for the discussion of general aspects raised by stakeholders, please see Section 4.5.7.

10.3.4 The Scope of the Exemption

Regarding RoHS legislation, problematically, there is in general no official definition for the term ‘special purposes’ at the current time and an overview of which lamps are covered by exemptions 1(f), 2(b)(4), 4(a) and 4(f) is not available. An attempt is made in the exemption request of the applicant to clarify the scope of each of these exemptions, however the consultants are not confident that explanations sufficiently clarify that overlaps do not occur. In some case it is also not clear that lamps explained to fall under these exemptions would not also be covered by other exemptions for general purpose lamps. Though exemptions should be clearly defined to avoid possible overlaps, available information does not allow a clear demarcation of all lamps covered by these exemptions, and establishing the availability of substitutes for various applications is thus also difficult.

The scope of exemption 2(b)(4) is said to include all other fluorescent lamps for general lighting and special purposes, which do not belong to any of the Annex III exemptions of the RoHS Directive. Furthermore it was stated by the applicant that lamps covered by Ex. 2(b)(4) have specific special purposes. The consultants thus conclude from this statement that this exemption does not cover lamps for general lighting purposes, which are already regulated in other exemptions of Annex III.

- In this respect, single capped lamps would be expected to fall under Ex. 1, with lamps used for general lighting falling under Ex. 1(a-e) and lamps used for special purposes falling under Ex. 1(f).
- Double-capped lamps for general purposes would be expected to fall under Ex. 2(a). The wording of Ex. 2(b)(1-3) does not limit their applicability to general purpose lamps and thus halophosphate phosphor lamps (Ex. 2(b)(1-2)) and tri-band phosphor non-linear lamps (Ex. 2(b)(3)) for both general and special purposes would be expected to be covered by these exemptions.
- Thus Ex. 2(b)(4) could only cover double capped fluorescent lamps used for special purposes as well as other than single and double capped fluorescent lamps (e.g. bayonet capped lamps, induction lamps).

10.3.5 Exemption Wording Formulation

LEU[269] does not have a proposal for a wording describing lamps falling under Ex. 2(b)(4). *"LEU is of the opinion that a split would increase complexity of the exemptions and it make already difficult for authorities act appropriately regarding market surveillance. Thus the benefit of yet another category is nearly zero as specialty lamps are by their nature sold in small numbers".*

In the consultants' opinion, the current wording with "general lighting and special purpose" however, leaves areas of uncertainty and overlap with other exemptions as mentioned in Section 10.3.4. Moreover according to the applicant, lamps covered by Ex. 2(b)(4) usually have a specific special purpose. Thus general purpose lamps should be excluded from this exemption altogether.

The consultants further do not believe that a differentiation, based on wattage, form, bases or colour, would allow a clear demarcation of lamps actually covered by this exemption.

Furthermore, in terms of the technical availability of substitutes, argumentation for justifying the exemption can only be followed in support of the lack of substitutes for applications in the non-visible range and in part for lamps used for emergency lighting. The consultants' thus recommend a distinction between visible and non-visible light as well as further provision of the exemption for emergency lamps, where safety regulation does not permit the use of other than discharge lamps. The definition for the initial scope of non-visible light in the draft[270] for the new Ecodesign Regulation for lamps refers to *"mainly visible optical radiation in a wavelength of 380-780 nm".*

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[269] Op. cit. LEU 2(b)(4)- (2015b)

[270] COMMISSION REGULATION (EU) …/ of XXX implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for lighting products

10.3.6 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

LEU provides no estimation as to how much time is needed for a replacement of the existing 2(b)(4)-lamps, explaining that due to the low market segments and the vast variety there is no general roadmap to develop LED alternatives for all lamps covered by this exemption.

In contrast to LEU, the consultants do not believe that LED substitutes need to be available for "the total variety of 2(b)4 lamps", i.e. for each and every type of lamp. In the consultants' view a substitute needs to provide the same function, in this case light with similar quality and in parallel a substitute should not create significant negative environmental or health related impacts, such as significant additional energy consumption or hazardous waste.

It can be followed that Hg-free fluorescent substitutes are not available and that the potential for further Hg reductions has been realised to a certain degree.

LED alternatives are understood to be developing rapidly, however from available information it still seems that LED replacements are limited in their variety and possibly also in their compatibility as retrofit replacements for all applications of Ex. 2(b)(4).

For lamps such as induction lamps, tanning, black light, blue light, medical lamps, lamps for colour comparison, lamps with high colour rendering index, T12 lamps for areas with explosion protection or with external ignition strips, LEU is not aware of existing replacement lamps. Parameters are not provided in most of these cases to clarify on what basis a substitute should be compared to establish comparable performance. Against this background, it is not possible to determine the availability of substitutes in terms of their coverage of other fluorescent lamp functionalities, their dimensions and their electric compatibility. LEU also does not provide information to substantiate why such substitutes are lacking from a technical perspective (i.e. why they could not be produced on the basis of current LED technology). In this sense, and as it is stated that there is no roadmap to develop alternatives for all of the lamps covered by this exemption, it cannot be concluded for most of the application range if the lack of substitutes is due to the limited economic motivation to develop substitutes or due to actual technology limitations.

Against this background, the consultants are of the opinion that there is no justification why the formulation of Ex. 2(b)4 should remain general in nature, creating a "blanket"

exemption that is open to applications covered by other exemptions of Annex III. Broad and unspecific wording formulations do not conform to the requirements of the recast Directive (RoHS 2), which requires limiting exemptions in their scope (see Recital 19). In contrast to LEU, the consultants do not believe that the current exemption wording covers only “other fluorescent lamps” which are understood to be Ex. 2(b)4 special purpose lamps. It is concluded that Ex. 2(b)(4) could only cover double capped fluorescent lamps used for special purposes as well as other than single and double capped fluorescent lamps. In this respect, technical justification as to the lack of substitutes can only be followed for UV lamps and in part for lamps used in emergency lighting.

In relation to the exemption mercury allowance, examples of lamps falling under this exemption show that in some cases the limit is needed but that in other cases a far lower threshold could be applied. Nonetheless, the consultants do not believe that leaving the threshold at its current level would motivate the development of new lamps taking advantage of the allowance and propose not to change the threshold.

10.4 Recommendation

In light of the lacking data related to replacement lamp availability, the consultants would recommend a short term renewal for most applications. This period should allow industry to compile data so as to clarify if indeed a substitution problem exists that could create substantial waste resulting from early EoL of luminaires, as well as allowing a demarcation of lamps actually requiring the availability of this exemption. The consultants would further recommend cancelling the exemption, should industry fail to provide substantiated information in this respect in the future. For this purpose the consultant proposes a 3 year exemption. This short period is recommended as it can be understood that stakeholders must only compile information as to current applicatons, which should thus be available. The consultants can follow that other applications may exist relevant for the scope of this exemption, however information has not been provided to clarify why such applications would indeed be covered by Ex. 2(b(4), nor to justify the renewal of the exemption on the basis of Article 5(1)(a) for such cases.

The only exceptions to this rule are the cases of emergency lighting lamps, for which replacement lamps are specified in safety regulation and standards, and UV lamps for which technical information is available to support why LED alternatives currently do not provide comparable performance. An exemption of the maximum permissible 5 year duration is recommended for such lamps.

In light of Article 5(2), from a legal perspective, excluding EEE falling under Cat. 8 and 9 from the scope of this exemption may not be possible.

Exemption 2(b)4	Duration*
(I) Lamps for other general lighting and special purposes (e.g. induction lamps); 15 mg may be used per lamp after 31 December 2011	For Cat. 8 & 9: 21 July 2021 For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024
(II) Lamps emitting light in the non-visible spectrum: 15 mg per lamp	For Cat. 5: 21 July 2021
(III) Emergency lamps: 15 mg per lamp	For Cat. 5: 21 July 2021
(IV) Mercury in other fluorescent special purpose lamps not specifically mentioned in this Annex: 15mg per lamp	For Cat. 5: 21 January 2019

Note: As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories which are newly in scope.

10.5 References Exemption 2(b)4

LEU Ex. 2(b)(4) (2015a) LightingEurope, Request to renew Exemption 2b(4) under Annex III of the RoHS Directive 2011/65/EU Lamps for other general lighting and special purposes (e.g. induction lamps): 15 mg may be used per lamp after 31 December 2011, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_b__3-4_/Lighting_Europe/2b4_LE_RoHS_Exemption__Req_Final.pdf

LEU Ex. 2(b)4 (2015b) LightingEurope, Response to Oeko-Institut regarding the 1st Questionnaire Exemption No. 2(b)4 (renewal requests) Mercury in other fluorescent lamps not exceeding (per lamp): (4) Lamps for other general lighting and special purposes (e.g. induction lamps): 15 mg per lamp”, submitted 25.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_2_b__3-4_/Lighting_Europe/Ex_2b4_LightingEurope_1st_Clarification-Questions_final.pdf

VHK & VITO (2015) VITO in cooperation with VHK, Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements (‘Lot 8/9/19’). Final report, Task 4 – Technologies, Prepared for the European Commission, DG ENER.C.3, available under: http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources%20Task4%20Final%2020151031.pdf

11.0 Exemption 3(a-c): "Mercury in other fluorescent lamps not exceeding (per lamp): (3) Non-linear tri-band phosphor lamps with tube diameter > 15 mm (e.g. T9)”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

Cat. 5	Lighting equipment
Cat. 8	Medical devices
Cat. 9	Monitoring and control instruments
CCFL	Cold cathode fluorescent lamps
EEE	Electrical and Electronic Equipment
EEFL	External electrode fluorescent lamps
EoL	End-of-life
Hg	Mercury
IMCI	Industrial monitoring and control instrument
LED	Light emitting diode
LEU	LightingEurope

11.1 Background

LightingEurope (LEU)[271] has applied for the renewal of Ex 3(a-c) of Annex III of the RoHS Directive. This exemption covers cold cathode fluorescent lamps and external electrode fluorescent lamps (CCFL and EEFL) for special purposes, explained to be a small group of lamps required on the EU market.[272]

LEU[273] explains that lamps falling under exemptions 3(a-c) *"are mostly used for applications for backlighting of liquid crystal displays such as in computer displays and monitors. These lamps are described in the ruling provided on March 13, 2014 in Annex IV to Directive 2011/65/EU under point 35*[274] *. While not all applications are specifically known to us some special lighting applications in equipment, displays and indicator panels, are replaced professionally, as these lamps are usually custom sizes and colours and are not made with typical lamp end caps that fit into standardized lamp sockets. While many new designs have already been changed to LEDs there are products made, although in very limited usage, that have not yet been redesigned. Based on the prior submission by The Test and Measurement Coalition, the subsequent Oeko recommendations and the EU adoption of the Category 35 exemption we respectfully amend the proposal for application in Category 5 and request consideration under Category 9 to allow for the continued limited use in these products where the change in technology has not yet been adopted*."

LEU applies for the renewal of the exemption, requesting the current wording formulation as listed in Annex III of the RoHS Directive and the maximum available duration allowed (based on Art. 5(2) of the Directive):

[271] LEU Ex. 3(a-c)(2015a), LightingEurope, Request to renew Exemption 3(a-c) Under Annex III of the RoHS Directive 2011/65/EU Mercury in cold cathode fluorescent lamps and external fluorescent lamps (CCFL and EEFL) for special purposes not exceeding per lamp: 3(a) Short length ≤ 500mm 3.5mg/lamp; 3(b) Medium length (> 500mm and ≤1500mm) 5mg/lamp; 3(c) Long length (> 1500mm) 13mg/lamp, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_3__a-c_/3a_3b_3c_LE_RoHS_Exemption_Req__Final.pdf

[272] Op. cit. LEU Ex. 3(a-c)(2015a)

[273] LEU Ex. 3(a-c)(2015b), LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 3, submitted 21.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_3__a-c_/LE_Ex_3_abc__1st_Clarification-Questions_final.pdf

[274] Referenced in LEU Ex. 3(a-c)(2015b), as http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32014L0075

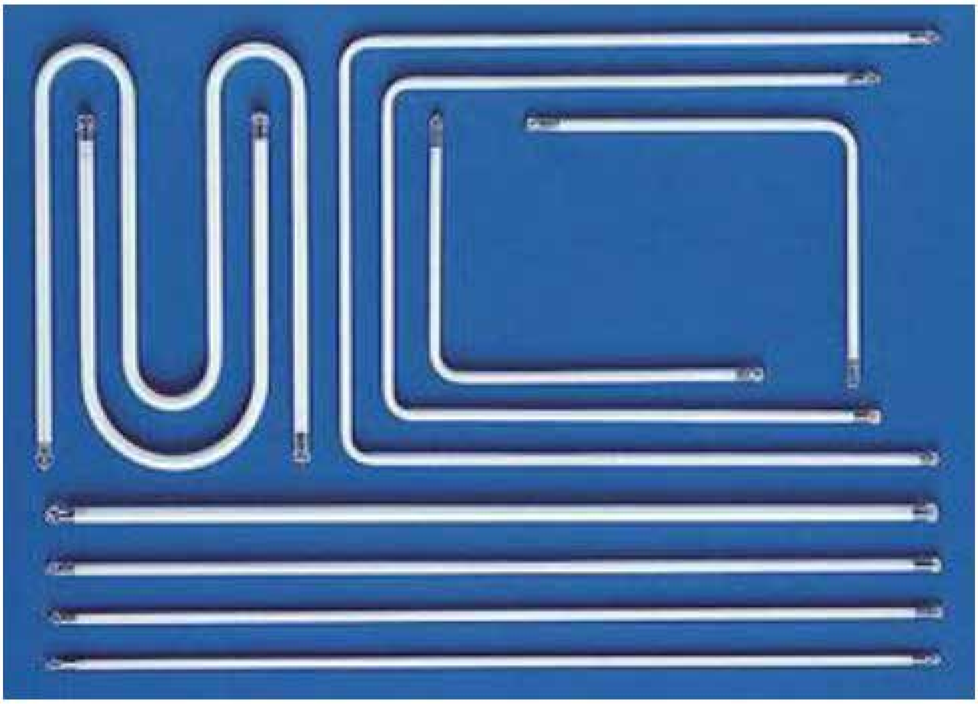
	Exemption	Scope and dates of applicability
3	Mercury in cold cathode fluorescent lamps and external electrode fluorescent lamps (CCFL and EEFL) for special purposes not exceeding (per lamp):	
3(a)	Short length (≤ 500 mm)	No limitation of use until 31 December 2011; 3,5 mg may be used per lamp after 31 December 2011
3(b)	Medium length (> 500 mm and ≤ 1 500 mm)	No limitation of use until 31 December 2011; 5 mg may be used per lamp after 31 December 2011
3(c)	Long length (> 1 500 mm)	No limitation of use until 31 December 2011; 13 mg may be used per lamp after 31 December 2011

11.2 Description of Requested Exemption

LEU[275] explains that there is a continued use of CCFL, otherwise known as sub-miniature cold cathode fluorescent lamps, for illuminating the backlight of a liquid crystal display, or in other equipment for such use as medical, inspection and professional equipment, backlit display, laptop computer displays and computer monitors. These lamps tend to have an extremely long effective life under normal use with typical rated life times at 25,000 hours or more. The lamps are not fitted with an industry standard end cap or termination and are typically hard wired into the appliance or connected via snap in terminals. These lamps are not typically used in general lighting applications and are not intended to be replaced by the user. Replacements are typically made by the equipment manufacturer or repair facility and the spent lamps would be required to be recycled. Examples of lamps covered by this exemption are shown in Figure 11-1.

[275] Op. cit. LEU Ex. 3(a-c)(2015a)

Figure 11-1; Examples of lamps covered by Ex. 3(a-c)



Source: LEU Ex. 3(a-c)(2015a)

LEU[276] elaborates that fluorescent lamps are low-pressure discharge lamps containing a phosphor coating. They contain a small amount of intentionally added mercury in the discharge tube, which is essential to convert electrical energy to light. Lamps in the scope of exemption 3(a)(b)(c) are in a variety of lamp families with mercury content from 3.5 mg up to 13 mg. They are mainly niche products with extremely low market size compared to the other fluorescent lamps.

LEU[277] details a few definitions appearing in other regulations for the term special purposes and proposes the following definition:

> "*Special purpose lamps have documented and communicated application-specific features. They [are] generally manufactured in accordance with general-purpose lamp making technology. The use of special design, materials and process steps provide their special features*."

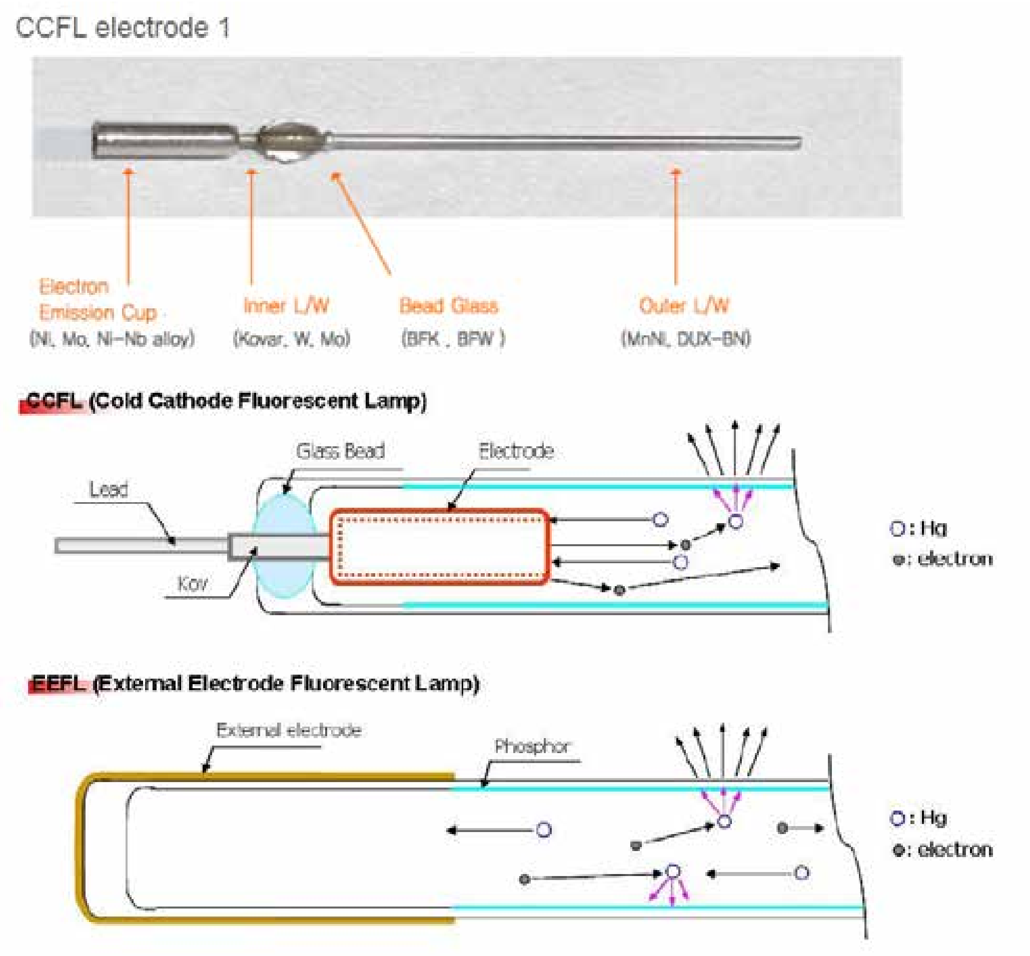
LEU[278] specifies various examples of lamps considered to be special purpose lamps (see application cited above as LEU Ex. 3(a-c)(2015a)) and contends that Ex. 3(a-c) includes an inhomogeneous group of lamps falling under most of the mentioned examples. CCFL and

[276] Op. cit. LEU Ex. 3(a-c)(2015a)
[277] Op. cit. LEU Ex. 3(a-c)(2015a)
[278] Op. cit. LEU Ex. 3(a-c)(2015a)

EEFL fluorescent lamps are always components of a lighting system. They reveal amongst others different:

- Form factors and bases, e.g. linear, circular, square shape;
- Technologies e.g. induction, external ignition;
- Phosphor types;
- Mercury content, from < 2 mg up to a maximum of 13 mg.

Figure 11-2: Technical schematic of CCFL and EEFL Lamps



Source: LEU Ex. 3(a-c)(2015a)

11.2.1 Amount of Mercury Used under the Exemption

Lamps covered by exemption 3(a)(b)(c) are a very small segment of all fluorescent lamps. Although this data is not formally collected, the total mercury content of lamps in this class are estimated at less than 1% of the total [not specified as total of what – consultants comment]. LEU provides representative data from 2009 to 2013 as to the number of produced lamps and the corresponding mercury amount put on the EU (plus Switzerland, plus Norway) market of all lamps falling in the current exemptions 1(e), 2(b)(2), 2(b3), 2(b4), 3(a)(b)(c) and 4(a) of Annex III, RoHS Directive (all non-linear lamps and all lamps for special purposes). The data shows a decreasing market from 2011 to

2012. In 2013 ca 17.3 million non-linear and special purpose lamps have been marketed. The overall roughly estimated yearly mercury input decreased from 2009 to 2013 from ca 437 kg to 174 kg. Based on this estimate the total mercury content placed on the market through Ex. 3(a-) in 2013 was less than 2kg. [279]

11.3 Applicant's Justification for Exemption

LEU states that while many new designs have already been changed to LEDs that these lamps do not lend themselves to retrofit. This is explained to be since neither form, fit nor function are adequate and the entire electrical/electronic control gear is different for a cold cathode fluorescent lamp. Any substitute of the cold cathode fluorescent lamp with an LED would require multiple changes to the equipment to enable proper function as explained below. Replacements and repairs using LEDs therefore would not be practical.[280]

11.3.1 Possible Alternatives for Substituting RoHS Substances

LightingEurope explains that during the last decades several approaches have been made to design low pressure discharge lamps where the light producing element Hg is replaced by a less hazardous material. So far no approach yielded a result with comparable luminous efficacy, product cost and product availability as the (still state of the art) Hg low pressure discharge lamps. However, it is said that with the arrival of equally efficient LED light sources, research into alternative discharge technologies has stopped at most companies and universities. Further details of such research efforts can be viewed in LEU's applications. [281]

Information is also provided as to the accomplishments in terms of Hg reduction. In lamps falling under Ex. 3(a-c) special phosphors and additives cause higher mercury consumption. Furthermore, non-linear fluorescent lamps (such as those falling under this exemption) always need more mercury compared to linear lamps. For such lamps it was necessary to implement a reduction to a range of 3.5 – 13 mg coming in force in 2012. Only a part of the lamps had to be changed. Most of them already had significantly lower mercury content as similar reduction measures, applied in other fluorescent lamp types used for general lighting, could be realized in such lamps as well. Dosage possibilities for the CCFL are lower than those of other specialty fluorescent lamps indicated for example in 2(b)(4). Further reduction of mercury might technically be possible with high economic effort and R&D resources. But these financial and human resources are needed for the investments and the running transfer to LED technology. The major part of development resources of lighting companies have already been allocated to LED based alternatives. On the other hand the lamps are required for the existing base of

[279] Op. cit. LEU Ex. 3(a-c)(2015a)
[280] Op. cit. LEU Ex. 3(a-c)(2015b)
[281] Op. cit. LEU Ex. 3(a-c)(2015a)

fixtures systems and luminaires, which are also highly efficient and have a long life time.[282]

11.3.2 Possible Alternatives for Eliminating RoHS Substances

LEU explains that there are two key ways to use LED technology in order to substitute fluorescent lamps can be distinguished: (1) replacement lamps, (2) new installations.[283] LEU[284] explains that, while many new designs of displays and control panels have already been redesigned to function with LEDs, there are products, although in very limited usage, that have not yet been redesigned.[285] Currently LEU has no reliable market data about LED retrofit/conversion lamps, which could be used as substitutes for lamps falling under Ex. 3(a-c). Many existing and new lamp manufacturers are working on new products. Standards are in preparation in order to address above mentioned technical challenges. [286]

LEU[287] explains that there is a growing market for mercury-free lamps based on LED technology with features such as energy efficiency and design flexibility as an array of LEDs on a printed circuit board. However, based on numerous performance criteria LED tubes, strips, strings or arrays are not fully equivalent to fluorescent lamps; hence cannot generally replace them in their broad usage base. It must be decided case by case, if the LED based solution can be an effective replacement for the existing device and situation. It mostly requires involvement of people with professional expertise due to the following issues (aspects raised have been mentioned in relation to other exemptions, see for example report for Ex. 2(b)(3) and are thus only summarised below):

- Electrical compatibility;
- Applicable legal and compliance requirements like conformity assessments, declaration, and labelling of the changed luminaire are needed;
- Different light distribution;
- Restricted choice in the LED based lamps;
- LED lamps contain components using materials such as the RoHS regulated substance lead in applications exempted by Annex III of the Directive.

LEDs do not lend themselves to retrofit since neither form, fit nor function, is adequate and the entire electrical/electronic control gear is different for a cold cathode fluorescent lamp vs. an LED. Any substitute of the cold cathode fluorescent lamp with an LED would require a complete change of the power supply and control gear. In addition the light dispersion is different in a cold cathode fluorescent lamp than an LED and

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[282] Op. cit. LEU Ex. 3(a-c)(2015a)
[283] Op. cit. LEU Ex. 3(a-c)(2015a)
[284] Op. cit. LEU Ex. 3(a-c)(2015b)
[285] Op. cit. LEU Ex. 3(a-c)(2015b)
[286] Op. cit. LEU Ex. 3(a-c)(2015a)
[287] Op. cit. LEU Ex. 3(a-c)(2015a)

would require a change in the light guides[288] to provide even light distribution. Replacements and repairs using LEDs therefore would not be practical. [289]

Linear LED luminaires are providing a viable alternative to the traditional fluorescent tube with such features as: efficacy, energy efficiency, and design flexibility and appearance. But the quality and performance of LED products varies among manufacturers. Many conformity and performance related issues have been solved. Dedicated designed luminaires directly comply as a system with all safety and standardization legislations which are tested and confirmed by the luminaire manufacturer. New installations might be especially relevant for exemption 3(a-c) as LED luminaires can offer many different optical and performance characteristics. Especially the new functionalities of LED solutions (colour changing, flexible form factors, tailor made sizes etc.) could lead to new lighting options and extension of the use of these products. [290]
LEU summarises that there is a fast increase in the use of LED based technologies. On the other hand LED retrofit or conversion lamps replacing lamps covered by Ex. 3(a-c) are nearly not available on the EU market.

11.3.3 Environmental Arguments

There are several external LCA's performed regarding lighting. There is general agreement, that the main environmental impact is created during the use phase, meaning through electricity consumption of the lamp. This means that currently the efficacy of the lamp is the determining parameter in regard to the total environmental performance. On the other hand, LEU states that for lamps covered by the exemption 3(a-c) the specific purpose is essential. It only makes sense to perform an LCA comparing it with a lead- and mercury-free lamp if the specific characteristics and requirements to the fluorescent lamp are met. LEU is not aware of such LCAs. [291]

11.3.4 Roadmap to Substitution

In new equipment, integrated LED solutions are rapidly entering the market. In existing equipment, however, replacing CCFLs/EEFLs with LED lamps is still problematic, as retrofit LED lamps are not available for the whole range of products. Since the equipment is diverse and not manufactured by the lighting companies, LEU cannot provide an accurate time line as to when such equipment shall be replaced (eliminating the need for replacement lamps). Stopping replacement (i.e., with CCFLs/EEFLs) would

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[288] According to AVAGO Technologies (2006), Light Guide Techniques - Using LED Lamps, Application Brief I-003, available under http://www.avagotech.com/docs/5988-7057EN: „A light guide is a device designed to transport light from a light source to a point at some distance with minimal loss. Light is transmitted through a light guide by means of total internal reflection."
[289] Op. cit. LEU Ex. 3(a-c)(2015b)
[290] Op. cit. LEU Ex. 3(a-c)(2015a)
[291] Op. cit. LEU Ex. 3(a-c)(2015a)

render otherwise well-functioning equipment useless, and would lead to unnecessary waste. [292]

11.4 Stakeholder Contributions

A number of contributions have been made by stakeholders raising general points in relation to discharge lamps. As none of these raise aspects specifically of relevance for this exemption, the information is not reproduced here, but can be viewed in Section 4.4 of the general lamp chapter.

11.5 Critical Review

11.5.1 Scientific and Technical Practicability of Substitution

From the information provided by LEU it can be understood that CCFLs and EEFLs are used as lights sources of various EEE equipment, for example in the lighting of displays, control panels etc. In many cases, such equipment has been redesigned and new models placed on the market at present use LED light sources. From the information provided, it is assumed that this is the case for most new EEE placed on the market, though there could be a very small amount of products that are yet to be redesigned.

In this respect, it can be followed that LEU requests the renewal of the exemption to allow further use of CCFLs and EEFLs for repair of equipment already on the EU market. It could be considered that parts needed for repair of equipment would benefit from the Article 4(f) provision, which allows the use of RoHS restricted substances in cables or spare parts for repair of EEE, which benefited from an exemption and which was placed on the market before that exemption expired, as far as the specific exemption is concerned. Assuming a lamp used in a display unit could be defined as a spare part, this article may apply. This aspect was dicussed in the evaluation of a request for exemption submitted by the Test and Measurement Coalition in 2011 as detailed below:

> *"The possibility of using non-compliant spare parts and components can be summarized as follows:*
>
> *Article 4(4)(e) provides an exclusion from the RoHS stipulations for cables and spare parts needed for repair, reuse, updating and upgrading of sub-category 9 industrial products placed on the market before July 2017. If the displays (containing the non-compliant CCFLs) can be considered to be spare parts, this exclusion would apply. However, it is unclear if components can be understood to be spare parts.*
>
> *Article 3(27) defines spare parts as:*
>
> > *'a separate part of an EEE that can replace a part of an EEE. The EEE cannot function as intended without that part of the EEE. The functionality of EEE is restored or is upgraded when the part is replaced by a spare part;'*

[292] Op. cit. LEU Ex. 3(a-c)(2015b)

Components are not specifically defined in the Directive, though they are mentioned in the stipulations made concerning cases in which exemptions may be justified, in the context of obtaining an exemption for "materials and components of EEE".

The EU Commission RoHS FAQ Document[293] provides some further insight as to the definition and use of components. Components, can 'be separated and used as fully functional separate products'. The relation between spare parts and components remains unclear, though the FAQ document also details when components need to be RoHS compliant and when not:

> *'Since equipment consists of different components, the EEE itself can only meet the substance requirements if all its components and parts meet the substance restriction requirements of RoHS 2... Therefore components being used in finished EEE or for repair or upgrade of used EEE, which is in the scope of RoHS 2 must meet the substance restrictions according to Art. 4 but do not need CE marking.'*

However, the document also makes a distinction to this avail, between the use of non-compliant components in products already in the scope of RoHS and between products that are excluded from scope – whether per directive exclusion or per exemption:

> *'Components... if produced to be used in a product benefiting from an exclusion do not have to be CE marked and do not have to comply with the substance requirements.'*

This clarifies, that if the 5mg mercury CCFL based displays are to be seen as components, they could be used in products benefiting from an exclusion, i.e., in sub-cat. 9 industrial products placed on the market before 22.7.2017. It is however unclear, if non-compliant components are further excluded for repair, reuse etc. in such products after this category comes into scope. To summarize:"

- *if the displays and the lamps fall under the definition of spare parts, their use benefits from a further exclusion, so that the exemption would not be needed;*
- *if they fall under the definition of components, it must be clarified:*
    - *whether components fall under the definition of spare parts, in which case an exemption is again not needed; or*
    - *if components are not covered by this exclusion, as it is unclear if non-compliant components can further be used for the repair of products placed on the market during the exclusion period, an exemption may be needed. This would require the fulfilment of one of the Article 5(1)(a) criteria for justifying an exemption."*

[293] Referenced as: EU COM, 2012, ROHS 2 FAQ Guidance Document, updated 12.12.2012, Q7.1 & Q 7.3; available under http://ec.europa.eu/environment//waste/rohs_eee/pdf/faq.pdf, accessed 16.5.2013

As the exemption recommended for the TMC evaluation was granted, it is understood that the EC concluded that a lamp (or at least a lamp used as part of a display) was not to be understood to fall under the scope of the term spare part.

It should further be noted that should an exemption not be granted, with the understanding that the application would be covered as a spare part benefiting from Article 4(f), that this could raise a general question as to when a lamp installed in an EEE is to be understood as a spare part.

In equipment already on the market using CCFLs or EEFLs in displays, there is little knowledge of the availability of LED replacements and it is explained that such replacements shall have difficulty in providing comparability with Ex. 3(a-c) lamps. Reasons for this include, among others, the large variety of CCFL/EEFL dimensions and forms, difficulties in electric compatibility, and differences in light distribution. LEU was thus asked if the exemption could be limited to use in EEE placed on the market in the past and if specific product sub-groups could be specified in which such lamps are still needed for new products to be placed on the market in the coming 5 years. LEU stated in response "Yes we agree that we can limit the use of these lamps as stipulated in Exemption request 20a of 2012 Consultation 4".

The request mentioned was submitted by the Test and Measurement Coalition in 2011. TMC explained that the mercury allowance of Ex. 3(a) would be limited to 3.5 mg after 31.12.2011, whereas for industrial monitoring and control instruments (IMCI) still not in the scope of RoHS at the time of this change, in some equipment, lamps with 5mg would still be needed. It was established that the exemption was only needed for IMCI to be placed on the market before 21.7.2017, as lamps in such equipment used up to 5mg. An exemption was thus recommended, limiting its scope to equipment placed on the market before this date. The recommendation was followed and Ex. 35 was thus added to Annex IV and reads as follows:

> "*Mercury in cold cathode fluorescent lamps for back-lighting liquid crystal displays, not exceeding 5 mg per lamp, used in industrial monitoring and control instruments placed on the market before 22 July 2017*"

The consultants thus conclude that if exemption 3(a-c) should be renewed, that it could be limited in a similar manner, as shall be discussed in Section 11.5.4 below.

11.5.2 Environmental Arguments

There are currently no LCA-studies available in relation to the application of CCFL and EEFL in the context of the exemption at hand. Taking into account the above mentioned situation that the scope of the exemption could be limited to EEE placed on the market in the past, the same environmental arguments, which were relevant with respect to Ex. 35 of Annex IV could be taken into account:

> "*If such replacement is not allowed, once a malfunction occurs in a relevant device, in cases where display substitutes are not drop-in, devices will not be repairable and thus shall have to be scrapped….Furthermore, the premature disposal of devices is perceived as negative from an environmental standpoint.*

Though a comprehensive comparison has not been made, the consultants can follow that favouring the replacement of displays with non-compliant units with up to 5 mg mercury per CCFL, over replacement of the whole device, would be in-line with the RoHS Directive intentions. In particular when referring to Item 20 of the RoHS 2 legal text, which states that '...product reuse, refurbishment and extension of lifetime are beneficial.'[294]... In this sense, not recommending an exemption would promote the early disposal of such devices before they have reached their full service potential, contributing to the production of more waste."

11.5.3 Stakeholder Contributions

There were no specific contributions submitted regarding the exemption at hand, for the discussion of general aspects raised by stakeholders, please see Section 4.5.7 of the general chapter.

11.5.4 Scope

As explained above, it can be understood that the scope of the requested exemption could be limited to use in EEE placed on the market before a certain date. It is understood that this was the situation already in October 2015, when LEU approved that this strategy was practical. In parallel, the current exemption is scheduled to expire on 21.7.2016, and it is thus assumed that manufacturers would be expected to consider that beyond this date the exemption could change. As manufacturers could be expected to prepare for a situation in which the exemption was no longer available, it is concluded that a renewal of the exemption could be limited to EEE placed on the market by the date of the EC decision on this exemption renewal.

In parallel, it is understood that there may be equipment for which redesign has not been completed yet, and for which new EEE placed on the market may still require an exemption in order to use CCFLs and EEFls currently addressed by Ex. 3(a-c). Despite being asked, LEU did not specify particular groups of such equipment. However, as their answers were part of the information submitted for this request to stakeholder consultation, manufacturers would have been expected to participate in the stakeholder consultation were this to be relevant for their equipment. The only EEE for which this may not be the case is equipment falling under Cat. 8 (medical devices) and Cat. 9 (monitoring and control instruments), for which the exemption is understood to remain available.

In the consultants view CCFLs and EEFLs are lamps, which as such, are understood to fall under Cat. 5 (lighting equipment). In this sense, the consultants would recommend providing an exemption for Cat. 5 lamps. This is understood not to limit the possibility of installing such lamps as components in equipment of other categories, as long as the

[294] See Directive 2011/65/EU (RoHS 2), item 20.

exemption wording does not limit its applicability to specific types of equipment and/or categories.

A further aspect to be considered in this respect is the current Ex. 35 listed under Annex IV. As explained above, equipment falling under other categories such as IMCI of Sub-Cat. 9 industrial, would still benefit from an exemption for lamps of Cat. 5, as long as such equipment was included in the scope of the exemption. It is thus recommended that the EC consider the possible merits of merging Ex. 35 of Annex IV with Ex. 3. This would require transferring Ex. 35 to Annex III and limiting its applicability to lamps of Cat. 5, used in IMCI of Sub-Cat. 9 industrial.

11.5.5 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

It can be followed that substitutes in the form of LED have become available, and that they are used as lighting sources in new equipment coming on the market. However, it is also understood that it is not feasible to use LED lamps as replacement for the repair of EEE originally designed with CCFL/EEFL light sources. Due to the expected variety of CCFL and EEFL lamps in terms of form, electrical configuration and light distribution, it can be followed that LED replacement lamps for such equipment may be lacking and/or may be non-comparable. Should an exemption be denied under such circumstances, it is possible that in some cases LED replacements would become available. However in others, it can be followed that replacements would either not be sufficiently reliable or that they would not be available. In such cases, the relevant component (display, control panel) and possibly the complete equipment would be scrapped as it would no longer function properly. As CCFLs and EEFLs are understood to have a wide variety, it is assumed that this scenario is relevant for a wide range of EEE placed on the market before 22.7.2016.

11.6 Recommendation

As explained above, it can be understood that LED replacements for CCFLs and EEFLs in EEE of Cat. 1-7 and 10, placed on the market before July 2016 (or before the EC's decision date on this exemptions renewal), are for the most part either lacking or not compatible. It is thus recommended to renew the exemption, while limiting its scope to such equipment. It is further recommended to merge Ex. 35 of Annex IV with this exemption, so that all exemptions for CCFL and EEFL are located under the same entry of one annex. Though it is possible that other equipment of Cat. 8 and Cat. 9 may also be

coming on the market with LED alternatives, Article 5(2) provides other duration periods of the current exemption for these categories. In this respect, in future evaluations, consideration could be given to the further need of the exemptions for these categories.

Exemption 3	Duration*
Mercury in cold cathode fluorescent lamps and external electrode fluorescent lamps (CCFL and EEFL) for special purposes not exceeding (per lamp):	
(a) Short length (≤ 500 mm), 3.5 mg may be used per lamp	For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024
(b) Medium length (> 500 mm and ≤ 1 500 mm), 5 mg may be used per lamp	
(c) Long length (> 1 500 mm) 13 mg may be used per lamp	
(d) Short length (≤ 500 mm), 3.5 mg may be used per lamp in EEE placed on the market before 22 July 2016*	For Cat. 5: 21 July 2021
(e) Medium length (> 500 mm and ≤ 1 500 mm), 5 mg may be used per lamp in EEE placed on the market before 22 July 2016*	
(f) Long length (> 1 500 mm) 13 mg may be used per lamp in EEE placed on the market before 22 July 2016*	
(g) For back-lighting liquid crystal displays, not exceeding 5 mg per lamp, used in industrial monitoring and control instruments placed on the market before 22 July 2017	Alternative a: For Cat. 5: 21 July 2021; or Alternative b: For Sub-Cat. industrial: 21 July 2024

Note: **or before the EC's decision date on this exemptions renewal.*
As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

11.7 References Exemption 3(a-c):

LEU Ex. 3(a-c)(2015a) LightingEurope, Request to renew Exemption 3(a-c) Under Annex III of the RoHS Directive 2011/65/EU Mercury in cold cathode fluorescent lamps and external fluorescent lamps (CCFL and EEFL) for special purposes not exceeding per lamp: 3(a) Short length ≤ 500mm 3.5mg/lamp; 3(b) Medium length (> 500mm and ≤1500mm) 5mg/lamp; 3(c) Long length (> 1500mm) 13mg/lamp, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_3__a-c_/3a_3b_3c_LE_RoHS_Exemption_Req__Final.pdf

LEU Ex. 3(a-c)(2015b) LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 3, submitted 21.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_3__a-c_/LE_Ex_3_abc__1st_Clarification-Questions_final.pdf

12.0 Exemption 4(a)"Mercury in other low pressure discharge lamps (per lamp): (a) 15 mg per lamp"

Declaration

In the sections that precede the "Critical Review" the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

AlGaN	Aluminium gallium nitride
CFL	Compact fluorescent lamp
DNA	Deoxyribonucleic acid
EEE	Electrical and Electronic Equipment
Hg	Mercury
JBCE	Japan Business Council
LCA	Life cycle assessment
LED	Light Emitting Diode
LEU	LightingEurope
NARVA	NARVA Lichtquellen GmbH + Co. KG
UV	Ultraviolet (subtypes UVA, UVB, UVC)
WPE	Wall plug efficiency
W	Watt unit of (electrical) power

12.1 Background

NARVA Lichtquellen GmbH + Co. KG (NARVA)[295] and Lighting Europe (LEU)[296] has submitted requests for the renewal of the above mentioned exemption.

LEU summarizes that Ex. 4a-lamps cover low pressure mercury vapour gas discharge lamps with a maximum Hg content of 15 mg per burner. These lamps are explained not to be included in any of the other categories of lamps in Annex III, neither for general lighting nor specialty lighting. The lamps are not phosphor coated and do not produce visible light nor are they intended for illumination purposes. The larger installations use high power lamps providing higher UVC dosage (germicidal function[297] is a key aspect of the specific spectrum) to produce the required treatment processes, such as destruction of DNA in the microorganisms, ozone generation and/or maintaining advanced oxidation processes[298].

NARVA Lichtquellen GmbH + Co. KG (NARVA) requests the exemption be renewed with the same wording[299]:

> "*Mercury in other low pressure discharge lamps (per lamp: No limitation of use until 31 December 2011; 15 mg may be used per lamp after 31 December 2011*"

Lighting Europe (LEU)[300] requests a modification of the current exemption wording as follows:

> *"Mercury in other low pressure non-phosphor coated discharge lamps not to exceed 15 mg per lamp"*

Both applicants request the maximum duration to be provided for the exemption.

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[295] NARVA (2014a), NARVA Lichtquellen GmbH + Co. KG, Exemption request for using of mercury in fluorescent lamps, submitted 19.12.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/

[296] LEU Ex. 4a(2015a), LightingEurope, Request to renew Exemption 4(a) under the RoHS Directive 2011/65/EU Mercury in other low pressure discharge lamps (per lamp), submitted 15.1.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_a_/Lighting_Europe/4a_LE_RoHS_Exemption_Req__Final.pdf

[297] A germicidal lamp is a special type of lamp which produces ultraviolet light (UVC).

[298] LEU Ex. 4a (2015b): Response to Oeko-Institut regarding the 1st Questionnaire Exemption No. 4a (renewal request); Exemption for "Mercury in other low pressure discharge lamps (per lamp) - 15 mg may be used per lamp after 31 December 2011" Date of submission: September 15, 2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_a_/Lighting_Europe/Ex_4a_LightingEurope_1st_Clarification-Questions_final.pdf

[299] Op. cit NARVA (2014a)

[300] LEU Ex. 4a(2015a), LightingEurope, Request to renew Exemption 4(a) under the RoHS Directive 2011/65/EU Mercury in other low pressure discharge lamps (per lamp), submitted 15.1.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_a_/Lighting_Europe/4a_LE_RoHS_Exemption_Req__Final.pdf

12.2 Description of Requested Exemption

According to LEU[301], such lamps are produced with similar manufacturing techniques as fluorescent lamps, but are used in highly specific applications to produce light in the ultra-violet C (UVC) region. *"The lamps are not phosphor coated and do not produce visible light nor are they intended for illumination purposes. Unlike general visible lighting lamps or specialty lighting lamps, which may be produced with soda-lime glass, which intentionally blocks UVC transmission, these lamp types will allow the transmission of light in the deep UVC region of 185-254nm. The practical uses of these lamps are for ultraviolet germicidal or bacterial disinfection of: fluids such as drinking water; waste water; water for food, beverage, pharmaceutical preparation; aquaculture; fish farming; semiconductor manufacturing; surface disinfection; air disinfection. The lamps are installed in equipment for industrial, commercial and residential applications and the use of these is growing as they have been accepted by Environmental Agencies worldwide to kill many forms of bacteria including, but not limited to giardia and cryptosporidia[302]. These low pressure gas discharge lamp types can be T5, T6, T8, T10 and T12, which are industry standards, but can also include other tubular lamp types outside dimensions or compact Hg discharge lamp shapes like single ended bended or bridged 2, 4, or 6 legged lamps. Due to their highly specialized use, the lamps may be double ended with standard lighting end caps or may be single ended with standard or custom end cap configurations. Lamps may also be made in custom sizes and lengths and power levels. Power ranges for these lamp types can vary from 1W/5W to 1000W and are typically dimmed in operation. The operating environment of these lamps varies greatly. The operating temperature range can potentially be 0˚C to 100˚C. They may be operated directly in air, in a sleeve in air, or in a sleeve in water. Thermal control may become a necessity for these lamp types especially in higher powered lamp types."*

Both LEU and NARVA[303] confirm that Ex. 4a-lamps transmit in the 185-254nm range of the UVC spectrum.

NARVA does not provide additional details in its application regarding the lamps covered under Ex. 4a.

LEU explains that the current Ex. 4(a) formulation leaves room for interpretation as to which lamp types are included in its scope. Their application details what low pressure lamps are understood to fall under the scope of other Annex III exemptions, and on this basis LEU concludes that lamps falling under the scope of Ex. 4a are low pressure gas discharge lamps which emit UVC radiation and which are characterized by not having a

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[301] Op. cit. LEU Ex. 4a(2015a)

[302] So-called "Cryptosporidium"

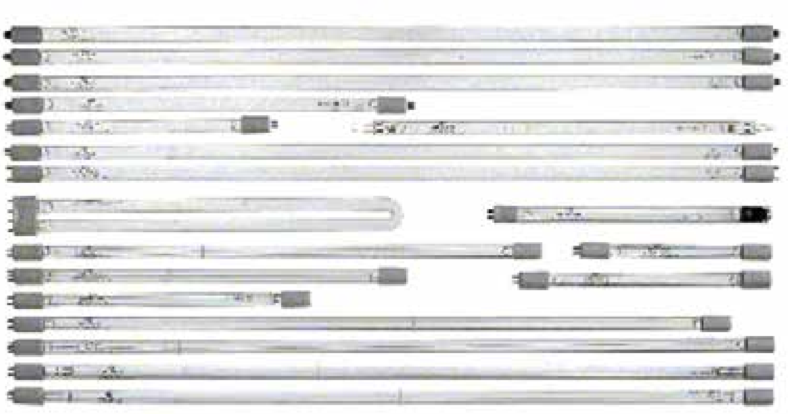
[303] NARVA (2015): NARVA Lichtquellen GmbH + Co. KG, Additional information provided after first questions for clarification Date of submission: August 24, 2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_a_/NARVA/Ex._4_a__Narva_Answers_2_Clarification_Questions_24.8.2015.JPG

phosphor coating. LEU proposes an amendment of the exemption formulation to reflect its applicability for such lamps as specified in Section 12.1.

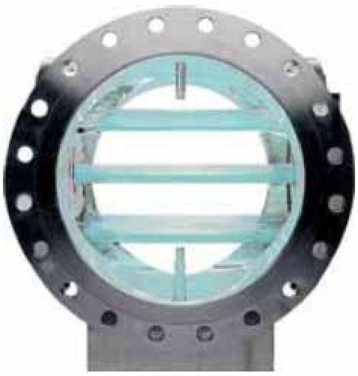
In the following table a non-exhaustive selection of lamps falling under Ex. 4(a) is listed.

LEU[304] explains the function process of mercury for these lamps in Table 12-1. In this process, a small amount of mercury is intentionally dosed as it is essential for the low-pressure gas discharge. When electric current flows through the lamp (=discharge tube), the mercury atoms inside are excited and produce UV radiation with a high efficiency. This UV light then passes through the tube and enters the application. This principle of the low pressure gas discharge lamp is the same for all fluorescent lamps (exemption entries 1 and 2).

Table 12-1: Non-exhaustive list of lamps falling in exemption 4(a)

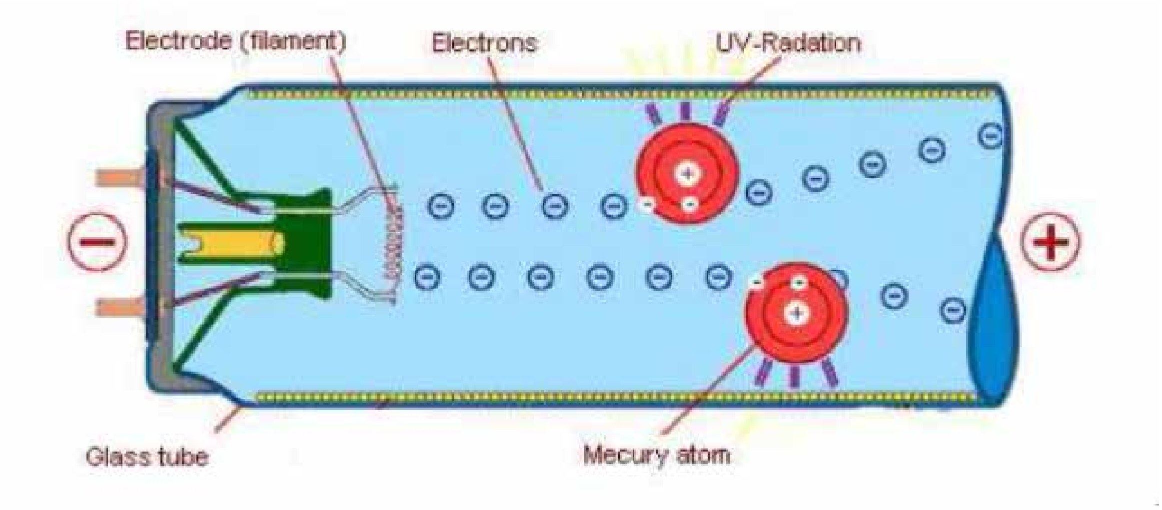
Lamps and applications	Example
Lamps types	
Ultraviolet lamps	
CFL UVC lamps	 

[304] Op. cit. LEU Ex. 4a (2015a)

Lamps and applications	Example	
Quartz Ultraviolet amalgam lamp		
Application Types		
Air disinfection unit	Water disinfection unit	Open channel water disinfection
		
Home water purifier	Waste water disinfection unit photo courtesy of Trojan Technologies	Municipal drinking water UV unit
		

Source: taken from LEU Ex. 4a(2015a)

Figure 12-1: Function of mercury in lamps



Source: taken from LEU Ex. 4(a) (2015a)

12.2.1 Amount of Mercury Used under the Exemption

LEU explains that lamps in the scope of exemption 4(a) have mercury content from < 4 mg and up to 15 mg. According to LEU it is not possible to give specific figures on market size and mercury amount for lamps falling under this exemption as there is no specific data for lamps of this exemption. To allow some insight, LEU provides data for lamps placed on the market falling under the exemptions 1(e), 2(b)(2), 2(b3), 2(b)(4) and 4(a), specifying sales of 19 million lamps for such lamps in 2013. [305] However, it is not clear how many of 19 million lamps would be distributed within Ex. 4(a) as many suppliers are based outside the EU[306].

In this respect it should be noted that according to information submitted by LEU, numbers and mercury amounts related to Ex. 1(f) can be estimated: Based on experience of LEU, single ended CFLs for special purpose lamps covered by Ex.1(f) count for 0,1% of the total CFL market share in Europe, which means approximately 400.000 special purpose lamps and a maximum of 2 kg of mercury entering the EU. [307]

Furthermore, the renewal of Ex. 2(b)(2) was not requested and it is thus expected to expire on the 13 April 2016. The consultants thus expect that in the 2013 data presented

[305] Op. cit. LEU Ex. 4a (2015a)
[306] Op. cit. LEU Ex. 4a (2015b)
[307] LEU Ex. 1f (2015a), LightingEurope, Request to renew Exemption 1(f) under Annex III of the RoHS Directive 2011/65/EU Mercury in single capped (compact) fluorescent lamps not exceeding (per burner) for Special purposes: 5 mg, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_f/Lighting_Europe/1f_LE_RoHS_Exemption_Req_Final.pdf

above related to the number of lamps placed on the market, that the volume of Ex. 2(b)(2) lamps would be negligible.

It can thus be assumed that in 2013 around 18.6 million lamps were placed on the EU market for Exemptions 2(b3), 2(b)(4) and 4(a). concluding as to how this volume is allocated between the three exemptions is not possible.

LEU claims[308] that this category of lamps is becoming more and more important (i.e. market segment is in growth) due to the importance of stopping the spread of diseases or germs and bacteria

12.3 Applicant's Justification for Exemption

LEU claims[309] that at present *"there is no available LED that can produce light in the 185-254nm range of the UVC spectrum or other lighting technology that may use less mercury, or can be used as a substitute for these lamps. There are UVC producing LEDs which are in the early stages of development and use, at the higher wavelengths of the UVC spectrum i.e. 365-405nm, however these would not perform the same germicidal function as the lamps covered under this request. It is estimated by the LED manufacturers that deep UVC LEDs will not be available for five to ten years due to the high power and long life requirements that are available with low pressure gas discharge lamps."*

12.3.1 Possible Alternatives for Substituting RoHS Substances

LEU details some of the efforts in seeking an alternative for mercury in the discharge lamps, concluding that substitutes for Hg in the discharge technology are not available. Details can be found in the application documents as well as in part in Section 4.5.2 of this report.

Regarding the reduction of the mercury content LEU provides further indication of aspects that may influence the availability of Hg for the various discharge processes over the lifetime or over different operation conditions. Such lamps are understood to be produced with similar manufacturing techniques as fluorescent lamps, but to be used with more mercury in highly specific applications where UVC light with a specific spectrum is needed. According to LEU following the last evaluation an exemption was granted requiring a reduction of the maximum limit for Hg to 15 mg for Ex. 4(a) lamps. This is explained to have required a great effort, as lamps are for niche applications and are produced by smaller and special manufacturers. It is possible that in some cases further technical reductions are possible, however only with high economic effort and research and development resources. Such resources have been directed towards the further development of LED technologies. Thus according to the applicant for lamps falling under Ex. 4(a) the maximum limit of 15 mg cannot be reduced further.

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[308] Op. cit. LEU Ex. 4a (2015a)
[309] Op. cit. LEU Ex. 4a (2015a)

12.3.2 Possible Alternatives for Eliminating RoHS Substances

LED based light sources are not a viable alternative, as the correct light spectrum is currently not reproduced in lamps available on the market. There are differences in wall plug efficiency (WPE), effectiveness, regulation / approbation and in the compatibility with the variety of ballasts used in relevant equipment.

Where it is possible to produce LEDs with non-visible UV light spectra (through AlGaN-LED) the efficiency is still very low. In the UVC (100-280nm) and UVB (280-315nm), the WPE of LEDs is below 1%, whereas the WPE of low pressure gas discharge UVC lamps is 30-40% or even higher. The rated life-time of Hg-lamps is also explained to be higher than that of UVC LED[310].

To illustrate this, LEU provides a performance comparison between UVC LEDs and conventional UVC lamps (see Table 12-2). The following comparison in the table below displays two examples:

- Residential water purification;
- Municipal / industrial water purification.

Table 12-2 Comparison of discharge lamps UVC with LED UVC lamps

	Residential purification		Municipal purification	
	Residential Hg UVC lamp	UVC LED	municipal Hg UVC amalgam lamp	UVC LED
input power (W)	9	0.1	325	0.1
output power (UVC W)	2.2	0.002	115	0.002
efficiency	24%	2%	35%	2%
price (Euro)	5.00	10.00	100.00	10.00
lifetime (h)	9000	3000	9000	3000
total number of units **[**for the compared application – consultants comment**]**	1	3300	1	172500
total price (Euro)	5.00	33.000	100.00	1725000
total input power (W)	9	110	325	5750

Source: taken from LEU Ex. 4(a) (2015b)

[310] However, the available power range of UVC LEDs as indicated below does not lend itself to today's typical applications for UVC lamps (Op cit LEU Ex. 4a(2015b)). Moreover no test results are available yet to allow evaluating the effectiveness of new technologies to reach the desired effect from studies (Op cit. LEU Ex. 4a(2015a)).

12.3.3 Road Map to Substitution

According to the applicant[311] currently the demand for the development of substitutes is low, so development efforts would result in higher costs for the smaller manufactures.

It is estimated by the LED manufacturers that deep UVC LEDs will not be available for five to ten years. This is the time explained to be needed before LEDs could provide comparable performance in relation to the high power and long life-time requirements of low pressure gas discharge lamps.

12.4 Stakeholder Contributions

A number of contributions of general nature have been made by stakeholders. These are summarised in Section 4.4 of the general chapter.

Two further contributions were submitted specifically related to Ex. 4(a) during the stakeholder consultation and are detailed below:

- Contribution by JBCE – Japan Business Council in Europe in a.i.b.l, submitted 15 October 2015[312]
- Contribution by Baxter Healthcare Corporation, submitted 15 October 2015[313],

JBCE explains that the category 8 & 9 should not be in scope of this exemption evaluation.

Baxter Healthcare requests the renewal of Exemption No. 4a of Annex II with the same wording formulation because of the need of an effective treatment of bacterial proliferation in dialysis water storage and distribution with ultraviolet wavelengths. Moreover Baxter states that no substitution will be available in the next ten years

12.5 Critical Review

12.5.1 Scientific and Technical Practicability of Substitution

LEU attests to the accomplishments in terms of Hg reduction and does not provide a roadmap related to further efforts for improvement of this technology. The consultants can follow that the potential for this strategy has been implemented for the most part

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[311] Op cit LEU Ex. 4a (2015a)

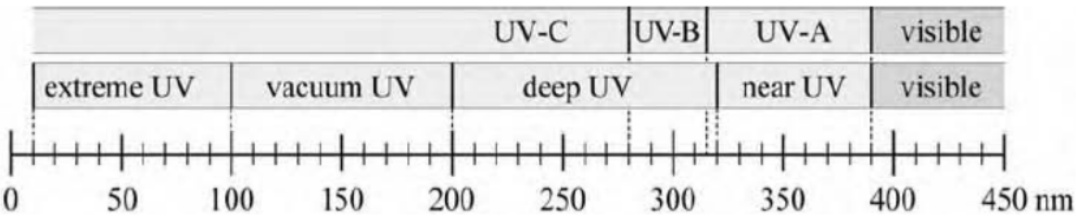
[312] JBCE (2015a): Japan Business Council (JBCE), Comment on public consultation of 4(a): "Mercury in other low pressure discharge lamps (per lamp) in 2015 Consultation submitted 14 October 2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_a_/Comment_on_public_cousulation_of_Exemption_request_2015-2_4_a_.pdf

[313] Baxter Healthcare (2015): Baxter Healthcare Corporation, Request for renewal of Exemption 4(a) "Mercury in other low pressure discharge lamps (per lamp) in 2015 Consultation submitted 15 October 2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_a_/Ex_4a_Baxter_Healthcare_Corporation_151015.pdf

and that further research is focusing on the development of LED alternatives and not on Hg reduction.

In order to discuss the issue of the wavelengths it is useful to illustrate the wavelength (nm) for the UV spectrum.

Figure 12-2 Classification of UV radiation



Source: https://www.fh-muenster.de/fb1/downloads/personal/juestel/juestel/AlGaN_____UV-LEDs_MatthiasMueller_.pdf

According to LEU, Ex. 4(a)-lamps are produced with similar manufacturing techniques as fluorescent lamps and lamps falling under Ex. 2(b)(4), but are used in highly specific applications (disinfection/purification of air/water/surfaces) to produce light in the deep ultra violet C (UVC) region with wavelengths of 185-254nm. There are materials available from which LED can be made that generate UV light (like AlGaN) but these do not produce a radiation in the spectral range required for UVC lamps. The consultants can follow as described in LEU's exemption request that the wall plug efficiency (radiated power out / electrical power in) of UV-LEDs with AlGaN materials is also still very low, and thus that even if they would be comparable in spectral output, their efficiency would still be much lower, resulting in higher energy consumption.

Interestingly the applicant claims that there are UV LEDs in the early development phase for use in the higher wavelengths of the UV spectrum i.e. 365-405nm, which would not perform the same UVC (germicidal) function as the lamps in the range of 185-254nm covered under this request. Based on the latter point the consultants agree with the statement regarding the lack of alternatives for the UVC range of 185-254nm.

12.5.2 Environmental Arguments

Regarding the environmental arguments made by LEU, most of these are not specific for lamps falling under Ex. 4(a) and are discussed in the general chapter (see Section 4.3.3).

The consultants are not aware of comparative LCAs in the public realm of relevance to low pressure discharge lamps and their LED replacements. However it is considered plausible that comparisons of low pressure discharge lamps and possible LED replacements may be more challenging due to the lack of products which are sufficiently comparable (UV wavelengths, wall plug efficiency etc).

As for aspects raised regarding possible reduced wall plug efficiency of current candidate alternatives, these are discussed above.

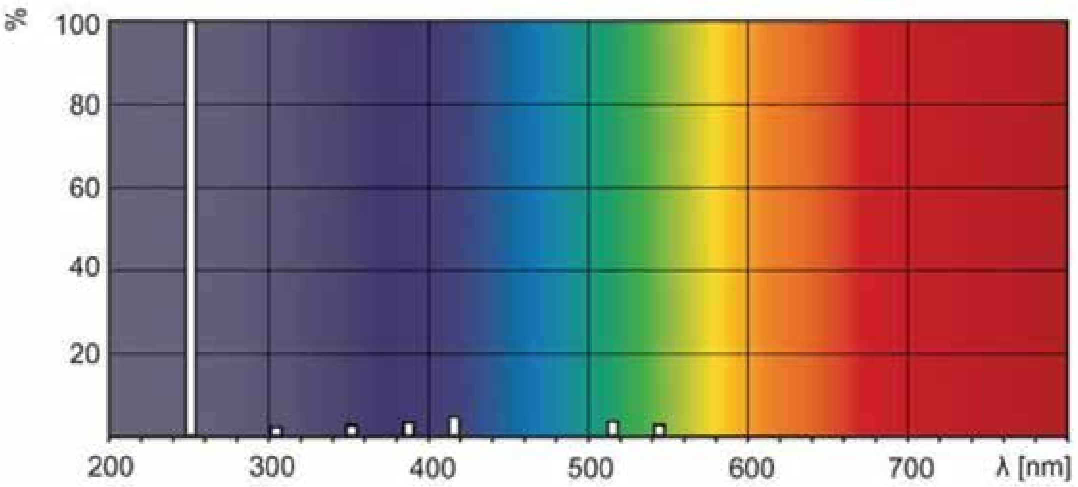
12.5.3 The Scope of the Exemption

LEU proposes an amendment of the current wording to limit the scope of the exemption to low pressure discharge lamps that are **not phosphor coated**. The information provided by LEU, however, also clarifies that lamps benefiting from this exemption and respectively placed on the EU market by LEU members can further be defined as lamps that transmit in the **185-254nm range of the UVC spectrum**. The other applicant NARVA also confirms that the lamps of Ex. 4(a) emit in the UV spectrum range of 185-254nm.

From information available regarding Ex. 4a, the consultants can understand that lamps that would fall under the scope of this exemption are low pressure gas discharge lamps which emit **UVC radiation** and are characterized by **not having a phosphor coating**.

LEU was thus asked if the exemption could further be limited to the UVC spectral output range. LEU[314] does not agree with this proposal, as lamps with fluorescent material for special purposes are covered in exemptions 1(f) and 2(b)(4). The interpretation of LEU is that 4a covers low pressure mercury lamps without phosphors. Although the definition of UV-C is the range of wavelength between 200-280 nm, the typical mercury lines at 184.95, 253.65, 296.73 and 365.02 nm etc. (see Figure 12-3, noting that wavelengths here are as specified by LEU, despite differences as would appear from the chart – consultant's comment) may also be transmitted with these lamps so the further limitation of the scope in this manner is not supported.

Figure 12-3: Example spectrum of a low pressure mercury discharge



Source: LEU Ex. 4a (2015b)

The consultants conclude that the function of these lamps is enabled through their radiation in the UVC Spectrum. Though lamps may emit some radiation in other ranges of the spectrum, Figure 12-3 clearly demonstrates that the main output is in the UVC range. In the consultants view, limiting the exemption to lamps emitting mainly in the

314 Op. cit. LEU Ex. 4a(2015b)

UVC spectrum would not restrict their radiating in other parts of the spectrum, and so this further limitation is concluded to be possible.

12.5.4 Exemption Wording Formulation

As mentioned above the consultants agree that the exemption can be limited to low pressure lamps without phosphor coating as suggested by LEU and as supported by NARVA. It is further suggested to limit the scope of the exemption to lamps emitting in the UVC spectral range, as this is understood to be an important spectral aspect of such lamps for their various applications. The following wording formulation is thus proposed:

> "*Mercury in low pressure non-phosphor coated discharge lamps, where the application requires the main range of the lamp-spectral output* ***to be in the UVC spectrum****; up to 15 mg mercury may be used per lamp*."

Though this formulation would require lamps covered by this exemption to emit in the UVC spectral range, the consultants do not understand this formulation to exclude lamps that have marginal radiation in other parts of the spectral range.

It can be understood however, that for lamps to radiate mainly in the UVA or UVB spectrum, that the use of phosphors would be needed. The consultants thus conclude that restricting the scope of the exemption to UV lamps as opposed to UVC lamps would have the same impact in terms of the actual lamps to be placed on the market. Ex. 4(a) lamps are explained to have some radiation beyond the UVC spectral range (see Figure 12-3). In the consultants' opinion, restricting the exemption to the whole UV range and not only to the UVC range would provide industry with more certainty that relevant lamps still fall under the scope of the exemption, while still defining a clearer and more narrow scope.

12.5.5 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

Such lamps are understood to be produced with similar manufacturing techniques as fluorescent lamps, but to be used in highly specific applications where UVC light enables the main function. They are understood to be used for bacterial disinfection of air, water or other liquids, solids, or UV curing of surfaces, print media and the like which use UVC radiation to dry the imprinted surface.

It can be followed that alternatives are currently not available for applications with specific characteristics covered by Ex. 4(a), as the spectral output of available LEDs

radiating in the UV spectrum is only in the UV spectrum with longer wavelength range (365-405nm): Such a spectral output would not provide for the function of lamps covered by this exemption, for which the main spectral output needs to be in the shorter wavelength UVC range of 185-254nm. Furthermore, current LED alternatives do not provide sufficient wall-plug-efficiency and would thus result in higher energy consumption should alternatives be in the relevant spectral output range.

12.6 Recommendation

The consultants recommend amending the exemption as proposed below and granting it only for Cat. 5, as lamps are understood to be components falling under this category, and thus could still be used as components in EEE of other categories.

In light of Article 5(2), from a legal perspective, it may not be possible to exclude EEE falling under Cat. 8 and 9 from the scope of this exemption.

Exemption 4(a)	Duration*	Comments
4(a)-I: Mercury in low pressure non-phosphor coated discharge lamps, where the application requires the main range of the lamp-spectral output to be in the UV spectrum; up to 15 mg mercury may be used per lamp.	*For Cat. 5: 21 July 2021*	The maximum transition period should be granted for other applications and other categories (18 months);
4(a)-II: Mercury in other low pressure discharge lamps (15 mg may be used per lamp)	*For Cat. 8 and Cat. 9: 21 July 2021* *For Sub-Cat. 8 in-vitro: 21 July 2023* *For Sub-Cat. 9 industrial: 21 July 2024*	

Note: As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

12.7 References Exemption 4(a)

Baxter Healthcare (2015) Request for renewal of Exemption 4(a) "Mercury in other low pressure discharge lamps (per lamp) in 2015 Consultation submitted 15 October 2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_a_/Ex_4a_Baxter_Healthcare_Corporation_151015.pdf

JBCE (2015a) JBCE comment on public consultation of 4(a): "Mercury in other low pressure discharge lamps (per lamp) in 2015 Consultation submitted 14 October 2015, available under; http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_a_/Comment_on_public_cousulation_of_Exemption_request_2015-2_4_a_.pdf

LEU Ex. 1f (2015a) LightingEurope, Request to renew Exemption 1(f) under Annex III of the RoHS Directive 2011/65/EU Mercury in single capped (compact) fluorescent lamps not exceeding (per burner) for Special purposes: 5 mg, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_f/Lighting_Europe/1f_LE_RoHS_Exemption_Req_Final.pdf

LEU Ex. 4a (2015a) LEU Ex. 4a(2015a), LightingEurope, Request to renew Exemption 4(a) under the RoHS Directive 2011/65/EU Mercury in other low pressure discharge lamps (per lamp), submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_a_/Lighting_Europe/4a_LE_RoHS_Exemption_Req__Final.pdf

LEU Ex. 4a (2015b) LEU Ex. 4a (2015b): Response to Oeko-Institut regarding the 1st Questionnaire Exemption No. 4a (renewal request); Exemption for “Mercury in other low pressure discharge lamps (per lamp) – 15 mg may be used per lamp after 31 December 2011” Date of submission: September 15, 2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_a_/Lighting_Europe/Ex_4a_LightingEurope_1st_Clarification-Questions_final.pdf

NARVA (2015) NARVA Lichtquellen GmbH + Co. KG, Additional information provided after first questions for clarification Date of submission: August 24, 2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_a_/NARVA/Ex._4_a__Narva_Answers_2_Clarification_Questions_24.8.2015.JPG

NARVA (2014a) NARVA Lichtquellen GmbH + Co. KG, Exemption request for using of mercury in fluorescent lamps, submitted 19.12.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/

13.0 Exemption 4(b)(I-III): " Mercury in High Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner) in lamps with improved colour rendering index Ra > 60”

This review of Annex III exemption 4(b)(I-III) covers the following exemption entries:

I) P ≤ 155 W
II) 155 W < P ≤ 405 W
III) P > 405 W

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

CFL	Compact fluorescent lamp
EEE	Electrical and Electronic Equipment
Hg	Mercury
HID	High intensity discharge lamps
HPS	High pressure sodium (vapour)
LED	Light emitting diode
LEU	LightingEurope
LFL	Linear fluorescent lamps
PCA	Poly-crystalline alumina
SDW	SDW lamps are lamps in the HPS family with a very high red rendering warm colour and a lifetime of 15000 hours.

13.1 Background

LightingEurope (LEU)[315] has applied for the renewal of Ex 4(b)(I-III) of Annex III of the RoHS Directive. This exemption covers mercury in high pressure sodium (vapour) lamps (HPS) with improved colour rendering, used for general lighting purposes.[316]

LEU explains that reduction or omission of mercury in these lamps inevitably leads to loss of their specific colour rendering properties. It is further stated that there are currently no substitutes – in the form of LED modules or otherwise - that can replace the products of exemption 4(b) with an alternative that realizes the same colour specification. [317]

The applicant thus requests the renewal of the exemption with the current wording formulation as listed in Annex III of the RoHS Directive and the maximum available duration allowed (based on Art. 5(2) of the Directive):

	Exemption	Scope and dates of applicability
4(b)	Mercury in High Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner) in lamps with improved colour rendering index Ra > 60:	
(I)	P ≤ 155 W	No limitation of use until 31 December 2011; 30 mg may be used per burner after 31 December 2011
(II)	155 W < P ≤ 405 W	No limitation of use until 31 December 2011; 40 mg may be used per burner after 31 December 2011
(III)	P > 405 W	No limitation of use until 31 December 2011; 40 mg may be used per burner after 31 December 2011

13.2 Description of Requested Exemption

High pressure sodium lamps with increased colour rendering index are explained to fall under the High Intensity Discharge Lamps (HID) group. The HPS family includes lamps designed for different purposes in the professional market. HPS lamps are handled by technically skilled installers and sold by specialized distributors or as part of lighting equipment. The customers are for example governments, installers, specialized wholesalers, designers of lighting equipment etc.[318]

HPS lamps consist of a cylindrical discharge tube made of poly-crystalline alumina (PCA), in which two electrode assemblies are mounted at each side (Figure 13-1). The

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[315] LEU Ex. 4(b)(I-III)(2015a), LightingEurope, Request to renew Exemption 4(b) under the RoHS Directive 2011/65/EU: Mercury in High Pressure Sodium lamps, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_b__I-III_/4b_LE_RoHS_Exemption_Req_Final.pdf

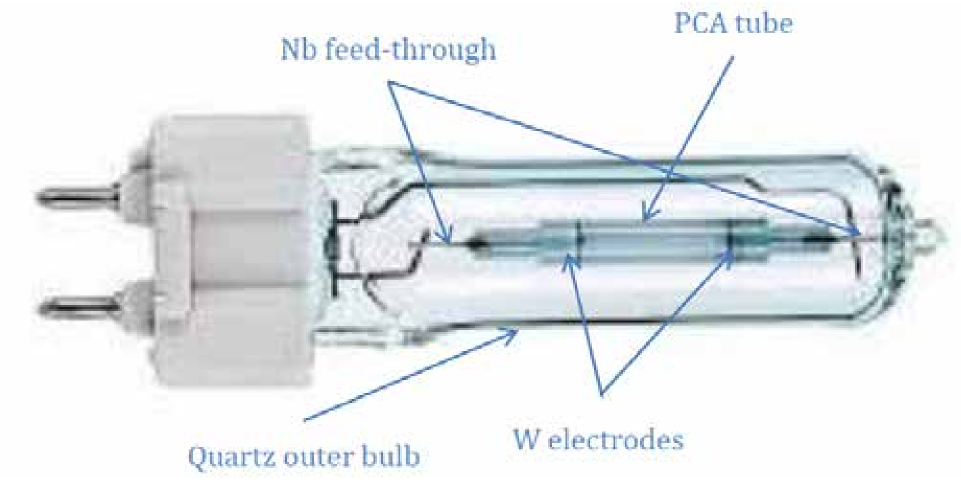
[316] Op. cit. LEU Ex. 4(b)(I-III)(2015a)

[317] Op. cit. LEU Ex. 4(b)(I-III)(2015a)

[318] Op. cit. LEU Ex. 4(b)(I-III)(2015a)

electrodes are made of tungsten and consist of a rod with, in some cases, coiled windings. The tungsten electrodes are welded to niobium tubes that serve as the electrical feed-through. The discharge tubes are sealed with a sealing frit which is designed such that it has the same expansion coefficient as PCA and niobium. This way there are no thermal stresses during the heating and cooling cycles present during starting and shut-down. The discharge tube is mounted in a vacuum quartz bulb in order to insulate it thermally.[319]

Figure 13-1: Construction of a HPS lamp with increased colour rendering



Source: LEU Ex. 4(b)(I-III)(2015a)

Inside the discharge tube xenon is present as a buffer gas. Mercury is dosed in the discharge tube during lamp manufacturing as sodium mercury. The amount of mercury dosed per lamp depends on aspects like lamp power and optical performance. For high pressure sodium lamps in the scope of Ex. 4(b)(I-III) the maximum dosed mercury amounts vary between 3 and 40 mg. Mercury and sodium are dosed as an amalgam of mercury and sodium in the form of a pill.[320]

Upon starting, a high voltage pulse is supplied to the electrodes and this breaks down the xenon gas allowing a current to flow through the resulting plasma. After ignition the heat released by the discharge warms up the discharge tube and evaporates part of the sodium and mercury. A liquid pool of sodium-mercury amalgam remains at the coldest spot in the discharge tube during operation. The HPS types with increased colour rendering index (CRI) have a higher sodium pressure. The increase in sodium pressure can be obtained by an increase in cold spot temperature of the saturated lamp and/or by an increase in the sodium to mercury ratio of the amalgam.[321] Increasing the arc tube

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[319] Op. cit. LEU Ex. 4(b)(I-III)(2015a)
[320] Op. cit. LEU Ex. 4(b)(I-III)(2015a)
[321] Referenced in LEU Ex. 4(b)(I-III)(2015a) as: Schmidt, K., Radiation characteristics of high pressure alkali metal discharges, Proc. 6th Int. Conf. On Phenomena in Ionized Gases, Paris, vol. 3, p. 323 (1963); and

diameter also contributes to a higher CRI.[322] There are two types of lamps covered under this exemption:[323]

- A lamp family with colour rendering index of 60, correlated colour temperature of 2200 K and luminous efficacies between 53 and 90 lm/W has successfully been introduced on the market in the range 150W-400 W. Some manufacturers also offer this lamp type for mercury retrofit applications. With improved colour rendering at low colour temperature and fairly high efficacies, these lamps find their application in outdoor situations where a better colour rendering is needed or in indoor applications where a good luminous efficacy is more important than high quality colour. Examples are parking lots and warehouses.
- The second type is used for high quality indoor lighting. With colour rendering index of 85, correlated colour temperature 2500-2700 K and luminous efficacies of 40-50 lm/W, this lamp is used as an incandescent lamp replacement with improved efficacy. Specifically, these lamps are used in applications where a very good rendering of red colours is required. The available wattage range is 35 W to 100 W This lamp family is often referred to as "White HPS". Electronic stabilisation is needed in order to minimise colour temperature, system-to-system variation and colour shift over life.

High Pressure Sodium lamps with increased colour rendering are characterized by long life-time (15,000 to 24,000 hours[324]), good luminous efficiency (from 40 to 92 lm/W) and good to very good colour rendering (Cri of 60 for the first type and 80+ for the second type). The High Pressure Sodium lamps with CRI 60 mostly are single-capped with Edison screw caps (E27 and E40 for Europe). The European types of CRI 80 are marketed with G12 and PG-12 bi-pin caps. All HPS lamps can only operate on designated drivers that switch the lamp on and regulate their power. These drivers are electro-magnetic ballast (inductive/capacitive load) used to stabilize the lamp current in combination with a high voltage pulse generator (ignitor) to ignite the lamp, or electronic power supplies that regulate the power and also provide the required ignition pulse.[325]

Mizuno, H., Akutsu, H. and Watarai, Y., New high pressure sodium lamp with higher colour rendition, CIE 17th Session, Barcelona, P. 71.14 (1971)

[322] Refferenced in LEU Ex. 4(b)(I-III)(2015a) as: Akutsu, H., Watarai, Y., Saito N. and Mizuno H., A new high-pressure sodium lamp with high color acceptability, J. of the IES, 13, no.4, p. 341-349 (1984)

[323] Op. cit. LEU Ex. 4(b)(I-III)(2015a)

[324] According to LEU Ex. 4(b)(I-III)(2015b), in this context, The term “long life” refers not to another HPS product but to the alternative lamp that will give the same functionality to the end user. For SDW lamps (lamps with a very high red rendering warm colour and a lifetime of 15000 hours), the only existing alternatives are halogen of normal incandescent lamps with lifetimes below 4000 hours. The HPS with colour rendering of approximately 60 gives a warm white light and has a lifetime of 24000 hours. There is no product yet that gives the same light from a compact luminaire. The CFL-ni lamps come close, but have a higher colour temperature (and better CRI). Their lifetime is shorter than the 24000 hrs of HPS CRI=60.

[325] Op. cit. LEU Ex. 4(b)(I-III)(2015a)

Figure 13-2: Different formats of HPS lamps with increased colour rendering: Edison

Source: LEU Ex. 4(b)(I-III)(2015a)

The product characteristics make HPS lamps with increased colour rendering a suitable choice for applications that require very good colour rendering with emphasis on warm colours. Typical applications for the CRI 60 types are outdoor applications where colour rendering matters, like city centres and parking lots where they provide a typical city atmosphere. The CRI 80+ types are mostly used indoors in shops where objects like red meat, breads or furniture have to be displayed. For these kinds of applications these lamps are the only energy efficient option since no other light sources but incandescent are capable of delivering the kind of red saturation that is required.[326]

In HPS lamps Hg has a number of roles:[327]

- The main role of mercury is to tune the resistance of the plasma in such a way that the efficiency of the combination lamp and driver functions in an optimal way. High Intensity Discharge lamps generate light in a compact plasma arc with a high brightness. After the lamp is started by a voltage pulse the initial noble gas discharge heats the lamp and evaporates part of the sodium/mercury amalgam pill. At first it is mainly the mercury that goes into the vapour phase. The increasing mercury vapour pressure increases the electrical resistance in the discharge which allows for putting more power into the discharge. As a consequence of more power coupled into the discharge, the discharge tube wall will heat up causing sodium and mercury to evaporate further until a state of equilibrium is established between the electrical power supplied to the discharge, the heat conducted to the surroundings and the radiation emitted from the discharge. The lamps are designed such that the optimal efficiency is reached at this equilibrium. The mercury is not consumed over life. However, the sodium in the discharge tube does chemically react with the PCA wall and the electrode emitter. As a

[326] Op. cit. LEU Ex. 4(b)(I-III)(2015a)
[327] Ibid.

consequence the fraction of mercury in the amalgam becomes higher and this raises the lamp voltage. At a certain point in time the lamp voltage becomes so high that the mains voltage can no longer sustain the arc and the lamp extinguishes. This is the end of the lamp life. For a given sodium consumption, a certain amalgam dose is required to reach the specified life. If the dose is too small, the ratio of mercury in the amalgam rises rapidly and so does the lamp voltage, leading to a premature end of life.

- The mercury in the plasma of a High Pressure Sodium lamp does not directly contribute to the spectrum of the lamp because the arc temperature is too low to excite the interesting (optical) energy levels of the mercury atom. However, there is a very significant indirect contribution of the mercury atoms: the proximity of mercury atoms shifts the energy levels of sodium and creates a very large broadening of the sodium resonance line in the red part of the spectrum. It is this red broadening of the sodium spectral resonance line that gives the High CRI HPS lamps their excellent red rendering properties. It is possible to shift the colour point for a given sodium pressure towards the black body locus by tuning the sodium to mercury ratio. Too low Hg content gives the lamp a greenish colour; too much Hg however, shifts the colour point to the pinkish side of the black body locus.
- The presence of the mercury vapour also greatly reduces the thermal conduction of the sodium-mercury-xenon plasma. As a consequence, there is less heat loss from the plasma to the discharge tube wall. The efficiency of the lamp is thereby greatly improved by the mercury pressure.
- The high pressure of mercury limits evaporation of the hot tungsten electrode. The low evaporation helps to maintain the light flux over lifetime, a high evaporation rate of tungsten will lead to blackening of the arc tube and a reduced transmission of light.

For classes (i.e. entries – consultants comment) I and II the amalgam dose increases with lamp power (=lamp size).

LEU was asked to explain how the two types of lamps and the mercury contents of lamps on the market refer to the three entries of the exemption. LEU[328] stated that:

- In **category I:** for lamps with a power below 155W both families are still available;
- In **category II**: lamps with a power 155W<P<405W, only one family is available (lamps with colour rendering > 60); and

[328] LEU Ex. 4(b)(I-III)(2015b), LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 4(b)(I-III), submitted 15.9.2015, avaialble under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_b__I-III_/Ex_4b__I-II-III__LightingEurope_1st_Clarification-Questions_final.pdf

- In **category III**: lamps with a lamp power >405W, no lamps are available anymore. This category could be eliminated completely since the industry does not produce lamps falling under this category anymore.

13.2.1 Amount of Mercury Used under the Exemption

The lamps have to be replaced about every 2 to 3 years. The estimated European market for these lamps cannot be disclosed publicly, thus the total amount of mercury brought on the European market through lamps of Ex. 4(b) could not be estimated.[329]

In a later communication LEU[330] provided a rough estimation that the total amount of mercury put on the market per annum through this application is in the range of 5-10 kg. They also explain that the boundaries on the mercury content in the exemption can be differentiated based on 60 < CRI < 80 or CRI >80. The lamps with CRI>80 are made with another technology and use less mercury.

13.3 Applicant's Justification for Exemption

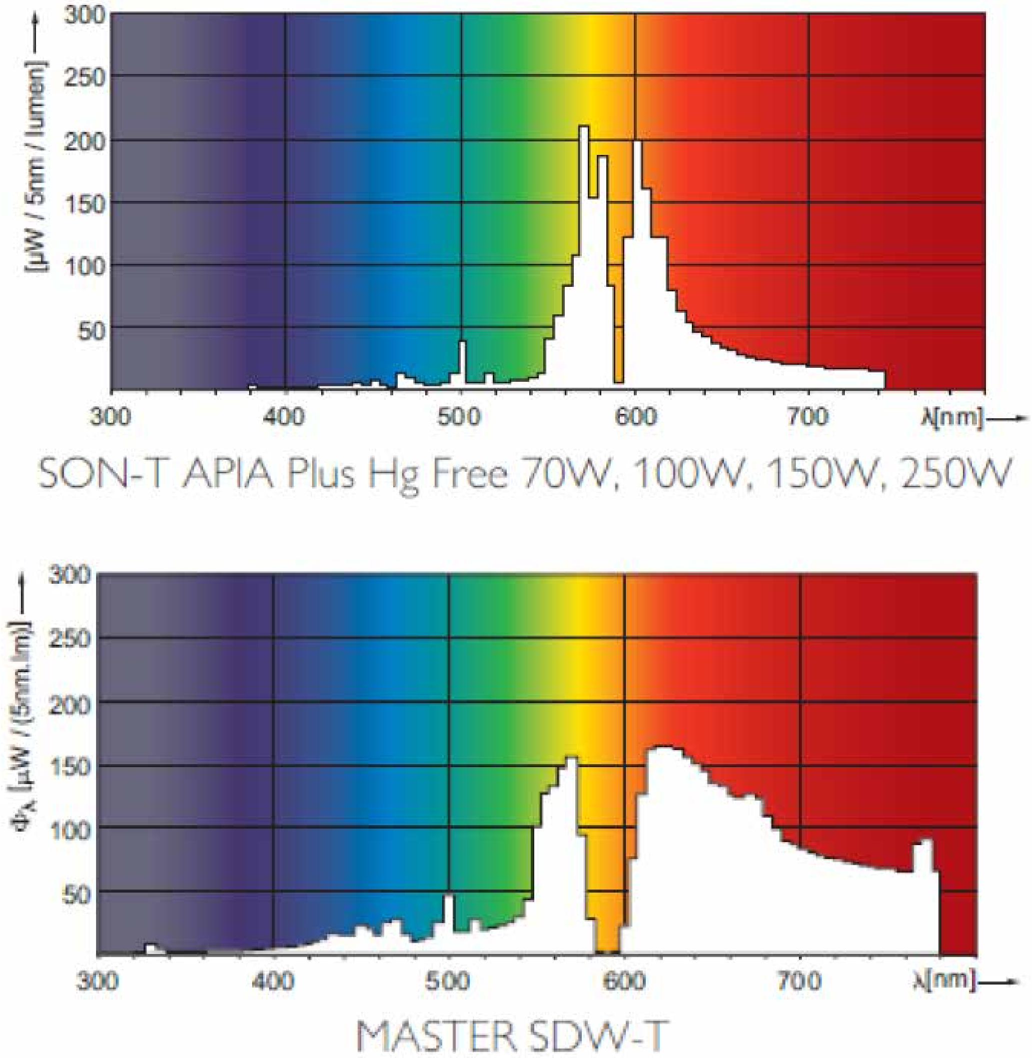
LEU claims that the replacement of mercury in non-linear fluorescents is scientifically and technically impracticable and that currently there are no significant LED lamps available on the market with comparable CRI.[331]

13.3.1 Possible Alternatives for Substituting RoHS Substances

LEU states that it is the presence of mercury that broadens the sodium resonance line dramatically into the red part of the spectrum (see also Figure 13-3). There are no other elements known that have the same influence on the spectrum of an HPS lamp. Replacing the mercury pressure by xenon (see also Figure 13-4) broadens the spectrum on both sides of the Na resonance line 24 and hence does not have the effect of a warm colour, high CRI lamp. Moreover, to have a similar effect with Xe as with Hg on the red side, the Xe pressure would have to be so high that ignition with existing ignitor systems would not be possible. LEU concludes that mercury is essential for high CRI HPS lamps and that without mercury they completely lose their properties.[332]

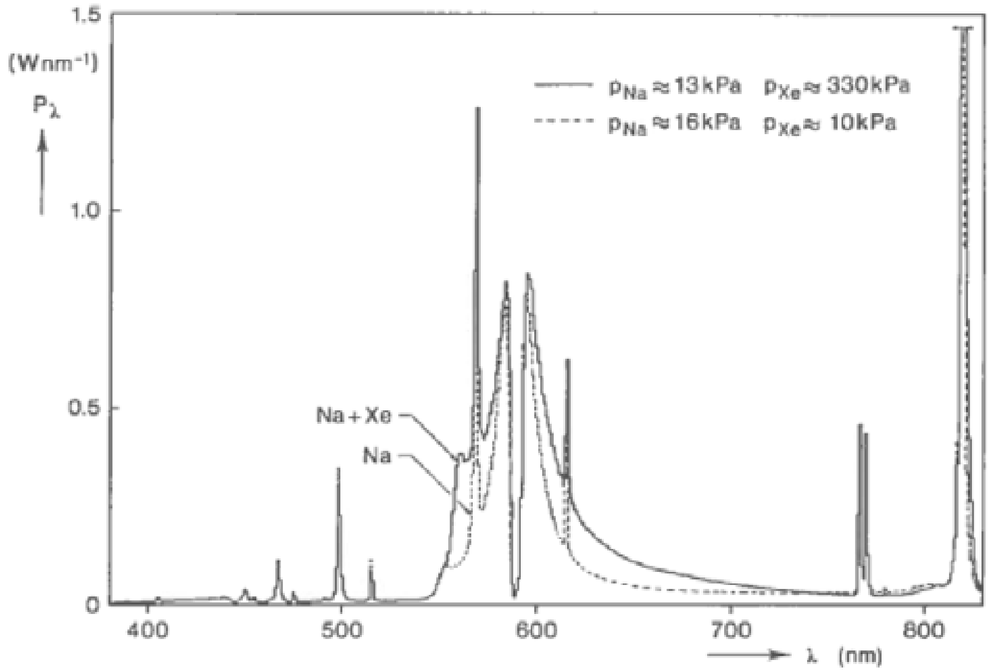
[329] Op. cit. LEU Ex. 4(b)(I-III)(2015a)
[330] Op. cit. LEU Ex. 4(b)(I-III)(2015b)
[331] Op. cit. LEU Ex. 4(b)(I-III)(2015a)
[332] Op. cit. LEU Ex. 4(b)(I-III)(2015a)

Figure 13-3: Spectra of an Hg-free and an improved CRI HPS lamp



Source: LEU Ex. 4(b)(I-III)(2015a)

Figure 13-4: Spectra of an Hg-free HPS lamp with increased Xe pressure



Source: Refered to in LEU Ex. 4(b)(I-III)(2015a) as Woerdman, J.P, Schleyen, J., Korving, J., Van Hemert, M.C, De Groot. J.J. and Van Hal, R.P.M., Analysis of satellite and undulation structure in the spectrum of Na+Hg continuum emission, J. Phys. B: At.Mol.Phys., vol.18, pp4204-4221 (1985)

LEU further explains that ever since the introduction of the HPS lamp in the 1960's, the possibility of operating this lamp in an unsaturated vapour mode -just as high pressure mercury lamps- has been suggested and discussed. In this mode all the Hg/Na amalgam is vaporised during operation, in contrast to the standard HPS types where only a fraction of the amalgam dose is vaporised. The unsaturated vapour mode offers a number of advantages over the saturated lamp: better voltage and power stability, no cycling at end-of-life, substantially reduced Hg dose and faster warm-up. However, the very low sodium dose (20-100µ g) makes this lamp extremely vulnerable for sodium loss reactions. HPS lamps with increased colour rendering operate at increased PCA wall temperature in order to realize the necessary Na pressure. At this PCA temperature the sodium reactions within the wall cause a rapid depletion of the sodium in the discharge tube. This reduction causes the colour point of the lamp to shift and also raises the lamp voltage with premature failure following. Hence, LEU concludes that reduction of mercury to unsaturated dosage is not possible.

13.3.2 Possible Alternatives for Eliminating RoHS Substances

LEU explains that there are no replacement lamps for the colour improved HPS family available, and assume that revoke of the exemption would subsequently result in a "loss of applications":

- On the component level (lamp replacement – retrofit/conversion): LED replacement lamps for HPS are proposed by a large variety of suppliers.

However, specific replacements for colour improved HPS that mimic its unique colour properties are said to be not yet available.

- LED replacement luminaires (system level): LED luminaires that mimic the unique colour properties of colour improved HPS lamps are also said not available yet.

LEU[333] later explains that several attempts were made to develop LED lamps with a similar colour impression like the SDW classification of lamps [SDW understood to be solely a coding system and not an acronym – consultants comment]. The main barrier is the emission of saturated red light. One way to produce this light is with quantum dots. "*The application for the best quantum dots (that use cadmium) is not granted yet and generates not enough red light.*[334] *This means that no breakthrough is ready at present. Research is ongoing for other options like phosphors, quantum dots or direct red light emission from the LED. The red light on itself is highly appreciated in all lighting applications. It is difficult to generate efficiently, so the granting of the exemption 4b will not limit the efforts to find a good solution for good red light emission since the solution will provide a competitive advantage*. "

13.3.3 Environmental Arguments

LEU explains that specific LCA's of high colour rendering HPS lamps are not publicly available. LEU discusses results of three public LCA's published for general HID lamps[335] and makes a comparison between results of these studies related to ceramic metal halide lamps in comparison with LEDs. However, LEU explains that the comparison made is not a suitable comparison for HPS, as according to LEU there would be no retrofit replacements for HPS lamps. A true comparison would need to assume that the luminaire is replaced and not just the lamp.

As the referenced studies are from 2009-2011, and it is possible that available LED alternatives have developed (i.e. results outdated), the discussed results are not reproduced here and can be viewed in the applicants document.

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[333] Op. cit. LEU Ex. 4(b)(I-III)(2015b)

[334] Referred to in LEU Ex. 4(b)(I-III)(2015b) as "Cadmium in color converting II-VI LEDs (< 10 µg Cd per mm2 of light-emitting area) for use in solid state illumination or display systems" (Request for renewal of Exemption 39 of Annex III of Directive 2011/65/EU) http://rohs.exemptions.oeko.info/index.php?id=182

[335] Referenced in LEU Ex. 4(b)(2015a) as:

- Department for Environment Food and Rural Affairs (DEFRA). Life Cycle Assessment of Ultra-Efficient Lamps. Navigant Consulting Europe Ltd. 2009
- AT. Dale.MM. Bilec,J. Marriott, D. Hartley,C.Jurgens,E. Zatcoff Preliminary comparative life-cycle impacts of streetlight technology. Journal of Infrastructure Systems193— 199,(2011).
- Preparatory Study for Eco-Design Requirements of EuP, Lot 9, Public Street Lighting, P. Van Tichelen, T. Geerken, B. Jansen , M. Vanden Bosch (Laborelec), V. Van Hoof, L. Vanhooydonck (Kreios), A. Vercalsteren

13.3.4 Road Map to Substitution

LEU claims that no solution (i.e. alternative) for the deep red rendering typical of colour improved HPS has been proposed yet. It is very probable that solutions will appear in the coming years but the timing and the performance/cost specifics are not known at this point in time.

13.4 Stakeholder Contributions

A number of contributions have been made by stakeholders raising general points in relation to discharge lamps. Such contributions are summarised in Section 4.4 of the general lamp chapter.

The European Environmental Bureau (EEB), the Mercury Policy Project and the Responsible Purchasing Network[336], submitted comments specifically in relation to Ex. 4(b) and 4(c), explaining that LEDs are increasingly being made to replace HPS lamps and are expected to increase for this application. EEB et al. recommend the Commission to monitor improvements in the availability, performance and price of LED replacements, to consider when an expiry date may be practical. EEB et al. present information showing that HPS lamps with lower mercury contents are available on the market. Such information is not reproduced here as such examples are understood to have relatively low CRI (<25) and are thus understood to only be relevant for Ex. 4(c). EEB et al. also claim that many companies offer a variety of drop-in LED replacements for HPS lamps, and it is further explained that the benefits of LEDs over HPS lamps are many:

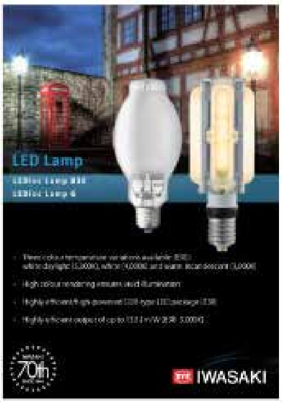
- LED lamps are much more energy efficient than HPS lamps.
- LEDs also have a longer rated life, which reduces their replacement and installation costs as well as their lifecycle environmental impacts.
- LEDs emit a higher quality of light, which is white rather than the yellow light that is emitted from HPS lamps.
- LED lamps do not cycle on and off.
- LEDs are mercury-free unlike HPS lamps.

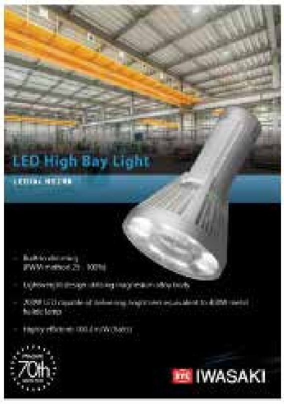
EEB et al. present a few LED examples to demonstrate their suitability:

[336] EEB et al. (2015a),The European Environmental Bureau, the Mercury Policy Project, and the Responsible Purchasing Network, Environmental NGOs Response to Stakeholder consultation 2015 #2 on mercury- containing lamps – Exemption 1-4 (Review of Annex to the RoHS directive), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1-4_EEP-RPN-MPP_Comments_on_RoHS_Request-final_20151016.pdf

- GE's LED Replacement for a 400-Watt HID lamp uses 50% less energy for a similar light output (approximately 200 watts for the LED), it lasts at least twice as long as an equivalent HID lamp (50.000 hours for the LED versus 24.000 for the HID lamp), and improved light quality (its Colour Rendering Index is 73, compared to 22 for a typical HPS HID lamp).[337]

- Other EU-based lighting equipment distributors sell LED drop-in retrofit products that can directly replace HID lamps. One example is Eye Lighting Company, which offers a variety of exterior and high-bay/interior LED lamps that can replace high-pressure sodium and metal halide HID lamps, which are often used to light gymnasiums, streets, pedestrian walkways, stadiums, and more[338]. Referenced LED lamps (left image) come in a CRI of 75 or 85. The right hand example is stated as an alternative for metal halide lamps and has a CRI of 65 or 80.





13.5 Critical Review

13.5.1 Scientific and Technical Practicability of Substitution

From the information that LEU provides it can be followed that eliminating mercury in HPS lamps with improved colour rendering is not practical. The presence of Hg allows broadening the spectrum of such lamps into the red part of the spectrum. Other substances that have been investigated such as xenon are understood not to allow a

[337] Referenced in EEB et al. (2015a), GE Lighting Company, LED Replacement Lamp for 400 Watt HID, GE webpage accessed 06 October 2015, http://www.gelighting.com/LightingWeb/na/solutions/led-lamps-and-modules/led-replacement-for-hid/
[338] Referenced in EEB et al. (2015a), as Eye Lighting Company, Iwasaki LED Lighting Brochures , 2014, http://www.eyelighting.co.uk/public/images/pdf/brochures/LEDleaflets2014.pdf

comparable performance in this respect as well as requiring a high ignition not compatible with current systems.

It can further be followed that reducing the amount of mercury in lamps is not practical. Investigations into unsaturated vapour modes for these lamps, in which all sodium and mercury would be in a vapour state when the lamp is operated, did not result in products with reduced Hg. Though such lamps have several advantages, it is also understood that the low dose of sodium would result in the colour point of the lamp shifting throughout the life of the lamp as well as in premature failure. A further aspect that shows that a reduction of Hg limits would not necessarily be needed is related to the dosing of Hg. It is explained that Hg is not "consumed" throughout the lifetime of the lamp. In this sense, in contrast with fluorescent lamps such as CFL and LFL for example, it is assumed that the Hg dosing in HPS lamps is in relation to the actual level of Hg needed for operation of the lamp and the dosing does not include additional Hg to ensure the lamp lifetime. This is also supported by the understanding that too little mercury results in a green light, whereas to much would result in a pinkish tone.

LEU explains that there are no LED alternatives that provide sufficient colour rendering properties. This is explained to be of relevance both for replacement lamps in existing HPS installations (retrofit/conversion) and for replacement luminaires (i.e., new LED installations). However examples provided by EEB et al. show that there are LED lamps on the market providing higher colour rendering, i.e. lamps with CRI of 65, 73, 75, 80, 85. LEU explained that Ex. 4(b) covers both lamps with CRI between 60-80 as well as lamps with CRI above 80. In this respect, at least the former group appears to be covered by such examples. Such lamps could thus replace HPS lamps at least to some degree when used in new installations (luminaire replacement). However, the consultants understand there to be technical limitations to replacing lamps in existing installations.

LEU provides a few examples of lamp data sheets in which HPS dimensions relevant for this exemption can be found. Example sizes in mm are 103,110 and 143 for the full length of the lamp and 20 and 32 for the diameter.[339] In comparison the examples provided by EEB et al. show dimensions of 155, 200 and 201 mm for the full length of the lamp and 70, 73 and 90 for lamp diameter[340]. It is therefore concluded that the difficulty of substitution is related to the dimensions of LED substitutes, which would probably not be compatible as replacement lamps in existing installations. In this respect, the problem of substitution appears to be related to replacement lamps but not necessarily to replacement luminaires.

[339] See Examples from Philips: http://download.p4c.philips.com/l4bt/3/323010/master_sdw-tg_mini_323010_ffs_nld.pdf and http://download.p4c.philips.com/l4bt/3/322803/master_sdw-t_322803_ffs_nld.pdf

[340] See Examples of Iwasaki Eyelighting under http://www.eyelighting.co.uk/public/images/pdf/brochures/LEDleaflets2014.pdf

13.5.2 Environmental Arguments

Though LEU mentions LCAs that could be used to provide an indicative comparison of HPS and LED alternatives, this information is explained not to compare the LED in a way that would represent an actual substitution situation. The reports are furthermore outdated and thus this information has not been evaluated. Further aspects raised are of general nature and are discussed in the general chapter under Section 4.5.3.

13.5.3 Stakeholder Contributions

For the discussion of general aspects raised by stakeholders, please see Section 4.5.7 of the general chapter. As for information provided by EEB et al. specifically for HPS lamps, it concerns both Ex. 4(b) and Ex. 4(c). Thus, not all aspects are understood to be relevant for this exemption. However, EEB et al. present a few examples of LED alternatives with CRI's that are comparable to lamps falling under Ex. 4(b). As the dimensions of such lamps are larger, it is understood that they currently would probably not be suitable for use as lamp replacements in existing HPS installations. However, it is concluded that such lamps could provide substitutes on the system level for use in new LED installations. The consultants thus agree with EEB et al. that the Commission should further monitor the development of such alternatives. This would allow understanding when the size of LED alternatives ceases to limit their applicability in existing luminaires, as well as observing the progress in the shift from HPS luminaires to LED alternative luminaires.

13.5.4 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

It can be followed that Hg cannot be substituted in HPS lamps with high colour rendering as investigations into such lamps show that alternatives did not provide the relevant red part of the spectrum. It can also be understood that reducing the amount of mercury would not be possible as this would result in colour shifting and premature failure of the lamps (unsaturated vapour mode) or in a change in the spectral output colour should Hg amounts in the current technology be increased.

Though LEU claims that LED alternatives are not available on the market, information provided by EEB et al. shows that alternatives providing CRIs of up to 85 are available. Such alternatives are understood to allow substitution at the system level in new installations. However, such lamps are larger in dimensions and are expected not to be

compatible with existing installations. Thus on the component level, lamps of Ex. 4(b) would still be needed to allow lamp replacement and thus to prevent early end-of-life of existing luminaires. Though a shift to LED luminaires can be expected, the consultants would recommend renewing the exemption and monitoring the development both of additional LED alternative lamps and of the shift in the luminaire stock from HPS to LED. This would allow understanding at what point environmental costs related to early end-of-life of luminaires would be acceptable to allow the elimination of Hg brought on the EU market through this exemption.

13.6 Recommendation

Though substitutes are understood to be available on the system level (for use in new LED luminaires), such substitutes are too large to allow their application as substitutes in existing HPS luminaires (component replacement). It is assumed that the shift of the luminaire stock from HPS to LED is still at its beginning and that an early phase-out could result in an early end-of-life of HPS luminaires. It is thus recommended to renew the exemption for a further 5 years. Furthermore, as raised by the applicant, this renewal should only apply to items I and II of the exemption as item III has become obsolete since manufacturers no longer place such lamps on the market.

In light of Article 5(2), from a legal perspective, excluding EEE falling under Cat. 8 and 9 from the scope of this exemption may not be possible.

<table>
<tr><th>Exemption 4(b)</th><th>Scope and dates of applicability</th></tr>
<tr><td>Mercury in High Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner) in lamps with improved colour rendering index Ra > 60:</td><td></td></tr>
<tr><td>(I) P ≤ 155 W; 30 mg may be used per burner</td><td rowspan="2">For Cat. 5, 8 & 9: 21 July 2021;
For Sub-Cat. 8 in-vitro: 21 July 2023;
For Sub-Cat. 9 industrial: 21 July 2024;</td></tr>
<tr><td>(II) 155 W < P ≤ 405 W; 40 mg may be used per burner</td></tr>
<tr><td>(III) P > 405 W; 40 mg may be used per burner</td><td>For Cat. 8 & 9: 21 July 2021;
For Sub-Cat. 8 in-vitro: 21 July 2023;
For Sub-Cat. 9 industrial: 21 July 2024;</td></tr>
</table>

Note: As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

13.7 References Exemption 4(b)(I-III):

EEB et al. (2015a) The European Environmental Bureau, the Mercury Policy Project, and the Responsible Purchasing Network, Environmental NGOs Response to Stakeholder consultation 2015 #2 on mercury- containing lamps – Exemption 1-4 (Review of Annex to the RoHS directive), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1-4_EEP-RPN-MPP_Comments_on_RoHS_Request-final_20151016.pdf

LEU Ex. 4(b)(I-III)(2015a) LightingEurope, Request to renew Exemption 4(b) under the RoHS Directive 2011/65/EU: Mercury in High Pressure Sodium lamps, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_b__I-III_/4b_LE_RoHS_Exemption_Req_Final.pdf

LEU Ex. 4(b)(I-III)(2015b) LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 4(b)(I-III), submitted 15.9.2015, avaialble under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_b__I-III_/Ex_4b__I-II-III__LightingEurope_1st_Clarification-Questions_final.pdf

14.0 Exemption 4(c)(I-III): "Mercury in other High Pressure Sodium (Vapour) Lamps for General Lighting Purposes not Exceeding (Per Burner):"

This review of Annex III exemption 4(c)(I-III) covers the following exemption entries:

I) P ≤ 155 W
II) 155 W < P ≤ 405 W
III) P > 405 W

Declaration

In the sections that precede the "Critical Review" the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

CRI	Colour rendering index
EEE	Electrical and electronic equipment
EoL	End of life
ErP	The European Directive ErP (Energy related Products) 2009/125/EC also known as EcoDesign
Hg	Mercury
HID	High intensity discharge lamps
HPMV	High Pressure Mercury Vapour
HPS	High pressure sodium (vapour)
LED	Light emitting diode
LEU	LightingEurope
PCA	Poly-crystalline alumina
WEEE	Waste electrical and electronic equipment

14.1 Background

LightingEurope (LEU)[341] has applied for the renewal of Ex 4(c)(I-III) of Annex III of the RoHS Directive. This exemption covers mercury in other high pressure sodium (vapour) lamps (HPS) used for general lighting purposes, i.e. it does not cover HPS with improved colour rendering, which would fall under Ex. 4(b)(I-III).[342]

LEU explains that reduction or omission of mercury in these lamps inevitably leads to loss of efficacy. On the component level (replacement lamps) the applicant further explains that replacing HPS lamps by LED retrofit lamps with conservation of the specification is not possible and is not expected anytime soon due to thermal limitations and compatibility issues. Though on the system level (installations), substitution of HPS installations with LED installations is explained to be underway, this is expected to require another 15-25 years or to result in WEEE prematurely (early end-of-life) if phase-in is forced.[343]

The applicant thus requests the renewal of the exemption with the current wording formulation as listed in Annex III of the RoHS Directive and the maximum available duration allowed (based on Art. 5(2) of the Directive):

	Exemption	Scope and dates of applicability
4(c)	Mercury in other High Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner):	
(I)	P ≤ 155 W	No limitation of use until 31 December 2011; 25 mg may be used per burner after 31 December 2011
(II)	155 W < P ≤ 405 W	No limitation of use until 31 December 2011; 30 mg may be used per burner after 31 December 2011
(III)	P > 405 W	No limitation of use until 31 December 2011; 40 mg may be used per burner after 31 December 2011

14.2 Description of Requested Exemption

High pressure sodium lamps are explained to fall under the High Intensity Discharge Lamps (HID) group. The HPS family includes lamps designed for different purposes in the professional market. HPS lamps are handled by technically skilled installers and sold by specialized distributors or as part of lighting equipment. The customers are for example governments, installers, specialized wholesalers, designers of lighting equipment etc. [344]

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[341] LEU Ex. 4(c)(I-III)(2015a), LightingEurope, Request to renew Exemption 4(c) under the RoHS Directive 2011/65/EU: Mercury in High Pressure Sodium lamps, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_c__I-III_/4c_LE_RoHS_Exemption_Req_Final.pdf

[342] Op. cit. LEU Ex. 4(c)(I-III)(2015a)

[343] Op. cit. LEU Ex. 4(c)(I-III)(2015a)

[344] Op. cit. LEU Ex. 4(c)(I-III)(2015a)

HPS lamps covered by Ex. 4(c)(I-III) are similar in structure and function to those covered by Ex. 4(b)(I-III). A short summary with some specific details is provided here, while additional details can be viewed in Section 13.2 of the Ex. 4(b)(I-III) chapter. HPS lamps consist of a cylindrical discharge tube made of poly-crystalline alumina (PCA), in which two electrode assemblies are mounted at each side (Figure 14-1). The electrodes are made of tungsten (W) and consist of a rod with coiled windings containing a mix of oxides, called the emitter. These oxides reduce the work function of the tungsten and hence reduce also the temperature of the electrodes during operation, thereby greatly improving the life time of the lamps. The tungsten electrodes are welded to niobium (Nb) tubes that serve as the electrical feed-through (Figure 2). The discharge tubes are sealed with a sealing frit which has the same expansion coefficient as PCA and niobium, to prevent thermal stresses during the heating and cooling cycles (start-up / shut-down). Inside the discharge tube xenon is present as a buffer gas, at a pressure of some 20-500 mbar, under room temperature conditions.[345]

Figure 14-1: Construction of a high pressure HPS lamp

Source: LEU Ex. 4(c)(I-III)(2015a)

HPS lamps are characterized by very long life (30,000 to 50,000 hours) and very high luminous efficiency (from 80 lm/W to 150 lm/W). They also typically have a lumen maintenance of more than 80% at end of life (EoL). Their ability to render colours is low (CRI around 20). The majority of HPS lamps are single-capped with Edison screw caps (E27 and E40 for Europe) but there exists also a double-capped range with R7s and Rx7s caps. Figure 14-2 shows different formats. Most manufacturers have both lamps in tubular clear glass format and in ovoid shape with a light diffusing coating. The wattage range is 35W to 1000W. [346]

[345] Op. cit. LEU Ex. 4(c)(I-III)(2015a)
[346] Op. cit. LEU Ex. 4(c)(I-III)(2015a)

Figure 14-2: Different formats of HPS lamps: tubular clear, ovoid coated and clear double-ended

Source: LEU Ex. 4(c)(I-III)(2015a)

HPS lamps can only operate on designated drivers that switch the lamp on and regulate the power. These drivers can be an electro-magnetic ballast (inductive/capacitive load) to stabilize the lamp current in combination with a high voltage pulse generator (ignitor) to ignite the lamp. Nowadays, also electronic drivers are used to stabilize the lamp at the correct power.[347]

LEU states that the product characteristics make HPS lamps a suitable choice for applications that require long life, high efficacy and very good lumen maintenance, but where colour rendering is less important. Typical applications are outdoor lighting: street lighting, parking's, city squares, flood lighting of buildings. Sometimes these lamps are also used indoors, like in warehouses where colour rendering is not important.[348]

14.2.1 Amount of Mercury Used under the Exemption

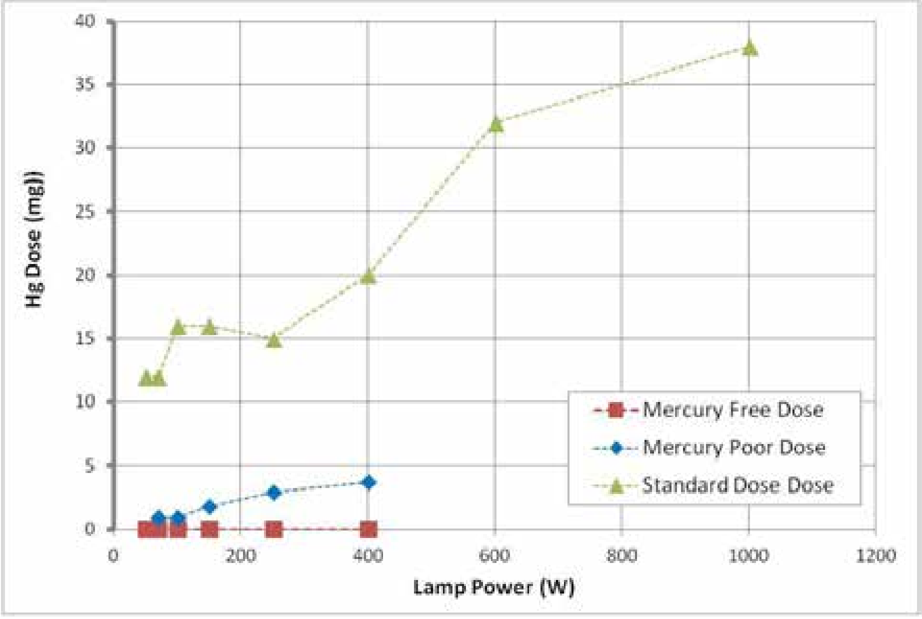
"*Mercury is dosed in the discharge tube during lamp manufacturing as sodium/mercury amalgam with an Hg/Na fraction of 75-97%. The amount of mercury dosed per lamp depends on aspects like lamp power and optical performance. For high pressure sodium lamps in the scope of the Exemptions 4(c) the dosed mercury amounts vary between 1 and 40 mg. There are three types of HPS lamps on the market*":[349]

- Standard dosed: HPS lamps with saturated amalgam dose (i.e. only part of the mercury and sodium is vaporized in the operational lamp) and optimized to yield the highest possible efficacies.
- Mercury poor: Lamps with an unsaturated amalgam dose (i.e. all the mercury and (almost) all the sodium is evaporated in the operational lamp). These lamps are mostly marketed in the USA.
- Mercury Free: Lamps without dosed mercury.

[347] Op. cit. LEU Ex. 4(c)(I-III)(2015a)
[348] Op. cit. LEU Ex. 4(c)(I-III)(2015a)
[349] Op. cit. LEU Ex. 4(c)(I-III)(2015a)

For the first two types listed above, the amalgam dose increases with lamp power (=lamp size). Figure 14-3 shows the dose versus the lamp power.

Figure 14-3: Amalgam doses of different types of HPS lamps on the market



Source: LEU Ex. 4(c)(I-III)(2015a)

The total amount of mercury brought on the European market in HPS lamps is calculated in the following way: an estimated 23 million HPS lamps will be brought onto the European market in 2016. The highest volumes are sold in 70W and 150W Standard dose lamps. The volumes of Mercury Free are low and the Mercury Poor lamps are not on the market in Europe (because of non-compliance with ErP[350] regulation). LEU estimates an average of 15 mg per lamp. Hence, LEU estimates that the total amount of mercury brought on the European market by new lamps of Ex. 4(c) is 345 kg per year. It is estimated that about 46% of the mercury brought onto the European market is recycled. Hence, the net amount brought onto the European market is 186 kg.[351]

LEU[352] mentions the VHK and VITO[353] study, which uses data, available from a report by McKinesy[354], EuroStat Data and LEU statistics (confidential), to develop a self-consistent overview of the EU28 market size and evolution for all lamp technologies. In the

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350 ErP - European Directive ErP (Energy related Products) 2009/125/EC, also known as EcoDesign
351 Op. cit. LEU Ex. 4(c)(I-III)(2015a)
352 Op. cit. LEU Ex. 4(c)(I-III)(2015a)
353 Quoted in LEU Ex. 4(c)(I-III)(2015a) as: Preparatory Study on Light Sources for Ecodesign and/or Energy Labeling Requirements ('Lot 8/9/19'), Prepared by VHK, in cooperation with VITO and JeffCott Associates, 19 November 2014. Available from http://ecodesign-lightsources.eu/documents
354 Quoted in LEU Ex. 4(c)(I-III)(2015a) as: Lighting the way: Perspectives on the global lighting market, McKinsey 2012 second edition

derivation of this data several assumptions had to be made by the study team and the number of lamps sold are finally tabulated (Table 57 in the report) for two different assumptions for the Average Selling Price (ASP) in the EU28 (low and high ASP). In LEU's application document, these two results are interpreted as confidence intervals and the average of the two is used. Further explanations and results are given in Table 14-1. From the results derived by this procedure it is clear that despite the fact that some new HPS applications are still installed, the installed base is decreasing rapidly in EU28: from 72 million in 2016 to 37 million in 2020. Also the number of HPS replacement lamps will drop drastically between 2016 and 2020: from 23 million to 12 million. The largest part of these lamps is nowadays replacement of lamps for existing luminaires.

Table 14-1: World and European market trend (in million pieces) for HID and HPS lamps according to VHK & VITO report

Source	Category	2011	2012	2016	2020
VHK & VITO	HID TOTAL	54	63	60	30
	LED TOTAL	30	72	407	634
	New	1075	1158	999	878
	Replacement	2817	2572	1399	728
	LAMPS TOTAL	3892	3730	2397	1606
LE Statistics	HPS/HID Ratio	35%	35%	39%	39%
This work	HID NEW	15	19	18	7
	HID Replacement	39	44	42	22
	HPS NEW	5	6	7	3
	HPS REPLACEMENT	14	15	16	9
	HPS TOTAL	**19**	**22**	**23**	**12**
	HPS INSTALLED BASE	**60**	**68**	**72**	**37**

The upper part of the table gives the sales numbers as derived by VHK & VITO for LED and HID as well as the division of all sold lamps over new installations (lamp in a newly installed fixture) and lamp replacements (a new lamp replacing an old one in an existing fixture). Confidential statistical data on lamp sales of LEU members shows that the percentage of HPS lamps in HID sales has been around 35% in the last 4 years and seems to be stable. We assume that this fraction can be extrapolated from LEU members to the whole EU28 sales. Knowing that High Pressure Mercury Vapour lamps will be banned in 2015 and assuming that these lamps will be replaced by a different technology than HID (mainly LED) we obtain that the ratio of HPS to HID sales in the EU28 will be 39% after 2015. The 2nd part in the table gives the projected HPS to HID ratio derived in this way. The division of HID over new and replacement is calculated from the division for all lamps given by VHK & VITO in the following way: assuming that all LED sold until 2020 are new installations and that the new to replacement ratio is the same for all conventional technologies, the total number of HID lamps can be split in new and replacement (third part in table). Using the HPS to HID ratio's obtained the number of new and replacement HPS lamps are then calculated. Finally, assuming a 4-year replacement cycle for HPS lamps, LEU derives the installed base of HPS light points in the EU28.

Source: LEU Ex. 4(c)(I-III)(2015a)

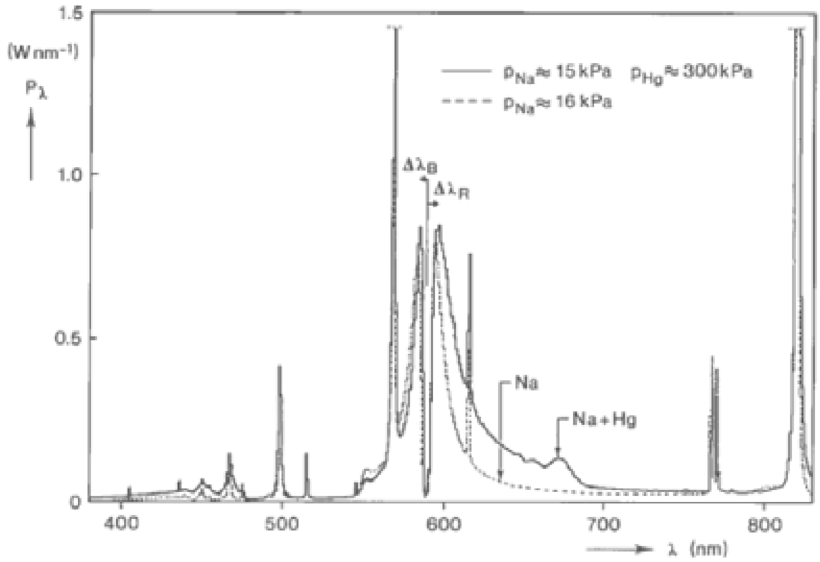
14.3 Applicant's Justification for Exemption

LEU[355] argues that the exemption is still needed as eliminating mercury is not possible and reducing mercury dose per lamp would not allow producing lamps of comparable performance. LEU states that alternatives are becoming more common, but are explained not to be suitable as lamp (component level) replacements in existing installations.

14.3.1 Possible Alternatives for Substituting RoHS Substances

If a sodium discharge lacks mercury, the energy radiated is considerably lower. The lamp with mercury radiates more between 600 and 700 nm and the lamp also produces more light in the blue range (Figure 14-4). The decrease in visible radiation in a lamp without mercury is due to the higher thermal losses of the Na-plasma as compared to an Na-Hg plasma. The loss of luminous efficacy is about 14 lm/W.[356]

Figure 14-4: Spectra of a Hg-containing and a Hg-free HPS lamp



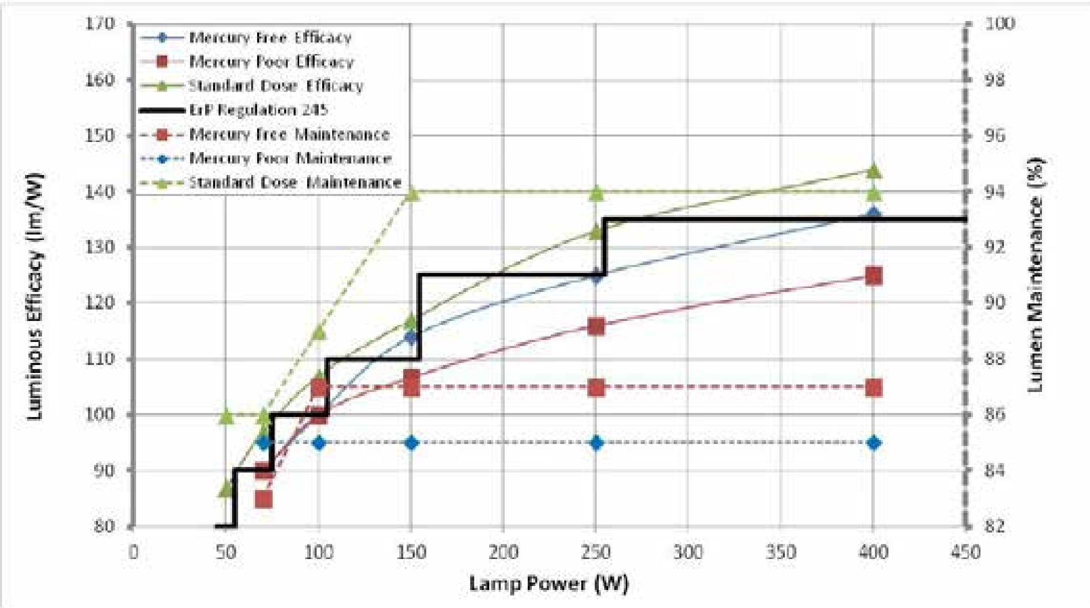
Source: Referred to in LEU Ex. 4(c)(I-III)(2015a) as Department for Environment Food and Rural Affairs (DEFRA), Life Cycle Assessment of Ultra-Efficient Lamps. Navigant Consulting Europe Ltd. 2009

By replacing the mercury pressure with an equivalent xenon pressure, the thermal losses can be kept constant. However, because the electrical conductivity of xenon is higher than that of mercury, a longer and narrower arc tube is required to bring the lamp voltage back to the specified value. The use of this type of tube decreases the luminous efficacy as compared to the standard lamps. Mercury is condensed in the amalgam when

[355] Op. cit. LEU Ex. 4(c)(I-III)(2015a)
[356] Op. cit. LEU Ex. 4(c)(I-III)(2015a)

the lamp is cold. Ignition of this lamp requires a relatively low peak voltage pulse (2 kV). As xenon is not condensed when the lamp is switched on, starting a lamp with a high xenon pressure is more difficult. A higher voltage pulse is needed to cause breakdown in the high pressure xenon and this voltage pulse alone is not enough: a special antenna needs to be provided to enhance the electric field during ignition. Even with the antenna, the pressure of xenon, which can be used, is limited by the requirement that ignition on all installed conventional ballasts is guaranteed.[357] To reach equivalent lumen output a higher sodium pressure would be required but the high temperature needed to evaporate the sodium limits the lifetime of the lamp. In practice the mercury free lamps are approximately 5% less efficient, have a reduced lumen maintenance (-5%) and a shorter lifetime (4 years of operation instead of 6 years), see also Figure 14-5.

Figure 14-5: Luminous efficacy and lumen maintenance of three types of HPS lamps



Source: LEU Ex. 4(c)(I-III)(2015a)

The luminous efficacy and lumen maintenance of mercury free and mercury poor HPS lamps are currently still lacking versus the standard dosed types. Mercury poor lamps are also not compliant with ErP Regulation 245/2009. While progress in efficiency, reliability and lumen maintenance has been made, the mercury containing counterparts have seen the same trend. It is not expected that Hg-free or mercury poor HPS will catch up on the performance of the highest performing Hg-containing HPS products, especially since R&D resources are increasingly dedicated to LED developments.

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[357] The consultants understand this to refer to the need for such lamps to be electrically compatible with existing installation to allow their use as replacement lamps.

The Preparatory Study for Eco-Design Requirements of ErP's for Public Street Lighting[358] shows that there is an almost linear relationship between environmental impact and energy efficiency (p. 212) of different lighting scenarios. The authors conclude that due to the lower efficiency of mercury free HPS lamps the studied scenario of replacing all installed HPS lamps with mercury free HPS has a negative overall environmental impact (p. 227) and is therefore not recommended.

14.3.2 Possible Alternatives for Eliminating RoHS Substances

LEU distinguishes in their application between the availability of LED alternatives on the component level (lamp replacement) and on the system level (luminaire/installation replacement.

14.3.2.1 LED Replacement Lamps

LEU explains that numerous LED replacement lamps for HPS are proposed by a large variety of suppliers. However, substitute comparability hinders acceptable retrofitting:

- The lumen output of the substitute is much lower than the HPS lamp it should replace (in the order of 25% of the HPS luminous flux);
- The replacement lamp is much larger than the HPS lamp and will not fit in the vast majority of the luminaires;
- The optical characteristics of the substitute lamp are completely different leading to distorted beam patterns of the luminaires.

A typical example of advertised "retrofit" solutions is given in Figure 14-6.

[358] Quoted in LEU Ex. 4(b)(I-III)(2015a) as Preparatory Study for Eco-Design Requirements of EuP, Lot 9, Public Street Lighting, P. Van Tichelen, T. Geerken, B. Jansen , M. Vanden Bosch (Laborelec), V. Van Hoof, L. Vanhooydonck (Kreios), A. Vercalsteren

Figure 14-6: Typical advertised LED retrofit lamp for HPS lamp replacement

Source: LEU Ex. 4(c)(I-III)(2015a)

In street lighting applications the light levels are strictly regulated and replacement with lamps with much lower luminous flux can cause dangerous situations in traffic. So at least for these regulated applications the use of these LED "retrofits" is not possible.

HID lamps are compact and are in general high power lamps. In the application it is required that HID lamps operate in closed luminaires. Since over 90% of the power supplied to the HID lamp leaves the burner as radiation (visible light, infrared radiation and some UV) the temperature of the luminaire and the lamp is stabilized without the need for heat sinking. The glass surface of the outer bulb of the lamp is heated by conduction of the heat generated in the burner (10% of total supplied power) and by absorption of about half of the infrared radiation from the burner. In total the glass envelope is heated by approximately 40% of the lamp power.

For a currently available 120 lm/W LED lamp the power that is transformed into light is about 40% and there is no IR or UV. So 60% of the power is transformed into heat that has to be removed by convection/radiation to the surrounding air in the closed luminaire. LEU gives an example of a future LED lamp with an efficiency of 150lm/W. To generate the same amount of light this lamp requires only 80% of the power of the 120 lm/W HPS (120/150*100%). For this LED the radiation is now 50% of the input power and the heat generation is the other 50%. So, the heat that needs to be removed by convection/radiation is now 40% of the input wattage to the 120 lm/W HPS.

Since a typical HPS lamp of intermediate power also has an efficacy of 120 lm/W, the power to be removed is now almost equal to the heat loss from the current HPS glass bulb. So for this hypothetical, very efficient LED lamp that might exist in the future, the envelope temperature will be approximately the same as for the current HID lamp. The question is thus whether this efficient LED lamp can operate in the hot lamp envelope? LED lamps can have a long lifetime, above 25000 hrs, as long as the junction temperature of the LED is not above 100°C. As argued above the heat loss to the envelope of 150lm/W LED and for a HPS lamp are the same. So measurement of the envelope temperature of the HPS lamps in a luminaire will predict the temperature of the envelope of the future LED lamp with the same size. Since the transport of heat in a lamp via the lamp base is limited, the only path for the heat to disappear is via conduction to the air surrounding the lamp. In a closed luminaire, warm air limits the transport, but even if the lamp would operate in open air, the compact size needed to fit as a retrofit lamp in the closed luminaire limits the cooling opportunities. On the basis of data concerning the measured surface temperature of HPS lamps of different power, LEU assumes that LED retrofit lamps (reaching at least the same temperature) will have a surface temperature from 160-400°C. This is much higher than the optimal LED junction temperature of 100°C, meaning that LED replacement lamps with the same size as the current HPS lamps cannot exist in the coming decades or that the emitted light flux is lower and/or the lifetime is limited.

It is also explained that should LED lamp replacement alternatives become available, that their use in existing installations would require rewiring of the luminaire.

LEU summarises that LEDs have insufficient performance. Whether it is mostly because of light output or dimensional depends on the approach: more light can be provided by making the lamps bigger, but the HPS specification is never reached and it makes the lamp even more out of dimensional specification. In practise, these lamps are only used in cases where the luminaires are oversized, where there are no requirements on light level and distribution and where it is acceptable to reduce the light level drastically. These conditions represent a very small fraction of the installations as the majority of HPS lamps are used in public lighting conditions where there are strict legal requirements for the lighting provided.[359]

14.3.2.2 LED Replacement Installations

According to LEU[360], LED solutions are entering the market rapidly. McKinsey[361] shows that on the world level LED is competing mainly in the initial market of new luminaires. It is reasonable to state this is also true in Europe.

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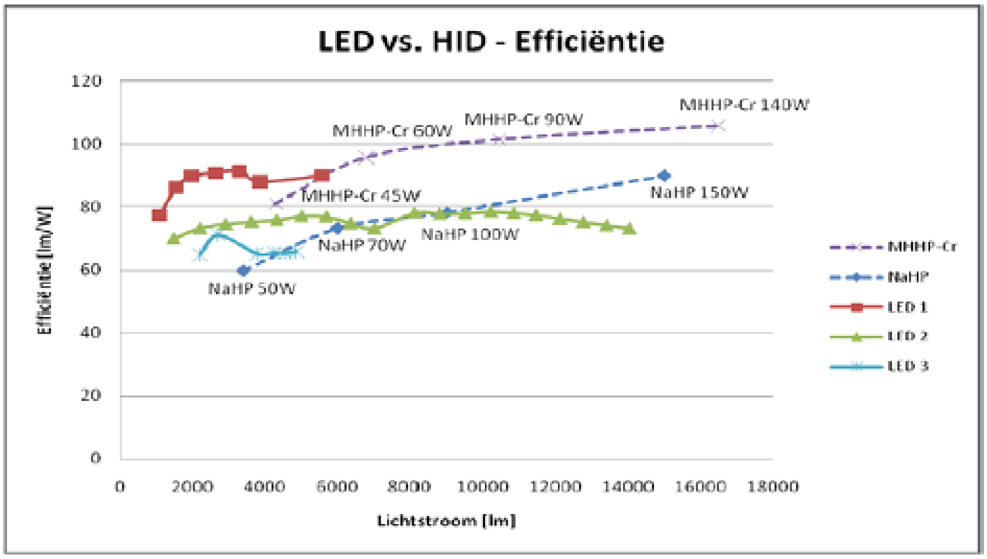
[359] LEU Ex. 4(c)(I-III)(2015b), Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 4c(I-III) (renewal request), submitted 15.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_c__I-III_/Ex_4c_LightingEurope_1st_Clarification-Questions_final.pdf

[360] Op. cit. LEU Ex. 4(c)(I-III)(2015a)

In principle, it is technically possible to replace the complete HPS installation by an LED solution. While this replacement has many advantages there are also significant drawbacks and challenges. A study[362] from the Renselaer Polytechnic Institute in Troy, NY, comparing street layouts with several HPS and LED light points found that, in order to guarantee uniformity and sufficient illuminance levels in accordance with the relevant regulations, the poles on which the fixtures are mounted have to be replaced and the spacing changed (more poles required). The reason for this is basically that LED luminaires are efficient or available below 6000 lumens only. LED streetlight layouts on average resulted in a slightly lower power demand than the average HPS streetlight layouts. The LED layout with the lowest power demand had 81% of the power demand of the HPS layout with the lowest power demand. However, the power demand per kilometre of street for individual layouts varied significantly.[363]

Figure 14-7: Luminaire efficiency of HPS (NaHP), ceramic metal halide (MHHP-Cr) and LED



Note: Efficientie = efficacy, Lichtstroom = Lumen output
Source: Quoted in LEU Ex. 4(c)(I-III)(2015a) as EANDIS presentation at Energiedag VVSG Openbare Verlichting - J. Delandtsheer and K. Putteman, Energiedag VVSG Openbare Verlichting, 19 march 2013. Available from http://www.vvsg.be/Omgeving/Documents/AV%20d4906_VVSG_Energiedag2013_S26_OpenbareVerlichting_JeroenDelandtsheer.pdf

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[361] Quoted by LEU Ex. 4(c)(I-III)(2015b) as: Lighting the way: Perspectives on the global lighting market, McKinsey 2012 second edition
[362] Quoted in LEU Ex. 4(c)(I-III)(2015a) as: [1] National Lighting Product Information Programme. 2010. Streetlights for Collector Roads. Rensselaer Polytechnic Institute. Available from http://www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SRStreetlights.pdf (August 2011); and
[2] National Lighting Product Information Programme. 2011. Streetlights for Local Roads. Rensselaer Polytechnic Institute. Available from http://www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SR_StreetlightsLocal.pdf (August 2011)
[363] Op. cit. LEU Ex. 4(c)(I-III)(2015a)

In a later communication, LEU confirms however that the feasibility for replacement of the luminaire with LED luminaires has improved over the last years. However, the light plan with the new luminaires on existing poles still has to be adapted to provide the required legal light fluxes. The characteristics of replacing an HPS (and more generally an HID) luminaire with an LED luminaire in 2015 are described in the draft interim Preparatory Study on Light Sources for Ecodesign and/or Energy Labeling Requirements[364] prepared by VITO and VHK, see par. 5.17.4. The report states that the LED luminaires nowadays need about 20% less lumen to provide the same lighting. However the cost of LED luminaires is still significantly higher than that of an HID luminaire, especially for the higher lumen packages. In paragraph 5.18.2 the report predicts that, nevertheless, the replacement of HID luminaires with LED luminaires will be common practise in the following years: "Considering current trends in street lighting and considering the advantages of LED luminaires over LED retrofit lamps, this is expected to be a frequently used option, in particular for low wattage HPS-lamps at the end of the luminaire life time (30 years)."[365]

It is not always commercially feasible for the owners of these professional lighting systems to invest in new LED luminaire solutions when lamps need to be replaced. Such a change requires not only changing the light source but the whole lighting system including luminaire, its optics and magnetic or electronic driver system.[366]

14.3.3 Environmental Arguments

LEU discusses results of three public LCA's published for general HID lamps[367] and makes a comparison between results of these studies related to ceramic metal halide lamps in comparison with LEDs. However, LEU explains that the comparison made is not a suitable comparison for HPS, as according to LEU there would be no retrofit replacements for HPS lamps. A true comparison would need to assume that the luminaire is replaced and not just the lamp.

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[364] Referenced in LEU Ex. 4(c)(I-III)(2015a) as Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19) Draft Interim Report, Task 4(Technologies), May.2015, VITO, VHK http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources_Task4_may2015_Draft.pdf

[365] Op. cit. LEU Ex. 4(c)(I-III)(2015b)

[366] Op. cit. LEU Ex. 4(c)(I-III)(2015a)

[367] Referenced in LEU Ex. 4(b)(2015a) as:

- Department for Environment Food and Rural Affairs (DEFRA). Life Cycle Assessment of Ultra-Efficient Lamps. Navigant Consulting Europe Ltd. 2009
- AT. Dale.MM. Bilec,J. Marriott, D. Hartley,C.Jurgens,E. Zatcoff Preliminary comparative life-cycle impacts of streetlight technology. Journal of Infrastructure Systems193— 199,(2011).
- Preparatory Study for Eco-Design Requirements of EuP, Lot 9, Public Street Lighting, P. Van Tichelen, T. Geerken, B. Jansen , M. Vanden Bosch (Laborelec), V. Van Hoof, L. Vanhooydonck (Kreios), A. Vercalsteren

As the referenced studies are from 2009-2011, and it is possible that available LED alternatives have developed (i.e. results are now outdated), the discussed results are not reproduced here and can be viewed in the applicants document.

In the case of a ban on mercury containing replacement lamps a huge investment into LED replacement luminaires will have to be made in the short time span of the replacement cycle of an HPS lamp (4 years). The environmental impact of early end-of-life for millions of still operational HID installations, to LEU's knowledge, has not been quantitatively assessed. However, it is reasonable to assume that the total negative environmental impact caused by this forced substitution is likely to outweigh the total environmental benefits. In view of the natural life of HPS installations, natural replacement of end-of-life installations by LED solutions will take 15 to 25 years.

14.3.4 Road Map to Substitution

LEU explains that, in reference to lamps for new installations, mainly LED luminaires solutions are used. Most of the currently produced HPS lamps are used in existing installations. For this market the LED solutions are not suitable and LEU estimates that the installed base of HPS lamps will be replaced by LED in a time frame of 12 years, i.e. by 2027. In view of the uncertainty involved in this extrapolation a period of 10-15 years seems the best estimate.[368]

14.4 Stakeholder Contributions

A number of contributions have been made by stakeholders raising general points in relation to discharge lamps. Such contributions are summarised in Section 4.4 of the general lamp chapter.

The European Environmental Bureau (EEB), the Mercury Policy Project and the Responsible Purchasing Network[369], submitted comments specifically in relation to Ex. 4(b) and 4(c), explaining that LEDs are increasingly being made to replace HPS lamps and are expected to increase for this application. EEB et al. recommend the Commission to monitor improvements in the availability, performance and price of LED replacements, to consider an expiry date as practical. It is explained that HPS lamps are rapidly being replaced by other technologies because:

- of their poor colour quality – they appear yellow because their CRI is typically in the 20s;
- they cycle on and off, which causes maintenance problems; and

[368] Op. cit. LEU Ex. 4(c)(I-III)(2015b)

[369] EEB et al. (2015a),The European Environmental Bureau, the Mercury Policy Project, and the Responsible Purchasing Network, Environmental NGOs Response to Stakeholder consultation 2015 #2 on mercury- containing lamps – Exemption 1-4 (Review of Annex to the RoHS directive), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1-4_EEP-RPN-MPP_Comments_on_RoHS_Request-final_20151016.pdf

- because of their relatively short life.

EEB et al. explain that some HPS lamps have already been phased out from the market due to energy efficiency under the ErP Directive. For those that remain, HPS lamps with a lower mercury content and more-efficient ceramic metal halide lamps, which also have a lower mercury content than equivalent HPS lamps, are widely available as practical drop-in replacements. A few examples are detailed:

- GE Lighting has a line of low-CRI (<25) Lucalux Standard High Pressure Sodium Lamps (in both tubular and elliptical shapes) in a wide array of common wattages including 70W, 100W, 150W, 250W, 400W and 1000W that can meet the following lower mercury levels through the use of amalgam technology:
  - P < 155 W = 20 mg per burner;
  - >155 W < P < 405 W = 20 mg per burner;
  - P > 405 W = 25 mg per burner.

  The datasheet for this product, which uses ceramic technology, explains that these products are easy drop-in replacements for standard HPS lamps. It states: *"Lucalox™ XO Superlife lamps comprise a sodium discharge system operating at a high pressure within a ceramic arc tube which is mounted in an outer glass bulb. These lamps offer outstanding luminous efficacy, lumen maintenance thus reducing energy and maintenance costs….Easy replacement of standard HPS lamps, fits standard HPS sockets – no new wiring, ballast or fixture are required"*[370]. From the referenced datasheet the consultants observe that lamp dimensions are 156/211/260/283 mm (lengths) by 39/48 mm (diameter) for tubular modules and 156/186 mm (length) by 72/76 for elliptical shapes, depending on wattage.

  Philips MASTER SON-T APIA Plus Xtra High Pressure Sodium Lamps, which contain a ceramic discharge tube, are this manufacturer's most energy-efficient and long-lasting HPS lamps (with rated lifetimes that range from 38.000 to 45.000 hours). It is promoted as *"the longest life, most reliable"* and *"most cost-effective solution in road lighting. All of the HPS lamps in this family of products, which include common HPS wattages of 50W, 70W, 100W, 150W, 250W and 400W) can meet our proposed limits."*[371] From the referenced data sheet the consultants observe that lamp dimensions are 156/210/257/283 mm (lengths) by 36/48 mm (diameter) for tubular modules, depending on wattage.

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[370] EEB et al. (2015a) refers to the following data sheet: http://www.gelighting.com/LightingWeb/emea/images/HPS_Lucalox_XO_Superlife_Lamps_Data_sheet_EN_tcm181-12784.pdf

[371] EEB et al. (2015a) refers to the following data sheet: Philips Company, Data Sheet for MASTER SON-T APIA Plus Xtra High Pressure Sodium Lamps, 3 July 2015, http://download.p4c.philips.com/l4bt/3/344247/master_son-t_apia_plus_xtra_344247_ffs_eng.pdf

EEB et al. thus recommend reducing the Hg allowance of lamps with P ≤ 405 W (Ex. 4(c)(I and II)) to 20 mg and lamps with P > 405 W of Ex. 4(c)(III) to 25 mg. They propose these reductions to take affect by 1 September 2018 at the latest

EEB et al. also claim that many companies offer a variety of drop-in LED replacement lamp for HPS lamps, and it is further explained that the benefits of LEDs over HPS lamps are many. For details please see Section 13.4 of chapter 13.0 (Ex. 4(b)).

14.5 Critical Review

14.5.1 Scientific and Technical Practicability of Substitution

From the information that LEU provides it can be followed that eliminating mercury in HPS lamps is not practical. Though HPS lamps without mercury are said to exist, it can be understood that they require a different ignition, and it is thus assumed that such lamps would not be practical as replacements in existing installations. Information also shows that HPS lamps with lower mercury levels exist. Some of these, termed poor-mercury-HPS, are said to have a lower efficacy and not to comply with the ErP regulation. In this respect it is understood that they are not available on the EU market and would thus not be practical as substitutes. However the data comparing such lamps to standard dosed HPS (see Table 14-2) suggests that the efficacy differences are between 5-17 lm/W. Information was not provided as to the difference in Hg dosing, however in the consultants opinion against such efficacy differences (ca. 5-12 % less efficient), it may make sense to integrate the Hg trade-off into considerations whether HPS-Hg-poor lamps should be prohibited on the EU market or not. Arguing as to which lamps should be prohibited under ErP and which should not is however beyond the consultants' mandate. In this context HPS-Hg-poor lamps can at present not be considered as a substitute.

Table 14-2: Comparative data for Hg-free, Hg-poor and standard dosed HPS lamps, related to efficacy and lumen maintenance

Wattage	*Mercury Free Technology*		*Mercury Poor Technology*		*Standard Dose Technology*		ERP Efficacy
	Mercury Free Efficacy	Mercury Free Maintenance	Mercury Poor Efficacy	Mercury Poor Maintenance	Standard Dose Efficacy	Standard Dose Maintenance	
50					83	85	80
70	90	83	90	85	95	89	90
100	100	87	100	85	107	90	100
150	114	87	106.7	85	117	91	110
250	125	87	116	85	130	92	125
400	136	87	125	85	142	92	135
600					150	88	135
1000					130	80	-

Values averaged over published values of main European suppliers

Source: Quoted in LEU Ex. 4(c)(I-III)(2015b)

In contrast, information from EEB et al. shows that there are HPS lamps on the market with significantly lower amounts of Hg, which could support a reduction of Hg allowances specified in Ex. 4(c).

Where LED alternatives are concerned, it can be understood that a distinction must be made between replacement of lamps on the component level (retrofit lamps) and on the system level (installation replacement). LEU explains that on the system level, LED alternatives are numerous; however it is argued that such replacements do not necessarily provide benefits in terms of energy efficiency, particularly for higher lumen output lamps. This argumentation is however substantiated with reports that may be outdated and LEU later confirms that the feasibility for replacement of the luminaire with LED luminaires has improved over the last years. Though current alternatives may show some drawbacks (e.g., lumen output, higher investment costs), LEU admits that the shift towards LED installations has already begun and that HPS lamps are mainly needed to allow lamp replacement in existing HPS installations. The consultants thus conclude that regardless of possible drawbacks, LED alternatives are already perceived on the market as an acceptable alternative.

Where LED alternatives are discussed as replacement lamps in existing HPS installations, it can be understood that alternatives have various limitations. The understanding that most alternatives have dimensions that would prevent their use as alternatives in existing installations clarifies that such lamps would not be practical as retrofit substitutes. Furthermore, as it is explained by LEU that most installations are closed, it can also be followed that the thermal incompatibility of LED alternatives would affect their service life, which would also make substitution with such lamps impractical.

14.5.2 Environmental Arguments

Though LEU mentions LCAs that could be used to provide an indicative comparison of HPS and LED alternatives, this information is explained not to compare the LED in a way that would represent an actual substitution situation. The reports are furthermore outdated and thus this information has not been evaluated.

LEU raises concern that an early phase-out of HPS lamps could result in early-end-of-life of HPS installations which would need to be scrapped, at the latest 4 years after the last HPS replacement was available. Assuming that replacement lamps shall not be available that would be compatible with existing installations, this can be followed in relation to an installed base of 72 million in 2016. In this respect it can be followed that LED alternatives are not a compatible replacement in most cases, supporting this argument. However, it cannot be concluded that other lamps, either Hg-free HPS, HPS-poor HPS, HPS with lower amounts of Hg or metal halide alternatives could not be used as replacements should the Hg allowances be reduced or should the exemption not be renewed. Of the installed stock, it is also assumed that some installations are already approaching EoL and shall be replaced with LED alternatives as a result of the trend in this direction. In this sense, this estimation is considered to be higher than the impacts that could actually be expected.

Further aspects raised are of general nature and are discussed in the general chapter under 4.5.3.

14.5.3 Stakeholder Contributions

For the discussion of general aspects raised by stakeholders, please see Section 4.5.7. As for information provided by EEB et al. specifically for HPS lamps, it concerns both Ex. 4(b) and Ex. 4(c). Thus, not all aspects are understood to be relevant for this exemption. EEB et al. present a few examples of HPS alternatives with lower amounts of mercury, in support of a reduction of the hg allowances of the exemption at hand. As some of these lamps are HPS lamps, their compatibility with current installations is assumed. The differences in Hg doses are understood to be considerable in some cases (for example for entry III the proposal is a reduction of 15 mg). It is also understood that replacement lamps could be needed for existing HPS installations for up to 12 years due to the lack of suitable LED alternatives. In this sense, the consultants agree that a reduction in Hg levels would be beneficial, even if this would mean that replacements are not available for a certain part of the product range (i.e. where Hg doses are above recommended levels). Though EEB et al. also provide examples of LED alternatives, as discussed in Section 13.5.3 of Chapter 13.0 regarding Ex. 4(b), it can be followed that such lamps would not be compatible with current installations due to their dimensions and also because of possible heat dissipation issues.

14.5.4 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

On the luminaire level it can be understood that a trend is already underway towards LED alternatives. Despite arguments raised by LEU that such installations have drawbacks in relation to lamps with higher lumen outputs as well as requiring higher investments, such alternatives are understood to be acceptable as LED installations are being placed on the market, among others to replace HPS ones. This is also supported by LEU's statements that most HPS lamps placed on the market are used as replacements in existing installations.

In contrast, on the level of lamp replacement/retrofit, LED alternatives are understood not to be sufficiently available. Though in some cases it is explained that they could be used (oversized luminaires and where there is acceptability of changes in light level and distribution), in most cases their dimensions would not allow their use. Thermal and

electrical incompatibility with existing HPS installations are also understood to limit their applicability at present.

It can further be followed that though Hg-free HPS lamps are available, that they would not be suitable as retrofit replacements in most HPS installations as their ignition is different and thus lamps would not be electrically compatible. It is also understood that despite the existence of Hg-poor HPS lamps, that these are prohibited by ErP and can thus not be considered as an available substitute in the EU. In contrast, it is observed that there are standard-dosed HPS lamps with lower amounts of Hg that would support a reduction of the Hg allowances currently specified in the exemption entries. In this respect, the proposal submitted by EEB et al. to reduce the Hg allowance of lamps with P ≤ 405 W (Ex. 4(c)(I and II)) to 20 mg and lamps with P > 405 W of Ex. 4(c)(III) to 25 mg, can be followed.

14.6 Recommendation

Though substitutes are understood to be available on the system level (for use in new LED luminaires), such substitutes are too large to allow their application as substitutes in existing HPS luminaires (component replacement). It is assumed that the shift of the luminaire stock from HPS to LED is already underway, but that a phase-out could result in an early end-of-life of existing HPS luminaires (i.e. in waste and potential overall environmental dis-benefit). It is thus recommended to renew the exemption for a further 5 years. However, as proposed by EEB et al., as alternatives with reduced mercury are available in different shapes and for different wattages, it is recommended to reduce that amounts of Hg currently specified in the exemption entries. LEU estimates that the installed base of HPS lamps will be replaced by LED in a time frame of 12 years, i.e. by 2027.[372] Considering the long period understood to be needed to allow the shift from HPS luminaires to LED luminaires, an Hg reduction is perceived as beneficial for the environment.

In light of Article 5(2), from a legal perspective, an exclusion of EEE falling under Cat. 8 and 9 from the scope of this exemption may not be possible.

[372] Op. cit. LEU Ex. 4(c)(I-III)(2015b)

Exemption 4(c)	Scope and dates of applicability
Mercury in other High Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner):	
(I) P ≤ 155 W; 25 mg may be used per burner after 31 December 2011	For Cat. 5: 31 August 2018; For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024;
(II) 155 W < P ≤ 405 W; 30 mg may be used per burner after 31 December 2011	
(III) P > 405 W; 40 mg may be used per burner after 31 December 2011	
(IV) P ≤ 405 W; 20 mg may be used per burner	For Cat. 5: from 1 September 2018 until 21 July 2021
(V) P > 405 W; 25 mg may be used per burner	

Note: As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

14.7 References Exemption 4(c)(I-III):

EEB et al. (2015a) The European Environmental Bureau, the Mercury Policy Project, and the Responsible Purchasing Network, Environmental NGOs Response to Stakeholder consultation 2015 #2 on mercury- containing lamps – Exemption 1-4 (Review of Annex to the RoHS directive), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1-4_EEP-RPN-MPP_Comments_on_RoHS_Request-final_20151016.pdf

LEU Ex. 4(c)(I-III)(2015a) LightingEurope, Request to renew Exemption 4(c) under the RoHS Directive 2011/65/EU: Mercury in High Pressure Sodium lamps, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_c__I-III_/4c_LE_RoHS_Exemption_Req_Final.pdf

LEU Ex. 4(c)(I-III)(2015b) Response To Oeko-Institut regarding the 1st Questionnaire Exemption No. 4c(I-III) (renewal request), submitted 15.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_c__I-III_/Ex_4c_LightingEurope_1st_Clarification-Questions_final.pdf

15.0 Exemption 4(e): "Mercury in Metal Halide Lamps (MH)”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Abbreviations

CRI	Colour rendering index
EEE	Electrical and electronic equipment
EoL	End of life
Hg	Mercury
HID	High intensity discharge lamps
HPMV	High pressure mercury lamps
IR	Infra-red
LED	Light emitting diode
LEU	LightingEurope
MH	Metal halide
WEEE	Waste electrical and electronic equipment

15.1 Background

LightingEurope (LEU)[373] has applied for the renewal of Ex 4(e) of Annex III of the RoHS Directive.

This exemption covers mercury in metal halide lamps (MH). LEU explains that MH lamps are very compact and used in (parabolic) reflectors where the compact light source needs to be at the exact position in the focal point to get the right light beam. MH lamps have long lifetimes, high light fluxes and high efficacy. LEU continues to explain LED alternatives that are compatible with MH luminaires and provide similar performance are currently not available on the market. The lifetime of MH professional luminaires is long (15-25 years) and thus the exemption shall be needed for many years.[374]

The applicant thus requests the renewal of the exemption with the current wording formulation as listed in Annex III of the RoHS Directive and the maximum available duration allowed (based on Art. 5(2) of the Directive):

"*Mercury in metal halide lamps (MH)*"

15.2 Description of Requested Exemption

Exemption 4(e) covers High Intensity Discharge Lamps (HID) containing Metal Halides (MH). As detailed bellow, a distinction is observed in metal halide between the use of a ceramic discharge tube and a quartz discharge tube as well as between different metal halide salts within the discharge tube.

Figure 15-1: Metal halide lamps

Source: LEU Ex. 4(e)(2015a)

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[373] LEU Ex. 4(e)(2015a), LightingEurope, Request to renew Exemption 4(e) under the RoHS Directive 2011/65/EU: Mercury in metal halide lamps (MH), submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4__e_/4e_LE_RoHS_Exemption_Req_Final.pdf

[374] Op. cit. LEU Ex. 4(e)(2015a)

The light in the HID lamp is generated by metal atoms, in metal halide lamps the metal atoms are transported into the arc as metal halide molecules. The name MH lamp refers to these molecules. LEU provides a description of the different families of lamps covered by Ex. 4(e), together with an indication of the efficiency of the lamps, the range of lamp powers available, colour properties and the lifetimes (see Table 15-1).

Table 15-1: Lamp types and properties

Lamp type (Application)	Metal halide salt fill	power range [W]	η (lm/W)	Ra	T_c (K) [K]	lamp life [kHr]
Shop lighting Ceramic Discharge tube	Na–Tl–(Ca,Ce)– Dy–Ho–Tm iodide	20 – 400	90-120	>85	3000-4200	12 – 20
Shop lighting Quartz Discharge tube	Na–Tl–Dy–Ho–Tm iodide	70 – 250	80	85	3000-4200	10
Outdoor Lighting HPI	Na–Tl–In iodide	250 – 2000-45kW *	80	67	4500	20
Outdoor Lighting Sodium Scandium	Na–Sc iodide	70 – 2000	85	65	4000	20
Entertainment Quartz Discharge tube	Dy–Ho–Tm–Cs iodide & bromide	400 – 2500-25kW	85-90	>90	5500	0.75-1.5

Source: LEU Ex. 4(e)(2015a)

Metal halide salts used by different manufacturers differ and are detailed in Table 15-1. In Table 15-2, the acronyms used for MH lamps by manufacturers are also given.

Table 15-2: MH abbreviations

Metal halide lamp	Names used:
Ceramic discharge tube (low-medium power)	CMH CDM HCI
Quartz discharge tube (Low power)	MHN ARC HQI MH
Quartz discharge tube (Medium-high power)	MVR MH HPI

Source: LEU Ex. 4(e)(2015a)

HID lamps generate light in a compact plasma arc with a high brightness. It is this brightness that enables the luminaire to gather the generated light efficiently into a broad or narrow beam of light with only a small reflector. After the lamp has started by a voltage pulse, the initial noble gas discharge heats the lamp and evaporates the condensed mercury. The increasing mercury vapour pressure increases the electrical resistance in the discharge which allows for putting more power into the discharge. As a consequence of more power coupled into the discharge, the discharge tube wall will heat up and the metal halide salts are evaporated. Once all mercury has been evaporated and the metal halides have entered the discharge, a state of equilibrium is established between the power entering the discharge and the light emitted from the discharge. The optimal efficiency is reached at this equilibrium. In contrast to low pressure fluorescent lamps, mercury is not consumed over the life time of MH lamps. Its initial amount is instrumental over life.

The metal halide family is a diverse family with lamps designed for different purposes in the professional market. MH lamps are designed for specific applications (lighting for cities, shops, roads, theatres, disco's, outside sports, etc.) and the shape and size varies from the lowest power 20 Watt in shop lighting to above 2000 W in sports lighting and lighting stages for concerts. These lamps are handled by technically skilled installers and sold by specialized distributors or as part of lighting equipment. The customers are for example institutions, governmental projects, municipalities, retail chains, sports facilities, designers of lighting equipment etc. The installation of the lamps requires knowledge how to handle these lamps that require special driving gear including igniters that generate high voltage pulses.[375]

The efficiency of MH light sources varies from good (80 lm/W) to highly efficient (120 lm /W). The ability to render colours ranges from good enough in street lighting, to excellent for lighting fashion shops or TV broadcasting. This broad range of lamp powers and spectral demands has led to a wide range of lamps each designed for its own field of use.[376] MH lamps can only operate on designated control gear that switch the lamp on, and regulate its power. Lamps of different MH families have dedicated control gear. These lamps can produce UV radiation and the lamps become very hot during operation.[377]

15.2.1 Amount of Mercury Used under the Exemption

Mercury is dosed in the discharge tube during lamp manufacturing as liquid metal. The amount of mercury dosed per lamp depends on aspects like lamp power and optical performance. For metal halide lamps in the scope of Ex. 4(e) the dosed mercury amounts mainly vary between 3 and 30 mg. Since the dosing determines the lamp voltage and the colour properties, the dosing process has to be performed accurately. For higher power lamps with a discharge tube with a larger volume the amount of mercury needed to realise the same pressure increases. The distribution of mercury dose is not Gaussian: the 10% lower boundary is at 3 mg, the median dose is 4.7 mg, the mean dose is at 11 mg and the 90% upper bound is at 28 mg. [378]

The lowest amount of mercury is used in low power lamps that have a discharge tube with a small volume. The higher power lamps used for instance in soccer stadia use almost 200 mg. These lamps have an operating power of 1.8 kW and generate 155000 lumen.[379]

Some of the Ex. 4(e) lamps are very high power lamps, designed for projection equipment, enabling extremely high lumen flux of daylight, essential for studios, theatre, and the movie industry. In such lamps more mercury is used. These lamps need a certain

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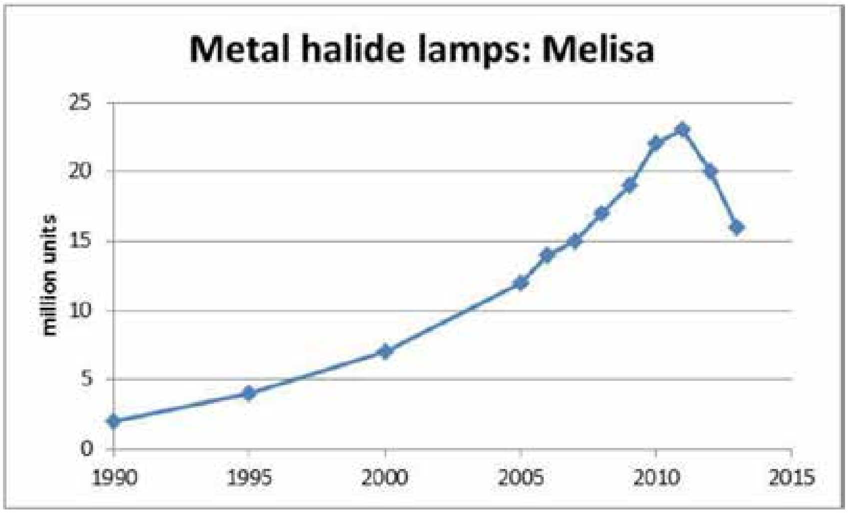
[375] Op. cit. LEU Ex. 4(e)(2015a)
[376] Op. cit. LEU Ex. 4(e)(2015a)
[377] Op. cit. LEU Ex. 4(e)(2015a)
[378] Op. cit. LEU Ex. 4(e)(2015a)
[379] Op. cit. LEU Ex. 4(e)(2015a)

lamp volume to prevent that the heat generated in the discharge melts the wall of the discharge vessel. If the same high power lamp is used for projection the arc must be very compact. This requires a very high mercury pressure. The combination of a very high pressure and a large discharge volume leads to the necessity of a large amount of mercury (up to 2 gram) compared to the other types of MH lamps. These high power lamps for entertainment consist of less than 0.05 % of the total market.

The total amount of mercury brought on the European market in the MH lamps is calculated in the following way: The database of one of the manufacturers is used to find the number of lamps sold in 2013 and the used mercury amount per lamp produced. Based on the estimated market share of this manufacturer in the different lamp families the total amount of mercury entering the European market is estimated to be around 16 Million lamps*11mg (mean dose)= 176 kg.

The market for MH lamps is slowly shrinking due to the fact that LED solutions are replacing MH lamps. The biggest part of the market is however the replacement of failed lamps. The installed luminaire stock is big and the lifetime of these professional luminaires is long. An indication of the European market size and the historical sales can be found in Figure 15-2, on the basis of the VHK & VITO study. The graph indicates that the fast growth of metal halide lamps is levelling off and even decreasing.

Figure 15-2: Historical sales of metal halide lamps, EU28 all sectors



Source: Referenced in LEU Ex. 4(e)(2015a) as "Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements" Draft Interim Report, Task 2 Markets, pag. 2-14, 19-November-2014. http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources_Task2_nov2014_Draft.pdf

15.3 Applicant's Justification for Exemption

LEU[380] argues that the exemption is still needed as eliminating mercury is not possible and reducing mercury dose per lamp would not allow producing lamps of comparable performance. LED alternatives are becoming more common, but are explained not to be suitable as lamp (component level) replacements in existing installations.

15.3.1 Possible Alternatives for Substituting RoHS Substances

LEU explains that for MH lamps several attempts were performed to replace mercury. The alternatives used are: [381]

- Zinc, but these lamps show severe loss of light over life;[382]
- A high rare earth pressure, but these lamps contain very narrow arcs due to arc contraction. This results in visual flicker of the light, due to movement of the arc and might lead to short lamp life when the hot arc touches the wall of the discharge vessel; [383]
- Xenon that reduces the thermal losses but gives a very low lamp voltage. Therefore a different operation mode is needed and the pressure makes the lamp difficult to ignite; [384]

In the SCHELP project, co-funded by the Belgium government (IWT), Philips attempted to replace each function of mercury with a separate substance.[385] The project led to reasonable efficacies for cool white light, however for the warmer colour impression no efficient solution was found. Apart from the problems mentioned above, several others occurred: problems occurred with ignition on existing driver systems due to the halogens[386], and severe chemical reactions occurred with the reactor vessel with new chemistries[387]. The study concluded that operation of the lamps on existing lamp driver

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[380] Op. cit. LEU Ex. 4(e)(2015a)
[381] Op. cit. LEU Ex. 4(e)(2015a)
[382] Referenced in LEU Ex. 4(e)(2015a) as M. Born. Untersuchungen zum Ersatz des Quecksilbers in keramischen Hochdruckgasentladungen mit Hilfe von metallischem Zink. ISBN: 3-89653-788-1, 2000 ; Born. Mercury free high pressure discharge lamps. In Proc. 9th Int. Symp. Sci. and Technol. of Light Sources, page 43, 2001; M. Born, H. Giese, and I. Niemann. Abschlusbericht BMBF-Projekt 13N8264, 2005
[383] Referenced in LEU Ex. 4(e)(2015a) as M. Käning, L. Hitzschke, B. Schalk, M. Berger, St. Franke and R. Methling, Mercury-free high pressure discharge lamps dominated by molecular radiation, J. Phys. D: Appl. Phys. 44 (2011) 224005
[384] Referenced in LEU Ex. 4(e)(2015a) as C. Stewart, M. Duffy, J.Dakin, V. Roberts,S-A El-Hamamsy, H. Witting,L. Inouye, K. Shimizu, K. Araki, Inductively Coupled HID Lighting System, The 6th International Symposium on the Science and Technology of Light Sources, Budapest, 1992
[385] Referenced in LEU Ex. 4(e)(2015a) as Rijke, A.J. (2013, Oktober 16). The power balance of ceramic metal-halide high intensity discharge lamps. TUE : Technische Universiteit Eindhoven (235 pag.) (Eindhoven: Technische Universiteit Eindhoven). Prom./coprom.: prof.dr.ir. M. Haverlag, prof.dr.ir. G.M.W. Kroesen & dr.ir. S. Nijdam.
[386] Referenced in LEU Ex. 4(e)(2015a) as E G Estupinan, R Pereyra, Y-M Li and W P Lapatovich The effect of hydrogen iodide on the ignition of Hg-free metal–halide lamps,J. Phys. D: Appl. Phys. 44 (2011) 224004
[387] Referenced in LEU Ex. 4(e)(2015a) as R. Hilbig, A. Koerber, S. Schwan and D. Hayashi, Novel molecular

systems was judged to be impossible if no concession could be done to the efficiency or lifetime of the mercury free lamps. The project did not lead to a mercury free lamp, or to an alternative lamp reduced in mercury, as a retrofit on existing lamp driver systems. [388]

In relation to mercury reduction in MH lamps, LEU explains that the presence of Hg is important to fulfil a few certain functions typical of MH lamps (or at least of some types of MH lamps):

- **Warm colour:** Due to the broadening process of the atomic sodium radiation by mercury atoms the yellow sodium line is broadened towards the red part of the spectrum. This red radiation is responsible for the good colour rendering in many metal halide lamps, but also for the low correlated colour temperature, for instance in 3000K ceramic metal halide lamps. Without mercury this warm colour is not possible. (This property is not valid for the high colour temperature lamps (>5000K) which do not have sodium in the discharge.)
- **Efficiency:** The most efficient radiating atom in the HID lamp is sodium: it radiates two yellow lines close to the maximum eye sensitivity. However this radiation would be absorbed in the colder regions of the plasma. Collisions of the radiating atom with other sodium atoms and mercury broaden the emission lines allowing the light to escape from the plasma. The efficiency of the lamp would thus be lower, were mercury not present. Mercury is very important for the lamp efficiency, not only for lamps with sodium but also for other radiating atoms like rare earth atoms. (This property is not valid for the small group of high colour temperature lamps (>5000K) that do not have sodium in the discharge.)
- **Lifetime:** The heavy mercury atoms move only slowly in the high temperature plasma. Therefore the heat flux lost from the centre of the arc tube by thermal convection and conduction is low. Much of the power remains inside the plasma and can only escape as visible radiation or as infra-red (IR) radiation. This improves the efficiency of the plasma in generating visible light. The reduced conduction of heat also protects the material of the discharge tube from overheating. The high pressure of mercury limits evaporation of the hot Tungsten electrode. This helps to maintain the light flux over lifetime, as a high evaporation rate of tungsten would lead to blackening of the arc tube and a reduced transmission of light. Replacement by a noble gas could help limiting the diffusion, but will increase the demands on the igniter.
- **Switch on:** Ignition of high pressure lamps is enabled by a short pulsed voltage of 3-5 kV. This is possible because the high pressure of mercury is absent when the cold lamp starts. Upon replacement of mercury by other

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discharge light sources, J. Phys. D: Appl. Phys. 44 (2011) 224009

[388] Op. cit. LEU Ex. 4(e)(2015a)

gases, for instance Xenon, the high buffer gas pressure is already present in a cold lamp. This makes the lamp difficult to ignite and pulses certainly over 10 kV, but more typically 25-60 kV are needed. Such high voltages would require special electrical isolation measures and new lamp holder base designs to prevent discharges outside the lamp. These measures prohibit the use of such lamps in existing installations. In MH lamps the salts react with the oxygen impurities that are inevitable in the lamp production process. This reaction results in the formation of iodine molecules. These are volatile at room temperature and effectively prohibit the lamp igniting (the molecules bind the mobile free electrons). When mercury is present in the lamp the iodine will react with mercury to the much less volatile mercury iodide that does not hinder ignition.

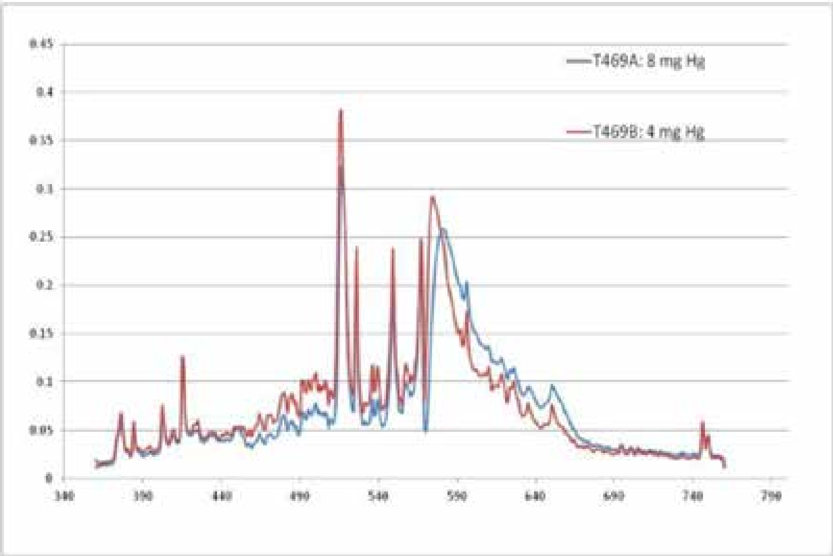
- **Stable operation:** The HID lamps are operated on alternating current. Each period when the current becomes zero, the radiation plasma cools down and the charge carriers disappear. The electrical resistance increases and the driver will encounter difficulties in keeping the lamp burning. The high density of mercury has enough heat capacity to keep the plasma warm enough for a short time. Eliminating the mercury makes the plasma extremely difficult to operate. The driver would need to supply very high voltage just after the current zero moment. The need for such a new driver effectively prevents the lamp [i.e. Hg-free lamps – consultant's comment] to be used as a replacement in an existing luminaire. Again a high noble gas pressure can have the same function, but these lamps cannot be started with the current igniters on the market.

Though some of these functions are understood to only be relevant for MH lamps containing sodium, LEU explains why mercury is also necessary for sodium-free MH lamps. Lamps with high colour temperature (>5000K) are mainly used in projection systems. The amount of red radiation needed is not large at these high correlated colour temperatures (but important for the colour rendering). Since these lamps are used in optical systems the brightness of the arc is the most important lamp property. This means that the lamp has a short electrode distance and needs a high mercury pressure to get a high enough lamp voltage. So also in the case of high colour temperature lamps a high mercury pressure is needed.

LEU explains that the main role of mercury is to make sure the lamp operates at the right power and to optimize the efficiency of the combination lamp and driver. Dosing less mercury will lead to lamps that will not perform the task they are designed for. Reduction of mercury first leads to a low lamp voltage. This will lower the power supplied by the driver to the lamp. This results in a lower light flux. As a secondary effect the lower power will reduce the temperature of the lamp causing reduced vapour pressure of the light emitting atoms in the discharge. This again leads to a change in light colour since not all metals have the same temperature dependence of the vapour

pressure and in many cases a reduced colour rendering, since part of the spectrum is not filled. An example of the effects on the spectrum is illustrated in Figure 15-3. In this case the red radiation is dramatically reduced.[389]

Figure 15-3: Spectrum change with mercury content



Note: Labels were not included in original. It is assumed that the X axis represents spectral output wavelength, while the y axis is assumed to represent lamp pressure.
Source: LEU Ex. 4(e)(2015a)

With the lower mercury dose the discharge tube needs to become longer to reach the same lamp voltage. This results in different colours when the lamp is used in different burning positions (for instance horizontal or vertical). To reduce this dependence, the physics of this process has been studied in a space station. Gravity is the driving force for the de-mixing that occurs in the lamp resulting in colour differences in different operating positions. No technical solution was found for this issue. [390]

Due to the nature of the lamp and driver combination a reduced lamp voltage leads to an increased current in the current limiting ballast. This will reduce the lifetime of the reactor ballast and can even lead to overheating. This limits the opportunity to design lamps with less mercury that can retrofit broken lamps in existing installations. Although a reflector, designed for efficient collection of light, demands a short arc (and high mercury pressure), in some cases of MH street lighting lamps the mercury dose is low. This is possible since the optical demands are such that a longer arc tube is not a disadvantage: the light has to be distributed over a long stretch of road and a longer arc is beneficial in this case. Moreover, these lamps are mainly used in horizontal burning position, such that the longer arc tube is no issue in this street lighting application. The

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[389] Op. cit. LEU Ex. 4(e)(2015a)
[390] Op. cit. LEU Ex. 4(e)(2015a)

colour rendering however falls below CRI 70, due to the low mercury dose, but for outdoor lighting this is good enough. [391]

15.3.2 Possible Alternatives for Eliminating RoHS Substances

LEU distinguishes in their application between the availability of LED alternatives on the component level (lamp replacement) and on the system level (luminaire/installation replacement.

According to LEU, LED cannot replace MH lamps on a one to one replacement basis when a lamp has failed because of the following reasons:[392]

- MH lamps are compact and are in general high power lamps.
- The optics in the luminaires are designed to operate efficiently when the compact light source (MH lamp) is in the optimal focal point. This limits the possibilities for creating retrofit LED lamps, as the LED lamps cannot be too big and the cooling fins must also not be in the optical path.
- MH lamps operate in closed luminaires. Since over 90% of the power supplied to the MH discharge vessel leaves the discharge as radiation (visible light, infrared radiation and some UV) the luminaire and the lamp do not become too warm. Over 33% of the energy is transformed into visible light. An LED replacement bulb will need to be operated in the existing luminaire and thus also needs to get rid of the excess heat. The MH lamp envelope is heated by the non-radiative losses (10%) and by the UV and infrared radiation absorbed by the glass envelope. The total heat flux to the glass is about 40% of the power supplied to the MH lamp. In efficient LED lamps over 35% of the power is transformed into light, while the other 65% is to be removed as heat. This means that the heat flux from an LED is currently 1.5 times the heat from an HID lamp. Modern LED's can operate at junction temperatures close to 100°C, higher temperatures lead to reduced efficiency, shorter lifetimes and might even damage the device. At 100°C a lifetime of close to 25,000 hours is possible. Since the transport of heat from a lamp to the luminaire via the lamp base is limited, the only path for the heat to disappear is via conduction and convection to the air surrounding the lamp, and possibly by radiation if the lamp is hot. In a closed luminaire, warm air limits the transport, but even if the lamp would operate in open air, the compact size needed to fit as a retrofit lamp in other closed luminaires limits the cooling opportunities. With a hypothetical LED that is even 25% more efficient than the MH lamp, the heat loss would not be 1.5 times higher than for MH lamps, but would about the same. The reduction is due in part because the LED uses now 25% less power, and furthermore the non-radiative losses decrease. The bulb temperature of the replacement LED lamps will then come close to the

[391] Op. cit. LEU Ex. 4(e)(2015a)
[392] Op. cit. LEU Ex. 4(e)(2015a)

temperature of the MH lamps. Measurements of the glass bulb of existing MH lamps (Table 15-3) demonstrate the common temperatures of relevance. The bulb is much warmer than the required temperature of the LED junction of retrofit lamps. (400°C >> 100°C). Therefore retrofit lamps of the same size as MH lamps cannot be made now, at least as long as the efficiency of the LED's is not much larger than that of the current MH lamps[393].

- The last design obstacle is of electrical nature: MH lamps are operated on electrical systems that generate high voltage pulses to ignite the lamps. These ignition pulses are typical 3,500V, but can reach 5,000V or even 60,000 V in systems with a called hot-restrike facility. These igniters have to be taken out of the system (if not integrated in the electronic driver) and rewiring of the luminaire is needed if LED's would be designed to replace the failed HID lamps.

To support their argumentation, LEU provides some details as to typical diameters, power ratings and temperatures of MH lamps when operating. These are reproduced in Table 15-3.

Table 15-3: Temperature measurement of common metal halide lamps

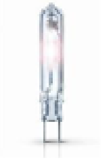
Lamp type	Bulb diameter [mm]	Power [W]	Twall [°C]	stdev [°C]
Ceramic metal halide	19.0	70	394	4
	19.0	150	525	5
	14.0	70	580	10
	13.3	50	490	10
Quartz metal halide	46.6	400	560	10
Studio Stage lamp	30	575	650	15

Source: LEU Ex. 4(e)(2015a)

Further data is provided to support argumentation related to differences in lamp dimensions, is reproduced in Table 15-4.

393 Consultant's comment: Although unclear from LEU's information, this conclusion may relate to the greater proportion of power converted to light within a more efficient LED (and more importantly to visible light). This would reduce the loss to heat. It is thus possible that LEU's statement is meant to reflect that once lamps are more efficient, the waste heat would be lower, the heat sink could be smaller and so the lamp could be smaller and thus possibly fit in existing luminaires.

Table 15-4: Examples of an LED replacement and MH lamps illustrating the problems with lamp size

Lamp type	Picture	Diameter	Length
LED		120 mm	300 mm
Ceramic Metal halide		14 mm	40 mm
Quartz Metal halide lamp		20 mm	117 mm

Source: LEU Ex. 4(e)(2015b) - The table shows the replacement lamp used in the VHK/VITO study (ref 2 task 4 page. 138) and possible metal halide alternatives.

In contrast, LEU explains that on the system level there are LED luminaires that can replace the HID system; examples are seen in luminaires for lighting fashion shops and even LED solutions are found for lighting tennis fields and soccer stadia. [394]

In a later communication, LEU[395] confirms that LED luminaire alternatives for MH luminaires can match the efficacy, life, CRI, light flux, and colour temperature of MH lamps.

15.3.3 Environmental Arguments

LEU mentions two public LCA's which have been published for HID lamps[396], however explains that in applications where directional lighting is involved an appropriate LCA is difficult, since both systems need to be compared on an equal basis [i.e. functional equivalence – consultant's remark]. In this respect, LEU raises aspects of light distribution of street lighting that make the comparison difficult. LEU explains that both, the LED and MH lamp efficiency are improving but perhaps "*to a lesser extent the HID efficiency/maintenance has been improved in the time since the publication of the studies. The HID efficiency is improved to from 90 lm/W to over 115 lm/W and the light flux over life stays above 90% at the end of life for some families*". LEU also explains that the comparison made is not a suitable comparison for MH and LED, as according to LEU

[394] Op. cit. LEU Ex. 4(e)(2015a)
[395] Op. cit. LEU Ex. 4(e)(2015b)
[396] LEU Ex. 4(c)(e)(2015a)

there would be no retrofit replacements for MH lamps. A true comparison would need to assume that the luminaire is replaced and not just the lamp.[397] LEU states that a definitive conclusion on the basis of the LCA's cannot be made at this time, at least not on the basis of the information that is publicly available.

In light of this last comment and as the referenced studies are from 2009-2011, and LEU itself claims that both MH and LEDs have improved, the discussed results are not reproduced here and can be viewed in the applicants document.

MH lamps are in the scope of EU Directives 2002/96/EC - WEEE and 2012/19/EU– WEEE Recast. Take back systems are installed in all EU Member States to facilitate the collection and recycling of lamps. The recycling percentage for the combination of household and non-household lamp waste combined is 45%[398] and is audited each year. LEU assumes that the return percentage is the same for all categories, also for MH lamps, and thus estimate 46% of 176 Kg (see Section 15.2.1) to mean that 81 Kg is recovered, or about 100 kg enters the environment. [399]

Substitution of mercury would inevitably lead into the changeover to a new light source technology, like LED. Since there are no LED replacement lamps for MH luminaires, as a consequence existing installations and drivers would need to be replaced completely resulting in high investments for customers and governments while the installed equipment is still capable to be used for many years should replacement lamps remain available (typical life cycle for professional luminaires is around 10-15 years for indoor use and 25-30 years in outdoor). This would create additional waste from the installations scrapped before end-of-life (EoL). The total installed number of luminaires with MH lamps installed is estimated to be about 500 million globally or approximately 150 million in Europe. [400]

15.3.4 Road Map to Substitution

LEU is not able to share the individual roadmaps the member companies have planned for their LED portfolio. There is no general roadmap to develop LED replacements for all existing applications. The expectation is that the penetration of LED's in the market of MH lamps will happen via the route of new luminaires. There are no MH retrofit lamps on the horizon yet. The market for MH lamps is declining. However since the existing professional luminaires are fully functional and have a long lifetime the customer needs replacement lamps on a regular basis. The MH lamps are also needed for customers with luminaires for high pressure mercury lamps (HPMV). These lamps are banned from the

[397] Op. cit. LEU Ex. 4(e)(2015a)
[398] This figure is elsewhere stated as 46%. The consultants assume that it is rounded here to 45% or that it is a typing mistake.
[399] Op. cit. LEU Ex. 4(e)(2015a)
[400] Op. cit. LEU Ex. 4(e)(2015a)

market [consultants comment – through the EcoDesign Directive due to their lower efficiencies]. The energy saving replacement lamps (i.e. MH) cannot be banned.[401]

15.4 Stakeholder Contributions

A number of contributions have been made by stakeholders raising general points in relation to discharge lamps. Such contributions are summarised in 4.4 of the general lamp chapter.

The European Environmental Bureau (EEB), the Mercury Policy Project and the Responsible Purchasing Network[402], submitted comments specifically in relation to Ex. 4(e). EEB et al. recommend the exemption to be limited after 1 September 2018, to ceramic MH for lamps with a wattage below 250 watts, whereas no limitation apply above this level. Ceramic MH lamps are explained to have less mercury, a higher efficiency and a longer rated life-time than quartz metal halide lamps. Ceramic metal halides are widely available up to 250 watts.

EEB et al. provide a few examples to support that quartz metal halide lamps – particularly low-wattage models – can be readily replaced with more energy-efficient ceramic metal halide (CMH) lamps, which have less mercury and longer rated life-time:

- Osram's 100-watt Powerstar HQI quartz metal halide lamp has a mercury content of 11,2 mg, while its 100-watt Powerball HCI ceramic metal halide lamp has a mercury content of only 8,5 mg and has a longer rated life of 12,000 hours. In addition, the quartz MH lamp is less energy-efficient (Class A) than the ceramic MH (Class A+). [403]
- GE manufactures both, quartz and ceramic double-ended MH lamps in equivalent wattages. Its 150-watt Arcstream Double-Ended Quartz MH Lamp[404] has a mercury content of 14.5 mg, while its 150-watt ConstantColor

[401] Op. cit. LEU Ex. 4(e)(2015b)

[402] EEB et al. (2015a),The European Environmental Bureau, the Mercury Policy Project, and the Responsible Purchasing Network, Environmental NGOs Response to Stakeholder consultation 2015 #2 on mercury- containing lamps – Exemption 1-4 (Review of Annex to the RoHS directive), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1-4_EEP-RPN-MPP_Comments_on_RoHS_Request-final_20151016.pdf

[403] EEB et al. (2015a) refers to: Osram, Data Sheet for Powerstar HGI Quartz Metal Halide Lamps, 30 September 2015, http://www.osram.com/osram_com/products/lamps/high-intensity-discharge-lamps/metal-halide-lamps-with-quartz-technology/powerstar-hqi-e-coated/index.jsp; and Osram, Data Sheet for Powerball HCI Ceramic Metal Halide Lamps, 30 September 2015, http://www.osram.com/osram_com/products/lamps/high-intensity-discharge-lamps/metal-halide-lamps-with-ceramic-technology/powerball-hci-ep/index.jsp

[404] EEB et al. (2015a) refers to: GE Lighting Company (Europe), Arcstream Double Ended Quartz Metal Halide Lamps with UV Control, November 2013, http://www.gelighting.com/LightingWeb/emea/images/Metal_Halide_Arcstream_Double_Ended_Lamps_Data_sheet_EN_tcm181-12560.pdf

Ceramic MH Lamp[405] has a mercury content of only 10 mg. Moreover, while the quartz MH lamp has a Class A rating and a rated life of 12,000 hours, the equivalent ceramic MH lamp has a Class rating of A+ and a rated life of 15,000 hours.

- Philips offers a wide array of ceramic MH lamps. Its 250-watt MASTER Plus CityWhite Tubular Ceramic Metal Halide lamp contains only 25.3 mg of mercury and has a Class A+ rating and a rated life of 27,000 hours.[406] In contrast, its equivalent 250-watt quartz MH lamp (MASTER HPI-T Plus Quartz Metal Halide Lamp contains 36 mg of mercury and has a Class A+ rating, also, but a shorter rated life of 20,000 hours.[407]

EEB et al. argues that since quartz and ceramic MH lamps are very often available in the same shape and type of lamps and bases, they are almost always interchangeable. Therefore, offering the RoHS Exemption on the ceramic models only would result in use of these easy, drop-in replacements with multiple environmental benefits, including significant mercury reduction as well as energy savings.

15.5 Critical Review

15.5.1 Scientific and Technical Practicability of Substitution

From the information that LEU provides it can be followed that eliminating mercury in MH lamps is not practical. Though available information shows that various investigations have been carried out into the possible replacement of mercury with other substances (e.g. zinc, rare earth, xenon, etc.), it is understood that none of these resulted in lamps coming on the market that could replace MH lamps.

A reduction of Hg in MH lamps is also understood not to be practical. As explained by LEU, mercury is important for facilitating various functions within MH lamps, including lamp power rating, lamp life and light flux. Reducing the mercury dose can affect the size of the lamp, when the lamp voltage is to be retained at a specified level. The changes in mercury pressure when the lamp is cold (not in use) and warm (operative) are of importance for enabling an ignition of the lamp with short pulsed voltages that are lower than for example required for igniting xenon lamps for which additional measures are needed to ensure ignition. In lamps with sodium, mercury is particularly understood to

[405] EEB et al. (2015a) refers to: GE Lighting Company (Europe), ConstantColor CMH TD Double Ended Ceramic Metal Halide Lamps: 35W, 70W and 150W, August 2013, http://www.gelighting.com/LightingWeb/emea/images/ConstantColor_CMH_TD_Double_Ended_Lamps_Data_sheet_EN_tcm181-12599.pdf

[406] EEB et al. (2015a) refers to: Philips Company (UK), MASTER CityWhite Ceramic Metal Halide Lamps, 28 August 2013, http://download.p4c.philips.com/l4bt/3/322972/master_citywhite_cdo-et_322972_ffs_eng.pdf

[407] EEB et al. (2015a) refers to: Philips Company (UK), MASTER HPI-T Plus Quartz Metal Halide Lamps, 29 August 2015, http://download.p4c.philips.com/l4b/9/928481300098_eu/928481300098_eu_pss_enggb.pdf

be of importance to ensure for example warmer colours and lamp efficiency. LEU also explains that the mercury is not consumed over the lifetime of the lamp, but rather that the dosed amount remains instrumental throughout life. As the amount of mercury is also understood to be related to the pressure that needs to be obtained in the lamp throughout operation, it is understood that the dose for each lamp needs to be accurate and cannot be increased or decreased without changing the characteristics of the lamp.

In relation to differences between ceramic and quartz MH discharge tubes, EEB et al. propose a phase-out of MH lamps with a quartz discharge tube, in favour of the more efficient ceramic ones. From information provided by EEB et al. specifically for this exemption, the examples of ceramic and quartz MH lamps are understood to show that ceramic lamps may have lower mercury amounts, at least in some cases. This would in general support measures to promote the substitution of quart MH lamps with ceramic ones in some cases.

VHK and VITO[408] also explain in this regard that "*the more recent ceramic arc tube allows higher operating temperatures, which also implies higher efficacies, especially when combined with the 'unsaturated' working conditions, that avoid the presence of halide salts in the liquid phase, even when the lamp is dimming down to 50% of its rated power. Considering that unsaturated ceramic arc tube MH-lamps have higher efficacies, it has been proposed to raise the minimum efficacy requirements in the regulations, thus effectively phasing-out the quartz versions. Stakeholders (LightingEurope, IALD) have warned against this, because in their opinion the ceramic version cannot replace the quartz version in all applications: the difference in size of light source area would compromise the optical performance of many fitting types*."

LEU[409] further provided the following input in this respect:

> "*The mercury content depends on the design parameters of the arc tube (electrode gap, volume of the arc tube, Metal Halide salt composition), so ceramic MH lamps do not systematically have a lower mercury content.*
>
> *There are examples for ceramic lamp families with a very low mercury amount like the CosmoPolis lamp family (1-2 mg)... But there are also some examples where the ceramic lamp contains more mercury. For instance the Osram HQI-TS Excellence 150 W NDL has with 12,3 mg less mercury than the HCI-TS 150 W/NDL with 18,2 mg. Likewise the quartz lamps HQI-T 250W D and HQI-T 250W/N Plus lamps contain 18 mg mercury whereas the two comparable ceramic lamps (they have the same socket and bulb but differ in the Light centre and/or the colour temperature) the HCI-TT 250W/942 and the HCI-TT 250W/830 do have 30,5 mg resp. 27,3 mg.*

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[408] VITO & VHK (2015), Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'), Final report, Task 4: Technologies,Prepared for the European Commission, DG ENER.C.3.

[409] LEU Ex. 4(e)(2015c), LightingEurope, RoHS, Summary of Critical Observations to the EEB Submission of 16.10.2015, submitted per email on 30.11.2015

Certain colour temperatures (daylight, cool daylight) of quartz MH lamps which have a wide distribution in the market do not have an equivalent in ceramic MH lamps. Customers cannot buy the desired light colours any more. There is no ceramic MH replacement for the 250 W (Fc2 socket) quartz MH lamps by any of the big manufacturers. There are quartz MH lamps with special properties like low ignition voltage or that lamps can be operated in open fixtures which have no equivalent as ceramic MH lamps. Again the whole luminaires have to be replaced with high costs and here also the functionality is not available any more…

Shapes are different between several quartz MH and Ceramic MH lamp types… The G12 socketed Quartz MH lamps for instance are considerably shorter than the ceramic counterpart, the different values are part of the standard for metal halide lamps. (IEC 61167 Edition 3 2015-01 "Metal halide lamps – Performance specification") see Figure 15-4*.*

A luminaire adjusted to the shorter length cannot accommodate the longer replacement and would have to be replaced entirely at higher costs. Similarly the shape of the double ended HQI Excellence allows for smaller reflector openings where a double ended ceramic MH cannot fit any more. Either the reflector or the entire luminaire would have to be exchanged at higher costs.

Many double-ended quartz MH lamps are not suitable for hot restrike (instant re-ignition after switch-off through higher ignition voltage). This is commonly not permitted for ceramic MH lamps, so the respective luminaires cannot be used anymore and the functionality cannot be replaced by ceramic MH lamps.

The optical properties differ between quartz MH lamps and ceramic MH lamps. The transparent burner of the quartz MH lamp allows precise projection of the arc while the translucent ceramic arc tube will scatter the light from the arc. The resulting light intensity distribution and beam control may be influenced undesirably. Uniformity and minimum illuminance levels may not be achieved anymore."

Figure 15-4: Illustration of possible ceramic vs quartz lamp size differences

Note: Quartz MH lamps with G12 base have as defined per standard IEC 61167 a maximum length of 76 mm for both 70 W and 150 W while MH lamps with ceramic arc tube and a G12 base have a maximum length of 90 mm until 70 W lamp power and 100 mm for 100 W and 150 W.

Source: LEU Ex. 4(e)(2015c)

To conclude, though it can be followed that in some cases, ceramic MH lamps would have lower doses of mercury, it cannot be concluded that this would always be the case. It can also not be concluded whether ceramic MH lamps could replace quartz MH lamps in luminaires, or whether this would require technical adjustments or replacement of the luminaire.

In relation to alternatives that could allow elimination, a distinction can be made between the component level (replacement lamps) and the system level (luminaire/installation replacement). Various LEDs are understood to have been developed that may supply sufficient light when used in a compatible luminaire. However, it can be followed that such lamps have various limitations for use in MH luminaires.

VHK & VITO[410] provide a comparison of various HID lamps (also including some MH examples), which is reproduced below (see Table 15-5). From the table it is understood that LED lamps are becoming comparable with MH lamps in terms of efficacy. Further detail is provided as to MH lamps on the market in Table 15-6. From these two tables it can be concluded that MH lamps and LEDs currently have similar efficacies.

LED alternatives are also understood to have larger dimensions that would prevent their use in MH luminaires which are explained to be very compact. The light distribution of such alternatives and measures applied for heat dissipation can also make the application of such alternatives in MH luminaires impractical, as these installations are specifically designed optically for MH lamps. A significant drawback is the understanding that most existing MH luminaires are compact and closed, and it is expected that this would result in the heating up of the internal environment of the lamp to above 100°C. As it is understood that the lamp life decreases when the LED junction is operated above this temperature, it can be followed that using LED alternatives as replacements would result in decreased lamp life. Furthermore, as mentioned for other discharge technologies, existing installations are understood not to be electrically compatible with LED alternatives, particularly requiring the ignition to be disconnected to allow LED use.

In parallel, it can be understood that alternative LED luminaires are coming onto the market and gradually replacing existing MH luminaires. This is reflected in the decreasing numbers of MH lamps sold on the EU market (see Figure 15-2) and also confirmed by LEU who estimates that most MH lamps sold are used to replace malfunctioning lamps in existing installations.

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[410] Op. cit. VHK & VITO (2015)

Table 15-5: Examples of HPM reference lamps, HPS- and CMH-substitutes, and LED retrofit lamps

Description	W	lm	lm/W class	CCT	CRI	Dim ming	L (mm)	D (mm)	Life (kh)	Price (€)	Note
HPM lamps (ref)											
Philips HPL N 100W E26 A23 HG	100	4400	44	3700	45		138	73	24000		1
Philips HPL N 250W E39 HG CL 211 91	250	11500 12000	46	5800 4100	20 40		211	91	24000		1
Philips HPL N 400W E39 HG	400	21000	52	4200	50		290	122	24000		1
Non-LED retrofits											
Havells-Sylvania Relumina 85W WDL E27 (CMH)	85	7500	88 A+	3000	84		178	62	18000		2
Havells-Sylvania Relumina 170W WDL E40 (CMH)	170	15000	88 A+	3000	84		228	87	18000		2
Philips SON H 110W E27 (HPS retrofit)	110	8000- 9600	84	2000	25	no	156	71	28000		3
Philips SON H 220W E40 (HPS retrofit)	220	19000	87	2000	25	no	227	91	26000	19.49	3
Philips SON H 350W E40 (HPS retrofit)	350	34000	98	2000	25	no	290	122	26000	20.99	3
Philips SON APIA Plus Xtra 100W E40 (HPS BAT)	100	10000	100 A+	1950	25		186	76	40000	(60)	4
Description	W	lm	lm/W class	CCT	CRI	Dim ming	L (mm)	D (mm)	Life (kh)	Price (€)	Note
Philips SON APIA Plus Xtra 250W E40 (HPS BAT)	250	31300	120 A+	1950	25		227	91	45000	(60)	4
Philips SON APIA Plus Xtra 400W E40 (HPS BAT)	400	55400	136 A++	1950	25		290	122	45000	(60)	4
LED retrofits											
Saled BS-S HP	27 54	3240 6480	120	3000/ 4000	>80		197 258	93x 107	50000		5
CroLED E40 80/100/120W	80 100 120	7200 9000 10800	90 A	6500			280 300 340	120		75 93 104	6
MLLG-GI-LED-RETRO from 35 to 400W	65 150 400	6000 13500 38000	92-95	4100- 5500	>75	Yes	119 264 320	58/119 38/122 76/240	70000 (L70)		7

1 http://download.p4c.philips.com/l4bt/3/332443/mercury_vapor_standard_332443_ffs_aen.pdf

2 http://www.havells-sylvania.com/media/Sylvania%20Lamps/English/Relumina%20-%20English.pdf These are CMH lamps with integrated starter specifically intended for HPM retrofit. Works on existing HPM control gear. Available from Q3 2014

3 http://download.p4c.philips.com/l4bt/3/323223/son_h_323223_ffs_aen.pdf These are HPS lamps specifically intended for HPM retrofit. Works on existing HPM control gear. https://www.lampdirect.be/nl/philips-son-h (for prices)

4 http://download.p4c.philips.com/l4bt/3/344246/master_son_apia_plus_xtra_344246_ffs_aen.pdf This has been identified as a BAT HPS solution to replace HPM. In this case, starter and ballast also have to be replaced. Price estimated by study team as lamp 22+ballast 18+starter 20 euros. Installation costs have to be added.

5 http://www.saled.nl/nl/catalogus/led-straatverlichting-lichtbron/bs-s-hp/ Available in powers of 27, 36, 45 and 54 W. Lamps have an integrated gear. Existing gear to be removed or bypassed.

6 http://www.amazon.de/Leuchtmittel-Hochleistung-Beleuchtung-AC100-240V-Strahler/dp/B00M7YK63I/ref=sr_1_1?ie=UTF8&qid=1429712506&sr=8-1&keywords=100+W+E40+led+lampe (and similar) for Indoor use only (?)

7 http://www.myledlightingguide.com/ledretrofit.aspx (see links to LED retrofit kits for various powers) These lamps are not bulb-like, but flat with E26/E39 cap or mounting bracket. The existing control gear has to be removed and replaced by the LED control gear (optionally dimmable).

VHK & VITO note: The LED-lamps are intended as HID-lamp replacements, not specifically for HPM.

Source: VHK &_ VITO (2015)

Table 15-6: Efficacies of MH lamps existing on the market, compared to the minimum efficacies requested by regulation 245/2009 (EcoDesign) from April 2017.

Metal-halide lamps existing on the market				Required efficacy (lm/W), regulation 245/2009, table 10, clear lamps, from April 2017
Lamp wattage (W)	CRI	CCT (K)	Efficacy (lm/W)	
20 *(cap G8.5)*	87	3000	102	≥ 70 lm/W (for power ≤ 55 W)
45	66	2800	110	
50	89	2800	104	
50	90	4200	100	
60	73	2700	120	≥ 80 lm/W (55 W ≤ power ≤ 75 W)
60	81	4000	107	
70	87	3000	105	
70	87	4200	101	
140	66	2800	118	≥ 85 lm/W (75 W ≤ power ≤ 255 W)
150	90	3000	100	
315	90	3100	115	≥ 90 lm/W (255 W ≤ power ≤ 405 W)
315	90	4200	109	

Source: VHK & VITO (2015)

15.5.2 Environmental Arguments

Though LEU mentions LCAs that could be used to provide an indicative comparison of HPS and LED alternatives, this information is explained not to compare the LED in a way that would represent an actual substitution situation. The reports are furthermore outdated and thus this information has not been evaluated.

LEU argues that an early phase out of MH lamps (should the exemption be revoked) could lead to a large amount of waste from luminaires to be scrapped before end-of-life in lack of sufficient replacement lamps. The consultants would like to note that it is not that the amount of waste would change, but rather that end-of-life of such articles would be accelerated. In this respect it is important to take into consideration that for example, in street lighting though in some cases the whole luminaire (the pole and lamp head) would be replaced, that there is a trend towards only the lamp head being exchanged[411]. Furthermore, the materials used in lamp heads, for the most part, are understood to include various metals: “The waste typically consists of a conventional control gear (1 kg Iron and copper) and a luminaire (1 kg aluminium).”[412] For such metals, recycling practices in the EU are well established and return a large amount of secondary material to the market.

Further aspects raised are of general nature and are discussed in the general chapter under Section 4.5.3.

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[411] Please see for example: http://www.dotlux.de/strassenlaternen-und-strassenlampen-mit-dotlux-auf-led-umruesten/ last accessed 03.04.2016

[412] Op. cit. LEU Ex. 4(e)(2015a)

15.5.3 Stakeholder Contributions

For the discussion of general aspects raised by stakeholders, please see Section 4.5.7 . As for EEB et al.'s proposal to phase-out quartz MH lamps in favour of ceramic ones, please see the discussion in Section 15.5.1.

15.5.4 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

As explained above, despite various efforts to develop such alternatives, it can be followed that Hg cannot be substituted with another substance within MH lamps. It can also be followed that reducing (and also increasing) the amount of mercury would affect the function and performance of the lamp and probably also its lifetime. In this sense alternatives are understood not to be available on this level. Though it may be possible to make a distinction in the future between certain MH sub-groups in relation to the amount of Hg required for proper function, this is not expected to create actual environmental benefits. Due to the rising use of LED technology it is assumed that the lighting industry is no longer developing MH technology, so reductions in Hg amounts are not expected. In parallel, the current lack of an Hg allowance is understood not to be of concern as increasing the amount of Hg in a specific lamp would affect the lamp function negatively.

On the component level, various limitations of LED alternatives for MH lamps are apparent, particularly regarding larger dimensions of lamps, differing optical design and consequences of overheating on the LED lamp-life. These aspects among others render current LED alternative lamps as non-compatible in existing MH installations and it can be followed that an early phase-out of MH lamps would thus result in the early EoL of existing installations or at least of the luminaire heads. In relation to replacement lamps, due to the limitations explained above and as LED efficacies are currently only understood to be comparable, and not superior to those of MH lamps, it is difficult to determine whether a phase-out is recommended at this stage. On the one hand, a phase-out may accelerate the production of waste, while on the other hand it would eliminate the use of mercury and help to avoid diffuse mercury emissions from EoL. Further factors relevant to such a comparison are discussed in Section 4.5.3.2 of the general chapter. A detailed investigation is not in the scope of this review and thus it is not possible to conclude at what point early EoL of MH luminaires could be viewed as acceptable in light of the elimination of Hg and in light of possible energy savings.

Though LED alternative installations are gradually entering the new installations market, the large number of existing MH installations that would lack replacement lamps should the exemption expire would result in a large amount of waste, i.e. in a negative environmental impact.

On the system level it can be understood that a trend is already underway towards LED alternatives. Such alternatives are understood to be acceptable as the volume of MH lamps placed on the market is already decreasing and it is understood that such lamps are used mainly as replacements in existing installations. Thus it is assumed that where new installations are concerned, that LED alternatives shall gradually dominate the market. For this reason the consultants also do not see a need to restrict the use of mercury in quartz MH lamps to lamps >250 watts. Assuming that ceramic MH lamps would not be one-to-one replacements, this may result in an early end of life of quartz MH luminaires and not in a replacement of one discharge lamp with another with less mercury.

Against this background, it is concluded that renewing the exemption would be justified to allow further use of existing MH installations. LEU claims that such installations have a long service life (15-25 years), arguing the need for a long termed exemption. As detailed in the general chapter in Section 4.5.3.2 the consultants cannot conclude whether the exemption would be justified for the full lifetime of existing MH installations, but would recommend monitoring the development of LED lamps and the uptake of LED luminaires on the market.

15.6 Recommendation

Substitutes are understood to be available on the system level (for use in new LED luminaires), as is apparent by the fact that consumers are shifting to LED in new installations. LED substitutes are explained to have various limitations to allow their application as replacement lamps in existing MH luminaires (e.g. size, optical compatibility, thermal compatibility, etc.). The consultants recommend waiting until the next review to consider elimination of MH lamps in favour of LED alternatives, as a phase-out at this stage is not understood to reduce energy consumption, though expected to accelerate the end-of-life of MH luminaires (or luminaire heads). It is thus recommended to renew the exemption for a further 5 years.

In light of Article 5(2), from a legal perspective, excluding EEE falling under Cat. 8 and 9 from the scope of this exemption may not be possible.

	Exemption	Scope and dates of applicability
4(e)	Mercury in metal halide lamps (MH)	For Cat. 5, 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024

Note: As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

15.7 References Exemption 4(e):

EEB et al. (2015a) The European Environmental Bureau, the Mercury Policy Project, and the Responsible Purchasing Network, Environmental NGOs Response to Stakeholder consultation 2015 #2 on mercury- containing lamps – Exemption 1-4 (Review of Annex to the RoHS directive), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/Ex_1-4_EEP-RPN-MPP_Comments_on_RoHS_Request-final_20151016.pdf

LEU Ex. 4(e)(2015a) LightingEurope, Request to renew Exemption 4(e) under the RoHS Directive 2011/65/EU: Mercury in metal halide lamps (MH), submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4__e_/4e_LE_RoHS_Exemption_Req_Final.pdf

LEU Ex. 4(e)(2015b) LightingEurope, Response to Oeko-Institut regarding the 1st Questionnaire Exemption Request No. 4(e) "Mercury in metal halide lamps (MH)", submitted 15.9.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4__e_/Ex_4e_LightingEurope_1st_Clarification-Questions_final.pdf

LEU Ex. 4(e)(2015c) LightingEurope, RoHS, Summary of Critical Observations to the EEB Submission of 16.10.2015, submitted per email on 30.11.2015

VITO & VHK (2015) VITO & VHK, Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'), Final report, Task 4, Technologies,Prepared for the European Commission, DG ENER.C.3.

16.0 Exemption 4(f): "Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Abbreviations

ANSI	American National Standards Institute
BAT	Best available technology
CFL	Compact Fluorescent
CCFL	Cold cathode fluorescent lamps
EEE	Electrical and Electronic Equipment
EEFL	External electrode fluorescent lamps
EEI	Energy Efficiency Index
EoL	End of Life
Hg	Mercury
HID	High Intensity Discharge -
HPMV	High Pressure Mercury (vapour) lamps
HPS	High Pressure Sodium (vapour) lamps
IEC	International Electrotechnical Commission
IR	Infrared
LCD	Liquid crystal displays
LED	Light emitting diode
LEU	LightingEurope
Lm	Lumen (unit)

MH	Metal halide
MPa	Megapascal (unit)
Mpcs	Million pieces
Pa	Pascal (unit)
UV	Ultraviolet (subtypes UVA, UVB, UVC)
VDMA	German Engineering Federation (Verband Deutscher Maschinen- und Anlagenbau)
VskE	German Association for Label and Narrow Web Converters
XeBr	Xenon Bromine
XeI	Xenon iodide
Zn	Zinc

16.1 Background

LightingEurope (LEU)[413], the German engineering federation Verband Deutscher Maschinen- und Anlagenbau (VDMA)[414] and the German Association for Label and Narrow Web Converters (VskE)[415] have submitted requests for the renewal of the above mentioned exemption.

LEU explains that the replacement of mercury in the lamps covered by this exemption is scientifically and technically impracticable. Replacement lamps using a different technology such as Light Emitting Diodes (LED) are available only in very exceptional cases and even then only for a part of the application range. [416]

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[413] LEU Ex. 4f(2015a): LightingEurope (LEU), Request to renew Exemption 4(f) under the RoHS Directive 2011/65/EU Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex, submitted 15.1.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_f_/Lighting_Europe/4f_LE_RoHS_Exemption_Req_Final.pdf

[414] VDMA Ex. 4f(2015a), Verband Deutscher Maschinen- und Anlagenbau (VDMA) Exemption Request 4(f) Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex, submitted 15.1.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_f_/VDMA/4f_VDMA_excempt_req_4f_RoHS_16Jan14.pdf

[415] VskE Ex. 4f(2015a): VskE - German Association for Label and Narrow Web Converters, Exemption Request 4(f) Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex, submitted 15.1.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_f_/Vske/4f_2014-12-09_RoHS_Application_VskE.pdf

[416] Op. cit. LEU Ex. 4f(2015a)

Applicants do not expect LED alternatives to allow for a full phase-out of Ex. 4(f) lamps within the coming 5 years, and thus request a renewal of the exemption with following wording and for the maximum available duration allowed:

> *"Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex"*

16.2 Description of Requested Exemption

According to LEU[417], the scope of exemption 4(f) covers all the lamps for special lighting purposes, which do not belong to any of the groups identified in the exemptions 1(a)-4(e) by technology and application in Annex III of RoHS Directive 2011/85/EU.

The function of Hg in mercury gas discharge lamps lies within the light generating process to convert electricity into light. Electrons are emitted from a heated electrode colliding with mercury atoms which elevates their electrons to an excited state. When these fall back to their original energy state they emit photons either in the ultraviolet (UVC, UVB, UVA & UVV) or in the visible light wavelength range, depending on the technology. By using a mix of different element atoms in the hot gas plasma, each emitting at specific wavelengths, the spectral distribution of the lamp as a whole as well as the quality of colour rendition properties can be controlled. [418]

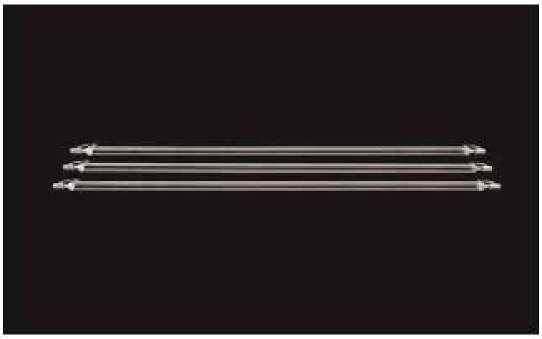
According to LEU[419] the use of mercury is essential for all lamps covered by Ex. 4(f) and needs to be kept valid. The mercury vapour is essential: all of the mercury is evaporated and the resulting pressure is chosen in such a way that:

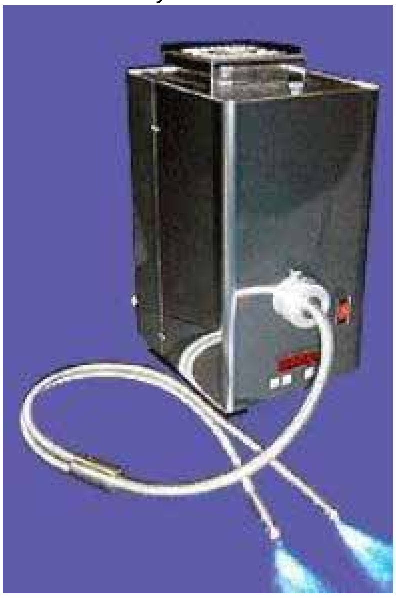
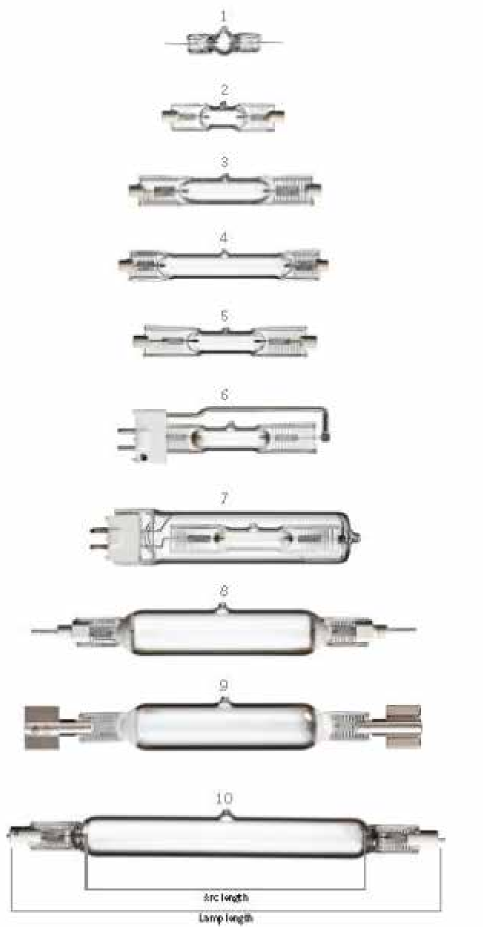
- *"the system can provide the exact power to the lamp,*
- *the discharge radiates as effective as possible,*
- *generates the required wavelengths for the desired application and finally*
- *with a brightness that allows the most effective collection of the light."*

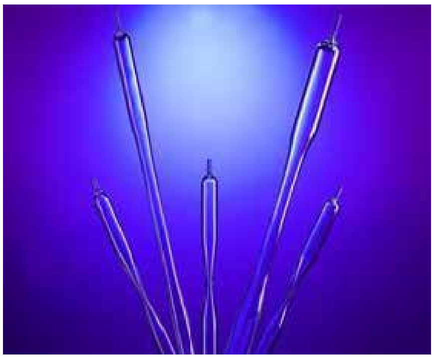
LEU provides a list and detail as to various technologies understood to be covered by Ex. 4(f), as reproduced in Table 16-1.

[417] Op. cit. LEU Ex. 4f(2015a)
[418] Op. cit. LEU Ex. 4f(2015a)
[419] Op.cit LEU 4(f) (2015a)

Table 16-1:Non-exhaustive list of examples of lamps and applications falling under Ex. 4(f)

Examples of application	Lamp types
UV lamp types	
Technologies include: · Curing lamps; · Photochemistry; · Development of polymers; · Cross-linking of resins in varnishes or inks; · Surface modification processes. Currently medium pressure lamps containing mercury are used in a wide range of manufacturing applications – including amongst others wood finishing, PCB manufacture, glass bottle decoration, metal container decoration, sewer rehabilitation, contact lens manufacture, plastic bottle decoration, optical fibre coating, ink jet printing, plastic parts coating etc.: · Vacuum ultraviolet (VUV) irradiation for surface cleaning; · Hardening and drying of UV-hardened ink, coating and adhesive; · Hardening of liquid crystal substrates bonded by dripping; · Bonding of CD and DVD; · Preliminary tests at chemical reaction plants; · Resin coating and others; · Photochemistry, e.g. photolysis of H2O2; · Skin tanning; · UV sterilisation with applications in municipal and industrial plants: sewage sterilisation, compact drinking water sterilisation plants; · UV oxidation e.g. activated wet air oxidation.	   

Examples of application	Lamp types
	UV radiation system for ultraviolet curing resin 
UV curing lamps High UV power densities, up to 30 W/cm in the UV-C, can be obtained from mercury arc discharges that are operated at medium pressure of a few bars. They have a broad, pronounced line spectrum in the ultraviolet and visible spectral range.	UV curing lamps 

Examples of application	Lamp types
HID Lamp types	
Projector lamps (visible light range)	
High pressure mercury short arc lamps, which are mainly used in: · Microlithography for producing integrated circuits, liquid crystal displays (LCDs) and printed circuit boards (PCBs); · Visual and fluorescence microscopy, irradiation for photo polymerisation (used in manufacturing processes for, among other things, efficient printing ink, reliable adhesives and effective compound materials); · Boroscopy (used in particular in the aviation industry as part of maintenance work on turbines, engines and other technical equipment); · Semiconductor production.	  
High Pressure Electrodeless Ultra-Violet Light Sources	

Examples of application	Lamp types	
High Pressure Sodium (HPS) lamps for special purposes High Pressure Sodium vapour lamps are used in the following special purpose applications: · Horticultural lighting; · Resin curing; · Plastics polymerisation.		

Source: LEU Ex. 4f(2015a)

As explained by LEU the table above is a non-exhaustive list. LEU states that it is impossible to give a complete overview of all design features and applications. There are numerous lamps with small market shares for very special applications.[420]

According to VskE[421], the request focuses on UV lamps which are defined as "high intensity discharge lamps" (HID) according to Commission Regulation EC No. 245/2009[422] (Ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps).

VDMA[423] explains that their application for extension of the existing exemption refers to Hg discharge lamps, which are used for curing / polymerisation (e.g. of layers of ink and coating, adhesives and sealants) and for disinfection (e.g. of water, in the medical field, beverage bottles).

LEU further provides some detail as to the technical function of various sub-groups of the lamps explained to fall under this exemption:

- According to LEU, Hg is used in medium-pressure lamps in a liquid form and generates UV radiation in a range between 200 and 440 nm. During the starting phase of these lamps, the mercury is vaporised and raised to higher energy unstable levels (i.e. exited). The drop from these higher energy levels (return of the electrons from the higher energy level) causes the emission of

[420] Op.cit LEU 4(f) (2015a)
[421] Op. cit. VskE Ex. 4f(2015a)
[422] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:076:0017:0044:en:PDF
[423] Op. cit. VDMA Ex. 4f(2015a)

UV light with the characteristic spectral lines. These spectral lines supply the necessary photons for UV curing and disinfection. [424]

As mentioned above LEU stated that lamps covered by Ex. 4(f) have higher internal pressure compared to fluorescent lamps falling under other exemptions. When asked as to the differences in internal pressure between Ex. 4(f) lamps and lamps of other exemptions, LEU provided the following overview (see Table 16-2)[425]. LEU states[426] further that the mercury pressure is orders of magnitude higher and varies for the different lamp types: roughly from 25 kPa to 35 MPa.

Table 16-2: Overview of Hg pressure in different lamp types

Exemption	Lamp sub-groups	Internal pressure	Application specification
1a-f, 2a, 2b, 3a-c, 4g	Fluorescent lamps (CFL, linear and non-linear FL, Cold cathode FL)	200 Pa ~ 700 Pa by noble gas, 0.1 Pa ~ 5 Pa by Hg	General lighting and special purposes,
4a	Other low pressure discharge lamps	0.1 Pa ~ 5 Pa by Hg	Germicidal and other UV
4f	Lamps for projection	10~35 MPa	White light Point source
	Short arc mercury lamps	1~5 MPa	High intensity light, point source
	High Pressure Sodium	0.1~0.8 MPa	Horticulture and other special purposes
	UV curing lamps	1~5 MPa	Spot area
		0.1~1 MPa	Plane area
	Other high pressure	> 1 MPa	

Source: taken from LEU 4(f) (2015b)

LEU explains[427] that the IEC has defined low pressure lamps as lamps having an internal mercury pressure below 100 Pa[428] (=0,001 bar=1mbar).

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[424] Op.cit LEU 4(f) (2015a)
[425] LEU 4(f) (2015b): LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption Request No. 4(f) “Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex” submitted September 15, 2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_f_/Ex__4f__LightingEurope_et-al_Clarification-Questions_final_20150915.pdf
[426] Op.cit LEU 4(f) (2015b)
[427] Op. cit. LEU Ex. 4f(2015b)
[428] The definition of a low pressure lamp: http://www.electropedia.org/iev/iev.nsf/display?openform&ievref=845-07-22
The definition of a high pressure lamp:

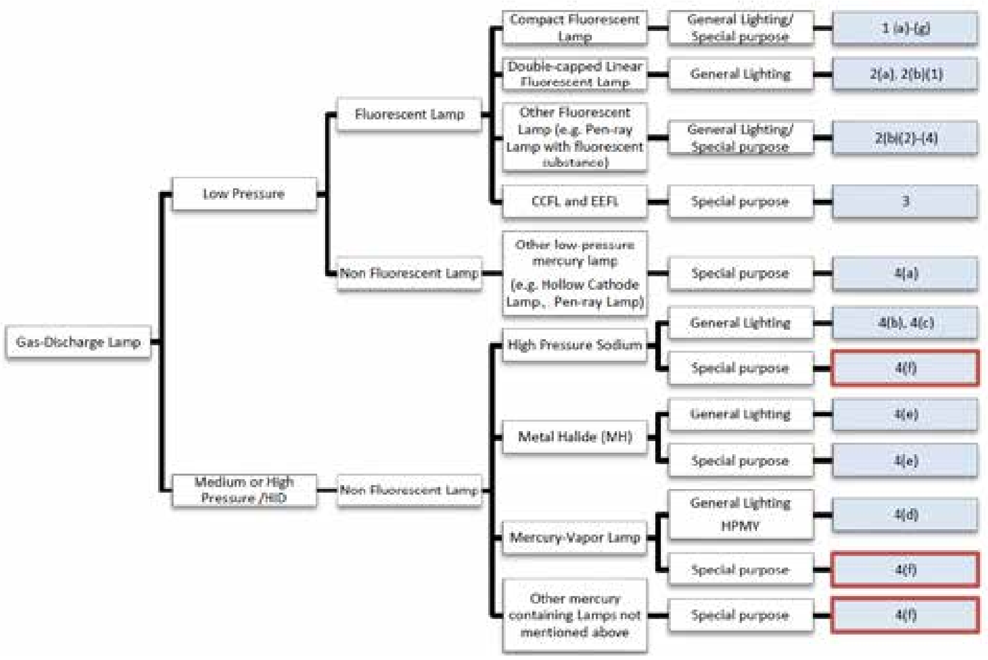
16.2.1 The Scope of the Exemption

LEU explains[429] the scope of Ex. 4(f) to cover all the lamps for special lighting purposes, which do not fall under any of the technology and/or application groups identified in the exemptions 1(a)-4(e) of Annex III of RoHS Directive 2011/85/EU. This is understood to exclude all low pressure discharge lamps and medium and high pressure discharge lamps (high pressure sodium vapour; high pressure sodium mercury; and metal halide lamps) used for general purposes. This also excludes special purpose lamps covered by some of the other exemptions. To summarize the following are understood not to be covered by ex. 4(f):

- Low pressure discharge lamps are understood to include:
  - Fluorescent lamps – compact (CFL), linear (LFL) and cold cathode (CCFL) and external electrode (EEFL); and
  - UV lamps without phosphor coating operating at low pressure.
- Medium and high pressure discharge lamps are understood to include:
  - High pressure sodium vapour (HPS);
  - High pressure mercury vapour (HPVM); and
  - Metal halide lamps (MH).

The figure below illustrates the hierarchy of lamps and currently existing Annex III exemptions for mercury in lamps

Figure 16-1 Chart on the hierarchy of lamps and exemptions



Source: LEU Ex. 4f(2015a)

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http://www.electropedia.org/iev/iev.nsf/display?openform&ievref=845-07-20
[429] Op. cit. LEU Ex. 4f(2015a)

LEU concludes that the scope of Ex. 4(f) covers lamps, which are not fluorescent, which have a higher internal pressure compared to fluorescent lamps, that are used for special purposes and for which a mercury limit is not specified. Such lamps include for example short-arc mercury lamps for producing LED components, lamps for projection or for UV curing applications. LEU provides multiple examples in its request, providing explanatory information and demonstrative pictures (see Table 16-1).[430]

16.2.2 Specified Lamp Technologies/Applications Falling under Ex. 4(f)

The lamp applications relevant for Ex. 4(f) vary in respect with the designs and the amount of mercury widely. For example very high power lamps, need a certain lamp volume to prevent that the heat generated in the discharge melts the wall of the discharge vessel. At the same time if the same high power lamp is used for projection, the arc must be very compact. This requires a very high mercury pressure. The combination of a very high pressure and a large discharge volume leads to the necessity of a large amount of mercury (up to 100 gram). Other lamps require very efficient UV generation for instance for water purification. Here the generated UV must escape from the discharge without radiation trapping, these lamps have a medium mercury pressure (below 1 bar). [431]

Information is provided in relation to various technologies/applications relevant for this exemption. As alternatives for Ex. 4(f) lamps need to be evaluated in the context of the function of a specific lamp in its application, details are summarised here according to type.

16.2.2.1 Lamps Emitting Light in The Visible Wavelength Range

Projection Lamps: LEU explains that projection applications are very demanding for the light source. In order to reach sufficient brightness, the light of the lamp has to be efficiently collected onto the imaging display. This can only be achieved with a lamp that resembles a point source, i.e. a lamp with a high luminance and a short arc. For UHP [ultra-high pressure lamps – consultants comment] lamps, the high luminance of the plasma is reached by using pure mercury at a very high pressure. [432]

- The fact that only mercury is used, results in the best luminance arc: compared to lamps with spectrum additives (high performance metal halides), the luminance is a factor of 2 higher[433]. Next to that, in a pure mercury gas it is possible to design a halogen cycle which keeps the wall clean. This is necessary to obtain long lifetimes with lamps of small sizes. Mainstream projector lamps currently have lifetimes of 6,000 to 10,000h,

[430] Op.cit LEU 4(f) (2015a)
[431] Op.cit LEU 4(f) (2015a)
[432] Op.cit LEU 4(f) (2015a)
[433] Referenced in LEU Ex. 4f(2015a) as: New UHP Lamp Technologies for Video Projection, Holger Mönch, 2001, SID-ME Meeting on display Materials and Components Fall 2001

whereas typical high performance metal halide lamps (with a lower pressure and less mercury) reach around 1,000h.

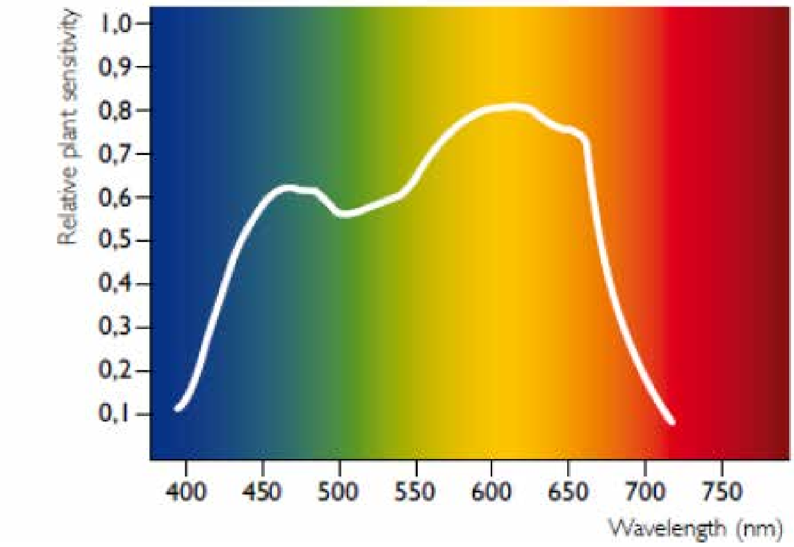
- The high pressure reduces the load on the electrodes by reducing the current and serves as a buffer gas to insulate the arc from heat losses. The high pressure limits diffusion of tungsten atoms away from the hot electrode. Next to the halogen cycle, these properties are required to enable long lifetimes compared to other high luminance lamps. The high pressure also improves the spectrum of the lamp so that it matches the required output spectrum for good picture imaging (according REC709 standards). The good colour quality is due to the extreme pressure and the so called Bremsstrahlung (i.e. deceleration radiation) generated by collisions of electrons with mercury atoms[434].

Lamps for Horticulture Applications: High Pressure Sodium (HPS) lamps for use in horticulture are a member of the High Intensity Discharge Lamps (HID) group. The HPS lamps for horticulture are designed to stimulate plant growth (examples are: tomatoes, cucumbers, flowers). The efficiency of the lamps is not expressed in lumens/W since the plant growth responds to the photons almost universally: each photon is of about the same efficiency. Research at universities and applied agricultural research stations has demonstrated that the rate of photosynthesis is related to the amount of photons roughly between 400– 700 nm. This is called 'Photo synthetic Photon Flux' (PPF). This is expressed in micro mole of photons per second (μmol / s)[435]. The PPF value ranges from 2.1 (micro mole photons/Watt), for the most efficient 1000W lamp to 1.6 (micro mole photons/Watt) for the 250W lamps. Since plants are used to receive light from above, these lamps are mounted above the plants and should be as compact as possible. The small size is to avoid blocking the useful sunlight. The luminaire might block the light even when the growth light is not used, for instance during summer. A recently discovered, secondary effect is the irradiation with infra-red light. Many crops benefit from infrared radiation from above from the direction of the sun, especially during winter. The flux depends on the plant but for tomatoes it is about 25-30 W/m² which is easily provided by the HPS lighting.

[434] Referenced in LEU Ex. 4f(2015a) as: Bremsstrahlung radiation from electron–atom collisions in high pressure mercury lamps, J E Lawler 2004 J. Phys. D: Appl. Phys. 37 1532; and
Infrared continuum radiation from high and ultra-high pressure mercury lamps, J E Lawler, A Koerber and U Weichmann ,2005 J. Phys. D: Appl. Phys. 38 3071

[435] Referenced in LEU Ex. 4f(2015a) as: Accuracy of quantum sensors measuring yield photon flux and photosynthetic photon flux. Barnes C1, Tibbitts T, Sager J, Deitzer G, Bubenheim D, Koerner G, Bugbee B, HortScience. 1993 Dec 28(12):1197-200.

Figure 16-2: Light sensitivity curve of plants



Source: LEU 4(f) (2015a)

High Pressure Sodium lamps are characterized by very long life (30,000 to 50,000 hours) and very high luminous efficiency (from 80 lm/W to 150 lm/W). HPS lamps can only operate on designated drivers that switch the lamp on and regulate the power. These drivers can be an electro-magnetic ballast (inductive/capacitive load) to stabilize the lamp current in combination with a high voltage pulse generator (ignitor) to ignite the lamp. Nowadays, also electronic drivers are used to stabilize the lamp at the correct power.

16.2.2.2 UV Lamps

LEU provides details for two types of UV lamps in terms of technologies – medium pressure UV lamps and short arc mercury lamps.

Medium pressure UV lamps contain a mixture of mercury and argon gas inside a sealed quartz tube. In operation, this mixture is heated to create a stable mercury plasma which emits radiation at specific wavelengths within the UV range (100-400nm), and which are characteristic of mercury. UV curable inks, coatings and adhesives are formulated to absorb the UV light at specific wavelengths by selecting photo initiators whose absorption profiles match the emission spectrum as closely as possible. [436]

UV energy can be used to disinfect water, surfaces and air. The process reduces the pathogen count in an economical and environmentally friendly way without the need for the addition of chemicals. Furthermore, the UV process can be used to kill-off chlorine resistant pathogens such cryptosporidium. In germicidal applications, the spectra have to be optimized to match the wavelengths required for cell deactivation. UV disinfection

[436] Op.cit LEU 4(f) (2015a)

is effective at wavelengths between 200-300nm: the spectral region for the most effective cell deactivation. The germicidal action curve peaks at 265nm. UV-C radiation has strong bactericidal effect. It is absorbed by the DNA of the microorganism, destroys its structure and inactivates the living cells. Microorganisms such as bacteria, yeasts and fungi are destroyed in a few seconds with UV radiation. [437]

Short Arc mercury UV lamps contain a mixture of mercury and xenon gas inside a sealed quartz tube. They are mainly used in: [438]

- Microlithography for producing integrated circuits, liquid crystal displays (LCDs) and printed circuit boards (PCBs);
- Visual and fluorescence microscopy, irradiation for photo polymerisation (used in manufacturing processes for, among other things, efficient printing ink, reliable adhesives and effective compound materials);
- Boroscopy (used in particular in the aviation industry as part of maintenance work on turbines, engines and other technical equipment);
- Semiconductor production;
- UV curing: Using the 2 atomic lines of mercury to polymerize the inside of the adhesive for UV ray curing at 365nm and to polymerize the surface layer of the adhesive at 248nm. That is why several wavelengths are necessary on one optical axis;
- Photolithography: For the exposure of the 193nm photo resists of semiconductors, UV rays having a specific wavelength between 193 and 250nm are used. The high energy of intensified light is needed to get the necessary discrimination between exposed and unexposed areas.

LEU[439] thus sees the bright line spectra of the mercury-arc lamp as indispensable.

16.2.3 Amount of Mercury Used under the Exemption

LEU explains that there are four common dosing technologies for lamps explained to fall under Ex. 4(f). After the first enquiry LEU details for each dosing technology, in which lamp types (UV lamps, protector, HPS etc.) it is used[440].

- Manual pipetting or needle injection of liquid mercury (100% Hg) in UV lamps (e.g. Short Arc Mercury lamps);
- Semi- or fully automatic dosing, disc needle injection of liquid mercury[441] (100% Hg) in projection lamps, UV lamps;

[437] Op.cit LEU 4(f) (2015a)
[438] Op.cit LEU 4(f) (2015a)
[439] Op.cit LEU 4(f) (2015a)
[440] Op.cit LEU 4(f) (2015b)
[441] Liquid dosing is applied to lamps either manually or in automated injection technologies. The choice is more related to production technologies and number of produced products. Op.cit LEU 4(f) (2015b)

- Mercury-Sodium amalgams Na-Hg (ca 20% Hg) in High Pressure Sodium lamps (Horticulture lamps);
- Amalgam sticks (ca. 20-50% Hg) also in High Pressure Sodium lamps (Horticulture lamps).

The amount of substance entering the EU market annually through Ex. 4(f) lamps is estimated based on different market studies and input of single manufacturing companies submitted to LEU. According to LEU, there is no single database or reliable evaluation that would give accurate data. The following amount of mercury is the best estimation of LEU[442].

Table 16-3 Estimation of the amount of mercury put on the market per year in lamps covered by exemption 4(f)

Lamp type	Mercury range per lamp	Estimated volume of lamps	Mercury put on EU market
Lamps for projection	10-40 mg depending on Wattage, average 15mg	Around 10 Mio projector lamps are marketed worldwide per annum. Calculating a market share of 30% for Europe will lead to 3 Mio lamps.	45 kg (maximum)
Short arc mercury lamps	Up to 100g per lamp, average ca. 1g	Not detailed	20 kg
UV Curing lamps	Typical range 10-3000 mg	According to a market report 2012[1], the worldwide market for UV curing mercury lamps is 440.000 pieces. Calculating a market share of 30% for Europe will lead to 132.000 lamps. These lamps (long and short lamps) will contain roughly 66 kg of mercury.	With a yearly market increase by 6 %, 75 kg in total can be estimated for 2014.
Other high pressure	No information available	Not detailed	No information available

[1] *Referenced as "UV LED Market" report from Yole Dveloppement, 2012*

Source: LEU 4(f) (2015a) – Information in the column "Estimated volume of lamps" was not originally part of the table and has been copied from the explanatory text for this table.

VDMA[443] further details that according to Yole (see note to Table 16-3 for reference), disinfection will use 535,000 lamps. These lamps are responsible for a worldwide mercury usage of 268 kg and therefore 81 kg within Europe for disinfection.

LEU stresses that Exemption 4(f), and the belonging lamp types represent a small market share and are responsible for a small part of mercury use compared to the other lighting exemptions. [444]

[442] Op. cit. LEU Ex. 4f(2015a)
[443] Op. cit. VDMA Ex. 4f(2015a)
[444] Op. cit. LEU Ex. 4f(2015a)

16.3 Applicant's Justification for Exemption

The applicants argue that the exemption is still needed as eliminating mercury is not possible and reducing mercury dose per lamp would not allow producing lamps of comparable performance. LED alternatives are becoming more common, but are explained not to be suitable as lamp (component level) replacements in existing installations.

16.3.1 Possible Alternatives for Substituting RoHS Substances

Alternative elements for mercury either lack the required vapour pressure at a low temperature, or do not radiate efficiently upon collisions with electrons or react violently with the transparent quartz wall and block the light when the lamp becomes older. All single elements, stable combinations of elements and stable compounds with suitable vapour pressure have been evaluated as possible alternatives to mercury and none give either the same broad UV spectrum or the required wavelengths with sufficient intensity to perform the required necessary functions. Therefore the only potential future alternatives to use of mercury could be from different technologies. [445]

To substantiate its claims in relation to substance substitutes, LEU provides a few examples of the shortcomings of discharge lamps using other substances, as presented in the following subsections.

16.3.1.1 Mercury-free Discharge Lamps for Projection Purposes:

Hg free discharge technology based on Zn is available[446]. For projection applications this technology is not suited due to a too low metal gas pressure which leads to a low lamp voltage. This results in low energy efficiency. Efforts have been made to develop a high pressure Zn discharge lamp in order to reach reasonable energy efficiency in a projection application. These efforts have been stopped because there was no technical solution to cope with the required extreme high operating temperatures. Further, the zinc atoms violently react with the quartz, damaging the transparency. The loss in transparency reduces the brightness of the source and makes the lamp unfit for the application. This prohibits zinc as an alternative for mercury. [447]

Xenon-lamps can offer the required high luminance for projection purposes, but they suffer from very low energy efficiency. Xenon-lamps are by about a factor of 4 less efficient than Ultra High Pressure-lamps, leading to much larger lamps. As a result, they are used in very limited projection applications[448].[449]

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[445] Op.cit LEU 4(f) (2015a)
[446] Referenced in LEU Ex. 4f(2015a) as: Patent WO2006046171
[447] Op.cit LEU 4(f) (2015a)
[448] Referenced in LEU Ex. 4f(2015a) as: Proc. SPIE 5740, Projection Displays XI, April 10 2005
[449] Op.cit LEU 4(f) (2015a)

The applicants do not provide detailed information about the possible reduction of mercury. VDMA[450] provides a general statement claiming that reduction of the amount of mercury in a certain range or its complete elimination in the lamp is not possible.

16.3.2 Possible Alternatives for Eliminating RoHS Substances

The suitability of alternative technologies is explained to differ per application. For horticulture lighting alternatives are LED's and are discussed under the chapter for horticulture lighting. Alternatives for water purification are chemicals like chlorine[451]. Discussion of other alternatives can be found under the UV lamp chapter. For the projection lamps LED's and lasers are alternatives. Though some of the mentioned alternatives may be applicable to a small part of the application range, LEU explains that they are not *"revers compatible"* with existing installations, i.e., that they cannot be used as replacement lamps in equipment already on the market. [452]

In the following, different Ex. 4(f) lamps and their applications are described in relation to possible alternatives for eliminating RoHS substances (mainly LED technology).

16.3.2.1 Lamps for Projection purposes – Solid State Technology

For projectors the ANSI Lumen (Lm) level on the screen determines the market segments. It is regarded as a basic requirement for a projector to have at least 2000 ANSI Lm brightness level. For lit environments, a brightness minimum level of 3000 ANSI Lm is regarded as the standard. All projectors between 2000 and 5000 Lm are defined as mainstream projectors. Some projector producers have started several years ago to use solid state light sources within a limited area. These can be categorized as: White LED (1), Scanning Laser (2), RGB LEDs (3), LED/Laser (-phosphor) Hybrid (4), Laser-phosphor (5) or RGB Laser (6):

- The luminance level of White LEDs (1) is too small to reach more than 500 Lm. For Scanning Lasers (2), safety requirements limit the scanning beam intensity. Usage of both White LED and Scanning Laser will be limited to the pico projector segment.
- RGB LEDs (3) used for projectors are a surface light source and have a limitation in luminance level. High luminance is required for optical imaging. The range of RGB LED projectors currently available on the market only covers lumen levels up to 1500 ANSI Lm (commercially specified). The measured brightness level is currently still limited to around 800 ANSI Lm[453]. This means that RGB LEDs (3) do not play a role in the mainstream segment.

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[450] Op. cit. VDMA Ex. 4f(2015a)
[451] Consultants comment: No further detail was provided in relation to this alternative, assumed to be addition of chlorine to water.
[452] Op.cit LEU 4(f) (2015a)
[453] Referenced in LEU Ex. 4f(2015a) as: See product reviews at e.g. www.projectorcentral.com, e.g. projectors HD91, DG-757, LGPF85U

- The remaining laser-based technologies (LED/Laser (-phosphor) Hybrid (4), Laser-phosphor (5) or RGB Laser (6)) entered the market quite some years ago, but the penetration rate is very low. For several years now, the level of projectors with hybrid or laser solution is stable at approximately 1.5% of the total market[454]. The slow penetration rate is explained through the need to apply various measures for each of the laser types, such as: cooling of semi-conductors, which is bulky, heavy and/or noisy and thus not practical for mobile applications; measures for supressing laser speckle noise, which would otherwise result in a varying intensity of light spots in the projected image; safety measures as the light sources are class 4[455] lasers.

16.3.2.2 Lamps for Horticulture Applications

In LED lighting, irradiation with infra-red light is absent. For the currently available most efficient LED lamps the power that is transformed into light is about 40% and there is no IR or UV. So 60% of the power is transformed into heat that has to be removed by convection/radiation to the surrounding air in the closed luminaire. This makes the design of the luminaire difficult especially since the environment temperature in the greenhouse is high and the size of the luminaire is limited because of the demand to minimise blocking of direct sunlight. LEU further explains that the operating temperature of LED alternatives within an HPS luminaire would be too high and could affect the lifetime of the lamp (see details in Section 14.3.2 of the chapter of HPS lamps of Ex. 4(b)(I-III))

16.3.2.3 Lamps for UV Curing Applications

UV LED lamps are available and may be considered as an alternative technology for medium pressure mercury lamps used in UV curing applications, but their performance characteristics are very different to UV mercury lamps. LEU details various applications of UV curing lamps (See Appendix A.3.0) and explains that inks, coatings and adhesives developed for these processes have been designed to respond very efficiently to the broad emission spectrum from the medium pressure mercury lamps to deliver a finished product that meets a wide range of very demanding product specifications. The broad band emission from the medium pressure lamps is important because it allows the photo initiator, the component in a UV formulation that absorbs the light, to absorb a wide range of wavelengths and thereby enable the ink, coating or adhesive to deliver the required combination of properties. For example, in coatings on interior plastic parts for cars, a hard, scratch resistant surface is required and this can be delivered by utilizing the shorter wavelengths (280-320nm). Other required properties such as resistance to

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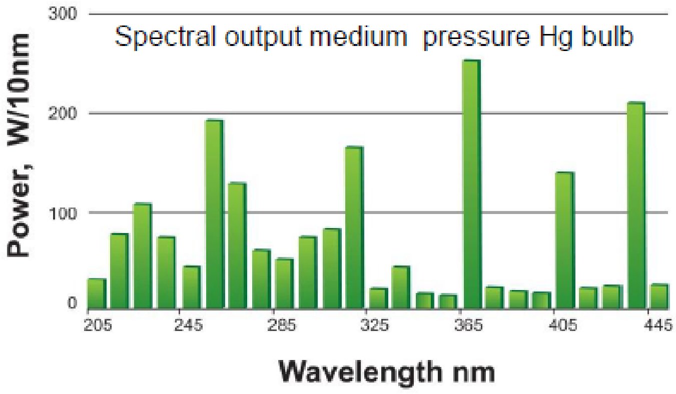
[454] Referenced in LEU Ex. 4f(2015a) as: Futuresource-consulting

[455] In the revised IEC 60825 standard, lasers are classified by wavelength and maximum output power into four classes and a few subclasses. The classifications categorize lasers according to their ability to produce damage in exposed people, from class 1 (no hazard during normal use) to class 4 (severe hazard for eyes and skin).

aggressive solvents or adhesion to plastic surfaces can be aided by utilising the longer wavelengths (320-365nm).

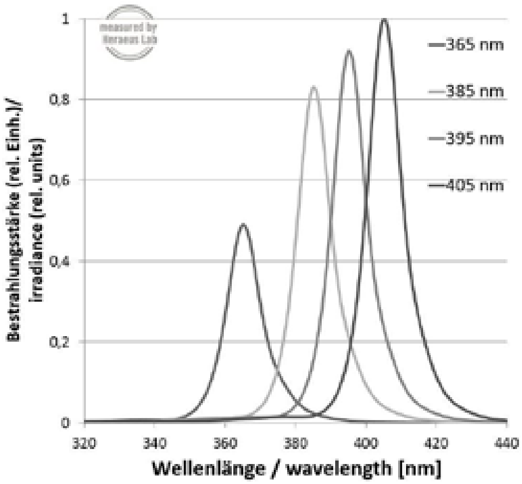
Table 16-4: Spectral output of medium pressure mercury lamps



Source: LEU 4(f) (2015a)

UV LED lamps are a potential alternative technology that has been introduced into UV curing applications. However, to date their commercial success has only been on a relatively small scale in some specific niche applications (see detail in application). One of the drawbacks of the UV LED is that the light is only produced in a very narrow band. UV LED lamps delivering 405nm, 395nm, 385nm and 365nm wavelengths are the most common, commercially available products. The most widely used products deliver 395nm and 385nm; these products have the highest output and the longest lifetimes. Furthermore, the lack of output from the UV LED in the UVB and UVC region means that it can be more difficult and sometimes not possible to produce the hard, scratch resistance coatings required by applications such as coating plastic parts for the automotive industry.

Table 16-5: Spectra of 4 different UV LED lamp types



Source: LEU 4(f) (2015a)

The following table provided by VDMA[456] demonstrates LEDs with a typical peak wavelength in comparison to Hg-UV lamps. The needed power levels (last column in Table 16-6) are calculated as 2/3 of the UV lamp output[457].

Table 16-6: LEDs with a typical peak wavelength

Wavelength [nm]	LED output [mW]	UV lamp output [mW]	To be seen as needed
205	Not available	> 12000	8000
215	Not available	> 15000	10000
225	Not available	> 22000	14500
235	Not available	> 24000	16000
245	0,1	> 9000	6000
255	1	> 30000	20000
265	10	> 24000	16000
285	25	> 4500	3000
300	25	> 6000	4000

Source: VDMA 4(f) (2015b)

VskE[458] details that LED chips with reasonable optical outputs at wavelengths down to 365 nm are available. But for most of the applications radiation at lower wavelength is also needed, or more precisely, the broad UV spectrum of a medium pressure mercury vapour lamp is needed. At lower wavelengths there are no LED chips with good optical yields and reasonable prices available.

In addition the output power of the UV LED is relatively low compared to the medium pressure lamps resulting in much slower processing speeds. Output power of UV LEDs is at present very low in comparison to mercury UV lamps.

- UV lamps maximum power rating for example, 0.370 to 1.26 watts;
- HID UV lamp 250 – 400 W lamps are widely used and more than 25kW are available.

VDMA[459] also explains that the development of printing inks, which are suitable for the radiation spectra of the UV-LEDs is impeded by the limited availability of suitable photo-initiators for UV printing inks (see further detail in application). The printing ink industry resorts to selecting the photo initiators that are most suitable for LED-UV inks from the photo-initiators available on the market and in this respect makes compromises with regard to the range of applications. The absorption curves of the photo-initiators show that most of those that can be used have their main absorption bands in the UVB and UVC range. At present, the radiation energy of LED-UV lamps in this spectral range is too

[456] Op. cit VDMA Ex. 4f(2015b)
[457] VDMA does not explain the basis for calculating 2/3 of the discharge lamp output as the minimum requirement for LED alternatives.
[458] Op. cit. VskE Ex. 4f(2015a)
[459] Op. cit. VDMA Ex. 4f(2015a)

low for the through-curing of ink and coating layers and the operation of UV dryers in an economical and energy-efficient way. Reliable curing is, however, needed for compliance with the European requirements for low migration of substances from food packaging materials (Regulation (EC) No 1935/2004 on materials and articles intended to come into contact with food). The synthesis, approval and registration (REACH) of new suitable photo-initiators requires substantial research efforts and tests. Furthermore, the ink manufacturers state that the development of new LED-UV printing inks, their CMR (CMR=Carcinogenic, Mutagenic and toxic to Reproduction) testing and approval takes 5 to 7 years and, therefore, is not economically reasonable considering the present market volume.

16.3.2.4 UV Lamps for Disinfection Applications

VDMA comments[460] that UV-LEDs cannot be used for disinfection since wavelengths of 265 nm or lower are required for the destruction of DNA. In this application area there are mercury free solutions, such as excimer lamps, however it is explained that these have only been successful in a few applications in niche markets.

LEU states that mercury lamps for disinfection have a wall plug efficiency of up to 50% for generating UV-C photons at 254nm. The stronger version, also mercury based, uses an amalgam to enhance the photon flux, but with a lower wall-plug efficiency of ~35%. The current efficiency of UV LED emitting in the UVA region is 20-30% with typical lifetimes of 10,000 hours but UV LEDs emitting in the UV-C or UV-B region have only a 1-2% efficiency with lifetimes less than 1,000 hours. This makes UV-C and UV-B LEDs unsuitable for many applications. For an explanation and further details as to wall plug efficiency please see Section 28.3.2 of the Ex. 18b chapter).

A possible mercury free solution could be a xenon bromide excimer lamp emitting at 282nm or a xenon iodide excimer lamp emitting 253nm photons. In both alternative cases, the wall-plug efficiency is below 10%. So this is not a realistic alternative given the power consumption comparison with Hg lamps and the poor efficiency. Furthermore the power supply technology is by far more complex and significantly more expensive compared to conventional ones used to drive Hg-based lamps.

Another alternative might be a Xe2- excimer lamp emitting 172nm photons with an efficiency of up to 40%. A phosphor might convert the radiation into the germicidal range around 265nm. Assuming a quantum efficiency for the phosphor of 90% and the Stokes shift being ~65% the total electrical lamp efficiency will come down to ~23%. This low value might only be partly compensated by a larger germicidal action due to the wavelength. Lifetime values for the Hg-based conventional low pressure lamps easily exceed 10,000h, but this would be very hard to achieve with a 172nm based Hg-free version. Currently, mercury free solutions, such as excimer lamps have only been successful in a few applications in niche markets.

[460] Op. cit VDMA Ex. 4f(2015a)

Other Hg free alternatives include Xe flash lamps but these have a very low germicidal efficiency.

LEU summarises that UV LED lamps are not a suitable alternative technology because UV-C LEDs are not commercially available; the current R&D prototypes have a very low power output, low efficiency, low lifetimes and high costs.

16.3.3 Environmental Arguments

Most environmental arguments provided by LEU are of general nature, inter alia: LCA comparisons; the use of materials and hazardous substances; the health and safety impact of substitutes; aspects related to the waste stream and recycling. Please see Section 4.3.3 of the general chapter in these respects.

According to the applicant[461] the lamps concerned in this exemption request are mainly for professional/commercial use and are used in a wide variety of applications which have different waste routes. This equipment is usually not disposed of in household waste (municipal waste), due to its large size, but is collected mainly by business-to-business collection schemes set up according to the WEEE legislation. Only a small portion could end in private households in projectors.

16.3.4 Socio-economic Impact of Substitution

LEU provides no descriptions of socio-economic impact of substitution as substitution is not possible. VDMA[462] provides an example in relation to products printed with UV inks. *"The prices of UV-LED inks are currently approx. 2/3 higher than those of conventional printing inks. One reason is the higher proportion of photo-initiators in order to achieve adequate curing even with the lower radiation dose of the UV-LEDs. The investment costs of the LED-UV modules for the curing process are substantially higher compared to conventional UV lamps (variety of chips required, integration of optical components and the related construction and connection technology). High expenses are needed for the development of materials and the implementation of reliable processes along the total value chain. The production of certain printed products could be transferred to other regions of the world, which would have direct effects on the employment situation in the European printing industry. Social effects are seen with regard to food safety (migration of low-molecular substances in the event of inadequate curing by means of UV-LED) and/or water treatment (lack of safe and environmentally friendly substitute technology)."*

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[461] Op. cit LEU Ex. 4f(2015a)
[462] Op. cit. VDMA Ex. 4f(2015a)

16.3.5 Roadmap to Substitution

LEU claims[463] that Ex. 4(f), and the belonging lamp types represent a small market share and are responsible for a small part of mercury use compared to the other lighting exemptions. Therefore the lamps must remain available on the market for:

- New equipment as there are nearly no (or for certain applications no) alternatives available on the EU market;
- Equipment in the field to replace end of life lamps (EoL) in order to avoid that existing equipment from turning into electronic waste before due time.

16.4 Stakeholder Contributions

A number of contributions have been made by stakeholders. Comments of general nature have been summarised in Section 4.4 in the Chapter regarding lamps in general.

Two further contributions were submitted during the stakeholder consultation and are listed below:

- Contribution by RadTech, submitted 9 October 2015[464]: a non-profit trade association (with around 700 members worldwide) dedicated to the advancement of ultraviolet (UV) and curing processes;
- Contribution by European Printing Ink Association (EuPIA), submitted 13 October 2015[465].

RadTech:

UV curing processes are commonly used in a number of industries including wood and building products, printing and packaging, electronics, automotive, aerospace, food packaging, and 3D printing/additive manufacturing, as well as numerous other applications[466]. RadTech recognize that UV LED is already on the market but they are currently not considered as a suitable replacement technology. Nevertheless, RadTech appreciates an evaluation of the potential for substitution by UV LED in the future.

EuPIA:

EuPIA explains that equivalent UV-LED mercury-free products are not widely available for the printing ink industry due to the limited range of output wavelengths and low

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[463] Op. cit LEU Ex. 4f(2015a)

[464] RadTech 4f (2015): RadTech Officers; Stakeholder Consultation RoHS II – Exemption 4(f), submitted 9.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_f_/Support_of_Application_to_renew_Exemption_4_f__in_Annexe_III_as_proposed_by_Lighting_Europe.pdf

[465] EuPIA 4f (2015a), European Printing Ink Association – EuPIA, Stakeholder Consultation RoSH II - Exemption 4(f) - EuPIA contribution; submitted 12.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_f_/151012_EuPIA_support_of_Medium_Pressure_Mercury_Lamp_RoHS_Exemption_Extension.pdf

[466] RadTech 4f (2015)

power output, UV-LED currently does not promote enough surface drying. However, EuPIA points out that UV-LEDs will become a capable technology for replacing mercury lamps in the future.

16.5 Critical Review

16.5.1 Scientific and Technical Practicability of Substitution

From the information that LEU provides it can be followed that eliminating mercury in lamps falling under Ex. 4(f) is not practical. Though available information shows that various investigations have been carried out, it is understood that none of these resulted in alternative lamps coming on the market. Such alternatives are explained to lack a sufficient vapour pressure at low temperatures (i.e. to facilitate ignition), do not radiate in the relevant spectrum or shall decrease lamp lifetimes.

A reduction of Hg in Ex. 4(f) lamps is also understood not to be practical. In contrast to low pressure fluorescent lamps, mercury is understood not to be consumed during the lifetime of these kind of lamps, and the amount dosed can neither be decreased (as this would affect lamp pressure and thus the function of the lamp) nor increased (as additional mercury is not required for the lamps function).

In relation to alternatives that could allow elimination, it is important to first make a distinction between the component level (replacement lamps) and the system level (luminaire/installation replacement). Regardless of the development of alternatives, it can be followed that for applications relevant to this exemption, difficulties can be expected with the compatibility of alternatives with existing equipment (i.e. replacement lamps). Many of the lamp technologies addressed in the examples (e.g. HPS) are compact in size, meaning that lamps with larger dimensions could not be used as replacement lamps. As luminaires are small and often closed, heat created by the lamp during operation remains within the luminaire. In the case of LED alternatives, their lifetime would be affected negatively due to higher temperatures within the luminaire. In short, it can be followed that irrespective of the development of alternatives, replacing lamps within existing installations require the retention of the exemption.

On the system level, various application areas are described and detail is given as to the possibility of elimination through alternatives to discharge technologies.

For **UV applications** (**curing** and **disinfection** are named), it can be understood that though first UV LEDs are coming on the market, their spectral output is currently not suitable to allow substitution in most cases. The wall plug efficiency of such lamps is also currently significantly lower compared to discharge lamps and thus would result in lamps which are less efficient, thus consuming more energy.

In the visible range, two applications are named:

1. For **projection lamps** it can be understood that first LED alternatives are coming on the market, however that these currently only operate below 2000 lumen ANSI and would thus not be suitable for a large part of the application range. Though it can also be understood that some laser alternatives have been developed, these are

understood to show various problems as they shall require the application of cooling measures that limit their mobility, measures for reducing speckle noise of the image which affect the function, and safety measures as all such lasers are class 4 under the IEC 60825 standard (severe hazard for eyes and skin). Though information is available[467] that some projection lamps are available in the UV range, LEU refers to projection lamps under the visible light category and it is thus assumed that lamps of relevance to this exemption are all in the visible range. It is also noted here that projector lamps are understood to be high pressure mercury lamps. Though LEU claims that such lamps fall under Ex. 4(f) as special purpose lamps not addressed in other exemption, Ex. 4(d) covers the use of Hg in high pressure mercury lamps and is not restricted to general purpose applications. Thus the consultants wondered whether projection lamps would have not been covered under Ex. 4(d) which expired in April 2015. In this respect it should be noted that in the 2008/2009 evaluation[468] it was explained that "*the corresponding EU Eco-design activities came to the following conclusion 'The proposed Eco-design requirement is to set minimum efficacy targets for street lighting lamps or for 'all' lighting applications so that HPM lamps are actually banned and HPS retrofits are used instead of them in installed luminaires. Even self-ballasted (mixed light) HPM lamps could be excluded, because these can be replaced by CFL's with integrated ballast'*[469]*"* It was however, concluded that for technical lamps that are used in special applications a substitution of HPMV lamps by retrofit HPS lamps is not possible and it was recommended to limit the exemption to "*Mercury in High Pressure Mercury (Vapour) lamps except for general lighting (HPMV)*". It is not clear why it was decided to grant the exemption for all HPMV lamps, however it can be followed that despite their possible lower efficiency (addressed through Eco-design for general purpose lamps) that for special purpose HPMV that a lack of suitable replacement lamps may still justify an exemption.

2. As for lamps used for **horticulture** purposes, from information regarding HPS lamps covered by Ex. 4(b) and Ex. 4(c), it can be followed that where LED alternatives are discussed as replacement lamps for existing HPS installations, there may be various limitations. Most alternatives have geometric dimensions that would prevent their use as alternatives in existing installations. Therefore such lamps would not be practical as retrofit substitutes. Other lamps, particularly in the higher lumen output range, shall not be compatible with existing HPS luminaires thermally, resulting in excess heat within the luminaire and consequently reducing the LED service life. In

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[467] VITO & VHK (2015), Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'), Final report, Task 1, Annexes Scope, Standards, Legislation ,Prepared for the European Commission, DG ENER.C.3: VKH & VITO indicates in theirits report claims that the projector lamp group comprises of lamps arc-lamps, ultraviolet lamps and as well infrared lamps.
[468] Gensch et al. (2009), Gensch, C-O., Zangl, S., Groß, R. and Weber A., Oeko-Institut e. V. and Deubzer, O., Fraunhofer IZM, Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, available under: http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.
[469] Referred to in Gensch et al. (2009) as: Vito 2007: Final Report Lot 9: Public street lighting, January 2007

contrast however, for new installations it appears that alternatives to Hg-HPS luminaires are available. From research of publicly available sources, it can be understood that for example LEDs produced by OSRAM stimulate plant growth, while reducing energy consumption through the use of targeted lighting at 730, 660 and 450 nano-meters, which is understood to provide sufficient lighting for all types of plants and flowers.[470] The consultants thus conclude that LED alternatives for horticulture lighting applications are already available on the market and can be used to replace HPS-based luminaires. Similar to other applications however, here too, possible drawbacks related to the replacement of lamps in existing luminaires and installations have to be taken into consideration.

16.5.2 Environmental Arguments

For UV lamps it can be understood that current alternatives based on LED technology have significantly lower wall plug efficiency in comparison to discharge lamps. As discussed above, this would result in lamps with lower efficiency, subsequently increasing the energy consumption and related environmental impacts of relevant applications.

In the case of curing lamps, the possibility to develop new curing inks that would be compatible with UV LEDs is also raised. Some detail is given clarifying that development of such inks would require their approval under chemical legislation. Though it is possible that some inks would be identified as hazardous, thus being considered problematic in comparison with current inks, detail is not given to evaluate this option. As new curing inks could also have advantages over current inks in terms of hazardousness as well as in terms of other aspects, the consultants would not disregard this development direction.

Aspects raised of general nature are discussed in the general chapter under Section 4.5.3.

16.5.3 Stakeholder Contributions

RadTech[471] and the European Printing Ink Association (EuPIA) [472] submitted comments specifically in relation to Ex. 4(f). They underline that although there is potential for substitution with UV LED, further development is needed to allow equivalent UV-LED mercury-free products to become available on the market.

Other comments were of a general nature. They are discussed in Section 4.5.7 of the general chapter.

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470 http://ledlight.osram-os.com/applications/horticultural-led-lighting/
471 Op.cit. RadTech 4f (2015)
472 Op.cit. EuPIA 4f (2015a)

16.5.4 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

As explained above, despite various efforts to develop such alternatives, it can be followed that Hg cannot be substituted with another substance used in discharge lamps relevant for Ex. 4(f). It can also be followed that reducing (and also increasing) the amount of mercury would affect the function of the lamp negatively. In this sense alternatives are understood not to be available on this level.

On the component level, various limitations of LED alternatives for lamps relevant for Ex. 4(f) are apparent, particularly regarding replacement lamps for existing equipment. For the various application sub-groups addressed, it can be followed that the exemption would further be needed to allow replacing lamps in existing applications, as alternatives (if available) shall not be compatible with existing equipment.

In relation to the availability of alternatives, it can be understood that on the system level, alternatives are available in some cases for applications in the wavelength of visible light:

- For **projector lamps**, it is understood that alternatives cover the range below 2000 lumen ANSI. The lack of alternatives is raised specifically in relation to the range of 2000-5000 lumen ANSI and thus the consultants conclude that an exemption could be limited to this range.
- As for **horticulture lamps**, it can be understood that LED alternatives are available, providing various types of spectral output.

As for the non-visible range, the applications of curing lamps and disinfection lamps have been discussed in detail, showing that current alternatives do not provide sufficient performance in terms of spectral output and wall plug efficiency. Furthermore an early phase-in of substitutes would also result in an increase of energy consumption due to the lacking wall-plug efficiency.

All three applicants recommend not changing the exemption wording. LEU argues in this respect that the list of applications is not exhaustive "*It is impossible to give a complete overview of all design features and applications. There are numerous lamps with small*

market shares for very special applications." [473] However, the consultants do not agree that the diversity of applications presented justifies the further renewal of an exemption with a relatively open scope, which leaves a large potential for misuse and makes market surveillance difficult. As shortly detailed, it is for example not clear if projection lamps should actually fall under the exemption at hand or whether they would be covered by Ex. 4(d), which has expired, but which was not restricted to lamps for general purposes. As neither further detail of additional applications, nor argumentation to justify the renewal of the exemption for such cases was made available, the consultants would recommend limiting the exemption to the specific applications addressed. Here too, development of alternatives should be monitored carefully in the future especially to determine the point in time at which the cost of early end of life of some luminaires is acceptable in relation to the availability and possible higher efficiency of possible system alternatives.

16.6 Recommendation

Though substitutes are understood to be available on the system level in a few cases (for use in new LED luminaires), such substitutes have various limitations to allow their application as substitutes in existing equipment of Ex. 4(f) lamps (lamp replacement). Furthermore, in most of the applications it can also be followed that first alternatives coming on the market would not cover the full product range. Thus it is also concluded that on the system level time is also still needed to develop sufficient alternatives. It is thus recommended to renew the exemption for a further 5 years. To avoid misuse and to ensure market surveillance effectively, the consultants propose narrowing the scope of the exemption to specific cases as detailed below.

It should be noted that the specification of the proposed formulation for Ex. 4(f)(IV) related to curing and disinfection applications could be removed. In general it can be understood that the limitations of LED alternatives emitting in the non-visible range would most likely apply to other applications, should such be communicated (i.e. non-comparable spectral output and insufficient wall plug efficiency). Nonetheless, as opposed to other exemptions permitting the use of Hg in discharge lamps in the UV range, Ex. 4(f) does not limit the amount of mercury that can be used. It is also observed that some lamps have significant doses of Hg, as can be observed from the information in Section 15.2.1. Against this specific background the consultants would recommend addressing relevant applications in the wording formulation, for which the exemption is available. This should at least facilitate awareness to cases, where relatively large amounts of mercury are dosed in single lamps.

Under Article 5(2), from a legal perspective, excluding EEE falling under Cat. 8 and 9 from the scope of this exemption may not be possible.

[473] Op. cit LEU Ex. 4f(2015a)

Exemption 4(f)	Scope and dates of applicability
(I) Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex	For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. industrial: 21 July 2024
(II) Mercury in high pressure mercury vapour lamps used in projectors where an output ≥2000 lumen ANSI is required	For Cat. 5: 21 July 2021
(III) Mercury in high pressure sodium vapour lamps used for horticulture lighting	For Cat. 5: 21 July 2021
(IV) Mercury in lamps emitting light in the ultraviolet spectrum for curing and disinfection	For Cat. 5: 21 July 2021

Note: As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

See also note within text above on the potential to remove Ex. 4(f)(IV).

16.7 References Exemption 4(f):

EuPIA 4f (2015a) European Printing Ink Association – EuPIA, Stakeholder Consultation RoSH II - Exemption 4(f) - EuPIA contribution; submitted 12.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_f_/151012_EuPIA_support_of_Medium_Pressure_Mercury_Lamp_RoHS_Exemption_Extension.pdf

LEU Ex. 4f(2015a) LightingEurope (LEU), Request to renew Exemption 4(f) under the RoHS Directive 2011/65/EU Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex, submitted 15.1.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_f_/Lighting_Europe/4f_LE_RoHS_Exemption_Req_Final.pdf

LEU 4(f) (2015b) LightingEurope, Response To Oeko-Institut regarding the 1st Questionnaire Exemption Request No. 4(f) “Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex” submitted September 15, 2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_f_/Ex__4f__LightingEurope_et-al_Clarification-Questions_final_20150915.pdf

RadTech 4f (2015) RadTech Officers; Stakeholder Consultation RoHS II – Exemption 4(f), submitted 9.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_f_/Support_of_Application_to_renew_Exemption_4_f__in_Annexe_III_as_proposed_by_Lighting_Europe.pdf

VDMA Ex. 4f(2015a) Verband Deutscher Maschinen- und Anlagenbau (VDMA) Exemption Request 4(f) Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex, submitted 15.1.2015, available under

http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_f_/VDMA/4f_VDMA_excempt_req_4f_RoHS_16Jan14.pdf

VskE Ex. 4f(2015a) VskE - German Association for Label and Narrow Web Converters, Exemption Request 4(f) Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex, submitted 15.1.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_f_/Vske/4f_2014-12-09_RoHS_Application_VskE.pdf

VITO & VHK (2015) Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'), Final report, Task 1, Annexes Scope, Standards, Legislation, Prepared for the European Commission, DG ENER.C.3

17.0 Exemption 5(b): "Lead in glass of fluorescent tubes not exceeding 0,2 % by weight”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

EEE	Electrical and Electronic Equipment
EoL	End of Life
LEU	LightingEurope
Pb	Lead
PbO	Lead oxide

17.1 Background

LightingEurope (LEU)[474] has applied for the renewal of exemption 5(b) related to the presence of lead in the glass of discharge lamps. In the past, leaded glass used to contain ca. 20 % lead, added in the form of PbO for functional reasons in the production process. However lead is no longer added intentionally during lamp glass production. In principle lead in the glass of fluorescent tubes has successfully been phased out by the lighting industry several years ago. Nonetheless, recycled glass from end of life lamps is used

[474] LEU (2015a), LightingEurope, Request to renew Exemption 5(b) under Annex III of the RoHS Directive 2011/65/EU Lead in glass of fluorescent tubes not exceeding 0.2 % by weight, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_5_b_/5_b__LE_RoHS_Exemption_Req_final.pdf

today in the manufacture of new glass tubes (e.g. discharge glass tubes). As this glass can contain differing amounts of lead, a maximum content of 0.2 % by weight lead may still be present in the glass of fluorescent lamps.

LEU thus requests the renewal of the exemption for use in lamps falling under Cat. 5, with the following wording formulation and for the maximum duration:

> "*Lead in glass of fluorescent tubes not exceeding 0.2 % by weight*"

17.1.1 Amount of Lead Used under the Exemption

According to LEU[475], the lead content in glass of fluorescent tubes can be up to 0.2% if recycling glass is used in the glass production process. The homogenous material is glass. Producers of lamp glass tubes are continuously monitoring the lead content in recycling glass. Regarding the amount of lead under the exemption, the applicant states:

> "*The amount of intentionally added substance entering the EU-28 market annually through application for which the exemption is requested: 0 tons. According to LightingEuropes' experience in average of all low pressure discharge lamps, the legal threshold of 0.1% wt in homogenous material glass is not exceeded.*
>
> *Theoretically assuming a lead content of 500 ppm average, roughly estimated 25 tons of lead would enter the EU-28 market bound in lamp glass. Worst case would be 100 tons assuming an average content of 0.2%*
>
> *(Basis of the rough estimation: ca 680 Mio fluorescent lamps put on the EU-28 market per year (Eurostat data for 2013), average 0,1 kg weight per lamp; ca. 75% average glass per lamp = 50.000 tons; hereof 0.05/0.2% lead)*" [476]

17.2 Description of Requested Exemption

The exemption covers lamp glass of fluorescent tubes. Fluorescent lamps are low pressure discharge lamps in the scope of RoHS Directive, addressed in Annex I as category 5 (lighting equipment). The lamp glass used in low pressure discharge lamps is mainly soda-lime glass (soft glass). It can be understood that though lead was used in the manufacture of lamp tube glass in the past for functional reasons, it was successfully phased out years ago and is no longer intentionally added in manufacture. It is however present in the tube glass of new discharge lamps in light of its presence as an impurity in recycled glass, originating from end-of-life (EoL) lamps. Such glass is used as a raw material in the manufacture process of new lamp glass. [477]

LEU[478] explains that fluorescent lamps have long lifetimes and that since the use of lead in the glass of fluorescent tubes was allowed in the EU until 2010 and is still allowed in

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[475] Op. cit. LEU (2015a)
[476] Op. cit. LEU (2015a)
[477] Op. cit. LEU (2015a)
[478] Op. cit. LEU (2015a)

most countries outside the EU, e.g. in China, that lead-containing recycled glass will be available for a foreseeable long term, probably decades. This is especially valid if the lamp glass is produced outside the EU. Lead in the glass is on the other hand safe as it will not leave the glass matrix under any circumstance. The requested maximum content of lead is only slightly above the RoHS threshold limit for lead in homogenous materials.

In a later communication, LEU details that under the first RoHS Directive, coming into effect in 2006, the use of Pb in glass for fluorescent lamps was exempted. In the second edition, this exemption was restricted to 0.2%. Thus a significant reduction was realized, leading to the current situation that glass for fluorescent lamps is still diluted with a small amount of Pb, sometimes slightly higher than the RoHS restriction of lead above 0.1% by weight. Hence in the long term, a declining trend of installed lamps with lead-containing glass is expected. On the other hand the market for fluorescent lamps is decreasing, which could lead to higher amounts of lamps or lamp glass produced outside the EU. The rejection of the exemption could lead to the limitation of the use of recycled glass (from lamps coming from the market) in lamp glass production.[479]

17.3 Applicant's Justification for Exemption

Lead has been added in fluorescent lamp glass production for decades in the form of PbO. Use of lead glass in lamps was for a long time standard technology. Adding lead to the glass in the past allowed better processability in all steps of glass smelting and glass soldering, leading to lower failure rates. Due to changes in the production processes lead in glass could be phased out in Europe during the last 4-8 years. However, lead can be found in the glass matrix of newly manufactured low pressure discharge lamps, if lead-contaminated recycling glass is used for glass production. In such cases the glass tubes can be contaminated with minimum amounts of lead, so that the general RoHS limit of 0.1% limit can slightly be exceeded, up to 0.2%. Depending on the levels of lead in the recycled material, the contents of lead in new discharge tube glass may vary. Thus, LEU explains that, despite internal measurements that show that most lamps do not exceed the threshold of 0.1% in the glass, the current threshold of 0.2% by weight is still considered to be necessary to ensure compliance where the 0.1% level is exceeded.

The use of recycled glass is explained to significantly reduce the energy consumption of glass production (-30% for the recycled glass amount according to experience of a LightingEurope member company).[480]

As it can be understood that the use of lead in the manufacture of lamp glass is not regulated in all countries outside the EU, LEU was asked, how it can be guaranteed that the presence of unintentional Pb in lamps manufactured with non-EU glass lamp

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[479] LEU (2015b), Lighting Europe, Answers to 1st Questionnaire Exemption No. 5(b) (renewal request), submitted 28.8.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_5_b_/Ex_5_b__LightingEurope_1st_Clarification_LE_Answers_20150828.pdf

[480] Op. cit. LEU (2015a)

recyclate (which may have higher lead levels) is similar to levels in glass tube manufactured with EU recyclate, or is at least within the allowances addressed in Ex. 5(b). LEU[481] explained in this regard that each manufacturer must ensure RoHS conformity of products by suitable measures e.g. according EN50581:2012. This includes the glass components. This requirement to ensure conformity applies evenly to different parts, different materials, different components, etc. LEU elaborated that glass coming from different glass furnaces may have differences in composition due to the specific mix of cullet and raw material, but not regarding the presence of lead. In general new produced lamp glass in Europe is lead-free (i.e. lead is not intentionally added - consultants comment). Fluorescent lamps put on the EU market since September 2010 have to be made of lead-free glass. No systematic differences could be recognized by LEU members regarding the origin of the glass.

17.3.1 Possible Alternatives for Substitution

LEU [482] states that there is no alternative. Lead in the glass of fluorescent tubes in amounts <0.2% has no intended or unintended function. It is a contaminant originating from the use of recycled glass as a raw material in glass production. There is no intended addition of lead or lead compounds other than in the form of recycled glass. However, manufacturers of lamp glass tubes use recycled glass in order to save resources and energy. The rejection of the exemption could lead to the limitation of the use of recycled glass for lamp glass production as well as to higher costs related to the use of resources and energy consumption. LEU also mentions that a limitation of the use of recycled glass in lamp glass production could result in an increase in the number of random conformity checks necessary, especially for lamps imported from outside the EU. If quality controls would reveal batches of lamps exceeding 0.1% lead, these lamps would not be allowed to be marketed in the EU-28. These non-conforming batches would then be exported out of the EU-28 or would need to be scrapped (recycled) directly before the lamps are used if export is not possible or too expensive (repackaging).

17.3.2 Environmental Arguments

According to one source a reduction of energy consumption of 2.5% per every 10% of recycled glass is achieved (lamp glass production of LightingEurope member OSRAM GmbH, Augsburg, Germany). Typically in the OSRAM GmbH, Augsburg glass production plant, 30 - 40 % recycling glass is used. Technically (theoretically) a recycled glass content of up to 80% is estimated to be possible, though such high amounts require that the recycled glass is nearly identical to the manufactured glass. The source of recycled glass is therefore mainly glass from lamp recycling. The content of lead (as well as mercury) is normally measured regularly in the above mentioned plant. [483]

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[481] Op. cit LEU (2015b)
[482] Op. cit. LEU (2015a)
[483] Op. cit. LEU (2015a)

LEU[484] further explains that lamps are in the scope of EU Directives 2002/96/EC - WEEE and 2012/19/EU– WEEE Recast. All lamps need to be collected and recycled, regardless of the levels of lead in lamp glass. Take back systems are installed in all EU Member States to facilitate the collection and the proper handling of lamps at end-of-life (further details in the exemption renewal application dossier, but are not detailed here as they concern lamps in general and do not provide specific details as to the fate of lead from the glass of lamps.

17.3.3 Socio-economic Impact of Substitution

According to the applicant there are no health impacts expected, irrespective of the lead content being below 0.2% (as requested) or below 0.1% (the RoHS threshold for Pb), as the lead is bound in glass. In parallel, as the use of recycled glass reduces the use of virgin resources and the consumption of energy, an increase in direct production costs could be expected should the exemption be revoked.[485]

17.4 Stakeholder Contributions

A single contribution was made during the stakeholder consultation regarding Ex. 5(b). The Test and Measurement Coalition (TMC)[486] includes the seven leading companies in the sector representing roughly 60% of the global production of industrial test and measurement products. It is TMCs' understanding that according to the RoHS Directive, the exemptions listed in Annex III and Annex IV for which no expiry date has been specified, apply to sub-category 9 industrial with a validity period of 7 years, starting from 22 July 2017. This is also said to be explained in the RoHS FAQ, p. 26 http://ec.europa.eu/environment/waste/rohs_eee/pdf/faq.pdf. TMC, thus does not interpret the current exemption evaluation related to package 9 to concern category 9 industrial equipment, for which the exemptions evaluated in pack 9 are understood to remain valid, and has thus not provided exemption specific information.

17.5 Critical Review

17.5.1 REACH Compliance – Relation to the REACH Regulation

Appendix A.1.0 of this report lists Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to

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484 Op. cit. LEU (2015a)

485 Op. cit. LEU (2015a)

486 TMC (2015), Test & Measurement Coalition, General comments related to RoHS exemption package 9, submitted 16.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/General_Contribution_Test___Measurement_Coalition_package_9_exemptions_20151016.pdf

establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restriction for substances under Entry 30 of Annex XVII does not apply to the use of lead in this application. Pb present as an impurity in the glass of lamps manufactured with recycled glass from EoL lamps, in the consultants' point of view is not a supply of a lead compounds as a substance, mixture or constituent of other mixtures to the general public. Pb is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII also restricts the use of lead and its compounds. Its restriction in jewellery would not apply in the case of this exemption. Paragraph 7 restricts the use of lead above certain concentrations in in articles supplied to the general public, where these may be placed in the mouth by children during normal use. Paragraph 8(k) however excludes articles in scope of RoHS 2 from this restriction, which thus does not apply to this case.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status January 2015).

Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

17.5.2 Scientific and Technical Practicability of Substitution, environmental arguments

From the available information it can be understood that the presence of lead in discharge lamp tube glass is a result of the use of recycled material originating from recycled lamps in the production of new lamp glass tubes. Lead is not added intentionally and in this sense a substitution does not require the provision of a specific function as such. Though discharge lamp tube glass could be manufactured without the use of recycled material (i.e., a possible form of substitution), this would result in a higher consumption of energy (as well as energy related emissions like greenhouse gas emissions) for the manufacture of the tube glass, as the manufacture of glass from primary material requires higher temperatures for the fusion of raw materials into glass. In this sense, it can be followed that revoking the exemption in favour of this potential substitute would result in a higher environmental impact. In parallel, it can be understood that impacts on health and or the environment related to the presence of lead in lamp tube glass would not be expected, as the lead is encapsulated in the glass and emissions leading to such impacts are not expected.

17.5.3 Stakeholder Contributions

The contribution submitted by TMC raises a legal question as to the availability of the current exemption to category 9 equipment. Regardless of TMCs claims as to the availability of Annex III exemptions to sub-category 9 industrial for 7 years starting in 22.7.2017, in the case of Ex. 5(b) the wording formulation limits its applicability to the

glass of fluorescent tubes. Fluorescent tubes are understood to be a product of the discharge lamp group, which can be used as a component in other equipment. As, stated by the applicant, this product is understood to fall under category 5 and not under Cat. 9. Thus from a practical perspective, in the consultants' opinion, sub-category 9 industrial equipment would not benefit from the exemption directly, though lamps benefiting from the exemption could be used in Cat. 9 equipment.

17.5.4 The Scope of the Exemption

In the consultants view the exemption could be limited to category 5. The applicant has stated that lamps benefiting from Ex. 5(b) fall under category 5 and in the consultants' view the exemption wording formulation excludes its availability to other EEE components when lamps are used in a specific EEE. Should discharge lamps be in use in equipment falling under categories other than category 5, they would still be understood to fall under Cat. 5 as a component of an EEE and would thus still benefit from the exemption as long as it would be valid. The reduction of the levels of Pb in lamp tube glass is a continuous process, affecting the glass of all lamps manufactured. The consultants thus expect this change to affect the glass of lamps evenly. In other words it is not expected that reduction in the level shall only affect lamps used in some EEE, but not others. Thus, differentiation between categories would not be relevant.

17.5.5 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

LEU states that there is no substitute as such, however in the consultants view, manufacturing discharge lamp glass from primary materials comprises a valid substitute. According to the statements of LEU, there would also be no problem with the reliability of such glass, which is expected to have comparable performance to lamp glass with up to 0.2 % by weight lead.

However, the consultants can follow that discontinuing the use of recycled glass in the manufacture of lamp glass would create negative impacts in relation to the need to use more primary materials (where secondary ones are available) and more energy needed for smelting the glass. In this sense, the consultants conclude that though there may be alternatives in the form of manufacture from primary materials, such alternatives would create negative environmental impacts that arguably outweigh the benefits of this substitute.

17.6 Recommendation

It is understood that although substitutes may exist, their associated environmental costs would be higher than in the case where the exemption is renewed and a use of up to 0.2% by weight Pb in the glass of discharge lamp tubes is further allowed. In this sense, one of the Article 5(1)(a) criteria is understood to be fulfilled and the renewal of the exemption is thus understood to be justified.

It is further observed that the intention of the RoHS Directive restrictions is to reduce the contents of harmful substances in the waste stream and the impacts related thereto. This is evident for example from Recital 8 of the Directive, stating *“Restricting the use of those hazardous substances is likely to enhance the possibilities and economic profitability of recycling of waste EEE and decrease the negative impact on the health of workers in recycling plants”*. In the case of Pb in the glass of fluorescent tubes, its content, currently as an impurity resulting from the use of recycled lamp glass, is understood not to limit the recycling of such waste, nor the use of such recycled glass as a secondary resource.

As it can further be followed that the reduction of lead in recycled glass from EoL lamps is expected to occur only very gradually due to long product lifetimes, the consultants would further recommend extending the exemption for a further five years, in line with the duration limitations addressed in Article 5(2).

Though in light of Article 5(2), from a legal perspective, an exclusion of EEE falling under Cat. 8 and 9 from the scope of this exemption may not be possible, the consultants do not see an added benefit from the availability of the exemption to categories other than Cat. 5. In the consultants view, through its formulation, the exemption is already restricted to use in lamps, which fall solely under Cat. 5. Since lamps can be used as a component of other articles, restricting the exemption to this category should not create any disadvantage to manufacturers of products of other categories using discharge lamps as a component. In such cases the Cat. 5 exemption would still be applicable to such lamps used as a component in equipment other than Cat. 5. All the more so as the formulation of the exemption is not to change and it already limits its applicability to lamps which are understood to fall under Cat. 5. If this is acceptable from a legal perspective, the exemption could be limited to Cat. 5. If Cat. 8 and Cat. 9 cannot legally be excluded from these exemptions; duration periods for these categories have been specified in the exemption formulation below.

Exemption 5(b)	Duration*
Lead in glass of fluorescent tubes not exceeding 0,2 % by weight	For Cat. 5: 21 July 2021
	For Cat. 8 and Cat. 9: 21 July 2021
	For Sub-Cat. 8 in-vitro: 21 July 2023
	For Sub-Cat. 9 industrial: 21 July 2024

Note: As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for certain categories on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

17.7 References Exemption 5b

LEU (2015a) LightingEurope, Request to renew Exemption 5(b) under Annex III of the RoHS Directive 2011/65/EU Lead in glass of fluorescent tubes not exceeding 0.2 % by weight, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_5_b_/5_b__LE_RoHS_Exemption_Req_final.pdf

LEU (2015b) Lighting Europe, Answers to 1st Questionnaire Exemption No. 5(b) (renewal request), submitted 28.8.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_5_b_/Ex_5_b__LightingEurope_1st_Clarification_LE_Answers_20150828.pdf

TMC (2015) Test & Measurement Coalition, General comments related to RoHS exemption package 9, submitted 16.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/General_Contribution_Test___Measurement_Coalition_package_9_exemptions_20151016.pdf

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18.0 Exemption 6a: "Lead as an alloying element in steel for machining purposes and in galvanised steel containing up to 0,35 % lead by weight"

Declaration

In the sections that precede the "Critical Review" the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

11SMn30	Lead-free cutting steel containing high sulphur and also manganese
11SMn37	Same as 11SMn30 but with a higher Mn content
1215	Lead-free low carbon free cutting steel
12L14	Leaded low carbon free cutting steel
ECHA	European Chemicals Agency
EGGA	The European General Galvanizers Association
EEE	Electrical and Electronic Equipment
ELV	End-of-Life Vehicle
EUROFER	The European Steel Association
KEMI	Kemikalieinspektionen, the Swedish Chemicals Agency
MnS	Manganese(II)sulphide
NSSMC	Nippon Steel and Sumitomo Metal Corporation
Pb	Lead
tpa	Tonnes per annum
TMC	The Test & Measurement Coalition
WEEE	Waste of Electrical and Electronic Equipment

18.1 Background

Exemption 6a covers different uses of lead in steel: the use of lead added as an alloying element in steel for machining purposes and the presence of lead in galvanized steel.

According to the European Steel Association (EUROFER) and the European General Galvanizers Association (EGGA),[487] lead is added to steel as a machinability enhancer for industrial production. Lead as an alloying element in steel for machining purposes has a lubrication effect that eases deep drilling and high speed operations. This kind of steel is also called free cutting or free machining steel. For the production of free cutting steels, lead provides a good hot workability.[488]

Galvanisation is the process of applying a protective zinc coating to steel in order to prevent corrosion. The most common form of galvanisation is hot dip galvanisation, where iron or steel articles are galvanised by dipping in a molten bath of zinc or zinc-alloy; a small amount of lead tends to be present in the zinc bath, and hence this the source of lead in the galvanised steel (as discussed further in Section 18.2). Hot dip galvanisation can be done in continuous or batch operation: In hot dip galvanization as a continuous process, the steel is continuously drawn through a bath with a liquid zinc alloy. Individual metal articles are hot dip galvanized by a process called batch galvanizing. Both the continuous and batch processes of hot-dip galvanizing result in a metallurgical bond between zinc and steel. The bonding region is an intermetallic compound, termed the “alloy layer”.[489] EGGA[490] states that the presence of lead in the continuous galvanizing process is sufficiently low to meet the default requirement of 0.1% Pb. Therefore EUROFER and EGGA[491] propose to restrict the exemption to batch hot dip galvanised steel instead of all types of galvanised steel.

EUROFER and EGGA[492] with the support of a number of organizations have submitted a request for the renewal of the above mentioned exemption with the following wording formulation (the additional wording is underlined):

> *“Lead as an alloying element in steel for machining purposes and in <u>batch hot dip</u> galvanized steel items containing up to 0.35% lead by weight.”*

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[487] EUROFER and EGGA (2015a), European Steel Association (EUROFER) and European General Galvanizers Association (EGGA) (2015a), Original Application for Exemption Renewal Request, submitted 16.01.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Eurofer/6a_RoHS_Application_Form_6a_16012015-.pdf

[488] According to EUROFER and EGGA (2015a and b), steel is being hot-rolled to the required size for a customer from a piece with a larger (as-cast) cross sectional area.

[489] Gensch et al. (2009), Carl-Otto Gensch, Oeko-Institut e. V., et al. 20 February (2009), Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf

[490] EGGA (2016), European General Galvanizers Association (EGGA) (2016), Answers to 3rd Clarification Questions, submitted 01.03.2016.

[491] Op. cit. EUROFER and EGGA (2015a)

[492] Op. cit. EUROFER and EGGA (2015a)

Besides the associations EUROFER and EGGA, two companies have submitted a renewal request, both referring to the use of lead as an alloying element in steel for machining purposes:

- **Dunkermotoren**[493] a manufacturer of electric drives, uses lead based steel alloys in gear parts because of the improved machinability that is achieved by lead. Dunkermotoren requests an exemption period of at least 5 years to allow requalification. Dunkermotoren estimates that if a substitute were available 2 to 5 years would be needed for this purpose.
- **Sensata Technologies Holland B.V.**[494] a manufacturer of sensor and control products purchases latching components within the tripping and actuation mechanism from the supply chain.[495] Sensata[496] generally refers to the function of lead in all alloys covered under Ex. 6 (steel, aluminium and copper) such as improved "*micro-machining, electrical conductivity, galvanic corrosion resistance, mechanical relaxation, tribological behaviour etc*.".

As for the history of the exemption, it has to be noted that when the RoHS 1 Directive was published in 2002, Exemption 6 covered lead as an alloying element in steels, aluminium and copper.[497] After the last revision in 2009[498], the exemption was split into three exemptions 6a, 6b and 6c in order to cover each alloy with a separate wording.

In the end-of-life vehicles (ELV) Directive 2000/53/EC, the corresponding exemption has been narrowed to refer only to batch hot dip galvanizing processes as a result of the last revision in 2008 and 2009.[499] The current wording of ELV Annex II Exemption 1(a) is "*Steel for machining purposes and batch hot dip galvanised steel components containing up to 0,35 % lead by weight*".

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[493] Dunkermotoren GmbH (2014), Dunkermotoren GmbH (2014), Original Application for Exemption Renewal Request, submitted 15.12.2014, English version available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/DUnkermotoren/Ex_6a_Dunkermotoren_150806_Ausnahmeantrag_Stahl_englisch.pdf

[494] Sensata Technologies (2015a), Sensata Technologies Holland B.V. (2015a), Original Application for Exemption Renewal Request, submitted 15.01.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Sensata_Technologies/6a_6b_6c_RoHS-Exemptions_Application-Format_Ex_6a_b_c_Pb_in_St_Al_Cu.pdf

[495] Sensata Technologies (2015b), Sensata Technologies Holland B.V. (2015b), Answers to Clarification Questions, submitted 20.08.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Sensata/Ex_6a6b6c_Sensata_Questions_response_20150820.pdf

[496] Op. cit. Sensata Technologies (2015a)

[497] The wording of exemption 6 was as follows: "Lead as an alloying element in steel containing up to 0,35% lead by weight, aluminium containing up to 0,4% lead by weight and as a copper alloy containing up to 4% lead by weight"

[498] Op. cit. Gensch et al. (2009)

[499] Zangl et al. (2010), Stéphanie Zangl et al., Oeko-Institut; Otmar Deubzer, Fraunhofer IZM (2010), Adaptation to scientific and technical progress of Annex II to Directive 2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS), final report; 28 July 2010; http://elv.exemptions.oeko.info/fileadmin/user_upload/Final_Report/Corr_Final_report_ELV_RoHS_28_07_2010.pdf

18.1.1 Amount of Lead Used under the Exemption

Steel for machining purposes

In their renewal request, EUROFER and EGGA[500] estimate the amount of substance entering the EU market annually through applications for which the exemption is requested as follows:

> *"Machining steels – in 2013 the import of steel products for machining purposes amounted to approximately 73,000 tons. Assuming that the lead content in steel for machining purposes is between 0,2 and 0,35%, this means that the lead annually entering in the EU market through the import of free cutting steels can vary between 146 to 255 tons. However, note that these figures do not correspond solely to steel intended for EEE (which was not possible to estimate) and that also contains the volumes of steel intended for automotive."*

During a 2nd round of clarification questions, EUROFER was asked to specify the production volume of leaded steel in the EU and to estimate the share of the total amount of leaded steel in the EU used for EEE by indicating at least a range of the amount of leaded steel in the EU used for EEE.[501] However, EUROFER[502] did not provide any further information.

The following estimations have been made during the last revision of the exemption:[503]

> *"The main production countries of leaded steels are UK, Germany, France and Spain. The total production volume of leaded steel in the EU is estimated to be 1,3 Mt per year. It is, however, not possible to accurately say how much of this material is used for applications covered by RoHS due to the length of supply chains and sales to stock-holders and intermediate processors selling steels to different applications. Within EEE, leaded steels are mainly used in larger equipment with smaller volumes. Therefore, yearly quantities are expected to be some tons at maximum."*

As for the other applicants of renewal requests, Dunkermotoren does not provide information on the amount of lead in the production of the engine and transmission parts (gear parts), whereas Sensata[504] estimates the amount of lead in the predefined components supplied to Europe to be less than 1kg.

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[500] Op. cit. EUROFER and EGGA (2015a)

[501] In analogy to the REACH registration, the following tonnage ranges were proposed: < 100 tonnes per annum (tpa); 100 - 1.000 tpa; 1.000 - 10.000 tpa; 10.000 - 100.000 tpa; 100.000 - 1.000.000 tpa.

[502] EUROFER (2016), European Steel Association (EUROFER) (2016), Answers to 2nd Clarification Questions, submitted 15.01.2016.

[503] Op. cit. Gensch et al. (2009)

[504] Op. cit. Sensata Technologies (2015a)

Galvanized steel

EUROFER and EGGA[505] estimate the amount of lead intentionally added "*for applications in the scope of WEEE/ROHS*" to be less than 1 tonne per year. They further state not to be able to estimate the amount of unintentional lead in the recycled zinc (see Section 18.3.2. for further details).

18.2 Description of Requested Exemption

Steel for machining purposes

According to EUROFER and EGGA,[506] lead is added as an alloying element in steel in order to enhance machinability "*if a variety of machining operations is required or if deep drilling of material is required*". EUROFER and EGGA further explain that lead acts as a lubricant and thereby provides "*a reduced cutting force when machining steel, appropriate chip formation (length and force), facilitation of a smooth surface finish, facilitation of a good dimensional achievement under commercial production conditions or reduced "tool wear" during the machining operation*" are of relevance.

EUROFER and EGGA are not able to provide an exhaustive list of EEE applications or of application sub-groups for which such steel is applied. EUROFER and EGGA[507] explain that the problem is a result of the long and complex supply chain "*with many different actors, including stockists and intermediate processors. The producer of the free cutting steel itself rarely has detailed, if any, contact with the final EEE producer (or even the producer of the components that become part of EEE).*"

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[505] Op. cit. EUROFER and EGGA (2015a)
[506] Op. cit. EUROFER and EGGA (2015a)
[507] EUROFER and EGGA (2015b), European Steel Association (EUROFER) and European General Galvanizers Association (EGGA) (2015b), Answers to Clarification Questions, revised version, submitted 15.09.2015, available under:
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Eurofer/Ex_6a_Eurofer_1st_round_of_Clarification-Questions_final-20150803_DRAFT_REPLY_-_EGGA_EUROFER_MCchanges15-9-15_revised.pdf
A number of organizations supported this compilation of information: European General Galvanizers Association (EGGA); European Steel Association (EUROFER); European Partnership for Energy and the Environment (EPEE); Digital Europe; Information Technology Industry Council (ITI); European Garden Machinery Industry Federation (EGMF); European Passive Components Industry Association (EPCIA); European Semiconductor Industry Association (ESIA); Japan Business Council in Europe (JBCE); Japan Business Machine and Information System Industries Association (JBMIA); Japan Electronics and Information Technology Industries Association (JEITA); Japan Electrical Manufacturers´ Association (JEMA); Knowles UK Ltd.; LIGHTINGEUROPE; WirtschaftsVereinigung Metalle (WVM); German Electrical and Electronic Manufacturers´ Association (ZVEI); European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry (COCIR); American Chamber of Commerce to the EU (AmCham EU); European Committee of Domestic equipment Manufacturers (CECED).

Instead, EUROFER and EGGA[508] provide the following list of typical components: fuel injector systems, hydraulic clips, keys, motor shafts, fasteners, printer shafts, and a wide range of office equipment parts – for example lap top screen screws.

Galvanized steel

Lead is present in the zinc coating of batch hot dip galvanised steels, but does not provide a function in the coated product.[509]

According to the EUROFER and EGGA[510], lead in galvanised steel is mostly unintentionally present as an impurity related to the use of recycled zinc. EGGA[511] explains that the unintentional lead content arises from the remelting of zinc metal from the crude galvanizers ashes (arising from oxidation of the zinc bath surface) and secondly from the recovery and recycling of scrap metallic zinc from roofing/gutters (often of 50 – 120 year vintage) made from former standard zinc grades with lead impurities[512] that additionally contain lead-based solders that were used to join roofing sheets and gutters.

EUROFER and EGGA[513] state that lead is intentionally added in the galvanizing bath to adjust the viscosity and reach optimal drainage of excess zinc "*in a small number of plants*". According of EUROFER and EGGA,[514] the intentional addition of lead to the galvanizing bath is rapidly declining due to technical innovation.

According to EUROFER and EGGA[515], batch galvanized steel is used in components like fasteners, brackets, fixings "*for a range of EEE items such as lighting units that require high levels of durability in outdoor or aggressive environments*" as well as in e.g. transformer housings and heat exchangers.

18.3 Applicant's Justification for Exemption

Steel for machining purposes

EUROFER and EGGA[516] argue that lead provides an excellent machinability in a variety of machining processes such as e.g. turning, drilling, tapping, parting, grooving which is favourable especially in cases where the manufacturing of an EEE component requires a combination of different machining operations.

EUROFER and EGGA further argue not to be able to provide an exhaustive list of functionalities respective of performance aspects of lead because *"'machinability' cannot be restricted to a property of the machined material. It is not a single material*

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[508] Op. cit. EUROFER and EGGA (2015b)
[509] Op. cit. Gensch et al. (2009)
[510] Op. cit. EUROFER and EGGA (2015a)
[511] Op. cit. EGGA (2016)
[512] So-called 'Good Ordinary Brand' / 'Prime Western' zinc.
[513] Op. cit. EUROFER and EGGA (2015a)
[514] Op. cit. EUROFER and EGGA (2015a)
[515] Op. cit. EUROFER and EGGA (2015b)
[516] Op. cit. EUROFER and EGGA (2016a)

property like tensile strength, ductility or electrical conductivity, which we can measure and have one value to characterize the material." Instead machinability depends also on the "*material of the tool, the geometry of the tool, the machining operation itself (turning, drilling…), the machine type (autolathes, machines for specific applications, single spindle, multispindle…), the machining parameters, the cooling conditions. All these parameters have an influence on tool life, chip form, process forces and surface quality. This means it is a sum of chemical, mechanical and tribological properties which cannot be examined with a simple statistical correlation. The combination of various machining operations with a set of different tools in one machine is an additional difficulty. In this case one single operation can be the limiting factor for the whole machining process of a special part."*

The other applicants Dunkermotoren and Sensata provide the following justifications:

- Dunkermotoren[517] argues with increased costs because the use of alternative material would increase the production time and shorten tool life.
- Sensata[518] who uses latching components within the tripping and actuation mechanism made from leaded steel argues that "*the Sensata supply chain for lead-containing steel alloys comprises companies whose expertise is in stamping and screw-machining. Neither Sensata nor the Sensata supply chain has the expertise or resources to develop alternatives to lead-containing steel alloys. For this reason the focus of the efforts made by Sensata has been on existing materials, none of which has proven to be a suitable replacement.*"

Galvanized steel

EGGA[519] explains that lead influences certain aspects of the process such as fluidity, drainage and ease of removal of dross for recycling. EUROFER and EGGA[520] cannot give an estimation on the share of hot dip galvanization that still needs the intentional addition of lead. EGGA[521] explains that "*there are no other limitations on the use of lead in the galvanizing process and the proportion of components coated that are within the scope of the WEEE directive is very small in volume terms. Decisions on the intentional use of lead or the use of recycled zinc would not be solely influenced by the processing of EEE-related components.*" EGGA further states that EEE normally represents a very small proportion of a plant's throughput.

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[517] Op. cit. Dunkermotoren (2015)
[518] Op. cit. Sensata Technologies (2015b)
[519] Op. cit. EGGA (2016)
[520] Op. cit. EUROFER and EGGA (2015b)
[521] Op. cit. EGGA (2016)

18.3.1 Possible Alternatives for Substituting RoHS Substances

Steel for machining purposes

In their application, EUROFER and EGGA[522] confirm that the steel mills are continuously researching, searching for new alternatives in order to find efficient substitutes to avoid the use of lead in steel. However they state that "*no alternatives have been identified that can effectively replace lead as a machinability enhancer in steel in all respects. Lead-free alternatives may show acceptable results in single machinability tests, but the overall performance of the lead-free steels is worse than that of leaded steel. The lack of hot workability of the lead-free alternatives is also an important obstacle towards the substitution*".[523]

EUROFER and EGGA[524] mention the following possible alternatives that each shows certain disadvantages according to EUROFER and EGGA:

- Lead-free alternatives from Nippon Steel and Sumitomo Metal Corporation are used for the manufacture of printer rails. EUROFER and EGGA[525] explain that printer rails are surface quality critical and are manufactured using very low feed rates. Initial problems related to built-up edge formation[526] on the cutting tool have been solved by new developments of the steel that contains finer inclusions of Manganese(II)sulfide (MnS).[527] EUROFER and EGGA[528] are not aware of a wider use then printer rails.
- A lead-free development of the steel grade C45 by Toyota is mentioned; however, EUROFER and EGGA[529] explain that a research project in 2005[530] tested deep hole drilling applications and complex machine features where this lead-free development failed; EUROFER and EGGA conclude that it would therefore not be applicable for EEE.

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[522] Op. cit. EUROFER and EGGA (2015a)
[523] Op. cit. EUROFER and EGGA (2015a)
[524] Op. cit. EUROFER and EGGA (2015b)
[525] Op. cit. EUROFER and EGGA (2015b)
[526] The so called "built-up edge" is a formation of metal deposits sticking to the tool close to the cutting edge. It can be observed usually at low cutting speeds, which causes chips to be torn away rather than cleanly cut, resulting in rough part surface, and it may damage the tool. Low cutting speed favour the formation of built-up edge as well as other cutting parameters such as e.g. large depth of cut. See e.g. https://www.researchgate.net/post/How_does_the_built-up_edge_lead_to_surface_damage.
[527] Hashimura M. et al (2007), Hashimura M., Miyanishi, K., Mizuno, A. (2007), Development of Low-Carbon Lead-Free Free-Cutting Steel Friendly to Environment, Nippon Steel Technical Report, No. 96, 2007. http://www.nssmc.com/en/tech/report/nsc/pdf/n9608.pdf
[528] Op. cit. EUROFER and EGGA (2015b)
[529] Op. cit. EUROFER and EGGA (2015b)
[530] P.E. Reynolds et al. (2005), Technically and commercially viable alternatives to lead as machinability enhancers in steel used for automotive component manufacture, Report EUR 21912, Office for Official Publications of the European Communities, Luxembourg, 2005.

- There is also lead-free steel with a higher quantity of sulphur in free cutting steels, so called resulfurized steel grades. According to EUROFER and EGGA,[531] they showed "*disappointing*" results compared to leaded steel in deep drilling operations or high speed machining, due to decreased machining speed, increased tooling wear and an increased fragility and reduction in hot workability which results in yield losses. EUROFER and EGGA[532] do not provide further details on this statement.
- As for the alternatives with bismuth, increased sulphur (with and without tellurium), tin (with low and high copper), phosphorus and calcium, EUROFER and EGGA[533] refer to results that already have been presented in the frame of the ELV Directive review of exemptions in 2008 and that are included in the corresponding report of Oeko-Institut.[534]
  In brief, "*Although the machining properties of bismuth-treated steels approach those of lead-treated steels for certain machining operations, in the majority of machining operations lead remains the most effective machinability additive through its wide range of machining characteristics. It was further concluded in the report that calcium can substitute lead in C45 steels for use at higher cutting speeds. However, calcium treated steels require higher cutting forces, have poorer chip form and have their best performance limited to a narrower range of machining speeds in comparison with the leaded product. The more limited benefits of calcium treated grades may not be able to match the benefits of leaded grades in many instances since it is very likely that a large variety of machining operations are required for many engineering components.*
  Steels containing tin generally did not show good performance in the machinability tests and thus, was not considered as a suitable replacement for lead in steel."

EUROFER and EGGA[535] also state that the lead-free alternatives that contain bismuth or tellurium show a decreased hot workability in the temperature range normally used for hot rolling of steel. According to EUROFER and EGGA,[536] bismuth containing steel needs to be rolled at very high temperatures and often rolled material shows surface cracks like those shown in the following figures. EUROFER and EGGA[537] explain that tellurium causes similar cracks.

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[531] Op. cit. EUROFER and EGGA (2015a)
[532] Op. cit. EUROFER and EGGA (2015a)
[533] Op. cit. EUROFER and EGGA (2015a)
[534] Op. cit. Zangl et al. (2010)
[535] Op. cit. EUROFER and EGGA (2016a)
[536] Op. cit. EUROFER and EGGA (2016a)
[537] Op. cit. EUROFER and EGGA (2016a)

Figure 18-1: Cracks in bismuth containing steel wire rods after rolling

Source: EUROFER (2016a)

As for bismuth containing steel, the following new efforts are reported:[538] "*Since 2010, this steel producer has carried out seven interconnected full scale trials related to the use of bismuth as an alternative to lead. During the last trial in 2012, a new 10MnSBi grade of steel (1215Bi) was manufactured under normal production conditions and supplied to customers. [...] The results from this and previous trials have indicated that bismuth steels are much more prone to surface break-up than normal leaded steels and the associated yield losses are not sustainable for routine production. [...]*

Overall the results of these trials confirm the conclusions from the collaborative ECSC project where bismuth was shown to be a potential alternative to lead for the purposes of enhancing machinability but that low hot ductility and limited availability (of Bi) could prevent the material being a feasible commercial product."

Generally, EUROFER and EGGA[539] raise concerns over the availability of bismuth and a higher price because bismuth production is most often a by-product of lead or tungsten production.

Galvanized steel

The research that EUROFER and EGGA mention for galvanizing processes do not deal with substitution of lead as it is mostly inadvertently present due to recycling of zinc scrap and galvanizers' ashes because the use of lead within the process have largely (but not completely) been replaced by other techniques, according to EUROFER and EGGA.[540] EGGA[541] explains that the general research approach targets to reach thinner coatings regardless of steel type ("*more zinc-efficient coatings*") and coatings of more consistent

[538] Op. cit. EUROFER and EGGA (2015b)
[539] Op. cit. EUROFER and EGGA (2015b)
[540] Op. cit. EUROFER and EGGA (2015a)
[541] Op. cit. EGGA (2016)

appearance and surface finish. EGGA argues that this goes hand in hand with a general "*desire to reduce the presence of hazardous substances, including lead. Intentional use of lead is now limited to a narrow, but important, set of processes and products.*" The problem that these processes cannot be separately dealt with is explored in Section 18.5.6.

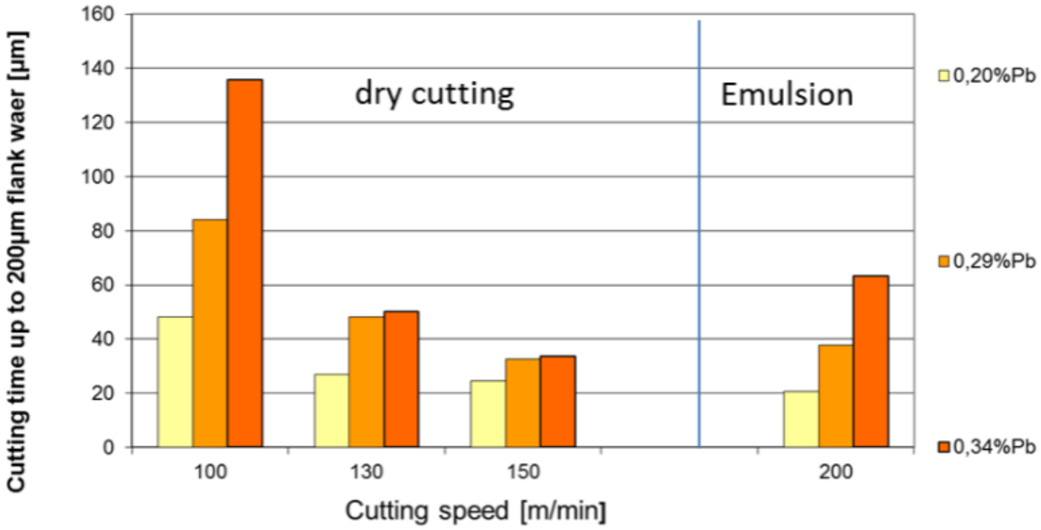
18.3.2 Possibilities for Reducing RoHS Substances

Steel for machining purposes

EUROFER and EGGA[542] report a recent collaborative project between Saarstahl and Tata Steel on the question whether the 0.35% threshold of lead in steel can be reduced. According to EUROFER and EGGA,[543] Tata Steel and Saarstahl produced several casts of low carbon free cutting steels with Pb contents from 0.11% up to 0.35%.

The machinability of the steel with different lead content was tested by producing a component on a single spindle automatic lathe using high speed steel tools under neat oil coolant and determining the maximum production rate than can be achieved. The tests showed "*progressive deterioration in machinability*" due to decreased tool life (see Figure 18-2) and higher cutting forces (see Figure 18-3), which result in either increased usage of cutting tools or longer machining times.

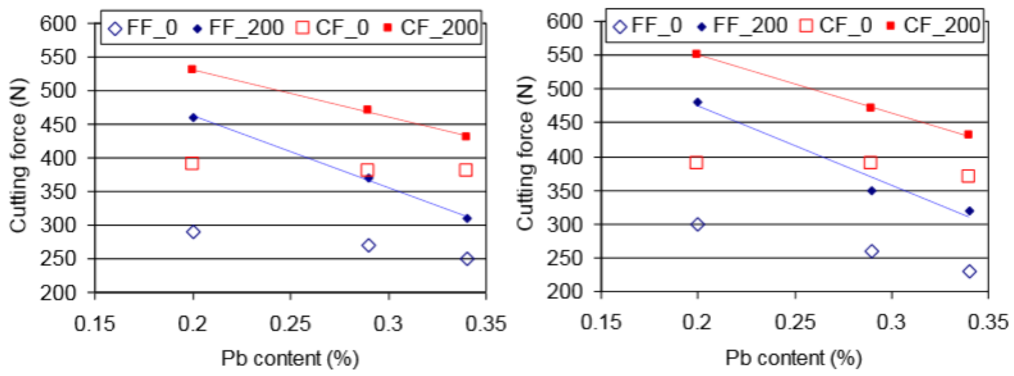
Figure 18-2: Tool wear by free cutting steels with different Pb content



Source: EUROFER and EGGA (2015b)

[542] Op. cit. EUROFER and EGGA (2015b)
[543] Op. cit. EUROFER and EGGA (2015b)

Figure 18-3: Cutting forces (CF) and feed forces (FF) of free cutting steels with different Pb content in dry cutting conditions (left: 100 m/min, right: 130 m/min)



Source: EUROFER and EGGA (2015b)

Galvanized steel

EUROFER and EGGA[544] expect the lead content within recycled zinc arising from scrap roofing/gutters to decrease in the long term "*(> ~50 years due to the very long product life)*", as a result of "*new solders*" being used. Also, customer-driven requirements for lower lead levels in markets outside EEE/ELV and the higher price of lead than zinc (affecting intentional use) might also result in lower lead levels in time.

EGGA[545] states *"There may be a downward trend in lead content from sources from galvanizers' ashes associated with a general trend to avoid the intentional use of lead additions to the galvanizing bath. Recyclers estimate that will be >50 years before the lead content of recycled zinc from scrap metallic zinc from roofing/gutters shows any significant decline."*

18.3.3 Environmental Arguments

Steel for machining purposes

EUROFER and EGGA[546] specify processes where the scrap coming from machining of free cutting steel is recycled and the lead recovered by off gas treatment to 90%. EUROFER and EGGA do not provide information on the steel recycling circuit.

Besides this, EUROFER and EGGA raise the following environmental arguments, however without providing further evidence in both cases:

- EUROFER and EGGA[547] mention as "*wider environmental implications of material choice*" that "*the lower energy consumption of machining leaded*

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[544] Op. cit. EUROFER and EGGA (2015b)
[545] Op. cit. EGGA (2016)
[546] Op. cit. EUROFER and EGGA (2015a)
[547] Op. cit. EUROFER and EGGA (2015a)

steels means that there is a potential benefit of reduced electricity consumption and CO_2 emissions in fabrication": According to EUROFER and EGGA,[548] "*the addition of lead into low carbon free cutting steels enhances machinability and can increase the production rate of a component by up to 40% depending upon part and machining process design, and a potential reduction in energy usage of approximately 27% when machining parts using the leaded steel are compared to the non-leaded steel.*"

- As for bismuth containing steel, EUROFER[549] claims that "*the high rolling temperatures and a second or even third rolling process will cause additional energy consumption.*"

Galvanized steel

For galvanized steel, EUROFER and EGGA[550] bring forward the argument in favour of using scrap zinc for galvanizing purposes:

> *"A life-cycle comparison of the embodied energy of (i) remelt secondary zinc and (ii) primary zinc has been published in 'Sachbilanz Zink', Prof. J. Krüger, Institut für Metallhüttenkunde und Elektrometallurgie der RWTH Aachen (ISBN 3-89653-939-6, 2001). This publication reports that: "The energy required for the extraction of zinc from scrap to obtain alloys capable of further use demands a primary energy input of only approximately 2.5 GJ/t. During the extraction of zinc from ores, the primary energy requirement for mining and ore dressing is around 5-9 GJ/t metal content in the concentrate. Concentrate processing to obtain a pure metal however calls for a primary energy input of 46-48 GJ/t zinc. Based on this information, the use of remelt secondary zinc reduces the embodied energy of the zinc used in batch galvanizing by over 20 times.""*

18.3.4 Socio-economic Impact of Substitution

No information has been submitted on socio-economic effects of substitution by EUROFER and EGGA. As for general economic impacts, EUROFER and EGGA mention the following, but without providing further evidence to substantiate or quantify their claims: EUROFER and EGGA argue that an increasing demand for bismuth might result in a strong rise in the bismuth price and consequently an increase in production costs.[551]

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[548] Op. cit. EUROFER and EGGA (2015a)
[549] Op. cit. EUROFER (2016a)
[550] Op. cit. EUROFER and EGGA (2015a)
[551] Op. cit. EUROFER and EGGA (2015b)

18.3.5 Road Map to Substitution

Steel for machining purposes

EUROFER and EGGA[552] do not provide a road map for substitution because substitutes in machining steel would need to first show the same level of hot workability as lead-containing free cutting steel, which has not occurred so far with the identified alternative materials.

Besides, EUROFER[553] explains that the huge diversity of applications in (often small) different machining companies and the diversity of parameters in the system "machining" makes it very difficult to provide a timeframe for the substitution.

Galvanized steel

EUROFER and EGGA[554] do not provide a road map because the inadvertent presence of Pb in the recycling chain does not demand substitution and the intentional addition of lead cannot be separated for the purpose of the production of EEE, which is explained to account for only a small portion of production (see Section 18.5.6).

18.4 Stakeholder Contributions

Six contributions to Exemption 6a have been submitted during the stakeholder consultation. The contributions are presented in order of submission and shortly summarized:

- The **Robert Bosch GmbH**[555] generally supports the applicants without providing further information.
- **JBCE[556]** – Japan Business Council in Europe in a.i.b.l. states that they understand that EEE of Category 8 and 9 are out of scope of this review. The JBCE understands that "*the exemption 6(a) in annex III can be applied to category 8&9 products for seven years from identified date when entry into force for each products, at the earliest July 2021.*"
- CETEHOR, the technical department of the Comite Franceclat (French Watch, Clock, Jewellery, Silverware & Tableware Centre)[557] generally states the better

[552] Op. cit. EUROFER and EGGA (2015a)
[553] Op. cit. EUROFER (2016)
[554] Op. cit. EUROFER and EGGA (2015a)
[555] Robert Bosch GmbH (2015), Contribution by Robert Bosch GmbH, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Bosch-Stakeholder-contribution-Exemption-request-6a.pdf
[556] JBCE (2015), Contribution by JBCE – Japan Business Council in Europe in a.i.b.l, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Comment_on_public_cousulation_of_Exemption_request_2015-2_6_a__.pdf
[557] CETEHOR (2015), Contribution by Comite Franceclat (French Watch, Clock, Jewellery, Silverware & Tableware Centre), CETEHOR, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Ex_6_a_Comite_Franceclat_Cetehor_20151012.pdf

machinability of leaded steel with a lead content of 0.2%; a greater weal tool with unleaded steel would hinder a profitable manufacturing "*in a severe context of competition with low-cost labour countries*" and the longer machining cycles would increase energy consumption. CETEHOR claims to use a leaded steel with a lead content of 0.2%; therefore "*the regulatory limit could be reduced to 0.3% to allow alloy suppliers to guarantee conformity to the regulatory value.*"
CETEHOR[558] estimates a quantity of lead of 1 kg per year based on the average amount of 1 g of machining steel per watch movement, a maximum lead content of this steel of 0.2% and the annual French production of quartz watches of 0.5 million.

- **KEMI** Kemikalieinspektionen, the Swedish Chemicals Agency[559], recommends to "*split into a number of more specific exemptions, related to applications where it has been verified that feasible alternatives are not currently available*" and argues that the "*broad and unspecific wording does not conform with the requirements in the updated RoHS Directive 2011/65/EU any longer*". KEMI lists the specific applications provided by the applicants: Electric drives, engines and transmission parts (gear parts), latching components within the tripping and actuation mechanism, fuel injection systems, hydraulic clips, keys, motor shafts, printer shafts, lap top screen screws and the following articles manufactured in batch galvanised processes fasteners and support brackets/fixings in lighting units that require high levels of durability in outdoor or aggressive environment, transformer housings and heat exchangers.
- **PennEngineering,**[560] a designer and manufacturer of specialty fasteners,[561] objects the renewal request because they have substituted lead-free cutting steel with "*traditional grades of low carbon, rephosphorized, resulfurized, free machining steels*" by applying "*changes to tool materials and other subtle proprietary changes to minimize the loss of efficiency*".
PennEngineering requests a transition period of more than 18 months because of the "*significant inventory of steel fasteners with up to 0.35 % lead content in the distribution channels*" and because "*customers will stop accepting non-compliant product many months before it becomes non-compliant*".
PennEngineering states that they currently use 907 t (*"2,000,000 lb"*) of leaded steel per annum globally; the amount of the contained lead is calculated at 2.3

[558] Op. cit. CETEHOR (2015)
[559] KEMI (2015), Contribution by KEMI Kemikalieinspektionen, Swedish Chemicals Agency, submitted 19.10.2015 , available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Ex_6a_KEMI_Answer_to_SC_RoHS_20151016_Lead_in_Steel.pdf
[560] PennEngineering (2015), Contribution by PennEngineering, submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Ex_6a_PennEngineering_Consultation_Questionnaire_PE_AS_20151016.pdf
[561] For fasteners used in EEE, see at http://www.pemnet.com/fastening_products/pdf/kdata.pdf

tpa ("*5,000 lb*"). PennEngineering estimated that approximately 25% of their sales of leaded products go towards EEE in the EU.

- The **Test & Measurement Coalition**[562] (TMC) submitted a general contribution on Category 9 Industrial monitoring and control instruments similar in its nature to that of JBCE.

18.5 Critical Review

18.5.1 REACH Compliance – Relation to the REACH Regulation

Appendix A.1.0 of this report lists Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restriction for substances under Entry 30 of Annex XVII does not apply to the use of lead in this application as lead is used as an alloying element. In the consultants' point of view it is not a supply of lead as a substance, mixture or constituent of other mixtures to the general public. Pb is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

Appendix A.1.0 of this report lists Entry 63 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0,05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children.[563] Entry 63 however further specifies this restriction not to be applicable for articles within the scope of the RoHS Directive 2011/65/EU.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status January 2016).

Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

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[562] Test & Measurement Coalition (2015), Contribution by Test & Measurement Coalition, submitted 19 October 2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/General_Contribution_Test___Measurement_Coalition_package_9_exemptions_20151016.pdf

[563] Other restrictions of entry 63 cover e.g. jewellery and are thus not applicable here.

18.5.2 Scientific and Technical Practicability of Substitution

Steel for machining purposes

The basic problem for assessing the scientific and technical practicability of substitution of leaded steel is the fact that the applicant EUROFER as an association of steel producers does not have information on the detailed machining procedures. Therefore, EUROFER was not able to provide an exhaustive list of applications nor to specify in which EEE applications available alternative material might be practicable and reliable.

Nippon Steel and Sumitomo Metal Corporation were contacted to gain more information on their lead-free steel development. Nippon Steel and Sumitomo Metal Corporation[564] state that they are supplying the material in the Asian market, however unfortunately not in Europe at this moment. They indicated that their lead-free steel is used for "*printer shafts, pins and small parts for automobile and industrial machines*", which are produced by many different companies, and confirm that these components are also applicable in EEE. It has to be noted that printer shafts are among the typical components that require leaded steel according to EUROFER and EGGA.[565] The following figure shows machine intensive application examples provided by NSSMC.[566]

Figure 18-4: Application examples of the lead-free steel developed by NSSMC

Source: Nippon Steel and Sumitomo Metal Corporation (NSSMC) (2016)

The lead-free steel by NSSMC[567] is resulfurised free cutting steel; the hardness is stated to be almost equivalent to that of other low-carbon free cutting steels; it has a higher

[564] NSSMC (2015), Nippon Steel and Sumitomo Metal Corporation (2015), Information submitted by email, 07 December 2015.
[565] Op. cit. EUROFER and EGGA (2015b)
[566] NSSMC (2016), Nippon Steel and Sumitomo Metal Corporation (2016), Information submitted by email, 08 January 2016.
[567] Op. cit. Hashimura M. et al (2007)

sulphur content and contains MnS which is distributed in very fine particles through controlled manufacturing conditions. NSSMC[568] indicated the following chemical composition of their lead-free cutting steel (Figure 18-5).

Figure 18-5: Chemical composition of the lead-free free cutting steel developed by NSSMC

		Chemical composition(mass%)					MnS control
		C	Mn	P	S	Pb	
SAE Leaded free cutting steel	12L14	≦0.15	0.85 –1.15	0.04 –0.09	0.26 –0.35	0.15 –0.35	–
JIS Leaded free cutting steel	SUM24L	≦0.15	0.85 –1.15	0.04 –0.09	0.26 –0.35	0.10 –0.35	–
NSSMC Lead free free cutting steel	Sumigreen CS	≦0.15	0.90 ～1.70	0.04 ～0.09	0.40 ～0.70	-	Spindle shaped
	EZ	≦0.15	0.90 ～1.30	0.07 ～0.12	0.35 ～0.60	-	Fine dispersed

Source: Nippon Steel and Sumitomo Metal Corporation (NSSMC) (2016)

Nippon Steel and Sumitomo Metal Corporation[569] estimate that the application of their lead-free steel does not require large process changes but some modifications of the cutting conditions. NSSMC[570] estimates that the adaptations could comprise changes in the material and/or design of cutting tool, cutting speed, feeding speed, depth of cut, oil etc. NSSMC further estimates that the application of their lead-free steel does not require large investment costs but is not able to determine the costs. NSSMC[571] states that the cost of their lead-free steel approaches the same as leaded free cutting steel.

The contribution by PennEngineering shows that plant-specific adaptations in the machining procedures makes it possible to use lead-free steel grades that are available on the market: PennEngineering[572] is a designer and manufacturer of specialty fasteners.[573] It has to be noted that fasteners are one of the typical components that according to the application of EUROFER and EGGA[574] needs the use of leaded steel.

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568 Op. cit. NSSMC (2016)
569 Op. cit. NSSMC (2016)
570 Op. cit. NSSMC (2016)
571 Op. cit. NSSMC (2016)
572 Op. cit. PennEngineering (2015a)
573 http://www.pemnet.com/comp_lit_files/, see bulletin K for fasteners used in EEE.
574 Op. cit. EUROFER and EGGA (2015b)

PennEngineering[575] states that they have started to test lead-free free cutting steel "*over three years ago*" (as of October 2015). For environmental and strategic reasons,[576] PennEngineering focused on "*traditional grades of low carbon, rephosphorised, resulfurised, free machining steels*", such as 1215, 11SMn30, and 11SMn37, that are commercially available in the small bar sizes PennEngineering uses.[577] PennEngineering states that for most of our product, these grades can be run at the same surface footage and feed rates as 12L14 leaded steel with some reduction in efficiency: "*In the majority of cases the decreased efficiency is from more frequent tool changes driven by faster deterioration of the surface finish. We are making changes to tool materials and other subtle proprietary changes to minimize the loss of efficiency.*" PennEngineering[578] explains that the machining is done on five and six spindle automatic screw machines that perform a variety of machining operations.[579]

PennEngineering states that they managed the increased cost of the machining operation down to the area of 10%. However, PennEngineering did not reveal details of the technical changes in order to protect the "*significant investment in preparing for the eventual removal of RoHS Exemption 6a*".

Besides the above mentioned examples of lead-free free cutting steel covering resulfurized (NSSMC) and rephosphorized and resulfurized (PennEngineering) steel grades, there are basically also lead-free alternatives available that contain bismuth or tellurium.[580] EUROFER and EGGA[581] state that "*bismuth alloyed low carbon free cutting steels have been supplied for certain applications*." However, EUROFER and EGGA do not further specify these applications with "*very specific machining conditions*" but rather claim that this alternative is not practicable due to the above mentioned difficulties in hot workability. It might be that the difficulties in how workability cause negative environmental impacts by increased energy costs in the steel production; however in the absence of detailed comparisons, the consultants cannot conclude on this statement.

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[575] Op. cit. PennEngineering (2015a)
[576] "We are well aware that other elements such as bismuth, selenium, tellurium, tin and calcium have been used to replace lead. Off these, bismuth, selenium and tellurium are the most commercially viable. Because environmental legislation is constantly changing, and because there are some environmental concerns with selenium and tellurium, we stayed away from steels with these two elements out of concern about future restrictions. We are still open to bismuth steels, but there are concerns about price and availability of bismuth."
[577] According to PennEngineering (2015b), "round bar in the 5/32 inch to 5/8 inch range and hex bar in the 3/16 inch to 5/16 inch range".
[578] Op. cit. PennEngineering (2015b)
[579] Most commonly performed machining operations are rough forming, finish forming, turning, shaving, knurling, facing, cut off, drilling, form tapping, back working (primarily countersinking). Other machining operations also performed include reaming, slotting, broaching and external threading (primarily rolling with some cutting).
[580] Op. cit. EUROFER and EGGA (2015a)
[581] Op. cit. EUROFER and EGGA (2015b) and (2016b)

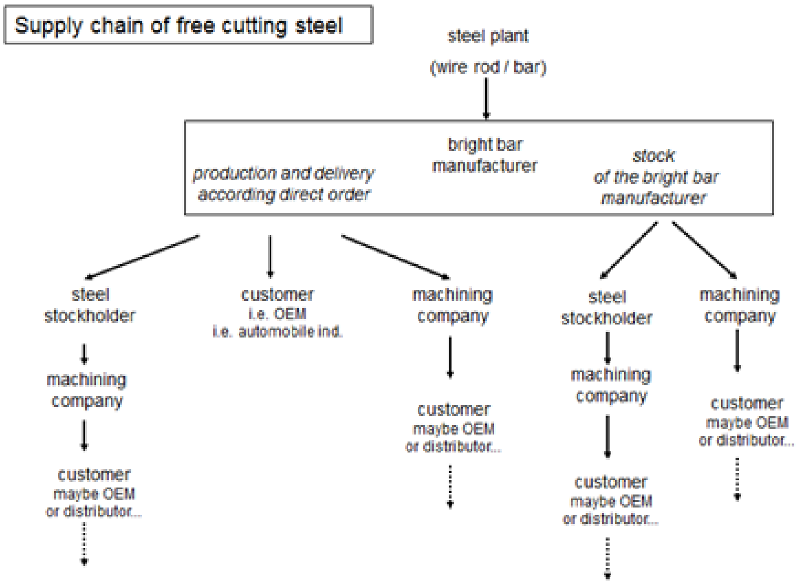
It is apparent from the paragraphs above that there are alternatives on the market that are scientifically and technically practicable for at least some applications: This is the case for resulfurised and rephosphorised and resulfurised steel grades; for bismuth or tellurium containing steel, the information is not conclusive.

These single cases are not reflected by EUROFER and EGGA as it seems that they rather search for an all-round alternative: "*No alternatives have been identified that can effectively replace lead as a machinability enhancer in steel in all respects. Lead-free alternatives may show acceptable results in single machinability tests, but the overall performance of the lead-free steels is worse than that of leaded steel."* Though the consultants understand this statement from a perspective of the steel producer, the example of PennEngineering shows that substitution efforts are successful when undertaken in the specific manufacturing case with different alternatives available.

The consultants understand that there might be components that require a combination of different machining operations and therefore that the machinability over a broad range of cutting parameters has to be guaranteed, which might only be provided by leaded steel. However these cases have to be specified in the future. If steel manufacturers or OEMs lack sufficient information to specify these aspects, they should embark on dialogue and joint investigation with the component manufacturers who are expected to be aware of modifications needed to allow workability with lead-free alloys. This need of a different approach is supported by the statement of EUROFER and EGGA[582] already mentioned above that the supply chain is complex and that the steel producer has limited, if any, contact to the final OEM producer. EUROFER[583] states that "*the steel producer has a direct contact usually only to the bright drawer. In some special cases there are contacts also with the final producer (e.g. Bosch) for the discussion of special properties. But this is not the case for the commodity products.*" The supply chain of free cutting is illustrated in the following figure.

[582] Op. cit. EUROFER and EGGA (2015b)
[583] Op. cit. EUROFER (2016b)

Figure 18-6: Supply chain of free cutting steel



Source: EUROFER (2016b)

To conclude, the consultants understand from the information provided by EUROFER and EGGA that the steel producers are not able to provide the detailed information on the specific applications of leaded steel in the EEE sector that would be needed to assess the technical and scientific practicability of available substitutes. NSSMC confirm this estimation by stating that "*NSSMC do not know the detailed machining procedure*".

The supply chain provided by EUROFER in the figure above points out that the machining companies might be the right stakeholders for providing more precise information. It is understood from the example of PennEngineering that alternative materials might need adaptations in the machining procedures, which every EEE component manufacturer has to carry out for his specific machining operations; however, substitution at least for some applications is understood to be possible.

Galvanized steel

As the intentional addition of lead in the galvanizing process cannot be separated from the unintentional presence due to the use of zinc scrap and galvanizers' ashes, substitution of lead is not further discussed. For further information, please see section 18.5.6.

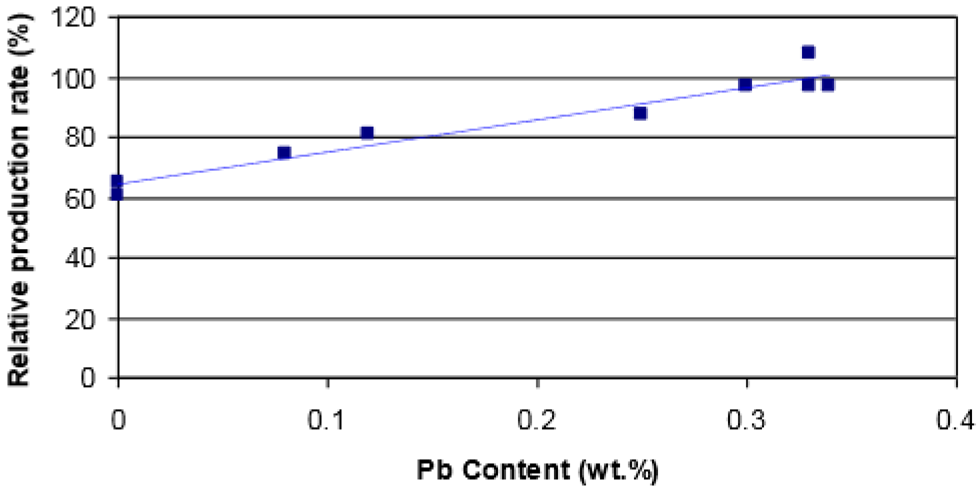
18.5.3 Possibilities for Reducing RoHS Substances

Steel for machining purposes

EUROFER and EGGA reported tests conducted by Tata Steel and Saarstahl according to which a reduction of lead in steel for machining purposes results in a decrease of production rate which subsequently caused an increased usage of cutting tools and/or longer machining times. The following figure shows this overall result according to EUROFER and EGGA. It is however unclear if attempts were made by Tata Steel and

Saarstahl to adjust the processing to accommodate the decreasing lead content materials tested. This makes it difficult to assess the overall conclusion of EUROFER and EGGA on the "*progressive deterioration in machinability*": Are longer machining times acceptable in some applications? Which possibilities can be explored to minimize the loss of efficiency as in the case of PennEngineering?

Figure 18-7: Effect of Pb reduction in steel alloy on production rate in a component production test



Source: EUROFER & EGGA (2015b)

The consultants can follow that steel with a lower lead content may suffer technical drawbacks for e.g. machining in automated series production. There might, however, be applications where a reduction of lead does not pose a significant problem as the contribution of CETEHOR shows, where generally leaded steel with a lead content of 0.2% is used. It might be that the required level of performance cannot be generally defined but depends on the machining processes. However, where substitution with lead-free alloys is not possible, the second approach in the future strategy of companies could be to apply lower leaded steel in their applications where a complete phase-out is not practical.

Galvanized steel

The consultants' understand the lead in the batch hot dip galvanization is expected to slightly decrease in the future due to different reasons such as reduction of intentional addition of lead, decrease of lead in the galvanizers' ashes together with decrease in the very long term (50 years and more) of lead in recycled zinc scrap.

18.5.4 Environmental Arguments

Steel for machining purposes

EUROFER and EGGA raise general environmental arguments on higher energy use of alternative material due to lower production rate in the components manufacturing[584] or higher temperature needed in the steel production.[585] Though those differences may be of relevance, available information does not allow a comprehensive comparison in this respect. Especially for comparison of the energy use in the component manufacturing, it is expected that this could be case specific and dependent on adaptations in the machining conditions, which helps to reduce the efficiency loss shown in the case of PennEngineering. However, it might be that the energy savings could support the exemption for specific applications if it is comprehensively documented.

Galvanized steel

It is understood that the introduction of lead is unintentional and merely a result of lead being present in the secondary zinc. From an environmental perspective, the consultants can follow that the recycling of zinc scrap and its reuse is a positive practice, as it enables a reuse of ressources and as stated by EUROFER and EGGA[586] this is understood to be more energy efficient than the use of primary zinc: "*the use of remelt secondary zinc reduces the embodied energy of the zinc used in batch galvanizing by over 20 times*"[587] (see section 18.3.3).

18.5.5 Stakeholder Contributions

Six contributions were submitted to the stakeholder consultation. The contributions of KEMI,[588] CETEHOR[589] and PennEngineering[590] are discussed in the sections above as well as below. Bosch[591] did not provide any evidence to its claims; therefore the contribution was not further considered.

The contributions submitted by TMC[592] and JBCE[593] raise a legal question as to the availability of the current exemption to category 8 and 9 equipment. TMC and JBCE claim the availability of Annex III exemptions to category 8 and 9 for seven years starting in 22.7.2017. EUROFER and EGGA[594]state in this regard:

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[584] Op. cit. EUROFER and EGGA (2015a)
[585] Op. cit. EUROFER (2016a)
[586] Op. cit. EUROFER and EGGA (2015a)
[587] Op. cit. EUROFER and EGGA (2015a)
[588] Op. cit. KEMI (2015)
[589] Op. cit. CETEHOR (2015)
[590] Op. cit. PennEngineering (2015a)
[591] Op. cit. Bosch (2015)
[592] Op. cit. TMC (2015)
[593] Op. cit. JBCE (2015)
[594] Op. cit. EUROFER and EGGA (2015a)

> *"We apply for renewal of this exemption for categories 1 to 7, 10 and 11 of Annex I for an additional validity period of 5 years. For these categories, the validity of this exemption may be required beyond this timeframe. Although applications in this exemption renewal request may be relevant to categories 8 & 9, this renewal request does not address these categories. Further, categories 8 & 9 have separate maximum validity periods and time limits for application for renewals."*

Since lead as an alloying element in steel for machining purposes and in galvanised steel is understood to be relevant to all categories, it can be concluded that expiration dates should be specified for all categories.

18.5.6 The Scope of the Exemption

The scope of the current exemption is viewed as very wide. As mentioned above, the contribution of the Swedish Chemicals Agency KEMI makes reference to Article 5(1)(a) that stipulates an inclusion of materials and components of EEE for specific applications in the lists in Annexes III and IV. The specifications of applications are so far missing for exemption 6a. KEMI therefore proposes to split into a number of more specific exemptions, related to applications where it has been verified that feasible alternatives are currently not available without specifying whether these are applications of lead in steel for machining purposes or of galvanizing processes. As the present exemption 6a covers these different uses of lead with different purposes and different entry pathways, possibilities to narrow down the scope differ and will be discussed separately for steel for machining purposes and galvanized steel below.

Steel for machining purposes

The scope of the current exemption is viewed as very wide. However, EUROFER and EGGA only provide a list of typical components and not an exhaustive list. Thus the consultants cannot conclude on specific applications to narrow the scope of the exemption.

The consultants understand that there are alternatives on the market for at least some applications. However, it is not clear in what cases, or on what basis they cannot be used as substitutes for other applications, where, from the information provided by EUROFER and EGGA, leaded steel cannot be substituted. To clarify if they are not used at all or just not for the full range of applications, further information is needed. It can however be followed that the steel producer association is not able to provide such information.

The consultants would expect that the scope could be narrowed based on application groups or based on critical properties and required performance in application groups. This could require a supply chain survey, in order to collect and compile relevant information and to allow conclusions as to relevant properties and performance levels. Time may be needed in order to initiate such a survey along the supply chain to gain this information and screen all relevant applications relevant to arrive at an exhaustive list (of applications or of properties). However, this effort is presumed to be feasible as well as important for communicating to the steel customers where additional effort is needed in the applications of substitutes in the future.

EUROFER[595] claims that "*conventional machinability testing (for example ISO standard for tool life testing) can only be made for a selected system. This explains why each research institute or machining company has its own trials for machinability assessment. And if one parameter is changed (in our case lead or no lead) it may be possible that the whole system consequently has to be adjusted. And this explains why such studies can be made for some special applications but not yet for the whole machining industry.*"

Therefore it might be that an exhaustive list of properties also specifying the required performance level and the relevant performance indicators that are relevant for such properties might not be practicable to refine the scope of the exemption. To support this understanding, however, the complexity of the situation at hand needs to be presented and substantiated. The wide scope currently addressed in the exemption is open to misuse in cases where substitution might be possible. Therefore the consultants conclude that although a comprehensive list of applications may be long for refining the scope of the exemption, this is however of importance for establishing the potential of a change in scope. The consultants consider this to be the first step to further narrow the scope of the exemption, which the industry must be induced to undertake.

Galvanized steel

EGGA[596] argues that the proposed addition in the wording formulation provides a narrowed scope for galvanized steel as the batch hot dip galvanized steel makes up less than 1% of the total galvanized steel.[597] It is however understood that this reduction in scope to batch hot dip galvanized steel has been introduced to the ELV in 2010. Therefore the consultants estimate that this narrowing under RoHS rather describes the current practice.

A split of this part of the exemption for batch galvanized steel into an exemption that covers the unintentional presence of lead and applications where the addition of lead is needed does not seem to be practical against the background that the production of EEE components cannot be separated from the production of components for other product groups. EGGA[598] argues that "*no galvanizing plant is dedicated to EEE and EEE will normally represent a very small proportion of a plant's throughput. To generate an exhaustive 'positive list' of such products would be complex and difficult given EGGA's position in the supply chain; a galvanizing plant may operate with a lead level requiring*

[595] Op. cit. EUROFER (2016a)
[596] Op. cit. EGGA (2016)
[597] "Oeko report 07.0307/2008/517348/SER/G4 (21 June 2010) [Op. cit. Zangl et al. (2010)] on the adaptation to technical progress of ELV and ROHS directives estimated that 99% of the galvanized steel used in ELV applications was of the continuously galvanized type and that <1% was of the batch galvanized type. We estimate that a similar positon exists for EEE applications, which illustrates the significant narrowing of the exemption as a result of the efforts of zinc suppliers and steel industry and places a suitable to context to the current exemption request regarding batch galvanized steel."
[598] Op. cit. EGGA (2016)

exemption due to requirements of a product or processing characteristic that relates to 'non EEE' products/customers."

Generally, EGGA stated that there is much pressure from the customer's side to remove lead so that the intentional addition would phase out with time, irrespective of the fact that other product groups besides EEE and automotive components do not have the same lead restrictions.

18.5.7 Exemption Wording Formulation

The present Exemption 6a covers completely different uses of lead in steel with different purposes that could also be specified with different thresholds. A split of the exemption in the opinion of the consultants is possible.

The first part of the exemption should cover the use of lead as an alloying element in steel. For this part, the consultants agree with KEMI that there is a need to narrow the scope of the exemption. However, the consultants cannot conclude a list of exhaustive applications of lead in steel on the basis of the available information. The consultants agree that such an exhaustive inventory is needed in the future in order to further specify possibilities to narrow down the exemption to specific applications. Further steps that the consultants deem necessary for a future review are explored in Section 18.5.8.

Concerning batch hot dip galvanized steel, EGGA[599] agreed to lower the threshold down to 0.2% provided that the wording formulation makes it clear that this threshold is calculated for the entire steel item.[600] This reduced threshold of 0.2% has been proposed based on consultations across the industry according to EGGA.[601]

EUROFER and EGGA explain that "*Pb levels range from <0.03% up to 0.8% Pb in the coating if this is considered the 'homogeneous material'. Steel items that have been batch hot dip galvanized would therefore readily comply with the upper exemption limit of 0.35% Pb previously established for machining steels*".[602] It is thus concluded that specifying a threshold for the presence of lead would depend on whether this threshold would relate only to the coating or to the complete steel part.

The current wording of ELV Annex II Exemption 1(a) is "*Steel for machining purposes and batch hot dip galvanised steel components containing up to 0,35 % lead by weight*". Thus, should it be decided to renew the exemption in relation to the amount of lead in

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[599] EGGA (2015), European General Galvanizers Association (EGGA) (2015), Answers to 2nd Clarification Questions, submitted 14.12.2015.
[600] EUROFER and EGGA (2015a) also state in this regard:
"Lead has a low solubility in the zinc-iron alloys that are formed during the galvanizing reaction. Hence, the quantity of lead present in the coating is normally significantly lower than the lead present in the process bath – typically half as much. For a given bath composition, the variations of lead concentrations in the coating mainly depend on the steel type (reactivity with molten zinc)."
[601] Op. cit. EGGA (2016)
[602] Op. cit. EUROFER and EGGA (2015a)

the entirety of the galvanised part, reference to "*batch hot dip galvanised steel components"* should be made. In this case the threshold could be lowered to 0.2%.

Otherwise, the formulation should refer to the presence of lead in the coating of components, whereas the threshold may need to be adjusted to accommodate the higher levels of lead (i.e., up to 0.8%). EUROFER and EGGA[603] explain that the batch hot dip galvanizing process allows the complete coverage of manufactured steel components with a metallurgically-bonded metallic coating that is formed through diffusion of iron and zinc, giving no clear delineation between coating and steel substrate. It is thus not clear if reference to the coating would be feasible in terms of market surveillance.

As further decrease in the lead content would only be expected in the long term due to the unintentional presence of lead in zinc scrap or irrespective of the requirement under RoHS, the consultants propose the exemption to be granted for the longest review period which is possible under RoHS.

18.5.8 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

Overall, it seems important to differentiate in the future between the different uses in steel where lead provides necessary properties in steel alloy and is intentionally added and between galvanizing processes where lead is mostly unintentionally present.

As for lead in steel for machining purposes

- Substitution with bismuth containing steel might not be reliable and might cause negative environmental impacts. For the latter, not enough data is available to comprehensively conclude on this.
- Substitution via steel that does not contain lead is scientifically or technically practicable at least for some applications as shown by examples of PennEngineering with lead-free rephosphorised and resulfurised steel used for the production of specialty fasteners and of NSSMC with resulfurised steel used for the production of printer rails and printer shafts.

[603] Op. cit. EUROFER and EGGA (2015a)

- The remaining applications have to be specified by performing and integrated survey of the supply chain in order to narrow the scope of the exemption to a comprehensive list of applications. This would need the engagement of EEE component manufacturers. As EUROFER and EGGA clarify the complexity of the supply chain, the consultants can follow that this would be time consuming. However, the consultants think that the current scope is not justified and recommend a short termed exemption to allow performing such a survey.
- The set-up of a comprehensive list of applications would also allow deciding, whether the lead content can be further reduced. Though the steel producers[604] object to this approach due to decreased tool life and higher cutting forces, these machinability conditions seem to be adaptable in specific cases as the example of CETEHOR shows.

As for lead in galvanized steel, the consultants understand that lead does not provide a function in the coating of parts used in EEE. It is understood that there are two cases for the presence of lead. In some plants, lead is present at the bottom of galvanisation baths as it precipitates from secondary zinc added to the process, and may thus be present in galvanised products. In other cases, lead may be added to facilitate the galvanising process of certain parts (for example steel mesh used for construction). Such practices were explained not to be directly relevant to EEE parts. However, as the galvanisation of parts for EEE is performed in the same baths, the presence of lead in some cases cannot be excluded. In both cases, lead is understood not to serve a functional purpose in the galvanisation of steel parts for EEE, but to be a result of the use of secondary zinc or of the manufacture of other parts: "*Lead is present in the zinc coating of galvanised steels. Lead has no beneficial (or adverse) effect on the coated product, but may have a technical influence on the galvanizing process in a small number of plants*".[605] The consultants conclude that the lead is mostly not intentionally added (or not added for itentions of relevance to the EEE part properties), but a result of the use of zinc scrap or of galvanizers' ashes. The intentional addition of lead to a galvanizing bath where it is technically required could not be separated for EEE specific processes or products, which are understood to have only a small share of all galvanised parts.

18.6 Recommendation

Based on the above considerations, it is recommended to split the exemption and provide different review periods for each entry.

A short review period of three years is proposed for applications where lead is present for machining purposes. The overall picture where substitution efforts are promising is not clear enough at present to allow an adjustment of the scope. In parallel it is

[604] Op. cit. EUROFER and EGGA (2015b)
[605] Op. cit. EUROFER and EGGA (2015a)

established that substitutes are practical at least for some applications. The aim of a future review should therefore be to evaluate results of a comprehensive survey of the supply related to the applications of leaded steel alloys together with their technical requirements. The aim should be to check the applicability of a more narrow scope for the exemption. The consultants would further recommend cancelling the exemption, should industry fail to provide detailed and substantiated information in the future.

As for the exemption for batch hot dip galvanized steel, a lower threshold is proposed in agreement with the applicant for lead in batch hot dip galvanized steel items and a review period of the maximum permissible validity of five years is proposed for this part of the exemption, as the lead is mostly an unintentional impurity in the galvanizing bath.

Exemption 6a	Duration*
I) Lead as an alloying element in steel for machining purposes containing up to 0,35 % lead by weight	For Cat. 1-7 and 10 and 11: 21 July 2019
II) Lead in batch hot dip galvanized steel components containing up to 0.2% lead by weight	For Cat. 1-7 and 10 and 11: 21 July 2021
III) Lead as an alloying element in steel for machining purposes and in galvanized steel containing up to 0,35 % lead by weight	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024;

Note: As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

18.7 References Exemption 6a

CETEHOR (2015) Contribution by Comite Franceclat (French Watch, Clock, Jewellery, Silverware & Tableware Centre), CETEHOR, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Ex_6_a_Comite_Franceclat_Cetehor_20151012.pdf

Dunkermotoren GmbH (2014) Dunkermotoren GmbH (2014), Original Application for Exemption Renewal Request, submitted 15.12.2014, English version available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/DUnkermotoren/Ex_6a_Dunkermotoren_150806_Ausnahmeantrag_Stahl_englisch.pdf

EGGA (2015) European General Galvanizers Association (EGGA) (2015), Answers to 2nd Clarification Questions, submitted 14.12.2015.

EGGA (2016) European General Galvanizers Association (EGGA) (2016), Answers to 3rd Clarification Questions, submitted 01.03.2016.

EUROFER & EGGA (2015a) European Steel Association (EUROFER) & European General Galvanizers Association (EGGA) (2015a), Original Application for Exemption Renewal Request, submitted 16.01.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Eurofer/6a_RoHS_Application_Form_6a_16012015-.pdf

EUROFER & EGGA (2015b) European Steel Association (EUROFER) & European General Galvanizers Association (EGGA) (2015b), Answers to Clarification Questions, revised version, submitted 15.09.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Eurofer/Ex_6a_Eurofer_1st_round_of_Clarification-Questions_final-20150803_DRAFT_REPLY_-_EGGA_EUROFER_MCchanges15-9-15_revised.pdf

EUROFER (2016a) European Steel Association (EUROFER) (2016a), Answers to 2nd Clarification Questions, submitted 15.01.2016.

EUROFER (2016b) European Steel Association (EUROFER) (2016b), Answers to 3rd Clarification Questions, submitted 24.02.2016.

Gensch et al. (2009) Oeko-Institut e. V., 20 February 2009, Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf

Hashimura M. et al. (2007) Hashimura M., Miyanishi, K., Mizuno, A., Development of Low-Carbon Lead-Free Free-Cutting Steel Friendly to Environment, Nippon Steel Technical Report, No. 96, 2007, available under: http://www.nssmc.com/en/tech/report/nsc/pdf/n9608.pdf

JBCE (2015) Contribution by JBCE – Japan Business Council in Europe in a.i.b.l, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Comment_on_public_cousulation_of_Exemption_request_2015-2_6_a__.pdf

KEMI (2015) Contribution by KEMI Kemikalieinspektionen, Swedish Chemicals Agency, submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Ex_6a_KEMI_Answer_to_SC_RoHS_20151016_Lead_in_Steel.pdf

NSSMC (2015) Nippon Steel and Sumitomo Metal Corporation (NSSMC) (2015), Information submitted by email, 07.12.2015.

NSSMC (2016) Nippon Steel and Sumitomo Metal Corporation (NSSMC) (2016), Answers to Clarification Questions, submitted 08.01.2016.

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PennEngineering (2015b) PennEngineering (2015b), Answers to Clarification Questions, submitted 14.12.2015.

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Sensata Technologies (2015a) Sensata Technologies Holland B.V. (2015a), Original Application for Exemption Renewal Request, submitted 15.01.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_a_/Sensata_Technologies/6a_6b_6c_RoHS-Exemptions_Application-Format_Ex_6a_b_c_Pb_in_St_Al_Cu.pdf

Sensata Technologies (2015b) Sensata Technologies Holland B.V. (2015b), Answers to Clarification Questions, submitted 20.08.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Sensata/Ex_6a6b6c_Sensata_Questions_response_20150820.pdf

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19.0 Exemption 6b: "Lead as an alloying element in aluminium containing up to 0,4 % lead by weight"

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

2011	AA 2011, leaded Al wrought alloy
Al	Aluminium
AA 6023	Lead-free bismuth containing wrought alloy
AlEco62Sn	Lead-free bismuth containing wrought alloy
EAA	European Aluminium Association
ECHA	European Chemicals Agency
EEE	Electrical and Electronic Equipment
ELV	End-of-Life Vehicle
EoL	End-of-Life
JBCE	Japan Business Council in Europe
KEMI	Kemikalieinspektionen, Swedish Chemicals Agency
Pb	Lead
tpa	Tonnes per annum
TMC	Test & Measurement Coalition
WEEE	Waste of Electrical and Electronic Equipment

19.1 Background

The European Aluminium Association (EAA), Sensata Technologies and Dunkermotoren have applied for the renewal of exemption 6b, requesting the current wording formulation of the exemption as appears in Annex III of the RoHS Directive.

Aluminium (Al) alloys can be differentiated into two principal classifications:[606]

- **Wrought alloys:** Al alloys primarily used for wrought products; they have an alloy content up to 10% and therefore strict and very low tolerance limits for the alloying elements. Wrought alloys are designated with a four-digit number according to the alloy designation system.
- **Cast alloys:** Al alloys primarily used for the production of castings; cast alloys have much higher tolerance limits for alloying elements; the alloy concentration is of up to 20%. For cast alloys, a different designation system with five digits is used.

The association of the Al manufacturers, EAA,[607] with support of many EEE manufacturer associations[608] requests the extension of the exemption without specifying an expiration date. Dunkermotoren,[609] a component manufacturer, requests the exemption specifically for the manufacturing of gear parts in engine and transmission parts for a period of two to five years. Sensata Technologies, a manufacturer of sensor and control

[606] EAA (202), European Aluminium Association EAA (2002), The Automotive Manual; http://www.european-aluminium.eu/wp-content/uploads/2012/01/AAM-Materials-3-Designation-system.pdf;
Paraskevas, D. et al. (2013), Closed and Open Loop Recycling of Aluminium: A Life Cycle Assessment perspective; 11th Global Conference on Sustainable Manufacturing, 23rd to 25th September Berlin, Germany.

[607] EAA (2015a), European Aluminium Association (EAA) (2015a), Original Application for Exemption Renewal Request, submitted 16.01.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_b_/AISBL/6b_Final_RoHS_Exemption_Renewal_Dossier_2015_01_16.pdf

[608] The EEA's exemption request was supported by the following bodies: American Chamber of Commerce to the EU (AmCham EU); Avago Technologies Limited; DIGITALEUROPE; European Committee of Domestic Equipment Manufacturers (CECED); European Copper Institute (ECI); European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry (COCIR); European Garden Machinery Industry Federation (EGMF); European Passive Components Industry Association (EPCIA); European Semiconductor Industry Association (ESIA); Gesamtverband der Aluminiumindustrie e.V.; Information Technology Industry Council (ITI); IPC - Association Connecting Electronics Industries; Knowles (UK) Ltd; LightingEurope; SPECTARIS; TechAmerica Europe; WirtschaftsVereinigung Metalle (WVM); ZVEI - Zentralverband Elektrotechnik- und Elektronikindustrie e.V..

[609] Dunkermotoren GmbH (2015), Original Application for Exemption Renewal Request, submitted 15.12.2015, English version available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_b_/Dunkermotoren/Ex_6b_Dunkermotoren_150806_Ausnahmeantrag_Aluminium_englisch.pdf

products, stated after an investigation within its supply chain that the company is not making use of this exemption.[610]

EAA thus requests the renewal of Ex. 6b with the following wording:

> "*Lead as an alloying element in aluminium containing up to 0,4 % lead by weight*"

19.1.1 History of the Exemption

As for the history of the exemption, it has to be noted that since the RoHS 1 Directive was published in 2002, Exemption 6 has covered lead as an alloying element in steels, aluminium and copper.[611] After the last revision on 2009[612], exemption 6 was split into three exemptions 6a, 6b and 6c for each alloy respectively.

A corresponding exemption exists under the ELV Directive 2000/53/EC (ELV, listed in Annex II, as Exemption 2(c)). It was reviewed in 2015; the evaluation report has yet to be published. During the ELV revision, the consultants investigated the possibility of introducing a split into the aluminium alloy exemptions making a distinction between cases where Al is not intentionally introduced and cases where a lead content of up to 0,4 % by weight is required in Al alloys to enhance machinability. This split was proposed due to the information of the automotive industry that showed a clear distinction could be made into cast alloys that are used for big parts in vehicles, e.g. engine-blocks or gearbox housings, and between wrought alloys that are mainly used for manufacturing small parts, e.g. valve actuation, axis pins for pivot levers or oil return stop valves. The use of cast alloys in the automotive sector makes up 95% of the total use of leaded Al alloys in this sector.

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[610] Sensata Technologies (2015b), Sensata Technologies Holland B.V. (2015b), Answers to Clarification Questions, submitted 20.08.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Sensata/Ex_6a6b6c_Sensata_Questions_response_20150820.pdf

[611] The wording of exemption 6 was as follows: "Lead as an alloying element in steel containing up to 0,35% lead by weight, aluminium containing up to 0,4% lead by weight and as a copper alloy containing up to 4% lead by weight"; http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32002L0095&from=EN

[612] Gensch, et al. (2009), Carl-Otto Gensch, Oeko-Institut e. V., et al. 20 February (2009), Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf

19.1.2 Amount of Lead Used under the Exemption

According to EAA,[613] data availability is limited as to the amount of lead used under this exemption, due to a lack of knowledge on the type of leaded Al alloys used in EEE products and components on the EU market. EAA[614] explains that there are data on the "*amount of wrought products, extruded products and secondary alloys shipped to the EEE and machinery sectors (consumption) from EU producers. However, there is no data available concerning which of these products/alloys contain lead and their quantity. Furthermore, no data available indicates that the amount of final EEE products produced using EU Al alloys is actually placed on the EU market.*"

When asked to indicate at least a range of the amount of leaded aluminium alloys in the EU used for EEE, EEA[615] states that "*the potentially lead-containing Al alloys produced by producers in the EU and EFTA region (not the ones placed on the EU market) used in the high tech engineering sectors (not necessarily only EEE products) is most likely in the range of 100Kt to 1 Mt pa.*"

In this respect it can be noted that the U.S. Geological Survey Minerals Yearbook of 2014[616] estimates that 6.9% of Al product shipments of US and Canada are shipped to electronic end-users. In 2014 this share represented 809 thousand metric tonnes.

19.2 Description of Requested Exemption

According to information provided by EEA[617] in the original renewal request, the use of leaded Al alloys can be differentiated into Al alloys where the lead content is unintentional, due to the use of secondary raw material from aluminium scrap and into aluminium alloys, where lead is intentionally added for machining purposes:

- **Cast alloys** unintentionally contain lead, due to the use of Al scrap for the manufacture of such alloys; relevant applications in which such alloys are used

[613] EAA (2015b), European Aluminium Association (EAA) (2015b), Answers to Clarification Questions, revised version, submitted 14.08.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_b_/AISBL/20150814_Ex_6b_EAA_Ex_1st_round_of_Clarification-Questions_final_EAA_answer.pdf
The additional information was supported by the following industry associations and companies: DIGITALEUROPE; European Committee of Domestic Equipment Manufacturers (CECED); European Passive Components Industry Association (EPCIA); European Semiconductor Industry Association (ESIA); Gesamtverband der Aluminiumindustrie e.V.; Information Technology Industry Council (ITI); European Garden Machinery Industry Federation (EGMF); LightingEurope; ZVEI - Zentralverband Elektrotechnik- und Elektronikindustrie e.V.

[614] Op. cit. EAA (2015b)

[615] EEA (2016), European Aluminium Association (EAA) (2016), Answers to 2nd Clarification Questions, submitted 29.01.2016.

[616] USGS (2015), U.S. Geological Survey (USGS) (2015), Minerals Yearbook of 2014 – Aluminium [Advanced Release], table 6, pg. 5-15, available under: http://minerals.usgs.gov/minerals/pubs/commodity/aluminum/myb1-2014-alumi.pdf

[617] Op. cit. EAA (2015a)

include e.g. frameworks of lamps and lights, heat sinks, electrical and electronic items in housings etc.

- **Wrought alloys**, or Al alloys intentionally containing lead for machining purposes: Relevant applications where such alloys are used are not detailed. The functions of lead are indicated as lubrication, better chip fracturing, surface finish, higher cutting speed and longer tool life. Wrought alloys are often used in screw machine products according to EAA[618], e.g. various machinery components, screws, bolts, fittings, nuts, automatic lathe products.

As this differentiation was in line with information available through the ELV review on leaded Al alloys used in the automotive sector, stakeholders were asked during the RoHS stakeholder consultation[619] whether a possible split of the exemption, differentiating between aluminium alloys where lead is not intentionally introduced and between aluminium alloys where lead is added to obtain certain properties would be practical. Thereupon, EAA[620] submitted a contribution stating the following:

> *"As already stated, lead can be added to the alloys to perform a certain function and lead can be present in the alloys when alloys are produced e.g. from scrap. The former is termed as intentionally leaded alloys and the later, unintentionally leaded alloys. However, there is no straightforward link between intentional/unintentional and wrought/casting, i.e. while casting alloys are mostly produced from scrap, for the production of wrought alloys, scrap can also be used as input. Therefore a distinction of intentional and unintentional cannot be made according to the type of alloys.*
>
> *The exemption 6b has been applied to Al alloys in general which has left the demand and market to determine the most effective utilisation of Al material available to EU producers. An arbitrary distinction of product by the purpose or none-purpose of lead could affect the supply and demand chain. The consequences of these changes are yet to be studied from technical, environmental and economical points of view. The industry will need time to comprehend such studies and changes."*

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[618] Op. cit. EAA (2015a)

[619] http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Consultation_Questionnaires/Ex_6b_Consultation_Questionnaire.pdf

[620] EAA (2015c), Contribution by European Aluminium Association (EAA) (2015c), submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_b_/Ex_6b_European_Aluminium_Consultation_Questionnaire_answer_final_20151016.pdf

19.3 Applicant's Justification for Exemption

EAA[621] claims that the exemption of 0,4% lead content in aluminium provides the possibility of the use of recycled aluminium within the EU. EAA[622] explains that the scrap metal arising from products from the past can contain lead and that the presence of lead as impurity in the scrap flow is tolerated to a certain level for the production of many secondary alloys, which is specified in European standards.

EAA[623] states that separation of lead from the scrap is feasible in the remelting stage by for example phase separation, electrochemical refining and vacuum distillation, but that these methods are only approved on a laboratory scale and from an environmental and economical perspective not practicable. According to EAA,[624] the dilution of the scrap with primary aluminium results in higher environmental impacts due to the fact that the production of primary aluminium is very energy intensive.

As for lead in Al alloys used for machining purposes, EAA[625] claims that lead acts as a lubricant during machining processes; through lead, better chip fracturing and surface finish as well as higher cutting speeds and a longer tool life are achieved. EAA was asked to exhaustively specify the functionality of lead in these applications e.g. specific function and properties, performance criteria, etc. EAA[626] provided the following functionalities and performance aspects for lead in Al alloys:

- Corrosion resistance of manufactured articles;
- Surface finish of manufactured articles;
- Longer life of manufacturing tools and less energy consumption during machining of parts;
- Cutting speeds of manufacturing tools;
- Lubrication effect in manufactured articles;
- Better chip fracturing in manufactured articles;
- Temperature resistance;
- Electrochemical potential (of additive);
- Shrinking from liquid to solid phase (of additive);
- Durability of part;
- Eutectic point of alloy.

EAA did not provide performance indicators for these functionalities / performance aspects which would form a basis for testing the performance and comparing between Al alloys with and without lead. EAA[627] stated thereupon that *"the industry will need*

[621] Op. cit. EAA (2015a)
[622] Op. cit. EAA (2015a)
[623] Op. cit. EAA (2015a)
[624] Op. cit. EAA (2015a)
[625] Op. cit. EAA (2015b)
[626] Op. cit. EAA (2016)
[627] Op. cit. EAA (2016)

sufficient time to organise a team of experts to conduct a comprehensive study, if enough number of manufacturers would be willing to take part in the study. This study shall address the following:

- *listing critical performance indicators for each of the functionalities of lead in Al alloys;*
- *measuring/testing these indicators for lead Al alloys;*
- *measuring/testing these indicators for potential substitutes if available.*

Such study, including an initial information and data collection and analysis and later on carrying out the necessary experiments, usually takes more than one year."

EAA[628] also claims that they cannot clearly distinguish between the use of cast and wrought alloys for specific components:

> *"The applications of Al Alloy (wrought and casting alloys) vary from one component to another. The use of the alloys is not strictly limited to a specific application in a component. Usually components producers design a component and specify the type of alloys they want to use to a supplier. There are hundreds if not thousands of components that may use Al alloys."*

19.3.1 Possible Alternatives for Substituting RoHS Substances

EAA[629] states that *"substitution of lead as alloying element with bismuth is technically feasible."* EAA[630] further states that *"lead-free alloys with bismuth as a substitute, such as AlEco62Sn or AA 6023, have been developed to replace as far as possible some applications of 2011 alloy in the automotive sector. However the current state-of-the-art does not indicate any suitable substitute for lead in aluminium alloys used in the production of EEE products."*

As major constraints, EAA[631] claims that bismuth hampers existing recycling schemes and that secondary aluminium producers observe that bismuth creates an unwanted microstructure effect leading to potential problems in the refining and casting process. According to EAA,[632] bismuth alloys (if in large amount) need to be separated from the others prior to the remelting stage.

EAA[633] further emphasises the possible restricted availability of bismuth as the production of bismuth is connected to the production of lead, in that the source of bismuth that comes to the market is a by-product of the lead production process.

[628] Op. cit. EAA (2015b)
[629] Op. cit. EAA (2015a)
[630] Op. cit. EAA (2015a)
[631] Op. cit. EAA (2015a) and (2015b)
[632] Op. cit. EAA (2015a)
[633] Op. cit. EAA (2015a) and (2015b)

19.3.2 Environmental Arguments

According to EAA,[634] a closed loop system exists for Al that includes the Al scrap from EEE. EAA[635] further states that Al recycling accounts for about 70% of the Al produced in the EU.

EAA[636] claims that any restriction introduced to the exemption would impact the recycling of Al scrap and thus the EU circular economy.

19.3.3 Socio-Economic Impact of Substitution

As for the substitution of lead by bismuth, EAA[637] expects an increase in direct production costs as bismuth is around 10 to 15 times more expensive than lead. Furthermore EAA states "*if the demand for bismuth increases and the demand for lead decreases, the price of bismuth may become even higher.*" EAA[638] also claims an increase in fixed costs, but without giving further information.

19.3.4 Roadmap to Substitution

EAA[639] did not provide a roadmap arguing that *"given the fact that there is no suitable alternative, it is impossible to draw up any detailed roadmap at this stage."*

19.4 Stakeholder Contributions

Five contributions to exemption 6b have been submitted during the stakeholder consultation. The contributions are presented in order of submission and shortly summarized:

- The **Robert Bosch GmbH**[640] generally supports the applicants without providing further information.
- **JBCE**[641] – Japan Business Council in Europe in a.i.b.l. states that they understand that EEE of category 8 and 9 are out of scope of this review. The JBCE understands that "*the exemption 6(b) in annex III can be applied to category 8&9*

[634] Op. cit. EAA (2015a)
[635] Op. cit. EAA (2015a)
[636] Op. cit. EAA (2015a)
[637] Op. cit. EAA (2015a)
[638] Op. cit. EAA (2015a)
[639] Op. cit. EAA (2015b)
[640] Robert Bosch GmbH (2015), Contribution by Robert Bosch GmbH, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_b_/Bosch-Stakeholder-contribution-Exemption-request-6b.pdf
[641] JBCE (2015), Contribution by JBCE – Japan Business Council in Europe in a.i.b.l, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_b_/Comment_on_public_cousulation_of_Exemption_request_2015-2_6_b__.pdf

products for seven years from identified date when entry into force for each products, at the earliest July 2021."

EAA[642] adds "*better heat treatment performance of the manufactured material*" as one more function of lead.

EAA further comments on the proposal to split the exemption as detailed in section 19.3.

- **KEMI** Kemikalieinspektionen, the Swedish Chemicals Agency[643], interprets Article 5 in the RoHS Directive in the way that both the material or component and the specific applications need to be defined in the wording formulation of an exemption. Thus, "*it is no longer legally possible to decide on an exemption for lead in aluminium alloys whatever the use is.*"
  KEMI therefore proposes the split into a number of more specific exemptions related to applications where it has been verified that feasible alternatives are currently not available.
- The **Test & Measurement Coalition**[644] submitted a general contribution on Category 9 Industrial monitoring and control instruments, similar in nature to the contribution made by the JBCE.

19.5 Critical Review

19.5.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists Entry 63 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0,05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children.[645] Entry 63 however further specifies this restriction not to be applicable for articles within the scope of the RoHS Directive 2011/65/EU.

Appendix A.1.0 of this report lists Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as

[642] EEA (2016), European Aluminium Association (EAA) (2016), Answers to 2nd Clarification Questions, submitted 29.01.2016.
[643] KEMI (2015),Contribution by KEMI Kemikalieinspektionen, Swedish Chemicals Agency, submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_b_/Ex_6b_KEMI_Answer_to_SC_RoHS_20151016_Lead_in_aluminium.pdf
[644] Test & Measurement Coalition (2015), Contribution by Test & Measurement Coalition, submitted 19 October 2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/General_Contribution_Test___Measurement_Coalition_package_9_exemptions_20151016.pdf
[645] Other restrictions of entry 63 cover e.g. jewellery and are thus not applicable here.

substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restriction for substances under Entry 30 of Annex XVII does not apply to the use of lead in this application as lead is used as an alloying element. In the consultants' point of view it is not a supply of a lead as a substance, mixture or constituent of other mixtures to the general public. Pb is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status January 2016).

Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

19.5.2 Scientific and Technical Practicability of Substitution

Generally, the assessment of scientific and technical practicability of substitution of lead in Al alloys is hampered by the fact that EAA did not provide data on the use and application of Al alloys in the manufacturing of EEE.

Substitution of lead is relevant in the applications where lead is present to perform a specific function. It is understood from the information provided by EAA that this is the case for Al alloys where lead is needed for machining purposes. Substitution options with tin and bismuth containing Al alloys are discussed in the following Section 19.5.2.1. The arguments provided by EAA generally object to bismuth as an appropriate general substitute for lead and are discussed in Section 19.5.2.2.

The other applicant Dunkermotoren[646] does not specify a substitute, but instead provides an estimate that to requalify each product with alternative materials of equivalent characteristics would require a period of 2 to 5 years.

19.5.2.1 Substitution of Lead in Al alloys

It has to be noted that EAA did not provide information of any new research or other activities that indicate efforts to substitute the applications of these leaded Al alloys. EAA states that there are lead-free bismuth containing Al alloys AlEco62Sn and 6023, but notes that they are used in automotive components. The automotive industry[647] indicated that AlEco62Sn and 6023 are used to substitute some applications of the 2011 Al alloy e.g. in "*housings, disk plates, closing bodies, hexagonal nuts, sealing plugs,*

[646] Op. cit. Dunkermotoren GmbH (2015)
[647] Op. cit. ACEA et al. (2014)

anchors, washers."[648] E.g. nuts are indicated by EAA to be manufactured by leaded Al alloys for EEE. Thus it can be assumed that the mentioned alloys are basically scientifically and technically practicable for substitution.

The Al manufacturer EURAL GNUTTI SpA.,[649] identifying itself as of the largest European extruders of rods and bars in aluminium alloys with lead, contacted the consultants with the following statement:

> *"Since several years all major extrusion companies have studied alloys which can substitute lead, and the results were multiple, and very much satisfactory and already well accepted by the market.*
>
> *We can assure and demonstrate that lead is absolutely unnecessary and can be eliminated, because there are now several alloys already well accepted in the automotive and electric/electronic industries, manufactured by several different extrusion companies, which can provide all the necessary characteristics by lead alloys which are: good machinability and chip forming, high mechanical properties, good surface finishing, good attitude to anodizing. There is no loss in any of the metal properties, no costs increase on the finished parts, on new aluminium lead-free alloys, which can justify the use of lead based alloys any further.*
>
> *I understand that the majority of the industry (aluminium extruders and machining companies) is asking to maintain the actual exemption 6b to remain at Pb max 0,40% on weight, but this is due to an unwillingness to modify the majority of existing industrial drawings. Nevertheless in United States, in Japan, a huge step towards the elimination of lead has been taken since years now, and automotive companies are already choosing lead-free alloys on new drawings and new applications. All worldwide industry, but the European, is expecting the elimination of lead in aluminium alloys."*

A patent and marked research on new Al alloy developments published in 2011 confirms that within wrought Al alloys, the AlMgSi alloys (6xxx series) and AlCu alloys (2xxx series) contain either lead with a maximum of 0.4% or as substitution elements tin or bismuth respectively a combination of both. EURAL[650] stated that lead-free tin containing Al alloys have good machinability and good surface finishing, but suffer temperature limitations > 140°C because tin *"causes weakness and cracking of the machined parts when submitted to stress and high temperature. Due to its brittle nature, tin has the dangerous tendency to sudden brakes without significant previous deformation*

[648] ACEA et al. (2015), ACEA, JAMA, KAMA, CLEPA and EAA (2015), Answers to Clarification Questionnaire during the review of ELV exemption 2c, provided 27 February 2015.

[649] EURAL (2016a), EURAL GNUTTI SpA. (2016a), Information provided by Email, submitted 26 February 2016

[650] EURAL (2016b), EURAL GNUTTI SpA. (2016b), Information provided by Email, submitted 29 February 2016

(strain)."[651] However, EURAL[652] stresses that as many applications do not have stress and high temperature expositions tin based alloys are largely used on the market. For the tin and tin/bismuth based alloys, EURAL[653] mentions different lead-free alloys of the following Al producers: Alcoa 6020, Eural 6012A, Constellium 6023, Impol 6028 and 2015, Aleris 6262A.

EURAL[654] further states that the bismuth based alloys do not have such temperature limits. EURAL lists as lead-free bismuth containing alloys the above mentioned lead-free alloy AlEco62Sn of Aleris[655] and lead-free developments by Kaiser (e.g. AA 6033)[656] and the EURAL alloy 6026. According to EURAL it took "*quite some time to set up such alloys [...], but now they are absolutely stable and giving excellent results, on each and every aspect related to machinability, chip forming, surface finishing, anodizing, corrosion resistance.*"

The EURAL 6026 alloy specification is presented in Annex A.4.0. The 6026 alloy is offered as being "*particularly suitable for being machined on high speed automatic lathes. It has good resistance to corrosion, medium-high mechanical properties, good suitability for decorative and industrial hard anodizing. It is also used for hot forging purposes.*" EURAL provided a technical laboratory report on the manufacture of brake pistons from alloy 6026, which is provided in Annex A.4.0. EURAL[657] concludes from their tests that there are "*no important differences in any of the mechanical factors, nor in the roughness on surface of the anodized samples, nor in the macro-graphical nor micro-graphical analysis.*"

The performance aspects indicated for leaded Al alloys by EAA such as corrosion resistance, surface finish, temperature resistance and durability of manufactured articles are understood to be covered. Also the machinability aspects such as longer life of manufacturing tools and less energy consumption during machining of parts, cutting speeds of manufacturing tools, lubrication effect and better chip fracturing are understood to be comparable.

As for the application of 6026 in the EEE sector, EURAL[658] explains to have "*customers who are switching to the Bi only in the field of electronic valves, safety components for gas kitchens and burners, pneumatic sector. Quantities are in the range of about 1000 metric tons/year global.*" EURAL[659] estimates that a switch to lead-free Al alloys could be feasible for EEE manufacturers within one year taking into account replacement

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[651] Cited from EURAL 6026 material data sheet provided in Annex A.4.0.
[652] Op. cit EURAL (2016b)
[653] Op. cit EURAL (2016b)
[654] Op. cit EURAL (2016b)
[655] https://www.aleris.com/wp-content/uploads/2014/08/Aluminum-Extrusion-Plant-Overview_engl_DC_2012_11_20_final_web.pdf
[656] http://www.kaiseraluminum.com/customers/products/extrusions/bar/#6033
[657] EURAL (2016c), EURAL GNUTTI SpA. (2016c), Information provided by Email, submitted 01 March 2016.
[658] Op. cit. EURAL (2016c)
[659] Op. cit. EURAL (2016c)

strategy, process of renewing drawings and making all trials and tests, looking for suppliers and the phase out of old remaining stock of old materials.

The consultants understand from this information that there are alternatives on the market for lead based Al alloys that are reliable according to Al producers. It is also understood that in some cases EEE manufacturers already apply lead-free alloys, however the extent of these applications is not conclusive.

19.5.2.2 Arguments provided by EAA

EAA[660] generally excludes bismuth as a substitute for lead in Al alloys for two reasons:

- Bismuth has no own primary production but is a by-product of lead production;
- Difficulties in Al recycling if the share of bismuth Al alloys rises.

A bismuth inventory set up for a life cycle assessment of solders for the US EPA in 2005[661] compiled data according to which bismuth is primarily co-mined with other metals, including lead (35 %), copper (35 %), tungsten (15-20 %, from China), and tin and other miscellaneous metals (10 to 15 %) concluding that lead and copper co-mining consist of the majority (70 percent) of the worldwide bismuth supply. The consultants assume that the co-mining of bismuth with lead is not a sufficient reason to claim that the substitution of bismuth causes higher negative environmental, health and consumer safety impacts compared to lead. It might show however that the availability of bismuth could be limited. Though bismuth is not considered as a critical raw material by the EC[662], there are individual studies[663] that consider bismuth to be critical due to the production in a small number of countries and the production by co-mining. However, those considerations are not foreseen to be part of an exemption evaluation under RoHS. Furthermore, where bismuth would be produced through co-mining of lead, if the lead could not be used for manufacture, it would be concentrated at a single location (the smelting location). This would make the sound handling of lead and the control of possible emissions easier than the case of lead being present at a low concentration in numerous applications, for which proper disposal, collection and treatment are more complex.

As for the argument that bismuth hampers recycling, EAA did not provide any further evidence then the following: "*It has been experienced and discussed within the*

[660] Op. cit. EAA (2015a)

[661] Geibig & Leet Socolof (2005), Geibig, J. R., Leet Socolof M. (2005), Solders in Electronics: A Life-Cycle Assessment, EPA 744-R-05-001, August 2005; available under: http://www.epa.gov/sites/production/files/2013-12/documents/lead_free_solder_lca_full.pdf

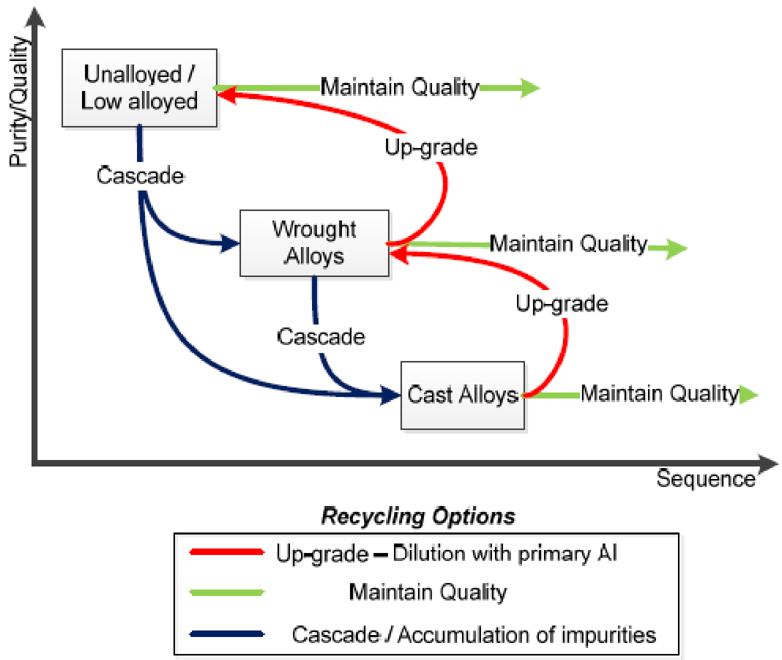
[662] http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical/index_en.htm

[663] E.g. a study available in German on mineral resources: Erdmann, L.; Behrendt, S. Institut für Zukunftsstudien und Technologiebewertung (IZT), Berlin; Feil, M. adelphi, Berlin (2011), Kritische Rohstoffe für Deutschland „Identifikation aus Sicht deutscher Unternehmen wirtschaftlich bedeutsamer mineralischer Rohstoffe, deren Versorgungslage sich mittel- bis langfristig als kritisch erweisen könnte", Berlin, den 30. September 2011; available under: https://www.izt.de/fileadmin/publikationen/54416.pdf

secondary aluminium producers that bismuth creates an unwanted microstructure effect leading to potential problems in the refining and casting process. Thus bismuth alloys (if in large amount) need to be separated from the others for remelting."

On the basis of available documents concerning Al recycling,[664] it is understood that in the recycling of aluminium the accumulation of impurities is a general problem for operators. E.g. the review of Gaustad et al. (2012) [665] but also other publications[666] mention two approaches commonly used today to deal with the presence of undesired impurities in the recycling of aluminium: Dilution and "Down-cycling" where wrought scrap is used in cast products because cast alloys have the lowest purity requirements. Compensation of impurities can take place by dilution with purer aluminium fractions or with primary aluminium in order to reach specified product quality. The following figure illustrates the Al recycling options that depend on the purity of the Al alloys.

Figure 19.1: Al recycling options and Al cascade recycling



Source: Paraskevas, D. et al. (2013)

[664] Gaustad et al. (2012), Gaustad, G. et al. (2012), Improving aluminum recycling: A survey of sorting and impurity removal technologies; Resources, Conservation and Recycling 58 (2012) 79– 87;
Op. cit. Paraskevas, D. et al. (2013);
EAA/OEA Recycling Division (2006), European Aluminium Association EAA and Organisation of European Aluminium Refiners and Remelters OEA (2006), Aluminium Recycling in Europe, The Road to High Quality Products, 2006; http://www.european-aluminium.eu/wp-content/uploads/2011/08/Aluminium-recycling-in-Europe-2007.pdf

[665] Op. cit. Gaustad et al. (2012)

[666] Paraskevas, D. et al. (2013)

Furthermore, EAA and OEA[667] anticipate a growing volume of wrought alloy scrap as of 2015/2020, due to an increased use of specialized wrought alloys and therefore envisage optimised sorting techniques of different wrought alloys both from cars[668] and from other sources in order to avoid dilution and down-cycling.

To conclude, the consultants cannot follow the arguments provided by EAA as to why bismuth poses a particular impurity problem in Al recycling. The consultants do not assume that if the exemption on leaded Al alloys for machining purposes will expire that Al recycling is endangered.

19.5.3 Environmental Arguments

As for cast alloys, the consultants understand that lead is unintentionally present due to the use of scrap and does not provide a function. In such cases, the consultants agree that the reuse of resources recycled from end-of-life (EoL) products has a positive value from an environmental perspective. According to EAA, the recycling of aluminium requires about 95% less energy than that required to produce primary aluminium.[669] It is thus understood that the use of secondary material results in a significantly lower environmental impact in terms of energy consumption. Furthermore, it has been explained by EAA that the removal of lead from aluminium through a metallurgical process is technically not yet feasible on an industrial scale[670] (see section 19.3). Thus the consultants can follow the estimation of EAA[671] that the elimination of lead from the Al recycling stream by methods such as phase separation, electrochemical refining and vacuum distillation is technically impracticable.

19.5.4 Stakeholder Contributions

Five contributions were submitted to the stakeholder consultation. The contributions of KEMI,[672] Bosch[673] and EAA[674] are discussed in the sections above as well as below.

The contributions submitted by TMC[675] and JBCE[676] raise a legal question as to the availability of the current exemption to category 8 and 9 equipment. TMC and JBCE claim the availability of Annex III exemptions to category 8 and 9 for seven years starting in 22.7.2017.

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[667] Op. cit. EAA/OEA Recycling Division (2006)
[668] Op. cit. EAA/OEA Recycling Division (2006)
[669] http://european-aluminium.eu/data/recycling-data/
[670] Op. cit. EAA (2015a)
[671] Op. cit. EAA (2015a)
[672] Op. cit. KEMI (2015)
[673] Op. cit. Bosch (2015)
[674] Op. cit. EAA (2015c)
[675] Op. cit. TMC (2015)
[676] Op. cit. JBCE (2015)

EAA[677] stated in this regard:

> *"We apply for renewal of this exemption for categories 1 to 7, 10 and 11 of Annex I for an additional validity period of 5 years. For these categories, the validity of this exemption may be required beyond this timeframe. Although applications in this exemption renewal request may be relevant to categories 8 & 9 this renewal request does not address these categories. Further, categories 8 & 9 have separate maximum validity periods and time limits for application for renewals...;"*

As leaded Al alloys are understood to be relevant to all categories, it can be concluded that expiration dates should be specified for all categories.

19.5.5 The Scope of the Exemption

The scope of the current exemption is viewed as very wide. As mentioned above, the contribution of the Swedish Chemicals Agency KEMI makes reference to Article 5(1)(a) that stipulates an inclusion of materials and components of EEE for specific applications in the lists in Annexes III and IV. The specifications of applications are so far missing for exemption 6b. KEMI therefore proposes to split into a number of more specific exemptions, related to applications where it has been verified that feasible alternatives are currently not available.

EAA indicated some components manufactured by e.g. cast and wrought alloys but did not provide a comprehensive list because "*there are hundreds if not thousands components may use Al alloys*".[678] It is possible that a comprehensive list of applications may be long and impractical for refining the scope of the exemption, though in lack of substitutes the consultants agree that clarifying this aspect would be of importance for understanding the potential for exemption specification. However, as discussed above there are substitutes for the use of leaded Al alloys for machining purposes. Therefore, it is assumed that such substitutes can be applied, whereas only for applications where performance can be proven as non-comparable could the exemption be renewed again should this be found to be justified in the next review of the exemption. If such applications would be made, it is expected that limiting the exemption to specific components or specific product ranges shall be addressed in applications. This would provide a basis for making such adjustments to future exemptions.

As for cast alloys, the consultants understand that lead is unintentionally present due to the use of scrap and does not provide a function. For the cast alloys produced from Al scrap, the substitution of lead is consequently not an issue. The consultants do not see the added value to specify applications for cast alloys but rather to specify the unintentional presence through an individual exemption. Therefore, the consultants favour the option of splitting the exemption, differentiating between aluminium alloys

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[677] Op. cit. EAA (2015a)
[678] Op. cit. EAA (2015b)

where lead is not intentionally introduced and between aluminium alloys where lead is added to obtain certain properties. This is further discussed in the following Section 19.5.6.

19.5.6 Exemption Wording Formulation

The need to narrow down the exemption is evident. However, the consultants cannot conclude a list of exhaustive applications of leaded Al alloys for cast and wrought alloys on the basis of the available information, nor would it be practicable at present to conclude for each component whether lead-free substitutes are applied in some cases or not, i.e. if it is justified to retain the exemption for such components. Instead, a split of the exemption is considered between lead in Al alloys, provided that it is not intentionally introduced and in lead in Al alloys for machining purposes.

The first part covering the cast alloys could be granted for the longest review period, which is possible under RoHS, as to completely eliminate lead in recycled Al would only be possible in the long term. The quicker the shift to lead-free alloys, the quicker such a reduction could be expected, though it must be kept in mind that alloys used for EEE probably consist of less than 10% of the Al alloy market share. The second part of the split would allow setting a short review period for leaded Al used for machining purposes, in order to signalize the short termed validity of the exemption, so that industry can prepare for its expiration.

EAA argues that a differentiation into alloys where lead is unintentionally added is not straightforward because for the production of wrought alloys, scrap can also be used as input. However, in the consultants' opinion the term "not intentionally introduced" is meant to describe the presence of lead where its presence does not provide a function. Where lead is needed for providing a function, regardless if it is added to the alloy or if its presence as an impurity in recycled content is sufficient to ensure the relevant functions, its presence has an intention, i.e. to provide a specific function for the machining and/or in the final component.

The consultants understand from the input of EAA that for wrought alloys, the lead might not always be "newly" added but rather present at a sufficient concentration in Al used for production. However, taking into account the strict chemical composition of wrought alloys, the consultants understand that if wrought alloy scrap is used as input it has to be strictly sorted scrap. According to Paraskevas et al.[679], the production of wrought alloys is heavily dependent on primary Al consumption due to their strict and very low tolerance limits for alloying elements. Thus the consultants understand that even if scrap is used in the production of wrought alloys, the lead level needs to be controlled and not only tolerated as impurity upon a specified level, i.e. the minimum amount needed to provide the relevant performance would need to be monitored and where lacking corrected.

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[679] Op. cit. Paraskevas, D. et al. (2013)

Another aspect for cast alloys, relevant in the long term is that the content of lead in cast alloys produced from scrap is expected to decrease: The automotive industry and European Aluminium Association[680] stated during the recent revision of the corresponding ELV exemption that *"since last stakeholder consultation [on the corresponding ELV exemption in 2009/2010], a slight reduction of the average Lead amount introduced by recycling could have been recognized. This can be explained by larger shares of the cars/industrial goods that will be recycled has been produced under Lead restrictions."* Questioned whether the same is true for WEEE recycling and whether all Al scrap is collected and treated together (or alternatively if applications from different sectors are collected and treated separately), EAA[681] states that *"this decreasing trend observed in the recycling of ELVs is not yet visible in the case of EEEs. Compared to Al scrap from ELVs, the amount of Al scrap from EEE is much smaller. Also, most of the Al scraps from EEE waste, though maybe collected and treated separately, are recycled together with other Al scraps. This could be the main reason that the change of Pb content is not so visible in the case of WEEE."* To conclude however, it can be expected the lead content will decrease, which could be reflected in future reviews by lowering the threshold for the unintentional presence of lead in Al alloys. The automotive industry[682] estimates the maximum lead content in recycled Aluminium from ELVs in 2023 at 0.2% in Western Europe and at 0.24% in South Eastern Europe. As it is understood that Al alloys from EEE are recycled with alloys of other sources, a similar reduction in the amount of lead in lead-based cast alloys can also be expected.

19.5.7 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

In the consultants' opinion, a split of the exemption would allow differentiating in the future between applications of aluminium alloys where lead is unintentionally present and between applications where lead provides necessary properties.

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[680] ACEA et al. (2014), ACEA, JAMA, KAMA, CLEPA and EAA (2014a), Industry contribution of ACEA, JAMA, KAMA, CLEPA and EAA, submitted during the online stakeholder consultation, retrieved from http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_2c/20141210_ACEA_AnnexII_2c_amended.pdf
[681] Op. cit. EAA (2015b)
[682] Op. cit. ACEA et al. (2015)

As for the unintentional presence of lead, elimination from the Al recycling stream does not seem to be technically practicable because available methods are not developed beyond a laboratory scale. It is further understood that the use of secondary lead in the production of Al alloys for casting allows a significant reduction in the energy consumed to produce the alloys (i.e. the energy associated with the manufacture of primary Al is significantly reduced). Thus, lead as an impurity is to be accepted though it is understood that the level of impurities in alloys is controlled. Therefore the consultants recommend granting the maximum exemption validity possible under RoHS for various categories. In the long term however, it is expected that that the lead content in the Al recycling stream will decrease and this should be monitored in the future as it can be expected to be the focus of future reviews.

As for lead in Al alloys for machining purposes, it can be followed that substitutes are available on the market for which reliability is claimed by alloy producers. In the consultants opinion EU COM should give a clear sign to industry that this exemption is to expire, that the available substitutes are to be tested and implemented as such. Further exemptions for specific applications shall only be acceptable where there is sufficient evidence that lead cannot be reliably substituted. In this case, the consultants propose a review period of three years.

From available documentation, the consultants cannot conclude to what degree, the majority of EEE manufacturers are aware of these new developments and subsequently if broad range substitution can be assumed to be underway or not. Manufacturers of EEE products and components did not participate in the stakeholder consultation and EEA claims not to have access to such data.

The consultants conclude that the exemption could be renewed for a short period, to allow EEE manufacturers a sufficient transition period for applying lead-free alloys available on the market. From EURAL's information the implementation of substitutes does not require more than a year. Though this could allow a phase-out of lead-based alloys within a short period, EURAL submitted its information shortly before the evaluation concluded. Other stakeholders have not had a chance to become familiar with such information and its possible implications, and shall not have one before the publication of this report, and it is thus anticipated that a longer period could be relevant. E.g. the applicant Dunkermotoren[683] estimates to need a period of 2 to 5 years for requalification of each product (gear parts in engine and transmission parts). Furthermore, as the amount of components to be covered could be significant, a longer transition period would be needed, also allowing manufacturers to apply for new exemptions for the use of specific lead-based alloys in specific components, where third party testing can substantiate that lead-free alloys provide inferior performance.

[683] Op. cit. Dunkermotoren GmbH (2015)

19.6 Recommendation

Based on the above considerations, it is recommended to split the exemption. A review period of five years is proposed for the exemption entry on the unintentionally introduced lead, i.e., alloys used for the production of non-machined parts.

A short review period of three years is proposed for applications where lead is present for machining purposes. This would allow industry a longer transition period towards substitutes, as well as providing time to apply for new exemptions should substitutes not be comparable in performance for specific applications.

Exemption 6b: Lead as an alloying element in aluminium	Duration*
I) with a lead content up to 0.4 % by weight, used for the production of parts not machined with shape cutting chipping technologies	*For Cat. 1-7 and 10 and 11: 21 July 2021*
II) for machining purposes with a lead content up to 0.4 % by weight	*For Cat. 1-11: 21 July 2019*
III) Lead as an alloying element in aluminium containing up to 0,4 % lead by weight	*For Cat. 8 and 9: 21 July 2021* *For Sub-Cat. 8 in-vitro: 21 July 2023* *For Sub-Cat. 9 industrial: 21 July 2024*

Note: As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

19.7 References Exemption 6b

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20.0 Exemption 6c: "Copper alloy containing up to 4% lead by weight"

Declaration

In the sections that precede the "Critical Review" the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

353 / C35300	Copper alloy with 1.5 to 2.5% Pb
360 / C36000	CuZn39Pb3, copper alloy with 3.3% Pb
CuZn21Si3P	Lead-free silicon-containing copper alloy
CuZn39Pb3	Copper alloy with 3.3% Pb
CuZn37Mn3Al2PbSi	Copper alloy with 0.2 to 0.8% Pb
CuZn42	Lead-free copper alloy with a higher zinc content
ECHA	European Chemicals Agency
EEE	Electrical and Electronic Equipment
ELV	End-of-Life Vehicle
HID	High intensity discharge lamps
JBCE	Japan Business Council in Europe
KEMI	Kemikalieinspektionen, Swedish Chemicals Agency
LEU	LightingEurope
Pb	Lead
TMC	Test & Measurement Coalition
Tpa	Tonnes per annuum
WEEE	Waste EEE

20.1 Background

Lead is embedded as tiny nodules in the matrix of copper alloys. It thereby acts as chip breaker and lubricant. This gives leaded copper alloys a favourable machinability, but also properties provided by lead in the finished component, such as e.g. electrical conductivity, slide functionality for parts with closely fit sliding surfaces and corrosion resistance.

The lead content in copper alloys (brass) can vary between 0.2 to 4.2% in accordance with European standards.[684] Among them, the alloy CuZn39Pb3 / C36000 is very commonly used as a standard alloy of copper and zinc containing 3.3% lead.

Six applications were made requesting a renewal of the exemption; they are presented here in alphabetical order of the applicants' names:

- **Bourns Inc.**,[685] an electronic component manufacturer, purchases different components manufactured from leaded copper alloys such as bushings, terminals, shafts, pins, backup strips, terminal strips, switch elements/ terminals, rivets. Bourns Inc.[686] explains that leaded copper alloys can be precisely processed in fast screw machines and provide corrosion resistance.
- **Dunkermotoren GmbH**[687] request the exemption for gear wheels and motor bushes for different motor applications. The leaded copper alloys allow a long lifetime of the machining tools and of the finished gear box application due to the slide functionality of lead. According to Dunkermotoren,[688] their applications could be manufactured with leaded copper alloys with a lead content of < 1%. Dunkermotoren[689] added that the lower threshold is only applicable to electrical drive technology and that their "*execution cannot be transferred to other industries*".

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[684] CEN EN 12164 and 12165

[685] Bourns (2015a), Bourns, Inc. (2015a), Original Application for Exemption Renewal Request, submitted 19.01.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Bourns/6c_Exemption_extension_ap_6c.pdf

[686] Bourns (2015b), Bourns, Inc. (2015b), Answers to Clarification Questions, submitted 29.08.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Bourns/20150811_Bourns_Ex_6c_1st_round_of_Clarification-Questions.pdf

[687] Dunkermotoren (2014), Dunkermotoren GmbH (2014), Original Application for Exemption Renewal Request, submitted 15.12.2014, English version available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Dunkermotoren/151008_Anmerkungen_Ausnahmeantrag_Dunkermotoren_6c_Messing_english.pdf

[688] Op. cit. Dunkermotoren (2014)

[689] Dunkermotoren (2015), Dunkermotoren GmbH (2015), Additional Information to the Application, submitted 08.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Dunkermotoren/Additional_information_to_our_application_6c___Dunkermotoren.pdf

- **Framo Morat GmbH & Co. KG**[690] produces the "*soft partner of worm gears*" from leaded copper alloys for good machinability and because it supports the dry-running of the gear parts.[691] According to Framo Morat the copper alloy CuZn37Mn3Al2PbSi that has been tested within the company over a long time period for its mechanical properties. Especially the "*load-carrying capacity*", is an essential manufacturing parameter, experience with which is based on "*decades of internal testing and recording*". Framo Morat sells "*more than a million worm gears to more than 275 customers all around the world placed in all branches.*" Therefore Framo Morat cannot specify all the applications where the worm gears are used in.
- **LightingEurope (LEU)**[692] requests the exemption for contact-pins of various fluorescent lamps and starters for fluorescent lamps, GU10 (a type of lamp fixture) reflector lamps and high intensity discharge (HID) R-mini lamps. LEU states that the presence of lead results in a higher ductility of the copper-alloy pins.
- **PHOENIX Contact GmbH&Co. KG and HARTING KGaA,**[693] both component manufacturers of connectors, device connection technology and network components, switchgears, fieldbus components etc. requested the exemption on behalf of a number of organisations.[694] They do not apply for their own

[690] Framo Morat (2014), Framo Morat GmbH & Co. KG (2014), Original Application for Exemption Renewal Request, submitted 10.12.2014, English version available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Framo/Ex_6c_Framo_Morat_2015-08-13_RoHS_Exemption_Request_fkn_Public.pdf

[691] Framo Morat (2015), Framo Morat GmbH & Co. KG (2015), Answers to Clarification Questions, submitted 18.08.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Framo/20150818_Ex_6c_FramoMorat_1st_round_of_Clarification-Questions_fkn.pdf

[692] LEU (2015a), LightingEurope (2015a), Original Application for Exemption Renewal Request, submitted 16.01.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Lighting_Europe/6c_LE_RoHS_Exemption_Req_Final.pdf

[693] Phoenix Contact and Harting (2015a), PHOENIX Contact GmbH&Co. KG and HARTING KGaA (2015a), Original Application for Exemption Renewal Request, submitted 16.01.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Phoenix/6c_RoHS_Exemption_6c_Renewal_Dossier_16_JAN_2015.pdf

[694] The following 26 organizations supported the request (in alphabetical order): American Chamber of Commerce to the EU (AmChamEU), Avago Technologies Limited, Communications and Information network Association of Japan (CIAJ), DIGITALEUROPE, European Committee of Domestic Equipment Manufacturers (CECED), European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry (COCIR), European Copper Institute (ECI), European Garden Machinery Industry Federation (EGMF), European Partnership for Energy and the Environment (EPEE), European Passive Components Industry Association (EPCIA), European Power Tool Association (EPTA), European Semiconductor Industry Association (ESIA), Information Technology Industry Council (ITI), IPC-Association Connecting Electronics Industries, Japan Business Council in Europe (JBCE), Japan Business Machine and Information System Industries Association (JBMIA), Japan Electrical Manufacturers' Association (JEMA), Japan Electronics and Information Technology Industries Association (JEITA), Knowles, LIGHTINGEUROPE, Littelfuse, Orgalime, the European Engineering Industries Association, SPECTARIS, TechAmerica Europe

specific applications but rather provide a generic review of the uses of leaded copper alloys. It is not always comprehensible whether e.g. publically funded research or research conducted by the automotive industry is cited or whether own research is presented by Phoenix Contact and Harting. Phoenix Contact and Harting indicate contact spring legs, crimp contacts, gear pinions and bearings and bushings as applications of leaded copper alloys.

- **Sensata Technologies**[695] purchases connectors, bushings, terminals, screws, hex nuts, washers, rivets for their following applications: thermal motor protectors, thermal circuit breakers, hydraulic magnetic circuit breakers.

Five out of six applicants[696] request a renewal of the exemption with the current wording:

"Copper alloy containing up to 4% lead by weight"

A further application submitted did not fulfil the minimum requirements of applications for exemptions stipulated in Annex V of the Directive and was not evaluated as such.

As for the history of the exemption, it has to be noted that since the RoHS 1 Directive was published in 2002, Ex. 6 has covered lead as an alloying element in steels, aluminium and copper.[697] Following the last revision on 2009[698], Ex. 6 was split into three exemptions 6a, 6b and 6c for each alloy respectively.

There is a corresponding exemption in the end-of-life vehicles Directive 2000/53/EC (ELV, listed in Annex II, as Exemption 3) with the same wording "*Copper alloy containing up to 4% lead by weight*". It was reviewed in 2015 by Oeko-Institut; the evaluation report has yet to be published. Where relevant within this chapter, it is referred to as the ELV revision.

(TAE), WirtschaftsVereinigung Metalle (WVM), Zentralverband Elektrotechnik-und Elektronikindustrie e. V. (ZVEI).

[695] Sensata (2015a), Sensata Technologies Holland B.V. (2015a), Original Application for Exemption Renewal Request, submitted 15.01.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_b_/Sensata/6a_6b_6c_RoHS-Exemptions_Application-Format_Ex_6a_b_c_Pb_in_St_Al_Cu.pdf
Sensata (2015b), Sensata Technologies Holland B.V. (2015b), Answers to Clarification Questions, submitted 20.08.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Sensata/Ex_6a6b6c_Sensata_Questions_response_20150820.pdf

[696] Dunkermotoren (2014) requested a lower threshold however stated later that this would be only applicable to their specific application (Dunkermotoren 2015)

[697] The wording of exemption 6 was as follows: "Lead as an alloying element in steel containing up to 0,35% lead by weight, aluminium containing up to 0,4% lead by weight and as a copper alloy containing up to 4% lead by weight"; http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32002L0095&from=EN

[698] Gensch et al. (2009), Carl-Otto Gensch, Oeko-Institut e. V., et al. 20 February 2009, Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf

20.1.1 Amount of Lead Used under the Exemption

Phoenix Contact and Harting[699] state that it is "*unfortunately not possible to identify exhaustively the components and EEE that use leaded copper alloys. As consequence the amount of lead per year cannot be calculated. An estimation based on the data of only two companies would not reflect the situation of the EEE industry.*" When asked to provide an estimation, Phoenix Contact and Harting stated the following:

> *"Ca. 2500 tpa lead based on a use amount of leaded alloys in EEE of 100,000 tpa with 2.5% lead threshold is assumed. Taken the recycling rate of more than 90% for these alloys 250 tpa new lead are needed for the market."*

The other applicants (in alphabetical order) provided the following amounts:

- Dunkermotoren[700] estimates that it places 1.7 t of lead per annum on the market.
- Framo Morat[701] estimates the amount of lead, which was placed on the market in 2014, at about 700kg.
- LightingEurope[702] calculates a total amount of approximately 38 ton of lead per year but stated that this amount will gradually decrease in the coming years because LED lamps have a longer life-time compared to conventional lamps.
- Sensata[703] estimates the amount of lead in lead-containing copper alloys used in Sensata products placed on the EU market at 500kg.

Bourns[704] provides a list that indicates the amount of Pb in its finished units. However, Bourns further states that it is not able to calculate the amount of lead because Bourns' parts are not finished parts. They are used in the assembly of other goods in the various EEE categories thus Bourns cannot determine the final use of their parts: "*Once our parts are sold either directly or through distribution, we do not have information on how all parts are used.*"

In the last revision of this exemption the following estimate was made: "*The average annual consumption of leaded brass in the EU is approximately 1,500,000 t. Figures on the share in the electronic sector have not been provided by the copper industry. However, it is estimated that yearly quantities in ICT equipment are ten tonnes at*

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[699] Phoenix Contact and Harting (2015b), PHOENIX Contact GmbH&Co. KG and HARTING KGaA (2015b), Answers to Clarification Questions, submitted 14.09.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Ex_6c_Phoenix_Harting_Answers_1st_round_clarifying_questions_14.09.2015.pdf
[700] Op. cit. Dunkermotoren (2015a)
[701] Op. cit. Framo Morat (2015)
[702] Op. cit. LEU (2015a)
[703] Op. cit. Sensata (2015b)
[704] Op. cit. Bourns (2015b)

maximum." Taking into account the amounts of lead indicated by LEU, this can be understood to have been heavily underestimated.

20.2 Description of Requested Exemption

According to Phoenix Contact and Harting,[705] it is not possible to exhaustively identify the components and EEE that use leaded copper alloys. Phoenix Contact and Harting[706] explain that this is due to a complex structure of the supply chain where material specifications are not recorded and manufacturers of components/parts supply their products to different industries:

> *"In electrical and electronic industry there is no common database on the chemical composition of single parts. In addition the diversity of products is very high as RoHS covers diverse types of EEE and their components. These components are used in different industries with different requirements, organisations and structures. The consequence of this situation is that it is not possible to provide a list of components or equipment that contains leaded copper alloys."*

From the applications of single companies, gears as mechanically moving components can be differentiated from other applications: For the manufacturing of the gear parts, the applicants Dunkermotoren and Framo Morat mention that a leaded copper alloy (CuZn37Mn3Al2PbSi) is used (Framo Morat) or can exclusively be used (Dunkermotoren) that contains a lead of < 1% by weight.

Other components mentioned by the applicants are a variety of small parts that partly have electrical/conductive functions, such as the contact-pins LEU specified in its renewal request. Bourns[707] indicate the following applications containing the following components of leaded copper alloys: Brass pins, shafts, bushings, brass backup strips, terminals, terminal strip, switch element/terminal. Sensata[708] indicate very similar components to be made from leaded copper alloys: bushings, terminals, screws, hex nuts, washers, rivets. Phoenix Contact and Harting[709] mention some examples of components made from leaded copper alloys: spring contacts, crimp contacts and gears as an example of mechanical connecting parts.

As for the applications related to the different components, the applicants explain the following:

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[705] Op. cit. Phoenix Contact and Harting (2015b)
[706] Op. cit. Phoenix Contact and Harting (2015b)
[707] Op. cit. Bourns (2015a)
[708] Op. cit. Sensata (2015b)
[709] Op. cit. Phoenix Contact and Harting (2015a)

- **Bourns**[710] uses the above mentioned components in counting dials, encoders, panel controls, precision potentiometers, rotary sensors and trimming potentiometers.
  Bourns further state: "*With the wide use of applications for electronic components, subassemblies containing electronic components and finished products containing electronic components, it is not possible for Bourns to determine the final use in the various EEE categories. Some, such as EEE categories 1-9 are highly likely along with 11. Once our parts are sold either directly or through distribution, we do not have information on how all parts are used. Bourns' parts are not finished parts but used in the assembly of other goods such as cell phones and computers to name a few. Bourns cannot determine where the global parts that claim exemption 6c are used and the final destination of that finished product. Further, the end products that use these parts may not be under the RoHS scope. There may be other applications using this exemption that are out of the scope of Bourns customer base. There are just too many unknowns to provide accurate information.*"
- According to **Dunkermotoren**,[711] the gear parts can be used in various EEE such as "slicers, retail scales, printers, woodworking machines, under water scooter, rehabilitation machines, dialysis machines, medial pumps, operating tables, magnetic resonance tomography, cash machines, automatic doors and automatic sun protection as well as in IT and telecommunication equipment, electrical and electronic toys, leisure and sports equipment, medical devices, automatic dispensers and other EEE not covered by any of the categories above."
- **Framo Morat**[712] explains that "*there are two possibilities to order a worm gear set. First there are catalogue sets which can be ordered right away and are in stock. The other opportunity is to order customized worm gears which are designed in a specific way for every customer himself. Considering the possibility of catalogue sets it is difficult to trace the final application, in which Framo worm gears can be found. One of the nameable examples is definitely the sector of geared motors and their affiliated surroundings.*"
- **Lighting Europe**[713] explains that the pins are used in various lamps and starters for lamps as already mentioned above.
- **Sensata**[714] describes that their sensor and control products are used in the following EEE: thermal motor protectors, thermal circuit breakers, hydraulic magnetic circuit breakers.

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[710] Op. cit. Bourns (2015b)
[711] Op. cit. Dunkermotoren (2014)
[712] Op. cit. Framo Morat (2014)
[713] Op. cit. LEU (2015a)
[714] Op. cit. Sensata (2015b)

20.3 Applicant's Justification for Exemption

The justifications of the applicants for their specific components are summarized in the following Table 20-1. The applicants generally refer to a favourable machinability of leaded copper alloys, which is not substantiated further. In most cases the applicants also claim that the lead in the finished product has an additional function in the finished product. These functions are e.g. conductivity, corrosion resistance, dry-running performance or wear resistance.

Sensata[715] generally claims that "*because leaded copper alloys are not cheap, nor light, these materials will only be selected in product designs when needed under harsh mechanical and environmental conditions from the application and manufacturing point of view. Mostly in small parts that require smooth surfaces and narrow tolerances alike sliding elements, mechanical contacting elements and electrical applications.*"

[715] Op. cit. Sensata (2015b)

Table 20-1: Summary of the justification for exemption

Applicant	Part of Leaded Copper Alloy	Aspects of Machinability	Function of Lead in the Manufacturing of Product	Function of Lead in the Finished Product	Additional aspects
Framo Morat	Worm gear	Excellent mechanical properties	n.s.	Dry-running performance -> Increases of product lifetime and safety	Calculation of load-carrying capacity of leaded copper alloy are based on decades of internal testing and recording,* Economical characteristics
Dunker-motoren	Gear parts, Motor parts, typically bushes	Higher lifetime of tools, Lower process time.	n.s.	Reduction of sliding properties of gear parts in the gear box	n.s.
Bourns	Brass pins, shafts, bushings, Brass backup strips, Terminals, terminal strip, Switch element	Lubrication and chip control in order to run on automatic screw machines, Lead reduces heat generation during screw machine process, Less wear on tooling	n.s.	Brass forms a tin protective patina, Mechanical strength	Competitive cost, Availability of material in small bar sizes to reduce waste
LEU	Contact-pins in different forms	Reference made to Phoenix Contact and Harting	Ductility to provide a reliable connection of lead wire from the lamp to the contact-pin -> safety issue	Conductivity, Corrosion resistance, Ductility -> Integrity over lifetime Elasticity, Tensile strength	Ongoing changes in the lighting industry -> reluctance of suppliers to investments
Sensata	Connectors, bushings, terminals, screws, hex nuts, washers, rivets	n.s.	n.s.	n.s.	Restricted use of leaded copper alloy because material not cheap and not light

Applicant	Part of Leaded Copper Alloy	Aspects of Machinability	Function of Lead in the Manufacturing of Product	Function of Lead in the Finished Product	Additional aspects
Phoenix Contact and Harting	Spring contacts	Chip breaker, Internal lubricant	n.s.	Corrosion resistance, Low relaxation behaviour -> maintenance of contact forces	
	Crimp contacts		n.s.	Corrosion resistance, Ductility -> prevention of cracks.	
	Mechanical connecting parts such as e.g. gears		n.s.	Corrosion resistance, Wear resistance	

*: Framo Morat[716] explains on the load carrying capacity the following *"The calculation of load-carrying capacity is an essential part of the designing of a drive including worm gears. To ensure a realistic computation several material properties have to be known. These properties relating to CuZn37Mn3Al2PbSi cannot be found in common literature like "Niemann/Winter - Maschinenelemente 3" or "Dubbel -Taschenbuch für den Maschinenbau". Therefore the used properties are based on decades of internal testing and recording. Framo is not able to perform any realistic and scientific proved calculation of load -carrying capacity, if CuZn37Mn3Al2PbSi will not be available for use anymore."*

Source: Bourns (2015b), LEU (2015b)[717], Phoenix Contact and Harting (2015a), Sensata (2015b)

[716] Op. cit. Framo Morat (2014)
[717] Op. cit. LEU (2015b), LightingEurope (2015b), Answers to Clarification Questions, submitted 28.08.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Lighting_Europe/Ex_6c_LightingEurope1st_round_Clarification_LE_Answers_20150828.pdf

20.3.1 Possible Alternatives for Substituting RoHS Substances

Bourns and **Sensata** both purchase components from suppliers, however, the efforts to stimulate the supply chain towards the development of possible alternatives to lead-containing copper alloys differs. Sensata[718] mostly leaves the responsibility on the component manufacturer and does not specify the efforts taken with "*existing materials, none of which has proven to be a suitable replacement*". On the other hand, Bourns[719] indicates that they cooperate with their suppliers to explore possible solutions and they experiment with possible alternatives. Concerning alternatives tested and the respective problems, Bourns mentions the following alternatives (though not specifying the tests any further) that all "*have a higher raw material cost, a slower machining rate which reduces our capacity and shortens tool life*":

- "*Aluminium – slow machining;*
- *Zinc die cast – seal integrity issues;*
- *Nickel silver – required slowing screw machine by 50%; material finish not as good as brass.*"

Bourns[720] also mentions to have evaluated Ecobrass, but that it is not available in the required bar diameter size and was therefore not tested.

Dunkermotoren state that they have tested "*an alternative material. But the tests were negative. Now we restart the material search*."

Framo Morat[721] also indicates to have tested "*for example ECOBRASS or other lead-free (0.1%) materials, were not satisfying. The substitutes did not reach the mechanical properties of the used one*." Framo Morat does not further specify the tested lead-free material.

LightingEurope[722] state that there are basically contact-pins made of lead-free alloys already available on the market by one supplier, but that the lighting industry has no experience with lead-free contact material: "*There is no evidence that lead-free materials cannot be used, but given the long life -time of lamps in combination with the mass scale application it also cannot be proven that lead-free contacts have the same performance regarding safety and reliability under all application conditions (current density, temperature, humidity etc.).*" LEU also raises the concern that the current supply would not be able to satisfy the present demand of the market. LEU does not further specify the lead-free copper alloy.

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[718] Op. cit. Sensata (2015b): "The Sensata supply chain for lead-containing copper alloys comprises companies whose expertise is in stamping and screw-machining. Neither Sensata nor the Sensata supply chain have the expertise or resources to develop alternatives to lead-containing copper alloys."
[719] Op. cit. Bourns (2015b)
[720] Op. cit. Bourns (2015b)
[721] Op. cit. Framo Morat (2014)
[722] Op. cit. LEU (2015b)

Phoenix Contact and Harting[723] show some machining examples with substitutes. It is not always comprehensible whether e.g. publically funded research by RWTH Aachen or research conducted by the automotive industry is cited or whether own research is presented by Phoenix Contact and Harting; therefore the information submitted by Phoenix and Harting is rather seen as a generic review of the current EU industry opinion:

- A drilling test with CuZn42, a lead-free copper alloy with a higher zinc content, and the silicon-containing CuZn21Si3P resulted in only 3% of the required life of the drill compared to the leaded copper alloy CuZn39Pb3; the lead-free alloys also needed significantly higher cutting forces in the case of the lead-free alloys.
- Crimp contact made from the alloy CuZn42 showed continuous cracks during the crimping process, which are not allowed for a mechanically resistant and permanently safe connection: A crack permits the penetration of any corrosive substances. As a consequence the resistance increases and the contact point is heated up. Thus the risk of fire or unreliability exists. Besides, if a crack reduces the required mechanical pressure exerted on the cable, the pull-out force is below the required value as given in standards. The pulled out cable can apply power to touchable parts and thus a hazard for people is the potential consequence. Also, due to the broken connection, equipment (for example a motor) would fail.
- A gear pinion made with the lead-free copper alloy CuZn31Mn2Si1Al1 mechanically connected to a gear pinion made from plastic as part of a gear box showed a higher wear, as compared to a gear wheel made from CuZn39Pb3; the corresponding plastic pinions showed a much greater wear with the lead-free copper alloys pinion, which could cause a premature failure.

Phoenix Contact and Harting[724] estimate that a connector pin as a simple component requires about 1000 labour hours for safety testing.

20.3.2 Possible Alternatives for Eliminating RoHS Substances

Two applicants mention the possibilities to use different materials:

- **Bourns**[725] generally mentions that a possible alternative would be stainless steel that has a higher cost of machining. Machinability ratings indicate that stainless steel is 40-50% as efficient as brass because stainless steel as a poor conductor of heat compared to brass results in elevated temperatures during machining operations reducing the life of tools. Besides, Bourns mentions

[723] Op. cit. Phoenix Contact and Harting (2015a)
[724] Op. cit. Phoenix Contact and Harting (2015a)
[725] Op. cit. Bourns (2015a)

that “*rod sizes for screw machines are readily available in 360 brass; not available in stainless without more scrap/waste.*”

- **Framo Morat**[726] mention that “*in the early 2010s*”, it explored “*new and high developed coatings like DLC or a particular shaped chrome layer. The first attempts had shown that there is a chance of potential in this technology to substitute CuZn37Mn3Al2PbSi. The continuation of this research would involve the generating of a non -assessable amount of costs and human resources. Anyway there are still future projects planned, which are connected to this technology.*”

20.3.3 Environmental Arguments

Phoenix and Harting[727] state that “*leaded brass is to nearly 100% made from recycled material. Without exemption 6c copper alloys for electric and electronic equipment could not, as it is common today, easily be made from recycled copper alloys. Thus the urban stock which is one of the most important sources for copper in Europe could not* be used *as it is possible today.*”

Within this context, the following environmental arguments are also provided by the applicants:

- **Framo Morat**[728] explains that waste material from manufacturing is collected and stored in order for waste coolant to naturally drip from the material; then a specialized recycling company picks up the cuttings and centrifuges the last leftovers to remove remaining coolant. These dry cuttings are then sent to the material supplier who turns them back into new and usable work pieces. Framo Morat emphasises the certified and long -term reliable partnership with the material supplier.
- **LightingEurope**[729] mentions that the waste stream of fluorescent lamps, responsible for about 70% of the total amount of lead in contact pins of lamps, has a specified take back system (see Section 4.3.3.3 in Lamp general chapter); other lamps that are sold in the consumer channel (mainly GU10 lamps) will not be recycled and are handled as normal waste; LEU estimates that about 50% of the TL-and CFLni lamps have been recycled in 2014 which suggests that 13.5 tons out of the 38 tons of lead were recycled via WEEE (i.e. accounting the 50% recycling rate with the 70% fluorescent lamps for which take back systems exist).

[726] Op. cit. Framo Morat (2014)
[727] Op. cit. Phoenix and Harting (2015a)
[728] Op. cit. Framo Morat (2014)
[729] Op. cit. LEU (2015a)

20.3.4 Socio-economic Impact of Substitution

Some applicants mention possible costs related to substitution, but in a general way, without further substantiating and quantifying possible impacts:

- **Bourns**[730] claims an increase in direct production costs, however without providing further evidence.
- **Framo Morat**[731] mentions the profitability of the used copper alloy concerning the costs and lifetime of tools whereas the continuation of the research on substitutes "*would involve the generating of a non-assessable amount of costs and human resources.*"
- **LightingEurope**[732] claims an increase in direct production costs and in fixed costs related to substitution: "*Investments are necessary to switch-over from lead-containing to lead-free contact pins. Next to that the reject level (waste material) will be higher than with lead-containing copper alloy. There are no estimations on the total sum.*"

20.3.5 Road Map to Substitution

None of the applicants provide a road map for substitution.

20.4 Stakeholder Contributions

Twelve contributions to exemption 6c have been submitted during the stakeholder consultation. The contributions are presented in order of submission and are shortly summarized:

- **Mitsubishi Shindoh Co. Ltd.**[733] proposes Ecobrass as a lead-free copper alloy alternative, which has high strength, excellent machinability, exceptional wear resistance, good creep properties and superior corrosion resistance, as a replacement material for free-cutting brass rod CuZn38Pb3 suggesting that there is no difference in productivity from leaded brass. Mitsubishi Shindoh Co. Ltd.[734] lists as examples of Ecobrass applications electrical and electronic component gears, terminals, medical devices and valves for electrical water heaters. The input of Mitsubishi Shindoh Co. Ltd. is further presented in section 20.5.2.

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[730] Op. cit. Bourns (2015a)
[731] Op. cit. Framo Morat (2014)
[732] Op. cit. LEU (2015a)
[733] Mitsubishi (2015), Contribution by Mitsubishi Shindoh Co. Ltd., submitted 07.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Exemption_6c__2015-10-mitsubishi-shindoh-rohs.pdf
[734] Mitsubishi (2015), Contribution by Mitsubishi Shindoh Co. Ltd., submitted 07.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Exemption_6c__2015-10-mitsubishi-shindoh-rohs.pdf

- **ODU GmbH & Co. KG**,[735] a leading international manufacturer of connection systems, supports the renewal request by Phoenix Contact and Harting. ODU GmbH & Co. KG[736] state that 95 % of their products would be affected if the exemption were not renewed and that they have made "*serious efforts in direct cooperation with our raw material suppliers, until now, no material could be found that would even rudimentarily be suitable and bearable as a substitute. Of course, we are continuing our efforts in this area, but desperately need the additional time the extension would bring.*"
- **GENBAND**[737] provides telecommunications equipment to many of the telecommunications companies in Europe and worldwide and supports the renewal of exemption 6c.
  GENBAND[738] points out that it purchases electrical components and products from other OEM manufacturers and therefore is not able comment directly on the technical aspects of material selection. GENBAND lists the following applications that need the use of leaded copper alloys: Connectors, power supplies, fans, heatsinks, electrical switches, potentiometers, EMI gaskets.
  GENBAND[739] also corrected the mistake in the consultation questionnaire, which correctly should say "*the lower relaxation behaviour achieved with leaded copper alloys maintains the contact forces in spring contacts*", and points out the relation to fire risk if the contact fails: "*The fire risk is created as the contact metal relaxes, causing the contact force to drop, increasing the contact resistance, increasing the heat in the connector, leading to melting and potentially fire.*"
- **The Robert Bosch GmbH**[740] generally supports the applicants without providing further information.
- **JBCE**[741] – Japan Business Council in Europe in a.i.b.l. states that they understand that EEE of category 8 and 9 are out of scope of this review. The JBCE

[735] ODU (2015), Contribution by ODU GmbH & Co. KG, submitted 12.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Stakeholder_Consultation_on_RoHS_Exemption_6c.pdf

[736] ODU (2015), Contribution by ODU GmbH & Co. KG, submitted 12.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Stakeholder_Consultation_on_RoHS_Exemption_6c.pdf

[737] GENBAND (2015), Contribution by GENBAND, submitted 14.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/EX_6c_GENBAND_STAKEHOLDER_CONTRIBUTION.pdf

[738] Op. cit. GENBAND (2015)

[739] Op. cit. GENBAND (2015)

[740] Robert Bosch GmbH (2015), Contribution by Robert Bosch GmbH, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Bosch-Stakeholder-contribution-Exemption-request-6c.pdf

[741] JBCE (2015), Contribution by JBCE – Japan Business Council in Europe in a.i.b.l, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Comment_on_public_cousulation_of_Exemption_request_2015-2_6_c__.pdf

understands that "*the exemption 6(c) in annex III can be applied to category 8&9 products for seven years from identified date when entry into force for each products, at the earliest July 2021.*"

- **CETEHOR**, the technical department of the Comite Franceclat (French Watch, Clock, Jewellery, Silverware & Tableware Centre)[742] explains that watch movements are 80 % made of leaded copper alloys (CuZn39Pb3). CETEHOR lists the following "*extremely small parts*" to be made of leaded copper alloys: plates, bridges, cogs, gears, screws, nuts, pins, pivots; their dimensional conformity have tolerances of 5 to 10 µm. CETEHOR[743] stated that these tight dimensional requirements are not met by lead-free copper alloys.
  CETEHOR[744] also claims that lead-free alternatives create a greater tool wear that needs a more frequent sharpening and higher consumption rates of tools and longer machining cycles required, which all cause financial problems.
  CETEHOR[745] estimated a quantity of lead of 120 kg per year based on the amount of 8 g of brass per watch for movement parts and the annual French production of quartz watches of 0.5 million.
- **ELTECNO**,[746] a producer of low-voltage switchgear and control gear assemblies, supports the renewal of the exemption with a content of lead in copper of 4%. ELTECNO uses leaded copper alloy for the terminals for the protective conductors and sometimes for the neutral conductors. ELTCNO[747] mentions the favourable machining properties but also corrosion resistance as performance requirement of leaded copper alloys.
  ELTECNO[748] indicates the following amounts of leaded copper alloys with a lead content of 3.3% used: 1.5 tpa, resulting in 47 kg lead per year.
- **HARTING KGaA**[749] discussed in its contribution the information provided by Dunkermotoren and Framo Morat that both indicate the use of a leaded copper alloy with a lead content of <1%. Harting KGgA stresses that both have used these alloys before and that their applications are very specific ones.

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[742] CETEHOR (2015), Contribution by Comite Franceclat (French Watch, Clock, Jewellery, Silverware & Tableware Centre), CETEHOR, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Ex_6.c_Comite_Franceclat_Cetehor_20151012.pdf
[743] Op. cit. CETEHOR (2015)
[744] Op. cit. CETEHOR (2015)
[745] Op. cit. CETEHOR (2015)
[746] ELTECNO (2015), Contribution with picture by ELTECNO, submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Ex_6c_ELTECNO_Answers_20151016.pdf
[747] Op. cit. ELTECNO (2015)
[748] Op. cit. ELTECNO (2015)
[749] HARTING al. (2015a), Contribution by HARTING KGaA et al., submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Ex_6c_HARTING_KGaA__stakeholder_consultation_2015-10-16.pdf

As for properties of lead, HARTING KGgA et al.[750] adds the following: "*electrical conductivity, thermal conductivity, cold deforming behaviour, resistance welding, galvanizing ability, soldering at higher temperatures than 450 °C, relaxation behaviour, crimp ability, spring behaviour, high-speed stamping, physical properties (melting point, coefficient of thermal expansion, etc.), fabrication process properties (hot forming, brazing, etc.), etc.*" HARTING KGgA et al.[751] stresses that these properties as well as their interrelations "*cannot be seen as independent from the application*".

- **HARTING KGaA**[752] submitted a response to the contribution of Mitsubishi Shindoh; this input is discussed in section 20.5.2.
- **KEMI** Kemikalieinspektionen, the Swedish Chemicals Agency[753], interprets Article 5 in the RoHS Directive in the way that both the material or component and the specific applications need to be defined in the wording formulation of an exemption. Thus, "*it is no longer legally possible to decide on an exemption for lead in copper alloys whatever the use is.*"
  KEMI[754] therefore proposes the split into a number of more specific exemptions related to applications where it has been verified that feasible alternatives are currently not available. KEMI[755] extracted the specific applications that were mentioned by the different applicants, further discussed in section 20.5.5.
- **PennEngineering**,[756] a designer and manufacturer of specialty fasteners, supports the renewal request, however states that it agrees with a lower threshold of 2.5% than the current 4.0 % because they have found "*353 to be an acceptable alternative to 360*".
  PennEngineering[757] explains that leaded brass offers the advantages in their machining environment (multi-spindle automatic screw machines or single spindle CNC lathes) of significantly longer tool life leading to higher efficiency (less downtime), better surface finish, significantly higher surface speed and

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[750] Op. cit. HARTING et al. (2015a)
[751] Op. cit. HARTING et al. (2015a)
[752] HARTING et al. (2015b), Contribution by HARTING KGaA et al. as a response to the contribution of Mitsubishi Shindoh, submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Ex_6c_HARTING_KGaA_response_Mitsubishi_Shindoh_2015-10-16.pdf
[753] KEMI (2015),Contribution by KEMI Kemikalieinspektionen, Swedish Chemicals Agency, submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Ex_6c_KEMI_Answer_to_SC_RoHS_20151016_Lead_in_copper.pdf
[754] Op. cit. KEMI (2015)
[755] Op. cit. KEMI (2015)
[756] PennEngineering (2015), Contribution by PennEngineering, Danboro, PA, USA, submitted 19.10.2015; available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Ex_6c_PennEngineering_Consultation_Questionnaire_PE_AS_20151016.pdf
[757] Op. cit. PennEngineering (2015)

significantly higher feed rate. PennEngineering stated that they have experimented with lead-free Ecobrass and found it to machine significantly worse than 353 leaded brass, however do not provide further evidence. PennEngineering[758] states that they currently use 190.5 t ("*420,000 lb*") of the two different leaded copper alloys (353 and 360) per year globally; the amount of the contained lead is calculated at 3.86 tpa ("*8,500 lb*"). PennEngineering estimated that approximately 25% of its sales of leaded product go to EEE in the EU.

- The **Test & Measurement Coalition**[759] submitted a general contribution on Category 9 Industrial monitoring and control instruments, similar in nature to the contribution made by the JBCE.

20.5 Critical Review

20.5.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restriction for substances under Entry 30 of Annex XVII does not apply to the use of lead in this application as lead is used as an alloying element. Copper alloys are used to produce various components and articles. In the consultants' point of view this is not a supply of a lead as a substance, mixture or constituent of other mixtures to the general public. Pb is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

Appendix A.1.0 of this report lists Entry 63 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0,05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children.[760] Entry 63 however further specifies this restriction not to be applicable for articles within the scope of the RoHS Directive 2011/65/EU.

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[758] Op. cit. PennEngineering (2015)

[759] Test & Measurement Coalition (2015), Contribution by Test & Measurement Coalition, submitted 19 October 2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/General_Contribution_Test___Measurement_Coalition_package_9_exemptions_20151016.pdf

[760] Other restrictions of entry 63 cover e.g. jewellery and are thus not applicable here.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status January 2016).

Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

20.5.2 Scientific and Technical Practicability of Substitution

Mitsubishi Shindoh Co. Ltd.[761] submitted a contribution to the consultation pointing out the lead-free copper alloy Ecobrass as a substitute material for many components, especially where high electrical conductivity is not critical although it is not possible for Ecobrass to replace all leaded copper alloys. According to Mitsubishi,[762] Ecobrass is used mostly as replacement material for free-cutting brass rod CuZn38Pb3 suggesting that there is no difference in productivity from leaded brass. Durability and corrosion resistance in various environments such as in soil or hot-humid conditions have also been validated.

As for examples of Ecobrass' applications for electrical and electronic components, Mitsubishi[763] list gears, terminals, medical devices, and valves for electrical water heaters.

Mitsubishi[764] also argue that Ecobrass has been adopted for the sliding component of vehicle air conditioner replacing C36000 and that the machining example of vehicle components is a model case for substituting small electrical and electronic components. Besides, Mitsubishi[765] argues that components used in large electrical home appliances are similar to valves and fittings used in drinking water fixtures and components.

For the suitability in electrical applications where the components require conductivity, which is understood to be the case for e.g. contact pins (applied for by LightingEurope), crimp contacts (mentioned by Phoenix Contact and Harting) or switch gears (mentioned by ELTECNO) or terminals (mentioned by Bourns), Mitsubishi states that "*Ecobrass can replace leaded-brass for high conductivity applications by plating with such materials as Ag or Sn, which is applicable for many components.*" E.g. Mitsubishi[766] mentions terminals to be manufactured from Ecobrass. Electrical conductivity is provided by silver plating that is applied after the machining process. According to Mitsubishi,[767] Ecobrass has been selected for terminals since 2005 and the total sales volume has reached 35

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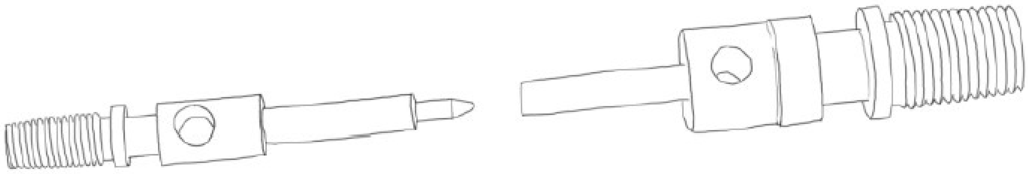
[761] Op. cit. Mitsubishi (2015)
[762] Op. cit. Mitsubishi (2015)
[763] Op. cit. Mitsubishi (2015)
[764] Op. cit. Mitsubishi (2015)
[765] Op. cit. Mitsubishi (2015)
[766] Mitsubishi (2016), Mitsubishi Shindoh Co. Ltd. (2016), Answers to Clarification Questions, submitted 15.01.2016.
[767] Op. cit. Mitsubishi (2016)

tones. Mitsubishi[768] indicates that the sizes of material in use are ϕ5, 7 and 9 mm and continues to explain that "*assuming the size of material is φ7×40 mm, more than 2,500,000 products have been manufactured.*" The following figure shows a picture of the Ecobrass terminal.

Figure 20-1: Terminals made of ecobrass



Source: Mitsubishi (2016)

For applications where high conductivity is required, Mitsubishi recommends other lead-free copper alloys such as C18625, a high copper alloy that has a high electrical conductivity with strength equal to or exceeding leaded brass.

On Ecobrass, the applicants and the contributing stakeholder provided the following objections:

- Bourns[769] explains that in January 2001, Ecobrass was evaluated for machining capability and that the plant had difficulty in machining this material at that time. As a recent problem, Bourns stated that Ecobrass is not available in small diameter bars: "*Some trimming potentiometers require a diameter size of 0.075. Using a 0.250" would mean 91% waste if machined down to 0.075.*"
- GENBAND states "*The Mitsubishi –Shindoh in their contribution indicate that electrical and thermal conductivity are affected by the lead content. This makes their material not suitable for electrical conductors.*"
- Framo Morat[770] explains that "*first tests with possible substitutes, for example Ecobrass or other lead-free (<0.1%) materials, were not satisfying. The substitutes did not reach the mechanical properties of the used one.*"
- PennEngineering "*have experimented with lead-free Ecobrass and found it to machine significantly worse than 353 leaded brass.*"

From the objections above it is apparent that the machining processes cannot be equally run. This problem was also discussed during the ELV revision of the corresponding exemption, wherein the consultants could follow that Ecobrass may suffer technical drawbacks that still delay their implementation, e.g. in the case of Ecobrass, for

[768] Op. cit. Mitsubishi (2016)
[769] Op. cit. Bourns (2015a)
[770] Op. cit. Framo Morat (2014)

micromachining in automated series production. During the ELV revision Mitsubishi[771] submitted a drilling report that used a different drilling bit (carbide compared to high speed steel) that suggests how machining processes could be adapted to process Ecobrass. These adaptations are important in cases where machining knowledge on these alloys or usability of required equipment for these alloys is a key requirement for successful application. The automotive industry argued during the ELV revision that machining and processing of alternative alloys is in a very basic research stage because public funded research on fundamental parameters is still on-going in the field of machining. Welter[772] stated in a report compiled on behalf of the automotive industry that there is little know-how among the subcontractors specialized in micromachining and their tool suppliers and machining companies:

> *"The subcontractors specialised in the field of micro-machining are in general small or medium size companies. Usually they do not have the competences and resources to do the development needed for low cost, high volume production. They have to rely on external expertise and education. Apparently, until now, no activities were started aiming to define the machining parameters for lead-free copper alloys. For instance, in France, the Centre Technique de l'Industrie du Décolletage (CTDec) starts to be active when their members come up with specific demands for assistance. The CTDec has developed testing recommendation and sensors for evaluating new materials. The opinion is that the machining shops could rapidly gain their own experience by using these helps and try to deal with lead-free brasses. Besides the loss of productivity, the major problems will be the need to invest in more rigid equipment, to develop software for adjusting the rotation speeds of the machine e.g. to the different steps of the drilling process, as well as to find more convenient cutting tools. Unfortunately, tools have arrived nowadays at a mature level and there is little margin for innovation. In the USA and Germany first publications are coming up in specialised magazines giving some hints how to work with such alloys. Thus, in the USA a paper was published in 2009 discussing the problems occurring when machining lead-free and low-lead brass with 0.25 % of lead (the paper aimed at plants fabricating plumbing fittings and fixtures for the Californian market): the point was that these alloys should not be run like leaded brass, but rather like steel (Free 2009). The paper made some general recommendations, but without giving any detailed information. The same holds for the educational courses organised since 2013 by the German copper trade association (Deutsches Kupferinstitut). Furthermore, some brass mills start*

[771] Mitsubishi (2015b), Mitsubishi Shindoh Co., Ltd., Micro-Drilling test report; submitted by Email 13 March 2015 during revision of the ELV exemption.

[772] Welter (2014) Jean-Marie Welter: Leaded copper alloys for automotive applications: a scrutiny; European Copper Institute, November 20, 2014; submitted as Annex 2 with the contribution of ACEA et al. (2014); http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3/E3__02__Welter_2014_leaded_copper_alloys_for_automotive_applications-a_scrutiny.pdf

also to provide general information about machining (mainly macro-machining) the lead-free brasses. Nevertheless the overall perception is that presently machining shops can expect very little support from outside. Thus the forced modification of processing technologies will lead to a distortion of the market to the profit of large machining companies or of speciality machining shops. It is neither very clear whether the lath, tool and lubricant manufacturers have yet started to develop specific equipment and ancillaries for dealing with these new alloys in a productive way. It will still take many years until both the necessary know-how will be obtained and spread on a larger scale and the money will be available to invest into the production tools adapted to the new situation."

A German research project[773] on the improvement of the machinability of lead-free copper alloys developed concrete solutions and approaches that comprise adaptations of tool geometries, targeted supply of coolant lubricant in order to provide chip breaking and improve the process reliability. The use of adapted cutting materials (polycrystalline diamond) and tool coating (diamond coatings) provides significantly increased tool life and reduces the rate of metal removal. Productivity was additionally increased by the use of cutting plates with wiper geometry.[774]

To conclude, it is understood that there may currently still be some restrictions on putting lead-free copper alloys such as Ecobrass into successful applications. The process for adapting machining might take time but it is understood that it basically can be overcome in the future for at least some applications.

Generally, the assessment of scientific and technical practicability of substitution of lead in copper alloys is hampered by the fact that Phoenix Contact and Harting who applied for the renewal of the exemption on behalf of 26 EEE organisations and associations did not provide an exhaustive or even indicative overview on the different applications of leaded copper alloys in EEE. Asked for initiatives among the different industry associations and companies to set up an inventory for applications of leaded copper alloys that would allow in the future defining key requirements that are provided by leaded copper alloys, Phoenix Contact and Harting state:[775]

"There is no such inventory and it is also not planned to set up an inventory. The manufacturers that use leaded copper alloys belong to completely different industries. There is some collaboration between the manufacturers and the associations. But as RoHS is applicable to all EEE the associations have completely different members and the overlap is often quite small. It has to be noticed that such an inventory would contain many sensitive data and companies will not be

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[773] Nobel & Klocke (2013), Nobel, C., Klocke, F. (2013), Zerspanen bleifreier Kupferwerkstoffe; IGF-Forschungsvorhaben 16867 N, available in German under: http://publications.rwth-aachen.de/record/230384/files/4856.pdf

[774] According to Nobel & Klocke (2013), wiper plates have a larger nose radius that allows high feed rates and results in a good surface quality.

[775] Op. cit. Phoenix Contact and Harting (2016)

able to give these data to others. Thus there will not be such an inventory where one could make an overview over all components or EEE with leaded copper alloys."

When asked to exhaustively specify the functionality of lead in EEE applications and to name performance indicators where possible which would allow assessing substitutes in the future, Phoenix Contact and Harting state:[776]

"As shown before the required properties of a material depend on the application and the environment the item will be used in. Thus it is not possible to give a general performance indicator for a material. Not all properties are relevant for all applications and every application will require different properties. Often these properties are not standardized values but it is the specific experience and expertise of the manufacturer. So there is no simple correlation that would allow defining performance indicators."

The consultants understand that there could be a large variety of different components in different surrounding conditions. However, the consultants are of the opinion that an inventory will help to define application groups to deduce the relevant properties. For example, during the ELV revision, the automotive industry[777] proposed as application groups for leaded copper alloys "sliding elements", "electric elements" and "mechanical connecting elements". The consultants expect that such an inventory would help to identify specific components in the future that could be evaluated as to the applicability of substitutes or of alloys with lower lead content.

20.5.3 Possible Alternatives for Eliminating or Reducing RoHS Substances

In this section there are two possibilities discussed, using different material in order to eliminate the use of lead or using leaded copper alloys with a lower lead content in order to reduce the use of lead.

The applicant Bourns[778] generally mentions that a possible alternative would be stainless steel, but claims that this has a higher cost of machining. Bourns does not specify the components where stainless steel could be used as a substitute. The consultants understand from the other alloy exemptions under RoHS that small connecting components, such as hex nuts or screws for example, are also manufactured by leaded steel and leaded aluminium alloys. Therefore in applications where the components have mechanically connecting functions and where the lead does not provide a function in the finished article, the use of different material should be explored.

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[776] Op. cit. Phoenix Contact and Harting (2016)

[777] ACEA et al. (2014), ACEA, JAMA, KAMA, CLEPA and EAA (2014a), Industry contribution of ACEA, JAMA, KAMA, CLEPA and EAA, submitted during the online stakeholder consultation, retrieved from http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3/20141210_ACEA_AnnexII_3.pdf

[778] Op. cit. Bourns (2015a)

PennEngineering[779] claimed in its contribution that they achieved using a lower leaded copper alloy and therefore agree to lower the lead threshold of the exemption down to 2.5% from the current 4.0 %. However, from the information provided from the applicants and from the stakeholders submitting contributions a lower threshold of lead cannot be unambiguously defined for all applications. The consultants understand that it might generally be applicable for mechanically moving components. This assumption is based on the one hand on the information provided by Framo Morat and Dunkermotoren, which use leaded copper alloys with a lead content of < 1% for their gear parts. However, information provided by the automotive industry[780] during the ELV revision showed that applications with a low lead content in copper alloys are within the "sliding elements" and "mechanical connecting elements" application groups (close to 0.3% Pb within sliding elements and 0.2% Pb within mechanical connecting elements). It might, however not be the case for all mechanically moving components: CETEHOR[781] claims to use the alloy CuZn39Pb3 for their extremely small parts. Phoenix Contact and Harting[782] added information that for watch components the possibility for dry-machining provided by lead is an important performance requirement while for lead-free alloys lubricants are required. To conclude, the consultants propose that the use of lower leaded copper alloys should systematically be explored where the use of lead-free alloys is not practical.

20.5.4 Environmental Arguments

The environmental arguments mentioned by the applicants relate to particular aspects of e.g. the recycling of fluorescent lamps, or to very general ones, such as the importance of copper recycling. Such aspects are not further discussed here as they do not provide insight as to the comparison of leaded copper alloys with lead-free ones in relation to environmental impacts.

20.5.5 Stakeholder Contributions

Five contributions were submitted to the stakeholder consultation. The contributions of KEMI,[783] CETEHOR[784] and PennEngineering[785] are discussed in the sections above as well as below.

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[779] PennEngineering (2015), Contribution by PennEngineering, Danboro, PA, USA, submitted 19.10.2015; available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Ex_6c_PennEngineering_Consultation_Questionnaire_PE_AS_20151016.pdf
[780] Op. cit. ACEA et al. (2014)
[781] Op. cit. CETEHOR (2015)
[782] Op. cit. Phoenix Contact and Harting (2015a)
[783] Op. cit. KEMI (2015)
[784] Op. cit. CETEHOR (2015)
[785] Op. cit. PennEngineering (2015)

The contributions submitted by TMC[786] and JBCE[787] raise a legal question as to the availability of the current exemption to category 8 and 9 equipment. TMC and JBCE claim the availability of Annex III exemptions to category 8 and 9 for seven years starting in 22.7.2017.

Phoenix Contact and Harting[788] state in this regard:

> *"We apply for renewal of this exemption for categories 1 to 7, 10 and 11 of Annex I for an additional validity period of 5 years. For these categories, the validity of this exemption may be required beyond this timeframe. Although applications in this exemption renewal request may be relevant to categories 8 & 9, this renewal request does not address these categories."*

As leaded copper alloys are understood to be relevant to all categories, it can be concluded that expiration dates should be specified for all categories.

20.5.6 The Scope of the Exemption

The scope of the current exemption is viewed as very wide. As mentioned above, the contribution of the Swedish Chemicals Agency KEMI makes reference to Article 5(1)(a) that stipulates an inclusion of materials and components of EEE for specific applications in the lists in Annexes III and IV. The specification of applications is understood not to be exhaustive for Ex. 6c. KEMI therefore proposes to split into a number of more specific exemptions, related to applications where it has been verified that feasible alternatives are currently not available. Though the consultants agree with the need to narrow the scope of the exemption, it is presently not possible to comprehensively conclude specific applications to narrow the scope of the exemption. Phoenix Contact and Harting[789] explain that *"in most cases the component manufacturer chooses the material due to the characteristics required for the specific component. The EEE manufacturer uses this component to build the EEE. As in the supply chain, often several stages between the component manufacturer and the EEE manufacturer exist the component manufacturer often does not know in which applications the component is used. On the other hand the EEE manufacturer normally does not know for which specific reasons the component manufacturer chose the material as this is the specific know-how of the component manufacturer."* This is similar to the situation of leaded steel alloys in Ex. 6a. Therefore a comparable approach will also be discussed for the leaded copper alloys, as follows below.

The consultants would expect that the scope could be narrowed based on application groups or based on critical properties and required performance in application groups. This could require a supply chain survey, in order to collect and compile relevant

[786] Op. cit. TMC (2015)
[787] Op. cit. JBCE (2015)
[788] Op. cit. Phoenix Contact and Harting (2015a)
[789] Op. cit. Phoenix Contact and Harting (2015b)

information and to allow conclusions as to relevant properties and performance levels. Time may be needed in order to initiate such a survey along the supply chain to gain this information and screen all relevant applications relevant to arrive at an exhaustive list (of applications or of properties). However, this effort is presumed to be feasible as well as important for communicating to the customers where additional effort is needed in the applications of substitutes in the future.

As in the case of leaded steel alloys, in the case of leaded copper alloys the applicants Phoenix Contact and Harting[790] also point out the individual and specific situation of each machining company: "*For example the machinability is not one isolated property but it depends on material, tool, coolant, machining technology and of course of the part that is to be made. Thus the change of one parameter also causes changes in the other parameters.*"

Therefore it might be that an exhaustive list of properties also specifying the required performance level and the relevant performance indicators that are relevant for such properties might not be practicable to refine the scope of the exemption. To support this understanding, however, the complexity of the situation at hand needs to be presented and substantiated. The wide scope currently addressed in the exemption is open to misuse in cases where substitution might be possible. Therefore the consultants conclude that although a comprehensive list of applications may be long for refining the scope of the exemption, this is however of importance for establishing the potential of a change in scope. The consultants consider this to be the first step to further narrow the scope of the exemption, which the industry must be induced to undertake.

20.5.7 Exemption Wording Formulation

As with the other alloy exemptions, the need to narrow down the exemption is evident. However, at this time on the basis of the available information the consultants cannot conclude a list of exhaustive applications of leaded copper alloys, which would be a prerequisite for narrowing the exemption.

20.5.8 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

790 Op. cit. Phoenix Contact and Harting (2015b)

The consultants understand from the information provided that there are substitutes available that could at least be used for some applications. However, the use of alternatives (e.g. Ecobrass) requires adaptations in the machining process. Consequently, substitution with Ecobrass is currently understood to have restrictions limiting its applicability to certain applications, and possibly requiring machining adaptations in others. There are results from publically funded research that suggest how to overcome machinability challenges. Therefore it can be assumed that at least for some applications, the machining problems can be overcome in the future. It can be understood that there are additional lead-free copper alloys; however information was not provided in relation to other specific alloys.

It is further noted that though the applicants and stakeholders provide some detail as to their efforts towards substitution, in most cases statements remain general in nature. Quantitative comparisons are not sufficiently available to allow comparing between leaded alloys and various lead-free candidates in relation to various application sub-groups.

The remaining applications have to be specified by performing an integrated survey of the supply chain in order to narrow the scope of the exemption to a comprehensive list of applications. This would need the engagement of EEE component manufacturers as different applicants mentioned the dependency of the supply chain. The consultants can follow that this would be time-consuming. However, the consultants think that the current scope is not justified and recommend a short-term exemption to allow performing such a survey.

The set-up of a comprehensive list of applications would also allow deciding, whether the lead content can be further reduced in a certain application range. It might be that for a specific application group a general lower lead threshold can possibly be achieved.

20.6 Recommendation

Based on the above considerations, it can currently not be concluded whether substitution of the use of copper alloys containing lead up to 4% by weight is scientifically or technically practicable. It appears that substitutes can be applied in some cases (lead-free or with lower lead content), however mutual factors that would allow conclusions for specific sub-groups cannot currently be identified. It can also be understood that at least in some cases, available substitutes cannot be applied.

The overall picture where substitution efforts are promising is not clear enough at present. The aim of a future review should therefore be an exhaustive inventory on the applications of leaded copper alloys together with their technical requirements in order to check the applicability of a more narrow scope for the exemption. This should also encourage machining process adaptation to be further investigated to process lead-free [and/or reduced lead] alloys. Various stakeholders explain that such a survey would not be practical; however it is the obligation of the applicants (and of stakeholders interested in the exemptions renewal) to provide sufficient information to justify exemptions and their renewal.

Thus, the consultants recommend the renewal of Exemption 6c with the current scope and wording. However to stress the need to set up such an inventory and to start an integrated approach and to initiate a comprehensive survey along the value chain with a view to, at least, identify lists of components or categories of applications for lead reduction or substitution, the consultants propose to set a short review period of three years. As it does not seem that most stakeholders have detailed plans as to how to promote substitution in the future, the consultants would further recommend cancelling the exemption, should industry fail to provide substantiated information in the future.

Exemption 6c	Duration*
Copper alloy containing up to 4% lead by weight	*For Cat. 1-7 and 10 and 11: 21 July 2019* *For Cat. 8 and 9: 21 July 2021* *For Sub-Cat. 8 in-vitro: 21 July 2023* *For Sub-Cat. 9 industrial: 21 July 2024*

Note: As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

20.7 References Exemption 6c

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21.0 Exemption 7a

Declaration

In the sections that precede the "Critical Review" the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms

CTE	Coefficient of thermal expansion; measure for the thermal mismatch between two materials bonded together
DA5	'Die Attach 5' – a partnership between Bosch, Infineon, Freescale, STM and NXP
DCB	Direct copper bonding
DBC	Direct-bonded copper, like DCB
EEE	Electrical and electronic equipment
HMP	High melting point
HMPS	high melting point solders
LHMPS	Lead-containing high melting point solders with at least 85 % of lead content
RoHS 1	Directive 2002/95/EC
RoHS (Directive)	Directive 2011/65/EU (recast RoHS Directive, RoHS 2) if not specified otherwise
SAC	Tin-silver-copper (solders)
SMT	Surface mount technology
TFCB	Thick film copper bonding
THT	Through hole technology

21.1 Description of the Requested Exemption

21.1.1 Overview of the Submitted Exemption Requests

Table 21-1 gives an overview of the various applications for the continuation of exemption 7(a).

IXYS apply for the continuation of exemption 7(a) with limited scope. This scope restrictionis related to the applicants' product portfolio and does not imply that IXYS have RoHS-compliant solutions for all other uses of lead-containing high melting point solders (LHMPS) in the scope of the current exemption 7(a). Bosch contributed to the stakeholder consultation in supporting the continuation of exemption 7(a) without changes, but alternatively proposed a specific exemption for their own specific use of LHMPS.

Table 21-1: Overview of applications and stakeholder inputs related to exemption 7(a)

Applicant	Requested Exemption	Requested Expiry Date/ Continuation	Remarks
Bourns[791]	Continuation of exemption without changes	5 years	-
Bosch[792]	Support for renewal without change, otherwise *"Lead in high melting temperature type solders used in high-power transducers (loudspeakers)"*	Not indicated	Submitted during public stakeholder consultation as answers to the consultation questionnaire
Chenmko	Unclear	Unclear	Application disqualified for formal reasons as lacking even most basic information
Formosa	Continuation of exemption without changes	5 years	Application disqualified for formal reasons as lacking even most basic information

[791] Bourns Inc. 2015a "Exemption Request Exemption 7a: Document "7a_Exemption_extension_ap_7a.pdf"," Bourns Inc., http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Bourns/7a_Exemption_extension_ap_7a.pdf

[792] Bosch Security Systems GmbH 2015 "Document "Bosch-Stakeholder-contribution-Exemption-request-7a.pdf", submitted during the online stakeholder consultation," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Bosch-Stakeholder-contribution-Exemption-request-7a.pdf

Applicant	Requested Exemption	Requested Expiry Date/ Continuation	Remarks
Freescale et al.[793]	Continuation without change	Maximum validity period (5 years)	-
IXYS[794]	Lead in soft solder alloys used in power semiconductor devices containing more than 90 % lead	Maximum validity period (5 years)	Applicant mentions alternative technology (DCB, direct copper bonding)
Yea Shin Technology	Unclear	Unclear	Application disqualified for formal reasons as lacking even most basic information

21.1.2 Background and History of the Exemption

Exemption 7(a) "Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)" was already listed in the annex of Directive 2002/95/EC (RoHS 1)[795], when it was officially published in 2003. In 2008/2009, the exemption was reviewed for the first time.[796] The evaluators found that exemption 7(a) allowing the use of lead-containing high melting point solders (LHMPS) is still required. However, exemption 7(a) is material specific, while most other RoHS exemptions are application specific. LHMPS can therefore be used in each application as long as it contains at least 85 % of lead, even if lead-free alternatives are available. In the course of the exemption evaluation in 2008/2009, the reviewers stated that:

> *"[...]HMP solders are used where alternative solutions reducing the amounts of lead are available* [797]

[793] Freescale Semiconductors/NXP et al. 2015a "Request for Continuation of Exemption 7a, document "Ex_7a_Freescale_Ex_Renewal_Dossier_2015_0723_v20_revised.pdf": Exemption request form," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Freescale_Semiconductor/Ex_7a_Freescale_Ex_Renewal_Dossier_2015_0723_v20_revised.pdf

[794] IXYS Semiconductor GmbH 2015a "Request for continuation of exemption 7a with limited scope, document "7a_IXYS_RoHS_V_Application_Form.pdf": Exemption request form," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/IXYS/7a_IXYS_RoHS_V_Application_Form.pdf

[795] Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment, RoHS 1, European Union (13 February 2003)

[796] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM, http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf

[797] Ibid., page 86

1) *The current general exemption for lead in HMP solders offers a loophole to bypass the use of lead-free solders or to avoid searching for other RoHS-compliant solutions that do not require the use of lead. Manufacturers use leaded HMP solders in applications, for which others offer lead-free solutions.*[798]

2) *The current general exemption unnecessarily increases the use of lead in applications, where lead-free solutions are technically impracticable and an exemption for the use of lower lead content solders would be possible or is already in place."*[799]
A component manufacturer stated that "It has become more apparent that some of our customers are tending towards using higher lead alloys (typically 95 % lead rather than 50 % lead) '....]". [we] have actively encouraged switching to the lower lead content In/Pb solder alloys allowed by exemption 24."
Instead of using available or applying for a new exemption for the use of lead in low lead-content solders like e.g. the tin-lead solder with 37 % lead (SnPb37), manufacturers may shift to HMP solders with high lead contents of 85 % and more.[800]*"*

In 2009, the reviewers therefore recommended transferring exemption 7(a) into an application specific exemption:

> *"[...] in line with the latest Commission decisions on exemptions which are application and technology oriented and thus are use specific. [...] It cannot be assumed that [the] stakeholder comments cover all uses, in which the use of lead in HMP solders needs to be exempted [...]. Parts of the electronics industry thus might suddenly see themselves producing non-RoHS-compliant products if the general exemption would be changed into an application specific based on the available information from the stakeholder consultation for this review process. A new stakeholder consultation is required to give industry worldwide the opportunity to apply for the necessary application and technology specific exemptions. [...]*
>
> *The reviewers propose leaving the exemption unchanged for now, but giving it an expiry date, which allows industry a reasonable time frame to apply for specific exemptions for the use of lead in HMP solders, where they are justifiable by the requirements set out in Art. 5(1)(b). [...] The consultants propose 30 June 2013 as the expiry date for exemption 7(a)."*[801]

[798] Ibid., page 86
[799] Ibid., page 86
[800] Ibid., page 86
[801] Ibid., page 87

The Commission did not set an expiry date. In 2011, exemption 7(a) was transferred to Annex III of the recast directive 2011/65/EU[802] (RoHS 2) without changes, and the maximum period to the next review or the expiry of the exemption was respectively extended from July 2014 under RoHS 1 to July 2016 under RoHS 2 for use in all electrical and electronic equipment (EEE) in the scope of the RoHS Directive other than EEE in categories 8 and 9.

As the RoHS Directive requires that *"Exemptions from the restriction for certain specific materials or components should be limited in their scope [...]"*, and in order to avoid abuse of exemption 7(a), the scope specification of exemption 7(a) is in the focus of the present review as far as such exemptions would be in line with the conditions for exemptions laid down in Art. 5(1)(b).

21.1.3 Technical Description of the Requested Exemption

The technical background of exemption 7(a) was described in detail in the report of the last review of this exemption in 2009.[803] This chapter therefore only presents the most relevant technical facts and information that is of relevance for this review.

The technical background of the Bourns[804] and IXYS[805] exemption requests are technically equivalent to the technical description submitted by Freescale/NXP et al.[806] They are therefore not specifically explained in this chapter.

According to Freescale et al.[807] the most important property for lead (Pb) HMP solders (LHMPS) is the high melting point, which is solely managed by the lead composition. Other practical properties, such as electrical conductivity, thermal conductivity, ductility, corrosion-resistivity, appropriate oxidation nature, and wettability are also inherent in lead. Lead is the only known element which gives all these properties. Table 21-2 sums up the properties of lead required in LHMPS.

21.1.3.1 Specific Properties of Lead in LHMPS

In Table 21-2 and in the subsequent figures, Freescale et al.[808] present the required properties of lead in HMPS. It is the physical and chemical properties of the alloys that are important. Some combinations of elements (e.g. AuSn) will meet some criteria, but the essential requirement is the unique combination of essential properties of HMP solders with lead, not any single property.

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[802] Recital 19 of the Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast), RoHS 2, European Union (1 July 2011)
[803] Op. cit. Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009, p. 76 et seqq.
[804] dddOp. cit. Bourns Inc. 2015a
[805] Op. cit. IXYS Semiconductor GmbH 2015a
[806] Op. cit. Freescale Semiconductors/NXP et al. 2015a
[807] Ibid.
[808] Ibid.

Table 21-2: Required performance of HMPS solder and specific properties of lead

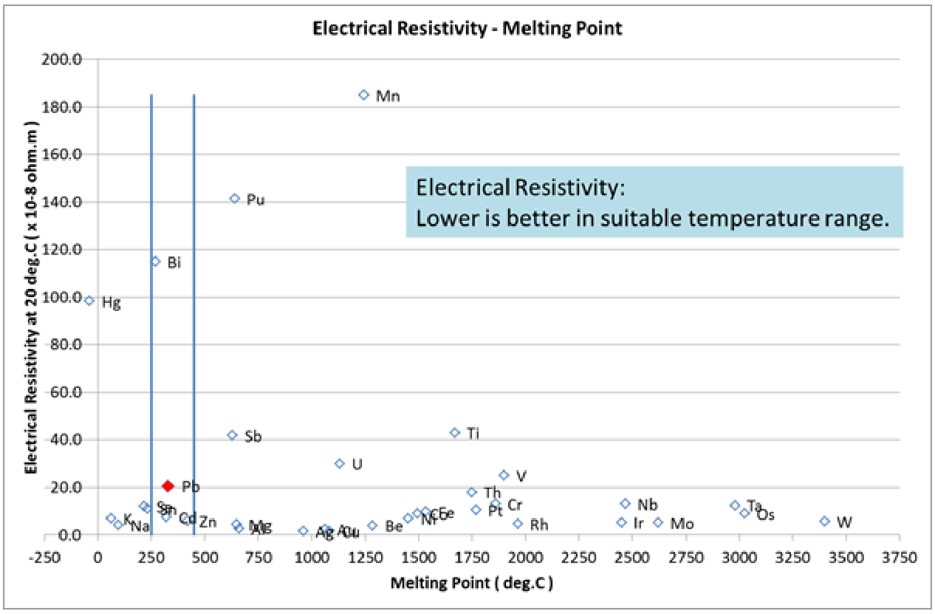
Performance requirements	Reasons for the requirements	Function of lead	Data
High melting points	Not to be melted during secondary assembly steps including soldering. Functionality of electrical parts not to deteriorate.	While HMPS applications require minimum melting points above 250°C, solder processes have an upper limit defined as 450 °C. Few elements have melting points in this range. 250°C is a critical limit, and in reality for most applications the melting point for the HMPS in specific applications is higher. Lead is the least hazardous among these elements such as tellurium, cadmium or thallium.	Melting points, cf. Figure 21-1 to Figure 21-11 below
Electrical connection	Electrical functionality	Lead is the unique element which has practical qualities of melting point, electrical conductivity, thermal conductivity, mechanical reliability and chemical stability with an ideal balance.	Electrical resistivity, cf. Figure 21-1 and Figure 21-2 below
Thermal conduction	To ensure the reliability of electronic components due to the heat dissipation		Thermal conductivity, cf. Figure 21-3and Figure 21-4 below
Ductility	To join the materials having the different coefficients of expansion together (To ensure mechanical reliability)		Young's modulus, cf. Figure 21-5 and Figure 21-6 below
Corrosion-resistivity	To ensure the reliability		Ionization tendency (very low next to hydrogen, it means difficult to oxidize), cf. Figure 21-7 and Figure 21-8 below
Oxidation nature	To prevent oxidation at the secondary mounting; To ensure the reliability		Standard electrode potential, cf. Figure 21-9 and Figure 21-10 below

Source: Freescale et al.[809]

[809] Ibid.

The below figures illustrate the properties of lead for wide and narrow temperature ranges respectively. Freescale et al.[810] plotted as many different metallic elements as possible in the 'wide temperature' range figures to show that elements present in the high melting point solder domain are extremely limited. The 'narrow temperature range' graphs are presented by enlarging the illustrations in order to make it easier to understand the properties of lead in the melting domain of high melting point solders. The narrow temperature range is necessary from the processability and usability points of view.

Figure 21-1: Electrical resistivity and melting points of elements (wide temperature range)

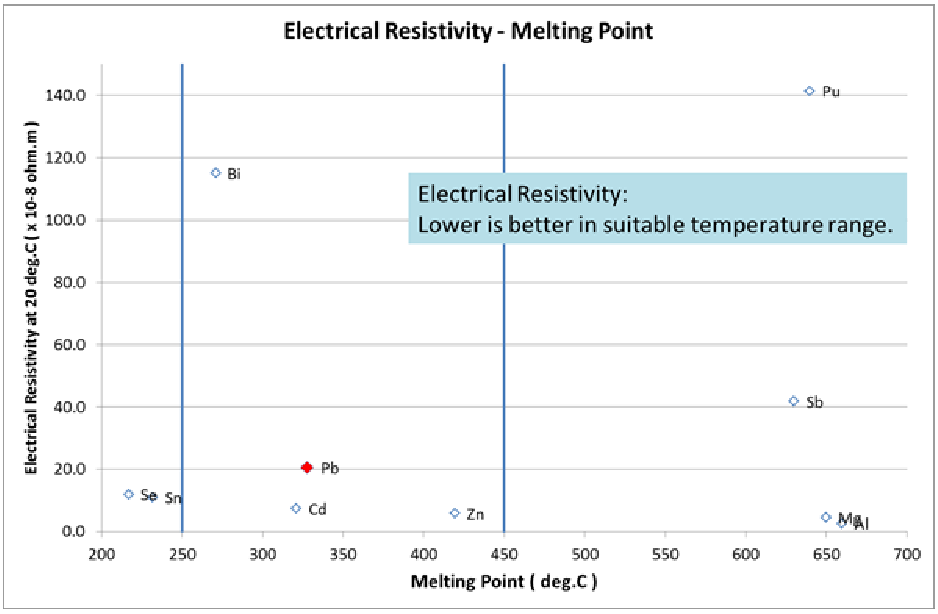


Source: Freescale et al.[811]

[810] Freescale Semiconductors/NXP et al. 2016a: "Answers to second questionnaire, document "Exe_7a_Questionnaire-2_Freescale_Response_2016-01-28.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, Freescale (NXP) et al., on 28 January 2016" unpublished manuscript,

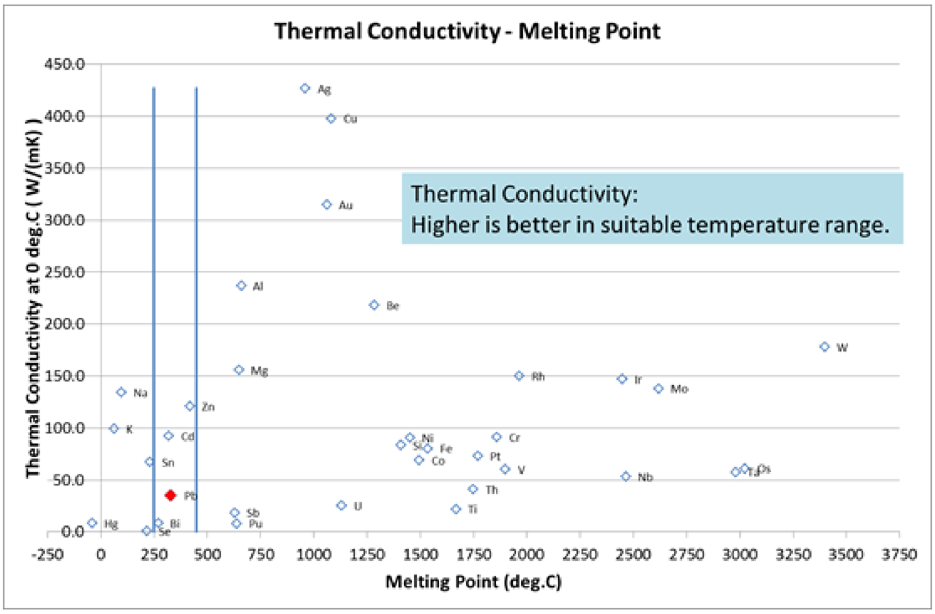
[811] Op. cit. Freescale Semiconductors/NXP et al. 2015a

Figure 21-2: Electrical resistivity and melting points by element (narrow temperature range)



Source: Freescale et al.[812]

Figure 21-3: Thermal conductivity and melting points by element (wide temperature range)



Source: Freescale et al.[813]

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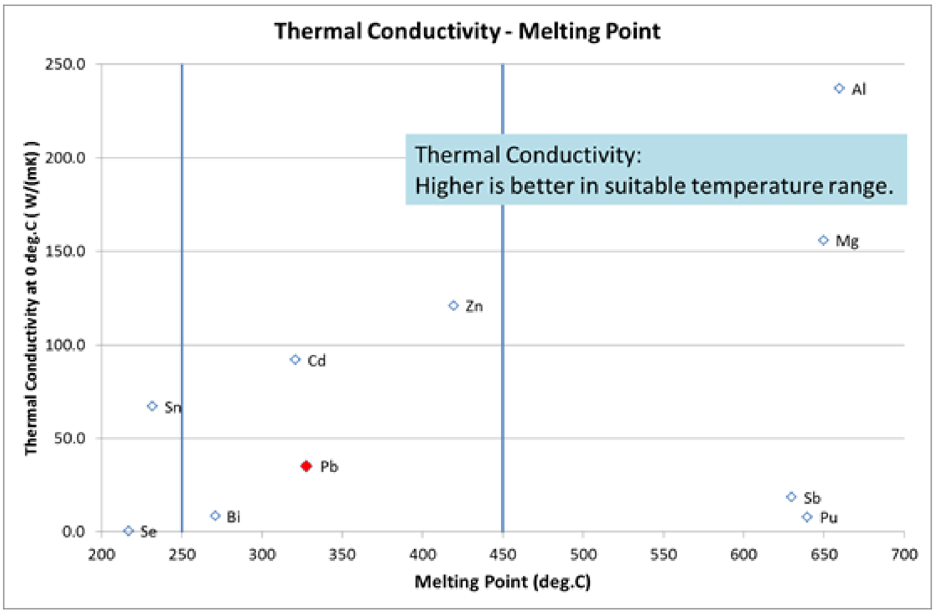
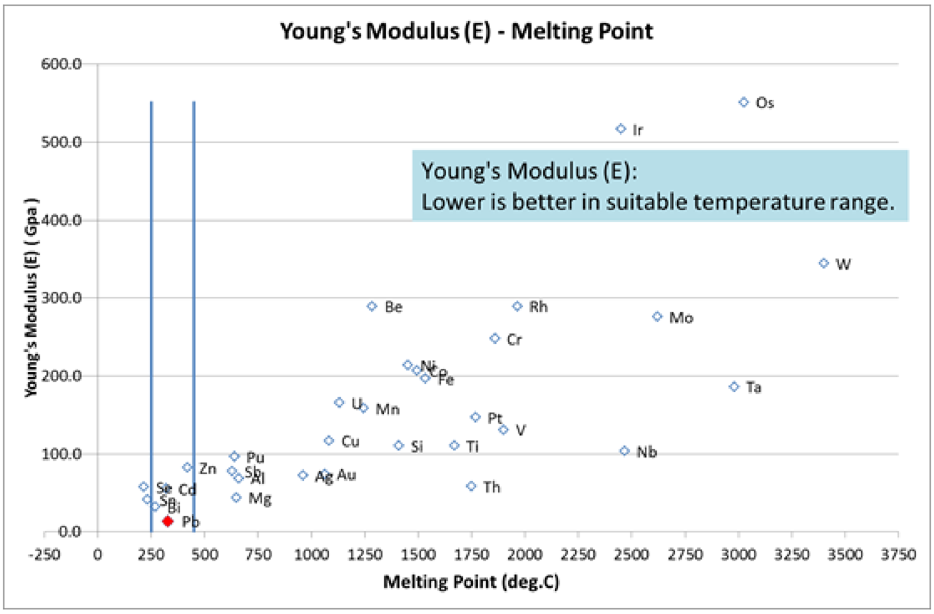
[812] Ibid.

Figure 21-4: Thermal conductivity and melting points by element (narrow temperature range)



Source: Freescale et al.[814]

Figure 21-5: Young's modulus (E) by melting points (wide temperature range)



Source: Freescale et al.[815]

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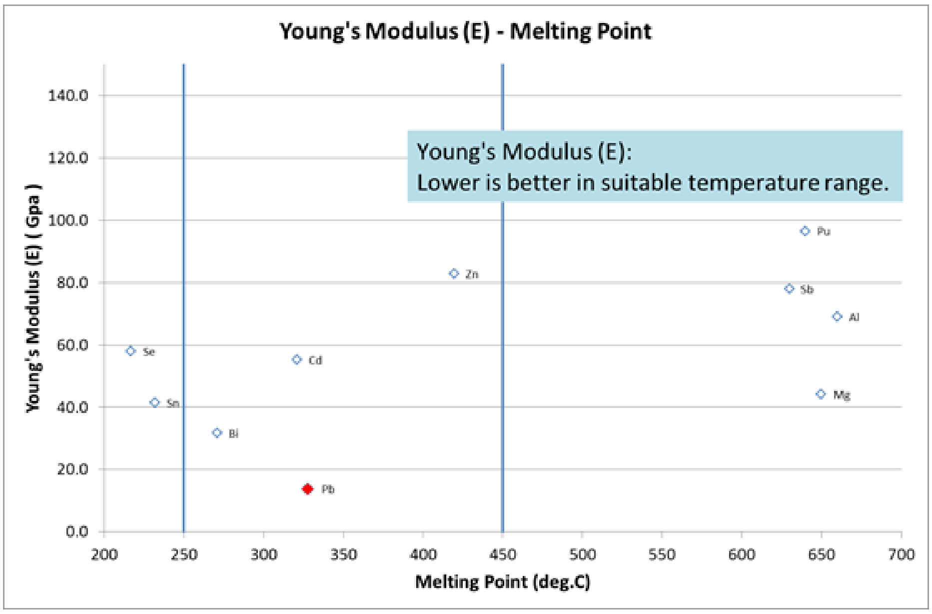
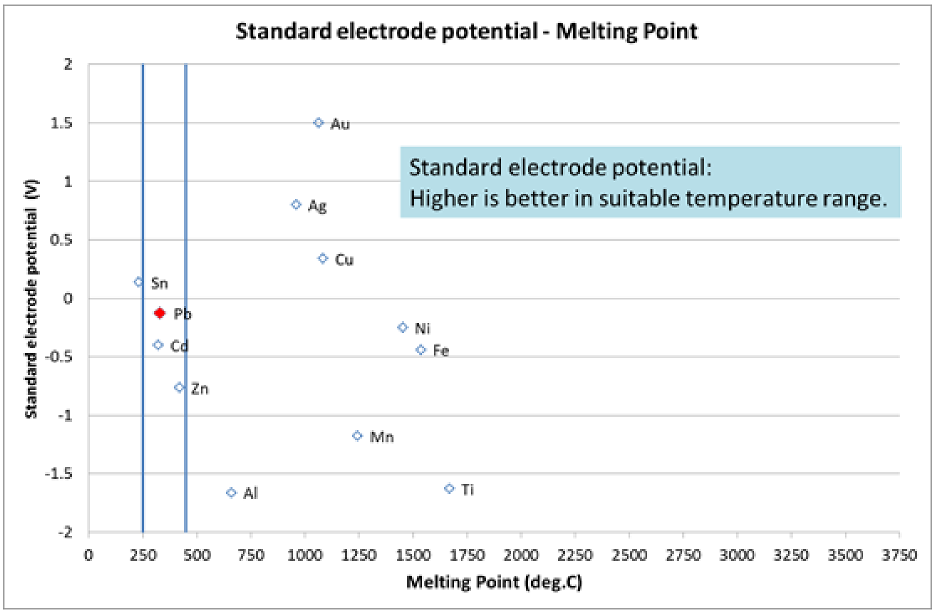
[813] Ibid.
[814] Ibid.

Figure 21-6: Young's modulus (E) by melting points (narrow temperature range)



Source: Freescale et al.[816]

Figure 21-7: Standard electrode and melting points of elements (wide temperature range)



Source: Freescale et al.[817]

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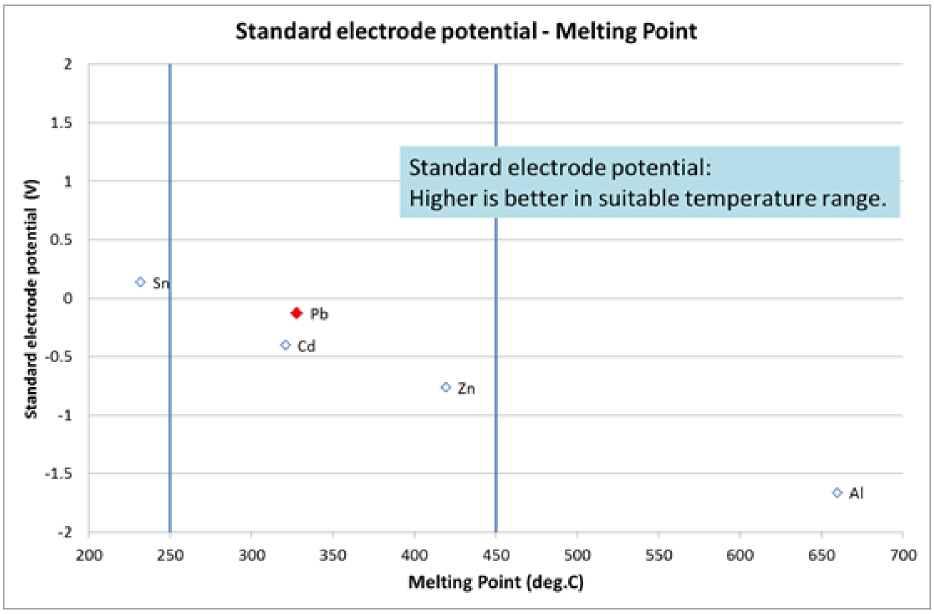
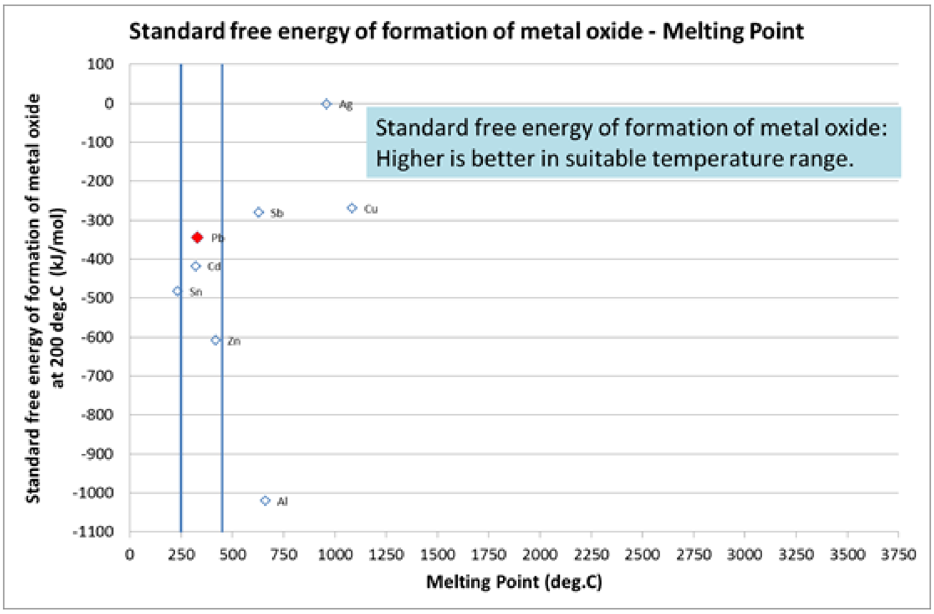
[815] Ibid.
[816] Ibid.

Figure 21-8: Standard electrode and melting points of elements (narrow temperature range)



Source: Freescale et al.[818]

Figure 21-9: Standard free energy of metal oxide formation and melting points of elements (wide temperature range)



Source: Freescale et al.[819]

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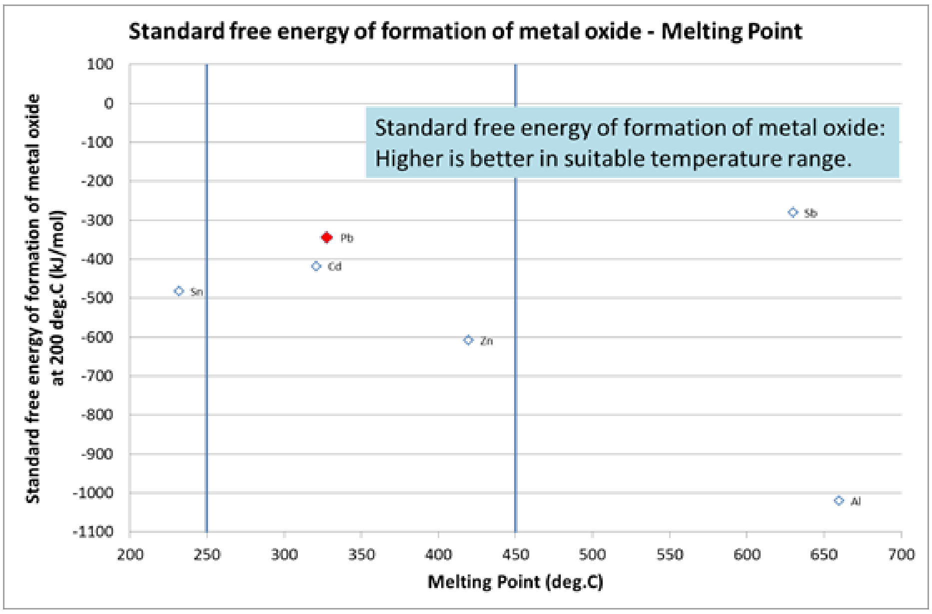
[817] Ibid.
[818] Ibid.

Figure 21-10: Standard free energy of metal oxide formation and melting points of elements (narrow temperature range)

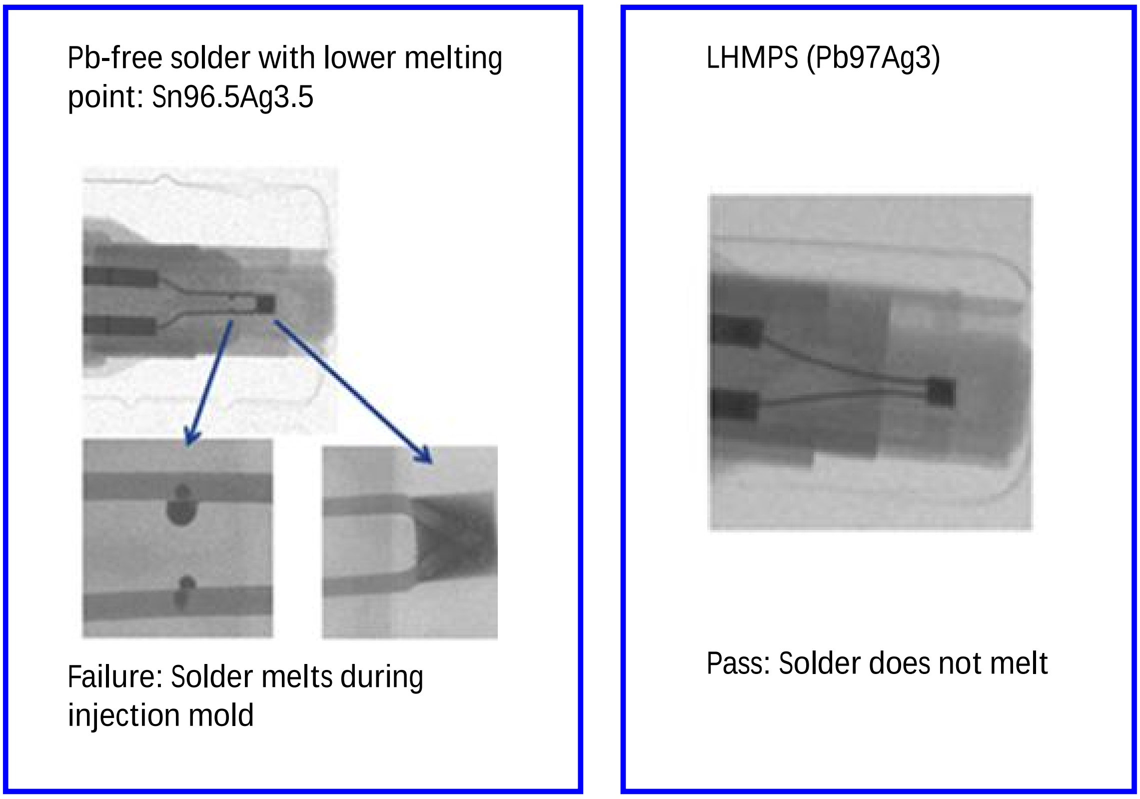


Source: Freescale et al.[820]

With Figure 21-11, Freescale et al.[821] explain why a thermistor requires high HMPS. Thermistor devices are used in high temperature / harsh environment applications. This requires plastic over-moulding with materials having a working temperature of ~ 260 ^{o}C. High temperature solder is required to avoid any reflows which weaken the connecting lead[822]-to-thermistor adhesion. The left picture in Figure 21-11 details the solder reflow from plastic over-moulding with lead-free type solders. The picture on the right depicts high temperature lead-based solder in the same over-moulding operation.

[819] Ibid.
[820] Ibid.
[821] Ibid.
[822] not Pb

Figure 21-11: Thermistor requirement for LHMPS



Source: Freescale et al.[823]

Freescale et al.[824] explain that similar circumstances are relevant with current limiting thermistor products. Current limiting thermistors can reach temperatures up to 240 °C during normal operating conditions in the field. In order to stay above the plastic and solder melting point for this application, LHMPS are the only commercial solution available at this time.

[823] Ibid.
[824] Ibid.

21.1.3.2 Uses of LHMPS

Table 21-3 lists the uses of LHMPS, which are illustrated with examples in the figures below the table.

Table 21-3: Uses of LHMPS

<table>
<tr><th>LHMP solder use</th><th>Examples of related products</th><th>Reasons for necessity</th></tr>
<tr><td>For combining elements integral to an electrical or electronic component:
- a functional element with a functional element; or,
- a functional element with wire/terminal/heat sink/substrate, etc.</td><td>· Resistors, capacitors, chip coil, resistor networks, capacitor networks, power semiconductors, discrete semiconductors, microcomputers, ICs, LSIs, chip EMI, chip beads, chip inductors, chip transformers, power transformers, lamps, etc.;
· see examples in Figure 21-12to Figure 21-17 below</td><td rowspan="3">· Stress relaxation characteristic with materials and metal materials at the time of assembly is needed.
· When it is incorporated in products, it needs heatproof characteristics to temperatures higher than 250 to 260°C.
· It is needed to achieve electrical characteristic and thermal characteristic during operation, due to electric conductivity, heat conductivity / high thermal dissipation, etc.
· It is needed to gain high reliability for temperature cycles, power cycles, etc.</td></tr>
<tr><td>For mounting electronic components onto sub-assembled modules or sub-circuit boards</td><td>· Hybrid IC, modules, optical modules, etc.
· See example in Figure 21-18 below</td></tr>
<tr><td>As a sealing material between a ceramic package or plug and a metal case</td><td>· SAW (Surface Acoustic Wave) filter, crystal resonators, crystal oscillators, crystal filters, etc.
· See example in Figure 21-19 below</td></tr>
</table>

Source: Freescale et al.[825]

LHMPS uses for combining elements integral to an electrical or electronic component

Freescale et al.[826] provide five examples in the below figures for how LHMPS are used to combine elements integral to an electrical or electronic component – either a functional element with a functional element, or a functional element with wire/terminal/heat sink/substrate, etc.

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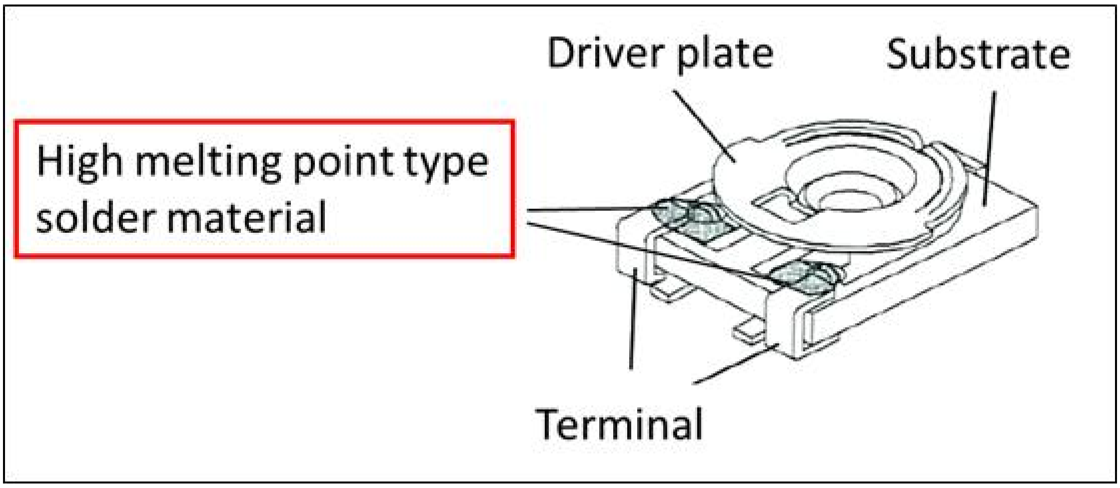
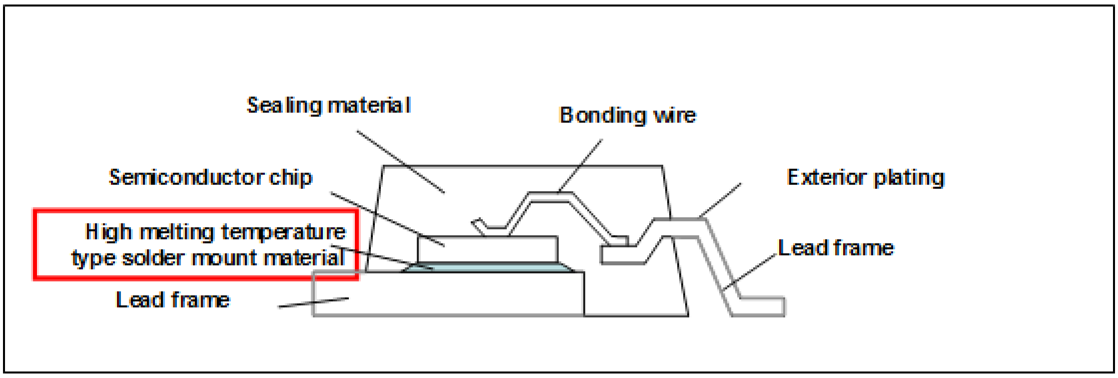
[825] Ibid.
[826] Ibid.

Figure 21-12: Schematic view of potentiometer with HMP lead (Pb) solder visible from the outside



Source: Freescale et al.[827]

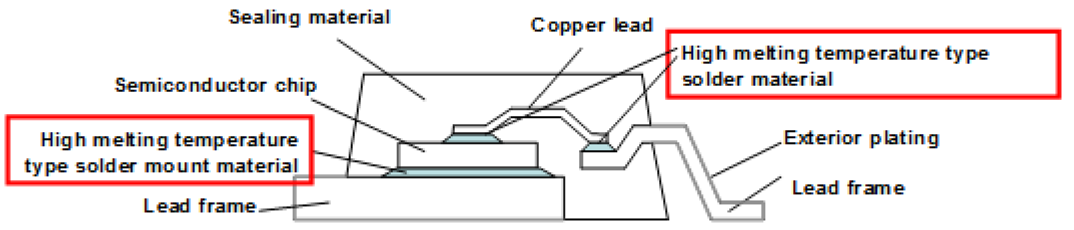
Figure 21-13: Schematic cross sectional view of a power semiconductor



Source: Freescale et al.[828]

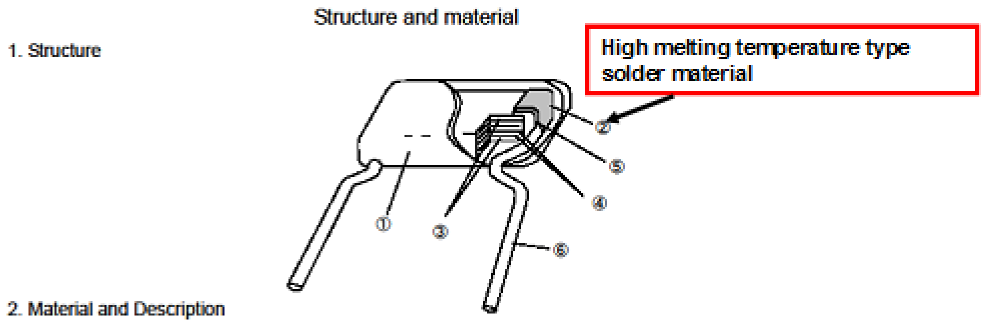
[827] Ibid.
[828] Ibid.

Figure 21-14: Schematic cross sectional view of internal connection of semiconductor



Source: Freescale et al.[829]

Figure 21-15: Schematic view of a capacitor with lead wire



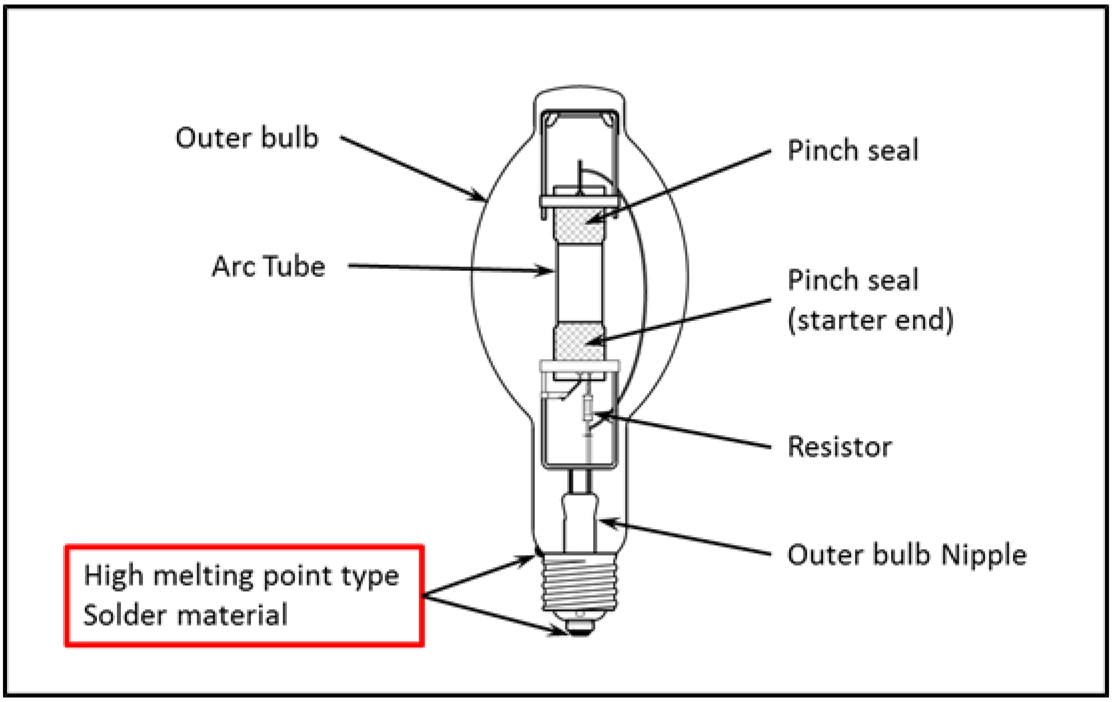
No.	Material	Description
①	Enclosure	Epoxy resin
②	Inner solder	Sn-Pb type solder *1
③	Dielectric	Ceramic
④	Inner electrode	Ni or Pd or Ag/Pd
⑤	Outer electrode	1)Ag/Pd or 2) Ag or Ag/Pd or Cu + Ni plating + Sn plating
⑥	Lead wire	Solder(Sn-2.5Cu) coated copper wire or Solder(Sn-2.5Cu) coated CP wire

*1 Lead in high melting temperature type solders (Pb:85% or more) are exempted from the requirements of RoHS.

Source: Freescale et al.[830]

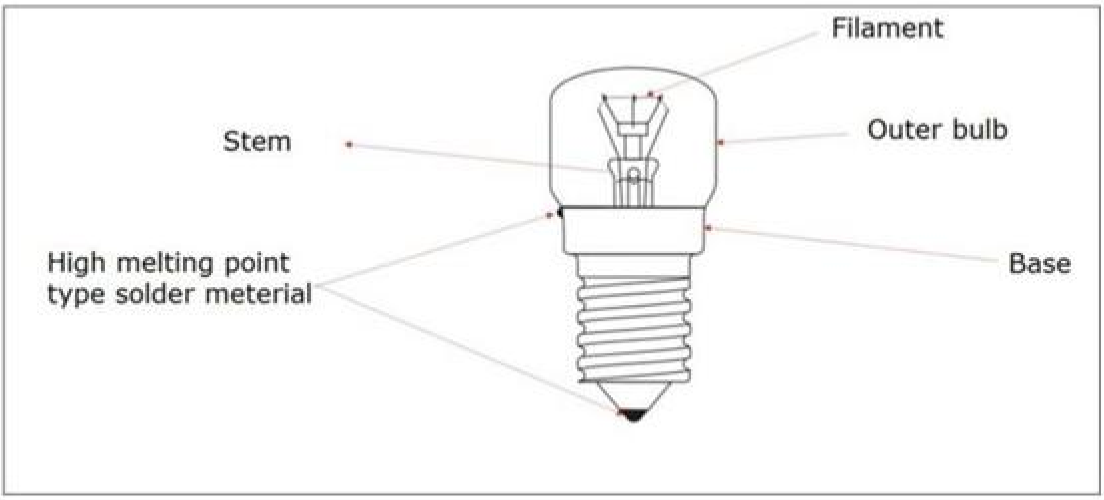
[829] Ibid.
[830] Ibid.

Figure 21-16: Schematic view of a HID lamp



Source: Freescale et al.[831]

Figure 21-17: Oven lamp with LHMPS



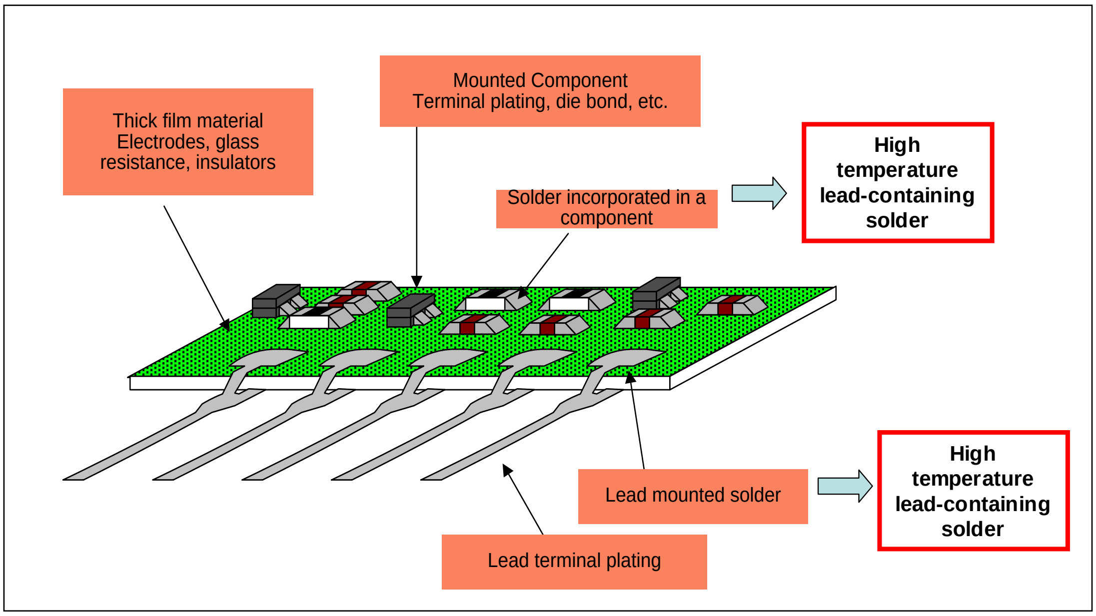
Source: Freescale et al.[832]

[831] Ibid.
[832] Ibid.

Examples for mounting electronic components onto sub-assembled modules or sub-circuit boards with LHMPS

Figure 21-18 shows examples for how LHMPS are used to mount electronic components onto sub-assembled modules or sub-circuit boards.

Figure 21-18: Schematic view of a circuit module component



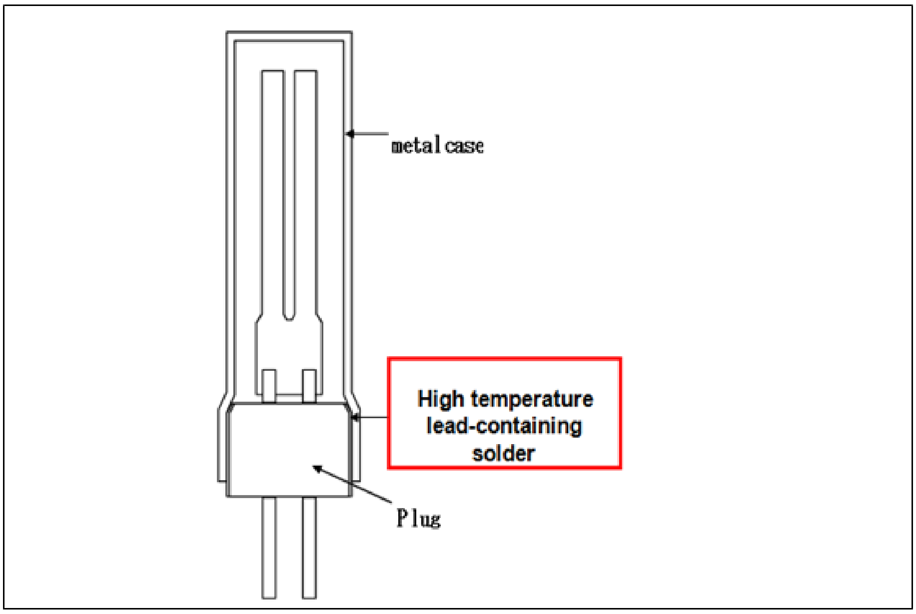
Source: Freescale et al.[833]

LHMPS uses as sealing material between a ceramic package or plug and a metal case

In Figure 21-19, Freescale et al.[834] illustrate the use of LHMPS for sealings between a ceramic package or plug and a metal case.

[833] Ibid.
[834] Ibid.

Figure 21-19: Schematic view of a crystal resonator



Source: Freescale et al.[835]

LHMPS in High PowerTransducers (Bosch)

Bosch[836] describes that high power transducers (both low and high frequency in professional sound applications) are used with power amplifiers capable of producing output greater than 200 V and 30 A. This amount of energy creates a significant amount of heat dissipated in the voice coil. The temperatures for low frequency transducers exceed the melting point of lead-free solders in less than 100 seconds, resulting in catastrophic failures. In addition, the solder used must be compatible with copper and aluminium wire.

In Bosch's[837] high power loudspeaker designs it is necessary to transition between a high flexibility, high cross sectional area conductor, down to the very fine gauge wire used to make the coil of wire that provides the electromotive force to drive the transducer. These solder joints must be made in close proximity to the magnet wire coil for a variety of reasons.

A primary reason for the proximity is structural integrity. The fine gauge magnet wire is often not able to withstand the high amounts of vibrational energy in the coil structure. This magnet wire can be aluminium, copper-clad aluminium, or copper. All of these magnet wires experience bending fatigue. If the solder joint is too far from the coil of magnet wire, this conjoining section of wire will mechanically fail due to highly

[835] Ibid.
[836] Op. cit. Bosch Security Systems GmbH 2015
[837] Ibid.

repetitious bending modes. These fractures can create an electrical arc across the break in the wire that can ignite nearby materials.[838]

This proximity of the solder joint to the magnet wire coil in conjunction with the high temperatures of the magnet wire in the coil, make HMP solder a necessity.[839]
Figure 21-20 and Figure 21-21 describe the situation.

Figure 21-20: Inner diameter of a typical high power woofer voice coil

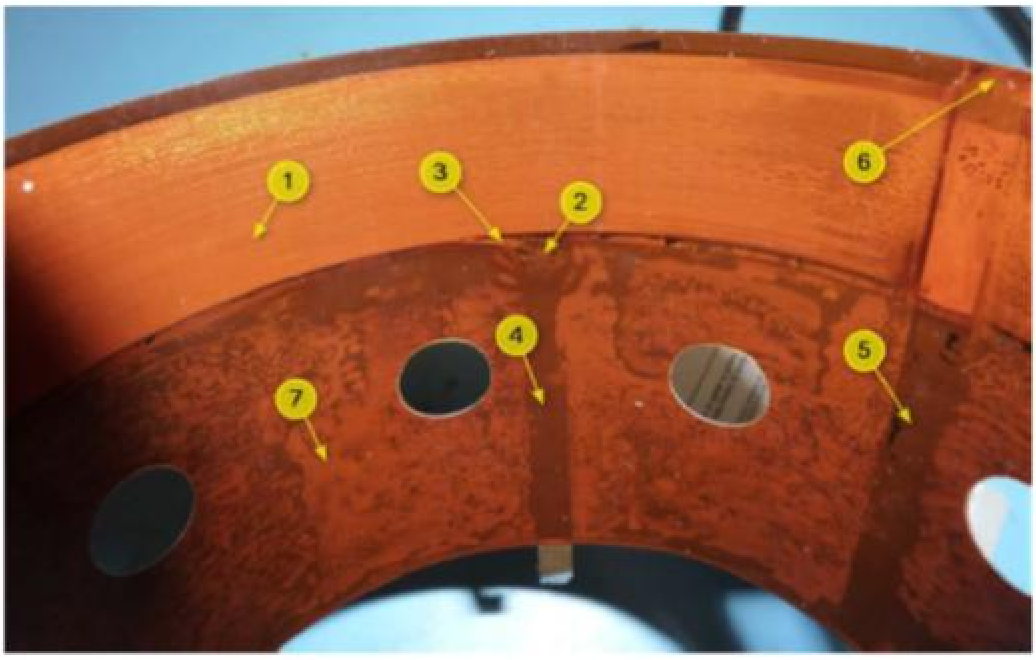


Image of the inner diameter of a typical high power woofer voice coil.

In this image;

1) Shows the coil of magnet wire. Visible through the coil bobbin (item 7).
2) The Upper solder joint. This joint is layered between the bobbin (7) and another high temperature resistance electrically insulating polymer. The magnet wire (3) is soldered to the flexible conductor (4) with HMP solder.
3) The magnet wire splitting off the coil (1) to go to the upper solder joint (2)
4) .1mm x 6mm flexible conductor (e.g. Phosphor Bronze.)
5) Same as 4 but extending under the coil of wire to make Lower Solder Joint (6)
6) The Lower Solder joint. This joint is layered between the bobbin (7) and a high temperature resistance adhesive. The magnet wire (3) is soldered to the flexible conductor (5) with HMP solder.
7) Bobbin – High temperature resistance polymer (e.g. Polyimide film)

Source: Bosch[840]

[838] Ibid.
[839] Ibid.
[840] Ibid.

Figure 21-21: Outer diameter of a typical high power woofer voice coil

Source: Bosch[841]

Figure 21-21 shows the black area which is the high temperature adhesive that overcoats the Lower Solder Joint and the magnet wire as it splits away from the coil of wire.

Although Bosch[842] started research two years prior to RoHS being required they have not discovered an alternative to LHMPS. Bosch[843] sells several products using these transducers in Europe. They are used in large installations including stadiums (e.g. World Cup stadiums), they have EN54 certifications for life safety applications.[844]

According to Bosch[845], these large installations are not large scale fixed installations, which would be excluded from the scope of the RoHS Directive.

21.1.4 Amount of Lead Used Under Exemption 7(a)

In 2000, the annual worldwide use of LHMPS in the scope of exemption 7(a) was investigated to be around 11,000 t corresponding to around 9,400 t based on the minimum lead content of 85 % mentioned in exemption 7(a).[846] In the 2008/2009 review, JBCE estimated the amount of LHMPS put on the EU market with 3,600 t/year,

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[841] Ibid.
[842] Ibid.
[843] Ibid.
[844] For product examples c.f. http://www.electrovoice.com/family.php?id=117; source as referenced by Bosch
[845] Bosch Security Systems GmbH 2016a "Answers to first questionnaire, document "Exe_7a_Questionnaire-1_Bosch_2016-03-13.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Erich Pudelko, Bosch, on 23 March 2016" unpublished manuscript,
[846] Otmar Deubzer 2007 Explorative study into the sustainable use and substitution of soldering metals in electronics: Ecological and economical consequences of the ban of lead in electronics and lessons to be learned for the future, Design for Sustainability Program publication 15 ([S.l.]: [s.n.]), http://repository.tudelft.nl/view/ir/uuid%3Af9a776cf-57c3-4815-a989-fe89ed59046e/; page 73 et seqq.

corresponding to at least 3,100 t of lead. This figure did not include the HMP solders contained in products imported into the EU market.[847]

In the current review, Freescale/NXP et al. [848] estimate the amount of LHMPS put on the EU market with around 2,700 t, which corresponds to at least 2,300 t of lead. The calculation below shows that this figure does not contain the lead from LHMPS in products imported into the EU.

Figure 21-22: Calculation of LHMPS solders in the EU

1,590,000 tonnes / year =	Electrolytic Pb consumption in Europe
X 1.3%	Ratio of Pb used in Pb solder applications
X 12.9%	HMP lead (Pb) solder ration of all solders
2,667 tonnes / year =	HMP lead (Pb) solder entering EU market

Source: Freescale/NXP et al.[849]

Bourns estimates the worldwide amount of lead from LHPMS based on some of its products with around 960 kg.[850]

IXYS[851] indicates the annual amount of LHMPS in power semiconductor devices containing more than 90% of lead with around 50 t/a for the EU market.

Bosch[852] estimates that they will place a mass of less than 15 kg of lead into the field per year in their high power loudspeaker products, less than 40 % of that quantity, around 6kg, will be used in the EU. This figure does not include lead that other manufacturers would use as LHMPS in high power transducers.

Overall, the figures differ depending on the applied calculation base and depending on the data quality and the product spectrum taken into account. The figures of JEITA et al.853 and of Deubzer854 have the broadest product scope and can therefore be assumed to be closest to the actual magnitude of HMPS solder use and related lead on the global and EU level, even though the data of Deubzer should be considered to reflect the magnitude of lead rather than the actual amounts since this data is now 16 years old.

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[847] Op. cit. Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009
[848] Op. cit. Freescale Semiconductors/NXP et al. 2015a
[849] Ibid.
[850] Bourns Inc. 2015b "1st Questionnaire (Clarification Questionnaire) Exemption 7a: Document "20150815_Ex_7a_Bourns_1st-Questionnaire_2015-07-14.pdf","
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Bourns/20150815_Ex_7a_Bourns_1st-Questionnaire_2015-07-14.pdf
[851] Op. cit. IXYS Semiconductor GmbH 2015a
[852] Op. cit. (Bosch Security Systems GmbH 2016a)
[853] Op. cit. Freescale Semiconductors/NXP et al. 2015a
[854] Otmar Deubzer 2007 Explorative study into the sustainable use and substitution of soldering metals in electronics: Ecological and economical consequences of the ban of lead in electronics and lessons to be learned for the future, Design for Sustainability Program publication 15 (Delft: TU Delft), http://repository.tudelft.nl/view/ir/uuid%3Af9a776cf-57c3-4815-a989-fe89ed59046e/

The actual use of lead thus is probably in the lower range of several thousand tonnes in the EU.

21.2 Applicants' Justification for the Continuation or Repealment of the Exemption

Freescale et al.[855] are requesting the renewal of exemption 7(a) in its current wording for categories 1 to 7, 10 and 11 of Annex I for an additional validity period of 5 years. They state that alternative technologies with similar ductility and strength as lead (Pb) that can survive one or several standard reflow processes with either leaded or unleaded solders are unavailable for the following uses:

- For combining elements integral to an electrical or electronic component:
  - a functional element with a functional element; or,
  - a functional element with wire/terminal/heat sink/substrate, etc.;
- For mounting electronic components onto sub-assembled modules or sub-circuit boards;
- As sealing materials between a ceramic package or plug and a metal case.

21.2.1 Substitution of LHMPS by Lead-free Solders and Conductive Adhesives

Freescale et al.[856] state that the RoHS Directive has encouraged the transition from lead solders to lead-free solders for external terminations and board attachment. Due to the higher melting points of lead-free solders, soldering temperatures in production processes have risen to between 250 °C and 260 °C for lead-free solders mainly composed of Sn-Ag-Cu. Soldering temperatures in production processes for solder joints were 230 °C to 250 °C for lead-containing solder joints. The increased processing temperature for lead-free solder joints expanded the requirement for HMP lead (Pb) solder. These high melting temperature solders typically contain more than 85 % lead.

Freescale et al.[857] present the Table 21-4, showing the current commercially available lead-free solders and their melting points.

The solders with a solidus line of less than 250 °C are not appropriate. In Table 21-5, Freescale et al.[858] explain the advantages and disadvantages of lead-free solders with a solidus line temperature of 250 °C or higher and electrically conductive adhesives. Those are the candidates for the replacement of high temperature type lead-containing solders.

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[855] Op. cit. Freescale Semiconductors/NXP et al. 2015a
[856] Ibid.
[857] Ibid.
[858] Ibid.

Table 21-4: Composition and melting temperatures of main lead-free solders

Category	Solder Type	Alloy Composition [wt %]	Melting Temperatures (Solidus Line / Liquidus Line)
Lead-free solders (Solidus Line 250℃ or lower)	Sn-Zn (-Bi)	Sn-8.0Zn-3.0Bi	190~197 °C
	Sn-Bi	Sn-58Bi	139 °C
	Sn-Ag-Bi-In	Sn-3.5Ag-0.5Bi-8.0In	196~206 °C
	Sn-Ag-Cu-Bi	Sn96Ag2.5Bi1Cu0.5	213~218 °C
	Sn-Ag-Cu	Sn-3.0Ag-0.5Cu	217~220 °C
		Sn-3.5Ag-0.7Cu	217~218 °C
		Sn-4Ag-0.5Cu	217~229 °C
	Sn-Cu	Sn-0.7Cu	227 °C
	Sn-low Sb	Sn-5.0Sb	235~240 °C
Lead-free solders (Solidus Line more than 250℃)	Bi system	Bi-2.5Ag	263 °C
	Au-Sn system	Au-20Sn	280 °C
	Sn-high Sb	Sn->43Sb	325~>420 °C
	Zn-Al system	Zn-(4-6)Al(Ga,Ge,Mg)	About 350~380 °C
	Sn system & high melting temperature type metal	Sn+(Cu, Ni, etc.)	≧about 230~ >400 °C

Source: Freescale et al.[859]

[859] Ibid.

Table 21-5: Properties of lead-free solders with solidus line temperatures of 250 °C or higher

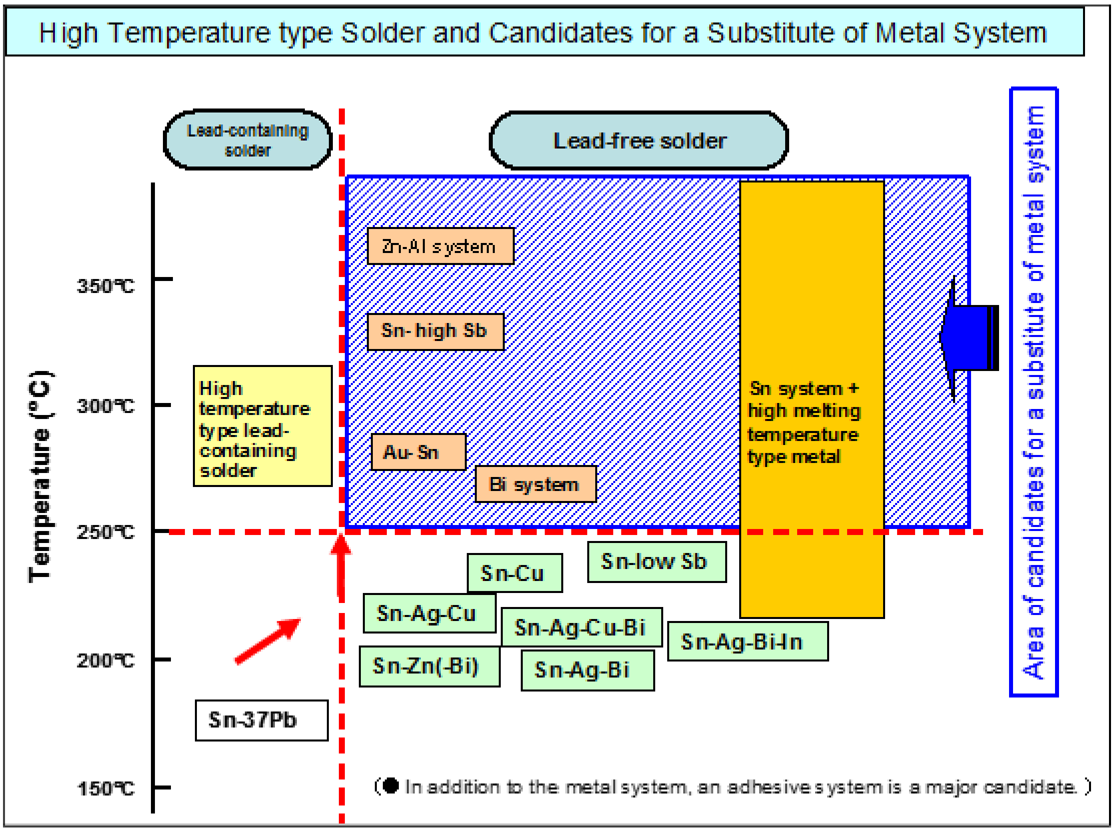
Candidate for Substitution		Advantages	Disadvantages
Metal System	Bi system	· Solidus line is high · Joint operating temperature is comparable with conventional high temperature type solders · Relatively low-cost	· Low ductility · Low strength · High electrical resistivity
	Au-Sn	· Solidus line is high · Joint operating temperature is comparable with conventional high temperature type solders · Strength is high	· Low ductility · Low melting point compared to LHMPS
	Sn-high Sb	· Solidus line is high	· Low ductility · Concern of Sb toxicity · Temperature required to solder is ~50 oC higher than Pb-based solder and is too hot for some processes
	Zn-Al system	· Solidus line is high	· Brittle or low ductility · Susceptible to corrosion and early failure · Temperature required to solder is significantly higher than Pb-based solder and is too hot for some processes.
	Sn system + High melting temperature type metal	· It is still retentive even if it is remelted. The joint operating temperature is comparable with that of conventional high temperature type solder, depending on a combination of remelting. · Solidus line is high if all can be made inter-metal compounds.	· For a resin mold, there is fear that a molten part may exude to outside of a component. · Joint operating temperature is high, extending solder duration, which might lead to high intermetallic growth which is often brittle and leads to a reliability issue. · Fragile or low ductility because joint is mainly made by inter-metal compounds.
Electrically conductive adhesive system		· No concern of remelting due to thermal hardening.	· Poor heat conductivity · Poor electrical conductivity which can deteriorate with age · Susceptible to humidity · Difficult to repair

Source: Freescale et al.[860]

[860] Ibid.

As a synopsis of Table 21-3and Table 21-4, Freescale et al.[861] show the relationship of types and melting temperatures of lead-containing and lead-free solders in Figure 21-23.

Figure 21-23: Relationship diagram of solders and melting temperatures



Source: ACEA, referenced in Freescale et al.[862]

Freescale et al.[863] conclude that both lead-free solders with solidus line temperatures of 250 °C or higher as well as electrically conductive adhesives presented in Table 21-5 have important disadvantages which do not qualify them for substituting LHMPS. No lead-free materials currently on the market meet or exceed the required functionality and reliability of LHMPS. Yet the materials industry continues to develop potential future alternatives in conjunction with component manufacturers.

Freescale et al.[864] state that additionally the proceeding trend of miniaturization of components and structures increases the thermal and mechanical load on components. The unique properties of LHMPS described on page 373 et seqq. ensure less defects

[861] Ibid.
[862] Ibid.
[863] Ibid.
[864] Ibid.

during manufacturing and high reliability throughout the life of the component, thereby also resulting in longer life of components and reduced waste[865].

In addition, Freescale et al.[866] claim a very careful scrutiny to be required in the event that a substitute production technology becomes available, so as to maintain the required high quality of components in the process, to avoid failure in the field, so that such new technology can be adopted.

The justifications of Bourns[867] and IXYS[868] for their uses of LHMPS follow the same rationale like Freescale/NXP et al. and are therefore not specifically explained.

21.2.2 Elimination of LHMPS

Besides for die attach, Freescale et al.[869, 870] do not mention any efforts or possibilities to eliminate the use of LHMPS with bonding technologies others than soldering.

21.2.2.1 Alternative bonding technologies without LHMPS use

Compression-bonded contact systems

IXYS[871] mentions that for very high power semiconductor systems, compression bonded contact systems are in use. Packaging is mostly realized as voluminous ceramic cases as illustrated in Figure 21-24. Alternatively, the ceramic was tried to be replaced by plastic cases, but still with compression bond technology,[872] which was, however, not successful because it is not reliable due to humidity leakages of the plastic housing.

865 Freescale et al. 2015b reference the document by the UK's BERR (now UK's BIS) at http://www.berr.gov.uk/files/file40576.pdf on page 18
866 Ibid.
867 dddOp. cit. Bourns Inc. 2015a
868 Op. cit. IXYS Semiconductor GmbH 2015a
869 Op. cit. Freescale Semiconductors/NXP et al. 2015a
870 Freescale Semiconductors/NXP et al. 2015b "1st Questionnaire (Clarfication Questionnaire) Exemption 7a, document "Ex_7a_Freescale_Response_to_Clarification_questions_2015_0817_Final_to_Oko_Questions_of_2015_0716.pdf": Questionnaire 1 (clarification questionnaire)," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Freescale_Semiconductor/Ex_7a_Freescale_Response_to_Clarification_questions_2015_0817_Final_to_Oko_Questions_of_2015_0716.pdf
871 Op. cit. IXYS Semiconductor GmbH 2015a
872 For details see patent DE2825682C2; referenced by IXYS 2015b

Figure 21-24: Compression bonded contact systems for very high power semiconductor systems

Source: IXYS Semiconductor GmbH[873]

According to IXYS[874], this technology is an alternative to LHMPS-bonded die components in "hockey pucks", where steady state currents of more than 500 A, surge currents of at least 50 kA and silicon die diameters of more than 25 mm occur. IXYS[875] describes typical applications to be "hockey puck" stacks for high-voltage direct current (DC) transmission of electricity, which are used in the range between 200V/2,900A and 6,500V/3,000A.

Upon further request, IXYS[876] states that they are not aware of any other applications of such compression-bonded contact systems that are clearly within the scope of the RoHS Directive, and where these types of components can replace components that use LHMPS for die attach.

The compression bonding technology therefore will not be followed up further in the review.

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[873] Ibid.
[874] Op. cit. Freescale Semiconductors/NXP et al. 2015b
[875] IXYS Semiconductor GmbH 2016b "Answers to questionnaire 2, document "Exe-7a_Questionnaire-2_IXYS.docx", received via e-mail from Markus Bickel, IXYS, by Dr. Otmar Deubzer, Fraunhofer IZM, on 21 January 2016" unpublished manuscript,
[876] Ibid.

Direct Copper Bonding

IXYS[877] explains that the combination of larger power dies with copper plates is a root cause for the use of LHMPS. The more expensive electrically isolated package versions in DCB technology with metal bonded alumina or AlN ceramic isolator substrates have better CTE (coefficient of thermal expansion) matches, and more and more lead-free tin-silver-copper type solders are used. IXYS Germany[878] (formerly BBC, ABB) claims to be a pioneer to offer an alternative based on DCB technology, which has been under strong dispute among competitors in the past, but which now most competitors[879] have adopted. IXYS[880] already introduced such products in the 1980s, for example the wide range of lead-free standard power semiconductor modules with screw connectors.[881]

The DCB technology is more costly, however, it includes the electrical insulation.[882] IXYS[883]mentions in this context, however, that their ISOPLUS devices incorporating the DCB technology for applications in the SMT (**s**urface **m**ount **t**echnology) need LHMPS for internal connections while THT (through hole technology) components can be wire bonded. This is due to the fact that during SMT processing the devices have to survive temperatures exceeding the lead-free SAC (tin-silver-copper alloy) melting point[884]. Otherwise the internal lead-free solder connections in the plastic moulded devices would remelt and degrade their quality. THT uses LHMPS for internal die attach because subsequent wave soldering process is with lead-free SAC.

IXYS[885] [886] state that DCB with Au-Si eutectics are applicable for die edge sizes smaller than 3 mm, and presents an example of such a product. IXYS has such products in its portfolio. LHMPS is especially important when combining larger power dies with copper base plates (headers).

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[877] Op. cit. IXYS Semiconductor GmbH 2015a

[878] IXYS Semiconductor GmbH 2015b “1st Questionnaire (Clarification Questionnaire) Exemption 7a, document document "20150804_Ex_7a_Ixys_Questions_answered_amended.pdf": Questionnaire 1, clarification questionnaire,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/IXYS/20150804_Ex_7a_Ixys_Questions_answered_amended.pdf

[879] http://www.semikron.com/dl/service-support/downloads/download/semikron-flyer-semitop-2015-04-22 see under key features – “No baseplate design”; source as referenced by IXYS 2016b

[880] Op. cit. (IXYS Semiconductor GmbH 2016b)

[881] IXYS Semiconductor GmbH, http://ixapps.ixys.com/DataSheet/MCC95-08io1B.pdf; source as referenced by IXYS

[882] For more information see http://www.ixys.com/SearchResults.aspx?search=ISOPLUS&SearchSubmit=Go, and for fully isolated TO-220 special packages https://de.wikipedia.org/wiki/Liste_von_Halbleitergeh%C3%A4usen#Plastikgeh.C3.A4use_mit_und_ohne_K.C3.BChlfahne; source as referenced in Op. cit. IXYS Semiconductor GmbH 2015b

[883] Ibid.

[884] For details see IEC 60749-20, table 6 and Fig. B.9 as well as IEC61190-1-3, table B.2; source referenced by IXYS Semiconductor 2015b

[885] Op. cit. Freescale Semiconductors/NXP et al. 2015b

[886] Op. cit. IXYS Semiconductor GmbH 2015a

According to IXYS,[887] the DCB process includes an alumina carrier plus chemical and high temperature process and is therefore more costly compared to LHMPS use.

21.2.3 Substitution and Elimination of Lead in High Power Transducers (Bosch)

Bosch[888, 889] states that they need LHMPS because they can only solder the magnet wire close to the coil where it is exposed to high temperatures. Although Bosch started research two years prior to 2006, when the substance restrictions in the RoHS Directive started to apply, and they search for new solders at least 3 times per year, to date they have not found any new high melting point solders introduced into the market that do not contain lead.

In new designs for low frequency transducers, Bosch[890] will move the wire solder joints away from high temperature areas where lead-free solders can probably be used, but this approach has not been proven and is not applicable for high frequency transducers since high frequency designs have high temperatures at much lower power levels already. In previous attempts to move the solder joint further away from the heat source Bosch[891] have found that the fine gauge magnet wire can fatigue from the high vibrational energy and fracture. When the wire fractures it can cause enough heat, due to electrical arcing, to start neighbouring parts on fire. Further investigation of this has shown that aluminium and copper clad aluminium wires are more subject to this failure. In their newest designs, Bosch[892] use pure copper magnet wires and the joints can be moved far enough away to use a lead-free solder. Unfortunately this would not be possible for all designs.

In a recent low frequency transducer introduction, Bosch[893] attempted the new technique but in the length of magnet wire leading from the voice coil windings to the top of the voice coil bobbin the wire would stress fatigue and fracture. This was due to standing waves that formed in the wire at frequencies in the 800 to 900 Hz range. They tried many ways to reinforce the area but could not stop the fractures from occurring without making the acoustic performance unusable.

Bosch[894] claims that modifying most of their existing designs is not possible because they use aluminium-based wires. The mass and resistance differences make an acoustically/electrically backwards compatible redesign impossible. This is why Bosch's

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[887] Op. cit. (IXYS Semiconductor GmbH 2016b)
[888] Op. cit. Bosch Security Systems GmbH 2015
[889] Op. cit. (Bosch Security Systems GmbH 2016a)
[890] Op. cit. Bosch Security Systems GmbH 2015
[891] Op. cit. (Bosch Security Systems GmbH 2016a)
[892] Ibid.
[893] Bosch Security Systems GmbH 2016c "E-mail communication, document "Exe_7a_Questionnaire-2_Bosch_2016-03-24.docx", received via e-mail from Erich Pudelko, Bosch, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016" unpublished manuscript,
[894] Op. cit. (Bosch Security Systems GmbH 2016a)

newest designs use pure copper magnet wires and the joints can be moved far enough away to use a lead-free solder.

Bosch[895] cannot put the new design into high frequency compression drivers because of mechanical reasons. The magnet wire cannot withstand the millions of cycles of flexing that occur in the suspension of the driver. This forces the transition from magnet wire to something that can withstand the flexing. This transition must be made very close to the source of heat and so it requires LHMPS.

Bosch[896] continues exploring possible solutions to resolve the issues that keep them from initiating new designs in all new low frequency transducers. The new design is not only better for the environment but it is easier to produce and less costly. Bosch has a financial incentive, besides the environmental one. This is a very strong motivator to resolve these issues. Even with that incentive Bosch has not been able to resolve all the issues. They will continue to use the new design in every application possible while they continue their investigations. Bosch expect to find techniques and materials that ultimately allow to no longer use the exemption in low frequency transducers, but they do not know when that solution will come. They also have strong doubts that they will find a solution that works in compression drivers in the near future as this would require an inventive step that cannot be predicted.

21.2.4 Other Stakeholder Contributions

21.2.4.1 TT Microelectronics/AB Mikroelektronik GmbH (AB)

AB[897] submitted information after the public stakeholder consultation on thick film copper bonding (TFCB) in the context of die attach where it could partially replace LHMPS and thus eliminate the use of lead. According to AB[898], thick film substrates are sintered structures so there is more flexibility in comparison to the laminated DCB substrates. This flexibility reduces stresses in the die attach materials as well as the large area soldering joint needed to contact to the heatsink or baseplates. In general, the thick film substrates can be directly substituted for a DCB for instance, when higher current applications demand thicker copper conductors electrically and thermally.

AB[899] has successfully tested TFCB on AlN (aluminium nitride ceramic) and Al_2O_3 (aluminium oxide ceramic) substrates. Organic substrates such as FR4 have not been tested as of yet, but the processing requires high temperatures of more than 800 °C.

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[895] Op. cit. (Bosch Security Systems GmbH 2016c)
[896] Ibid.
[897] TT Electronics/AB Mikroelektronik GmbH 2015a "Information on TFC, document "AB-Mikro_TFC.pdf", received via e-mail from Chris Burns, AB Mikroelektronik, by Dr. Otmar Deubzer, Fraunhofer IZM, on 8 January 2016" unpublished manuscript,
[898] TT Electronics/AB Mikroelektronik GmbH 2015b "E-mail communication, document "E-Mail-Communication_AB-Mikro.pdf", received via e-mail from Chris Burns, AB Mikroelektronik, by Dr. Otmar Deubzer, Fraunhofer IZM, on 14 March 2016" unpublished manuscript,
[899] Ibid.

AB[900] are a supplier to the automotive industry, and they have a sister company working in the aerospace industry, where TFCB has proven to be more effective concerning lifetime between zero and 350 °C.

The company's TFCB technology would require an in-depth review including a consultation with other stakeholders to evaluate whether and how far TFCB can eliminate the use of lead in applications under exemption 7(a) for EEE in the scope of the RoHS Directive. Given the considerable efforts undertaken already for the review of exemption 7(a) and the limited time and resources available, this in-depth review could not be performed in the course of this review process.

The stakeholder was, however, recommended to submit a separate exemption request applying for the partial revoke of exemption 7(a), where the company should explain where and how TFCB can be used in EEE in the scope of the RoHS Directive to eliminate the use of lead. This request can then be subjected to a public online stakeholder consultation and a subsequent review taking into account the applicant's and other information collected during the consultation. As the use of lead is also restricted in Directive 2000/53/EC (ELV Directive), AB Mikroelektronik can also apply the revoke of exemption 8(e) in Annex II of the ELV Directive, which is analogous to RoHS exemption 7(a).

21.2.4.2 Ministry of Environment, Finland

The Ministry of Environment in Finland and Finnish Safety and Chemicals Agency (Tukes)[901] contributed to the stakeholder consultation expressing concerns about purely material specific character of the exemption. They believe that the wording of exemption 7(a) is too wide and can be interpreted to cover all product categories. This may create problems for the enforcement of the RoHS Directive in Member States. In some applications there are already lead-free alternatives available so the wide use of exemption 7(a) is not consistent with aims of the RoHS Directive. From their point of view the exemption should be granted only for those applications and technologies where it is deemed necessary and where no lead-free alternatives are available.

The Finnish Ministry[902] demands that, if the exemption is needed in some applications or technologies and a more precise wording is not feasible at this stage, an end (i.e. an expiration date – consultants comment) should be set for the exemption as required in Article 5 (2) of the RoHS Directive.

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[900] Ibid.

[901] Ministry of the Environment, Finland 2015 "Document "Ex_7a_Finnish_Safety_and_Chemicals_Agency-comment_161015.pdf" submitted during the online stakeholder consultation," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Ex_7a_Finnish_Safety_and_Chemicals_Agency-comment_161015.pdf

[902] Ibid.

21.2.5 Environmental Impacts

Freescale et al.[903] estimate the amount of Pb in HMPS for EEE to be less than 0.2 % of the total Pb placed on the market per year. A research paper from AIST concludes that substitution of Pb in solders has a very small impact concerning risk to ecosystems.[904] Freescale et al.[905] consider the paper to be a useful reference, notwithstanding the fact that research is limited to the recycling of four types of consumer electronics (household air conditioning, TV, electric refrigerators / electric freezer, electric washing machines / clothes dryers) in Japan.

21.3 Roadmap for Substitution or Elimination of Lead

Freescale et al.[906] report that the "Die Attach 5" (DA5 – a partnership between Bosch, Infineon, Freescale, STM and NXP) have been working with suppliers for several years to identify and evaluate alternatives to LHMPS. They have evaluated a variety of new materials from leading global suppliers of solders, adhesives, silver sintering and transient liquid phase sintering (TLPS) materials. The DA5 evaluations recognize continuous improvement in the evaluated materials over the past five years, but even the best of these materials do not meet the DA5 requirements for quality, reliability and manufacturability. They are not at least as good as the traditional LHMPS. Many solutions are still under development, constantly being revised and strictly guarded by suppliers under non-disclosure agreements. They are not available for mass production. Details on the assessed materials and test results are provided in Appendix A.5.1.

Freescale et al.[907] offer International Rectifiers' information for its evaluation of promising Ag epoxy materials from four different suppliers and five different partial melt solders (SnCu, SnAgSb, SAC, SnCuSbCo and SnAgCuSb). The Ag epoxy materials each suffered unacceptable reliability failures due to package delamination causing shifts in Rds(on) (MOSFET "On-state" Drain Source Resistance). The partial melt solders failed industry criteria for MSL (Moisture Sensitivity Level) preconditioning prior to reliability testing; those solders partially melted during 260 °C reflow and caused massive package delamination and solder squirt. Details are available in Appendix A.5.2.

Concerning whether, once the DA5 or International Rectifiers have identified one or more practicable solutions for lead-free die attach, such solutions would be applicable to all the other LHMPS applications as well, Freescale/NXP et al.[908] state that industry

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[903] Op. cit. Freescale Semiconductors/NXP et al. 2015a

[904] National Institute of Advanced Industrial Science and Technology (AIST): http://www.aist-riss.jp/main/modules/product/RTA_cleaners_J_downloadform.html?ml_lang=en; referenced in Freescale et al 2015a

[905] Ibid.
[906] Ibid.
[907] Ibid.
[908] Op. cit. (Freescale Semiconductors/NXP et al. 2016a:)

cannot test solutions that are not available on the market. Market availability for alternatives to LHMPS requires extensive research, development of manufacturing processes and equipment, and verification of functionality and reliability. These steps must occur sequentially for the raw material supplier, for the component manufacturers, and for EEE manufacturers. Freescale/NXP et al. hope to find a single solution that might be applicable to all LHMPS uses, but years of research have found no such perfect solution.

According to Freescale/NXP et al.[909], LHMPS manufacturers have invested significant resources into developing potential alternative solutions. The DA5 continues to work with these suppliers to modify the formulations to develop or improve the manufacturability and reliability. Some solutions look promising for die attach, especially for very small die sizes. The example applications of LHMPS identified by Oeko have unique thermal, mechanical and reliability requirements. Every Pb-free solutions eventually found for DA5 die-attach will subsequently require qualification for other LHMPS applications based upon their unique specifications. While 1:1 usability for a DA5 die-attach solution within other LHMPS applications cannot be guaranteed and is not likely, the anticipated future DA5 solutions will require further investigation into the feasibility of adoption for other applications.

Freescale/NXP et al.[910] report further on that the DA5 has concentrated on finding a proof of concept for high reliability Pb-free replacements to LHMPS die attach materials. Once available, the resulting materials *could* be useful for many applications. The initial research will not qualify material for other applications, but will help to develop materials that *might* work in different applications. The alternatives will require testing and verification for each industry application. In this sense, Freescale/NXP et al.[911] agree that different alternatives may be necessary for different LHMPS applications. Freescale/NXP et al.[912] claim the electronics industry will continuously research for alternatives, however, currently no lead-free alternative technology can be predicted for the future. If a possible substitute is identified for evaluation, widespread conversion from use of high temperature type lead-containing solders in related applications will require time for the appropriate EEE qualifications based on the long term reliability requirements. Conversions cannot begin until lead-free alternatives are developed and perfected by solder manufacturers; processes and equipment are installed and implemented within component manufacturing lines; components are qualified, and those components are made available to EEE manufacturers for:

- development,
- assessment, and
- replacement with alternative products.

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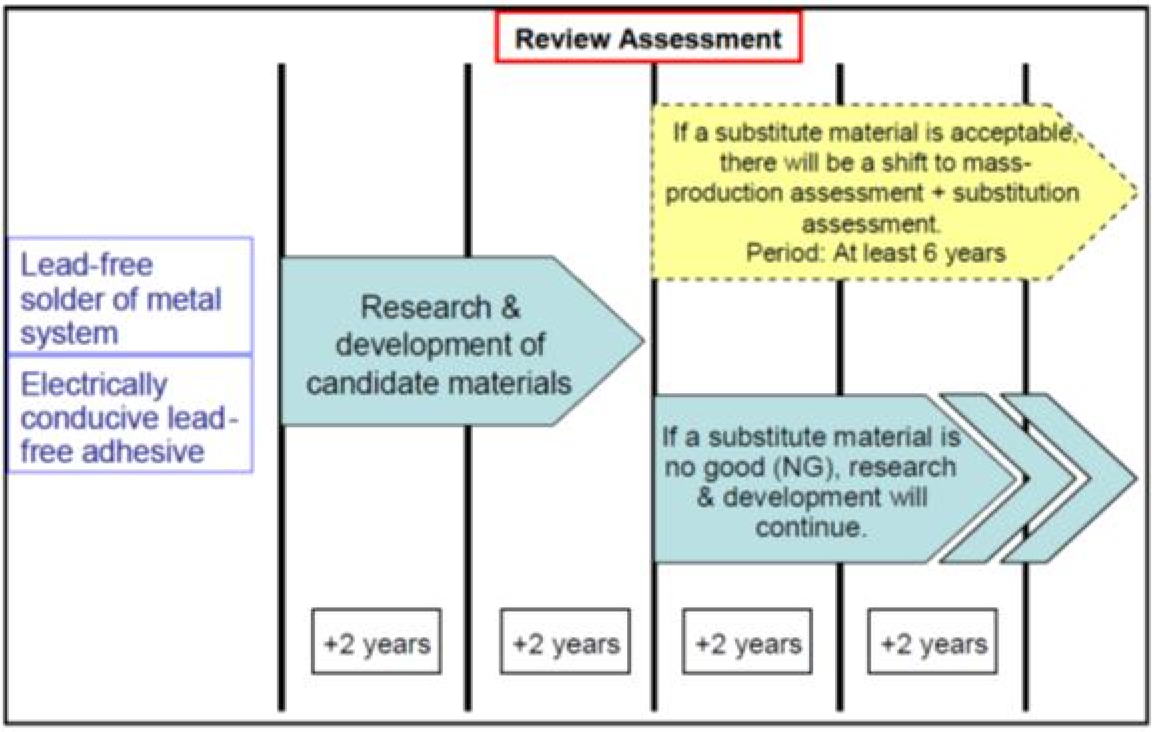
[909] Ibid.
[910] Ibid.
[911] Ibid.
[912] Ibid.

Figure 21-25: Material transition process

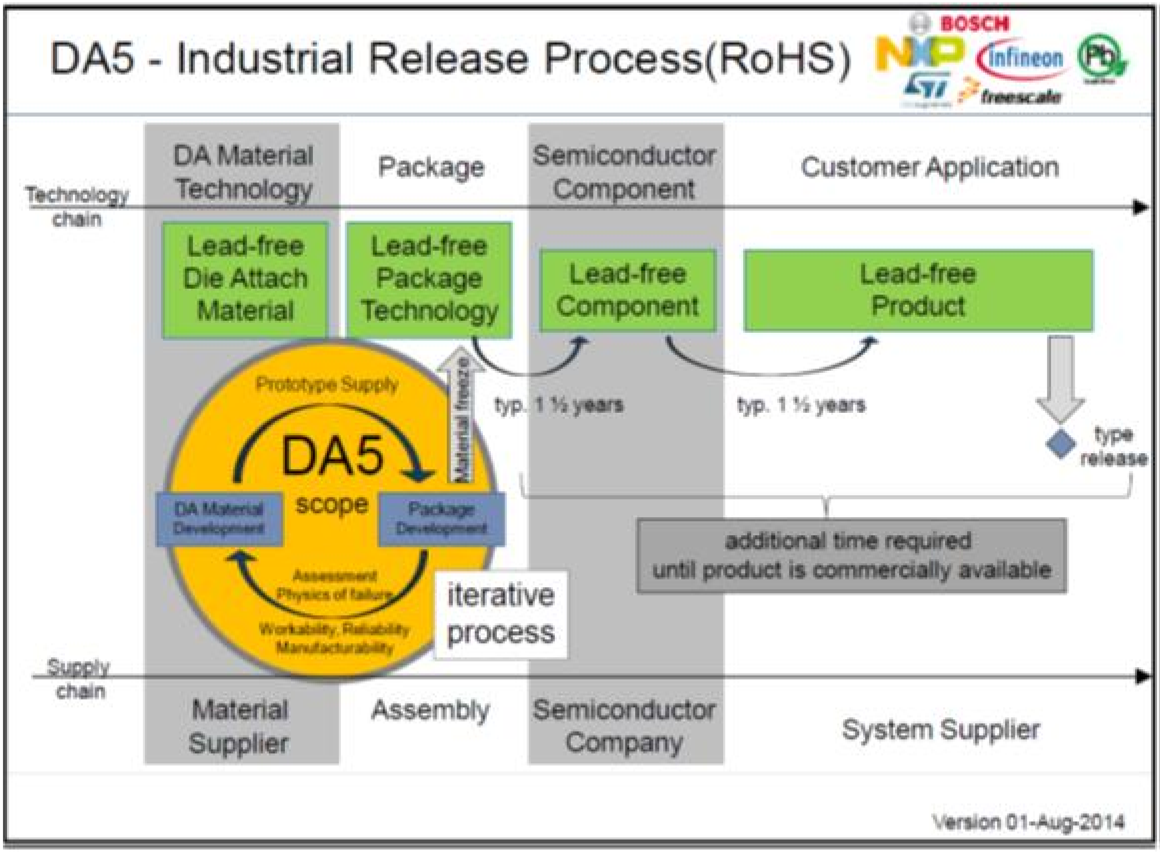


Source: Freescale/NXP et al.[913]

Looking at high-lead solder for attaching die to semiconductor packages, the DA5 consortium is working with selected material suppliers on the development of an appropriate replacement for lead solder (DA5 scope). The properties of the needed die-attach material is specified by the DA5 (material requirement specification) and provided to the material suppliers. Selected material suppliers offer their materials, which are evaluated by one of the DA5 companies together with the supplier. The detailed results are discussed with the material suppliers and all DA5 companies on a regular basis in face-to-face meetings. The results lead to further optimizations of the materials (development loop). The combined results are published by DA5 (c.f. Appendix A.5.1)[914]

[913] Ibid.
[914] Ibid.

Figure 21-26: Cycle time to conversion



Source: Freescale/NXP et al.[915]

After a material is chosen and material development is frozen, another 3 to 5 years will be required to qualify the new material through the whole supply chain. Based on current status, DA5 cannot predict a date for customer sampling as no suitable materials have yet been identified.[916]

Concerning further plans and steps in the next five years to substitute or eliminate lead in the various other types of LHMPS applications mentioned in their exemption request, Freescale/NXP et al.[917] want to support the overall RoHS objective of contributing to the protection of human health and the environment, including the environmentally sound recovery and disposal of waste electrical and electronic equipment. They remain committed to supporting the procedure for the adaptation to scientific and technical progress, and will continue developing, requesting the development and/or applying

[915] Ibid.
[916] Ibid.
[917] Freescale Semiconductors/NXP et al. 2016d "Answers to questionnaire 3a, document "Exe_7a_Questionnaire-3a_Freescale_2016-03-28.pdf", received via e-mail from Griffin Teggeman, NXP, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016" unpublished manuscript,

possible alternatives taking into account the practicability, reliability or environmental, health and consumer safety impacts of substitution.

21.4 Critical Review

21.4.1 REACH Compliance - Relation to the REACH Regulation

The exemption allows the use of lead. Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as directly added substance nor as substance that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists entry 28 and entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under entry 28 and entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds…

- *"shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight."*
  This restriction does, however, not apply to crystal glass as defined in Annex I (categories 1, 2, 3 and 4) to Council Directive 69/493/EEC (*), and to internal components of watch timepieces inaccessible to consumers
- *"shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and*

those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children."

This restriction does, however, not apply to articles within the scope of Directive 2011/65/EU (RoHS 2)

The restrictions of lead and its compounds listed under entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

21.4.2 Substitution and Elimination of Lead in High Power Transducers (Bosch)

Bosch contributed to the public stakeholder consultation stating that exemption 7(a) should stay unchanged or alternatively this specification should be added:

"Lead in high melting temperature type solders used in high-power transducers (loudspeakers)"

As the RoHS Directive requires exemptions to be as specific as possible, the consultants reviewed the proposed specific wording in light of the requirements of Art. 5(1)(a). Bosch states that they have to use LHMPS because they can only solder the fine magnet wire close to the coil where high temperatures occur, which would melt lead-free solders. While this basic fact is plausible and clear, several questions remained open in the further discussions with the stakeholder.[918, 919, 920]

Moving away the solder joint from the coil reduces the temperature the solder joint is exposed to and may facilitate the use of lead-free solders instead of LHMPS. It is understood that Bosch has verified this approach at least in some newer low frequency high power transducer designs. This approach seems to be viable in low and possibly in mid frequency, but not in high frequency transducers, whereas it is not clear whether it would make the substitution of lead practicable in all low and mid frequency power transducers.

Bosch states that they cannot modify their old designs so that lead-free solders could be used. A complete redesign is required, which raises the question whether this redesign would in all cases allow the substitution of lead, and why this redesign has not been performed already. Bosch also mentions that other manufacturers of high power

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[918] Op. cit. (Bosch Security Systems GmbH 2016a)

[919] Bosch Security Systems GmbH 2016b "Answers to second questionnaire, document "Exe_7a_Questionnaire-2_Bosch_2016-03-24.docx", received via e-mail from Erich Pudelko, Bosch, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016" unpublished manuscript,

[920] Op. cit. (Bosch Security Systems GmbH 2016c)

loudspeakers have new designs on the market, but it is unclear whether these new designs are actually produced without lead.

It was attempted[921, 922, 923] to narrow the scope of the exemption by demarcating "power" transducer from other transducers, which then would not require the use of LHMPS. The consultants and Bosch agreed on the below wording of the exemption to better describe the actual use of LHMPS in high power transducers:

Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) for electrical connections on or near the voice coil in power transducers.

Bosch's information suggests that LHMPS is actually required where solder joints in high power transducers have to be exposed to high temperatures that exclude the use of lead-free solders. It remains unclear how far a redesign can help to avoid the higher temperatures enabling the use of lead-free solders, but the information submitted plausibly explains that this is currently not yet possible in all power transducers.

Taking into account the available information and in the absence of contrary information, the consultants recommend granting this exemption appraising the situation that LHMPS is required in high power transducers, justifying an exemption according to Art. 5(1)(a). However, it is recommended to grant the exemption for three years only as to further specify the scope of the exemption. This would still leave sufficient time for stakeholders to apply for the renewal should the exemption still be required in three years.

Granting the exemption would also allow splitting this use of LHMPS from the presently material specific exemption 7(a). Vice versa, the use of LHMPS in the high power transducers could still be permitted under exemption 7(a) even though there are prospects of eliminating or substituting lead.

21.4.3 Substitution and Elimination of Lead Die Attach

The information submitted by Bourns, Freescale/NXP et al. and IXYS suggests that generally, the substitution or elimination of lead is scientifically and technically still impracticable. IXYS provided, however, examples of components where alternative technologies such as direct copper bonding (DCP) eliminate the use of lead.

Freescale/NXP et al.[924] comment on IXYS' statements and achievements:

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921 Op. cit. (Bosch Security Systems GmbH 2016a)
922 Op. cit. (Bosch Security Systems GmbH 2016b)
923 Op. cit. (Bosch Security Systems GmbH 2016c)
924 Freescale Semiconductors/NXP et al. 2015c "Document "7aEx__RoHS_Freescale_Consultation_Response_2015_1015_Final_to_Oeko.pdf", submitted during the stakeholder consultation: Consultation questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/7aEx__RoHS_Freescale_Consultation_Response_2015_1015_Final_to_Oeko.pdf

- DBC solution with AuSi die attach material does not address any LHMPS applications besides die attach. AuSi eutectic die attach on a bare copper leadframe may become brittle and unreliable.
- The IXYS solution addresses only THT (through hole technology), but not SMT (surface mount technology) packages.
- Operating power: IXYS only suggests converting LHMPS customers to their DBC alternative in low and medium power ranges, but Freescale/NXP et al. are not aware of a standard industry definition for low, medium and high power products. The IXYS power definition may be specific to their technologies.
- Freescale/NXP et al. agree that the IXYS solution may be reliable for certain applications with very small die size. The 3 x 3 mm die size lacks industry consensus. Vishay tested a gold-silicon solder process and determined the maximum reliable die size to be 0.5 x 0.5 mm rather than 3 x 3mm as indicated by IXYS. Reliable die size for DCB may vary by manufacturing process, equipment, materials and/or power range. Failure points for power and die size are not known.

Freescale/NXP et al.[925] conclude that exemption 7(a) has broad usage for critical applications, but the DCB bonding method can only be adapted to limited applications. It is not obvious that these applications are easily categorized or that they represent a substantial volume of LHMPS reduction. More important, it is very difficult to determine whether a narrowed exemption scope would affect the applications, which really require LHMPS. Freescale/NXP et al. thus contend that the exemption wording should be kept in its present form.

IXYS was asked to comment the above statements. IXYS[926] agrees that gold-silicon DCB is useful for die attach only. There is also risk of brittleness. Concerning the die sizes that can accommodate DCB die attach, IXYS specifies that they spoke of die sizes less than 3 mm, and not sizes equal to 3 mm, which includes the 0.5 mm x 0.5 mm size which Freescale/NXP et al.[927] mention as a reliability limit for DCB.

IXYS' information and product examples show that at least in specific cases, DCB can eliminate the use of lead in LHMPS, but these are restricted to ceramic substrates, and SMT components require LHMPS in the internal interconnects. The discussion between Freescale/NXP et al. and IXYS remains inconclusive with respect to a clear definition of criteria for die attach where DCB can eliminate the use of lead from other die attach cases, where the use of LHMPS is still scientifically and technically impracticable.

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[925] Ibid.
[926] Op. cit. (IXYS Semiconductor GmbH 2016b)
[927] Op. cit. Freescale Semiconductors/NXP et al. 2015b

Nevertheless, the consultants proposed a wording for a more specific scope for die attach with LHMPS in the context of a further specification of exemption 7(a) in order to start an in-depth discussion. Since Freescale et al. as well as IXYS speak of power semiconductors in the context of LHMPS required for die attach, an attempt was made to specify the scope of LHMPS in die attach to power semiconductors. IXYS[928] state that power devices should be capable to sustain steady state currents of more than 1 A and/or blocking voltages beyond 200 V with no upper limit. Additionally, Freescale et al.[929] mention Vishay's test results that the maximum reliable die size for DCB is 0.5 mm x 0.5 mm. These criteria were integrated into a wording proposal for die attach for a future exemption 7(a):

> *Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) used for die attach in power semiconductors with steady state currents of more than 1 A and/or blocking voltages beyond 200 V and die edge sizes larger than 0.5 mm.*

Freescale/NXP[930] et al. expressed their principal disagreement with splitting exemption 7(a), but did not comment directly on the wording proposal related to die attach. IXYS[931] agreed to the proposed wording, but Bourns[932] commented that the above wording would exclude several components that require LHMPS for die attach. Bourns was therefore asked to propose a wording that would include all their components where the use of LHMPS is still technically indispensable and came back with a modified proposal[933], which was sent out to all applicants for commenting:

> *Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) used for die attach in power semiconductors with steady state or transient/impulse currents of 1 A or greater and/or blocking voltages beyond 200 V, or die edge sizes larger than 0.5 mm*

Only Freescale/NXP et al.[934] reacted, this time including technical comments directly related to die attach. The core arguments were that the wording mentions

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928 Op. cit. IXYS Semiconductor GmbH 2015b

929 Op. cit. Freescale Semiconductors/NXP et al. 2015c

930 Freescale Semiconductors/NXP et al. 2016b "Answers to first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1_All-Applicants_2016-02-16_NXP-et-al.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, NXP, on 25 February 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders

931 IXYS Semiconductor GmbH 2016a "Answers to the first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1-All-Stakeholders_Reply-Ixys_2016-02-26.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Markus Bickl, Ixys Semiconductor GmbH, on 26 February 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders

932 Bourns Inc. 2016a "Answers to first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1_All-Applicants_Bourns_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Cathy Godfrey, Bourns Inc., on 7 March 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders

933 Ibid.

934 Freescale Semiconductors/NXP et al. 2016c "Answers to second questionnaire to all stakeholders,

transient/impulse currents. The inclusion of IMPULSE improves the wording compared to the previous one, but still does not capture all the key criteria driving the LHMPS. Other criteria would include peak transient currents, resistance and the size of the power region within the die. The wording still appears to exclude some products that require LHMPS. The immediately identified indicative examples include Zener diodes with die sizes less than 0.5mm; clip bonded diodes and other products with currents less than 1 A and 200 V and more; SMD diodes or axial diodes with less than 1 A and more than 200 V; SMD or axial diodes with less than 0.5 mm; some triodes for alternating currents or silicon controlled rectifiers with 1 A; and transient suppressors.

Freescale/NXP et al. [935] did not explain why LHMPS would be required in components with die sizes less than 0.5 mm x 0.5 mm despite Vishay's findings, and they did not provide any alternative formulation that would include those components claimed to be excluded in the current wording, nor did they provide information to show that the use of LHMPS in such components could not be avoided.

Based on the above feedback to the wording proposals and the other available information, the consultants conclude that it is currently possible to define criteria for a few individual companies, where the substitution and elimination of lead in LHMPS for die attach is scientifically and technically practicable depending on their product portfolio. It was however not possible to perform this exercise within the available time and resources of the current evaluation due to the multitude and high variety of components and criteria.

For LHMPS used in die attach, Freescale/NXP et al. present past research (DA5, International Rectifier) to substitute or eliminate lead and ongoing efforts planned for the next years. So far, even though progress has been made, no possibilities for elimination or substitution of lead have been reported, so that granting an exemption would be in line with Art. 5(1)(a). This was also the result when these efforts were evaluated in 2015 in the course of the review of exemption 8(e)[936] (the equivalent of RoHS exemption 7(a)) in the Annex of Directive 2000/53/EC (ELV Directive).[937]

The information provided suggests that all research efforts are focused on finding a drop-in solution for LHMPS in die attach, i.e. a lead-free material that can replace LHMPS 1:1. Besides searching for one single solution to accommodate all needs of die attach, research for replacements of LHMPS avoiding the use of lead in specific die attach

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document "Exe_7a Questionnaire-2-All-Applicants_2016-02-16_NXP.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, NXP, on 22 March 2016: NXP answers to questionnaire to all stakeholders" unpublished manuscript,

[935] Ibid.

[936] Gensch et al. 2015 "7th Adaptation to Scientific and Technical Progress of Exemptions 8(e), 8(f), 8(g), 8(h), 8(j) and 10(d) of Annex II to Directive 2000/53/EC (ELV): Report for the European Commission DG Environment under Framework Contract No ENV.C.2/FRA/2011/0020"

[937] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles, ELV Directive, European Union (21 October 2000)

applications could be a further option for progress. The at least partial viability of lead-free solutions like the IXYS DCB-based products show that specific solutions should be taken into account as well, including integrated approaches aligning die attach materials and the overall component design. Further research and new approaches may open possibilities for elimination or substitution of lead, possibly, if applicable also taking into account technologies like TFCB presented by AB Mikroelektronik.[938]

The accessible information suggests that the substitution or elimination of lead is still scientifically and technically impracticable so that granting an exemption would be in line with the requirements of Art. 5(1)(a). The applicants did not provide substantiated information that would have allowed clarifying where and under which conditions DCB is scientifically and technically practicable to replace lead, or why this should not be possible. It can thus not be excluded that the substitution of lead generally is scientifically and technicaly practicable within less than five years. The consultants therefore recommend granting the exemption for three years only, which on the one hand would allow to narrow the scope in order to gradually phase out the use of lead or otherwise clarify why this is scientifically and technically impracticable, and on the other hand still leave sufficient time for industry to apply for the continuation of the exemption should it still be required.

21.4.4 Substitution and Elimination of Lead in Other Applications of LHMPS

The applicants claim that the applications of LHMPS are numerous, and they explain this for various examples in their exemption request. They claim that once the DA5 have identified a solution, which should be a drop-in solution, they will transfer and adapt this solution into other applications using LHMPS (see Section 21.3 – Roadmap for Substitution or Elimination of Lead from page 401).

LHMPS offers the advantage to accommodate all needs of various applications by adapting the lead content of the LHMPS solder. In the consultants' understanding, however, it cannot be concluded that all applications of LHMPS will have a lead-free solution based on the same basic material and technology. The requirements in the various LHMPS applications are different, even though they all use LHMPS at present. For the various applications, different individual or combined properties of LHMPS are relevant to a different degree, and it is reasonable to assume that this requires different alternative solutions and thus also application-specific research to substitute or eliminate lead.

The applicants do not present specific future efforts towards the replacement of LHMPS in the provided example applications of LHMPS besides die attach. They state that they cannot test materials that are not available. In the consultants' opinion, however, this

[938] Op. cit. (TT Electronics/AB Mikroelektronik GmbH 2015a)

situation will continue if no research is started to find materials that can specifically accommodate the needs of particular LHMPS applications.

Based on the information made accessible, elimination or substitution of lead are still scientifically and technically impracticable for LHMPS applications as well as possibly for die attach. As there are no prospects that this situation will change within the next five years, it is recommended to continue the exemption for five years. The applicants will then, however, have to present clear and dedicated research efforts to find specific lead-free solutions for the various applications of LHMPS.

21.4.5 Specification of Exemption 7(a)

According to the RoHS Directive[939] "Exemptions from the restriction for certain specific materials or components should be limited in their scope and duration, in order to achieve a gradual phase-out of hazardous substances in EEE, given that the use of those substances in such applications should become avoidable."

Exemption 7(a) in its current wording has a purely material-specific scope. It allows the use of lead in high melting point solders regardless of where and how these lead-containing high melting point solders (LHMPS) are used. It is thus a priority within RoHS that the scope of both exemptions should be reduced now, where possible, and further in future exemption review rounds through the promotion of research and development of lead-free solutions, as well as through improvements in exemption wording specifications.

21.4.5.1 Consultant's Proposed Rewording of Exemption 7(a)

Based on information provided by the applicants in this review and in previous exemption reviews, the consultants formulated a wording, targeting a scope, which is as narrow as possible to exclude the abuse of the exemption and promote specific research into lead-free solutions. In parallel, the same proposed wording is as wide as necessary to ensure all applications are covered where substitution and elimination of lead is still impracticable. Following two rounds of discussions with the stakeholders[940, 941, 942, 943], the consultants modified their original proposal to the below wording.

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[939] Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast), RoHS 2, European Union (1 July 2011), recital clause (19)

[940] Freescale Semiconductors/NXP et al. 2016b "Answers to first questionnaire to all stakeholders, document "Exe_7(a)_Questionnaire-1_All-Applicants_2016-02-16_NXP-et-al.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, NXP, on 25 February 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders

[941] Knowles et al. 2016a "Answers to first questionnaire to all stakeholders, document "Exe_7(a)_Questionnaire-1_All-Applicants_Knowles-et-al_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Hopwood, Knowles Capacitors, on 25 February 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders

[942] IXYS Semiconductor GmbH 2016b "Answers to questionnaire 2, document "Exe-7(a)_Questionnaire-

Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) used

a) for internal interconnections in electrical and electronic components, i.e.

i) for die attach in power semiconductors with steady state or transient/impulse currents of 1 A or greater and/or blocking voltages beyond 200 V, or die edge sizes larger than 0.5 mm

ii) in components with steady state currents of more than 1 A and/or blocking voltages beyond 200 V other than die attach

iii) for other internal interconnections in electrical and electronic components excluding those in the scope of exemption 24

iv) in HID lamps and oven lamps

b) in solder balls for the attachment of ceramic BGA to the printed circuit board (second level interconnect)

c) for the attachment of components to printed circuit boards (second level interconnect) in high temperature plastic overmouldings (> 220 °C)

d) for mounting electronic components onto subassemblies (first level interconnect), i.e. modules or sub-circuit boards

e) as a hermetic sealing material between a ceramic package or plug and a metal case

f) other applications; expires on 1 January 2021 for EEE in cat. 1-7 and 10

In a final round, this proposal was discussed with the stakeholders[944, 945, 946, 947] again. The following summarizes the applicants' comments.

2_IXYS.docx", received via e-mail from Markus Bickel, IXYS, by Dr. Otmar Deubzer, Fraunhofer IZM, on 21 January 2016" unpublished manuscript,

[943] IXYS Semiconductor GmbH 2016a "Answers to the first questionnaire to all stakeholders, document "Exe_7(a)_Questionnaire-1-All-Stakeholders_Reply-Ixys_2016-02-26.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Markus Bickl, Ixys Semiconductor GmbH, on 26 February 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders

[944] Freescale Semiconductors/NXP et al. 2016c "Answers to second questionnaire to all stakeholders, document "Exe_7(a) Questionnaire-2-All-Applicants_2016-02-16_NXP.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, NXP, on 22 March 2016: NXP answers to questionnaire to all stakeholders" unpublished manuscript,

[945] Knowles et al. 2016b "Answers to second questionnaire to all stakeholders, document "Exe_7(a)_Questionnaire-1_All-Applicants_Knowles-et-al_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Steve Hopwood, Knowles Capacitors, on 21 March 2016" unpublished manuscript,

[946] Knowles et al. 2016c "Answers to third questionnaire, document "Exe_7(a)_Questionnaire-2_Knowles_2016-03-29.pdf", received via e-mail from Steve Hopwood, Knowles, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016" unpublished manuscript,

[947] Bourns Inc. 2016a "Answers to first questionnaire to all stakeholders, document

The applicants[948] disagree with the proposed rewording of RoHS Exemption 7(a). Further, they disagree with the need to reword the existing RoHS-2 exemption 7(a) and they voiced concerns with splitting the exemption into multiple sub-sections. In order to maintain a simple exemption renewal process, they also object to the proposed inclusion of an expiry date for any application that is less than the 5 years allowed under RoHS 2. They further urge Oeko-Institut and Fraunhofer IZM to recommend to maintain consistent wording for RoHS exemption 7(a) and ELV exemption 8(e) based upon the wording included in the related European Commission's draft legislative proposal to amend ELV's Annex II currently under scrutiny by the European Parliament and the Council of the EU.[949]

Freescale/NXP et al. [950] are concerned about the technical complexity to determine, which sub-exemption applies to each homogeneous material, and the lack of incremental environmental, health and consumer benefits resulting from this delineation since alternative Pb-free solutions are not available on the market. Furthermore, they do not believe that any one company or group of companies can currently adequately define the revised wording for a more detailed application and ensure that the new wording accounts for all required uses for LHMPS.

21.4.5.2 Applicants' Alternative Wording Proposals

Below, the applicants[951] attempt to enumerate the primary arguments related to the infeasibility of interpreting and applying the proposed exemption wording as given above:

- The 7(A)a)i structure is STATEMENT1 or STATEMENT2 and/or STATEMENT3 or STATEMENT4. The AND creates logic problems. [952]
- 7(A)a)i mentions "*transient/impulse currents*". The inclusion of "*impulse*" improves the wording in comparison to the prior questionnaire, but still does not capture all the key criteria driving the LHMPS. Other criteria would include *'peak transient currents'*, *'resistance'* and the *'size'* of the power region within the die.[953]
- 7(A)a)i and 7(A)a)ii appear to exclude some products that required LHMPS. The immediately identified indicative examples include Zener diodes with die sizes < 0.5mm; clip bonded diodes and other products with currents ≤ 1 A &

"Exe_7(a)_Questionnaire-1_All-Applicants_Bourns_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Cathy Godfrey, Bourns Inc., on 7 March 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders

[948] Op. cit. (Freescale Semiconductors/NXP et al. 2016c)

[949] Ibid.

[950] Ibid.

[951] Ibid.

[952] Ibid.

[953] Ibid.

≤ 200 V; SMD diodes or Axial diodes < 1 A and < 200 V; SMD or Axial diodes < 0.5 mm; some triacs or SCRs < 1 A; and transient suppressors.[954]

- 7(A)a)iii must cover LHMPS for all connections within a component, whether they are electrical or nonelectrical. The definition of internal connection does not provide this certainty. Some connections require LHMPS for electrical and / or electronic functions, others for thermal functions, and others for reliability under harsh conditions. As one example, it is not clear that this definition includes a heat shield that is attached to a component with LHMPS to allow subsequent Pb-free step soldering for mounting the component. This heat shield is part of the component when sold.[955]

  Knowles et al.[956] add that from some points of view, an 'interconnect' is only an electrical connection so that the consultants' rewording proposal does not cover a non-electrical connection such as heat sink attachment. They would suggest that 'interconnect' is replaced with 'connection' or simply 'joint'. Knowles et al. ask, whether with regards to the definition of 'internal' – it is meant to include all connections within the space envelope of a single component, or if it only means connections that are hidden internally in the design. They also stress the example of the shielding cover and heatsink assembled onto the top of a ceramic substrate as part of an electronic filter. As the finished component will be surface mounted to a circuit board using Pb free alloys, the cover is soldered in place using LHMP solder alloy with the resulting joint being visible on the outside of the component. The connection to shield the device is made as part of the component manufacture and as such is part of the component and internal to its design, but as the joint is on the outside of the component the term 'internal' for a connection like this could be disputed. Knowles et al. in this case suggest that the reference to 'internal' could possibly be removed or changed to 'integral', covering all joints made as part of the component manufacture.

- 7(A)c) appears to exclude second level interconnections for lead frame products where molding occurs at temperatures ≥ 180°C but ≤ 220°C. [957]

Freescale et al. [958] state that also at the consultants' urging, they reluctantly considered and shared the below preliminary suggestions for a more detailed and functional wording. *None* of the proposals is acceptable to all members of the Freescale/NXP et al. working group. The differences between these proposals indicate a variety of subtle issues that arise when changing the exemption wording.

[954] Ibid.
[955] Ibid.
[956] Op. cit. (Knowles et al. 2016b)
[957] Op. cit. (Freescale Semiconductors/NXP et al. 2016c)
[958] Ibid.

- 7(a) LHMPS used for internal or external interconnections in or to electrical and electronic components, HID lamps, oven lamps, hermetic sealing materials between a ceramic package or plug and a metal case, or other applications.
- 7(a) Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) used:
  - for combining elements integral to an electrical and electronic component, including a functional element with a functional element; or, a functional element with wire/terminal/heat sink/substrate, etc.;
  - for mounting electronic components onto sub-assembled modules or sub-circuit boards;
  - as a sealing material between a ceramic package or plug and a metal case;
  - other applications.
- 7(a) Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) used for:
  - internal interconnections within electrical and electronic components;
  - die attach;
  - plastic overmoulding;
  - ceramic BGA;
  - high power applications;
  - solders for mounting electrical and electronic components onto sub-assembled modules or sub-circuit boards;
  - solders used as a hermetic sealing material between a ceramic package or plug and a metal case;
  - HID lamps and oven lamps.
- 7(a) Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) used:
  - for internal interconnections in electrical and electronic components;
  - in HID lamps and oven lamps;
  - in solder balls for the attachment of ceramic BGA to the printed circuit board;
  - for the attachment of components to printed circuit boards in high temperature plastic overmouldings;
  - for mounting electrical and electronic components onto subassemblies;
  - as a hermetic sealing material between a ceramic package or plug and a metal case; or
  - in other applications.

21.4.6 Conclusions

21.4.6.1 Continuation of Exemption 7(a)

The information made available to the consultants suggests that the substitution and elimination of lead in LHMPS generally is still scientifically and technically impracticable so that granting an exemption could be justified by Art. 5(1)(a).

The applicants present future efforts towards the substitution or elimination of lead in die attach. Such clear perspectives for future efforts are missing for other application examples of LHMPS, which the applicants present in their exemption request. Lead-free solutions for die attach are, however, available at least for some smaller die sizes where the applicants did not provide a sound justification as to why these lead-free solutions may or may not be generally practicable to a degree that would allow narrowing the scope of the exemption for the use of LHMPS in die attach.

The consultants therefore recommend explicitly mentioning die attach in the wording of Exemption 7(a) and to renew the exemption for die attach for three years.

For the use of LHMPS in high power transducers, the consultants can understand that substitution of lead via design changes is possible in some cases but not in others. In this application, the information submitted plausibly explains that LHMPS is currently still required, but the actual status of the redesign efforts remains unclear, and the substitution and elimination of lead may become scientifically and technically practicable within less than five years. Granting the exemption for five years would therefore not be in line with the stipulations of Art. 5(1)(a), and it is consequently recommended to re-evaluate the situation in three years.

To cover the manifold other uses of LHMPS that could not yet be specified, the consultants recommend adding a third clause exempting the use of LHMPS in all applications others than die attach and high power transducers.

Exemption 24 covers the use of lead-containing solders including LHMPS for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors. This application of LHMPS should be excluded from exemption 7(a) to avoid overlapping scopes of exemptions. The consultants propose different options for the wording of exemption 7(a) depending on whether or not the Commission decides to renew exemption 24 as recommended or to include it within the scope of exemption 7(a) (for details please refer to the review of exemption 24).

21.4.6.2 Further Specification of Exemption 7(a)

The discussion related to the consultants' rewording proposal for exemption 7(a) shows that a consensus on the technical details of such a rewording proposal requires further exchange with the various stakeholders to clarify the architecture and the definitions of terms. Obviously, the alternative proposals of Freescale/NXP et al. and the contributions of Knowles et al. also require further discussions to achieve a technical consensus among the stakeholders. The limited time and resources available for the review of this exemption did not allow further discussions with the applicants and other stakeholders. The above proposals and discussions can however, be a basis to a further specification of

Exemption 7(a) in a future review taking into account the then achieved status of elimination and substitution of lead.

In the consultants opinion, the slightly modified rewording proposal recommended in Section 21.5 for the time being is a first step towards a specification of exemption 7(a) maintaining the clarity of the wording, taking into account the applicant's current and future research efforts and narrowing the scope to phase out the use of lead.

In case the Commission would like to follow the stakeholders' principal arguments against any rewording of Exemption 7(a), it is recommended to grant the exemption in its current wording for three years.

21.5 Recommendation

21.5.1 Wording of Exemption 7(a)

The information made available to the consultants suggests that the substitution and elimination of lead in LHMPS generally is still scientifically and technically impracticable so that granting an exemption could be justified by Art. 5(1)(a).

For die attach, the applicants do not provide a sound justification why available lead-free solutions for small dies may or may not be generally practicable.

The use of LHMPS in high power transducers can at least partially be avoided via design changes. While the applicant plausibly explains that LHMPS is currently still required, the actual status of the redesign efforts remains unclear. It is consequently recommended to re-evaluate the situation in three years.

The consultants therefore recommend granting Exemption 7(a) for die attach and for the use of LHMPS in power transducers for three years. A period of five years would not be in line with Art. 5(1)(a) since substitution or elimination of lead at least partially may become scientifically and technicaly practicable within the next five years.

A further specification of Exemption 7(a) to better reflect the broad range of LHMPS applications and to exclude abuse of the exemption is currently not yet possible. The consultants therefore recommend to add a general clause allowing the use of LHMPS in all applications others than in die attach and in high power transducers, and to grant this part of the exemption for five years because there is no prospect that lead-free solutions will become available within the next five years. The applicants should by then present dedicated research efforts to find specific lead-free solutions for the various applications of LHMPS.

The use of LHMPS in Exemption 24 should be excluded from exemption 7(a) to avoid overlapping scopes of exemptions. The consultants propose the below wording options of exemption 7(a) depending on whether or not the Commission decides to renew exemption 24 as recommended or to include it within the scope of exemption 7(a) (for details please refer to the review of exemption 24).

Exemption 7(a)	Expires on
I) *Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)*	*21 July 2021 for medical equipment in category 8 monitoring and control instruments in category 9*
	21 July 2023 for in vitro diagnostic medical devices in category 8
	21 July 2024 for industrial monitoring and control instruments in category 9
Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)	
<u>Recommended wording if the Commission decides to renew exemption 24 as recommended:</u>	
II) *in all applications not addressed in items III and IV, but excluding applications in the scope of exemption 24*	*21 July 2021 for categories 1 to 7 and 10*
III) *for die attach*	*21 July 2019 for categories 1 to 7 and 10*
IV) *for electrical connections on or near the voice coil in power transducers*	
<u>Alternative wording, if exemption 24 is not renewed:</u>	
II) *in all applications not addressed in items III, III and IV*	*21 July 2021 for categories 1 to 7 and 10*
III) *for die attach*	*21 July 2019 for categories 1 to 7 and 10*
IV) *for electrical connections on or near the voice coil in power transducers*	
V) *in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors*	*21 July 2021 for categories 1 to 7 and 10*

21.5.2 Applicants' Statements Concerning the Split of Exemption 7(a)

Bourns, Freescale/NXP et al. and Knowles et al. raised concerns on a splitting of exemption 7(a). These arguments refer to the proposed rewording with a more detailed split presented in chapter 21.4.5412. The consultants would like to nevertheless present those arguments, as they may also apply to the above proposed moderate rewording of exemption 7(a), as the split proposed above was not subject to further discussion in light of the lacking time and resources. The arguments of Freescale/NXP et al. are listed below as representatively reflecting the applicants' concerns.

Bourns, Bosch, Freescale/NXP et al. and Knowles et al. advocate the renewal of exemption 7(a) with its current wording. Freescale/NXP et al.[959] mention that the EEE industry and automotive industry have an extensive overlap in their supply chains. They

[959] Op. cit. (Freescale Semiconductors/NXP et al. 2015a)

would recommend that the EU maintain consistent wording between RoHS exemption 7(a) and ELV exemption 8(e) where feasible. [960]

According to Freescale/NXP et al.[961], splitting the exemption will not eliminate existing functional requirements for LHMPS, nor will it improve the availability of Pb-free alternatives. They are not aware of readily available and manufacturable Pb-free HMPS with the required melting points, conductivity, ductility and reliable performance. The proposed changes to the wording would likely divert resources to rework the existing EEE material content reports and conformity declarations in support of CE certifications. This might reduce resources investigating technical solutions.[962]

Furthermore, they[963] believe an application list of OEM EEE end-uses for LHMPS is not feasible. The supply chain cannot link LHMPS to all EEE applications or intended uses. Freescale/NXP et al.[964] do not understand the benefit of increasing the complexity of this exemption. They see no evidence that the language change will reduce the amount of lead placed on the EU market in the coming five years. LHMPS is a lead solder. LHMPS already represents a tangible application. They believe the existing wording already defines an application for upstream users (i.e. LHMPS). The proposed changes to the wording would increase the complexity for certifying and verifying compliance, resulting in increased errors. It would create challenges for regulatory compliance. [965] [966]

In case the Commission would like to follow the applicants' arguments, it is recommended to continue the current exemption for a minimum of three years period.

21.6 References Exemption 7(a)

Bosch Security Systems GmbH 2015 Document "Bosch-Stakeholder-contribution-Exemption-request-7a.pdf", submitted during the online stakeholder consultation. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Bosch-Stakeholder-contribution-Exemption-request-7a.pdf.

Bosch Security Systems GmbH 2016a Answers to first questionnaire, document "Exe_7a_Questionnaire-1_Bosch_2016-03-13.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Erich Pudelko, Bosch, on 23 March 2016.

Bosch Security Systems GmbH 2016b Answers to second questionnaire, document "Exe_7a_Questionnaire-2_Bosch_2016-03-24.docx", received via e-mail from Erich Pudelko, Bosch, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016.

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[960] Op. cit. (Freescale Semiconductors/NXP et al. 2015a)
[961] Op. cit. (Freescale Semiconductors/NXP et al. 2016b)
[962] Op. cit. (Freescale Semiconductors/NXP et al. 2016b)
[963] Ibid.
[964] Ibid.
[965] Ibid.
[966] Ibid.

Bosch Security Systems GmbH 2016c E-mail communication, document "Exe_7a_Questionnaire-2_Bosch_2016-03-24.docx", received via e-mail from Erich Pudelko, Bosch, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016.

Bourns Inc. 2015a Exemption Request Exemption 7a. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Bourns/7a_Exemption_extension_ap_7a.pdf.

Bourns Inc. 2015b 1st Questionnaire (Clarification Questionnaire) Exemption 7a. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Bourns/20150815_Ex_7a_Bourns_1st-Questionnaire_2015-07-14.pdf.

Bourns Inc. 2016a Answers to first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1_All-Applicants_Bourns_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Cathy Godfrey, Bourns Inc., on 7 March 2016.

Deubzer, Otmar 2007 Explorative study into the sustainable use and substitution of soldering metals in electronics: Ecological and economical consequences of the ban of lead in electronics and lessons to be learned for the future. Design for Sustainability Program publication 15. [S.l.]: [s.n.]. http://repository.tudelft.nl/view/ir/uuid%3Af9a776cf-57c3-4815-a989-fe89ed59046e/.

Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles. ELV DirectiveEuropean Union. October 21, 2000.

Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. RoHS 1European Union. February 13, 2003.

Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast). RoHS 2European Union. July 1, 2011.

Freescale Semiconductors/NXP et al. Document "7aEx__RoHS_Freescale_Consultation_Response_2015_1015_Final_to_Oeko.pdf", submitted during the stakeholder consultation 2015c. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/7aEx__RoHS_Freescale_Consultation_Response_2015_1015_Final_to_Oeko.pdf.

Freescale Semiconductors/NXP et al. 2015a Request for Continuation of Exemption 7a, document "Ex_7a_Freescale_Ex_Renewal_Dossier_2015_0723_v20_revised.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Freescale_Semiconductor/Ex_7a_Freescale_Ex_Renewal_Dossier_2015_0723_v20_revised.pdf.

Freescale Semiconductors/NXP et al. 2015b 1st Questionnaire (Clarfication Questionnaire) Exemption 7a, document "Ex_7a_Freescale_Response_to_Clarification_questions_2015_0817_Final_to_Oko_Questions_of_2015_0716.pdf".

http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Freescale_Semiconductor/Ex_7a_Freescale_Response_to_Clarification_questions_2015_0817_Final_to_Oko_Questions_of_2015_0716.pdf.

Freescale Semiconductors/NXP et al. 2016a: Answers to second questionnaire, document "Exe_7a_Questionnaire-2_Freescale_Response_2016-01-28.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, Freescale (NXP) et al., on 28 January 2016.

Freescale Semiconductors/NXP et al. 2016b Answers to first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1_All-Applicants_2016-02-16_NXP-et-al.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, NXP, on 25 February 2016.

Freescale Semiconductors/NXP et al. 2016c Answers to second questionnaire to all stakeholders, document "Exe_7a Questionnaire-2-All-Applicants_2016-02-16_NXP.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, NXP, on 22 March 2016.

Freescale Semiconductors/NXP et al. 2016d Answers to questionnaire 3a, document "Exe_7a_Questionnaire-3a_Freescale_2016-03-28.pdf", received via e-mail from Griffin Teggeman, NXP, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016.

Gensch et al. 7th Adaptation to Scientific and Technical Progress of Exemptions 8(e), 8(f), 8(g), 8(h), 8(j) and 10(d) of Annex II to Directive 2000/53/EC (ELV) 2015.

Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM.
http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

IXYS Semiconductor GmbH 2015a Request for continuation of exemption 7a with limited scope, document "7a_IXYS_RoHS_V_Application_Form.pdf".
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/IXYS/7a_IXYS_RoHS_V_Application_Form.pdf.

IXYS Semiconductor GmbH 2015b 1st Questionnaire (Clarification Questionnaire) Exemption 7a, document document "20150804_Ex_7a_Ixys_Questions_answered_amended.pdf".
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/IXYS/20150804_Ex_7a_Ixys_Questions_answered_amended.pdf.

IXYS Semiconductor GmbH 2016a Answers to the first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1-All-Stakeholders_Reply-Ixys_2016-02-26.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Markus Bickl, Ixys Semiconductor GmbH, on 26 February 2016.

IXYS Semiconductor GmbH 2016b Answers to questionnaire 2, document "Exe-7a_Questionnaire-2_IXYS.docx", received via e-mail from Markus Bickel, IXYS, by Dr. Otmar Deubzer, Fraunhofer IZM, on 21 January 2016.

Knowles et al. 2016a Answers to first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1_All-Applicants_Knowles-et-al_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Hopwood, Knowles Capacitors, on 25 February 2016.

Knowles et al. 2016b Answers to second questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1_All-Applicants_Knowles-et-al_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Steve Hopwood, Knowles Capacitors, on 21 March 2016.

Knowles et al. 2016c Answers to third questionnaire, document "Exe_7a_Questionnaire-2_Knowles_2016-03-29.pdf", received via e-mail from Steve Hopwood, Knowles, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016.

Ministry of the Environment, Finland Document "Ex_7a_Finnish_Safety_and_Chemicals_Agency-comment_161015.pdf" submitted during the online stakeholder consultation 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Ex_7a_Finnish_Safety_and_Chemicals_Agency-comment_161015.pdf.

TT Electronics/AB Mikroelektronik GmbH 2015a Information on TFC, document "AB-Mikro_TFC.pdf", received via e-mail from Chris Burns, AB Mikroelektronik, by Dr. Otmar Deubzer, Fraunhofer IZM, on 8 January 2016.

TT Electronics/AB Mikroelektronik GmbH 2015b E-mail communication, document "E-Mail-Communication_AB-Mikro.pdf", received via e-mail from Chris Burns, AB Mikroelektronik, by Dr. Otmar Deubzer, Fraunhofer IZM, on 14 March 2016.

22.0 Exemption 7c-I: “Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated, and the views presented should not be taken to represent the views of the consultants (authors of this report).

Acronyms and Definitions

Curie temperature	Temperature at which piezoelectric ceramics lose their piezoelectric properties; *Source: Zangl et al. 2010*[967]
Electro Mechanical Coupling Coefficient (k) of piezoelectric ceramics	Coefficient to show the efficiency to transform and communicate electric alteration into the energy of mechanical alteration (or vice versa) due to the piezoelectric effect $k = \sqrt{\frac{\text{mechanical energy stored}}{\text{electrical energy applied}}}$ or

[967] Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010a “Adaptation to scientific and technical progress of Annex II to Directive Adaptation Directive2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS): Final report - revised version,” Final Report Oeko-Institut e. V. und Fraunhofer IZM, accessed August 4, 2015, http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3_2010_Review_Final_report_ELV_RoHS_28_07_2010.pdf; or https://circabc.europa.eu/sd/d/a4bca0a9-b6de-401d-beff-6d15bf423915/Corr_Final%20report_ELV_RoHS_28_07_2010.pdf

$$k = \sqrt{\frac{\text{electrical energy stored}}{\text{mechanical energy applied}}}$$

In order to gain filter characteristics, materials with high values in this category are essential;
Source: Zangl et al. 2010[968]

Mechanical Quality Factor Coefficient of piezoelectric ceramics	Shows the extent of mechanical loss near frequencies where the piezoelectric substance resonates; in resonators and oscillators, as the value becomes higher, the oscillator becomes more efficient and the fluctuation in the resonance frequency decreases; *Source: Zangl et al. 2010*[969]
NTC	Negative Temperature Coefficient, materials decreasing their electrical resistance with increasing temperature; *Source: Zangl et al. 2010*[970]
Piezoelectric Strain Coefficient (d constant) (Piezoelectric material constant)	Indicates how efficient an electric field can generate strain of the piezoelectric material, or vice versa how efficient a strain applied on the ceramic can generate an electrical field. Higher values indicate higher efficiency. d=strain / applied electrical field If the value is high, the piezoceramic can generate displacement efficiently from a low electric field. Also, the output is larger for sensors and it can be used as a good sensor material with high sensitivity *Source: Zangl et al. 2010*[971]
PTC	Positive Temperature Coefficient, materials increasing their electrical resistance with increasing temperature *Source: Zangl et al. 2010*[972]
PTCR	Positive temperature coefficient of resistance
PZT ceramics	Ceramics consisting of a mixture of $PbZrO_3$ and $PbTiO_3$ *Source: Zangl et al. 2010*[973]
Saturation polarization	Highest practically achievable magnetic polarization of a material when exposed to a sufficiently strong magnetic field *Source: Zangl et al. 2010*[974]

[968] Ibid.
[969] Ibid.
[970] Ibid.
[971] Ibid.
[972] Ibid.
[973] Ibid.

22.1 Background and History of the Exemption

The current wording of exemption 7c-I in Annex III of Directive 2011/65/EC (RoHS 2), is:

"Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound"

When Directive 2002/96/EC (RoHS 1) (EuropeanUnion) was published in 2003, the above exemption did not yet exist in this form. The use of lead in glass and ceramics was covered by two different exemptions with a different wording: Exemption 5 allowed the use of lead in glass:

"Lead in glass of cathode ray tubes, electronic components and fluorescent tubes"

Exemption 7d covered the use of lead in ceramics of electronic components:

"Lead in electronic ceramic parts (e.g. piezoelectronic devices)"

In 2007, the Commission received an application for exemption of

"Lead in cermet-based trimmer potentiometer elements"

The applicant requested this exemption claiming that exemptions 5 and 7 in the annex of directive 2002/95/EC (RoHS 1) in the status of 2006/2007 did not cover the use of lead in these cermet-based trimmer potentiometers. The applicant said that this resistive layer in the cermet-based trimmer potentiometer is a homogeneous material, as it can be mechanically separated from the ceramic base. This homogeneous material, the thick-film layer containing the lead, in itself is neither a glass nor a ceramic material. The exemption request was reviewed[975] and the Commission granted the exemption as exemption 34 in the annex of RoHS 1.

Exemption 11 of Annex II in Directive 2000/53/EC (ELV Directive), the equivalent to exemption 7c-I of RoHS Annex III, was reviewed in 2007/2008[976]. The stakeholders decided that the wording in the ELV Directive covers applications like lead in cermet-based trimmer potentiometers. To avoid insecurities whether and how far similar uses of lead like in the cermet-based trimmer potentiometers are exempted, it was decided in the review of RoHS exemption 7d in 2008/2009[977] to take over the wording of ELV

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[974] Ibid.

[975] For details see report of Gensch, Carl-Otto, Stéphanie Zangl, and Otmar Deubzer 2007 "Adaptation to scientific and technical progress under Directive 2002/95/EC: Final report." Accessed August 11, 2015. http://ec.europa.eu/enviro nment/waste/weee/pdf/rohs.pdf., page 18 et sqq.

[976] Lohse, Joachim; Gensch, Carl-Otto; Groß, Rita; Zangl, Stéphanie, Oeko-Institut e.V.; Deubzer, Otmar, Fraunhofer IZM (2008): Adaptation to Scientific and Technical Progress of Annex II Directive 2000/53/EC. Final Report - Amended Final. https://circabc.europa.eu/sd/a/f5d79a51-2e5a-47eb-85d3-7b491ae6a4b3/Final_report_ELV_2008_Annex_II_revision.pdf; page 65 et sqq.

[977] Carl-Otto Gensch, Oeko-Institut e. V., et al. (2009): Adaptation to scientific and technical progress under Directive 2002/95/EC. Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM.

exemption 11 with further slight adaptations, resulting in the current wording of exemption 7c-I.

The exemption was transferred from the annex of RoHS 1 into annex III of RoHS 2 without changes and has become due for review as stakeholders have requested its continuation prior to its expiry in July 2016.

22.2 Description of the Requested Exemption

22.2.1 Overview of the Submitted Exemption Requests

Several stakeholders have requested the continuation of exemption 7c-I. Table 22-1 gives an overview of the submitted requests.

Pyreos' request for exemption[978] had actually been submitted as part of pack 8 of the RoHS exemption reviews[979]. Since the applicant asks for the application-specific renewal of exemption 7c-I, Pyreos[980] agreed that its exemption request will be evaluated in the broader context of exemption 7c-I in this review round.

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http://ec.europa.eu/enviro nment/waste/weee/pdf/final_reportl_rohs1_en.pdf; http://ec.europa.eu/enviro nment/waste/weee/pdf/report_2009.pdf; page 98 et sqq.

[978] Pyreos Ltd. 2015a "Document "Questionnaire-1_Clarification_Exe-Req-Pyreos_cg130415 final - publication.pdf": 1st questionnaire (clarification questionnaire)," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_7/2015_1/Questionnaire-1_Clarification_Exe-Req-Pyreos_cg130415_final_-_publication.pdf

[979] C.f. reviews of pack 8 and 9 RoHS exemption requests, http://rohs.exemptions.oeko.info/index.php?id=221

[980] Pyreos Ltd. 2015b "Document "Pyreos_Suspension-of-Request-with-Conditions.pdf", sent via e-mail to Dr. Otmar Deubzer, Fraunhhofer IZM, by Torben Nørlem, Intertek, on 20 July 2015,"

Table 22-1: Overview of requests for the continuation of exemption 7c-I and application-specific wordings

Applicant	Requested Exemption	Requested Expiry Date/ Continuation	Remarks
Bandelin[981]	Annex III: Continuation with specification: **Piezoelectric hard PZT containing lead for high performance ultrasonic and** electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound Annex IV: Lead in single crystal piezoelectric materials for ultrasonic transducers and in **piezoelectric hard PZT containing lead for high performance ultrasonic transducers**	Maximum validity period (5 years)	Applicant additionally requests amendment of exemption 14 in Annex IV
Bourns[982]	Continuation of exemption without changes	Maximum validity period (5 years)	Applicant mentions lead-free glasses applied in some components
IXYS	Lead in coatings of high voltage diodes	Maximum validity period	IXYS had applied for this exemption under Exemption 37; it was agreed with the applicant that the exemption is related to glass coatings of high voltage diodes, and not to lead in the platings of such diodes. The exemption request therefore was shifted to Exemption 7c-I.

[981] Bandelin Electronic GmbH 2015a "Request for continuation of exemption 7c-I with addition, document "Ex_7c_I_Application_Bandelin.pdf: Exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/BANDELN/Ex_7c_I_Application_Bandelin.pdf

[982] Bourns Inc. 2015a "Exemption request, document "7c-I_Exemption_extension_ap_7c-I.pdf": Request for continuation of exemption 7c-I," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Bourns/7c-I_Exemption_extension_ap_7c-I.pdf

Applicant	Requested Exemption	Requested Expiry Date/ Continuation	Remarks
JEITA et al.[983]	Continuation of exemption with clarification of scope: “Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in **discrete** capacitor **components**, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound”	Maximum validity period (5 years)	Request almost identical to that of Murata et al.
Murata et al.[984]	Continuation of exemption with clarification of scope: “Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in **discrete** capacitor **components**, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound”	Maximum validity period (5 years)	Request almost identical to that of JEITA et al.
Ralec[985]	Continuation of exemption without changes	Maximum validity period (5 years)	Applicant did not reply timely to clarification questionnaire; application has therefore not been followed up

[983] JEITA et al. 2015a “Exemption request, document "JEITA/7c-IandII_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf": Exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/JEITA/7c-IandII_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf
[984] Murata et al. 2015a “Original exemption request, document "Exemption_7_c_-I/Murata/7c-I_RoHS_V_Application_Form_7c1_20140116_combined_final.pdf": Exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Murata/7c-I_RoHS_V_Application_Form_7c1_20140116_combined_final.pdf
[985] Ralec Technology 2015 “Exemption request, document "7c-I_RoHS_V_Application_Form_to_RoHS.pdf": Exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/RALEC/7c-I_RoHS_V_Application_Form_to_RoHS.pdf

Applicant	Requested Exemption	Requested Expiry Date/ Continuation	Remarks
Pyreos[986 987]	Add following exemption to Annex III and Annex IV: Lead in thin film electronic sensor elements such as pyroelectric sensors or piezoelectric sensors	7 years	Sensors currently used in monitoring and control instruments (category 9) for both industrial and non-industrial use, but can possibly expand to other product groups of RoHS Directive;
Schott[988]	Continuation of exemption without changes	Maximum validity period (5 years)	Schott specifies the application of lead in "solder glasses" to attach optical elements like windows or lenses into metal components for high quality hermetic package for optoelectronic devices
Sensata[989]	Continuation of exemption without changes	Not specified	Request for lead in glasses to manufacture sensors and to bond sensors to other materials like e.g. metals

[986] Pyreos Ltd. 2014 “Original exempiton request for renewal of exemption 7c-I with new wording, document "RoHS_V_Application_Form-Pyreos_final 14112014 - publication.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_7/2015_1/RoHS_V_Application_Form-Pyreos_final_14112014_-_publication.pdf
[987] Op. cit. Pyreos Ltd. 2015a
[988] Schott AG 2015a “Exemption request document "20150820_Ex_7c-I_Schott_Application_Revised_A.pdf": Exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/SCHOTT/20150820_Ex_7c-I_Schott_Application_Revised_A.pdf
[989] Sensata Technologies 2015a “Request for continuation of exemption 7c-I, document "7c-I_RoHS-Exemptions_Application-Format_Ex_7cI_Pb_in_glass_20150115.pdf": Exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Sensata/7c-I_RoHS-Exemptions_Application-Format_Ex_7cI_Pb_in_glass_20150115.pdf

Applicant	Requested Exemption	Requested Expiry Date/ Continuation	Remarks
Vishay[990] [991]	Continuation of exemption without changes; provides application examples with below wordings in support of the unchanged continuation of exemption 7c-I: “Wire wound resistors with enamel coatings containing lead (Pb) as lead-oxide (Pb3O4) in glass” “Lead in glass of the Ag top and bottom electrode of NTC chips”	Maximum validity period (5 years)	Member of the consortium of Murata et al.[992] (Annexed to exemption request document)
YAGEO Corporation [993]	Continuation of exemption without changes		Applicant did not reply to clarification questionnaire; application has therefore not been followed up

[990] Vishay 2015a 2015 “Document "RoHS-Exe-7c-I_Pb-in-glass-Enamel-Coating_Wirewound_Resistors.pdf", submitted as additional reference for the exemption request of Murata et al. 2015a: Document referenced in the exemption request of Murata et al. 2015a” (January 2015) unpublished manuscript,

[991] Vishay 2015c “Document "Request for exemption 7c-I NTC chips update dec15.pdf", submitted as additional reference for the exemption request of Murata et al. 2015a: Document referenced in the exemption request of Murata et al. 2015a” unpublished manuscript,

[992] Op. cit. Murata et al. 2015a

[993] Yageo Corporation 2015 “Exemption request, document "7c-I_RoHS_V_Application_Form_YAGEO_2015-01-19.pdf",” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/YAGEA/7c-I_RoHS_V_Application_Form_YAGEO_2015-01-19.pdf

22.2.2 Technical Background of the Requests for Renewal of Exemption 7c-I (Murata/JEITA et al.)

Murata/JEITA et al.[994] [995] request the renewal of the exemption for five years, but ask for a slight modification of the exemption wording to clarify its scope without extending it:

> *"Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in **discrete** capacitor **components**, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound"*

The background of this proposed change is explained in detail in the review of exemption 7c-II, see Chapter 23.0.

The technical background for the use of lead in glass[996] and in ceramics[997] under exemption 7c-I was explained in detail in the report of the 2008/2009 review. The exemption is used in all types of electrical and electronic equipment (EEE) listed in Annex I of the RoHS Directive. The description of the exemption is therefore limited to the main aspects.

Murata et al.[998] state that the applications of lead in ceramic and glass are too numerous and that it is impossible to list all of them. They provide illustrative examples, reproduced in Table 22-2, which they claim not to constitute a comprehensive list of the uses of lead in ceramics and in glass used in electronic components.

Murata et al.[999] explain that lead is used to obtain appropriate physical characteristics in glass and/or ceramic. In ceramics, lead provides particular dielectric, piezoelectric, pyroelectric, ferroelectric, semiconductor, magnetic properties over a wide use ranges in terms of temperatures, voltages and/or frequencies.

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[994] Op. cit. Murata et al. 2015a
[995] Op. cit. JEITA et al. 2015a
[996] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf, page 52 et seqq.
[997] Ibid., page 98 et seqq.
[998] Op. cit. Murata et al. 2015a
[999] Ibid.

Table 22-2: Example applications of lead in exemption 7c(I)

Application	Function	Product examples
Ceramic (including applications using thick film & thin film technology)		
PZT in piezoelectric ceramic	Piezoelectric effect	Transformer, filter, resonator, buzzer, actuator, sensors (pressure, shock)
Semiconductor ceramic (PTC)	Temperature dependent resistance	PTC resistor / thermistor, heater
Pyroelectric ceramic	Pyroelectric effect	Infrared sensor, temperature sensor
Ferroelectric /magnetic ceramic	Ferroelectric / Magnetic effect	Ferroelectric memories, ferrite core
Dielectric ceramic	Energy storage by polarization effect	Capacitive layers in electronic components (discrete capacitor components are in scope of 7c(II) and 7c(III))
Glass and glass-ceramic matrix compounds (including applications using thick film & thin film technology)		
Glass and/or glass frits for amorphous isolating solid or interconnection	Protection, Insulating	Discrete Semiconductors
		Glass passivation of semiconductor chips
		Glass sleeve diodes (various sizes)
		Thick film resistors
		Wire wound resistors
		NTC – Glass coating
		Metal pressure sensors
	Adhesives / Bonding	MEMS
		SMD Components
		Capacitive pressure sensing element
		Resistive pressure sensing element
	Hermetic sealing	Electronic components with hermetically sealed ceramic package
Glass-ceramic matrix compound	Functional glass compound, resistance	Thick film resistors coating, resistance and conductor layer
		High voltage resistors
		Outer electrode of ceramic components
Glass-ceramic material	Functional glass	Glass-ceramic cooking field

Source: Murata et al.[1000]

22.2.2.1 Electrical and Electronic Components Containing Lead in Ceramic

Murata et al.[1001] explain that ceramic constituted by oxides of tetravalent cations of Group 4 elements and divalent cations of lead (Pb) have the outstanding special characteristics of stably bringing out electrical properties (dielectric, piezoelectric,

[1000] Murata et al. 2015b “Questionnaire 1 (clarification questionnaire), document "RoHS_7c-I_Murata__1st_Questionnaire_answers_final_20Aug.pdf",” Clarification questionnaire, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Murata/RoHS_7c-I_Murata__1st_Questionnaire_answers_final_20Aug.pdf
[1001] Op. cit. Murata et al. 2015a

pyroelectric, ferroelectric, semiconductor, magnetic properties) over a wide use range (temperature, voltage, frequency).

According to Murata et al.,[1002] these lead-containing ceramics are widely used as main constituent materials of electrical and electronic components and as important additives for controlling and enlarging the usable environment range (temperature, voltage) of other ceramic. Moreover, lead-containing ceramic has characteristics of densely sintering throughout a wide range of sintering conditions, low energy consumption in manufacturing and high electrical and mechanical durability of the product after sintering. By controlling the sintering conditions, a fine layered structure can be internally formed and the functionality of the electronic components can be largely improved.

The specific examples of various types of ceramics containing lead and the status of substitution or elimination are explained in Section 22.3.1 (General Status of Lead Substitution in Ceramics of Electrical and Electronic Components from page 444).

22.2.2.2 Electrical and Electronic Components Containing Lead in Glass or Ceramic Matrix Compounds

According to Murata et al.[1003] glass for electronic components is an amorphous isolating solid. In electrical and electronic components, together with making use of the various properties exhibited by glass, the desired function is obtained by the combination of glass with other materials such as metal, ceramic, etc. Lead as a constituent element of glass:[1004]

- Lowers the melting and softening points;
- Improves workability and machinability;
- Increases wettability with metal and ceramic and improves the bonding strength with other materials;
- Facilitates controlling electrical properties like conductivity, resistance values in combination with other materials over a wide range and thus provides excellent functionality; and
- Improves the chemical stability and mechanical strength of glass and helps to achieve excellent reliability;

Murata et al.[1005] state that lead-containing glass can be used over a wide range of applications. It is used for insulating, protection, resistance, adhesives, bonding, hermetic sealing and other uses. Table 22-3 provides examples.

[1002] Ibid.
[1003] Ibid.
[1004] Ibid.
[1005] Ibid.

Table 22-3: Example applications of glass containing lead

Example#	Functional group	Product and Parts example
# 1.1	Protection & Insulating	Discrete Semiconductors
# 1.2		Glass sleeve diodes (various sizes)
# 1.3		Thick film resistors
#1.4		Wire wound resistors
#1.5		NTC – Glass coating
#1.6		Metal pressure sensors
#2.1	Functional glass compound/Resistance	Thick film resistors coating and/or contact layer
#2.2		High ohmic / high voltage resistors materials
#2.3		NTC – Inner electrode
#3.1	Adhesives / Bonding	MEMS
#3.2		SMD Components
#3.3	Hermetic sealing	Electronic components with hermetically sealed ceramic package

Source: Murata et al.[1006]

Murata et al.[1007] [1008] highlight that in the above list neither the functional groups nor the product examples are exhaustive. The list serves to explain why lead in glass is needed and lead-free substitutes are not technically suitable. The examples for the various functional groups and the prospects to substitute or eliminate lead are explained in more detail in Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds from page 460).

[1006] Ibid.
[1007] Ibid.
[1008] Murata et al. 2016a "Answers to second questionnaire, document "Exe_7c-I_Questionnaire-2_Murata-JEITA_2015-12-30_answers_final.pdf", received by Dr. Otmar Deubzer, Fraunhofer IZM, from Wolfgang Werner, Vishay, on 29 January 2016" unpublished manuscript, Second questionnaire

22.2.3 Technical Background of the Bandelin Application-specific Exemption Request

Bandelin[1009] requests an addendum to the current exemption wording:

> ***Piezoelectric hard PZT containing lead for high-performance ultrasonic transducers and*** *electrical and electronic components containing lead in glass or ceramic materials other than dielectric ceramic in capacitors*

Bandelin[1010] claims that the wording of exemption 7c-I does not clearly describe the applied use, as no differentiation is made between soft PZT and hard PZT. Only hard PZT is suitable for high-performance applications. Soft PZT is used for actuators and sensors.

Bandelin[1011] explains that they use piezoceramic material, which is used as lead zirconium titanate (PZT) in great quantities and various forms to create high-performance piezoelectric transducers, which are a major part of equipment such as ultrasonic cleaning systems and homogenisers. Piezoceramic “hard PZT” in the form of perforated discs is the exclusive material used for these high-performance transducers worldwide. In Europe, it bears the designation PZT 4 or PZT 8, and it contains more than 0.1 % by weight of lead.

Bandelin[1012] considers itself a leading manufacturer of high-performance ultrasound equipment with a wide range of devices for cleaning technology and ultrasound technology for industrial, medical and laboratory applications. They install roughly 70,000 perforated discs made of hard PZT 4 and PZT 8 in their high-performance ultrasonic transducers every year.

The development of high-performance piezoceramic ultrasonic transducers began in the 1950s and has undergone an enormous upswing since the invention of lead zirconium titanate materials – especially in the overall field of cleaning technology. Among other things, this led to chlorinated hydrocarbons and chlorofluorocarbons being replaced by water-based ultrasonic cleaning processes.[1013]

As an equipment manufacturer, Bandelin[1014] absolutely relies on purchasing high-performance piezoelectric ceramics made of hard PZT for the construction of high-performance ultrasonic transducers.

[1009] Op. cit. Bandelin Electronic GmbH 2015a

[1010] Bandelin Electronic GmbH 2015b “Questionnaire 1 (clarification questionnaire), document "Ex_7c-I_Bandelin_1st_Questionnairie_and_Answers.pdf",” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/BANDELN/Ex_7c-I_Bandelin_1st_Questionnairie_and_Answers.pdf

[1011] Op. cit. Bandelin Electronic GmbH 2015a

[1012] Ibid.

[1013] Ibid.

[1014] Ibid.

22.2.4 Technical Description of the Bourns Exemption Request

Bourns[1015] uses lead in thick films, which are resistive and conductive films greater than 0.0001 inches thick, resulting from firing a paste or ink that has been deposited on a ceramic substrate. These thick film inks typically contain a glass material that includes lead.

Bourns[1016] also uses lead-containing glass frits that have several applications including barrier layers for stopping the migration of silver and a sealing material for hermetic packages. Glasses are typically part of a thick film formulation. Various oxides are melted together to form a glass matrix. It is also used as a sealant in hermetic ceramic and metal electronic (semiconductor and hybrid) component packages. The lead oxide is used to lower melting temperature and viscosity for processing below 550 °C and to raise the dielectric strength. The lead oxide content of the glass can be adjusted controlling the coefficient of thermal expansion which is favourable for high sintering temperature operations.

Components using lead-glass include chip arrays, chip resistors, ESD protectors, transient voltage suppressor diodes, encoders, fuel cards, ceramic PTC resettable fuses, thick film moulded dips, panel controls, power resistors, trimming potentiometers. These electronic components are typically used on circuit boards and other internal electronics in products of all RoHS categories in Annex I by Bourns' customers.[1017]

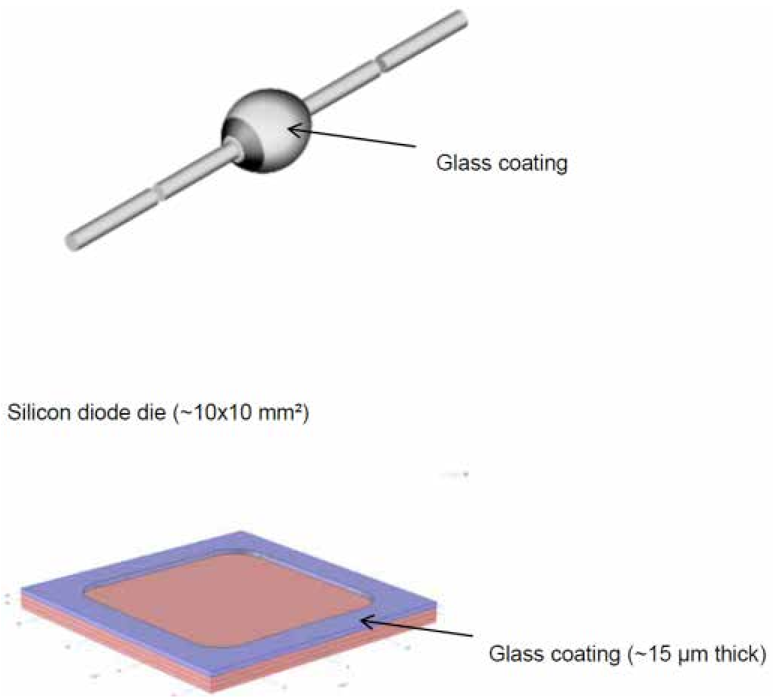
The homogeneous material is the glass included in the thick film ink or encapsulation, which is then fired on a substrate. The lead content will vary and can range from 1-75 % in the glass only. The total ink/encapsulation including the glass is generally less than 1 % of the finished part.[1018]

22.2.5 Technical Description of the IXYS Application-specific Exemption Request

IXYS[1019] request an exemption for lead in coatings of high voltage diodes. The glass coatings used for high reliability semiconductor power device passivation and packaging contain lead. Lead-based glasses are used because they have unique combinations and characteristics that cannot be achieved by other materials or methods. Zinc borosilicate glasses with lead are used to prevent degradation of high reliability semiconductor devices in applications at or above 100 V AC for rectification and other electric power converters.

1015 Op. cit. Bourns Inc. 2015a
1016 Ibid.
1017 Ibid.
1018 Ibid.
1019 IXYS Semiconductor GmbH 2014 2014 "Request for continuation of exemption 37, document "37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf": Original exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/IXYS/37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf

Figure 22-1: Lead glass in high voltage diodes and on silicon diode dies



Source: IXYS[1020]

Examples are provided by IXYS of lead glass used in high voltage diodes and on silicon diode dies in Figure 22-1. According to IXYS,[1021] these components are used in transportation, automotive, and in high power equipment in the industry, from which only the latter is in the scope of the RoHS Directive.

IXYS[1022] explains that lead provides good physical properties in combination with pure silicon crystals and a good ability to withstand high electric fields in the range of 200,000 V/cm in alternate and direct current power semiconductor devices.

[1020] Ibid.
[1021] Ibid.
[1022] Ibid.

22.2.6 Technical Background of the Pyreos Application-specific Exemption Request

Pyreos[1023] requested to add an exemption with the following wording to both RoHS Annex III and Annex IV with a maximum validity of seven years:

> *"Lead in thin film electronic sensor elements such as pyroelectric sensors or piezoelectric sensors"*

Pyreos[1024] explains the request to relate to lead in thin film $PbZrTiO_3$ (PZT) sensors for pyroelectric or piezoelectric applications. The sensors are currently used in monitoring and control instruments but the future use could expand to other product groups under RoHS.

According to Pyreos[1025], lead in the sensing elements of thin film PZT sensors is used for pyroelectric applications such as:

- low power gesture / proximity detection;
- gas detection;
- safety and security applications such as gas detection and intruder alarms;
- Infrared spectroscopy for industrial and consumer applications; or
- piezoelectric applications such as piezo actuators or transducers.

Pyreos[1026] states the lead atoms are fundamental to the unique properties of the PZT material system and it is the special electronic structure of lead together with its weight that gives the PZT material system its unique properties. Present lead-free alternatives are not commercially viable and the substitution of lead may potentially adversely impact the performance of monitoring and control equipment relying on the PZT thin film sensors whereby consumer and worker safety may be impaired.

Pyreos[1027] explain that there are a total of 32 crystal configurations of which 10 are polar showing a pyroelectric effect. Ferroelectric materials form a sub-class of the polar materials, and some ferroelectric materials are characterised by a very high pyroelectric effect. Figure 22-2 shows the technically most relevant material groups including some key performance parameters.

[1023] Op. cit. Pyreos Ltd. 2015a
[1024] Op. cit. Pyreos Ltd. 2014
[1025] Ibid.
[1026] Ibid.
[1027] Ibid.

Figure 22-2: Ferrocelectric materials and pyroelectric effects

Material	Example	$\varepsilon/\varepsilon_o$	$\tan\delta$	p $10^{-4} C/m^2K$	F_D $10^{-5}/\sqrt{Pa}$
Ferroelectric single crystals	$LiTaO_3$	45	0.005	2.0	4.4
Modified ferroelectric ceramics	$PbTiO_3$	250	0.007	4.2	4.3
Ferroelectric thin films on silicon	PZT	250	0.006	2.2	2.4
Ferroelectric polymers	PVDF	12	0.015	0.3	0.9

Source: Pyreos[1028]

Pyreos[1029] states that for most applications it is not only important to have a large pyroelectric effect, but other factors, such as temperature dependence of the pyroelectric material, its Curie temperature and the manufacturing costs are also important factors that will ultimately determine the commercial success of a sensor material.

Pyreos[1030] claim that they can realise all of the above mentioned requirements with thin-film, ferroelectric lead zircon titanate (PZT) layers on silicon (line 4 in the above table). This is compared to the most commonly used ceramic pyroelectric infrared sensors based on PZT and lead titanate ($PbTi0_3$, line 2 of the table above), for which a RoHS exemption is required. The sensors with thin-film PZT layers on silicon contain only about 1/3000 of lead.

The PZT layers, which are the homogeneous material, contain around 80 % of lead resulting in only around 1 g of lead annually that would be used in the EU under this requested exemption.

[1028] Ibid.
[1029] Ibid.
[1030] Ibid.

Pyreos[1031] concludes that it requests the new exemption as the quantity of lead and the technology used for thin film sensors is fundamentally different from the conventional technology covered by the existing exemption 7c-I.

22.2.7 Technical Background of the Schott Exemption Request

Schott[1032, 1033] supports the continuation of exemption 7c-I in its current wording and scope, but specifically lead-oxide-based glasses, so called "solder glasses", to attach optical elements like windows or lenses into metal components to achieve a glass-to-metal sealing for the hermetic packaging of electronic devices. This assembly is part of a hermetic package ("Cap") for optoelectronic devices like laser diodes, photo detectors etc.

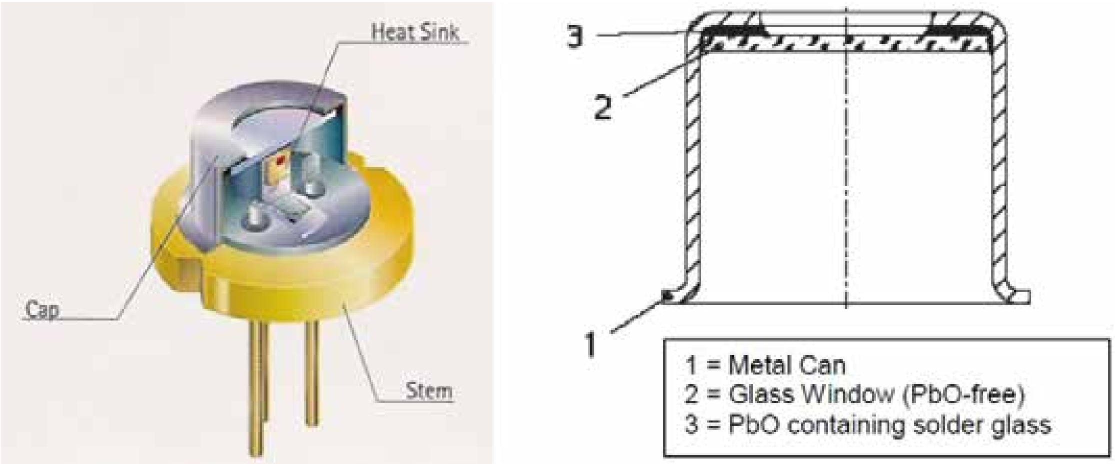
SCHOTT AG produces components for many types of EEE. Applications of these components are[1034]:

- Fibre Optic Data Communication Components:
    - Laser Diodes for Transmit Modules; and
    - Photodiodes and Avalanche Photo Diodes for Receive Components;
- Laser Packaging;
- Optical Sensor Devices:
    - Laser Diode-based Gas Sensors;
    - Infrared Sensors;
    - Photodiodes and photoresistors;
- Optical micro-electromechanical systems (MEMS) Packaging;
- High Power light emitting diode (LED) Packaging;

The "solder" glass contains around 75 % of lead to achieve a sufficiently low working temperature.

[1031] Op. cit. Pyreos Ltd. 2015a
[1032] Op. cit. Schott AG 2015a
[1033] Schott AG 2015b "Questionnaire 1 (clarification questionnaire), document "20150820_Ex_7c-I_Schott_Ans_Questionnaire-1_Schott_2015-07-30.pdf": Questionnaire 1 (clarification questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/SCHOTT/20150820_Ex_7c-I_Schott_Ans_Questionnaire-1_Schott_2015-07-30.pdf
[1034] Op. cit. Schott AG 2015a

Figure 22-3: Laser diode package (left) and cross section of its window cap (right)



Source: Schott[1035]

22.2.8 Technical Background of the Sensata Exemption Request

Sensata applies for the renewal of exemption 7c-I in its current scope and wording. Sensata[1036] uses lead in glass to obtain good bonding, sealing and encapsulation properties in for example: [1037]

- Bonding ceramic to ceramic to form a pressure sensing element;
- Bonding diverse sensing elements on steel including sealing; or
- Encapsulating electronic components, like thick film paste for hybrid integrated circuits, resistors, capacitors, etc..

The use of lead in bonding glasses results in lowering the softening point, lowering the viscosity, matching the coefficient of thermal expansion (CTE), improving affinity and strengthening environmental resistance of parts to be bonded, sealed and/or encapsulated.[1038]

The lead glass is used in sensors for measuring for example pressure and temperature to improve safety, increase energy efficiency, reduce emissions etc.[1039] The lead in the glass helps to achieve the following glass properties:

- Lead in the glass lowers the softening point. The glass is used to bond for example silicon strain gages with aluminium bond pads on stainless steel

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1035 Ibid.
1036 Op. cit. Sensata Technologies 2015a
1037 Ibid.
1038 Ibid.
1039 Ibid.

diaphragm. The firing temperature (at which the silicon is bonded to the stainless steel) must not exceed the (eutectic) temperature of the aluminium, potentially causing junction spiking and other reliability issues in the aluminium on silicon. Firing temperature is normally in the 850 °C range.[1040]

- Lead glass also has a low viscosity needed to flow well during the bonding process. Bad flow potentially causes pin holes and other (surface) imperfections which makes the glass sensitive to cracks and other mechanical damages when subjected to mechanical stresses which will occur during normal operation (= pressure exerted on steel and ceramic diaphragm). Cracks cause unacceptable sensor drift and potential sensor failure. Lead-free glasses have much higher viscosity (in the order of 100).[1041]
- Match the coefficient of thermal expansion of parts to be bonded. The coefficient of thermal expansion (CTE) of the glass should be within a specific range and compatible with stainless steel and alumina. Too low values cause a too high compressive stress in the glass, too high values can cause tensile stress. Both may result in glass cracks and, consequently, sensor failure.
- Improve affinity - to guarantee a sufficient adhesion between ceramic element and metal electrode or between semiconductor device and glass.
- Increase the resistance against adverse environmental conditions.

There is a growing need in for example household and industrial applications for mission critical sensors as made by Sensata, to make applications safer, more energy efficient and less emissive.[1042]

22.2.9 Amount of Lead Used Under the Exemption

Murata/JEITA et al.[1043, 1044] quantify the amount of lead used under the exemption in the EU with around 350 tonnes annually.

Murata/JEITA et al.[1045, 1046] base their estimate on 2013 data from the below companies, which represent the major players on the EU market:

- Ceram Tec;
- Emerson;
- EPCOS;
- Freescale;

[1040] Ibid.
[1041] Ibid.
[1042] Ibid.
[1043] Op. cit. Murata et al. 2015a
[1044] Op. cit. JEITA et al. 2015a
[1045] Op. cit. Murata et al. 2015a
[1046] Op. cit. JEITA et al. 2015a

- Johnson Matthey Piezo ProductsMeggitt DK;
- Morgan Advanced Materials;
- Murata;
- PI Ceramic.

Murata/JEITA et al.[1047, 1048] state that electrical and electronic components are used in a wide range of final products and markets, it is impossible to provide a precise figure of the amount of lead included in glass and ceramic components in the EU for EEE. The electronic equipment industry is engaged in the reduction of lead and environmental burdens within its powers, although it is impossible to completely cease the use of lead under the scope of 7(c)-I. They present the above estimate based on company figures. It should be noticed that there may be components with lead-containing ceramic and companies which are not included in this estimation. For this reason, the values presented here are given for reference purposes only.

22.3 Applicants' Justifications for the Exemption

Murata et al.[1049] state that our society requires the best health care and safety technology. Many components containing lead in a glass and/or ceramic matrix compound provide high security performance in EEE or save lives like, for example, overcurrent or over-temperature protection.

Murata et al.[1050] investigated the substitution of lead in glass and/or ceramic used in electrical and electronic components prior to the last review and have continued the investigation after 2009 as well; however, they have not found any substitution technology up to the present day, and extensive research has shown that there are no prospects of finding substitutes in the next five years. Consequently, they claim that it is necessary to extend exemption 7(c)-I for an additional validity period of 5 years for categories 1 – 7 and 10 equipment.

22.3.1 General Status of Lead Substitution in Ceramics of Electrical and Electronic Components

According to Murata et al.[1051] numerous potential compositions have been investigated for ceramic in the last 10 years and the main task is still the development of reliable technical solutions on an industrial scale. However up to the present moment, substitution technology has not been found and there is no prospect of finding it at least until the maximum validity period. No lead-free substitute with equivalent electrical properties, environmental adaptability range, reliability, workability and productivity has been found. Consequently, lead-containing glass and/or ceramic are indispensable for

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[1047] Op. cit. Murata et al. 2015a
[1048] Op. cit. JEITA et al. 2015a
[1049] Op. cit. Murata et al. 2015a
[1050] Ibid.
[1051] Ibid.

bringing out the required functionality and properties of the electrical and electronic components applicable to exemption 7(c)-I.

For piezoelectric ceramics, according to Murata et al.,[1052] niobium, tantalum, antimony, lithium, rare earth elements etc. have been investigated as elements for substituting lead as a constituent element of ceramic. However, the electrical (piezoelectric) properties are inferior when compared with lead-containing ceramic and cannot be stably achieved throughout a wide temperature range. Moreover, the properties described in research papers were obtained in the laboratory and experience has shown that these cannot generally be achieved stably at a mass production scale. There are still many remaining technical issues needing to be solved in order to achieve mass production of practical products. Adding to that, even in the case that mass production technology is achieved; the research has shown that the required properties for substituting almost all of the applications cannot be obtained.

Murata et al.[1053] claim that replacing PTC even in a certain resistance-Tc range only at the moment would need an overall change in powders conception used in the production of PTC. This is because not just one powder is used in production of a certain product but usually a mixture of two or more powders. With the alternative materials examined up until now, because of the strong limitations in regard to certain properties, only ceramic for applications with low Curie temperatures might be meaningful to undergo further investigation and development. Also for these low Tc applications, several constraints still exist.

22.3.1.1 Principle Elements for Lead Substitution in Ceramics

Murata et al.[1054] state that electrical properties of ceramic strongly depend on their crystal structure. According to Pauling's rule, in order to form the same crystal structure, constituent elements of ceramic, which can substitute lead are restricted to ions with a divalent valence and an ionic radius of 0.93-1.81 Å. On a purely scientific basis the elements which meet these conditions are limited to the following four:

- Cadmium;
- Calcium;
- Strontium; and
- Barium.

Cadmium is much more toxic than lead and is already restricted by the RoHS Directive, and thus is not appropriate even for consideration as a substitute material. "Lead-free" ceramics formed from alkaline-earth metals and titanium and zirconium, etc. have electrical properties strongly dependent on the operating environment temperature and voltage, and as they lack stability throughout a wide use environment range, i.e.

[1052] Ibid.
[1053] Ibid.
[1054] Ibid.

temperatures, voltages, frequencies, the alkaline-earth metals cannot be used as substitute materials of lead.

22.3.1.2 New Ceramics

Murata et al.[1055] report about the alternative approach of ceramics having a completely different composition than those using lead, as a substitute material for lead-containing ceramics. In spite of that, up to the present moment it has not been possible to achieve mass production of electrical and electronic components using substitute materials and having the same level of functionality. The electrical properties (piezoelectric properties) of (K, Na)NbO_3-type ceramics constituted of potassium, sodium and niobium are inferior when compared with lead-containing ceramic and cannot be stably achieved throughout a wide temperature range. [1056] Moreover, the properties obtained in the laboratory cannot generally be stably achieved at a mass production scale. There are still many remaining issues needing to be solved in order to achieve mass production of practical products. Adding to that, even in the case that mass production technology is achieved; the required properties for substituting almost all of the applications cannot be obtained.

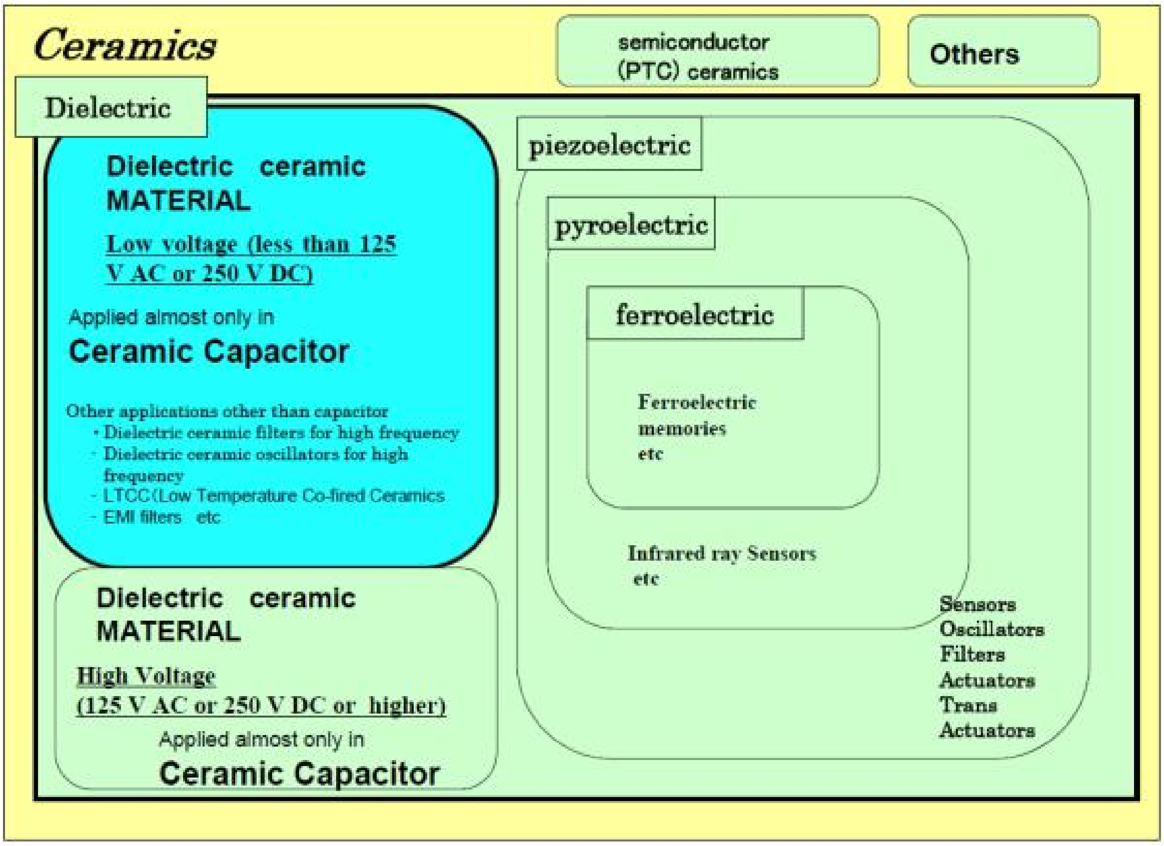
22.3.1.3 General Conclusion for Substitution or Elimination of Lead in Ceramics

Murata et al.[1057] conclude that for lead-containing ceramic falling into the technical scope of exemption 7(c)-I it is not possible to substitute lead by simply replacing it by another element. Moreover, attempts to obtain equivalent electrical properties from a completely different perspective have not progressed beyond ultimately obtaining similar results at best for a small part of the properties at laboratory level, and there are absolutely no technical perspectives to comprehensively eliminate lead from ceramic as of now.

Figure 22-4 gives an overview on the main types of ceramics in the scope of exemption 7c-I.

[1055] Ibid.
[1056] Jing-Feng Li, Ke Wang, Fang-Yuan Zhu, Li-Qian Cheng and Fang-Zhou Yao. "(K, Na) NbO3-Based Lead-Free Piezoceramics: Fundamental Aspects, Processing Technologies and Remaining Challenges", J. Am. Ceram. Soc., 1-20 (2013); source referenced in Murata et al. 2015a
[1057] Ibid.

Figure 22-4: Classification of ceramic materials and their main uses



Source: JEITA et al. in Zangl et al. (2010 [1058]*)*

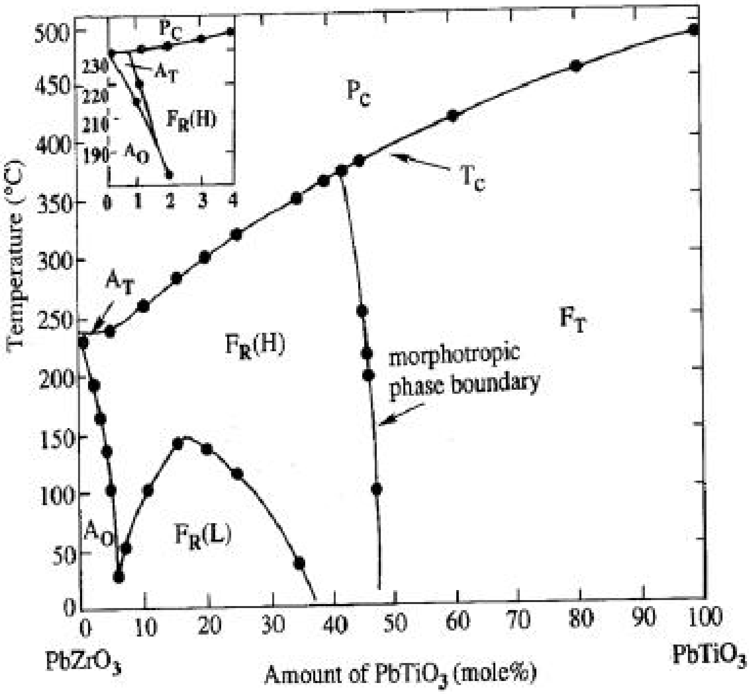
The following applicants present justifications for the continued use of lead in piezoelectric and PTC ceramics. The use of lead in dielectric ceramics in ceramic capacitors is covered by exemptions 7c-II, 7c-III and 7c-IV.

22.3.2 Substitution of Lead in PZT Ceramics

Murata e al.[1059] explain that Lead Titanium Zirconium Oxide abbreviated as PZT is the main material for piezoelectric devices. Lead (Pb^{2+}) is the main constituent in the solid solution of Lead Titanium Oxide with a tetragonal crystal structure and lead zirconium oxide with a rhombohedral crystal structure. Lead titanium oxide and lead zirconium oxide form a unique morphotropic phase boundary which is vertical above temperature as shown in the following phase diagram.

[1058] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010a
[1059] Op. cit. Murata et al. 2015a

Figure 22-5: Phase diagram with morphotropic phase boundary of PZT



Source: Jaffe, Cook Jaffe: Piezoelectric ceramics, referenced by Murata et al.[1060]

According to Murata et al.[1061], this special perovskite structure in combination with the unique electron structure of Pb brings out the unique combination of piezoelectric properties over a wide temperature range, like:

- High Curie temperatures;
- High piezoelectric charge constants;
- High electromechanical coupling factors;
- High quality factors and low losses for ultrasonic devices;
- High stability under different driving and environmental conditions, especially temperature;
- High reliability.

Murata et al.[1062] put forward that those properties are required for the applications. To aid the understanding of the applicant's justification, Table 22-4 explains essential parameters of PZT ceramics.

[1060] Ibid.
[1061] Ibid.
[1062] Ibid.

Table 22-4: Essential characteristics of PZT ceramics

Curie temperature	Temperature at which piezoelectric ceramics lose their piezoelectric properties.
Electro Mechanical Coupling Coefficient (k) of piezoelectric ceramics	Coefficient to show the efficiency to transform and communicate electric alteration into the energy of mechanical alteration (or vice versa) due to the piezoelectric effect: $k = \sqrt{\frac{\text{mechanical energy stored}}{\text{electrical energy applied}}}$ or $k = \sqrt{\frac{\text{electrical energy stored}}{\text{mechanical energy applied}}}$ In order to gain filter characteristics, materials with high values in this category are essential.
Mechanical Quality Factor Coefficient of piezoelectric ceramics	Shows the extent of mechanical loss near frequencies where the piezoelectric substance resonates. In resonators and oscillators, as the value becomes higher, the oscillator becomes more efficient and the fluctuation in the resonance frequency decreases.
Piezoelectric Strain Coefficient (d constant) (Piezoelectric material constant)	Indicates how efficient an electric field can generate strain of the piezoelectric material, or vice versa how efficient a strain applied on the ceramic can generate an electrical field. Higher values indicate higher efficiency. d=strain / applied electrical field If the value is high, the piezoceramic can generate displacement efficiently from a low electric field. Also, the output is larger for sensors and it can be used as good sensor material with high sensitivity.
PZT ceramics	Ceramics consisting of a mixture of $PbZrO_3$ and $PbTiO_3$.
Saturation polarization	Highest practically achievable magnetic polarization of a material when exposed to a sufficiently strong magnetic field.

Source: Zangl et al. 2010[1063]

Murata et al.[1064] inform that intensive work has been done in the past to identify alternatives for PZT resulting in more than 2,500 patent publications[1065]. Most of them go back to the known base compositions and indicate the development effort to improve the piezoelectric properties related to the base lead-free compositions. Murata et al.[1066] claim to continuously review the possibility of using alternative lead-free piezoelectric materials and have done internal and external developments towards lead-

[1063] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010a
[1064] Op. cit. Murata et al. 2015a
[1065] C.f. http://www.geocities.jp/kusumotokeiji/wadi.htm, source as referenced by Murata et al.
[1066] Ibid.

free materials, e.g. in the REALMAK[1067] and DELLEAD[1068] projects funded by the German Government, and in the sfb 595 at TU Darmstadt[1069], Germany.

Based on the state of the art in the development of lead-free alternatives for PZT, Murata et al.[1070] list three main groups of compositions as potential lead-free piezoceramic candidates:

- Barium titanate-based;
- Bismuth sodium titanate (BNT)-based; and
- Potassium sodium niobate (KNN)-based.

According to Murata et al.[1071], none of the above materials can be considered as a suitable overall lead-free substitute for PZT applications in the scope of the RoHS Directive. Figure 22-6 presents a comparison of basic physical properties of PZT and lead-free ceramics.

[1067] RealMAK - Technische Informationsbibliothek (TIB); Link: https://www.tib.eu/de/suchen/?id=198&tx_tibsearch_search%5Bquery%5D=RealMAK&tx_tibsearch_search%5Bsearchspace%5D=portal&tx_tibsearch_search%5Bsrt%5D=rk&tx_tibsearch_search%5Bcnt%5D=20; source as referenced by Murata et al./JEITA et al. 2016b

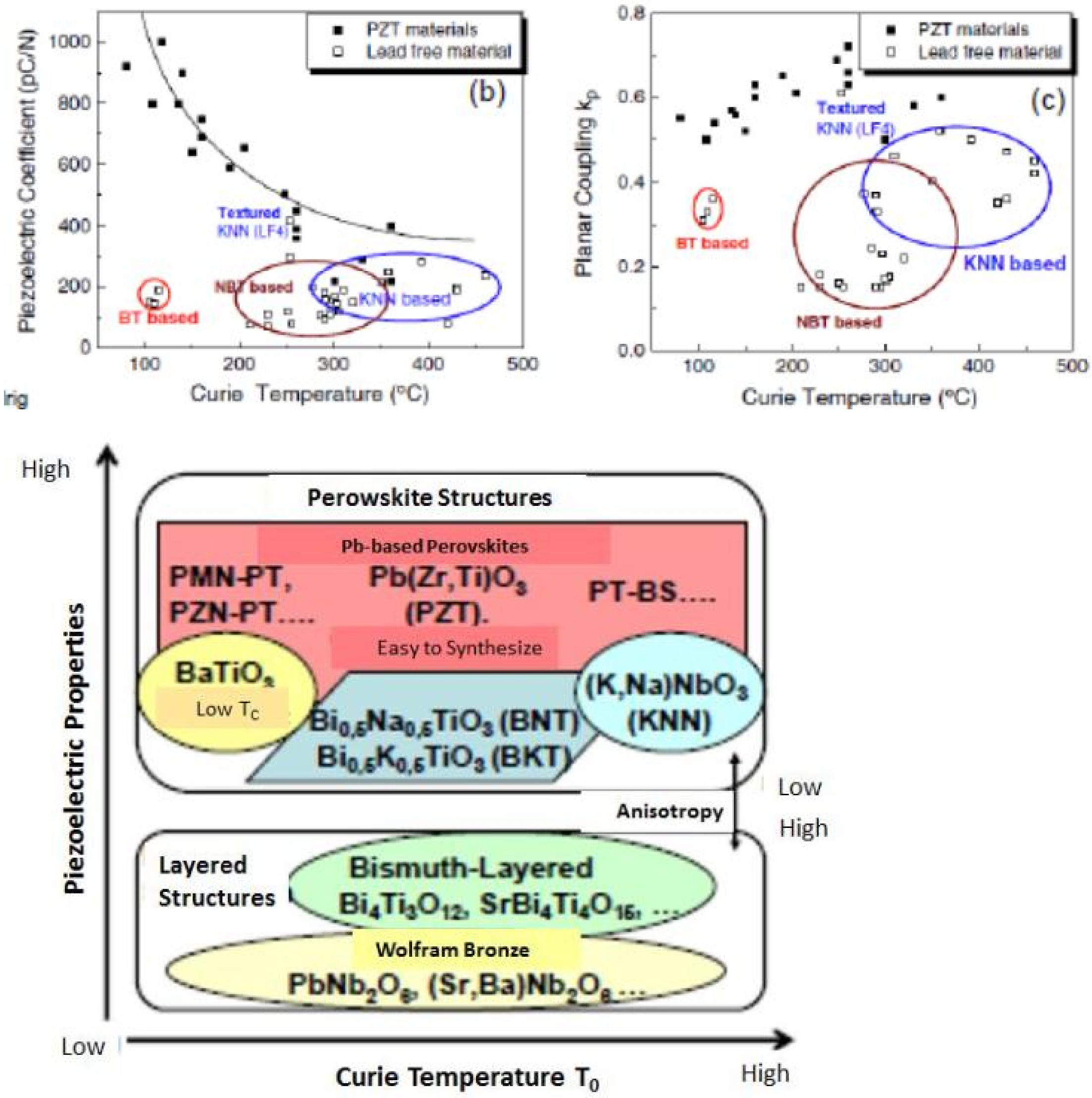
[1068] DelLead Bleifreie Piezokeramik für die Aktorik DelLead - Technische Informationsbibliothek (TIB); Link: https://www.tib.eu/en/search/id/TIBKAT%3A577111779/; source as referenced by Murata et al./JEITA et al. 2016b

[1069] Sfb595 – Technische Universität Darmstadt; Link: http://www.sfb595.tu-darmstadt.de/sfb595/sfb595_1.de.jsp; source as referenced by Murata et al./JEITA et al. 2016b

[1070] Ibid.

[1071] Ibid.

Figure 22-6: Performance comparison of lead-free and PZT ceramics



Source: M. Matsubara[1072], T.R. Shrout et al.[1073], referenced in Murata et al.[1074]

According to Murata/JEITA et al.[1075], the two top figures in Figure 22-6 show that the piezoelectric characteristics of piezoelectric ceramics largely fluctuate in a domain close

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[1072] M. Matsubara 2005: Processing and piezoelectric properties of lead-free (K, Na)NbO^3; dissertation department of applied chemistry, Graduate School of Engineering, Nagoya University
[1073] T.R. Shrout, S.J.Zhang: Lead-free piezoelectric ceramics: Alternatives for PZT?, in: Journal of Electroceramics 19, 2007, page 113 - 126
[1074] Murata et al. 2015c “Addendum to original exemption request, document "Leadfree_PZT_comparison.pdf",”
[1075] Murata et al./Jeita et al. 2016b “Answers to third questionnaire (ceramics), document "Exe_7c-I_Questionnaire-3_Murata-JEITA_2016-03-03_ceramics.pdf", received via e-mail by Dr. Otmar Deubzer,

to the Curie temperature, and when exceeding the Curie temperature the functionality of the ceramics is lost through depolarization. In order to use piezoelectric ceramics in practice, it is necessary that the piezoelectric characteristics be stable, therefore when considering the use environment and manufacturing conditions of general EEE, the Curie temperature needs to be 200 °C or more as a minimum, and preferably 250 °C or more.

22.3.2.1 Barium Titanate-Based Ceramics as PZT Substitute

Murata et al.[1076] [1077] state that lead-free barium titanate ($BaTiO_3$), the first piezoceramic ever, to their best knowledge for historic reasons is still used for niche military applications, specifically for naval underwater acoustics, which are outside the scope of the RoHS Directive. In the lead-free versions the working temperature is limited to the low Curie temperature of about 120 °C.

According to Murata et al.[1078] [1079], all other $BaTiO_3$ materials are modified with up to 10 % lead titanate to increase the Curie temperature. These materials are not used as a replacement for PZT, but are used due to other properties, e.g. density, where PZT cannot be used. Murata/JEITA et al.[1080] to the best of their knowledge, however, do not know applications for which such $BaTiO_3$ can be used, but PZT cannot. Upon further request, Murata/JEITA[1081] reaffirm that they do not know other properties besides density that would qualify the use of the $BaTiO_3$-based ceramics with up to 10 % of lead and that they do not know applications where they could be used where PZT cannot be used.

In principle, the $BaTiO_3$ materials with up to 10 % of lead titanate could be used to replace PZT ceramics, which contain 50 % of lead and more, in order to reduce the total amount of lead where its material properties are sufficient. Murata/JEITA et al.[1082] explain that the modification of $BaTiO_3$ with up to 10 % $PbTiO_3$ is a compromise to increase *Tc* from ~120 °C to ~150 °C. But with increasing lead content, the piezoelectric properties decrease. Therefore, $BaTiO_3$ with a lower lead content still have piezoelectric properties which are inferior compared to PZT. It is actually inferior even compared to other lead-free compounds.[1083] Moreover, in almost all applications, heat is applied in manufacturing processes or use environments, therefore higher Curie temperatures (200 °C or more, preferably 250 °C or more) are required. Even by partially substituting $BaTiO_3$

Fraunhofer IZM, from Klaus Kelm, Murata, on 22 March 2016" unpublished manuscript,

[1076] Op. cit. Murata et al. 2015a

[1077] Op. cit. (Murata et al. 2016a)

[1078] Op. cit. Murata et al. 2015a

[1079] Op. cit. (Murata et al. 2016a)

[1080] Op. cit. (Murata et al./Jeita et al. 2016b)

[1081] Murata et al./JEITA et al. 2016d "Answers to questionnaire 5a, document "Exe_7c-I_Questionnaire-5a_Murata-JEITA_2016-03-28_Ceramics_final.pdf", received via e-mail from Klaus Kelm, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016" unpublished manuscript,

[1082] Op. cit. (Murata et al./Jeita et al. 2016b)

[1083] Jaffe, Cook, Jaffe; Piezoelectric Ceramics; Academic Press Ltd.; 1971; source as referenced by Murata/JEITA et al. 2016b

by lead titanate, the Curie temperatures will increase to levels of not more than 20-30 °C, which is insufficient.

22.3.2.2 Bismuth Sodium Titanate (BNT) as PZT Substitute

BNT-based compositions are characterized by so called depolarization temperatures, at which the macroscopic piezoelectric properties are lost within a very narrow temperature range, which is much lower than the Curie temperature. Therefore, the usable working temperature range is limited to about 200 °C. BNT-based compositions show a strong anisotropic behaviour, which means that these materials have a low planar mode but a high thickness mode piezoelectric coupling with low piezoelectric charge coefficients, a low dielectric permittivity and moderate dielectric losses. Sometimes a high normalized charge coefficient d_{33}, i.e. induced strain / applied electric field strength, is mentioned in the literature suggesting a strong piezoelectric effect. At this point it must be clarified that this so called "giant piezoelectric effect" is caused by a field induced phase transition and it is not a linear piezoelectric effect. For PZT or similar components field induced phase transitions or domain switching processes lead to reliability issues due to crack propagation in the grains. Nonetheless, no reliability study is currently available according to Murata et al.[1084]

22.3.2.3 Potassium Sodium Niobate (KNN) as PZT Substitute

KNN-based compositions, textured or non-textured, have the highest potential to be an alternative to PZT because the Curie-temperatures are comparable to the PZT family and piezoelectric coefficients are between the BNT-based materials and PZT. But it must be pointed out that this strong piezoelectric coupling is found around polymorphic phase transitions and therefore shows a remarkable temperature dependence.

Murata et al.[1085] state that besides the dielectric and piezoelectric properties for the possible alternatives for PZT, the technological requirements for production on an industrial scale must be considered. The safe mass production of PZT materials based on conventional ceramic processes, including water-based mixing and milling processes as well as sintering in normal atmosphere, is well established. In contrast, for BNT-based materials as well as for KNN-based materials, different processes must be developed to bring out the properties obtained in the laboratory to mass production. In particular the KNN-based materials are the most challenging with respect to the synthesis. It is well known that the properties are strongly dependent on real stoichiometric composition, which can hardly be controlled because of the volatility of the alkaline metals. For both KNN and BNT materials, especially the mixing and milling play a crucial role. Because of the water solubility of most of the raw materials, processes must be switched from water- to solvent-based ones, with a high impact on health and environment protection.

[1084] Op. cit. Murata et al. 2015a
[1085] Ibid.

Murata/JEITA et al.[1086] state that new technological routes for a stable mass production must be developed. At the moment this is not yet achieved, and it is not foreseeable when a breakthrough can be achieved. In summary, Murata et al.[1087] conclude, none of the known lead-free piezoelectric materials is a suitable overall substitute for PZT.

22.3.2.4 Bandelin's Application-specific Exemption Request for use of PZT Ceramics in High Power Transducers

Bandelin[1088] claims they are in constant contact with the manufacturers Ceram Tec and Pi Ceramic in Germany in order to develop potential alternatives to substitute lead in high-performance piezoelectric ceramics, especially for the early testing of lead-free perforated discs in high-performance ultrasonic transducers. Bandelin has already conducted such tests with samples from Honda/JP, but the results were quite negative. It is not possible to substitute PZT by changing the construction of high-performance ultrasonic transducers and substituting the material with a lead-free ceramic has not been conceivable to date.

High-performance applications with hard PZT basically employ the inverse piezoelectric effect to produce high dynamic alternating oscillations in high-frequency resonant operation, with amplitudes of up to 10 µm per ceramic element in continuous operation without cooling.[1089]

The known material threshold values also yield clear evidence of the unsuitability of lead-free BNT and KNN piezo ceramics for high-performance applications. Table 22-7 compares the mean values for core performance parameters of various ceramics.[1090]

Table 22-7: Comparison of material properties of ceramics

Material	tanδ (10^{-3}) (electrical loss angle)	Qm (mechanical Q)	Tc/Td Curie/depolarisation temperature
Soft PZT	20	70	260 °C (Tc)
Hard PZT	4	800	320 °C (Tc)
BNT ceramic	30	200	200 °C (Td)
KNN ceramic	30	unknown	290 °C (Tc)

Source: Bandelin[1091]

Due to the higher internal losses in lead-free piezo ceramics, a higher proportion of the supplied electric power is converted into heat, leading to significantly lower energy

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[1086] Op. cit. (Murata et al./Jeita et al. 2016b)
[1087] Op. cit. Murata et al. 2015a
[1088] Op. cit. Bandelin Electronic GmbH 2015a
[1089] Op. cit. Bandelin Electronic GmbH 2015b
[1090] Ibid.
[1091] Ibid.

efficiency in the products. For instance, high-performance ultrasonic transducers are pre-stressed by the sonication liquid by up to 80 °C in ultrasonic baths, so the remaining permitted range for the piezo ceramic operating temperature is extremely limited (a continuous operation temperature of only 120 °C is generally prescribed by the manufacturers), and thus the piezo ceramic must have high efficiency rates or low losses.[1092]

To Bandelin's knowledge, no commercial technology is available for manufacturing adequate piezoelectric components from BNT/KNN, which could replace PZT material. Moreover, there is still no reliable evidence of the reliability, long-term stability or availability of piezoelectric components made from these materials.

Bandelin[1093] used lead-free BNT piezo ceramic material from HONDA ELECTRONICS, Japan, with the same geometrical dimensions as their own hard PZT ceramics. This permitted direct comparison with high-performance ultrasonic transducers of identical construction. The results showed that, due to the lower Q and higher loss factor, the necessary amplitude and performance range in the analogue HF operating voltage range for hard PZT could not be achieved. Even in the ordinary continuous operation test, the transducers constructed with BNT discs heated up so strongly as to preclude their use in Bandelin's products. Due to the low losses, cooling of their high-performance transducers with hard PZT is unnecessary, and, in fact, functionally impossible.

Bandelin[1094] does not expect any alternative materials to substitute the PZT ceramics in the next 10 years. PZT is the only material that can be used in high-performance ultrasonic transducers. PZT in a finished component is said by Bandelin to be neither harmful to the health nor hazardous to the environment and can be disposed of properly.

Bandelin[1095] fulfil their duties in the disposal of electronic waste (including piezo materials) in the scope of their electronic waste registration and annual verification thereof. In light of these facts, they apply for the amendment of exemption 7c-I.

22.3.2.5 Pyreos'Application-specific Exemption Request for Lead in Ceramics

Pyreos[1096] claims it has spent considerable resources to reduce the content of lead in the sensors resulting in a lead reduction compared to the incumbent pyroelectric sensor technology by about a factor 1,000. As a result, the amount of lead in the sensors already implemented by Pyreos today is extremely low. In order to reduce the amount of lead in the sensors, Pyreos[1097] used PZT materials with the same lead-content like other

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[1092] Ibid.
[1093] Ibid.
[1094] Op. cit. Bandelin Electronic GmbH 2015a
[1095] Ibid.
[1096] Op. cit. Pyreos Ltd. 2014
[1097] Pyreos Ltd. 2016a "Answers to questionnaire 2, document "Questionnaire-2_Pyreos_2016-03-06.pdf",

manufacturers, but the PZT thinfilm on the silicon decreases the total amount of PZT in the sensors and as a consequence the amount of lead.

In a next step, Pyreos[1098] wants to develop an infrared absorption layer that will allow to further reduce the thickness and the pixel area of the pyroelectric sensor by a factor of 10-100 within an intended timescale until 2018, and a lead-free infrared absorption layer until 2020. Pyreos[1099] recently located a new partner for the absorption layer implementation with superior performance and is evaluating manufacturability. With the lead-free infrared sensor they have just started as partners of a government funded project to further investigate and establish the production of useful lead-free pyroelectric thin films. If successful, it would in principle enable lead-free thin film sensors, but it will take considerable time for it to mature to be industrially accepted at a cost effective price.

22.3.3 Substitution of Lead in PTC Semiconductor Ceramics

Murata et al.[1100] explain that PTC ceramics (Positive Temperature Coefficient) increase their electrical resistance with increasing temperature. Examples of material compositions are doped barium (BT) and lead titanate (PT) mixtures. The basic PTC material barium-strontium-lead-titanate is a perovskite which undergoes a phase transition from ferro- to paraelectric at the Curie temperature. If properly processed and slightly donor doped (< 1 mol%) such materials are PTCR active so to speak, i.e. semiconductive at low temperatures and quite highly resistive at temperatures above the Curie temperature. It is possible with dopants and some changes in proportions of components and additives to tune the properties of a composition to a specific targeted application.

22.3.3.1 Classification of PTC Ceramics

Murata et al.[1101] divide the active PTCR materials into four sections based on resistivity and Curie temperature, in which each individual section contains hundreds of material recipes based on BT and PT:

- **Materials with Curie temperatures below 120 °C and resistivity values below 1,000 ohm.cm:**
  These materials serve applications like overload protection, inrush current limitation, heating, telecom line protection, motor protection, motor start and temperature sensing. Lead titanate is added to the recipes to decrease the resistivity and increase performance because lead increases the ferroelectricity in the ceramic material.

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received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Torben Norlem, Intertek, on 23 March 2016: Second questionnaire" unpublished manuscript,

[1098] Op. cit. Pyreos Ltd. 2014

[1099] Op. cit. (Pyreos Ltd. 2016a)

[1100] Op. cit. Murata et al. 2015a

[1101] Ibid.

Lead-free materials are available for this region but the performance and durability that can be achieved is significantly lower and for most applications, such materials can therefore not be used. Based on the current state of the art, breakdown voltages are lower by approximately 30 % for lead-free ceramics. As a result, the present situation is that no lead replacement with sufficient performance has been found yet to produce a PTC with a Curie temperature below 120 °C and low resistance values.

- **Materials with high Curie temperatures above 120 °C and resistivity values below 1,000 ohm.cm:**
  This is the most commonly used material type. It serves applications like overload protection, inrush current limitation, telecom line protection, motor protection, motor start, temperature sensing and heating. Lead is added to the recipes to achieve both higher Curie temperatures and lower resistance.
  A lead-free bismuth-based perovskite material was the main material investigated as a substitute in the literature. It exhibits higher Curie temperatures and can therefore be used to increase the Curie temperature of a solid solution with barium titanate. However, it has been demonstrated that such components as BNT (bismuth sodium titanate) have limited solubility in barium titanate and can increase the Curie temperature only to regions around 160 °C. At the same time electrical parameters including important ones like steepness of resistance change and breakdown voltage strength deteriorate dramatically. Especially the energy efficiency for switching applications like motor starters will be influenced strongly. The break down voltage for typical motor start elements would be reduced by approximately 30 % and the resistance stability during application would decrease as well. The performance in terms of reliability is affected most. Tests according to the industry standard IEC 60738-1 like electrical endurance, electrical cycling, temperature storage, show higher resistance changes by an order of magnitude, compared to the current standard. In the IEC 60738-1 test procedure for humidity even higher changes of up to two orders of magnitudes are observed.
- **Materials with low Curie temperature and resistivity values of 1,000 ohm.cm and more:**
  This section is one of the most critical ones in regard to material development. It mainly serves applications like overload protection, inrush current limitation, temperature sensing and heating. Nevertheless, Industry has started some further investigations in this direction. The reduction of lead would reduce the breakdown voltage performance by approximately 30 %. Additionally, materials with reduced or no lead are especially problematic in terms of reproducibility of the resistance and resistance spread.
- **Materials with high Curie temperature and resistivity values of 1,000 ohm.cm and more**:
  They serve applications like overload protection, inrush current limitation and especially heating. These materials require lead titanate compounds in the

ceramic because of the high Curie temperature of up to 300 °C. So far no material system beside BT and PT has been developed that achieves Curie temperatures above 200 °C. Adding lead to the barium titanate matrix of the PTC ceramic is the only known procedure to raise the Curie temperature of the basic barium titanate without loss of important properties and functionality.

22.3.3.2 Substitution of Lead in Ceramic Materials with Curie Temperatures below 120 °C

Murata et al.[1102] explain that adapting strontium titanate generally may achieve certain temperature ranges for applications with Curie temperatures Tc < 120 °C.

In the low ohmic section at Tc<120°C, Murata et al.[1103] report that the reduction of lead reduces the ferroelectricity (permittivity, polarization) of the material involved. BNT and BKT are reported to have a relative permittivity of less than 5,000 where lead titanate shows a relative permittivity of around 10,000. The effectiveness of the charge compensation, which appears at temperatures below Tc, is due to the magnitude of the ferroelectric material involved. According to Heywang[1104], the mechanism which causes the PTC effect decreases if relative permittivity at the grain boundary is reduced.

According to Murata et al.[1105], the replacement of lead will decrease the lifespan of the product as well as its voltage breakdown strength for around 30 % depending on the material type in question. Even if PTC materials are produced without lead for Tc lower than 120°C, it will come at the cost of reduced performance.[1106] Hence, increased dimensions, more material and energy need to be used to produce the individual product. Furthermore, lead-free materials cannot serve all applications and functions. This demonstrates the still many problems need to be solved before a "lead-free" material can be produced in practice.

Murata et al.[1107] see a major challenge in substituting lead in ceramic materials with low Tc and high resistance because of the difficulties with reproducibility and resistance spread.

[1102] Ibid.
[1103] Ibid.
[1104] W.Heywang. Semiconducting Barium Titanate. J Mater Sci 1971; 6:1214-1226; source as referenced by Murata et al.
[1105] Ibid.
[1106] H. Takeda et.al.: Fabrication and operation limit of Lead -Free PTCR ceramics using BT-BNT; Journal of Electroceramics (2009) 22, 263-269; source as referenced by Murata et al.
[1107] Ibid.

22.3.3.3 Substitution of Pb in Ceramics with Curie Temperatures of 120 °C and Higher

For high temperature sections, Murata et al.[1108] consider BNT (bismuth sodium titanate) and BKT (bismuth potassium titanate) to be the most promising materials to push the lead-free limit. Those materials work best at higher resistances above 1,000 ohm-cm. In this high ohmic section above 120°C, a Tc could be reached up to 200°C according to Takeda et al.[1109]. This limitation is mainly caused by the volatility of Bi which changes the composition and incorporation mechanism and thereby the sintering characteristics and achievable resistance, respectively. Wei et al.[1110] suggest a limit at 160 °C because above that temperature the ceramic becomes highly resistive. The best performances were reported at Curie temperatures below 150 °C, which are, however, still distinctly inferior to the traditional materials containing lead titanate.

Murata et al.[1111] expect the breakthrough voltage to be rather low due to the fact that the PTCR steepness α [%/C] around Tc is below 10 %/C, which influences the maximum resistance that is directly related to the break down voltage. For comparison, values of 60 %/C can be achieved with the standard lead titanate material. At the moment it is not possible to make a reliable statement about the Tc reproducibility. However, due to the volatility of Bi a poor Tc reproducibility and predictability is expected.

Murata et al.[1112] point out that the results obtained so far are at laboratory (research) level, and reliability and mass production technology have not been ensured. Consequently, there are no prospects for actual mass production supply being provided, and the current situation does not allow the substitution in the next few years.

According to Murata et al.[1113], the low ohmic section above 120°C, which is the economically most important section, is even more challenging. Naturally, the PTC effect is weaker than for higher resistances due to the very basic principles involved. The drawback of the new BNT- and BKT-based materials in terms of steepness; break down voltage and so on, becomes even more dominant than at high ohmic quarters. B.Y. Wu et.al.[1114] assessed the limit at Tc=160°C for BT PTC materials doped with BNT. Higher additions of BNT to BT in order to increase the Tc to higher temperatures would lead to high resistivity well above 1,000 ohm-cm in the PTCs, which Murata et al.[1115] deem

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[1108] Ibid.

[1109] H. Takeda et.al.: BaTiO 3–(Bi 1/2 Na 1/2) TiO 3 Solid-Solution Semiconducting Ceramics with Tc> 130 C; Appl. Phys. Lett. 87 (2005) 102104; source as referenced by Murata et al.

[1110] J. Wei et.al.: Effects of BNT Addition on the Microstructure and PTC Properties of La-Doped $BaTiO_3$-Based PTCR Ceramics; Ferroelectrics, 403; 91-96, (2010); source as referenced by Murata et al.

[1111] Ibid.

[1112] Ibid.

[1113] Ibid.

[1114] B.Y. Wu et.al.: A Study of PTC Ceramics Based on (V1-x, Crx)2 O3 Electroceramics; British Ceramic Proceedings No.41 Stoke-on-Trent, 1989, p.195-203 Institute of Ceramics; referenced by Murata et al.

[1115] Ibid.

unacceptable. According to Wei et al.[1116], the limited solubility of BNT in BT causes the effect due to which Bi^{3+} as an acceptor would occupy Ti^{4+} positions, which would lead to a reduction of free charge carriers.

According to Leng et al.[1117], the use of BKT-doped BT induces a similar limitation. Although there are reports of BNT and BKT-containing materials as an additive to BT replacing lead titanate in the range up to 160 °C for low voltage applications, Murata et al.[1118] explain that it is most important that the lowest resistance that is achievable is in the range of 100 Ohm-cm. This is still well above the limit of 2 Ohm-cm for lead-containing materials (traditional technique).

Murata et al.[1119] conclude that material studies on BNT reveal the lower performance and lower reliability of these lead-free PTC materials compared to the standard lead-containing materials. Actual results show 30 % lower breakdown voltage, 30 % lower steepness of the RT-curve and more than 1,000 % less stability at temperatures above 160 °C.

22.3.4 Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds

Murata et al.[1120] claim manufacturers have investigated boron, phosphorus, zinc, tin, bismuth, etc. as potential elements for substitution of lead as a constituent element of glass. "Lead-free" glasses using these elements can partially promote machining efficiency (ability to minimize energy consumed to apply heat, mechanical pressure, etc. in manufacturing processes) and affinity (ability for mutually wetting and bonding different materials such as metal and ceramic) which are necessary properties for achieving the required functionality of electrical and electronic components. However, when compared with lead-containing glasses, chemical stability and mechanical strength of the glasses are insufficient and do not meet the required functionality.

Murata et al.[1121] state that boron, phosphorus, zinc, bismuth, etc. are, in a general manner, inadequate for substituting lead as constituent elements of glass and as of now there are absolutely no technical perspectives for comprehensively eliminating lead from glass of electrical and electronic components.

[1116] J. Wei et.al.: Effects of BNT Addition on the Microstructure and PTC Properties of La-Doped BaTiO3-Based PTCR Ceramics; Ferroelectrics, 403; 91-96, (2010); source as referenced by Murata et al.

[1116] Ibid.

[1117] [2] S. Leng et.al.: Synthesis of Y doped BT-BKT Lead-Free Positive Temperature Coefficient of resistivity ceramic and their PTC effects; Journal of American Ceramic Soc. (2009) 92 [11], 2772-2775; source as referenced by Murata et al.

[1118] Ibid.

[1119] Ibid.

[1120] Ibid.

[1121] Ibid.

Murata et al.[1122] conclude that no substitution technology is available that can provide the high functionality required for electrical and electronic components. Only lead glass can bring out the necessary characteristics such as integrity of the layer, step coverage, delamination resistance, hermetic sealing, charge balance etc. and reliability to ensure public safety and avoid additional waste from premature failure, simultaneously satisfying high reliability requirements and usability over a wide range of applications. Lead glass is used for insulating, protection, resistance, adhesives, bonding, hermetic sealing and other uses.

Murata et al.[1123] state they cannot set a technical goal for a comprehensive substitution of lead glass concerning the technical scope of exemption 7(c)-I, and there are no perspectives for such in the foreseeable future. Therefore Murata et al. request the renewal of the exemption at least until the maximum validity period. Otherwise, Murata et al.[1124] fear accidents originating from crucial failures in EEE incorporating electrical and electronic components composed of glass with lead substituted by these elements due to their insufficient reliability and quick deterioration.

Bourns[1125], Murata et al.[1126], Schott[1127], Sensata[1128] and Vishay[1129] present specific and exemplary applications where lead in glass and glass ceramic matrices cannot be fully replaced. The below presentation of the application examples follows the system of Murata et al.[1130] presented in Table 22-3 on page 435.

22.3.4.1 Lead Glass for Protection and Insulation

Example 1.1 – Lead Glass Frits to Hermetically Seal Semiconductor Devices

Murata et al.[1131] explain that semiconductor device circuitries are susceptible to corrosion. They are protected by depositing a thin layer of glass to form a hermetic seal. This passivation glass layer must not impose stresses to the silicon or circuitry so its physical characteristics must be precisely controlled and its chemical composition is

[1122] Ibid.
[1123] Ibid.
[1124] Ibid.
[1125] Bourns Inc. 2015b “Request for continuation of exemption 7c-I, document "20150818_Ex_7c-I_Bourns_Questionnaire-1_2015-07-28.pdf", clarification questionnaire: Clarification questionnaire,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/20150818_Ex_7c-I_Bourns_Questionnaire-1_2015-07-28.pdf
[1126] Op. cit. Murata et al. 2015a
[1127] Op. cit. Schott AG 2015a
[1128] Op. cit. Sensata Technologies 2015a
[1129] Op. cit. (Vishay 2015a January 2015)
[1130] Op. cit. Murata et al. 2015a
[1131] Ibid.

important to avoid interactions with dopants or with subsequent process step chemicals. The glass must have the following properties and processability:[1132]

- Temperature of the annealing process > 800 °C to better flow glass into the silicon groove / step coverage integrity of the layer (to avoid cracks);
- Chemical compatibility with the further steps of the process, and the back end: dicing and assembly integrity of the layer (holes);
- Compatibility of the thermal expansion coefficient with the silicon for mechanical behaviour to control stress resistance (delamination); and
- Electric charges in the glass balanced with the dopants in the junctions, for electrical stability in temperature and electrical stress (leakage current drift under high voltage stress).

According to Murata et al.[1133], the glass passivation is needed to protect the junction and to guarantee the proper behaviour of the semiconductor under high reverse voltage and the reliability of the component. The glass layer must not impose stresses on the silicon and must be compatible with the chemical process integration. The electrical insulation capability of glass is very high: it helps to achieve high voltage devices with a limited periphery area.

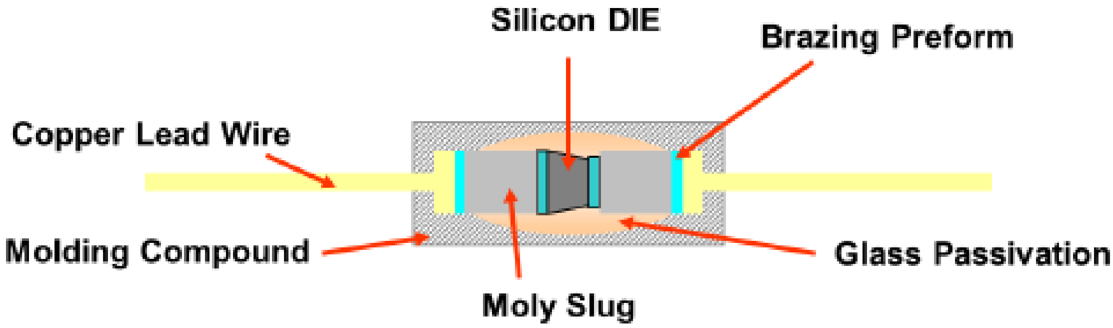
Murata et al.[1134] do not mention any specific research or efforts to substitute or eliminate lead in this application besides the general justification directly under Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds, page 460).

Example 1.2 – Glass for Hermetical Sealings of Diode Chips

According to Murata et al.,[1135] glass sleeve diodes in various sizes like in DO-35, DO-41, SOD-80 MELF (Metal Electrode Leadless[1136] Faces) packages, glass bead diodes, super-rectifiers etc., use glass to hermetically seal the diode chip. The advantage of packages with glass as the body or part of the body is the ability to hermetically seal the chip. This has technological advantages like better reliability, moisture-resistance, etc. over non-glass packages. Lead is needed in the glass to lower the melting point and reduce the viscosity, which together provides good hermetic sealing and adhesion to the adjacent metal plugs. Figure 22-8 shows an example.

[1132] Ibid.
[1133] Ibid.
[1134] Ibid.
[1135] Ibid.
[1136] “Lead” does not stand for the chemical element Pb, but for the carrying structure of the component

Figure 22-8: Schematic view of a high voltage “Superectifier ®” diode with glass as part of the package



Source: Murata et al.[1137]

Murata et al.[1138] do not mention any specific research or other efforts to substitute or eliminate lead in this application besides the general justification directly under Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds, from page 460).

Example 1.3 – Lead Glass for Insulation and Protection in Thick Film Resistors

Glass passivation layers block or help to block the sulfur, e.g. from traces of atmospheric hydrogen sulphide, from reaching the silver in the inner electrodes of thick film resistors, which might cause open circuit failures. The lead makes the glass pliable in the manufacturing process of the chip resistor to form a hermetic seal. The lead addition allows for lower oven temperatures, better quality and higher yields.

Murata et al.[1139] do not mention any specific research or efforts to substitute or eliminate lead in this application besides the general justification directly under Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds, from page 460).

Example 1.4 – Lead in Enamel Coatings of Wire Wound Resistors

Vishay[1140] requests an exemption for wire wound resistors with enamel coatings containing lead (Pb) as lead-oxide (Pb_3O_4) in glass. In order to limit thermal stresses and gain long term stability and high reliability, the applicant claims that exemption 7(c)-I is needed to reach:

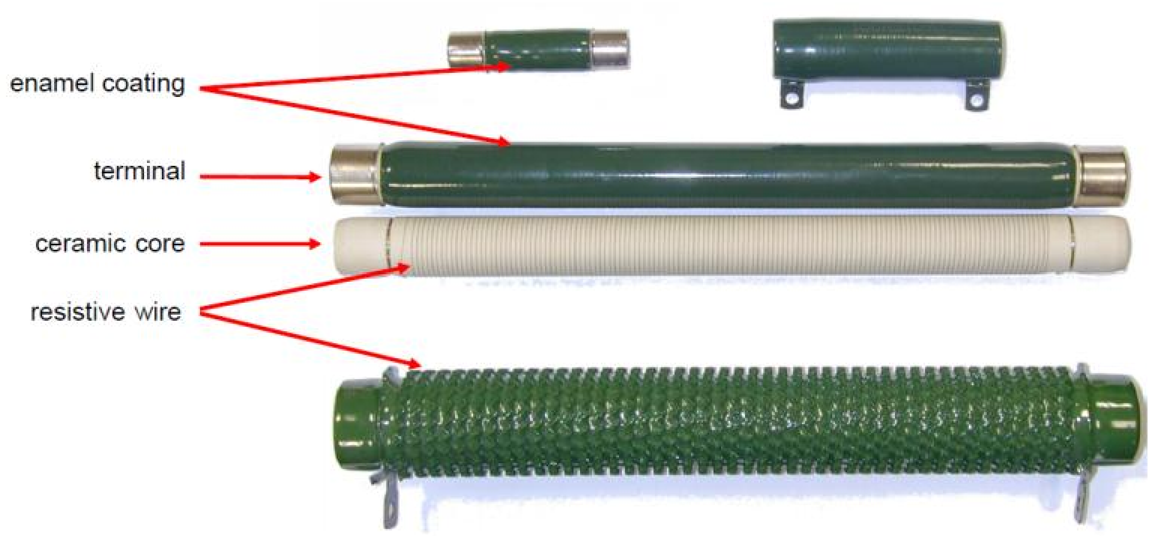
- Good flow conditions of the molten glass during production;

[1137] Ibid.
[1138] Ibid.
[1139] Ibid.
[1140] Op. cit. (Vishay 2015a January 2015)

- Virtually void free coverage of resistive metal wire and ceramic core; and
- Thermal expansion well matched to the resistive metal wire and ceramic core.

Vishay [1141] explains that wire wound resistors are made long-lasting and reliable by protecting the resistive wire from detrimental ambient conditions such as high humidity by virtually impenetrable enamel coatings (glass) that contain lead. Examples provided are shown in Figure 22-9.

Figure 22-9: Wire wound resistors



Source: Vishay[1142]

Vishay[1143] states that the thermal expansion of the different materials (ceramic, metal and glass) must match each other in order to limit destructive thermal stresses. The enamel coating (glass) otherwise cracks and can delaminate from the ceramic core and/or the metal wire, as Figure 22-10 illustrates.

[1141] Ibid.
[1142] Ibid.
[1143] Ibid.

Figure 22-10: Cracks (left) and delamination (right) in enamel wire wound resistor coatings

Source: Vishay [1144]

Vishay[1145] describes that cracks allow humidity to penetrate and reach the metal wire. This can lead to detrimental corrosion of the wire. Delamination reduces the effectiveness of heat transport away from the resistive wire. This can lead to hot spots and over-heating. Both effects can destroy the resistor within a fraction of the usual lifetime even under standard operating conditions.

According to Vishay[1146], wire wound resistors are used in many applications in the industry and transportation sector because of their unrivalled high pulse load capability. The load, continuous or pulse, leads to an excess temperature of the resistor of up to 600 °C. Therefore, the thermal expansion of the different materials (ceramic, metal and glass) must match each other in order to limit destructive thermal stresses. The enamel coating is non-flammable too, making the durable wire wound resistors an excellent choice for relevant "safety" applications.

Vishay[1147] takes significant effort to eliminate lead (Pb) in the enamel coating of wire wound resistors, but so far no technically equivalent solution is available to allow for the present quality standard under usual operating conditions. Vishay[1148] had carried out a first project to use lead-free enamel coating on wire wound power resistors from 1999 to 2002, and was not successful. A following project has been started in December 2014. An enamel coating has to comply with the following requirements like, to name some:[1149]

- Melting temperature;

[1144] Ibid.
[1145] Ibid.
[1146] Ibid.
[1147] Ibid.
[1148] Op. cit. Murata et al. 2015b
[1149] Ibid.

- Viscosity;
- Surface tension;
- Coefficient of thermal expansion; and
- Alkaline ions.

According to Vishay[1150], typical lead (Pb) free enamel coatings usually have too high melting temperatures, and the viscosity, surface tension, and the coefficient of thermal expansion do not meet specifications for suitable processing. From today's viewpoint the most likely replacement of lead is bismuth (Bi).The melting temperature of the lead-free enamel coating can be lowered to some extent by adding considerable amounts of bismuth. However, this may pose unforeseeable health risks due to the lack of knowledge about the level of toxicity of bismuth. Other materials than lead containing glass, such as cement or epoxy, do furthermore not fulfil the specifications of long term stability or non-flammability, respectively. Only the present mix of glass frits with special additives fulfils all of the technical/physical requirements to meet customers' specifications concerning reliability and long term stability.

Example 1.5 – Glass Coatings for Insulation in Negative Temperature Coefficient (NTC) SMD Resistors

Vishay[1151] uses lead-containing glass in two series of NTC surface mount device (SMD) thermistors illustrated in Figure 22-11. The thermistors cover a size range of 0402 to 1206 and a large resistance range from 2 kΩ to 470 kΩ.

Figure 22-11: NTCS and NTHS SMD thermistors

Source: Vishay[1152]

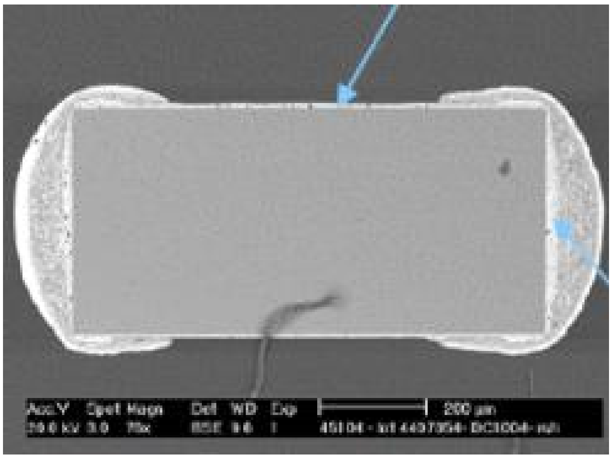
As shown in Figure 22-12, the thermistors contain lead silicate glass on four sides (upper arrow) and a lead silicate glass frit in Ag wrapped around the termination (lower / right hand arrow).

[1150] Ibid.

[1151] Vishay 2015b 2015 "Document "NTC – Glass coating for insulation.pdf", submitted as additional reference for the exemption request of Murata et al. 2015a: Document referenced in the exemption request of Murata et al. 2015a" (January 2015) unpublished manuscript,

[1152] Ibid.

Figure 22-12: Lead-silicate class in thermistors



Source: Vishay[1153]

Vishay [1154] reports that NTC SMD (Surface Mounted Devices) resistors need lead-containing glass coatings for several reasons:

- **High accuracy:**
  The distance between the two terminations does not influence the R value as the glass layer insulates the ceramic body.
- **Insulation of the ceramic body during the plating process**:
  Without the glass coating, Sn and Ni metals are deposited as well on the ceramic body modifying the electrical properties.
- **Variety of ceramics compositions:**
  Each resistance value has a specific ceramic composition. More than 60 different ceramic compositions are used with thermal expansion coefficient going from 6 ppm/K to 14 ppm/K. So it is very difficult to find one glass that can be used for the complete resistance range.
- **Firing temperature:**
  The firing temperature of the glass must be high enough to sustain the firing of the silver termination in the subsequent process.
- **Purity and stability of the glass**:
  The glass is deposited onto the ceramic body by electrophoretic deposition. Therefore a stable glass suspension must be achieved. Very pure glass (free of alkali) and a narrow particle size distribution are needed.
- **Adhesion of the silver layer (Ag) to the ceramic:**
  Glass frits with Ag paste are used to achieve good adherence of the Ag layer

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[1153] Ibid.
[1154] Op. cit. (Vishay 2015a January 2015)

onto the ceramic. During firing, the glass diffuses into the ceramic and reacts with it creating an interface between ceramic material, glass and silver. Again here, it is very difficult to find a lead-free glass reacting properly with the complete ceramic range keeping all the performances: ohmic contact, no cracks, good adherence, good reliability in thermal cycling, damp heat, endurance tests. Furthermore, the interface must be resistant to the acidic plating bath solutions entering the porous terminations during plating. It is known that Pb free glasses are not well resistant to those solutions. The chemical attack of the interface by plating solutions has a dramatic effect on the reliability of the parts as the termination is coming lose from the ceramic body.

Vishay[1155] claims to undertake significant efforts to eliminate lead in the glass coating and silver termination of the NTC SMD but so far, no technical mature solution is available. As each resistance value has a specific ceramic composition, more than 60 different ceramic compositions are used with thermal expansion coefficient going from 6 ppm/K to 14 ppm/K. So Vishay[1156] states that it is very difficult to find one glass that can be used for the complete resistance range.

Example 1.6 - Metal Pressure Sensors

Murata et al.[1157] report the use of lead oxide glass in glass metal pressure sensors. The glass provides a seal and an electrically insulating surface for a capacitor plate.

Murata et al.[1158] do not mention any specific research or other efforts to substitute or eliminate lead in this application besides the general justification directly under Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds, from page 460).

22.3.4.2 Lead in Functional Glass Compounds/Resistance

Example 2.1 - Pastes with Lead in Glass

According to Murata et al.[1159], pastes with lead in glass are generally used as functional (resistive) material, glass coating and/or contact layer.

Murata et al.[1160] claim that substitutes are unreliable as current product specifications or stability requirements cannot be fulfilled. In substitutes, lead is replaced by bismuth (Bi) with possible environmental concerns, c.f. Section 22.3.5 from page 478.

[1155] Op. cit. (Vishay 2015b January 2015)
[1156] Ibid.
[1157] Op. cit. Murata et al. 2015a
[1158] Ibid.
[1159] Ibid.
[1160] Ibid.

Example 2.2 - Pastes With Lead In Glass And Lead Containing Functional Complex Oxides For High Ohmic Resistive Materials

According to Murata et al.[1161], pastes for high ohmic resistive layers require lead in glass and lead containing functional complex oxides in order to meet required specifications:

- No reaction with the glass matrix and no decomposition;
- Sufficiently high sheet resistivity;
- Low TCRs (Temperature Coefficient of Resistance);
- Low temperature sensitivity;
- Low moisture sensitivity – this alters resistance;
- Low humidity sensitivity – this changes the resistance value;
- Low process sensitivity;
- High resistance deviation after soldering processes used in surface mount processes.

Murata et al.[1162] claim lead-free resistor pigments in combination with the lead-free glasses showed:

- A reaction with the glass matrix and decomposition;
- Too low sheet resistivity;
- Too high TCRs (Temperature Coefficient of Resistance);
- Too high temperature sensitivity;
- Too high moisture sensitivity – this alters resistance;
- Too high humidity sensitivity – this changes the resistance value;
- Too high process sensitivity;
- Too high resistance deviation after soldering processes used in surface mount processes.

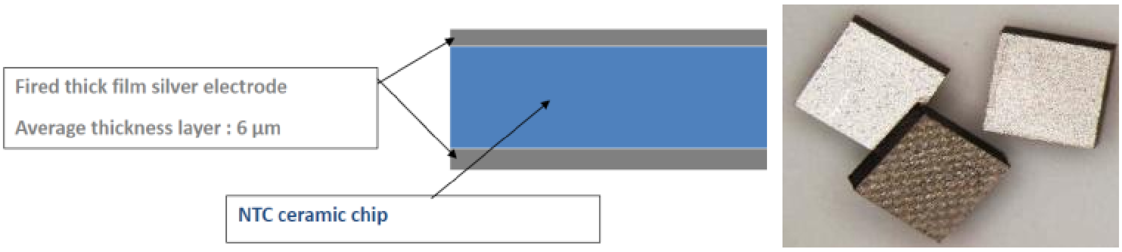
Murata et al.[1163] conclude that substitutes are technically impracticable and/or unreliable so that these materials cannot yet replace lead-containing glasses in this function.

Example 2.3 - Lead in Glass of the Silver Top and Bottom Electrode of NTC Chips

Vishay[1164] requests an exemption for NTC (negative temperature coefficient) chips with a silver top and bottom electrode that contains 4.5 ± 0.3% lead silicate glass as illustrated in Figure 22-13.

[1161] Ibid.
[1162] Ibid.
[1163] Ibid.
[1164] Op. cit. (Vishay 2015c)

Figure 22-13: NTC ceramic chips with thick film silver electrodes



Source: Vishay[1165]

Vishay[1166] applies the thick film silver paste electrode, a low firing Ag paste with lead containing glass frit, by screen printing and firing. The lead glass serves as interface for good adherence properties, electrical characteristics and reliability of the electrode, for which the lead in the glass is indispensable. The whole product range of NTC chips is produced with more than 60 different ceramic compositions. The actual silver electrode is compatible with all ceramic compositions and excellent in reliability tests and electrical behaviour.

According to Vishay[1167], these NTC chips are mainly used for accurate temperature sensing or compensation mainly in automotive, medical, and domestic applications. The total number of manufactured NTC chips accounts for 60,000,000 pieces per year.

Vishay[1168] mentions that Ag pastes with lead-free glass frits are available on the market, but claims there is no single one fitting to Vishay's wide variety of ceramics. Since one product series requires this many ceramics, it is impossible to change to a lead-free Ag paste for practical purposes.

Vishay[1169] claims to undertake significant efforts to eliminate lead in glass frit of the Ag electrode of the NTC chip, but so far no technical mature solution is available. A study is being started up to develop an NTC chip with a Pb free glass frit.

22.3.4.3 Lead Glass Used as Adhesive/Bonding Material

Example 3.1 - Micro Electro Mechanical Systems (MEMS)

According to Murata et al.[1170], lead-based glasses are used in MEMS devices for low temperature compatibility with aluminium pads in a glass frit wafer-to-wafer bonding process. Such devices are used in e.g. accelerometers, gyroscopes, etc.

According to Murata et al.[1171], only lead glass can achieve the low process temperature of less than 450 °C. Moreover, the lead glass frit is compatible with a wide variety of

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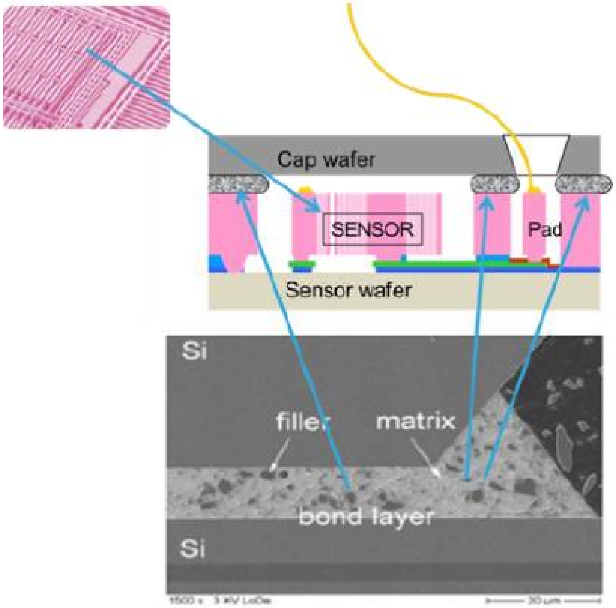
[1165] Ibid.
[1166] Ibid.
[1167] Ibid.
[1168] Ibid.
[1169] Ibid.
[1170] Op. cit. Murata et al. 2015a

substrates, not only silicon, and can adapt to different types of surfaces and topology (rough, smooth, with steps), which are typical of MEMS devices. Lead-glass frit bonding ensures a strong bond between different substrates, and ensures a stable and hermetic sealing of the device, unlike with lead-free glass frits.

Figure 22-14: MEMS device with lead-containing glass (Arrows)



Source: Murata et al.[1172]

According to Murata et al.[1173] glass frit wafer bonding is the most commonly used process for MEMS devices, where fully processed wafers have to be bonded at wafer level. This end-of-line wafer level bonding process must fulfil stringent requirements, and must not affect the final yield of bonded wafers. Specifically, the process temperature (i.e. the bonding temperature) must be below 450 °C in order to be compatible with the aluminium pads of the device and to avoid thermal stress on the wafer. This low melting temperature can be obtained only by adding lead to the glass. Moreover, the glass frit is compatible with a wide variety of substrates, not only silicon, and can adapt to different types of surfaces and topology (rough, smooth, with steps), which are typical of MEMS devices. Lead-glass frit bonding ensures a strong bond between different substrates, and ensures a stable and hermetic sealing of the device, unlike with lead-free glass frits.

Murata et al.[1174] do not mention any specific research or other efforts to substitute or eliminate lead in this application besides the general justification directly under

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[1171] Ibid.
[1172] Ibid.
[1173] Ibid.
[1174] Ibid.

Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds, from page 460).

Example 3.2 – Lead Glass in SMD Components

Murata et al. report that SMD components are being used to control operating conditions in power semiconductor modules. To achieve a useful temperature signal, the SMD temperature sensors should be placed as close as possible to the silicon dies. To guarantee customers' reliability conditions the assembly processes - usually soldering processes - are being operated by temperature profiles that are far away from JEDEC profiles for standard SMD dies. SMD components, which are available on the global market, and which ride out increased process temperatures are MELF dies (Metal Electrode Leadless Faces) whose glass insulator contains lead oxide (PbO) in addition to quartz.

Murata et al.[1175] report that no lead-free dies are available on the global market that provide a comparable (or better) reliability and which are approved for the required or even higher process temperatures than those assembled with lead-containing glass. Lead-free dies would not ride out the high temperatures of the soldering process.

Murata et al.[1176] do not mention any specific research or other efforts to substitute or eliminate lead in this application besides the general justification directly under Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds, from page 460).

Example 3.3 - Electronic Components with Hermetically Sealed Ceramic Package

According to Murata et al.[1177], electronic component packages with hermetic sealings using a ceramic body with a ceramic or glass lid require lead glass as sealing material between the two parts of the package. The lead in the glass reduces the melting temperature enough to not harm the functional element itself. At the same time, the temperature is still sufficiently high to withstand the reflow soldering temperatures without losing its strength and sealing properties. Even a temporary loss of the sealing properties would be fatal as in many cases the inside of the hermetically sealed package is under vacuum.

Murata et al.[1178] state that many materials have been tested to replace the Pb in glass in this function, but failed either due to a too high melting point (i.e. $Bi2O_3$-100 °C or higher and V_2O_5-50 °C or higher) or extreme sensitivity to moisture and humidity (i.e. P_2O_5-based materials), which destroys the vacuum and causes corrosion of the internal circuitry. The use of Au-Sn-based sealings leads to failures, especially in applications which need to cover wide operating temperature ranges. This is because the thermal expansion coefficient of ceramic ($7.1*10^{-6}$/°C) is vastly different to that of Au-Sn

[1175] Ibid.
[1176] Ibid.
[1177] Ibid.
[1178] Ibid.

(17.5*10^{-6}/°C), thus generating extensive mechanical stress inside the sealing, resulting in reliability problems and finally yielding in component failures (cracks).

22.3.4.4 Bourns Exemption Request for Lead in Glass

Bourns[1179] have developed lead-free glasses internally. These glass formulations are proprietary. These limited solutions do not solve the lead-glass issue in all applications. Obviously, any successful substitution will be used to eliminate lead in glass when possible. The majority of applications are still in the research stage. It is a lengthy process to identify potential solutions, test on a small scale basis, test on a larger scale, and qualify with reliability checks. The test phase is trial and error taking an unspecified amount of time. To date, Bourns' internal analysis as well as published information clarifies that more time is needed to find suitable substitutes.[1180]

There is no drop-in solution or a one-size-fits-all solution. Any change will take research, testing, final qualification, process changes, etc. for each specific application. Potential substitutes in these articles do not yet meet all the positive characteristics of lead-based glasses that are also cost-effective. There may be one or more alternatives to address each individual application. It appears that at this time there may be solutions; however, most likely the solutions will not be identified, tested, qualified and adapted to the process in the mid-2016 time frame when the exemption is set to expire.[1181]

Bourns[1182] references the below research papers:

- *Review of High-Lead Solder and Lead-Glass RoHS Exemptions,* http://rohs.exemptions.oeko.info/fileadmin/user_upload/Stakeholder_comments/Exemption-7a_5_Pecht_Uni_Maryland_25_March_2008.pdf
- *REACH Dossier: Exemption from registration for glass under REACH regulation n. 1907/2006/EC.,* http://www.glassallianceeurope.eu/images/cont/dossier-glass-alliance-europe-on-glass-exemption-under-reach_1_file.pdf
- *Position paper concerning the status of the raw materials for the production of glass, as intermediates, under the EU REACH regulation,* http://www.glassallianceeurope.eu/images/cont/glass-alliance-europe-statement-for-intermediates-revision-may-2012_1_file.pdf

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[1179] Op. cit. Bourns Inc. 2015a
[1180] Ibid.
[1181] Ibid.
[1182] Ibid.

22.3.4.5 IXYS' Application-Specific Exemption Request for Lead in Coatings of High Voltage Diodes

IXYS[1183] requests the renewal of the exemption for the use of lead in **coatings of high voltage diodes.** Lead-based glasses are used because they have unique combinations and characteristics that cannot be achieved by other materials or methods. Lead is required in combination with pure silicon crystals for good withstandability against high electric fields in the range of 200,000 V/cm in alternate and direct current power semiconductor devices. The justification follows the same rationale like that of Murata/JEITA et al.

IXYS[1184] mentions, however, new passivation systems under development, i.e. diamond-like carbon coatings or amorphous silicon-oxide layers (SIPOS, semi-insulating polycrystalline silicon). Their long term stability in various environments, workability, and the fabrication equipment are still under research and development. These developments could replace the use of lead glass in the high voltage components.

IXYS[1185,1186] states that the diamond like carbon coating method very much depends on equipment design and manufacture – where IXYS has minimum influence. SIPOS (semi-insulating polycrystalline silicon) is under development at IXYS in several lower voltage applications.

As mostly with new developments and technologies, IXYS[1187] states that there is no guarantee on when there will be a breakthrough on the whole front of this kind of power semiconductors.

22.3.4.6 Schott Request for Renewal of the Exemption

To ensure the production of high quality hermetic packages for opt-electronic devices it is crucial to use lead-oxide-based glasses. These so called "solder glasses" are necessary to attach optical elements like windows or lenses into metal components.[1188]

SCHOTT[1189] started a PbO substitution project for solder glasses in the year 2000. New glass systems have been developed for replacement of PbO containing solder glasses. These new glasses were based on the following substitutes:

[1183] Op. cit. IXYS Semiconductor GmbH 2014
[1184] IXYS Semiconductor GmbH 2014 "Request for continuation of exemption 37, document "37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf": Original exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/IXYS/37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf
[1185] IXYS Semiconductor GmbH 2016a "Answers to questionnaire 1 (clarification questionnaire), sent via e-mail to Dr. Otmar Deubzer, Fraunhofer IZM, by Markus Bickel, Ixys Semiconductor GmbH, on 27 January 2016,"
[1186] Ibid.
[1187] Ibid.
[1188] Op. cit. Schott AG 2015a
[1189] Ibid.

- Bismuth-oxide, Bi_2O_3;
- Phosphate glasses P_2O_5.

The development for these glasses was mainly done for glass to glass or glass to ceramic joints. In a separate project, which was launched 2004, Schott tested all these new systems for usability for metal to glass joints.[1190]

The substitute glass has to meet the following requirements:

- Gas tight seal: hermeticity better than 1x10-8 mbar*l/s; must remain unchanged after 15 cycles of thermal shock liquid to liquid (-65°C <> 150°C);
- No outgassing;
- Mechanically strong bond: the assembly has to pass stringent shock, typically 1500 g gravitational acceleration and vibration testing;
- Chemical resistance: No performance change after 1000 h at 85°C and 85 % relative humidity;
- Low cost, which excludes the usage of metalized windows and metal solder;
- Working temperature less than 500 °C;
- Mechanically stable up to 260 °C.

Table 22-5 shows the test results. The metal solders used with the metalized windows were gold/tin solders with 80 % (weight) of gold (AuSn 80/20) to achieve a melting point of more than 260 °C, which is higher than the conventional lead-free and lead-solders. This solution is only applicable to window caps. Moreover, these products will not fit Schott's customers´ requirements because they have to accept that the counterpart is gold-plated. [1191]

[1190] Ibid.
[1191] Op. cit. Schott AG 2015b

Table 22-5: Test results of lead-free alternatives to leaded solder glass

Glass System	Weaknesses	Positive Findings	Further conclusion
Bi_2O_3	• Sealing Temperature 550-570°C (dependant on Cap geometry) • Optical elements damaged by high sealing temperature • Metal surface requirement cannot be met (Damp Heat, Bellcore Spec GR468)	• Mechanically good bonding to metal and glass • Chemical resistance of solder glass improved compared to PbO	• Launch of new project for improved Bi_2O_3 glass with lower sealing temp (see next line)
Bi_2O_3 Next Gen. Glasses	• Sealing Temperature only reduced to 530-550°C No glass composition identified with lower seal temp. (appr. 50 new glass compositions tested)	• See above	• No Solution found with Bi_2O_3 system
P_2O_5	• No bond to suitable metal surfaces • Chemical resistance no adequate for Cap application	• None	• No further activities
SnO_2-P_2O_5	• Environmental Stability not adequate	• Sealing Temperature requirement <500°C met • Bond between Solder glass and metal achieved	• No further activities
Metalized Windows & Metal Solder	• Metallization process is too costly for this application (costs are about 5-10x too high) • Not applicable to all products (i.e. ball lenses)		• No further activities

Source: Schott[1192]

Lead oxide as a glass constituent is responsible for the low working temperature of the glass, yet maintaining an acceptable level of environmental resistance. Higher working temperatures will damage the optical elements of the components. Without using lead containing solder glasses Schott will no longer be able to produce their huge variety of high level electronic components.[1193]

Regarding the small amount of lead containing solder glass needed for Schott's purposes and the fact that glass is an inert and stable material, which does not pose any danger to human health and environment along the lifecycle, Schott applies for the extension of the existing exemption in Annex III, no. 7(c)-I.[1194]

[1192] Ibid.
[1193] Op. cit. Schott AG 2015a
[1194] Ibid.

As no substitutes are available or foreseeable in the near future, Schott[1195] requests the continuation of Exemption 7(c)-I for the maximum five year period.

22.3.4.7 Sensata's Request for the Renewal of the Exemption

Alternative lead-free glasses meeting the requirement of matching coefficient of thermal expansion of parts to be bonded are available, but these materials do not fulfil other requirements as shown in Table 22-6. Experiments on alternative materials are conducted but with marginal results. The material match and process profiles are not fulfilling the requirements. Lead glasses are superior in the combination of characteristics versus for example Zn, P-S and Na-Al-P-B glasses.

Table 22-6: Test results of lead-free glasses

Characteristics	Pb glass	Zn glass	P-Sn glass	Na-Al-P-B
Affinity	Good	Not good	Not good	Good
Low melting point	Yes	No	Yes	Yes
Coefficient to thermal expansion	Good	Good	Good	Not good
Weather resistance	Good	Good	Not good	Not good

Source: Sensata[1196]

Sensata[1197] claims there are no applications where not all of the characteristics listed in Table 22-6 are required, so that neither lead-free glasses nor alternative technologies like lead-free solders can be applied.

Sensata[1198] states that beyond the above arguments, the rationale of its exemption request is based on the justifications of Murata/JEITA et al. [1199] [1200]

[1195] Ibid.
[1196] Sensata Technologies 2015b "Questionnaire 1 (clarification questionnaire), document "7c-I_Questionnaire_Sensata_20150901.pdf": Questionnaire 1 (clarification questionnaire)," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Sensata/7c-I_Questionnaire_Sensata_20150901.pdf
[1197] Ibid.
[1198] Ibid.
[1199] Op. cit. JEITA et al. 2015a
[1200] Op. cit. Murata et al. 2015a

22.3.5 Impacts on Environment, Health and Resources

Murata et al.[1201] claim that so far no substitution technology has been found, but many potential compositions have been investigated in order to develop reliable technical solutions on industrial scale, however below are further examples of environmental and health and production impacts of major candidates:[1202]

- Potential future candidates under investigation are expected to have more difficult raw materials and processes, even under mass production considerations;
- Niobium and bismuth-based substitutes have a higher impact on environment during extraction and purification than lead, as lead is already recycled with high recovery and is relatively abundant in nature (10 to 70 times more than Bi and 3 times more than niobium).

The environmental impact of lead in ceramic and glass is low, because of the low water solubility of lead contained in ceramic and glass, therefore, leakages into the environment are very low. Current PZT production is based on water; potential substitutes would require alternative technology based on organic solvents (e.g. isopropyl alcohol, ethanol, acetone). Such solvent-based technologies and the requirement to meet ATEX regulations would result in higher efforts and risks in health and environment protection, e.g. to avoid emission of solvents (Isopropyl alcohol, Ethanol, Acetone) that are VOCs (volatile organic carbon) which also need to be minimized in the EU due to the Industrial Emissions Directive 2010/75/EU.

PZT is used in industry for processing of ceramic for many years under controlled worker conditions. Health impacts have been well investigated.

Murata et al.[1203] provide the following references to support their environmental statements:

- Worker Exposure to Lead Titanate Zirconate in an Ontario Company M.L. Roy, MD, PhD; S.Siu, Md; W.Waddell, MD; P.Kennedy, BSc, J Occup Med. 1989 Dec;31(12):986-9.

- Comments on an Annex XV Dossier for Identification of a Substance as SVHC and Responses to these Comments, http://echa.europa.eu/documents/10162/25b4427f-1c53-4497-8ca2-29d24a55f4b5

Murata et al.[1204] also present the EU critical raw materials from the 2013 list (reproduced in Figure 22-15).

[1201] Ibid.
[1202] Ibid.
[1203] Ibid.
[1204] Ibid.

Figure 22-15: EU critical raw materials 2013

Antimony	**Beryllium**	**Borates**	**Chromium**	**Cobalt**	**Coking coal**	**Fluorspar**
Gallium	**Germanium**	**Indium**	**Magnesite**	**Magnesium**	**Natural Graphite**	**Niobium**
PGMs	**Phosphate Rock**	**REEs (Heavy)**	**REEs (Light)**	**Silicon Metal**	**Tungsten**	

Niobium, one of the potential candidates used in lead-free ceramics, is listed as a critical raw material. Additionally, Murata et al.[1205] state that tantalum was on the EU's critical material list prior to the 2013 one.

22.4 Roadmap for Substitution or Elimination of Lead

22.4.1 Substitution and Elimination of Lead in Piezoelectric and PTC Ceramics

According to Murata et al.,[1206] there are still many remaining technical issues to be solved in order to achieve mass production of practical products. Adding to that, even in the case that mass production technology is achieved, the research has shown that the required properties for substitutes in the various applications of ceramics cannot be obtained.

For ceramics, Murata et al. indicate the following steps towards the substitution or elimination of lead:

- Achievable material properties are known;
- First demonstrations of applications published;
- Technologies for industrial production must be developed;
- Simple replacement of PZT components have already been shown not to be possible;
- Adaption or new development of EEE, reliability investigations;
- Certain replacements: time frame >5 years, overall replacement not foreseeable;

Murata et al.[1207] states that introducing new chemical compounds and materials in order to replace PTC ceramics even in a certain resistance-Tc range would need an overall change in powders conception used in the production of PTC at the moment. This is because not just one powder is used in production of a certain product but usually a mixture of two or more powders is used. With the alternative materials examined up to now, only ceramic for applications with low Curie temperatures might be meaningful to

[1205] Ibid.
[1206] Ibid.
[1207] Ibid.

undergo further investigation and development because of the strong limitations in regard to certain properties as mentioned above. Furthermore, for these low Tc applications there still exist several constraints as explained in the justification of the exemption for PTC ceramics.

Overall, Murata et al.[1208] do not see any perspectives for a comprehensive transition to ceramic in the next five years and therefore claim they cannot set a technical goal.

Murata/JEITA et al.[1209] were asked again about their plans and the steps they want to undertake in the next five years towards the substitution and/or elimination of lead for the various types of ceramics (roadmap) described in their exemption request. They replied they will continue developing, requesting development and/or applying possible alternatives taking into account the practicability, reliability or environmental, health and consumer safety impacts of substitution. However, as this involves individual company policies, unpredictable technical and scientific findings and market and consumer developments it is impossible to draw any serious roadmap under the present circumstances.

22.4.2 Substitution and Elimination of Lead in Glass and Glass or Ceramic Matrix Compounds

Murata/JEITA et al.[1210] [1211] claim that there are no prospects concerning the technical scope of exemption 7(c)-I for a comprehensive substitution to "lead-free" glass and/or ceramic at least until the next revision (21 July, 2021)

Murata et al.[1212] report that boron, phosphorus, zinc, tin, bismuth, etc. as elements for substituting lead as a constituent element of glass, have been investigated. However, when compared with lead-containing glasses, chemical stability and mechanical strength of the glasses are insufficient (to meet the required functionality). As a result, there are concerns of accidents originating from crucial failures in EEE incorporating electrical and electronic components composed of glass with lead substituted by these elements due to their insufficient reliability and quick deterioration.

Murata/JEITA et al.[1213] remain committed to supporting the procedure for the adaptation to scientific and technical progress, and will continue developing, requesting the development and/or applying possible alternatives taking into account the practicability, reliability or environmental, health and consumer safety impacts of substitution.

[1208] Ibid.
[1209] Op. cit. (Murata et al./JEITA et al. 2016d)
[1210] Op. cit. Murata et al. 2015a
[1211] Op. cit. JEITA et al. 2015a
[1212] Op. cit. Murata et al. 2015a
[1213] Murataet al./JEITA et al. 2016e "Answers to questionnaire 6a, document"Exe_7c-I_Questionnaire-6a_Murata-JEITA_2016-03-2.pdf", received from Klaus Kelm, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016" unpublished manuscript,

However as this involves individual company policies, unpredictable technical and scientific findings and market and consumer developments it is impossible to draw any serious roadmap under the present circumstances.

Schott[1214] states that after spending 5.5 person years of research, and thorough testing of substitute systems, Schott sees no adequate replacement for PbO to attach optical elements like windows or lenses into metal components. Therefore, no substitutes are likely to be developed in the foreseeable future and so the maximum validity period is required for this exemption.

IXYS[1215] wants to continue with the development of new passivation systems, i.e. diamond-like carbon coatings or amorphous silicon-oxide layers (SIPOS, semi-insulating polycrystalline silicon). As mostly with new developments and technologies, IXYS[1216] states that there is no guarantee on when there will be a breakthrough on the whole front of this kind of power semiconductors.

Bourns[1217] will continue to work with their suppliers, explore possible solutions, and experiment with possible alternatives. It is a slow process with research, experimentation, testing, scale-up, qualification & reliability testing. If there is a failure along the way, the process starts over.

22.5 Critical Review

22.5.1 REACH Compliance - Relation to the REACH Regulation

Lead is used in glass in the scope of Exemption 7c-I. Barium titanate (BT), lead titanate (PT), lead zirconium titanate (PZT) as well as barium strontium lead titanate are used in the ceramics in the scope of this exemption according to the applicants. These ceramics and their constituents therefore need to be evaluated whether their use weakens the environmental and health protection afforded by Regulation (EC) No 1907/2006 (REACH Regulation). There are, however, hundreds of material recipes for each of the ceramics, which could not be addressed and mentioned in this review and which may be even proprietary knowledge. They cannot be taken into account.

Since no substitutes have been identified in the review process that would result in the restriction of the exemption scope, the various substances used in lead-free ceramics were not specifically taken into account. As, however, lead-free lithium tantalate sensors have been identified as a potential future alternative to PZT-based sensors, lithium tantalate will be evaluated as well.

[1214] Op. cit. Schott AG 2015a
[1215] Op. cit. IXYS Semiconductor GmbH 2014
[1216] Op. cit. IXYS Semiconductor GmbH 2016a
[1217] Bourns Inc. 2016a “Request for continuation of exemption 7c-I, document "20150818_Ex_7c-I_Bourns_Questionnaire-1_2015-07-28.pdf": Answers to second questionnaire” unpublished manuscript,

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as directly added substances nor as substances that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under Entry 28 and Entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, Entry 28 and 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds

- *"shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight."*
  This restriction does not apply to internal components of watch timepieces inaccessible to consumers;
- *"shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children."*
  This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under entry 63 thus do not apply to the applications in the scope of this RoHS exemption. Should the ceramics in the scope of the exemption actually be used in watch timepieces, this use of lead would be allowed.

Various entries in the REACH Regulation annexes restrict the use of barium and strontium compounds in several articles and uses. Nickel barium titanium primrose priderite and strontium chromate are specified for Annex XVII entry 28. These compounds are, however, not relevant for the ceramics in the scope of Exemption 7c-I. The same applies to strontium chromate, which is also listed in Annex XIV under Entry 29.

No other entries for the above mentioned ceramics and their compounds relevant for the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

Lithium nickel dioxide, cobalt lithium nickel oxide, lithium perfluorooctane sulfonate and lithium heptadecafluorooctanesulfonate are also listed under Entry 28 and Entry 30 in Annex XVII of the REACH Regulation so that the same conditions apply to these substances like for lead and its compounds. These substances and compounds are not relevant for the use of lithium tantalate in sensors, which may be a potential and commercially available alternative to PZT-based sensors. No other entries relevant for the use of lithium tantalate in these sensors could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the use of lithium tantalate to substitute or eliminate lead would not weaken the environmental and health protection afforded by the REACH Regulation.

22.5.2 Substitution and Elimination of Lead in Ceramics

The applicants argue that none of the known lead-free piezoelectric materials is a suitable overall substitute for PZT. Art. 5(1)(a) would, however, require to apply lead-free solutions if they were available for specific application fields. Not all applications of PZT-containing components may require the all properties of PZT to the highest level at the same time, these being:

- High Curie temperatures;
- High piezoelectric charge constants;
- High electromechanical coupling factors;
- High quality factors and low losses for ultrasonic devices;
- High stability under different driving and environmental conditions, especially temperature; and
- High reliability.

22.5.2.1 Use of Lower Performing Ceramics in Less Demanding Applications

Murata et al.[1218] explain that the functions and properties (e.g. Curie temperature, breakdown voltage, etc.) required for ceramic of electrical and electronic components and the usage environment are not only diverse but also change during use due to changes in the usage environment. For example, a high voltage of a few tens of thousands of volts may be instantly applied over electrical/electronic equipment, or temperature loads exceeding the expectations may occur, etc. In order to use these items with safety it is necessary that they can withstand such conditions. Since lead-containing ceramics, which are stable and show excellent functionality over a wide range of usage environments, are essential for compatibility with the required functionality and usage environment, the decision on whether substitution by “lead-free” ceramics is possible or not will vary with the equipment type and subpart on a case-by-case basis and it is not possible to identify applications, which can be substituted.

Murata et al.[1219] furthermore state that electrical and electronic components have to withstand conditions in manufacturing that are different from those during use so that it is impossible to decide on the use of lead-free PTC only by application. For example, in the manufacturing of electrical and electronic equipment the components can be heated to 150 °C so that ceramic that breaks down or deteriorates at this temperature cannot be used. $BaTiO_3$ with a T_C of 120 °C would, for instance, simply depole during such processes.

Murata et al.[1220] also point out that piezoelectric materials are selected based on a combination of properties. Even if a given lead-free composition fits the sensitivity criteria, it does not necessarily mean that it will be stable over a given temperature range or have the required dielectric or mechanical properties. In addition to this, lead-free materials are known to have different and generally more complex temperature characteristics such as additional phase transitions within the operating temperature range. Moreover, the reproducibility of lead-free piezoceramics’ properties is significantly lower due to the fact that their production is considerably more sensitive to process parameters.

Overall, the information provided by the applicants explains that currently the substitution of lead in the ceramics in the scope of exemption 7c-I is scientifically and technically still impracticable. The available information suggests that lead-free ceramics are still inferior in performance, and their manufacturing in industrial scale is not yet achieved. The submitted information also suggests that such lead-free ceramics cannot be used in components that could be applied where not all of the properties of lead-containing ceramics are required.

1218 Op. cit. (Murata et al. 2016a)
1219 Ibid.
1220 Ibid.

The applicants' exemption requests and the answers to the clarification questionnaire were made available through the online consultation to the public, i.e. to industry, governments, NGOs and other stakeholders, and a consultation questionnaire had been prepared for the public online consultation with specific questions to stakeholders. No further information supporting or discrediting the technical application in question was received, and there were no hints that lead-free solutions would be foreseeable for the near future.

22.5.2.2 Commercial Availability of Lead-free Sensors

In the last questionnaire received on 1 April 2016, Pyreos [1221] mentions that Panasonic commercially offers lead-free lithium tantalate sensors for specific applications. A short internet investigation actually showed that there are scientific publications on lithium tantalate sensors[1222] and examples of commercial sensor products[1223] where it is explicitly stated that these pyroelectric elements "*[...] contain lithium tantalate and are lead-free. Typical PIR sensing elements are ferroelectric ceramic (PZT) containing lead*."

According to Pyreos,[1224] lithium tantalate can substitute thick film PZT-based sensors in applications, which have lower performance requirements and are not so robust, such as low operating temperatures (-20 to +85 °C). Lithium tantalate cannot so easily substitute thin film PZT as there are even more different performance requirements such as temperature shock response etc. In general, litihium tantalate cannot substitute thin film PZT in applications where higher cost, reproducibility and superior performance are a consideration.

The Panasonic data sheet[1223] lists commercial / residential equipment (including lighting fixtures, sensor switches, video intercoms, vending machines, home automation control panels) and home appliances (including television and PC monitors, air conditioners and air purifiers) as applications for the lead-free pyroelectric sensors.

Thus, the substitution or elimination of lead is viable at least in pyroelectric sensors even though they might not have the properties that would allow covering the whole range of applications where PZT ceramics are used. In the consultants' understanding, the results of the internet investigation are at least an indication that contrary to the statements in particular of Murata et al., substitution or elimination of lead may be scientifically and technically practicable to a certain degree. The considerable efforts already spent on the

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[1221] Pyreos Ltd. 2016b "Answers to third questionnaire, document "Exe_7c-I_Questionnaire-3_Pyreos_2016-03-30_final.pdf", received via e-mail from Torben Norlem, Intertek, by Dr. Otmar Deubzer, Fraunhofer IZM, on 31 March 2016" unpublished manuscript,

[1222] Vincent Stenger, Michael Shnider and Sri Sriram, SRICO, Inc.; Donald Dooley and Mark Stout, Gentec-EO USA, Inc.: Thin Film Lithium Tantalate (TFLT™) Pyroelectric Detectors; SPIE Photonics West 2012, Optoelectronic Materials and Devices THz Technology and Applications V – OE107, Paper Number 8261-27 http://www.srico.com/files/PW2012_TFLT%20Pyro%20Detectors.pdf

[1223] Panasonic: PaPIRS Passive Infrared Motion Sensor, http://datasheet.octopart.com/EKMC1601111-Panasonic-datasheet-43724067.pdf

[1224] Ibid.

review of exemption 7c-I and the time restrictions did not allow a further clarification with Murata et al.

Adding to the above, Murata et al. provide only very general and unspecific information on their future efforts to substitute or eliminate lead in ceramics. They justify this with confidentiality, but the consultants believe that even though the members of the industry consortium are competitors, there should be possibilities to describe in more details future steps, which should also be related to the various types of ceramics and their application-specific requirements to find specific solutions where general drop-in alternatives are not viable.

22.5.2.3 Bandelin

Bandelin requests to add a specific application (identified by the bold addition) to the current wording of exemption 7c-I, and to add this exemption to Annex IV as well:

> ***"Piezoelectric hard PZT containing lead for high-performance ultrasonic transducers and*** *electrical and electronic components containing lead in glass or ceramic materials other than dielectric ceramic in capacitors"*

The principle rationale of the exemption request follows the arguments of the other stakeholders that the substitution or elimination of lead is currently scientifically and technically not possible, and Bandelin explains this plausibly for the PZT used in high performance ultrasonic transducers.

Based on this information and in the absence of contrary information, granting the exemption would be in line with the requirements of Art. 5(1)(a).

Technically, the use of lead in the applicant's transducers is fully covered by the current exemption 7c-I, and it shall be decided in the context of the future wording of this exemption 7c-I whether and how to take into account this specific exemption in RoHS Annex III.

The applicant applies to adopt the same exemption wording to RoHS Annex IV. It is the consultants' understanding that, to avoid the proliferation and overlapping of exemptions, Annex IV should only list exemptions that are exclusively required for EEE in categories 8 and 9 of RoHS Annex I, which according to Bandelin[1225] is not the case for their high power transducers. The consultants therefore recommend not to adopt this exemption to Annex IV as long as an exemption in Annex III covers the use of lead in this application and consequently allows the uses of lead in the scope of the exemption for all categories of EEE.

[1225] Op. cit. Bandelin Electronic GmbH 2015a

22.5.2.4 Pyreos

Pyreos asks to add the following exemption to Annexes III and IV of the RoHS Directive:

> *"Lead in thin film electronic sensor elements such as pyroelectric sensors or piezoelectric sensors"*

The information submitted by Pyreos suggests that the company uses lead zirconium titanate (PZT) as thin films instead of thicker films and thus has successfully reduced the amount of lead in its sensors. They are not lead-free at the current state of development, and despite further investigation[1226], it could not be clarified whether they would actually become lead-free in the next development step in the sense of the RoHS Directive, i.e. containing less than 0.1 % of lead in any homogeneous material applied.

Pyreos[1227] explains its motivation for its request that a specific exemption focused on lead in thin film PZT sensors will significantly reduce the quantity of lead used in PZT sensors sold on the market today when compared to conventional technology using other types of PZT sensors not falling within the scope of the specific exemption.

This effect will, however, not be achieved if the proposed exemption is adopted as a specific exemption, or if the current wording is amended accordingly. It would then allow the use of lead in thin film PZT sensors – which is already the case in the current exemption 7c-I – but it would not restrict the use of lead in any other sensors.

It was pointed out to the applicant[1228] that the only way to achieve their intention would be to exclude other types of sensors than PZT thin film sensors from the scope of the future exemption 7c-I allowing the use of lead in ceramics. This would require a detailed technical specification, where other sensors can be replaced, and it will also require feedback and discussions from other stakeholders, and it would best have been discussed in the online stakeholder consultation. Such an intention of Pyreos' exemption request was not obvious based on the documents submitted.

Pyreos[1229] stated thereupon that in line with the purpose of the RoHS legislation as far as possible, they would like to seek support for this specific exemption by:

- Specifically exempting the use of lead in thin PZT film (e.g. total thickness cannot exceed 10 microns) in applications where thin PZT film can replace other PZT (e.g. thickness greater than 10 microns) sensors with an equivalent or superior cost effectiveness, performance and reliability.
- Specifically allowing the use of lead in thin film PZT sensors until a lead-free thin film pyroelectric (or sensor) material with an equivalent or superior cost effectiveness, performance and reliability, is available.

[1226] Op. cit. (Pyreos Ltd. 2016b)
[1227] Op. cit. (Pyreos Ltd. 2016a)
[1228] Op. cit. (Pyreos Ltd. 2016b)
[1229] Ibid.

The consultants agree that the reduction of lead is an important contribution to the objectives of the RoHS Directive and as such the applicant's approach is worthy of support. The approach the applicant chose does not allow to actually restrict the use of lead in the sensors in the scope of Pyreos' request for the reasons explained above. It actually required some time and discussion[1230, 1231, 1232] with the applicant to fully understand the intention. Restriction criteria in the applicant's answer to the last questionnaire[1233] are examples, and there was no further time to discuss whether these criteria are sufficient and clear with the applicant and other stakeholders.

Technically, the use of lead in the applicant's sensors is fully covered by the current exemption 7c-I, and it remains to be seen in the total context of the future wording of this exemption whether it makes sense to add an explicit exemption to Annex III as the applicant requested. In any case, the applicant can explicitly apply for the restriction of the scope of the future exemption 7c-I, and the request can then undergo the public online stakeholder consultation and subsequent review of the stakeholder information to find out how the scope of the exemption could actually be narrowed. It will then also have to be clarified whether and how far lead-free pyroelectric sensors[1223] can actually replace PZT-based pyroelectric sensors.

The applicant applies to adopt the same exemption wording to RoHS Annex IV. According to Pyreos,[1234] the exemption would be relevant for all categories of EEE. For the same reasons like explained for Bandelin's request, the consultants recommend not to follow the applicant's request.

22.5.3 Substitution and Elimination of Lead in Glass and Glass or Ceramic Matrix Compounds

22.5.3.1 Bourns and IXYS

Bourns' and IXYS' arguments for the use of lead glass and lead in glass/ceramic matrix compounds are plausible, and no information has been received during the stakeholder consultation or later discrediting the applicant's arguments. They follow the rationale of the justification of Murata/JEITA et al. for the use of lead in glass.

Bourns have developed some proprietary lead-free solutions. These, however, are not drop-in solutions and are said to only work on a case by case basis for certain components. Consequently, no rule can be accordingly deduced to demarcate applications where lead-free glass can be used to specify the exemption. Some of these components are trimmer potentiometers. The situation is therefore described in more

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[1230] Op. cit. Pyreos Ltd. 2015b
[1231] Op. cit. (Pyreos Ltd. 2016a)
[1232] Op. cit. (Pyreos Ltd. 2016b)
[1233] Ibid.
[1234] Op. cit. Pyreos Ltd. 2014

detail in the review of exemption 34 (trimmer potentiometers), but also applies to other Bourns components.

IXYS is working on passivation systems that would allow substituting lead in the glass of high voltage diodes. The development still requires time and, according to the applicant, it is not foreseeable that lead can be replaced in the near future.

The situation shows, however, that the elimination or substitution of lead in glass and glass/ceramic matrix compounds is obviously scientifically and technically practicable in some cases. As such it may be possible to restrict the scope of the exemption at a future time, and hence setting a short expiry on a renewed exemption 7c-I may bring forward the potential for this to occur in the next exemption review.

22.5.3.2 Schott

Schott present research on lead-free alternatives to the lead-containing glass they use to attach optical components into metal components. The results show that there is currently no lead-free glass that can replace the lead-containing glass. The tested gold-tin metal solder seems to be viable in principle for some window caps, but Schott says it is too expensive and requires gold contacts on the customers' side as well so that their customers cannot accept this solution. Thus, technically, the substitution and elimination of lead is not yet practicale and granting an exemptin for this application would be in line with the requirements of Art. 5(1)(a).

The cost argument as raised by the applicant cannot justify an exemption in accordance with the stipulations of RoHS Art. 5(1)(a) unless the availability of the substitutes or the socioeconomic impacts would make the manufacturing of such components impossible so that the products depending on these components could no longer be produced, or similarly severe impacts. The applicant does not provide substantiated information that would suggest such severe impacts.

Schott also justifies its exemption request with the small amounts of lead used and the fact that the glass is inert and thus not hazardous along the life cycle. This is, however, only partially true as the lead has to be mined and refined, where it is not inert but emissions into the environment do occur, and the same applies to processing and disposal at end of life. Furthermore, RoHS Art. 5(1)(a) would only justify an exemption if the negative impacts from the use of lead-free alternatives are likely to outweigh the positive effects of lead substitution. The applicant does not provide information showing that this might be the case. The small amount of lead used cannot be accepted as a justification for an exemption either, as RoHS Art. 5(1)(a) does not set a threshold for minimum amounts of restricted substances that would justify granting an exemption.

Technically, the applicant's information suggests that, currently and in the foreseeable future, the substitution of lead is scientifically and technically not yet practical and granting an exemption for five years would thus be justified in line with Art. 5(1)(a).

22.5.3.3 Sensata

Sensata[1235] shows test results suggesting that there have been tests of lead-free glass, which showed that they are not a viable substitute. They claim that all properties of lead glass are required in all their applications so that lead-free glasses, which do not exhibit this combination of materials, cannot be used. There is no information available to the consultants that disproves this statement.

Beyond this specific information, Sensata's justification follows the rationale of Murata/JEITA et al. and is therefore not further discussed separately, the more as Sensata's information does not allow to deduce a specific wording for their uses of lead in glass.

22.5.4 Specification of the 7c-series Exemptions

Exemption 7(c) is related to lead in glass and ceramic type materials which may be used in electrical and electronic components. Given the broad range of ceramic and glass materials, and their multiple uses and functionalities in components, the scope of this exemption is wide so that it may hinder the gradual phase-out of lead. Following the same rationale like for exemption 7(a), it was tried to specifiy the scope of exemption 7(c)-I.

Based on information provided by the applicants in this review and in previous exemption reviews, the consultants formulated a wording targeting a scope which is as narrow as possible to exclude the abuse of the exemption and promotes specific research into lead-free solutions. In parallel, the same proposed wording is as wide as necessary to ensure all applications are covered where substitution and elimination of lead is still impracticable.

A specification of Exemption 7(c)-I in the current numbering and wording is not viable. The exemption was therefore split into two specific wordings for ceramics on the one hand, and glass and glass ceramic matrix compounds on the other hand.

22.5.4.1 Lead in Ceramics of Electrical and Electronic Components

The consultants proposed the below wording for the ceramic-part of exemption 7(c)-I. Exemptions 7(c)-II, 7(c)-III and 7(c)-IV were integrated into this wording proposal:

Lead in

i) *piezoelectric ceramics in electrical and electronic components, i.e.*
   - *ferroelectric ceramics*
   - *pyroelectric ceramics*
   - *other piezoelectric ceramics*

[1235] Op. cit. Sensata Technologies 2015b

ii) positive temperature coefficient (PTC) ceramics in electrical and electronic components

- *with T_C < 120 °C (T_C: Curie temperature) and resistivity of less than < 1000 Ωcm*
- *with T_C < 120 °C and resistivity of 1,000 Ωcm and more*
- *with T_C ≥ 120 °C and resistivity of less than 1,000 Ωcm*
- *with T_C ≥ 120 °C and resistivity of 1,000 Ωcm and more*

iii) dielectric ceramics in discrete capacitor components for a rated voltage of 125 V AC or higher, or for a rated voltage of 250 V DC or higher

iv) dielectric ceramic in discrete capacitor components for a rated voltage of less than 125 V AC, or for a rated voltage of less than 250 V DC; for use in spare parts of EEE placed on the market before 1 January 2013

v) PZT-based dielectric ceramic materials for capacitors which are part of integrated circuits or discrete semiconductors

vi) other ceramics

Murata/JEITA et al.[1236] [1237] recommend keeping the current wording with slight modifications (see review of exemption 7c-II). They claim that the exemption scope cannot be correctly understood in the above proposed wording and fear that the effectiveness of the legal enforcement will be damaged. They strongly assert that a wording to be adopted should summarize a wide knowledge of Industry, and be carefully examined in order to not cause any misinterpretation of the legal text to avoid any unnecessary misunderstanding, misinterpretation and/or wrong usage of lead in the supply chain. Therefore, they strongly insist a wording should remain as proposed in the original application form of Murata/JEITA et al.[1238] [1239]

[1236] Murata et al./Jeita et al. 2016b "Answers to third questionnaire (ceramics), document "Exe_7c-I_Questionnaire-3_Murata-JEITA_2016-03-03_ceramics.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Klaus Kelm, Murata, on 22 March 2016" unpublished manuscript,

[1237] Murataet al./JEITA et al. 2016f "Answers to questionnaire 5b, document "Exe_7c-I_Questionnaire-5b_Murata-JEITA_2016-03-2.pdf", received via e-mail from Klaus Kelm, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 5 April 2016" unpublished manuscript,

[1238] Murata et al. 2015a "Original exemption request, document "Exemption_7_c_-I/Murata/7c-I_RoHS_V_Application_Form_7c1_20140116_combined_final.pdf": Exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Murata/7c-I_RoHS_V_Application_Form_7c1_20140116_combined_final.pdf

[1239] JEITA et al. 2015a "Exemption request, document "JEITA/7c-IandII_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf": Exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/JEITA/7c-IandII_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf

Murata/JEITA et al.[1240] put forward the following more specific justifications for their position:

- Splitting further the exemption will not eliminate existing functional requirements for lead in glass and ceramic, nor will it improve the availability for Pb-free alternatives because different functions are combined for each individual product application.
- Part i) and part ii) of the wording proposal are not based on physical laws, being simply a classification for convenience based on end-use applications in EEE. For this reason they consider that unless they prepare an application list of end-uses for all OEM/EEEs identifying the scope, it is impossible to define the exemption scope from the wording proposal.
- It is believed that a comprehensive application list of OEM EEE end-uses for lead in glass and ceramic is not currently feasible because the applications are extremely numerous and thus impossible to quantify, requiring different and complex parameters for their specification (definition).
- It is believed that the division of RoHS Ex. 7(c) into eleven applications, intended uses or components is not necessary and would be confusing.
- The proposed wording would misalign with the ELV exemption 10(a) wording included in ELV's Annex II.
- If the wording is so deeply changed, how would customers interpret this complex definition to determine how it applies?
- The application-specific wording proposals are too ambiguous, which may result in interpretation issues. It is impossible to define all end-use applications. Many of these component devices have unique characteristics, which may be excluded with the current application-based proposals. Trying to develop categories under the 7(c) exemptions that will cover all current components/devices is extremely difficult. Some products will ultimately be left out creating a compliance and economic issue for those component companies affected.
- Additionally from a technical point of view the categorization proposed above by Oeko-Institut and Fraunhofer IZM has some technical problems as well. From the point of view of properties, ferroelectric materials are a subgroup of pyroelectric materials that are a subgroup of piezoelectric materials and all should be considered as dielectrics etc. However, when this categorization is used to distinguish between applications as it seems to be the case here, it leads to ambiguity, since all piezoelectric ceramics need to be ferroelectric and thus also pyroelectric. This also leads to undesired side effects for many

[1240] Op. cit. (Murata et al./Jeita et al. 2016b)

piezoelectric applications: the ferroelectric character may lead to depoling (loss of polarisation) due to an external electric field in actuators and transducers, and the pyroelectric character may give rise to pyroelectric charges in sensors due to a temperature change. It will be extremely difficult to make exhaustive lists of applications of piezoelectric ceramics covering all present and future uses, and Murata/JEITA et al. foresee that in practice it will not be possible for customers to clearly identify a category in cases where their application relies on a number of properties.

The discussion related to the consultants' rewording proposal for exemption 7(c)-I shows that a consensus on the technical details of such a rewording proposal requires further exchange with the various stakeholders to agree on the architecture and the definitions of terms. The limited time and resources available for the review of this exemption did not allow further discussions with the applicants and other stakeholders. The consultants therefore recommend to continue the exemption as proposed in the review of Exemption 7(c)-I. The above proposals and discussions can, however, be a basis to a further specification of Exemption 7(a) in a future review taking into account the new status of elimination and substitution of lead.

22.5.4.2 Lead in Glass and Glass or Ceramic Matrix Compounds in Electrical and Electronic Components

The consultants proposed the below wording related to lead in glass and glass/ceramic matrix compounds in exemption 7c-I. Exemption 34 (Lead in cermet-based trimmer potentiometers) was integrated into this wording as well as the glass beads of high voltage diodes where the use of lead glass is the root cause for contaminations in the plating, which is in the scope of exemption 37).

Lead in glass or in a glass or ceramic matrix compound

- *used for protection and electrical insulation*
  - *in glass beads of high voltage diodes on the basis of a zinc-borate glass body*
  - *in other electrical and electronic components*
- *used as resistance material*
  - *in cermet-based trimmer potentiometers*
  - *other electrical and electronic components*
- *used for bonding purposes in electrical and electronic components*
- *for hermetic sealings between ceramic packages and glass or ceramic lids in electrical and electronic components*
- *used for any other purposes in electrical and electronic components*

Murata/JEITA et al.[1241] state that the time available was not enough to allow a cross-industry association discussion. They principally disagree with the splitting of the exemption for the same reasons as mentioned above in the ceramic part of the proposed rewording.

More specifically, Murata/JEITA et al. [1242] [1243] put forward that attempting to develop categories under the 7(c) exemptions that will cover all current components/devices is extremely difficult. Some products will ultimately be left out creating a compliance and economic issue for those component companies affected.

The consultants do not share this argument. The last clause of the proposed wording should cover all those cases, which are out of the scope of the previous clauses. It is, however, crucial that the other clauses actually address specific uses of glass and glass and ceramic matrix compounds containing lead as otherwise the specification of the exemption would not make sense. The replies of Murata/JEITA et al. are not detailed enough to allow clear insights on the viability of the proposed specific uses.

Murata/JEITA et al.[1244] state that there is not just one type of lead glass but there are different glasses for different functions/applications. Even though lead in glass material used today might be rather similar in their chemical composition, potential alternative materials will not likely be the same for the different applications. Based on previous investigations and studies it does not seem likely that one material compound could be found which fulfills the specific requirements for all the variety of applications.

This statement supports in principle the specification of the exemption to gradually phase out the use of lead, as stated in recital 19 of the RoHS Directive. [1245]

In the consultants' understanding, a clear consensus should be achieved with the applicants that the exemption technically covers all applications of glass and glass ceramic materials correctly, so as to avoid that misunderstandings and misinterpretations, which had occurred in the discussion process, result in an inappropriate wording. The limited time and resources available for the review of this exemption did not allow more time for further discussion. The above wording proposal should, however, be a good basis for a specification of the exemption in the next review.

[1241] Murata et al./Jeita et al. 2016c "Answer to questionnaire 4 (glass), document "Exe_7c-I_Questionnaire-4_Murata-JEITA_2016-03-09_glass.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Wolfgang Werner, Vishay, on 22 March 2016" unpublished manuscript,

[1242] Ibid.

[1243] Murataet al./JEITA et al. 2016g "Answers to questionnaire 6b, document "Exe_7c-I_Questionnaire-6b_Murata-JEITA_2016-03-3.pdf", received via e-mail from Wolfgang Werner, Vishay, on 5 April 2016" unpublished manuscript,

[1244] Ibid.

[1245] *Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast)*, recital clause (19)

22.5.5 Conclusions

22.5.5.1 Lead in Ceramics of Electrical and Electronic Components

The accessible information suggests that the substitution of lead in ceramics is scientifically and technically still impractical in the majority of applications. Contrary to the statements in particular of Murata et al., substitution or elimination of lead may be scientifically and technically practical to a certain degree even though it could not be clarified whether this would justify and enable narrowing the scope of the exemption.

Appraising the overall situation, Art. 5(1)(a) would justify renewing the exemption for lead in ceramics, taking into account the fact that the substitution or elimination of lead scientifically and technically is still impractical at least in the majority of cases. It can, however, not be excluded that lead-free solutions are or shall become available in the nearer future. Granting the exemption for five years would thus not be justifiable according to Art. 5(1)(a). The consultants hence recommend a validity period of three years, which would allow restricting the scope of the exemption, while still leaving enough time to for the stakeholders to apply for the renewal of the exemption 18 months prior to its expiry, should it still be required at that time. The applicants would then also have to show dedicated efforts to achieve the substitution and elimination of lead.

22.5.5.2 Lead in Glass or in Glass or Ceramic Matrix Compounds in Electrical and Electronic Components

The information provided by the applicants suggests that currently the substitution of lead in glass and in glass/ceramic matrix compounds in the scope of exemption 7c-I is scientifically and technically still impracticable. Bourns and IXYS are both continuing to work on lead-free solutions, though at present, these are understood not to be sufficiently mature to allow narrowing the scope of Exemption 7c-I in the foreseeable future.

The applicants' exemption requests and the answers to the clarification questionnaire were made available through the online consultation to the public, i.e. to industry, governments, NGOs and other stakeholders, and a consultation questionnaire had been prepared for the public online consultation with specific questions to stakeholders. No further information supporting or discrediting the technical application in question was received, and there were no hints that lead-free solutions would be foreseeable for the near future.

Murata et al. provide only very general and unspecific information on their future efforts to substitute or eliminate lead in ceramics. They justify this with confidentiality, but the consultants believe that even though the members of the industry consortium are competitors, there should be possibilities to describe in more detail the future steps to be taken. These efforts should also be related to the various types of glass and glass/ceramic matrix compounds and their application-specific requirements to find specific solutions where general drop-in alternatives are not viable.

Taking into account the overall situation, the consultants recommend granting the exemption given the fact that lead is still required in glass and glass and ceramics matrix

compounds. As no substitutes are foreseeable in the near future, Art. 5(1)(a) would justify renewing the exemption for the maximum validity period of five years. It will, however, be essential that the applicants will have undertaken dedicated efforts in the coming five years to find application-specific solutions for the various types of glass applications should they apply for another renewal of this exemption.

22.5.5.3 Specification of Exemption 7(c)-I

The discussion related to the consultants' rewording proposal for exemption 7(c)-I shows that a consensus on the technical details of such a rewording proposal requires further exchange with the various stakeholders to agree on the architecture and the definitions of terms. The above wording proposal should, however, be a good basis for further efforts to specificy the exemption in the next review.

22.6 Recommendation

The applicants' information suggests that the substitution and elimination of lead generally is still scientifically and technically impracticable in the applications in the scope of Exemption 7c-I. Art. 5(1)(a) thus would allow renewing the exemption. While for lead in glass and glass or ceramic matrix compounds no possibilities for substitution or elimination of lead are foreseeable, the information available does not allow excluding that lead-free solutions for ceramics are or will become available within less than five years.

The consultants therefore recommend renewing the exemption for five years for lead in glass or glass or ceramic matrix compounds, and for three years only for lead in ceramics of electrical and electronic components.

It should also be noted here that the exemption for lead in glass or glass or ceramic matrix compounds of electrical and electronic components technically covers the use of lead in cermet-based trimmer potentiometers, which is in the scope of Exemption 34. To avoid overlapping scopes of exemptions, Exemption 34 should be excluded from this part of the exemption.

Exemption 7(c)-I	**Expires on**
Electrical and electronic components containing lead in a ceramic other than dielectric ceramic in discrete capacitor components, e.g. piezoelectronic devices	*21 July 2019 for categories 1-7 and 10*
Exemption 7(c)-V	**Expires on**
Electrical and electronic components containing lead in a glass or in a glass or ceramic matrix compound. *This exemption does not cover the use of lead in the scope of exemption 34 (cermet-based trimmer potentiometers).*	*21 July 2021 for categories 1-7 and 10*

Exemption 7(d)	Expires on
Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound	*21 July 2021 for medical equipment in category 8 monitoring and control instruments in category 9* *21 July 2023 for in vitro diagnostic medical devices in category 8*
	21 July 2024 for industrial monitoring and control instruments in category 9

Exemptions 7(c)-II, 7(c)-III and 7(c)-IV can be integrated into the above table.

In order to keep the purely ceramic-related exemptions together, it is recommended above to give the exemption valid for cat. 8 and 9 a new number and to list all ceramic-related exemptions under 7c-I. This numbering would also prevent that exemptions 7(c)-II, 7(c)-III and 7(c)-IV have to be renumbered, which overall reduces the administrative burden.

If the Commission decides not to change the numbering of the part of the exemption that covers Cat. 8 and 9, the consultants recommend the below wording and numbering for Exemption 7c-I.

Exemption 7(c)-I	Expires on
Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound	*21 July 2021 for medical equipment in category 8 monitoring and control instruments in category 9* *21 July 2023 for in vitro diagnostic medical devices in category 8* *21 July 2024 for industrial monitoring and control instruments in category 9*
Exemption 7(c)-V	**Expires on**
Electrical and electronic components containing lead in a glass or in a glass or ceramic matrix compound. *This exemption does not cover the use of lead in the scope of exemption 34 (cermet-based trimmer potentiometers).*	*21 July 2021 for categories 1-7 and 10*
Exemption 7(d)	**Expires on**
Electrical and electronic components containing lead in a ceramic other than dielectric ceramic in discrete capacitor components, e.g. piezoelectronic devices	*21 July 2019 for categories 1-7 and 10*

Exemptions 7(c)-II, 7(c)-III and 7(c)-IV can be integrated into the above table.

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Vishay 2015a Document "RoHS-Exe-7c-I_Pb-in-glass-Enamel-Coating_Wirewound_Resistors.pdf", submitted as additional reference for the exemption request of Murata et al. 2015a 2015.

Vishay 2015b Document "NTC – Glass coating for insulation.pdf", submitted as additional reference for the exemption request of Murata et al. 2015a 2015.

Vishay 2015c Document "Request for exemption 7c-I NTC chips update dec15.pdf", submitted as additional reference for the exemption request of Murata et al. 2015a.

Yageo Corporation 2015 Exemption request, document "7c-I_RoHS_V_Application_Form_YAGEO_2015-01-19.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/YAGEA/7c-I_RoHS_V_Application_Form_YAGEO_2015-01-19.pdf.

Zangl, Stéphanie [Oeko-Institut e.V.] et al. Adaptation to scientific and technical progress of Annex II to Directive Adaptation Directive2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS) 2010. http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3_2010_Review_Final_report_ELV_RoHS_28_07_2010.pdf; or https://circabc.europa.eu/sd/d/a4bca0a9-b6de-401d-beff-6d15bf423915/Corr_Final%20report_ELV_RoHS_28_07_2010.pdf.

23.0 Exemption 7c-II "Lead in Dielectric Ceramic in Capacitors for a Rated Voltage of 125 V AC or 250 V DC or Higher"

Declaration

In the sections that precede the "Critical Review" the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated, and the views presented should not be taken to represent the views of the consultants (authors of this report).

Acronyms and Definitions

HVC	high voltage capacitor(s), capacitor(s) with rated voltage of 125 V AC or 250 V DC or higher

23.1 Description of the Requested Exemption

The current wording of exemption 7c-II in Annex III of the RoHS Directive is:

> *"Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher"*

Murata et al.[1246] apply for the renewal of Exemption 7c-II for five years with a modified wording to clarify the scope:

> *"Lead in dielectric ceramic in **discrete** capacitor **components** for a rated voltage of 125 V AC **or higher**, or **for a rated voltage of** 250 V DC or higher**"***

[1246] Murata et al. 2015a "Request for Renewal of Exemption 7c-II from 16 January 2015," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-II/7c-II_RoHS_V_Application_Form_7c2_20140115_final.pdf

23.1.1 Background and History of the Exemption

When Directive 2002/96/EC (RoHS 1)[1247] was published in 2003, Exemption 7d covered the use of lead in ceramics of electronic components:

"Lead in electronic ceramic parts (e.g. piezoelectronic devices)"

In the 2008/2009 review[1248] of this exemption it was found that the substitution of lead is scientifically and technically practicable in the low voltage area and the wording detailed below was thereupon recommended and adopted to the Annex of RoHS 1 demarcating the lead-free ceramic low voltage ceramic capacitors from the high voltage ones that still required the use of lead:

"7(c)-II Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher

7(c)-III Lead in dielectric ceramic in capacitors for a rated voltage of less than 125 V AC or 250 V DC"

Exemption 7c-III was transferred without changes from the Annex of RoHS 1 to Annex III of RoHS 2 and expired on 1 January 2013.

Exemption 7c-II was also transferred without changes from the Annex of RoHS 1 to Annex III of RoHS 2 and would expire on 21 July 2016 if application for renewal had not been received.

23.1.2 Technical Description of the Exemption

Murata et al.[1249] explain that discrete ceramic capacitors for a rated voltage of 125 V AC or 250 V DC or higher (high voltage capacitors, HVD) bear the capability of storing and releasing electric charges (electrostatic capacitance) and are incorporated into high voltage circuits in a wide variety of electrical and electronic equipment. They are used in all types of markets and applications, for example: [1250]

- Social infrastructure systems;
- Industry automation;
- Oil and mineral exploration;
- Power conversion;
- High power supplies;

[1247] Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment, RoHS 1, European Union (13 February 2003)

[1248] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf

[1249] Op. cit. Murata et al. 2015a

[1250] Ibid.

- Telecommunication;
- Medical.

Typical applications are: [1251]

- Power electronic inverters;
- Pulsed power electronics and pulse forming networks;
- Capacitive discharge units;
- Transient high voltage suppression;
- Magnetization/demagnetization devices;
- Plasma generators;
- High-energy flashes;
- Lamps;
- Radio frequency interference suppression and electrical safety.

Murata et al.[1252] say that the above are nothing more than representative examples only partially showing markets and applications in which the exemption is used.

Murata et al.[1253] state that even though the major trend is miniaturization with low voltage rating and low power, other optimization parameters are often required for HVC, for example the need for high capacitance at high voltage and high power. The function of lead in the dielectric ceramic is to obtain:[1254]

a. High dielectric constant at high operating voltage;
b. High energy storage capability (also at high temperatures);
c. Low leakage at high voltage and high temperatures; and
d. Low loss at high current, frequency, and temperatures.

Murata et al.[1255] indicate that design engineers frequently call upon these parameters to meet technical requirements. Lead-containing dielectric ceramic has the outstanding feature of stably bringing out the above functions.

23.1.3 Amount of Lead Used under the Exemption

In Table 23-1, Murata et al.[1256] present a rough estimate of the total amount of lead included in glass/ceramic of the main electrical and electronic components. These figures were estimated from the production and sales results of electrical and electronic component manufacturing companies from Japan and Europe.

[1251] Ibid.
[1252] Ibid.
[1253] Ibid.
[1254] Ibid.
[1255] Ibid.
[1256] Ibid.

Table 23-1: Estimated amount of lead used in HVC

2007					2013				
Number of pieces placed on the market (G*5 pcs)		Lead use amount*2 / Per piece unit (mg)	Lead use amount (t) / Total amount placed on the market		Number of pieces placed on the market (G*5 pcs)		Lead use amount*2 / Per piece unit (mg)	Lead use amount (t) / Total amount placed on the market	
World*1	Europe*4		World*3	Europe*4	World*1	Europe*4		World*3	Europe*4
1.3	0.39	78	100	30	1.6	0.38	30	50	11.9

Source: Murata et al.[1257]

**1: Estimate by JEITA.*
**2: There are components with several different shapes and masses. We have estimated the lead use amount of an average component.*
**3: Rough estimate from *1 and *2.*
**4: Estimated from the EU/World GDP ratio.*
**5: G = 10^9 pieces.*

Murata et al.[1258] state that HVC are used in large quantities in a wide range of final products. It is impossible to provide an actual estimate of the amount of lead included in dielectric ceramic entering the EU. The above presented numbers result from an estimate concerning HVC for which production figures are comparatively easy to obtain by JEITA. It should also be noted that there may be capacitors for high voltage applications with lead-containing dielectric ceramic which are not included in the calculation. For this reason, although the estimates were done in good faith with the data resources available, the values shown here are provided strictly for reference purposes, and Murata et al.[1259] shall bear no responsibility concerning their accuracy or enforceability.

The around 12 t of lead indicated by the applicants should be considered as a minimum and the actual amount could be much higher given the fact that high volumes of EEE are imported into the EU.

1257 Ibid.
1258 Ibid.
1259 Ibid.

23.2 Applicants' Justification for the Renewal of the Exemption

23.2.1 Clarification of the Exemption Scope

Murata et al.[1260] and JEITA et al.[1261] clarify that in the existing wording electronic components expressed as "capacitors" are precisely speaking "discrete capacitor components". They propose the underlined additions to the current wording for clarification of the technical scope of 7(c)-II.

> *Lead in dielectric ceramic in <u>discrete</u> capacitor <u>components</u> for a rated voltage of 125 V AC <u>or higher</u>, or <u>for a rated voltage of</u> 250 V DC or higher*

Murata[1262] and JEITA et al.[1263] explain that the current wording may be understood as also covering lead-containing dielectric ceramic in other components aside from discrete capacitor components, e.g. lead containing dielectric ceramic incorporated in ICs, boards, etc. These dielectric ceramic materials as well can store and release electricity, which is technically determined as capacitance. Those materials are, however, already in the technical scope of exemption 7(c)-I.

In the applicants' opinion[1264, 1265] the rated voltage limits in the current wording do not clearly determine the limits with respect to 125 V AC and 250 V DC resulting in an ambiguous wording. The proposed additions would clearly determine those limits.

Murata[1266] and JEITA et al.[1267] assure that their proposal only targets a more precise and less ambiguous wording and does not intend to enlarge the technical scope of Ex. 7(c)-II.

23.2.2 Substitution of Lead

Murata et al.[1268] claim that they had investigated the substitution of lead in lead-containing dielectric ceramic in discrete ceramic capacitor components for a rated voltage of 125V AC or higher, or for a rated voltage of 250 V DC or higher before the last review and continued the investigation after 2009 as well. Nevertheless, no substitution technology has been found up to the present day and there are no prospects of finding it within the foreseeable future. The reasons for the exemption presented by the

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[1260] Ibid.
[1261] JEITA et al. (Japan 4EEE) 2015 "Request for renewal of exemption 7c-II" unpublished manuscript, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-II/7c-II_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf
[1262] Op. cit. Murata et al. 2015a
[1263] Op. cit. (JEITA et al. (Japan 4EEE) 2015)
[1264] Op. cit. Murata et al. 2015a
[1265] Op. cit. (JEITA et al. (Japan 4EEE) 2015)
[1266] Op. cit. Murata et al. 2015a
[1267] Op. cit. (JEITA et al. (Japan 4EEE) 2015)
[1268] Op. cit. Murata et al. 2015a

stakeholders in 2009 are still valid. Consequently, it is necessary to extend the exemption.

Of central importance, as stated above, according to Murata et al.[1269] lead-containing dielectric ceramic has the outstanding feature of stably bringing out all of the below functions:

a. High dielectric constant at high operating voltage;
b. High energy storage capability (also at high temperatures);
c. Low leakage at high voltage and high temperatures; and
d. Low loss at high current, frequency, and temperatures.

Design engineers frequently call upon these parameters to meet technical requirements. Even for use at the condition of a rated voltage of 125 V AC or higher, or 250 V DC or higher, lead elimination can be achieved in practice for some partial applications, nevertheless in applications requiring all of the functions (a)-(d) the addition of lead is indispensable.

For example, in ceramic capacitors composed of barium titanate, which is known for its high dielectric constant and, which is used in lower voltage capacitors, these functions cannot be achieved without the addition of lead. If high voltage is applied to electrical and electronic equipment containing barium titanate capacitors, the equipment becomes unstable and even breaks down in the worst cases due to heat dissipation through energy loss and mechanical distortion due to electrostriction, the conversion of electric energy into mechanical distortion. Lead is added to suppress energy loss and electrostriction at the time when high voltage is applied. [1270]

Murata et al.[1271] report that ceramic capacitors having a material composed of strontium titanate show low energy loss and low electrostriction characteristics when high voltage is applied, meaning that functions (b)-(d) can be achieved. In spite of that, function (a) cannot be achieved due to a small dielectric constant, and so addition of lead becomes indispensable in order to increase the dielectric constant and have such capacitors operable in practice.

Murata et al.[1272] state that according to Pauling's rules, in order to form the same crystal structure, the constituent elements of ceramic, which can substitute lead, are restricted to those having a divalent valence and an ionic radius of 0.93-1.81 Å. The elements, which meet these conditions, are restricted to cadmium and alkaline-earth metals. Among those, cadmium has a higher toxicity than lead, and thus is not appropriate as a substitute material. In the case of alkaline-earth metals other than strontium (calcium, barium) are added, energy loss and electrostriction increase and therefore they cannot be used as substitute materials.

[1269] Ibid.
[1270] Ibid.
[1271] Ibid.
[1272] Ibid.

Murata et al.[1273] report that for particular use conditions, the required functions can be achieved with lead-free dielectric ceramic, however lead-containing dielectric ceramic is indispensable in applications for which it is necessary that multiple parameters coexist. It is required that the lead-containing dielectric ceramic used in ceramic capacitors for utilization at the condition of rated voltages of 125 V AC or higher, or 250 V DC or higher, must have a high dielectric constant capable to produce the required electrical capacitance in circuits of electrical and electronic equipment, as well as low energy loss and low electrostriction characteristics when high voltages are applied.[1274]

Lead is indispensable for the stable achievement of excellent functionality (high dielectric constant, low energy loss) over a wide range of use conditions (temperature, voltage, frequency). Moreover, as these use conditions vary during the use of electrical and electronic equipment, it is impossible to specify a technical range for elimination of lead with values based on a single condition. Consequently, there are no technical prospects for the general elimination of lead from dielectric ceramic materials in high voltage capacitor applications.[1275]

For further information, Murata et al. reference the 2008/2009 review report[1276] and the input from JBCE[1277] to the 2008/2009 review.

23.2.3 Elimination of Lead

Murata et al.[1278] explain that there are cases when substitution is possible in specific fields, as for example, film capacitors. There may exist other cases as well. However, to their knowledge, no product exists, which can substitute the advantages obtained in practice by lead-containing ceramic capacitors.

23.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

Murata et al.[1279] report about technical advances to reduce the amount of lead. The electrical and electronic equipment industry has enhanced the performance of discrete ceramic capacitors for high voltage applications in relation to their size. This has been achieved by improving the dielectric constant through the addition of lead, by using the multilayer technology, which takes advantage of the characteristic that lead-containing

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[1273] Ibid.
[1274] Ibid.
[1275] Ibid.
[1276] Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009), in particular page 104 et sqq.
[1277] C.f. JBCE, http://rohs.exemptions.oeko.info/fileadmin/user_upload/Stakeholder_comments/Exemption-7c_JBCE_1_April_2008.pdf
[1278] Murata et al. 2015b “Answers to questionnaire 1 (clarification questionnaire)” unpublished manuscript, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-II/7c-II_Questionnaire-1_ZVEI-et-al_2015-09-06_final.pdf
[1279] Op. cit. (Murata et al. 2015a)

ceramic can be densely sintered over a wide range of sintering conditions and by promoting miniaturization.

At the same time, with the advance of IT/wireless technology in recent years and the increase of high-frequency equipment associated with it, the number of electrical and electronic components per unit of electrical and electronic equipment has drastically increased. Overall, industry has nevertheless been successful in reducing the total amount of lead included in the ceramic of discrete ceramic capacitors for high voltage applications placed on the world market, including Europe.[1280] Table 23-1 on page 505 shows the detailed figures calculated by Murata et al.[1281]

Murata et al.[1282] conclude that although it is impossible to completely cease the use of lead under the scope of exemption 7(c)-II, improvements concerning its use have been implemented within their power, and industry is engaged in the reduction of the environmental burden as well as the amount of lead brought into the EU.

Concerning further stages for establishing possible substitutes and respective time frames needed for their completion, Murata et al.[1283] claim there are no prospects for substitution for the foreseeable future because of the technical reasons explained in their request for the renewal of exemption 7c-II.

23.4 Critical Review

23.4.1 REACH Compliance - Relation to the REACH Regulation

Barium titanate, strontium titanate and lead are used in the ceramics according to the applicants and therefore need to be evaluated whether their use weakens the environmental and health protection afforded by Regulation (EC) No 1907/2006 (REACH Regulation).

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is

[1280] Ibid.
[1281] Ibid.
[1282] Ibid.
[1283] Ibid.

relevant for this case, neither as directly added substances nor as substances that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under Entry 28 and Entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, Entry 28 and 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds

1) *"shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight."*
   This restriction does not apply to internal components of watch timepieces inaccessible to consumers;
2) *"shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children."*
   This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under entry 63 thus do not apply to the applications in the scope of this RoHS exemption. Should HVC actually be used in watch timepieces, this use of lead would be allowed.

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of barium, strontium and compounds in various articles and uses.

Nickel barium titanium primrose priderite is specified for Annex XVII entry 28. This barium-containing substance is, however, not relevant for the ceramics in the scope of Exemption 7c-II. The same applies to strontium chromate, which is listed in Annex XIV.

No other entries, relevant for the use of substances relevant for the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based

on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

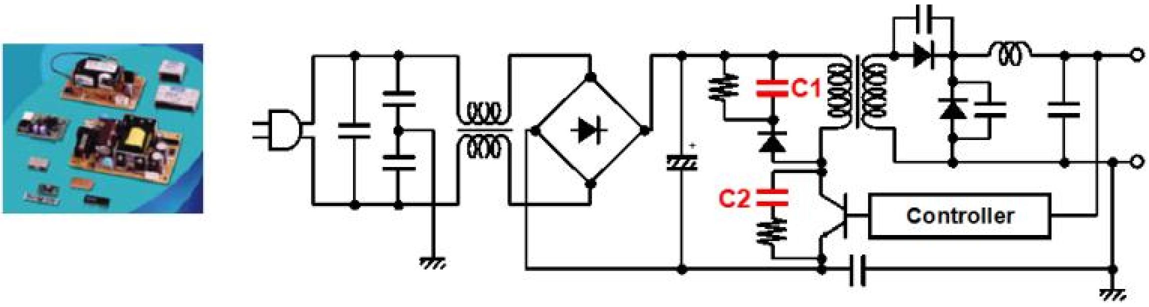
23.4.2 Substitution and Elimination of Lead

Murata et al.[1284] stated that HVC applied at a rated voltage of 125 V AC or higher, or 250 V DC or higher, lead elimination can be achieved in practice for some partial applications. They were asked to explain this in more detail with respect to applications that do not require the full range of properties that lead-containing dielectric ceramics can provide:

1) High dielectric constant at high operating voltage;
2) High energy storage capability (also at high temperatures);
3) Low leakage at high voltage and high temperatures;
4) Low loss at high current, frequency, and temperatures.

Only upon repeated requests[1285] [1286] [1287] Murata et al finally presented two examples of lead-free HVC snubber capacitors that are used in switching power supplies (C1, C2 in Figure 23-1).

Figure 23-1: Switching power supply



Source: Murata et al.[1288]

Murata et al.[1289] explain that the lead-free HVC C1 and C2 in the above figure eliminate high-frequency noise, for which ceramic HVC are generally used. C1 and C2 are operated

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[1284] Ibid.
[1285] Op. cit. (Murata et al. 2015b)
[1286] Murata et al. 2016a “Answers to second questionnaire, document "Exe_7c-II_Questionnaire-2_ZVEI-et-al_2015-01-25_answers_final.pdf", received via e-mail from Walter Huck, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 February 2016” unpublished manuscript,
[1287] Murata et al. 2016b “Answers to third questionnaire, document "Exe_7c-II_Questionnaire-3_ZVEI-et-al_2016-03-14.DOCX", received via e-mail from Walter Huck, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 24 March 2016” unpublished manuscript,
[1288] Ibid.

with high frequencies and high voltages. However, in case “lead-free” HVCs are used, there is the possibility of a short circuit failure occurring over a short period of time depending on the voltage conditions of the equipment and use conditions in the market. In practice, according to Murata et al., equipment using “lead-free” HVCs have recently caused short failure accidents in the market. The applicants did not provide further information substantiating this statement.

Murata et al.[1290] state that in recent years, as voltage and use conditions become more severe, high reliability and longer longevity of the equipment are being required by society in order to promote accident prevention in the market and reduce maintenance burdens including environmental aspects. “Lead-free” HVCs cannot fulfill the requirements of high reliability and longevity, thus there is the risk that they may cause serious accidents in the market.

Murata et al.[1291] ask to note that the use conditions required by equipment applications utilizing snubber capacitors C1 and C2 stretch over a very wide range as shown below, and moreover, there are applications requiring compatibility to further high frequency trends and high voltage.

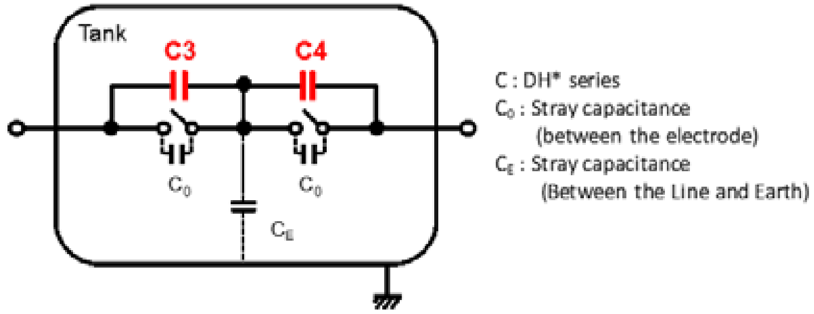
- Frequency: Generally 50 - 150kHz; there are market trends of shifting to higher frequencies.
- Voltage: Generally 150Vp-p - 1000Vp-p, however there are cases exceeding 1000Vp-p depending on the input voltage to the equipment and noise conditions.
  Vp-p = Volt peak to peak (electrical potential difference between minimum and maximum values of AC voltage).

Murata et al.[1292] indicate that in order to fulfill these use conditions, capacitance (electrostatic capacity) and nominal voltage are listed as performance parameters required for C1 and C2, however neither of them can be specified. The capacitance changes according to the noise frequency to be eliminated, so that the capacitance range cannot be specified. Besides requirements that change depending on the input voltage and noise conditions, safety design conditions of equipment are diverse. As there are cases where higher nominal voltages are (also) required, it is not possible to specify the voltage range.

As a second example of lead-free HVC uses, Murata et al.[1293] present circuit breakers of power (C3 and C4 in Figure 23-2).

[1289] Ibid.
[1290] Ibid.
[1291] Ibid.
[1292] Ibid.
[1293] Ibid.

Figure 23-2: Circuit breaker



Source: Murata et al.[1294]

Murata et al.[1295] explain that C3 and C4 are capacitors used dividing voltage and reducing restriking voltage. The voltage of these subparts is some hundreds of kilovolts AC at 50/60Hz with multiple capacitors being used in series. Therefore, the applied voltage onto individual capacitors is a high voltage (maximum AC40kV) at 50/60 Hz.

However, as high voltage noise is generated when switching the circuit breaker, high resistance to surge (impulse) voltage performance is required. There are cases when “lead-free” HVCs are used in this subpart. As impulse (surge) resistance performance of “lead-free” HVCs is low compared to lead-containing HVC, it is necessary to increase the thickness of the ceramic element or to increase the number of serial HVC in order to adopt those “lead-free” HVC. This results in the upsizing of the equipment as a whole. In order to reduce the environmental load, including the amount of lead used, and promote the downsizing of the entire equipment, lead-containing ceramic materials, which have excellent surge (impulse) resistance performance, are indispensable.

Murata et al.[1296] summarize the use conditions required by the equipment application concerning C3 and C4 listing capacitance, nominal voltage and surge (impulse) resistance as performance parameters required for C3 and C4. However, regardless of the parameters it is not possible to specify a technical scope for which “lead-free” HVC may be utilized.[1297]

- **Frequency**: 50/60Hz
- **Voltage**: some hundreds kV AC as a circuit
  As multiple capacitors are used connected in series, the applied voltage changes according to the circuit design and thus cannot be specified.
- **Capacitance**
  As capacitors are used as multiple units in a series, the capacitance of the equipment is the total sum of those capacitances. Consequently, it is not

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[1294] Ibid.
[1295] Ibid.
[1296] Ibid.
[1297] Ibid.

possible to specify the capacitance values required by each individual capacitor.

- **Nominal Voltage**
  As capacitors are used as multiple units in a series, the required nominal voltage changes with the circuit design. The safety design conditions of the equipment are diverse, and as there are also cases when higher nominal voltages are required it is not possible to specify them. For this reason, it is not possible to specify the nominal voltage of the individual capacitor units.
- **Surge (Impulse) Resistance Performance**
  There is a correlation between surge (impulse) resistance performance and nominal voltage, and as the safety design conditions of equipment are set for surge (impulse) performance and nominal voltage respectively, it is not possible to determine a specification for surge (impulse) performance individually.

There are cases when it is not possible to fulfill the required performance of the product with "lead-free" HVC depending on the applied voltage conditions. For this reason, it is impossible to comprehensively substitute specific applications by "lead-free" HVC.[1298]

23.4.3 Rewording of the Exemption

Murata/JEITA et al.[1299] [1300] propose a slight modification of the exemption wording (c.f. Section 23.2.1 on page 506) to clarify that actually the discrete capacitor components are in the scope and not other dielectric ceramic materials that may also have a capacitance, but that are covered by exemption 7c-I. As this was actually the intended scope of exemption 7c-II, the consultants recommend to adopt the proposed wording based on the applicants' assertion that these modifications clarify, but do not change the technical scope of the exemption.

According to the applicants, such dielectric ceramic materials are not only used in discrete ceramic capacitors. The consultants therefore wonder whether in the low voltage area below 125 V AC or 250 V DC the substitution of lead would not be scientifically and technically practicable in all dielectric ceramic materials with capacitance or where the capacitance is the reason for their use. As this question arose, however, at the very end of the review process, it could not be discussed with the stakeholders and shall need to be followed up in the next evaluation.

23.4.4 Conclusions

The applicants provide plausible information that the substitution of lead is scientifically and technically impracticable in HVC for applications that require all of the properties which currently only lead-containing dielectric ceramics can deliver. In the absence of

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[1298] Ibid.
[1299] Op. cit. (Murata et al. 2015a)
[1300] Op. cit. (JEITA et al. (Japan 4EEE) 2015)

contrary information, granting an exemption would therefore be in line with RoHS Art. 5(1)(a).

In the light of the stipulations for exemptions in Art. 5(1)(a) the core criterion is, however, where the substitution or elimination of lead is scientifically and technically practicable. This raises the question whether all ceramic capacitors in all applications in the high voltage area actually need the combination of all properties of the leaded dielectric ceramics.

The applicants did not provide information on lead-free HVC or possible other alternatives to substitute or eliminate the use of lead, e.g. where not all of the leaded ceramics' properties are required. Only upon repeated request[1301, 1302, 1303] did they submit two examples of lead-free HVC and where they are used. The declaration as "examples" suggests that there are other lead-free HVC as well.

It is comprehensible that the applicability of such lead-free HVC depends on multiple parameters that may be difficult to be linked to criteria, which would allow a clear demarcation of application fields, where such lead-free HVC can be used. It can be assumed that such lead-free HVC have certain performance parameters such as rated voltages, temperature and frequency ranges, which circuit designers need to know in order to decide about their usability to verify certain requirements. Furthermore, electronic circuits could at least in part be redesigned to better accommodate the limits of such lead-free HVC and allow their use to thus reduce the amount of lead-containing HVC. The applicants did not provide information to clarify these questions.

Murata et al.[1304] also mention film capacitors as another example to substitute or eliminate lead and mention that there may be other options as well, but do not provide more comprehensive information about the properties of such devices.

Appraising the overall situation against the criteria stipulated in Art. 5(1)(a), the consultants recommend granting the exemption. The information available shows that lead-free alternatives are available for some applications, even though it was not possible to clarify with the available resources and time whether these lead-free alternatives would allow restricting the scope of the exemption. Substitution or elimination of lead thus may be scientifically and technically practicable in some cases within the maximum five years validity period. According to Art. 5(1)(a), it would not be justified to grant the maximum validity period of five years. The consultants propose to continue the exemption for three years only. This would on the one hand accommodate the scientific and technical impracticability to substitute or eliminate lead in HVC and give the applicants sufficient time to apply for the renewal of the exemption 18 months

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[1301] Op. cit. (Murata et al. 2015b)
[1302] Op. cit. (Murata et al. 2016a)
[1303] Op. cit. (Murata et al. 2016b)
[1304] Op. cit. (Murata et al. 2015b)

prior to its expiry. On the other hand it would facilitate a further clarification of those areas where lead can already be substituted or eliminated.

23.5 Recommendation

The information which the applicants submitted suggests that many if not most applications require HVC containing lead in the dielectric ceramic material so that the substitution or elimination of lead in those HVC is scientifically and technically impracticable. In the absence of contrary information, granting an exemption would therefore be justified in line with Art. 5(1)(a). For some applications, alternative components such as lead-free HVC are, however, available on the market. The applicants did not provide comprehensive information about these components. In light of the lacking data related to availability of alternatives, the consultants would recommend a short term renewal, restricting the validity period of the exemption to three years. Should industry fail then again to provide substantiated information about specific research and available lead-free HVC in the future, the consultants recommend cancelling the exemption in the next review.

Exemption 7c-II	**Expires on**
Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher	*21 July 2021 for medical equipment in category 8 monitoring and control instruments in category 9*
	21 July 2023 for in vitro diagnostic medical devices in category 8
	21 July 2024 for industrial monitoring and control instruments in category 9
Lead in dielectric ceramic in discrete capacitor components for a rated voltage of 125 V AC or higher, or for a rated voltage of 250 V DC or higher	*21 July 2019 for categories 1-7 and 10*

The modified wording to clarify the scope of exemption 7c-II should also be reflected in exemption 7c-III, whose current wording is:

> *"Lead in dielectric ceramic in capacitors for a rated voltage of less than 125 V AC or 250 V DC"*

The table below proposes a modified wording for exemption 7c-III.

Exemption 7c-III	Expires on
Lead in dielectric ceramic in discrete capacitor components for a rated voltage of less than 125 V AC, or for a rated voltage of less than 250 V DC	*1 January 2013 and after that date may be used in spare parts for EEE placed on the market before 1 January 2013*

23.6 References Exemption 7c-II

Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

JEITA et al. (Japan 4EEE) 2015 Request for renewal of exemption 7c-II. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-II/7c-II_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf.

Murata et al. 2015a Request for Renewal of Exemption 7c-II from 16 January 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-II/7c-II_RoHS_V_Application_Form_7c2_20140115_final.pdf.

Murata et al. 2015b Answers to questionnaire 1 (clarification questionnaire). http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-II/7c-II_Questionnaire-1_ZVEI-et-al_2015-09-06_final.pdf.

Murata et al. 2016a Answers to second questionnaire, document "Exe_7c-II_Questionnaire-2_ZVEI-et-al_2015-01-25_answers_final.pdf", received via e-mail from Walter Huck, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 February 2016.

Murata et al. 2016b Answers to third questionnaire, document "Exe_7c-II_Questionnaire-3_ZVEI-et-al_2016-03-14.DOCX", received via e-mail from Walter Huck, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 24 March 2016.

24.0 Exemption 7c-IV “Lead in PZT based dielectric ceramic materials for capacitors which are part of integrated circuits or discrete semiconductors”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated, and the views presented should not be taken to represent the views of the consultants (authors of this report).

Acronyms and Definitions

ADSL	Asymmetric Digital Subscriber Line, a communication technology
BST	Barium-Strontium-Titanate (ceramic)
F	Farad, unit for electrical capacitance
FRAM	Ferroelectric random access memory (or memories)
IC	Integrated circuit
IPD	Integrated passive device(s)
MEMS	Micro-Electro-Mechanical Systems
MFIS FeFET	Metal-ferroelectric-insulator-semiconductor Fe-Field Effect Transistor
MIM capacitor	Metal/insulator/metal type capacitor
MIS capacitor	Metal/insulator/semiconductor type capacitor
MOS capacitor	Metal oxide/silicon type capacitor
SBT	Strontium bismuth tantalite
SST	Strontium bismuth tantalite (ceramic)
STM	ST Microelectronics
PZT	Lead-Zirconium-Titanate (ceramic)

24.1 Description of the Requested Exemption

STMicroelectronics (STM) et al.[1305] request the continuation of exemption 7c-IV in Annex III of the RoHS Directive with the current scope and wording.

> "*Lead in PZT-based dielectric ceramic materials for capacitors which are part of integrated circuits or discrete semiconductors*"

24.1.1 Background and History of the Exemption

Exemption 7c was reviewed during the last adaptation of the Annex to the scientific and technical progress in 2008/2009.[1306] The Commission adopted the consultants' recommendation and adopted the following exemption wording:

- ***"7(c)-I** Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound*
- ***7(c)-II** Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher*
- ***7(c)-III** Lead in dielectric ceramic in capacitors for a rated voltage of less than 125 V AC or 250 V DC until 1 January 2013, and after that date may be used in spare parts for EEE placed on the market before 1 January 2013."*

Exemption 10 in Annex II of the ELV Directive exempted the use of lead in ceramics and glass as well. The background of this exemption technically is the same as exemption 7c in the RoHS Directive. Exemption 10 of the ELV Directive was reviewed[1307] in 2009/2010 and it was recommended to restrict the use of lead in dielectric ceramic materials of capacitors following the example in the RoHS Directive.

During the review of exemption 10 in the Annex of the ELV Directive, stakeholders informed the consultants that ceramic capacitors being part of integrated circuits or discrete semiconductors use dielectric ceramic materials based on PZT ceramics. These ceramics require the use of lead. As these capacitors are conceived for rated voltages of less than 125 V DC or 250 V AC, the use of lead in these components would no longer be allowed after December 2012.

[1305] STMicroelectronics et al. 2015a "Request for continuation of exemption 7c-IV, document "7c-IV_RoHS_V_Application_Form_7c-IV_Final.pdf": Original exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-IV/7c-IV_RoHS_V_Application_Form_7c-IV_Final.pdf

[1306] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM, page 194 et sqq.

[1307] Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010 "Adaptation to scientific and technical progress of Annex II to Directive Adaptation Directive2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS): Final report - revised version," Final Report Oeko-Institut e. V. und Fraunhofer IZM; page 194 et sqq.

The stakeholders at that time could plausibly justify the need for this exemption and the Commission followed the contractors' recommendation[1308] to grant the exemption in the ELV Directive with the following wording as exemption 10(a)(iv) in the Annex of the ELV Directive[1309]:

> *"Lead in PZT-based dielectric ceramic materials of capacitors being part of integrated circuits or discrete semiconductors"*

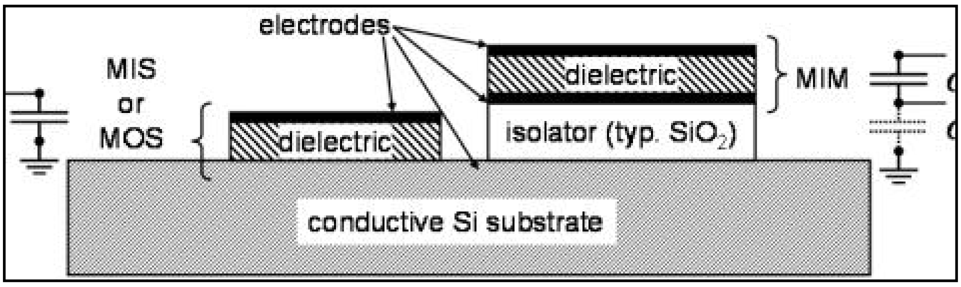
The stakeholders requested an identical exemption under the RoHS Directive (RoHS 1) in 2011 which was granted with the same wording like above and adopted to the annex of RoHS 1. The exemption was later transferred to Annex III of RoHS 2 and would have expired in July 2016 if no applications for renewal had been submitted.

24.1.2 Technical Description of the Requested Exemption

The technical background of the exemption was described in detail in the review report of this exemption[1310] under the scope of the ELV Directive in 2010. Capacitors store electrical energy in dielectric materials. Two electrodes are used to conduct the energy to and from the capacitor.

Figure 24-1 illustrates the two common capacitor types for integrated capacitors. The silicon substrate can be used as electrode (MIS or MOS). In this case, all capacitors share the substrate as ground electrode. MIM capacitors can be used in any configuration.[1311]

Figure 24-1: Typical thin film capacitor configurations



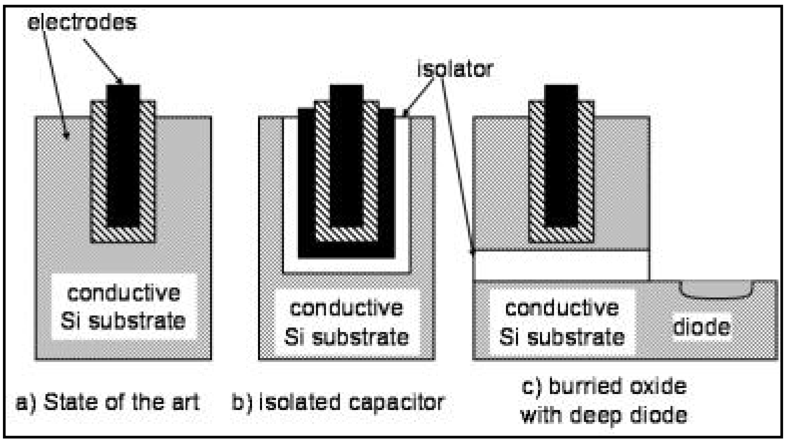
MIM metal/insulator/metal type capacitor
MIS metal/insulator/semiconductor type capacitor
MOS metal oxide/silicon type capacitor

Source: NXP in Zangl et al.[1312]

[1308] Ibid.
[1309] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles, ELV Directive, European Union (21 October 2000), http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0053:EN:NOT
[1310] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010, page 194 et sqq.
[1311] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010, page 194 et sqq.
[1312] Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010 "Adaptation to scientific and technical progress of Annex II to Directive Adaptation Directive2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC

Trench (MOS) capacitors could be a potential alternative to high-density silicon integrated capacitors, as illustrated in Figure 24-2. [1313]

Figure 24-2: Trench capacitors



Source: NXP in Zangl et al.[1314]

Trench capacitors have disadvantages compared to PZT capacitors as they offer:[1315]

- Much lower capacitance density; and
- Significantly lower breakdown voltage (only 30 V, compared to 100 V for PZT-based materials).

The disadvantage of the lower capacitance density can partially be compensated by using the 3rd dimension making the capacitors larger. However, the breakdown voltage of PZT-based capacitors cannot be reached.[1316]

PZT offers:[1317]

- A high piezoelectric effect;
- A high dielectric constant, especially large at the morphotropic phase boundary;

(RoHS): Final report - revised version," Final Report Oeko-Institut e. V. und Fraunhofer IZM, accessed August 4, 2015, http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3_2010_Review_Final_report_ELV_RoHS_28_07_2010.pdf; or https://circabc.europa.eu/sd/d/a4bca0a9-b6de-401d-beff-6d15bf423915/Corr_Final%20report_ELV_RoHS_28_07_2010.pdf

[1313] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010, page 194 et sqq.

[1314] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010

[1315] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010, page 194 et sqq.

[1316] Ibid.

[1317] STMicroelectronics et al. 2015b 2015 "Answers to questionnaire 1 (clarification questionnaire), document "Ex_7c-IV_STM_Answer_to_Oeko_questionnaire_2015-09-15_final2.pdf": Questionnaire 1 (clarification questionnaire)," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-IV/Ex_7c-IV_STM_Answer_to_Oeko_questionnaire_2015-09-15_final2.pdf

- Pyroelectric behaviour;
- Ferroelectric properties.

STM et al.[1318] highlight that lead-zirconium-titanate (PZT) material has the highest known dielectric constant (εr = 1000 – 1200) and thus can be used as a planar Metal/Insulator/Metal (MIM) capacitor with a breakdown voltage of more than 100 V. No alternative to PZT is currently known for thin film capacitors and Ferroelectric Random Access Memory (FRAM) that achieves the same combination of high dielectric constant, high breakdown field and temperature stability of 20 % in a temperature range from -25 to +85 °C. This combination of properties is indispensable to realize capacitors as parts of integrated circuits and discrete semiconductors.

According to STM et al.,[1319] integrated circuits or discrete semiconductors involving PZT-based dielectric ceramic materials for capacitors are used in:

- **IPD**[1320]
  Integrated passive devices (IPD) include functional blocks such as impedance matching circuits, harmonic filters, couplers, baluns and power combiner/divider, generally fabricated using standard wafer fab technologies such as thin film and photolithography processing, realized on thin substrates like silicon, alumina or glass. The IPD technology enables high-density capacitors, MIM capacitors, resistors, high-Q inductors, PIN diodes or Zener diodes to be integrated on the same silicon. These passives combined with active functions in one component respond to the high integration and low power consumption featured by high performing wireless devices.
- **FRAM**[1321]
  Ferroelectric Random Access Memories use a ferroelectric layer to achieve non-volatility. FRAM is one of a growing number of alternative non-volatile random-access memory technologies that offer advantages over flash memories including lower power usage, faster write performance and a much greater maximum number of write-erase cycles. FRAM products are found in a variety of sectors including, but not limited to, electricity meters, automotive electronics, business machines, instrumentation, medical equipment, industrial microcontrollers, and radio frequency identification tags.
- **Other uses**[1322]
  MEMS (Micro-Electro-Mechanical Systems) as integrated circuits or discrete semiconductors involving PZT-based dielectric ceramic materials. There may

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1318 Op. cit. STMicroelectronics et al. 2015a
1319 Op. cit. STMicroelectronics et al. 2015b 2015
1320 Ibid.
1321 Ibid.
1322 STMicroelectronics et al. 2016a “Answers to second questionnaire, document "Exe_7c-IV_Questionnaire-2_STM_2016-01-17.pdf", received via e-mail from Frederic Chapuis, STMicroelectronis, by Dr. Otmar Deubzer, Fraunhofer IZM, on 3 March 2016” unpublished manuscript,

also be applications where it is needed to implement decoupling or bypass capacitors. In such cases, the IPD technology would not be the only one which uses PZT material. It could be of interest also to build decoupling capacitors above integrated circuits (IC's) or MEMS's core technologies.

The use of PZT-based thin-film technologies includes, but is not limited to capacitors embedded in filters for wireless devices and other applications as shown in Figure 24-3.[1323]

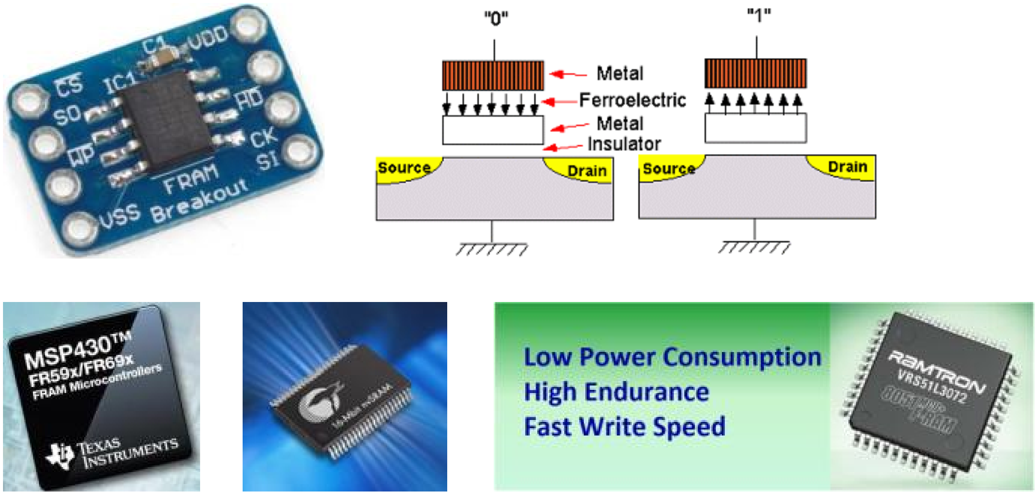
Figure 24-3: Use of PZT-based thin-film technologies in wireless and other devices

Source: Yole referenced in STM et al.[1324]

Pb is also present in PZT thin-film used for FRAMs memories as shown in Figure 24-4.[1325]

[1323] Op. cit. STMicroelectronics et al. 2015a
[1324] Ibid.
[1325] Ibid.

Figure 24-4: PZT thin-film in FRAM



	SRAM/DRAM	FLASH E²PROM	FUJITSU FRAM
Fast Unlimited Read/Write Access	Fast Unlimited R/W Access	Slow Block Access ROM	Fast Unlimited R/W Access
Non-Volatile	Volatile – Power Required	Non-Volatile	Non-Volatile

Source: Switch Science, Egloos, Texas Instruments, Cypress Semiconductor, Fujitsu (Internet); referenced in STM et al.[1326]

24.1.3 Amounts of Lead Used under Exemption 7c-IV

STM et al.[1327] reference the Yole production forecast 2012-2018 for IPDs, FRAMs and MEMS combined, where the number of 6 inch equivalent wafers shipped for the thin film PZT market was 578,000 (6'' eq.) in 2012 and is estimated to be 533,700 (6'' eq.) wafers by 2018. Based on this forecast, a yearly worldwide average estimation over 2014-2020 can be set at 550,000 wfs (6'' eq.) /annum, including MEMS.

The estimated weight of Pb in 6" wafers: 50 mg maximum[1328]

Estimated weight of Pb in devices annually sold on the market: 550,000 x 50 mg, which is equivalent to around 27.5 kg for the worldwide market.[1329]

The amount of substance entering the EU market annually through application for which the exemption is requested is thus below 27.5 kg.[1330]

1326 Ibid.
1327 Ibid.
1328 Ibid.
1329 Ibid.

24.2 Applicants’ Justification for the Continuation of the Exemption

STM et al.[1331] claim that alternatives to PZT-based dielectric ceramic capacitors are not available. Trench capacitors have a breakdown of less than 30 V, compared to more than 100 V for PZT-based MIM capacitors.

Potential alternative materials such as Barium-Strontium-Titanate (BST) have only half the dielectric constant, which results in much larger devices that do not meet the size dimensions of semiconductor applications. Performance characteristics with alternatives – trench or BST capacitors – are severely degraded. These potential alternative techniques are not able to fulfil the electric requirements that are needed for such applications, i.e. a high breakdown voltage and low internal resistance at low leakage currents and high capacitance values. New materials without Pb will have to be invented. [1332]

24.2.1 Alternatives to PZT-based Integrated Passive Devices in Thin Film High Density Capacitors

24.2.1.1 Barium Strontium Titanate as Substitute for PZT

Thin film high density capacitor integrated passive devices (IPD) are made with PZT. STM et al.[1333] state that for these PZT in thin film high density capacitors since 2010-2011, basic research has not evidenced a new material which could be a substitute so that no alternative to PZT is currently known that achieves the same combination of high dielectric constant, high breakdown field and temperature stability in a temperature range from -25 to +85 °C, this combination of properties being indispensable to realize capacitors as parts of integrated circuits and discrete semiconductors.

STM et al.[1334, 1335] conducted a study after 2011 on Barium Strontium Titanate (BST), from which publications are available as well.[1336] STM[1337] interpret the results of the study as follows:

- At equal thickness of the dielectric, BST has a much lower capacity density than PZT;

[1330] Ibid.
[1331] Ibid.
[1332] Ibid.
[1333] Op. cit. STMicroelectronics et al. 2015b 2015
[1334] Ibid.
[1335] Op. cit. (STMicroelectronics et al. 2016a)
[1336] Comparison of Paraelectric and Ferroelectric Materials for Applications as Dielectrics in Thin Film Integrated Capacitors; http://www.imaps.org/journal/2000/q2/ulrich.pdf; source as referenced by STM 2016a; contact for the study: CEA – LETI (Commissariat à l’Energie Atomique et aux Energies Alternatives)

[1337] Op. cit. STMicroelectronics et al. 2015b 2015

- When the BST thickness is reduced at its minimum, it is possible to catch up with PZT in terms of capacitance density, but the reliability is then much below what is expected for the targeted electronic applications;
- In combination with trench capacitances, e.g. a 3-dimensional structure, it is possible to obtain comparable densities, but with two parameters affected:
    - higher series resistance:
      for density lower than 45 nF/mm² (nF: Nano-Farad), PZT and 3D capacitors have almost the same series resistance, but from around 45 nF/mm² on, dielectrics must be stacked into the trenches in the case of 3D capacitors. This stacking induces an increase of the series resistance from x 2 up to x 10 depending on the layout, which can be very damaging for the frequency answer of the device. It can increase the current going through the capacitor during an electrostatic discharge pulse leading to an earlier fuse or breakdown of the device.
    - lower breakdown voltage: for capacitance with medium density (~ 30 nF/mm²), the breakdown voltage is around 2 or 3 times lower for 3D capacitors than for PZT capacitors (30V versus 70V). For applications using DC voltage like ADSL (Asymmetric Digital Subscriber Line), PZT capacitors do not require very low voltage ESD clamping diodes in parallel to being correctly protected, contrary to 3D capacitors. If required, a basic protection diode can then be integrated on the same die as the PZT capacitance, improving the frequency answer at reduced cost.

STM et al.[1338] conclude from the above that the use 3D/trench capacitors leads to a quite different parametric compromise than PZT, requiring the re-design of the complete electronic functions. STM et al.[1339] estimate that the re-design would take a three to five year minimum timeframe to get validation and adoption of such alternatives.

STM et al.[1340] state that most electronic needs tend to be compatible with 3D capacitances when the acceptable breakdown voltage is low and the series resistance high. According to STM et al.[1341], this is valid for applications in which the DC (direct current) supply nominal voltage is a few tens of volts, for instance in computers, telecom equipment, industrial electronics and automotive applications. The use of PZT cannot be restricted to those types of electrical and electronic equipment since low and high voltage DC supplies can be found in the same application type so that both technologies can be useful on the same electronic board. Other applications like for example ADSL decoupling capacitors and analogic microphones demanding high voltage or low

[1338] Ibid.
[1339] Op. cit. (STMicroelectronics et al. 2016a)
[1340] Op. cit. STMicroelectronics et al. 2015b 2015
[1341] Op. cit. (STMicroelectronics et al. 2016a)

resistance require the use of PZT. For those applications, a new material without lead will have to be invented.

24.2.1.2 New Materials and Technologies to Replace PZT

STM et al.[1342] claim that previous extensive research has ruled out the use of the early-touted lead-free strontium bismuth tantalite (SST), but they closely monitor the current investigations of the alternative lead-free ferroelectric material hafnium oxide, as reported in 2011 by the combined groups of NaMLab, Fraunhofer CNT and Global Foundries in Dresden.[1343] A Taiwan group is reporting ferroelectricity in a similar system of materials in a MFIS FeFET (Metal-ferroelectric-insulator-semiconductor Fe-Field Effect Transistor) structure with similar results.[1344]

STM et al.[1345] deems that the Dresden team has an evident embodiment with a memory window. Although $Si0_2$:$Hf0_2$ may be a ferroelectric, there is no evidence to show it will be ferroelectric in other than a gate stack. This would need to be accomplished before full productisation. Table 24-1 summarizes the performance of the hafnia-based FeFET.

Table 24-1: Overview of Hafnia-based FeFET (red) performance

	Endurance	Retention	Speed	
			Program /Erase	Read
FRAM (130nm) FM22LDI6, 4Mbit, parallel	10^{14} cycles	10 yrs/85° C	55-ns access time	55-ns access time, 110-ns 4 Mbit
FeFET (Desden) (32 mm)	10^{4} cycles	10 yrs/25° C	100 ns?	<50ns?
FeFET (Expect)	Same as FRAM ?	Same as FRAM ?	100 ns?	<50ns?

Source: STM et al.[1346]

STM et al.[1347] comment the properties in Table 24-1 in more detail:

[1342] Op. cit. STMicroelectronics et al. 2015b 2015
[1343] Ferroelectricity in hafnium oxide: CMOS compatible ferroelectric field effect transistors, Electron Devices Meeting (IEDM), 2011 IEEE International P24.5.1 - 24.5.4; source as referenced by STM et al.2015a
[1344] Low-Leakage-Current DRAM-Like Memory Using a One-Transistor Ferroelectric MOSFET with an Hf-Based Gate Dielectric, Cheng and Chin, IEEE Electron Device letters, Vol. 35, No. I, January 2014
[1345] Ibid.
[1346] Ibid.

- **Retention**
  The confidence level of the extrapolated 10 year data retention is low because it is based on 240 hours at room temperature. Extended bakes at higher temperatures will help to increase the confidence level and verify that the extrapolation is indeed linear with log time. The Dresden lead technologist[1348] agrees with this evaluation that retention is limited.

- **Endurance**
  This FeFET technology will not replace the FRAM performance as most applications require very high endurance. The endurance is clearly inferior to current FRAM. This FeFET would be far too slow and malfunction almost instantly in most applications. The characterization of the present FeFET devices is interesting but more work needs to be done. The distribution of individual devices would be very interesting and, if anything like typical memory weak bit issues, could require a significant amount of work to control. The anomalous behaviour seen on the 32 nm devices may be a side effect of the channel implants; so more work is needed to prove there is not a fundamental limitation of ferroelectric hafnia-based FeFET at these geometries. STM et al. expects and hopes the Dresden group proceeds on this issue.

- It is not sure that a higher coercive voltage is advantageous as claimed. To compete with existing floating gate technology, the required ferroelectric layer for the FeFET is so thin that the applied electrical field will be very high. This will limit the endurance performance of the IT FRAM due to polarization fatigue, which is demonstrated by this paper. The current Dresden films require ~2.5 V to fully switch the ferroelectric polarization while the PZT FRAM films saturate polarization at less than 1.35 V. In addition, the Dresden films' polarization saturation behaviour does not improve at thinner films making it currently impossible to achieve the same low voltage behaviour of the PZT.

- The Dresden group continues to publish based on the original work and good progress is indicated.

Upon request, STM et al.[1349] provide information about more recent publications than the 2011 Dresden Group report:

- Impact of Scaling on the Performance of HfO-based Ferroelectric Field Effect Transistors, Ekaterina Yurchuk et al, IEEE Transaction Devices VOL.61 No.11 November 2014, Page 3699

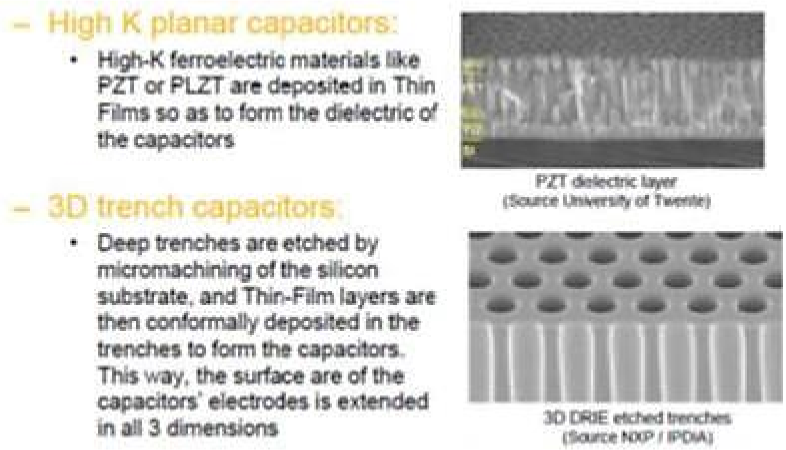
1347 Ibid.
1348 Stefan Müller (Stefan.mueller@namlab.com); contact provided by STM et al. 2016a
1349 Op. cit. (STMicroelectronics et al. 2016a)

- Origin of the Endurance Degradation in the Novel HfO2-based 1T Ferroelectric Nonvolatile Memories, Ekaterina Yurchuk et al, IEEE Proceedings 978-1-4799-3317-4/14, 2014, page 2E.5.1

STM et al.[1350] report that a start-up company (Ferroelectric Memory Company), a spin-off from NaMlab, formed in 2015, based on the Dresden Group's study results. A 100 bit array of 28 nm FeFET was demonstrated in May 2015. According to STM et al., the company is not ready for production of lead-free products at this time, but indications are that sometime in the future there will be commercial lead-free offerings. The product specifications are yet to be determined, however.

STM et al.[1351] reference a Yole report[1352] from 2013 identifying a new material and a new technology which would, however, only further improve the capacitance density, but still contain lead. STM et al.[1353] explain that the new material is "high K planar PZT capacitors" as one of the two alternative technology tracks typically followed to integrate high density decoupling capacitors. STM et al. provide Figure 24-5 in this respect.

Figure 24-5: New material and new technology for integration of high density decoupling factors



Source: Yole[1352] referenced in STM et al.[1354]

According to the referenced Yole report, in both approaches the thin film deposition of the dielectric layer (PZT or PLTZ (lead lanthanum zirconate titanate)) allows for the making of thin capacitor dielectrics. The optimal dielectric thickness is a trade-off

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1350 Ibid.
1351 Op. cit. STMicroelectronics et al. 2015a
1352 Yole: "Thin Film PZT for Semiconductor - Application trends &Technology update (FRAM, IPDs and MEMS)" – 2013; source as referenced by STM et al.2015a
1353 Op. cit. (STMicroelectronics et al. 2016a)
1354 Op. cit. STMicroelectronics et al. 2015a

between capacitance density and the breakdown voltage. STM et al.[1355] explain that the highest values of capacitance density will not be reached without PZT, but possibly combined with Trench capacitors in applications.

STM et al.[1356] conclude that since 2011, the situation of fundamental research in the world has not allowed the research and development departments of companies, which design electronic components requiring exemption 7(c)-IV, to progress towards the substitution or the elimination of lead, while thanks to the unique properties of PZT-based capacitors in ICs or discrete semiconductors, many applications could feature higher integration, extended performance and lower power consumption. Those features are real advantages expected in the development of new electronic devices and, considering the extremely low quantity of lead involved in those components, call for the renewal of the 7(c)-IV exemption.

24.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

The Semiconductor Industry is working independently with selected material suppliers on the selection of an appropriate replacement for PZT. The properties of the needed capacitance and piezoelectricity material are specified by the industry (material requirement specification) and provided to the material suppliers. Selected suppliers offer their materials, which are evaluated by one of the companies together with the suppliers. The combined results are evaluated by the industry. After a material is chosen and material development is frozen, a minimum of 6 years will be required to qualify the new material through the whole supply chain. Based on current status, the Semiconductor Industry cannot predict a date for customer sampling. However the Semiconductor industry is already engaged in evaluating different alternative materials and evaluating other in-house material synthesis as well.[1357]

Development of BST - barium strontium titanate (Ba1-xSrxTiO3) - and SBT - strontium bismuth tantalite (SrBi2Ta2O9) - materials in order to solve the RoHS issues with Pb in PZT is considered, but no fixed timeline can be defined. However, SBT and BST have a 2x lower performance than PZT so there is a reluctance to switch to SBT and BST.[1358] Elaborating on this, STM et al.[1359] provide the data and general requirements in Table 24-2.

[1355] STMicroelectronics et al. 2016b "Answers to third questionnaire, document "Exe_7c-IV_Questionnaire-3_STM_2016-03-14.pdf", received via e-mail from Frederic Chapuis, STMicrelectronics, by Dr. Otmar Deubzer, Fraunhofer IZM, on 23 March 2016" unpublished manuscript,
[1356] Op. cit. STMicroelectronics et al. 2015b 2015
[1357] Op. cit. STMicroelectronics et al. 2015a
[1358] Ibid.
[1359] Ibid.

Table 24-2: Comparative table between PZT- and BST-based capacitors

	PZT	BST	Requirements
Operating Temperature	-40C to +125C	-10C to +85C	-40C to +125C
Longevity	≥ 40 years	~10 years	>40 years
Endurance	1E12 r/w [1] cycles	1E9 r/w cycles	Unlimited cycles
Relative dielectric K	1700 [2]	500 [3]	Highest Possible

[1] r/w = read/write
[2] MEMS,Dec 1995,Vol.4,No.4, p.234
[3] Scott, J.F., "High-dielectric Constant Thin Films for Dynamic Random Access Memories (DRAM)," Annu. Rev. Mater. Sci. 1998. 28:79–100

Source: Texas Instruments referenced in STM et al.[1360]

24.4 Critical Review

24.4.1 REACH Compliance - Relation to the REACH Regulation

PZT (lead zirconium titanate) and possibly PLZT (PZT containing lanthanum) are used in the PZT-based ceramics in the scope of exemption 7c-IV. No lead-free ceramic material can currently replace the PZT-based ceramic.

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as directly added substances nor as substances that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

[1360] Ibid.

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under Entry 28 and Entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds

- *"shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight."*
  This restriction does not apply to internal components of watch timepieces inaccessible to consumers;
- *"shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children."*
  This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

Various entries are listed in the REACH Regulation Annex XVII, restricting the use of titanium and zirconium compounds.

As titanium-related compounds, nickel barium titanium primrose priderite, nickel titanium trioxide and nickel titanium oxide are specified for Annex XVII entry 28, and nickel zirconium trioxide is specified as zirconium-related compound. These compounds are, however, not relevant for the PZT ceramics used in exemption 7c-IV.

No other entries, relevant for the use of substances relevant for the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

24.4.2 Substitution and Elimination of Lead - Specification of the Exemption

STM et al.[1361] justify their exemption request in considerable parts citing the reviewers' conclusions from the 2010[1362] and 2011[1363] exemption review reports. Those conclusions can, however, no longer justify the exemption after five years and more, as the core objective of this review process is to assess the scientific and technical progress. The applicants were therefore asked to show the efforts they have undertaken since the last reviews to find lead-free alternatives. The applicants provide additional information related to the two main application fields, thin film high density capacitors and FRAMs. This information was integrated into the applicant's justification of the exemption.

From the applicants' submitted information, the consultants understand that 3D capacitances (trench capacitors) can be used as a lead-free alternative where the acceptable breakdown voltage is low and the series resistance high. STM et al.[1364] state that "*[...] most electronic needs tend to be compatible with 3D capacitances when the acceptable breakdown voltage is low and the series resistance high*." According to STM et al.[1365], this is valid for applications in which the DC (direct current) supply nominal voltage is a few tens of volts, for instance in computers, telecom equipment, industrial electronics and automotive applications. Since low and high voltages can occur in the same applications/devices, the use of PZT dielectric ceramics integrated circuits and semiconductors cannot be restricted to certain applications/devices. The consultants therefore proposed to restrict the use of PZT ceramics on the component level taking into account the above-mentioned limits of use:

> *Lead in PZT-based dielectric ceramic materials for capacitors which are part of integrated circuits or discrete semiconductors with a nominal voltage of 30 V DC or less and a series resistance of yy Ω or more*

The applicants were asked to comment on the proposed wording and to suggest limits for the series resistance and the voltage limit, which in the above version reflects the status of some years ago.

STM et al.[1366] expressed their disagreement "*with splitting RoHS Exemption No. 7c-IV into multiple sub-sections*." They stated that no possible alternative substance matching PZT dielectric properties can be found at present in the current state of material physics

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[1361] Ibid.
[1362] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010
[1363] Zangl, Stéphanie, Oeko-Institut e.V. 2011 "Adaptation to Scientific and Technical Progress under Directive 2002/95/EC: Evaluation of New Requests for Exemptions and/or Review of Existing Exemptions," Final Report Oeko-Institut e. V. und Fraunhofer IZM, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IV/RoHS_final_report_May_2011_final.pdf
[1364] Op. cit. STMicroelectronics et al. 2015b 2015
[1365] Op. cit. (STMicroelectronics et al. 2016a)
[1366] Op. cit. (STMicroelectronics et al. 2016b)

knowledge. STM et al.[1367] say that they extracted this information from the Oeko Institute Final report - revised version - Freiburg, 28 July 2010: "*Adaptation to scientific and technical progress of Annex II to Directive 2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS)*"[1368] and from Yole: "*Thin Film PZT for Semiconductor - Application trends &Technology update (FRAM, IPDs and MEMS)" – 2013*". They also state that the works led by the Semiconductor Industry are relying on selected materials offered by suppliers, which are evaluated by one of the companies together with the suppliers. The combined results are then evaluated by the industry and after a material is chosen and material development is frozen, a minimum of six years are required to qualify the new material through the whole supply chain.

At the present date, no alternative material has been identified to substitute PZT with equivalent physical properties, even for partial replacement in the involved product portfolio of the IC and discrete semiconductor manufacturers. STM et al. are still six years minimum ahead of any viable substitutive material, without consideration of cost.

STM et al.[1369] put forward that splitting the ICs or discrete semiconductor devices, which include lead in PZT-based dielectric ceramic materials for capacitors into categories defined by a specified voltage or a series resistance value is currently too early, the risk of choosing wrong values by lack of R&D supporting such a split being much too high. STM et al. recall that the Oeko-Institut stakeholder 28/07/2010 report was concluding that "*technically there are no alternatives for integrated MIM like PZT capacitors. PZT is the only material to integrate highest capacitance density with high breakdown voltages on silicon to ensure best filter- and ESD-performance at low leakage current levels. 3d (trench) and BST capacitors cannot fulfil the requirements*."

STM et al.[1370] further assert that the amount of lead entering the EU market annually through applications for which the exemption is requested is much less than 27.5 kg, which applies to the global market, including the MEMS (this value being deduced from the mass of PZT deposited on the wafers). Splitting the exemption into multiple sub-sections would just lead to divide the above mass at planetary level into fragments of a few kg each, with extremely low incremental environmental, health and consumer benefits resulting from such a split.

STM et al.[1371] put into perspective that what was expressed with respect to IPDs, in the Second Questionnaire Exemption No. 7c-IV with response to Oeko sent on February 2, 2016, is only the perspective of a tendency of the application needs to be compatible with 3D (trench) capacitances when the acceptable breakdown voltage is low and the series resistance high. "*In other words, we know for sure that 3D capacitances cannot be*

[1367] Ibid.
[1368] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010
[1369] Op. cit. (STMicroelectronics et al. 2016b)
[1370] Ibid.
[1371] Ibid.

used in applications in which the DC supply nominal voltage is several tens volts, without being able to precise a significant voltage threshold at the present time". [1372]

Finally, STM et al.[1373] do not believe that any one company or group of companies can currently define a revised wording splitting the exempted products and ensure that the new wording would account for all required uses of PZT-based dielectric ceramic materials in capacitors which are part of ICs or discrete semiconductors.

24.4.3 Conclusions

The above information in the consultants' view is not plausible. On the one hand, the applicants' information suggests that trench capacitors can be an alternative for low voltage and low series resistance areas even though it is clear that they cannot replace PZT completely at the current state of science and technology. On the other hand they state that they cannot indicate any voltage or resistance limits as it is too early and more research is needed. However, the applicants do not mention any research related to lead-free trench capacitors besides the reference to the Yole report and yet it should be noted that this source does not refer to lead-free alternatives, only to materials with improved capacitance density yet still containing lead. They just mention that a redesign of EEE and components would be required, which would take three to five years.

STM et al. were again asked whether the statement that most electronic needs tend to be compatible with 3D capacitances after such a redesign actually refers to lead-free trench capacitors. STM et al.[1374] confirm that the statement actually is related to the lead-free trench capacitors.

The applicants' information thus suggests that there are areas where lead-free alternatives are possible. The applicants did, however, not provide substantiated and plausible information that would allow either identifying those physical and electrical parameters where lead-free alternatives could be used, or that would otherwise plausibly explain why this is impossible.

Besides the above case, the information submitted by the stakeholders plausibly explains that PZT-based capacitors are actually required in PZT-based dielectric ceramic materials of capacitors being part of integrated circuits or discrete semiconductors. The applicants' exemption request and the answers to the clarification questionnaire were made available through the public online consultation to industry, governments, NGOs and other stakeholders. A questionnaire had been prepared for the public stakeholder consultation with specific questions to stakeholders. No further information supporting or discrediting the technical application in question was received. Based on the available

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[1372] Ibid.

[1373] Ibid.

[1374] STMicroelectronics et al. 2016c "E-mail communication, document "E-mail-Communication_STM_2016-04-01.pdf", received via e-mail from Frederic Chapuis, STMicroelectronics, by Dr. Otmar Deubzer, Fraunhofer IZM, until 1 April 2016" unpublished manuscript,

information, the consultants conclude that the complete substitution or elimination of lead is still scientifically and technically impracticable and granting an exemption could therefore be justified by Art. 5(1)(a).

Taking into account the overall situation, the consultants recommend renewing the exemption for three years. As the applicants' information does not allow excluding that the substitution or elimination of lead is scientifically and technically practicable within less than five years, Art. 5(1)(a) would not allow granting the exemption for the maximum five years. A three year validity period would make sure there is sufficient time to apply for the renewal of the exemption on the one hand, and on the other hand to clarify the applicability range of eliminating lead with the trench capacitors, and to take into account recent research results of researchers such as the above-mentioned Dresden Group which according to the applicants has made good progress.

24.5 Recommendation

The applicant's information substantiates that overall the ~~complete~~substitution and elimination of lead is scientifically and technically still impracticable in PZT-based dielectric ceramic materials of capacitors that are part of integrated circuits or discrete semiconductors.

Nevertheless, the applicants' information also suggests that lead-free alternatives may already be available for some components in particular applications. The applicants neither defined those possibilities nor could they plausibly explain why the elimination or substitution is scientifically and technically still impracticable in these cases. Additionally, upon request the applicants report about progress in the research of lead-free dielectric ceramic materials that may allow further progress towards the substitution of lead prior to the next five years.

Appraising the overall situation, Art. 5(1)(a) would allow renewing the exemption. The exemption should, however, only be granted for a maximum of three years since the information provided clarifies that substitution or elimination of lead could be implemented in some cases in a period shorter than five years. This period should suffice to allow clarifying the scope of applications in which substitutes could eliminate the need for lead as well as whether the exemption is still needed for other applications.

<table>
<tr><th>Exemption 7c-IV</th><th>Expires on</th></tr>
<tr><td rowspan="4">Lead in PZT-based dielectric ceramic materials of capacitors being part of integrated circuits or discrete semiconductors</td><td>21 July 2019 for categories 1-7 and 10</td></tr>
<tr><td>21 July 2021 for
· medical equipment in category 8
· monitoring and control instruments in category 9</td></tr>
<tr><td>21 July 2023 for in vitro diagnostic medical devices in category 8</td></tr>
<tr><td>21 July 2024 for industrial monitoring and control instruments in category 9</td></tr>
</table>

24.6 References Exemption 7c-IV

Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles. ELV DirectiveEuropean Union. October 21, 2000. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0053:EN:NOT.

Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

STMicroelectronics et al. 2015a Request for continuation of exemption 7c-IV, document "7c-IV_RoHS_V_Application_Form_7c-IV_Final.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-IV/7c-IV_RoHS_V_Application_Form_7c-IV_Final.pdf.

STMicroelectronics et al. 2015b Answers to questionnaire 1 (clarification questionnaire), document "Ex_7c-IV_STM_Answer_to_Oeko_questionnaire_2015-09-15_final2.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-IV/Ex_7c-IV_STM_Answer_to_Oeko_questionnaire_2015-09-15_final2.pdf.

STMicroelectronics et al. 2016a Answers to second questionnaire, document "Exe_7c-IV_Questionnaire-2_STM_2016-01-17.pdf", received via e-mail from Frederic Chapuis, STMicroelectronis, by Dr. Otmar Deubzer, Fraunhofer IZM, on 3 March 2016.

STMicroelectronics et al. 2016b Answers to third questionnaire, document "Exe_7c-IV_Questionnaire-3_STM_2016-03-14.pdf", received via e-mail from Frederic Chapuis, STMicrelectronics, by Dr. Otmar Deubzer, Fraunhofer IZM, on 23 March 2016.

STMicroelectronics et al. 2016c E-mail communication, document "E-mail-Communication_STM_2016-04-01.pdf", received via e-mail from Frederic Chapuis, STMicroelectronics, by Dr. Otmar Deubzer, Fraunhofer IZM, until 1 April 2016.

Zangl, Stéphanie [Oeko-Institut e.V.] et al. Adaptation to scientific and technical progress of Annex II to Directive Adaptation Directive2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS) 2010. http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3_2010_Review_Final_report_ELV_RoHS_28_07_2010.pdf; or https://circabc.europa.eu/sd/d/a4bca0a9-b6de-401d-beff-6d15bf423915/Corr_Final%20report_ELV_RoHS_28_07_2010.pdf.

Zangl, Stéphanie, Oeko-Institut e.V. Adaptation to Scientific and Technical Progress under Directive 2002/95/EC 2011. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IV/RoHS_final_report_May_2011_final.pdf.

25.0 Exemption 8b: "Cadmium and its Compounds in Electrical Contacts"

Declaration

In the sections that precede the "Critical Review" the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders unless otherwise stated, and the views presented should not be taken to represent the views of the consultants (authors of this report).

Acronyms and Definitions

AC	Alternating current
Cd	Cadmium
DC	Direct current
EEE	Electrical and electronic equipment
NEMA	National Electrical Manufacturers Association

25.1 Description of the Requested Exemption

The current wording of exemption 8b in RoHS Annex III is

> *"Cadmium and its compounds in electrical contacts"*

Sensata[1375] and the National Electrical Manufacturers Association (NEMA)[1376] et al. apply for the continuation of exemption 8b. While NEMA et al. call for the unchanged

[1375] Sensata Technologies Inc. 2015a "Request for Continuation of Exemption 8b, document "RoHS-Exemptions_Application-Format_Cd_Sensata_20150115.pdf" and document "Sensata_Cd-Exemption-Request_Jan-2015.pdf": Original exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/RoHS-Exemptions_Application-Format_Cd_Sensata_20150115.pdf

[1376] NEMA et al. 2015a 2015 "Request for continuation of exemtion 8b, document "8b_Final_RoHS_Exemption_Renewal_Dossier_2015_01_16.pdf": Original exemption request," National Electrical Manufacturers Association, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/8b_Final_RoHS_Exemption_Renewal_Dossier_2015_01_16.pdf

continuation of the exemption, Sensata[1377] proposes the following wording with a specification of the scope[1378]:

> *"Cadmium and its compounds electrical contacts for temperature sensing controls, thermal motor protectors and motor starter relays applied in various end applications"*

In the course of the review process, Sensata[1379] changed their exemption request to:

> *"Cadmium and its compounds in electrical contacts for circuit breakers, thermal sensing controls, and thermal motor protectors"*

Marquardt[1380] contributed to the stakeholder consultation supporting NEMA's exemption request, but proposing the following reformulation of the exemption in case it should not be continued with the current scope and wording:

> *"Cadmium and its compounds in switches of*

- *cordless power tools rated 20 A at 18 V DC and more*
- *corded power tools rated with 1,500 W and more (6A 250VAC, 12A 125VAC)*
- *specialised heavy duty power tools used with high frequency power supplies (200 Hz and more)"*

In the course of the review, a stakeholder, Ubukata submitted information that they shifted their product portfolio of thermal sensing controls and thermal motor protectors to cadmium-free contacts and will have implemented these cadmium-free devices in their customers' products in the course of 2016.

25.1.1 Background and History of the Exemption

The use of cadmium in electrical contacts was already exempted under exemption no 8 in the annex of Directive 2002/95/EC (RoHS 1) when RoHS 1 entered into force in 2003:

> *"8. Cadmium plating except for applications banned under Directive 91/338/EEC amending Directive 76/769/EEC relating to restrictions on the marketing and use of certain dangerous substances and preparations."*

[1377] Sensata Technologies Inc. 2016a "Answers to questionnaire 2, document "Exe-8b_Questionnaire-2_Sensata_Response_2016-01-22.docx", sent via e-mail to Dr. Otmar Deubzer, Fraunhofer IZM, by Albert van der Kuji, Sensata: Answers to second questionnaire" unpublished manuscript,

[1378] Sensata had proposed a different wording in its original exemption request, but corrected it in the course of the review.

[1379] Sensata Technologies Inc. 2016c "Answers to third questionnaire, document "Exe-8b_Questionnaire-3_Response_Sensata_2016-02-11.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Albert van der Kuij, Sensata Technologies, on 11 February 2016" unpublished manuscript,

[1380] Marquardt GmbH 2016a "Contribution to the stakeholder consultation, answers to the consultation questionnaire," Consultation questionnaire, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Marquardt_Questionnaire_Exemption_8b__with_table__4_Publication.pdf

With the Commission Decision 2005/747/EC in October 2005, the exemption wording was changed to:

> *"8. Cadmium and its compounds in electrical contacts and cadmium plating except for applications banned under Directive 91/338/EEC amending Directive 76/769/EEC relating to restrictions on the marketing and use of certain dangerous substances and preparations."*

The exemption was first reviewed in 2005/2006[1381], and again in 2008/2009[1382] and thus gradually transferred into its current status with a split into exemption 8a and 8b:

> *"8(a) Cadmium and its compounds in one shot pellet type thermal cut-offs Expires on 1 January 2012 and after that date may be used in spare parts for EEE placed on the market before 1 January 2012*
>
> *8(b) Cadmium and its compounds in electrical contacts"*

In the 2009 report, the expiry date 31 July 2014 was recommended for exemption 8b, which was the maximum possible under RoHS Directive 2002/95/EC (RoHS 1) (four years from 2010 on). It was clear that cadmium-free contact materials are available for applications under exemption 8b), but that there are no drop-in replacements. Industry therefore required time to adapt the cadmium-free solutions to their applications and to test them to make sure the cadmium-free contacts suffice in terms of safety and other requirements. The five years from 2009 to 2014 were deemed appropriate to cope with this task, and to ask for specific exemptions should cadmium-free solutions not be feasible in defined cases.

The exemptions in the Annex of RoHS 1 were transferred into the recast RoHS Directive 2011/65/EU (RoHS 2). In the course of that process, the expiry dates of all exemptions with maximum validity duration of four years were systematically extended to five years, but from July 2011 on. This gave industry a total of seven years from 2009 on to substitute or eliminate cadmium in contacts.

25.1.2 Amount of Lead Used Under the Exemption

Sensata[1383] used 920 kg of cadmium in electrical contacts in 2013 and wants to bring down this amount to 350 kg in 2016. NEMA et al.[1384] indicate the amount of cadmium entering the EU market in electrical contacts at less than 10 tonnes and claim the actual

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[1381] Gensch, Carl-Otto [Oeko-Institut e.V.], et al. 2006 "Adaptation to scientific and Technical progress under Directive 2002/95/EC: Final Report - final version"; http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf, page 25 et seqq.

[1382] For details see report of Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009), page 114 sqq.

[1383] Op. cit. Sensata Technologies Inc. 2015a

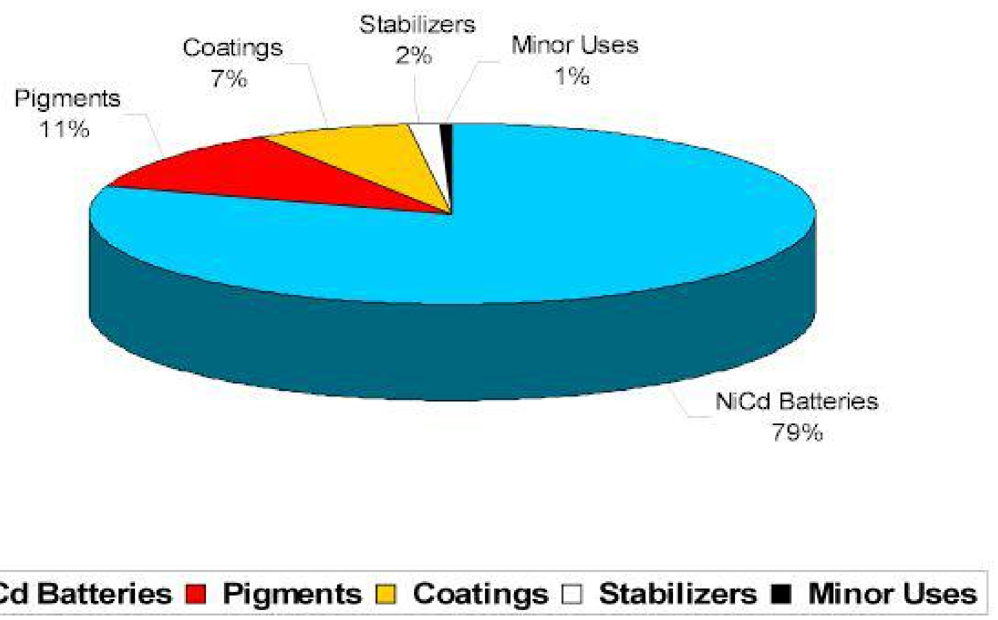
[1384] Op. cit. NEMA et al. 2015a 2015

amount will be much lower as the current estimate is based on worst case, taking into account:[1385]

- The maximum of the tonnage band in the REACH registration dossier; and
- The relative use of cadmium for minor uses, including but not limited to cadmium in electric contact alloys.

NEMA et al.[1386] reference the REACH registration information[1387] for cadmium where the total tonnage band is 1 000 – 10 000 tonnes (17 February 2013). The International Cadmium Association (ICdA) presents relative data on the use of cadmium in applications as follows:[1388]

Figure 25-1: Uses of cadmium



Source: International Cadmium Association, referenced by NEMA et al.[1389]

Cadmium in electrical contacts is considered one of the applications identified under the group of “Minor uses”. Considering the maximum values of these data NEMA et al. conclude that 10 tonnes of Cadmium are the maximum amount, which would enter the EU market under the requested exemption.

[1385] Ibid.
[1386] Ibid.
[1387] REACH registration information on cadmium: http://echa.europa.eu/documents/10162/13641/annex_xv_cd_in_artist_paints_en.pdf, (“B.2.1 Manufacture, import and export of cadmium”, p. 15); source as referenced by NEMA et al.

[1388] The International Cadmium Association – Cadmium applications: http://www.cadmium.org/pg_n.php?id_menu=9; source as referenced by NEMA et al.
[1389] Ibid.

25.1.3 Technical Description of the Requested Exemption

The technical background of the exemption was described in detail in the report[1390] of the 2008/2009 review of exemption 8b. In the following, only the applicants' main arguments are detailed.

NEMA et al.[1391] explain that cadmium (Cd) is being used in electrical contacts in the form of silver cadmium oxide (AgCdO). Electrical contact materials are used in many electromechanical devices as components, which can carry current intermittently through contact surfaces. In particular, the exemption request is relevant to various EEE making use of electrical contacts, in particular:[1392]

- Electrical contacts used in power switching of electric motors, specifically thermal protectors and switches;
- Electrical contacts used in relays and contactors;
- Electrical contacts in switches for power tools and appliance switches;
- Electrical contacts in circuit breakers for switching equipment; and
- Electrical contacts in power packs, occupancy/time delay sensors, lighting control panels, line voltage switching control devices (1A-20A, 120V AC-480V AC).

The basic properties required for the contact materials are that they should possess high electrical and thermal conductivity, high melting point and good oxidation resistance. The high melting point is required to avoid any accidental overheating because of fusion of the contact points whereas high thermal conductivity helps to dissipate heat effectively. In order to keep the contacts clean and free of insulating oxides, it is essential that the material possesses good oxidation resistance.

NEMA et al.[1393] state that electrical arc erosion plays a crucial role in the reliability and life of power switching devices. Depending on the contact material's behaviour in response to an electrical arc, surface damage can induce severe changes in contact material properties that will impact the power switching device's functioning. Consequently, electrical arc effects and consequences on the contact material surface are of first importance. Welding of contacts could present a safety concern if the contactor cannot open the circuit. Cadmium prevents tack welding, both under severe operation conditions and when the product nears end-of-life. The following characteristics have made cadmium an essential element for contact materials[1394]:

- Superior performance – lasts longer;

[1390] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, RoHS III, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf, page 114 et sqq.
[1391] Op. cit. NEMA et al. 2015a 2015
[1392] Ibid.
[1393] Ibid.
[1394] Ibid.

- Quenches arcs – resists contact welding;
- Higher conductivity – smaller size of contacts;
- Less contact erosion – essential for critical and safety applications ; and
- Relatively easy to manufacture compared to alternatives.
- According to Sensata,[1395] the following standards govern the requirements for thermal sensing controls, thermal motor protectors and circuit breakers:
- EN/IEC60730-1 Automatic electrical controls - Part 1: General requirements.
- EN/IEC60730-2-2 Particular requirements for thermal motor protectors.
- EN/IEC60730-2-4 Particular requirements for thermal motor protectors for motor-compressors of hermetic and semi-hermetic type.
- EN/EN60730-2-9 Particular requirements for temperature sensing controls.
- EN/IEC60947-1 Low-Voltage Switchgear and Controlgear - General rules.
- EN/IEC60947-2 Circuit-breakers.

25.2 Applicants' Justification for the Continuation of the Exemption

25.2.1 NEMA et al.

NEMA et al.[1396] explain that they have not yet found substitutes offering the same reliability as the exempted application for a number of applications. A number of alternative substances are suggested, of which $AgSnO_2$ is considered the most suitable alternative, particularly for higher switching currents.

NEMA et al.[1397] state that there are no alternative substances for which the capability to extend life and reduce tack welding is as good as cadmium. In addition, typically the entire contactor will need major redesign in order to perform with the alternative substances. Replacement contacts built with alternative contact materials would be larger, requiring larger contactors that may not fit in the space of the original contactor. This could result in disposal and replacement of the entire end-product increasing the volume of products disposed into the waste stream. A drop-in replacement of cadmium with other materials alone is therefore not feasible.

According to NEMA et al.[1398], exemption 8b is still relevant to various EEE making use of electrical contacts, in particular:

- Electrical contacts used in power switching of electric motors, specifically thermal protectors and switches;
- Electrical contacts used in relays and contactors;
- Electrical contacts in switches for power tools and appliance switches;

[1395] Op. cit. (Sensata Technologies Inc. 2016c)
[1396] Op. cit. NEMA et al. 2015a 2015
[1397] Ibid.
[1398] Ibid.

- Electrical contacts in circuit breakers for switching equipment; and
- Electrical contacts in power packs, occupancy/time delay sensors, lighting control panels, line voltage switching control devices (1A-20 A, 120 V AC-480 V AC).

NEMA et al.[1399] state that $AgSnO_2$ semi-refractory tin oxide particles potentially could provide performance properties, especially resistance to contact welding and arc erosion, comparable to those of cadmium oxide. Particular advantages would be: [1400]

- Superior corrosion resistance; and
- Better anti-welding properties;

While disadvantages would be: [1401]

- Rate of contact erosion;
- Higher contact resistance;
- Higher bulk resistance;
- Higher temperature rise; and
- No standard composition.

NEMA et al. [1402] report that in general, the 10 %, 12 % and 15 % (weight) of cadmium oxide grades are replaced with 8, 10 and 12 % tin oxide. To improve the electrical characteristics of the $AgSnO_2$, a range of additional oxides (dopants) can be added, e.g. tungsten oxide, molybdenum oxide, bismuth oxide. Dopants improve the arc-quenching characteristics and prevent the formation of high resistance oxide layers on the surface of the contacts. The particular dopants required depend on the type of switching application of the electrical contact.

NEMA et al.[1403] explain that higher SnO_2 shares increase the welding resistance, contact resistance and hardness, but decrease the conductivity and ductility. Individual manufacturers have tested various alternatives with little success. In the case where substitution is possible the nature of the alternative materials will, however, require redesign of the coils, magnets, armatures and contact springs.

NEMA e al.[1404] admit that Cd-free substitutes are available for some applications. Nevertheless, there remain applications, for which no material other than AgCdO can perform to the necessary safety and performance standards. In NEMA motor control

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1399 Ibid.
1400 Ibid.
1401 Ibid.
1402 Ibid.
1403 Ibid.
1404 NEMA et al. 2015b “Questionnaire 1 (clarification questionnaire), document" "http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Ex_8b_NEMA_renewal_response_to_questions_MODIFIED_23_Sept_2015.pdf": Clarification questionnaire,” National Electrical Manufacturers Association, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Ex_8b_NEMA_renewal_response_to_questions_MODIFIED_23_Sept_2015.pdf

products (sizes 00-9), transfer switching products, motor hermetic overload relays, bypass contactors, and general purpose power switches for less than 30 A AC or greater than 600 V DC at 600 A, efforts to find a suitable replacement for AgCdO have been largely unsuccessful.

So, NEMA et al.[1405] conclude that, while research regarding Cd-free formulations has led to advances consistent with the goals of the RoHS Directive, this should not be viewed as evidence that viable substitutes for Cd contacts are – or will soon be - commercially available for electrical contacts in all circumstances. The suitability of alternative materials is affected by a range of factors such as voltage, current range, and the required number of cycles associated with the application. This multiplicity of factors leads to a substantial amount of trial-and-error by manufacturers and their suppliers during product development. It also makes it highly impractical to specify with precision the conditions, under which alternative formulations offered by material suppliers are suitable for a particular application. That being the case, Exemption 8(b) should be renewed in its current broadly stated form to allow manufacturers maximum flexibility in product design. Renewing the exemption as it stands will not impede the continued search for Cd-free substitutes.

25.2.2 Sensata

Sensata[1406] [1407] has been aggressively eliminating the use of cadmium oxide in contact systems since 2000 to remain fully committed to the intent of the RoHS directive. Where suitable alternatives have been found to provide comparable cycle reliability and product performance, the contact system is converted to a cadmium-free alternative. Sensata conducts the development of all new products without the use of cadmium oxide contacts. Significant progress has been made finding Cd free alternatives. Nevertheless, the exemption remains necessary for Sensata products which are applied as circuit breakers, temperature sensing controls and thermal motor protectors. Sensata[1408] puts forward that its testing results with substitute materials and design changes has shown that elimination of Cd in contacts in these applications reduces the cycle life, thermal stability, and product performance. This could lead to safety issues for consumers employing safety related products. Therefore it is Sensata's position that exemption number 8(b) needs to be extended for an additional period with respect to circuit breakers, temperature sensing controls and thermal motor protectors.

Sensata[1409] stated that it has made good progress in its portfolio as illustrated in the below below table.

[1405] Ibid.
[1406] Op. cit. Sensata Technologies Inc. 2015a
[1407] Op. cit. (Sensata Technologies Inc. 2016a)
[1408] Op. cit. Sensata Technologies Inc. 2015a
[1409] Op. cit. (Sensata Technologies Inc. 2016a)

Table 25-1: Sensata substitution of cadmium product history

Sensata Technologies Cadmium Free History					
Products Effected by EU RoHS					
	2000	2005	2008	2014	2016
No. of Sensata Products that fall under EU RoHS for Cadmium Contacts	73	73	77	73	73
Products with Cadmium Free Contacts	27	39	47	45	62
Products with Contacts containing Cadmium	46	34	30	28	11
Estimated kg of Cadmium in Products Sold Worldwide	1,538	1,456	979	920	350
	Summary of Changes				
No. of Cadmium Free Products	37%	53%	61%	62%	85%
Converted to Cadmium Free		12	4	2	17

Source: Sensata[1410]

However, for certain safety controls using high capacity electrical contact systems, Sensata[1411] still needs cadmium for the reliability of the safety function. Sensata[1412] explains that high capacity is defined, among other criteria, by:

- voltage,
- current,
- type of load (resistive/inductive),
- number of cycles,
- contact pressure, and
- switch velocity, etc.

According to Sensata[1413], it is hard to define criteria limiting the scope of the RoHS 8b exemption due to these multiple criteria, and for this reason it also takes time to find proper alternatives for cadmium replacement. Sensata therefore supports the continuation of exemption 8b) for thermal sensing controls and motor starter relays in its exemption request to provide additional time to make design modifications as required and to qualify silver cadmium oxide replacements with comparable cycle

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[1410] Op. cit. NEMA et al. 2015a 2015
[1411] Ibid.
[1412] Op. cit. (Sensata Technologies Inc. 2016a)
[1413] Ibid.

reliability, thermal stability, and performance. The additional time is necessary to also obtain approvals in the many different end applications that utilize these temperature sensing control safety products and motor starter relays.

Sensata[1414] reports they have been involved in testing and evaluating silver nickel and silver tin oxide materials as alternatives for the past ten years and has achieved a high number of successful conversions to cadmium-free as shown in Table 25-1 showing that over 85 % of Sensata's portfolio is forecasted to be Cadmium free in 2016. This required a significant amount of product testing that has occurred to reach this conversion rate, which is illustrated as an example for the thermal sensing controls between 2007 and 2014. Executing qualification test plans on over 500 product lots has involved considerable Sensata resources.

Table 25-2: Temperature sensing control product test summary 2007 to 2014

Product Family	Products Tested	No. Qual Builds	Cd Free Materials	Contact Suppliers	Electrical Perf		Cycle Life	
					Groups	No. Pcs	Tests	No Pcs
1 Ø External	6	26	5	5	124	4,092	88	700
1 Ø Internal	7	34	6	5	128	4,174	120	1160
3 Ø Internal	9	77	5	3	286	6,921	282	1692
Total	**22**	**137**			**538**	**15,187**	**490**	**3,552**

Source: Sensata[1415]

Sensata[1416] explains that despite the effort and success, there remain significant hurdles to convert the remainder 15 % of their portfolio:[1417]

5) Only a few suppliers are capable of producing Cd free contacts with the multilayer contact construction required for Sensata's product designs. Each material supplier's $AgSnO_2$ has unique chemistries which cause variations in performance and reliability. This drives the need to test each supplier's custom material and prevents product approvals by material type. Considering the 30 products on the 2008 conversion list, this has created a heavy burden on Sensata's test capacity. The test volume has limited the number of qualification iterations per product.
6) Many of Sensata's products are applied as safety devices and certified by global standard agencies. Besides the relevant European Norm standards (see list of standards in Section 25.1.3) there are similar standards published by agencies such as Underwriter Laboratories (UL) and the Canadian Standards Agency (CSA). Agency standards associated with temperature sensing controls require cycle lifes up to 10,000 cycles minimum with a maximum temperature drift of + 5 °C.

[1414] Op. cit. NEMA et al. 2015a 2015
[1415] Ibid.
[1416] Ibid.
[1417] Ibid.

Cadmium free contacts are faced with increased levels of temperature drift and decreased cycle life creating an obstacle to agency approval.

7) Sensata products also receive agency approval as thermal motor protectors. These are not subjected to specific standard test specifications but must be evaluated by OEM's in the application to verify system safety performance. OEM testing has not been performed for the products that are the reason for this exemption continuation request. There may be specific application conditions, which will be a challenge for Cd free options, but will not be known until products are submitted for OEM approval.

Sensata presents the below high level planning for follow up on phasing out of cadmium in electrical contacts for circuit breakers, temperature sensing controls and thermal motor protectors.

Table 25-3: Time plan for the phase out of cadmium

	circuit breakers	protective controls such as thermal cut-outs and thermal ballast protectors	thermal motor protectors excluding hermetically sealed THERMAL motor protectors
Qualification of Cd-Free Solutions by Sensata	January-2018	January-2018	January-2019
Qualification by Customers of Sensata	July-2018	July-2018	July-2019
Sensata Depletion of Inventory of Cd Contacts	January-2019	January-2019	January-2020
Final Shipment to Customers of Sensata Product Containing Cd in Contacts*	July-2019	July-2019	July-2020
Last European-Market Entry Date**	July-2020	July-2020	July-2021

*For European market.

**Estimated Last European-Market Entry Date of Goods Manufactured with Sensata Product Containing Cadmium Contacts (not controlled by Sensata).

Source: Sensata[1418]; products in the third column are thermal sensing controls

25.2.3 Marquardt

Marquardt[1419] manufactures switches for many applications such as household appliances. Only a small portion of the Marquardt power tool switches still need cadmium, for which Marquardt[1420] presents its conversion plan towards cadmium-free power tool switches in Table 25-4.

[1418] Sensata Technologies Inc. 2016d "Answers to fourth questionnaire, document "Exe-8b_Questionnaire-4_Sensata_2016-04-01.docx", received via e-mail from Albert van der Kuij, Sensata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016" unpublished manuscript,

[1419] Marquardt GmbH 2016c "Answer to the first questionnaire to all stakeholders, document"Exe_8b_Questionnaire-1_All-Stakeholders_Marquardt_2016-03-07.docx", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, on 7 March 2016" unpublished manuscript,

[1420] Op. cit. Marquardt GmbH 2016a

Table 25-4: Conversion plan for cadmium-free switches in Marquardt tools

History: Marquardt cadmium-free contacts used in Powertool Switches – Affected Powertool Switches						Target		
	2007	2008	2010	2012	2014	2016	2018	2020
Annual number of Powertool Switches sold	29.400.000	28.500.000	27.200.000	29.960.000	30.460.000	30.500.000	32.000.000	33.500.000
Powertool Switches with Cadmium-Free Contacts	27.500.000	26.900.000	26.400.000	29.460.000	29.910.000	30.050.000	31.775.000	33.475.000
Powertool Switches with Contacts containing Cadmium, including spare parts for product repairs	1.900.000	1.600.000	800.000	500.000	550.000	450.000	225.000	25.000
New introduced switch families with AgCdO Contacts	0	0	0	0	0	0	0	0
Estimated Mass (Kg) of CdO in the affected Powertool Switches	16,4	13,8	6,9	4,3	4,7	3,9	2,9	0,9
Ratio of Cadmium Free Powertool Switches	93,5%	94,4%	97,1%	98,3%	98,2%	98,5%	99,3%	99,9%

Source: Marquardt[1421]

Based on the above conversion program, Marquardt[1422] proposes to restrict the scope of exemption 8b for the use of cadmium in power tool switches:

"Cadmium and its compounds in switches of

- *cordless power tools rated 20 A at 18 V DC and more;*
- *corded power tools rated with 1,500 W and more (6 A 250 V AC, 12 A 125 V AC);*
- *specialized heavy duty power tools used with high frequency power supplies (200 Hz and more)"*

Marquardt[1423] states that the exemption is no longer required for most switches in power tools, but that they need five more years to actually implement the more challenging high voltage, high current and high frequency cadmium-free switches in their customers' product portfolios.

Marquardt[1424] claims it needs up to two years for an individual customer with a specific application and a specific switch family. This includes:

- The preparation of testing samples for the customer and qualification of the switch internally at Marquardt;
- Testing of the switch at the customer including testing under real life conditions;

[1421] Marquardt "Answers to consultation questionnaire: Consultation questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Marquardt_Questionnaire_Exemption_8b__with_table__4_Publication.pdf
[1422] Op. cit. Marquardt GmbH 2016a
[1423] Ibid.
[1424] Ibid.

- Optimization with subsequent further testing; and
- After the customers' approval, the preparation of the required documentation and possibly adaptations of the production process.

Marquardt[1425] needs the five additional years to actually implement the cadmium-free solutions for around 200 switch variants from 27 switch families for around 100 different customers worldwide.

25.2.4 Ubukata

In the course of their investigations, Ubukata Industries, a manufacturer of thermal motor protectors and thermal sensing controls, contacted the consultants. Ubukata[1426] claim they can offer cadmium-free thermal motor protectors and thermal sensing controls that satisfy the IEC/EN60730 safety standards which govern the requirements for these safety-relevant devices (c.f. chapter Technical Description of the Requested Exemption in Section 25.1.3 from page 542). Ubukata[1427] presents an example certificate for a thermal sensing control.

Ubukata[1428] also states that their cadmium-free thermal motor protectors and thermal sensing controls can cover the whole spectrum of market requirements according to those standards as well as all customers' technical requirements. By the end of 2016, Ubukata wants to have implemented its cadmium-free products in its customers' products.

Thermal motor protectors and thermal sensing control need a certificate according to the above mentioned standards. Ubukata[1429] says that depending on the certifying body, it may take up to several months to obtain these certificates, but some certification bodies are faster than others. After that, Ubukata[1430] states it takes around another 3 months to qualify the device with the customers for their products. Figure 25-2 illustrates the various steps and the approximately required times.

[1425] Marquardt GmbH 2016b "E-mail communication, document "E-mail_Marquardt_5-Year-Conversion.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Klaus Fiederer, Marquardt, on 18 February 2016" unpublished manuscript,

[1426] Ubukata Industries 2016b "Answers to first qustionnaire, document "Exe_8b_Questionnaire-1_Ubukata_2016-02-05.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from A.K. Morshad, Ubukata Industries, on 17 February 2016" unpublished manuscript,

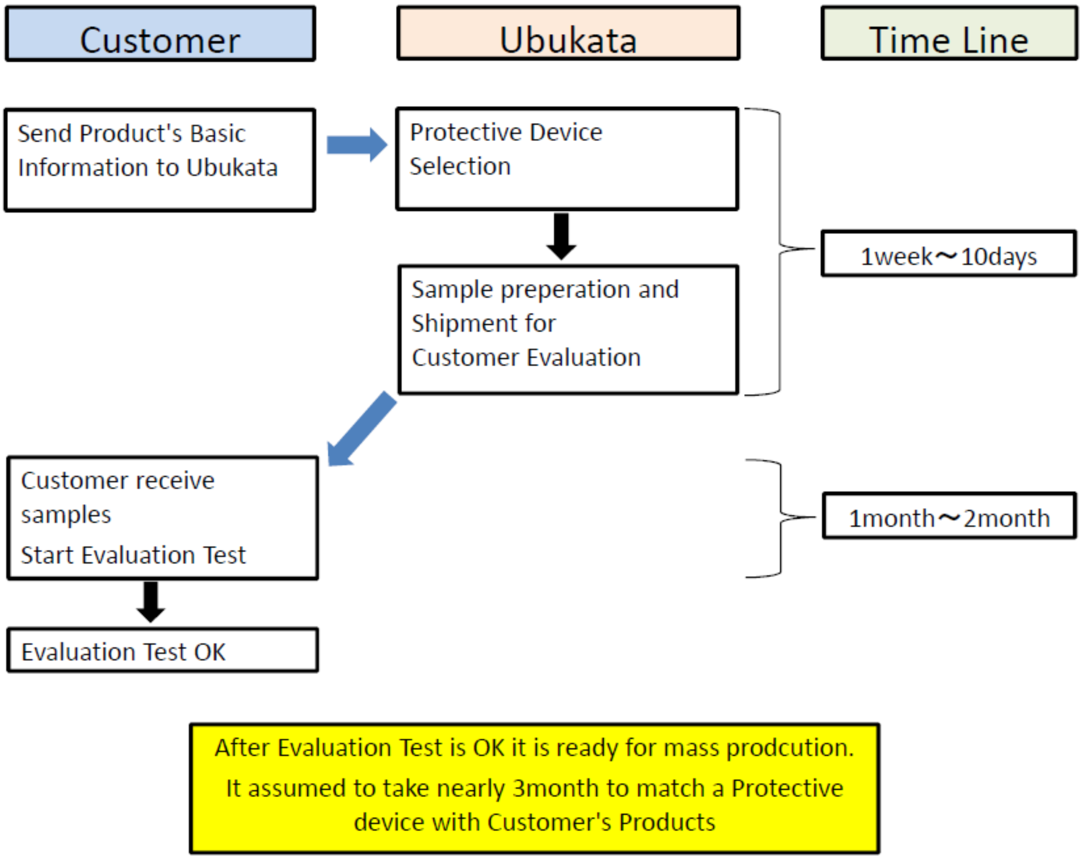
[1427] Ubukata Industries 2016c "Example certificate thermal sensing controls, document"Ubukata_Certificate_Thermal-Sensing-Control.pdf", received via e-mail from A.K. Morshad, Ubukata Industries, by Dr. Otmar Deubzer, Fraunhofer IZM, on 23 March 2016" unpublished manuscript,

[1428] Op. cit. (Ubukata Industries 2016b)

[1429] Ubukata Industries 2016d "E-mail communication, document "E-mail-communication_Ubukata_Thermal-Sensing-Controls_2016-03-29.pdf", received from A.K. Morshad, Ubukata Industries, by Dr. Otmar Deubzer, Fraunhofer IZM, until 29 March 2016" unpublished manuscript,

[1430] Ubukata Industries 2016e "E-mail communication, document "Time_Protective-Device-Development.pdf", received from A.K. Morshad, Ubukata Technologies, by Dr. Otmar Deubzer, Fraunhofer IZM, on 26 February 2016" unpublished manuscript,

Figure 25-2: Time plan for customer qualification of thermal sensing controls and thermal motor protectors



Source: Ubukata[1431]

Ubukata states that customer qualifications are expected to be finalized in 2016 for the thermal motor protectors as well as for the thermal sensing controls.

25.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

25.3.1 NEMA et al.

NEMA et al.[1432] claim that the methods for manufacture, proprietary or otherwise, of cadmium-free contact materials vary significantly among suppliers, and these methods influence such properties as arc erosion, contact resistance and tendency to weld in service. As part of the qualification on initial samples it is recommended that the user electrically test the materials in a functional manner for all devices applicable to the

[1431] Ibid.
[1432] Op. cit. NEMA et al. 2015a 2015

material's use. Discrete contact parts produced under this guide shall be sampled and tested on a lot basis. This means that extensive testing will be necessary for each supplier in relation to:[1433]

- Voltage;
- Switching current;
- Steady current;
- Switching speed;
- Life cycle;
- Mechanical wear; and
- Environmental;

Because of the potential significant variation in properties from lot to lot, from supplier to supplier, NEMA et al.[1434] state that much more extensive testing will be required as compared to AgCdO. In the process of substitution they distinguish between the following steps:[1435]

- Materials research;
- Testing; and
- Implementation;

NEMA et al.[1436] put forward that the process of substitution will take more time when potential substitutes are found not to be suitable to replace the exempted substance. On the one hand a substitute may fail tests before reaching any stage of implementation. On the other hand substitutes may be successfully implemented at one or more levels in the value chain, but fail when further being integrated in specific equipment or equipment being used under specific conditions. In either case the process of looking into suitable alternative substances shall need to start all over again. As a consequence it may take several years before substitution at the material level will lead to successful implementation in final equipment.

25.3.2 Sensata

Sensata[1437] presents a conversion table (c.f. Figure 25-2 on page 551) for the further substitution of cadmium in electrical contacts, and will continue to examine:

8) Additional potential material sources of supply;
9) Additional material alloys and additives;
10) Contact mating with dissimilar alloys;
11) Alternate contact attachment processes where feasible;
12) Product design modifications where feasible;

[1433] Ibid.
[1434] Ibid.
[1435] Ibid.
[1436] Ibid.
[1437] Ibid.

13) Alternate device series which will require customer re-application and agency re-certification.

25.3.3 Ubukata and Marquardt

Ubukata have converted their thermal sensing controls and the thermal motor protectors to cadmium-free versions. Marquardt presented a plan how to achieve RoHS compliance for its last cadmium-containing switches in power tools (category 6 of RoHS Annex I) until around 2020 (c.f. Section 25.2.3 on page 548) and states that the other switches in their product portfolio are already cadmium-free and qualified for use in all their customers' products.

25.4 Critical Review

25.4.1 REACH

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of cadmium in various articles and uses.

Entry 23 of Annex XVII of REACH restricts the use of Cd in applications. Paragraph 1 regards various materials that can be summarised as plastic materials, thus not relevant for this exemption, which relates to the use of Cd in electrical contacts. Use in metal plating, in brazing fillers and in metal parts (jewellery, beads) is also restricted in later paragraphs, but understood not to be relevant to the application at hand.

Entry 28 and entry 30 in Annex XVII of the REACH Regulation, stipulate that various cadmium compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. In the consultants' understanding, the restriction for substances under Entry 28 and Entry 30 of Annex XVII does not apply to the use of cadmium in this application. Cd used in electrical contacts, in the consultants' point of view is not a supply of cadmium and its compounds as a substance, mixture or constituent of other mixtures to the general public. Entry 28 and Entry 30 of Annex XVII of the REACH Regulation would thus not apply.

No other entries, relevant for the use of cadmium in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016).

Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. The exemption could thus be granted for this use of Cd if other criteria of Art. 5(1)(a) apply.

25.4.2 Substitution and Elimination of Cadmium

The last review[1438] of this exemption in 2008/2009 showed that cadmium-free materials for electrical contacts at that time had been available already on the market for a while. However, these cadmium-free materials were not drop-in replacements for the cadmium-containing contacts. On the contact manufacturers and the equipment manufacturers' side, it was understood that it required comprehensive testing and evaluation, of the cadmium-free contacts and geometrical adaptations and other redesigns in the contacts and in the EEE, to decide on a case-by-case base, whether and how they are appropriate for the intended application. Cadmium-free switches and relays were on the market and used in EEE for switching medium to moderately high currents. For safety and durability/reliability reasons, the applicants in 2008/2009 stated that AgCdO could not be replaced in most types of electrical switches and circuit breakers. Despite numerous tests over years, it has not been possible so far to replace all cadmium-containing electrical contacts.

The findings from 2009 imply that the transition to cadmium-free contacts on the one hand requires time to implement solutions on the contact level and to realize these solutions in the electrical and electronic equipment of their customers. On the other hand, in particular the higher voltage and higher current area as well as the safety relevant applications of electrical contacts are understood to be the most challenging. They may require even more time, and possibly no solutions might be available for specific cases.

Looking at each applicant's and stakeholder's information individually, Sensata's exemption request is in line with these findings of the last review and as such technically plausible. Sensata showed that they have successfully converted a large portion of their product portfolio and present a conversion plan when to replace cadmium in circuit breakers, thermal sensing controls and thermal motor protectors until 2021.

The same applies for Marquardt who ask to continue the exemption for high current, high voltage and high frequency switches in tools (cat. 6) only, as they have already achieved the full conversion for their other switches.

NEMA et al. request the continuation of Exemption 8b in its current wording for another five years. The technical arguments and the status they describe more or less represents the status and arguments of the last review in 2008/2009. It was clear at that time that cadmium-free alternative materials do not provide the same functions and that they are not drop-in replacements. NEMA et al. do not present any more specific information such as conversion achievements or plans. Thus it is plausible that the transition to cadmium-free contacts may require more time and possibly might be scientifically and technically not yet practicable in particular for high current and high voltage contacts. The applicants' arguments do, however, not justify the general continuation of the exemption request in its current wording for another five years, all the more as other

[1438] Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009)

stakeholders present cadmium-free solutions that may allow the specification of the exemption.

25.4.3 Conclusions

Through the consultation process, the consultants developed the below wording for a tightening of the scope of the current exemption in discussions with NEMA et al.,[1439] [1440] [1441] Sensata,[1442] [1443] [1444] [1445] [1446] Marquardt[1447] [1448] [1449] [1450] and Ubukata[1451] [1452] [1453]:

Cadmium and its compounds in electrical contacts of

- *a) circuit breakers*
- *b) thermal sensing controls; expires on 21 July 2019*
- *c) thermal motor protectors excluding hermetically sealed thermal motor protectors*
- *d) switches for electrical and electronic equipment in categories 1 to 5, 7 and 10 of Annex I, i.e.*

[1439] NEMA et al. 2016a "Answers to second questionnaire, document "Exe-8b_Questionnaire-2_Response_NEMA_2016-01-22.pdf", sent via e-mail on 1 February 2016 to Dr. Otmar Deubzer, Fraunhofer IZM, by Mark Kohorst, NEMAS: Answers to second questionnaire" unpublished manuscript,
[1440] NEMA et al. 2016b "Answers to questionnaire 1 to all stakeholders, document "Exe_8b_Questionnaire-1_All-Stakeholders_NEMA_2016-02-26.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Mark Kohorst, NEMA, on 26 February 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders
[1441] NEMA et al. 2016c "Answers to second questionnaire to all stakeholders, document "Exe_8b_Questionnaire-2_All-Stakeholders_NEMA.pdf", received via e-mail from Mark Kohorst, NEMA, by Dr. Otmar Deubzer, Fraunhofer IZM, on 22 March 2016" unpublished manuscript,
[1442] Op. cit. (Sensata Technologies Inc. 2016a)
[1443] Sensata Technologies Inc. 2016b "Answers to questionnaire 1 to all stakeholders, document "Exe_8b_Questionnaire-1_All-Stakeholders_Sensata_2016-02-26.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Albert van der Kuij, Sensata Technologies, on 26 February 2016"
[1444] Op. cit. (Sensata Technologies Inc. 2016c)
[1445] Op. cit. (Sensata Technologies Inc. 2016d)
[1446] Sensata Technologies Inc. 2016e "Answers to second questionnaire to all stakeholders, document "Exe_8b_Questionnaire-2_All-Stakeholders_2016-03-21 SENSATA.docx", received via e-mail from Albert van der Kuij, Sensata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 21 March 2016" unpublished manuscript,
[1447] Op. cit. (Marquardt GmbH 2016a)
[1448] Op. cit. (Marquardt GmbH 2016b)
[1449] Op. cit. (Marquardt GmbH 2016c)
[1450] Marquardt GmbH 2016d "Answers to second questionnaire to all stakeholders, document "Exe_8b_Questionnaire-2_All-Stakeholders_2016-03-15_MQ.docx", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, on 17 March 2016" unpublished manuscript,
[1451] Op. cit. (Ubukata Industries 2016b)
[1452] Op. cit. (Ubukata Industries 2016d)
[1453] Op. cit. (Ubukata Industries 2016e)

i) AC switches rated at 6 A and more in combination with 250 V AC and more; expires on 21 July 2019

ii) AC switches rated at 12 A and more in combination with 125 V AC and more;
expires on 21 July 2019

iii) [DC switches rated at 20 A and more in combination with 18 V DC and more]

iv) [switches for electrical and electronic equipment conceived to be used with power supplies of 200 Hz and more]

e) switches for tools in category 6 of Annex I, i.e.

i) AC switches for corded tools rated at 6 A and more in combination with 250 V AC and more,

ii) AC switches for corded tools rated at 12 A and more in combination with 125 V AC and more

iii) DC switches for cordless tools with a rated current of 20 A and more in combination with at a rated voltage of 18 V DC and more

iv) switches for tools conceived to be used with power supplies of 200 Hz and more

Based on the information submitted and on the technical background from the previous review, the substitution or elimination of cadmium in electrical contacts is in principle scientifically and technically practicable. The applicants' information suggests, however, that substituting cadmium is most challenging in circuit breakers, thermal sensing controls and high power and high frequency switches. More time is needed for adapting designs, to find contact materials, and for qualifying cadmium-free solutions in the supply chain and in the EEE manufacturers' products, since the cadmium-free contact materials are not drop-in replacements. The time for qualification of substitutes according to the qualification procedures applied in specific sectors has been taken into account in the past review rounds of exemptions in line with Art. 5(1)(a) to ensure the reliability of the substitutes.

Generally, Art. 5(1)(a) does not justify granting exemptions to make sure each company has converted its product portfolio to cadmium-free contacts in cases where the substitution or elimination of cadmium in contacts is scientifically and technically practicable. Art. 5(1)(a) allows, however, granting exemptions if more time is required to ensure the reliability of substitutes even in cases where the substitution or elimination of cadmium is scientifically and technically practicable under two conditions: Applicants prove that they are undertaking reasonable efforts to find and implement cadmium-free solutions as soon as possible, and that there are no other producers that can supply and implement reliable cadmium-free solutions. These aspects are considered separately for each type of electrical contact application in the following subsections.

25.4.3.1 Circuit Breakers and Thermal Sensing Controls

The consultants conclude from the applicants' information and in the absence of contrary information that the renewal of the exemption could still be justified for another five years in line with the requirements of Art. 5(1)(a) for circuit breakers in part a) of the above wording proposal.

Ubukata can offer cadmium-free alternatives for thermal sensing controls in part b) of the above exemption wording. The consultants had proposed to exclude the thermal sensing controls covered by the standards EN/IEC60730-1 (Automatic electrical controls - Part 1: General requirements) and EN/EN60730-2-9 (Particular requirements for temperature sensing controls) from an exemption, for thermal sensing controls, possibly with a transition period based on the fact that Ubukata can offer cadmium-free alternatives for these thermal sensing controls. There was, however, an ongoing technical discussion between the applicants[1454] whether and how thermal sensing controls should be differentiated into operating and protective thermal sensing controls. The consultants additionally raised the question, which other thermal sensing controls are in the market besides the ones covered by the standards EN/IEC60730-1 and EN/EN60730-2-9. The stakeholders could not provide clear information on this aspect. Given the considerable efforts undertaken already to restrict the exemption and the limited time and resources available, the consultants could not conclude the technical discussions. Instead, the consultants recommend granting part b) of the exemption for three years. This approach offers the advantage to set an expiry date for all types of thermal sensing controls and leaves time to apply for the renewal of the exemption in specific cases where the substitution or elimination of cadmium would scientifically and technically still be impracticable.

25.4.3.2 Thermal Motor Protectors

Ubukata offers cadmium-free thermal motor protectors, whereas NEMA et al. and Sensata request the renewal of the exemption for these devices for another five years. Several rounds of discussions[1455, 1456, 1457, 1458, 1459, 1460] were held aimed at clarifying the exemption wording. Taking into account the technical situation of cadmium-substitution in thermal motor protectors, the stakeholders, and the consultants agreed on the wording as proposed in part c) of the rewording proposal of NEMA et al.[1461]

[1454] Op. cit. (Ubukata Industries 2016d)
[1455] Op. cit. (NEMA et al. 2016b)
[1456] Op. cit. (Sensata Technologies Inc. 2016b)
[1457] Op. cit. (Sensata Technologies Inc. 2016e)
[1458] Op. cit. (Ubukata Industries 2016d)
[1459] Sensata Technologies/Ubukata Industries "E-mail communication with Sensata and Ubukata, document E-mail-communication_Sensata-Ubukata_2016-03-14.pdf, received by Dr. Otmar Deubzer, Fraunhofer IZM, from Sensata and Ubukata on 14 March 2016" unpublished manuscript,
[1460] Op. cit. (NEMA et al. 2016c)
[1461] Ibid.

This wording proposal takes into account that Ubukata's cadmium-free thermal sensing controls are all hermetically sealed and can therefore be excluded from the exemption, while there is no evidence that other thermal motor protectors have been fully converted to cadmium-free, i.e. ones that are not hermetically sealed.

25.4.3.3 Switches

NEMA et al. requested the continuation of Exemption 8b) in its current wording whereas Marquardt has converted its switches to cadmium-free and states that the exemption is only required for another five years in tools with the specifications listed in part e) of the exemption wording. The consultants therefore propose this wording, which was agreed upon with Marquardt to make sure it adequately covers those applications where more time is required to implement the cadmium-free solutions into the customers' EEE in order to ensure the reliability of the substitutes, which justifies granting an exemption in line with Art. 5(1)(a).

Besides switches for power tools, Marquardt produces a broad range of switches for other applications where exemption 8b) is no longer required. Marquardt[1462] puts this situation into perspective stating that there are definitely other switch applications in the market, which are not covered by the Marquardt product range, but cannot specify them.

Technically, the challenges related to switches in high voltage, high current and high frequency applications are the same for tools and for other applications. In agreement with Marquardt[1463], the consultants therefore propose part d) in the new exemption wording transferring the situation in the power tool sector to other switches. Upon request, Marquardt[1464] provided, however, cadmium-free AC-switches with ratings exceeding the limits of 6 A at 250 V AC or 12 A at 125 V AC where Marquardt no longer requires Exemption 8b).

Taking into account that Marquardt cannot cover the full spectrum of switches outside Cat. 6, the consultants nevertheless recommend a three year transition period for the AC switches in part c), which would leave sufficient time to apply for specific exemptions in case the use of cadmium would still be required for some specific switches.

Marquardt[1465] states that the high power DC switches and the high frequency switches may only be relevant for tools in Cat. 6, but not for EEE in other categories of RoHS Annex I. NEMA et al. were presented Marquardt's examples of high voltage/high current AC switches and asked to comment, and to clarify whether the respective AC and high

[1462] Op. cit. (Marquardt GmbH 2016d)
[1463] Op. cit. (Marquardt GmbH 2016b)
[1464] Marquardt GmbH 2016e "E-mail communication, document "E-mail_Marquardt_Cd-free-Switches.pdf", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, until 15 March 2016" unpublished manuscript,
[1465] Ibid.

frequency switches are actually relevant outside category 6. NEMA et al. replied[1466] on 22 March 2016 that there was not enough time to acquire the data needed to respond to the question whether the DC switches in part d) are actually relevant, but "That may change and if so, I will forward any relevant information to you immediately." Until 3 April 2016, there was no further input from NEMA et al. For this part of the exemption there is thus no justification, or it is actually irrelevant. Thus, the consultants recommend to delete this part of the exemption.

25.5 Recommendation

25.5.1 Rewording of the Exemption

Based on the information submitted in the exemption requests, during the online stakeholder consultation and the subsequent review, the substitution or elimination of lead is still scientifically and technically impracticable in several types of devices with electrical contacts, or requires more time to ensure the reliability of the substitutes. Granting an exemption for these cases would thus be in line with the requirements of Art. 5(1)(a). The consultants recommend the renewal of Exemption 8b with the following wording that reflects the current situation of substitution and time requirements for the qualification of cadmium-free contacts noting that this modifies the wording as listed in Section 25.4.2 in line with the judgements made in Section 25.4.3

Exemption 8 (b)	**Expires on**
8(b) Cadmium and its compounds in electrical contacts	*21 July 2021 for medical equipment in category 8 and monitoring and control instruments in category 9*
	21 July 2023 for in vitro diagnostic medical devices in category 8
	21 July 2024 for industrial monitoring and control instruments in category 9
8(c) Cadmium and its compounds in electrical contacts of	
I) circuit breakers *II) thermal motor protectors excluding hermetically sealed thermal motor protectors*	*21 July 2021 for categories 1-7 and 10*
III) thermal sensing controls	*21 July 2019 for categories 1-7 and 10*
IV) AC switches rated at 6 A and more in combination with 250 V AC and more V) *AC switches rated at 12 A and more in combination with 125 V AC and more*	*Applies to EEE in* categories 1 to 5, 7 and 10 21 July 2019 for categories 1 to 5, 7 and 10

[1466] Op. cit. (NEMA et al. 2016c)

Exemption 8 (b)	Expires on
VI) AC switches for corded tools rated at 6 A and more in combination with 250 V AC and more, *VII) AC switches for corded tools rated at 12 A and more in combination with 125 V AC and more* *VIII) DC switches for cordless tools with a rated current of 20 A and more in combination with at a rated voltage of 18 V DC and more* *IX) switches for tools conceived to be used with power supplies of 200 Hz and more*	*Applies to category 6 EEE* *21 July 2021 for category 6*

25.5.2 Stakeholders' Comments on the Rewording Proposal

Even though the proposal was worked out with the applicants, Sensata[1467] and NEMA et al.[1468] prefer the following alternative rewording:

Cadmium and its compounds in electrical contacts of circuit breakers, thermal sensing controls, thermal motor protectors (excluding hermetic thermal motor protectors), DC switches rated at 20 A at 18 V DC and more, AC switches rated at 6 A 250 V AC - 12 A 125 V AC and more, and switches used at voltage supply frequencies of 200 Hz and more

They are afraid the consultants' rewording worked out with the stakeholders may cause high administrative burdens on their side and foresee further difficulties for market surveillance.

Marquardt agree with the new wording, but "*[...] understand that the use of sub-clauses [...] might increase unnecessarily the related administrative efforts for all stakeholders. Therefore we would recommend to use simple indents or bullet points indicating the various application cases like:*

- *circuit breakers*
- *thermal sensing controls...*"[1469]

[1467] Op. cit. (Sensata Technologies Inc. 2016e)
[1468] Op. cit. (NEMA et al. 2016c)
[1469] Marquardt GmbH 2016f "E-mail communication, document "Marquardt_Drop-Subclauses.pdf", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, until 7 March 2016" unpublished manuscript,

25.6 References Exemption 8b

Carl-Otto Gensch, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

Gensch, Carl-Otto [Oeko-Institut e.V.], et al. Adaptation to scientific and Technical progress under Directive 2002/95/EC 2006.

Marquardt GmbH 2016a Contribution to the stakeholder consultation, answers to the consultation questionnaire. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Marquardt_Questionnaire_Exemption_8b__with_table__4_Publication.pdf.

Marquardt GmbH 2016b E-mail communication, document "E-mail_Marquardt_5-Year-Conversion.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Klaus Fiederer, Marquardt, on 18 February 2016.

Marquardt GmbH 2016c Answer to the first questionnaire to all stakeholders, document"Exe_8b_Questionnaire-1_All-Stakeholders_Marquardt_2016-03-07.docx", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, on 7 March 2016.

Marquardt GmbH 2016d Answers to second questionnaire to all stakeholders, document "Exe_8b_Questionnaire-2_All-Stakeholders_2016-03-15_MQ.docx", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, on 17 March 2016.

Marquardt GmbH 2016e E-mail communication, document "E-mail_Marquardt_Cd-free-Switches.pdf", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, until 15 March 2016.

Marquardt GmbH 2016f E-mail communication, document "Marquardt_Drop-Subclauses.pdf", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, until 7 March 2016.

NEMA et al. 2015a Request for continuation of exemtion 8b, document "8b_Final_RoHS_Exemption_Renewal_Dossier_2015_01_16.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/8b_Final_RoHS_Exemption_Renewal_Dossier_2015_01_16.pdf.

NEMA et al. 2015b Questionnaire 1 (clarification questionnaire), document" "http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Ex_8b_NEMA_renewal_response_to_questions_MODIFIED_23_Sept_2015.pdf" . http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Ex_8b_NEMA_renewal_response_to_questions_MODIFIED_23_Sept_2015.pdf.

NEMA et al. 2016a Answers to second questionnaire, document "Exe-8b_Questionnaire-2_Response_NEMA_2016-01-22.pdf", sent via e-mail on 1 February 2016 to Dr. Otmar Deubzer, Fraunhofer IZM, by Mark Kohorst, NEMAS.

NEMA et al. 2016b Answers to questionnaire 1 to all stakeholders, document "Exe_8b_Questionnaire-1_All-Stakeholders_NEMA_2016-02-26.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Mark Kohorst, NEMA, on 26 February 2016.

NEMA et al. 2016c Answers to second questionnaire to all stakeholders, document "Exe_8b_Questionnaire-2_All-Stakeholders_NEMA.pdf", received via e-mail from Mark Kohorst, NEMA, by Dr. Otmar Deubzer, Fraunhofer IZM, on 22 March 2016.

Sensata Technologies Inc. 2015a Request for Continuation of Exemption 8b, document "RoHS-Exemptions_Application-Format_Cd_Sensata_20150115.pdf" and document "Sensata_Cd-Exemption-Request_Jan-2015.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/RoHS-Exemptions_Application-Format_Cd_Sensata_20150115.pdf.

Sensata Technologies Inc. 2016a Answers to questionnaire 2, document "Exe-8b_Questionnaire-2_Sensata_Response_2016-01-22.docx", sent via e-mail to Dr. Otmar Deubzer, Fraunhofer IZM, by Albert van der Kuji, Sensata.

Sensata Technologies Inc. 2016b Answers to questionnaire 1 to all stakeholders, document "Exe_8b_Questionnaire-1_All-Stakeholders_Sensata_2016-02-26.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Albert van der Kuij, Sensata Technologies, on 26 February 2016.

Sensata Technologies Inc. 2016c Answers to third questionnaire, document "Exe-8b_Questionnaire-3_Response_Sensata_2016-02-11.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Albert van der Kuij, Sensata Technologies, on 11 February 2016.

Sensata Technologies Inc. 2016d Answers to fourth questionnaire, document "Exe-8b_Questionnaire-4_Sensata_2016-04-01.docx", received via e-mail from Albert van der Kuij, Sensata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016.

Sensata Technologies Inc. 2016e Answers to second questionnaire to all stakeholders, document "Exe_8b_Questionnaire-2_All-Stakeholders_2016-03-21 SENSATA.docx", received via e-mail from Albert van der Kuij, Sensata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 21 March 2016.

Sensata Technologies/Ubukata Industries E-mail communication with Sensata and Ubukata, document E-mail-communication_Sensata-Ubukata_2016-03-14.pdf, received by Dr. Otmar Deubzer, Fraunhofer IZM, from Sensata and Ubukata on 14 March 2016.

Ubukata Industries 2016b Answers to first qustionnaire, document "Exe_8b_Questionnaire-1_Ubukata_2016-02-05.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from A.K. Morshad, Ubukata Industries, on 17 February 2016.

Ubukata Industries 2016c Example certificate thermal sensing controls, document"Ubukata_Certificate_Thermal-Sensing-Control.pdf", received via e-mail from A.K. Morshad, Ubukata Industries, by Dr. Otmar Deubzer, Fraunhofer IZM, on 23 March 2016.

Ubukata Industries 2016d E-mail communication, document "E-mail-communication_Ubukata_Thermal-Sensing-Controls_2016-03-29.pdf", received from A.K. Morshad, Ubukata Industries, by Dr. Otmar Deubzer, Fraunhofer IZM, until 29 March 2016.

Ubukata Industries 2016e E-mail communication, document "Time_Protective-Device-Development.pdf", received from A.K. Morshad, Ubukata Technologies, by Dr. Otmar Deubzer, Fraunhofer IZM, on 26 February 2016.

26.0 Exemption 9: "Hexavalent chromium as an anticorrosion agent of the carbon steel cooling system in absorption refrigerators up to 0,75 % by weight in the cooling solution"

Declaration

In the sections that precede the "Critical Review" the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

CrVI	Hexavalent chromium
CrIII	Trivalent chromium
ECHA	European Chemicals Agency
EEE	Electrical and electronic equipment
ELV	End-of-life vehicle
EoL	End-of-life
EU COM	European Commission
RAC	Risk Assessment Committee
RV	Recreational vehicles
SEAC	Socio-Economic Analysis Committee
TMC	The Test and Measurement Coalition

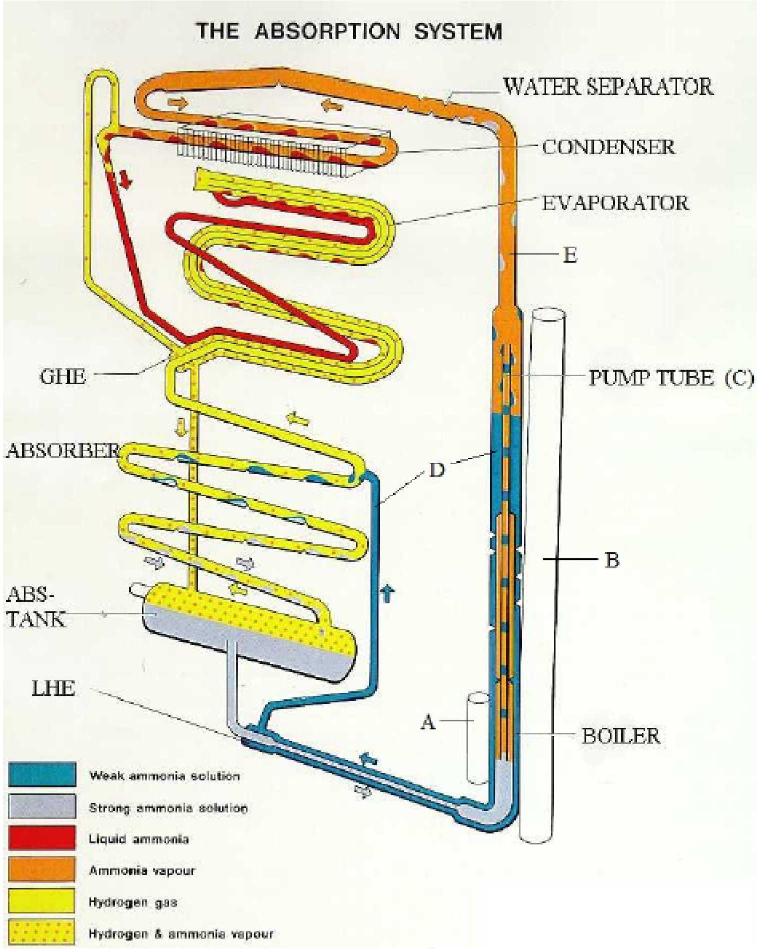
26.1 Background

According to the applicant,[1470] absorption refrigerators are used in recreational vehicles (RV), marine applications, camping boxes and mobile cooling boxes for medical purposes[1471] and generally in cases of restricted space e.g. for hotel minibars, in lodges and small apartments, because they operate silently and vibration-free. Absorption refrigerators can be run on different energy sources like electricity, kerosene or gas. Some products are designed to run on variable energy sources. The noiseless operation and the possibility to switch between the energy sources are the important performance criterion according to the applicant.

In absorption refrigeration, a heat source (e.g. gas or electricity) is used to separate the ammonia from the water that then enters the evaporator where the presence of hydrogen lowers the ammonia vapour pressure sufficiently to allow the liquid ammonia to evaporate. The evaporation of the ammonia extracts heat from the air, thereby lowering the temperature inside the refrigerator.[1472] This is schematically shown in the following figure.

[1470] Dometic (2015a), Original Application for Exemption Renewal Request, submitted 20.01.2015, available under:
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_9/9_150120_RoHS_V_Application_Form_Dometic.pdf
Dometic (2015c), Dometic GmbH, Analysis of Alternatives and Socio-Economic Analysis, available under http://echa.europa.eu/documents/10162/0783ee3a-7de9-45ec-a72a-c1689ee49e09
[1471] For e.g. transportation of vaccine and blood according to Dometic (2015c)
[1472] Op. cit. Dometic (2015c)

Figure 26-1: Absorption cooling system schematic



Source: Dometic (2015c)

Hexavalent chromium (CrVI) acts as an anticorrosion agent of the carbon steel cooling system in absorption refrigerators. According to the applicant[1473], CrVI is used to create a thin and tight layer on the interior surface of the steel tubes to protect them from the cooling solution that contains corrosive ammonia. The cooling system is comprised from carbon steel because of its strength and its good welding- and cold-working properties.

Dometic has submitted a request for the renewal of Ex. 9:

> "*Hexavalent chromium as an anticorrosion agent of the carbon steel cooling system in absorption refrigerators up to 0,75 % by weight in the cooling solution*"

Dometic requests an extension of the exemption for another three years in order to finalize substitution with an alternative corrosion inhibitor in the absorption refrigerator

[1473] Op. cit. Dometic (2015a)

range of products falling under RoHS. According to the applicant[1474], most of the products used in the lodging industry and in private homes are covered by the RoHS Directive. The applicant[1475] states that products falling under the RoHS Scope belong to category 1.

The applicant further explains that products for recreational vehicles (RV) and marine applications with absorption technology are most often specifically designed for that purpose and thus fall outside of the scope of RoHS. Several products for RV fall within the scope of the ELV-directive.[1476] A corresponding exemption is available under the ELV Directive (2000/53/EC, Annex II, Ex. 14) and is formulated as follows:

> "*As an anti-corrosion agent of the carbon steel cooling system in absorption refrigerators in motorcaravans up to 0,75 weight % in the cooling solution except where the use of other cooling technologies is practicable (i.e. available on the market for the application in motor caravans) and does not lead to negative environmental, health and/or consumer safety impacts*".

26.1.1 History of the Exemption

During the last revision of Exemption 9, the same wording was proposed as under the ELV Directive mentioned in the para above.[1477] It was understood that research and development of alternatives for CrVI was still underway and required additional time. Furthermore, alternative cooling technologies such as thermoelectric refrigeration and compressor refrigeration that do not need CrVI were discussed during the last revision. At the time, Dometic stated that for some areas of use compressor-based alternatives are available. However, being noisier than absorption refrigerators, this may be a health concern for some consumers. Though noise could possibly be mitigated through design changes, it was further understood that small-scale compressor-based refrigerators are only available for a small number of applications, starting with approximately 80 l, and thus not suited as e.g. built-in minibars of approximately 40 l. Thus it was concluded at the time that such compressor-based units cannot be used as alternatives on the system level to eliminate the need for absorption refrigerators using CrVI as a corrosion resistance agent. The renewal of the exemption was therefore recommended, resulting in the exemption currently listed in Annex III.

[1474] Dometic (2015b), Answers to Clarification Questions, submitted 13.08.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_9/20150813_Ex_9_Dometic_replay_on_questions.pdf

[1475] Op. cit. Dometic (2015a)

[1476] Op. cit. Dometic (2015b)

[1477] Gensch, et al. (2009), Carl-Otto Gensch, Oeko-Institut e. V., et al. 20 February 2009, Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf

26.1.2 Amount of Hexavalent Chromium Used under the Exemption

Dometic[1478] states that the average amount of CrVI used for a typical refrigerator model is around 2 grams.

Regarding the amount of substance entering the EU market annually through the application for which the exemption renewal is requested, Dometic estimates:

> "*approximately 200 kg per annum referring to units produced by Dometic*."

This is understood to be relevant only for products that Dometic considers to fall under RoHS (i.e., used in lodging industry and private homes), which are part of its manufacture.

Dometics' total annual use of CrVI for its whole product range (also including products with a gas running heater and a high boiler temperature) is estimated at 700 kg/year.[1479]

26.2 Description of Requested Exemption

According to the applicant[1480], sodium chromate (a hexavalent chromium compound) functions as a corrosion inhibitor in the carbon steel structure of the cooling unit in absorption refrigerators. The cooling solution consists of ammonia, water, sodium chromate and hydrogen gas, retained at a sufficient pressure to condense ammonia at the ambient temperature. To allow a long service life of the sealed cooling system, the sodium chromate in the cooling solution protects the steel pipes from interior corrosion that would arise in the presence of the corrosive ammonia.

Dometic[1481] states that they have searched for alternatives to CrVI "*for decades*" and that their tests included solutions such as coatings, substrate materials and altering design parameters. Dometic[1482] further explains that they have identified an alternative corrosion inhibitor, which has reached successful laboratory results:

> "*This inhibitor, named inhibitor #7, was found to be able to protect the carbon steel tubing from corrosion after 3 years of continuous circulation and it was consequently selected for further testing.*"

Dometic considers inhibitor #7 as a candidate to replace CrVI, with an acceptable expected life time, performance and safety level. However, some tasks need to be completed before inhibitor #7 can be used on a large scale.

[1478] Op. cit. Dometic (2015a)
[1479] Op. cit. Dometic (2015c)
[1480] Op. cit. Dometic (2015a)
[1481] Op. cit. Dometic (2015c)
[1482] Op. cit. Dometic (2015a)

26.3 Applicant's Justification for Exemption

According to Dometic, a renewal of the exemption for three years is needed in order to complete the following tasks that are needed to ensure a long service life of the absorption refrigerators:[1483]

- "*Finalising and extension of field tests and increased testing of some specific models.*
- *Redesign of our cooling units to decrease the boiling temperature and minimising the risk for corrosion inside the tubes. This is an extensive work as we have close to 100 different models of cooling units in production.*
- *Design and installation of factory equipment for inhibitor #7. This important step includes also reliability testing of inhibitor #7 in combination with the new equipment.*"

In order to use sodium chromate in minibars Dometic has applied for an exemption under the RoHS directive for a period of 3 years, until 2019.[1484]

Dometic considers the minibars to fall under RoHS and characterises them as products with low boiler temperatures (<180°C). It is understood from the information provided by Dometic that the heater in products with low boiler temperature is exclusively run on electricity.

According to Dometic[1485], *"products with higher boiler temperatures are mostly (but not exclusively) included in the RV and medical box product groups. Coincidentally these products are used in a harsher environment than products with lower operating temperature. They are exposed to considerable variation in outside temperature, vibration and they are on discontinuously."* It is understood that these applications run on other energy sources then electricity (e.g. gas) or are able to run on variable energy sources. According to Dometic, for products with higher boiler temperature, the whole cooling unit has to be redesigned.

The timeline for the substitution strategy for the different products specified by boiler temperature is depicted in Section 26.3.3.

The identity of the possible substitute is not revealed by Dometic. Dometic[1486] indicates that the alternative corrosion inhibitor "inhibitor #7" is a mixture containing an inorganic salt and stabilisers.

[1483] Op. cit. Dometic (2015a)
[1484] Op. cit. Dometic (2015c)
[1485] Op. cit. Dometic (2015c)
[1486] Op. cit. Dometic (2015c)

26.3.1 Environmental Arguments

Dometic[1487] states that a closed-loop system exists for the absorption refrigerators and the refrigerant:

> "*The products are at end-of-life recycled as other refrigerators in a step 1 process (reclaim of refrigerant) and step 2 (shredding and material separation). The total recycling rate is more than 95%.*"

According to Dometic,[1488] the disassembling of the absorption refrigerators is specified through a recycling manual[1489], which states that *"The cooling unit should be emptied by an authorized recycling company"*.[1490] Absorption refrigerators in recreational vehicles have to be removed and handled separately before shredding the complete vehicle.[1491]

Dometic[1492] explains that they have developed recycling equipment together with another company, Herco, to reclaim cooling media from absorption fridges.[1493] This equipment enables reclaiming a minimum of 95% of the refrigerant. Dometic[1494] states that the reclaimed refrigerant is to be treated as hazardous waste.

Dometic notes that at end-of-life, less CrVI is recovered then initially applied: In the formation of the very thin and tight corrosion protective layer of chromium oxide (Cr_2O_3) on the interior tube surface, CrVI is reduced to less toxic trivalent chromium (CrIII).[1495] If the layer is damaged, it will be replenished by the sodium dichromate available in the solution. Dometic[1496] estimates that "*90% of Cr(VI) is reduced to Cr(III) in the first 2-3 years of operating time. At the end of the product lifetime it can therefore safely be assumed that, more than 75% of the Cr(VI) has been consumed.*"

1487 Op. cit. Dometic (2015a)
1488 Dometic (2016a), Dometic (2016), Answers to 2nd round of Clarification Questions, submitted 13.01.2016.
1489 http://www2.dometic.com/FileOrganizer/1-international/x-environment/Environmental%20Documents/Recycling%20Manuals/English/Manual-Recycling-Hotel.pdf
1490 For the authorization of such companies, Dometic states that "an important element in this authorization is the harmonized standards that have been developed under WEEE-Labex and are now transformed into EN-standards. EN 50574 (Collection, logistics & treatment requirements of end-of-life household appliances containing volatile fluorocarbons or volatile hydrocarbons) sets up detailed requirements for the end-of-life treatment of cooling appliances including absorption fridges."
1491 Global ISDS system for car recycling: http://civd.adm.in/fileadmin/civd/images/technik/Dismantling_Manual_CIVD_for_IDIS_evo4-1.pdf
1492 Op. cit. Dometic (2016a)
1493 http://www.herco-gmbh.com/en/products/cooling-unit-recycling/ammonia-based-chillers/
1494 Op. cit. Dometic (2015a)
1495 Op. cit. Dometic (2015c)
1496 Op. cit. Dometic (2015c)

26.3.2 Socio-economic Impact of Substitution

Dometic[1497] states in its renewal request that the substitution will have an economic impact in light of the increase in direct production costs and the increase in overhead. In the context of the RoHS Directive, Dometic did not provide further detail; however, additional details are available in an application that Dometic submitted to ECHA in the application for authorisation under REACH for the use of sodium chromate as an anticorrosion agent.[1498]

26.3.3 Road Map to Substitution

As mentioned above, Dometic plans to finalize the substitution within three years and therefore applies for a renewal of exemption 9 for this duration. Dometic[1499] states that this timeline only applies to those products that are – in the opinion of Dometic – within the scope of RoHS. Dometic considers the products that are used, for instance, in the lodging industry and in private homes to fall under the RoHS Directive.

For the whole product range, Dometic[1500] plans to phase out the existing inhibitor gradually depending on application: The first products that will be placed on the market in 2018 with the substitute (i.e. CrVI-free) will be products running with electrical heater in low boiler temperature applications (140-180°C), which are typical for a minibar. To complete substitution in such units, the cooling unit needs to be re-designed and a boiler temperature management system needs to be introduced. These changes require some development and testing planned to be completed by 2018. According to Dometic[1501], the tasks already listed in bullet points under Section 26.3 have to be carried out in order to ensure reliable and safe products (field tests, redesign of cooling unit models, development of appropriate factory equipment).

The timeline for other products that Dometic considers to be outside the scope of RoHS can be found in Dometic's application for authorisation under REACH.[1502] According to Dometic[1503], the products with higher boiler temperatures need more work before the new inhibitor can replace sodium chromate because the cooling units need to be

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[1497] Op. cit. Dometic (2015a)

[1498] Dometic (2015c), Dometic (2015c), Dometic GmbH, Analysis of Alternatives and Socio-Economic Analysis, available under http://echa.europa.eu/documents/10162/0783ee3a-7de9-45ec-a72a-c1689ee49e09

Regarding the application for authorization, see also section 26.5.1.

[1499] Op. cit. Dometic (2015b): "Most of the products covered by the RoHS Directive are used in lodging industry and in private homes. Products for recreational vehicles (RV) and marine applications with absorption technology are most often specifically designed for that purpose and thus fall outside of the scope or RoHS. Several products for RV fall within the scope of the ELV-directive."

See section 26.5.5 for the discussion on the scope of the exemption.

[1500] Op. cit. Dometic (2015b)

[1501] Op. cit. Dometic (2015a)

[1502] Op. cit. Dometic (2015c)

[1503] Op. cit. Dometic (2015c)

redesigned and new safety equipment has to be included. According to Dometic[1504], "*products with higher boiler temperatures are mostly (but not exclusively) included in the RV and medical box product groups.*" Dometic[1505] explains that technical challenges arising for these product groups are also due to the more diverse operating conditions, e.g. varying ambient temperature, vibration and more frequent starts and stops.

Dometic[1506] makes a distinction within the products with higher boiler temperatures, and plans a gradual product launch from 2025 on. The complete phase out is envisaged by 2029 by Dometic.

26.4 Stakeholder Contributions

A single contribution was made during the stakeholder consultation regarding Ex. 5(b). The Test and Measurement Coalition (TMC)[1507] includes the seven leading companies in the sector representing roughly 60% of the global production of industrial test and measurement products. It is TMC's understanding that, according to the RoHS Directive, the exemptions listed in Annex III and Annex IV for which no expiry date has been specified, apply to sub-category 9 industrial with a validity period of 7 years, starting from 22 July 2017. This is also said to be explained in the RoHS FAQ.[1508] TMC, thus does not interpret the current exemption evaluation related to Exemption 9 to concern category 9 industrial equipment, for which the exemptions evaluated in the study "RoHS evaluations Pack 9" are understood to remain valid, and has thus have not provided exemption specific information.

After the consultation, other manufacturers of absorption refrigerants placing their products on the EU market were contacted in order to establish if some or all of these other manufacturers support the exemption request, or alternatively do not need the requested exemption renewal. Three manufacturers were urged to provide a statement. However, only Thetford actively provided information on their product range and substitution efforts.[1509]

Thetford stated that their product portfolio differs from Dometic: It is limited to recreational vehicle absorption refrigerators and does not include minibar applications.[1510] Thetford's absorption cooling units are manufactured in the USA. According to Thetford "*All absorption refrigerators currently on the market use sodium*

[1504] Op. cit. Dometic (2015c)
[1505] Op. cit. Dometic (2015b)
[1506] Op. cit. Dometic (2015c)
[1507] Test & Measurement Coalition (2015), Contribution by Test & Measurement Coalition, submitted 19 October 2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/General_Contribution_Test___Measurement_Coalition_package_9_exemptions_20151016.pdf
[1508] p. 26; http://ec.europa.eu/environment/waste/rohs_eee/pdf/faq.pdf
[1509] Thetford (2016a), Information provided by Thetford by Email, submitted 9 February 2016 and Thetford (2016b), Information provided by Thetford by Email, submitted 16 February 2016.
[1510] http://www.thetford-europe.com/product-category/refrigerators/

chromate as a corrosion inhibitor as far as we are aware." Thetford already indicated during the last revision in 2009 that they were in the process of starting up a research project to investigate alternatives for the substitution of CrVI.

As for the scope of the exemption and its duration, Thetford[1511] is of the opinion that RoHS is as applicable to RV specific refrigerators as it is to generic household refrigerators. Thetford argues that any extension of exemption 9 should cover all relevant applications, and allow enough time to cover substitution or elimination for all these applications.

As for end-of-life, Thetford[1512] also claims to have a closed loop system operated by third party waste management service operators so that the refrigerant is removed and treated as hazardous waste.

26.5 Critical Review

26.5.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of CrVI in various articles and uses.

Sodium chromate (CAS 7775-11-3; EC 231-889-5) is included in REACH Annex XIV in light of its being identified as carcinogenic (category 1B), mutagenic (category 1B) and toxic for reproduction (category 1B).[1513]

Dometic GmbH and Dometic Hűtőgépgyártó és Kereskedelmi Zrt. submitted an application for authorisation under REACH for:

> "*the use of sodium chromate as an anticorrosion agent of the carbon steel cooling system in absorption refrigerators up to 0.75% by weight (Cr6+) in the cooling solution*".[1514]

Dometic GmbH in Germany and Dometic Hűtőgépgyártó és Kereskedelmi Zrt. in Hungary produce absorption refrigerators in Europe and would thus not be able to use sodium chromate without an authorisation after the sunset date of this substance specified in Annex XIV as 21 September 2017.

The application of authorisation covers the whole product range of absorption refrigerators produced in Europe: minibars, refrigerators for recreational vehicles and medical cold equipment. Dometic plans to phase out sodium chromate stepwise beginning with the electrically operated refrigerators. The phase out is planned to be

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[1511] Op. cit. Thetford (2016b)
[1512] Op. cit. Thetford (2016b)
[1513] Entry No 22in Annex XIV, sunset date 21/09/2017, latest application date 21/03/2016; http://echa.europa.eu/addressing-chemicals-of-concern/authorisation/recommendation-for-inclusion-in-the-authorisation-list/authorisation-list/-/substance-rev/62/term
[1514] http://echa.europa.eu/addressing-chemicals-of-concern/authorisation/applications-for-authorisation-previous-consultations/-/substance-rev/10106/term

finalized in 2029. According to Dometic[1515], absorption refrigerators that operate with gas and therefore have higher boiler temperatures need more technical development before the new inhibitor can replace sodium chromate (e.g. re-design of the cooling units, new safety equipment).

On 1 February 2016, ECHA's Risk Assessment Committee (RAC) and Socio-Economic Analysis Committee (SEAC) published its opinion recommending the requested authorisation to be granted with a review period scheduled within 12 years.[1516] Assuming the authorisation is granted sodium chromate could still be manufactured and used in EU manufacture. In the opinion, the following condition for authorisation is noted:

> "*SEAC recommends that after the end of 2019 as described in the application, the authorisation of the use of sodium chromate is limited to the high boiler temperature product range only.*"[1516]

Assuming that the authorisation is approved, the renewal of the RoHS exemption would not be understood to weaken the protection afforded by REACH.

Entries 28, 29 and 30 of REACH Annex XVII also apply to sodium chromate. These entries require that specified substances "*Shall not be placed on the market, or used: as substances; as constituents of other substances; or in mixtures, for supply to the general public when the individual concentration in the substance or mixture*" is above a certain threshold.

Though one could argue that these entries do not restrict the presence of specified substances in articles, in which case they would not apply to the use of Dometic (since the refrigerator is an article), it is not completely clear how to interpret these restrictions. In the products at hand, sodium chromate is used as a constituent in a mixture which is enclosed within the cooling system. Though the consultants assume that the legislator mainly had in mind the provision to the public of substances and mixtures in containers that can be opened to allow use of the substance at hand, the derogations to these entries suggest otherwise. Paragraph 2 of this entry excludes some articles from this restriction, among others specifying in (c)(second item) that the restriction shall not apply to "*fuels sold in closed systems (e.g. liquid gas bottles)*". In this sense the legislator would need to confirm whether the application at hand would be restricted through these entries or not.

Chromium VI also features in entry 47 REACH Annex XVII, where the use in cement is restricted. This is not considered to be relevant for absorption refrigerators.

[1515] Op. cit. Dometic (2015c)

[1516] ECHA RAC SEAC (2016), ECHA's Committee for Risk Assessment (RAC) and Committee for Socio-economic Analysis (SEAC) (2016), Opinion on an Application for Authorisation for Sodium chromate use: The use of sodium chromate as an anticorrosion agent of the carbon steel cooling system in absorption refrigerators up to 0.75% by weight (Cr6+) in the cooling solution, Consolidated version, 1 February 2016; http://echa.europa.eu/documents/10162/5a39678c-4e9a-42bc-878c-8997c74caeba

If the ECHA RAC SEAC recommendations to grant the authorisation for sodium chromate are to be followed, and assuming that Entries 28 through 30 do not apply, it can be considered that the requested RoHS exemption renewal would not weaken the environmental and health protection afforded by the REACH Regulation. In this case an exemption could therefore be granted if other criteria of Art. 5(1)(a) apply. The option that one of the restrictions addressed above and its implications on a possible exemption are discussed below in Section 26.5.6.

26.5.2 Scientific and Technical Practicability of Substitution

Dometic provides information according to which they plan to phase-out the use of CrVI from the entire product range, starting with the products understood to be the least technically challenging. It is understood that the first products applying the substitute shall be the absorption refrigerators with low boiler temperatures running exclusively with electricity. Dometic estimates the tasks to adapt these products to take three years. Dometic is confident that it shall meet this timeline:

> *"Our tests for the substitution alternative are still positive in relation to the main part of the products covered by RoHS (low boiler temperature applications – see below). We are currently making significant investments into production equipment in order to be able to meet the time line. In parallel there are still tests ongoing.*
>
> *There is of course an existing risk that our following tests involving new production equipment and large quantities of products will fail. Should this happen we will have to renew the application to extend the exemption. However, we are very committed to the change when technically viable and given this we do not want to extend the exemption period longer than necessary."*

It is understood that the substitution in products with higher boiler temperature still needs basic evaluation and technical development. In 2015, Dometic stated that the "*validation studies of inhibitor #7 function in higher boiler temperatures are ongoing.*" The launch of first products applying the substitute in higher boiler temperature conditions is planned by Dometic for 2025. This time frame is longer than the maximum validity period possible for category 1 products under RoHS.

It further appears that other manufacturers are yet to achieve substitution in their absorption refrigerators and that they also need more time to complete the substitution tests and to achieve substitution in products to come on the market (e.g. Thetford).

To summarize, the consultants can follow that the development of substitutes has progressed, however also that implementation requires additional time in order to ensure the reliability of the substitute before it can come onto the market in absorption refrigerators.

26.5.3 Environmental Arguments

As already explored in Section 26.3.1, from information provided by Dometic, the consultants can follow that absorption refrigerators are recycled and that the cooling system with the cooling solution containing the CrVI is collected by recyclers with separate equipment.

This information suggests that possible environmental emissions related to End-of-Life (EoL) would be controlled, when the products are disposed of properly. Further information related to other environmental aspects was not provided.

26.5.4 Stakeholder Contributions

The contribution submitted by Test & Measurement Coalition raises a legal question as to the availability of the current exemption to category 9 equipment. Regardless of TMC's claims as to the availability of Annex III exemptions to sub-category 9 industrial for 7 years starting in 22.7.2017, in the case of exemption 9 the wording formulation limits its applicability to the anticorrosion agent applied in carbon steel cooling systems of absorption refrigerators. These products are understood to be a product, which as stated by the applicant fall under category 1 and not under category 9. Thus from a practical perspective, in the consultants' opinion, sub-category 9 industrial equipment would not benefit from the exemption directly.

26.5.5 The Scope of the Exemption

Dometic have requested the exemption for products that Dometic interprets to be in the scope of the RoHS Directive: These are mainly the low boiler temperature applications, where the heater is exclusively run on electricity. According to Dometic,[1517] "*most of the products covered by the RoHS Directive are used in lodging industry and in private homes. Products for recreational vehicles (RV) and marine applications with absorption technology are most often specifically designed for that purpose and thus fall outside of the scope or RoHS. Several products for RV fall within the scope of the ELV-directive.*"

Generally speaking in article 2(4)(c)the RoHS Directive excludes "*equipment which is specifically designed and is to be installed, as part of another type of equipment that it is excluded or does not fall within the scope of this Directive…*". The consultants assume that Dometic interprets the applicability of RoHS to its products on this basis. For example, where absorption refrigerators are specifically designed and are to be installed in caravans, this interpretation would mean that the equipment would be excluded from RoHS.

In this respect, Dometic[1518] states: *"a) For the 2015 sales approximately 7 % of our products designed for recreational vehicles (RV) have been sold in after-market. Remaining 93 % have been sold in B2B direct to RV producers. It should however here be*

[1517] Op. cit. Dometic (2015b)
[1518] Op. cit. Dometic (2016)

highlighted that the major sales in after-market is not to private customers. We estimate that only less than 10 % of the sales in after-market is to private customers for product replacement and as do-it-yourself installations. The vast majority of the after-market sales is to professional companies providing installation. The absorption refrigerators for RV do have the option of running on several energy sources, and the installation of gas burner systems must only be carried out by certified personnel. Furthermore, the installation of a safe exhaust system is necessary to avoid flue gases into the living compartment. Due to this the installations made by private customers are limited. b) All Dometic absorption refrigerators designed for RV have electrical functions. One or two electrical heaters are assembled for running the refrigerator when electricity is available."

Thetford as another manufacturer of absorption refrigerators in RVs, however disagrees and claims that exemption 9 applies to RV specific refrigerators as it does to generic household refrigerators.

In this respect, the consultants believe that there may be room for interpretation regarding this issue. For example, in the case of units manufactured for caravans, it is understood that most units are originally installed as part of the vehicle before its sale, whereas in some cases units are purchased separately and possibly installed by the user. To begin with, this means that the same units are available both to manufacturers of caravan vehicles as well as on the open market (i.e. available to the public), where it is not straightforward to conclude that they would only be used for their intended purpose (i.e., to be installed in vehicles).

A more important aspect however seems to be the fate of such units at end-of-life, both in the case where the unit itself reaches EoL as well as in the case that the vehicle reaches EoL. In both of these cases it is understood that the unit would be dismantled from the vehicle and transferred to EoL treatment. When this is done by a vehicle dismantling facility, it is assumed that the unit is subsequently sent directly to a suitable recycler. In parallel, when the dismantling is done by the end-user, it is assumed that the unit would be seen as EEE and would be transferred to a Waste-EEE handling facility, subsequently also reaching a suitable recycler. Though the fate in both cases may be similar, the allocation of the unit at EoL to the EEE waste stream would suggest that the scope of articles falling under the RoHS Directive may be wider than suggested by Dometic. As it is assumed that in any case articles would be sent to treatment by a recycler of other refrigeration units (i.e., EEE recycler and not ELV recycler), the consultants conclude that the RoHS restrictions should apply as their original intention was to prevent and limit the presence of certain substances in the EEE waste stream. All the more so as the RoHS Directive restricts the use of additional substances in comparison with the ELV Directive. This logic is all the more applicable to units used for medical purposes, as long as they would not be excluded for example as large scale fixed installations (see Article 4(2)(e)). This is assumed as, medical devices fall under the scope of the RoHS Directive in any case. That said, it should be noted that only medical devices falling under the scope of the Medical Devices Directives (see RoHS Article 3(21-23)) would be considered as medical devices (Cat. 8) under RoHS, with others still falling

under Cat. 1. Even if refrigeration units would be covered by these Directives, the applicability of the RoHS restrictions would only be delayed in comparison with articles of category 1.

To conclude, the consultant interprets that a wider range of absorption refrigerators would be under the scope of the RoHS Directive and would need to comply with the substance restrictions, provided they have at least one electrical function and can thus be considered as EEE according to the Article 3(1 and 2) definitions.

26.5.6 Exemption Wording Formulation

Taking into account the considerations in the scope of the exemption as discussed above and the road map for substitution as provided by Dometic, a split of the exemption is proposed in light of the stepwise approach to substitution communicated by Dometic.

The consultants understand that CrVI shall be phased out within three years in the low boiler temperature applications that are run only on electrical supply in stable and favourable ambient conditions. An exemption for such applications would thus only require a three years duration as originally requested by the applicant. The proposed split of the exemption was discussed with the applicant to ensure a precise wording.

As a criterion to distinguish the different applications, it was discussed with the applicant if the boiling temperature could be used as e.g. done in Dometic's application for authorization under REACH because the internal corrosion increases significantly with the boiling temperature. However Dometic[1519] stated that the boiling temperature varies significantly with the ambient conditions and the heat load of the cooling unit and that market control of boiling temperature would be difficult. The consultants proposed to describe the first split of the exemption via the energy source ("*absorption refrigerators designed to operate with electrical heater only*"). This is also understood to be a practicable solution from a market surveillance perspective.

Dometic[1520] then proposed a shorter duration for this split of the exemption for 2 ½ year until 1 January 2019. Though the consultants understand that Dometic assumes that this period shall suffice, possibly giving it a short termed advantage over competitors when the exemption expires, the consultants do not support this change. In the past review, industry requested to renew the exemption for additional 5 years, anticipating that substitution would be completed within this period. It is observed that the research and development of substitutes required additional time, currently leading to the request of an additional period. Dometic now request to shorten the exemption duration by 6 months. The consultants do not see this period as significant, whereas it shall provide a short termed margin for implementing substitutes, should the process be a bit longer than expected. The consultants propose to keep the original three years to ensure that substitution is reached by at least one manufacturer at this time so that a further

[1519] Dometic (2016b), Dometic (2016b), email communication, submitted 12.02.2016
[1520] Dometic (2016c), Dometic (2016c), email communication, submitted 22.02.2016.

extension of this exemption in 2019 is not necessary. However if the EU COM sees this differently, the duration could be shortened, ending on 1 January 2019.

It has to be noted that this first split of the exemption would also be in line with the recommendation of ECHA RAC SEAC[1521] where SEAC recommends the authorisation for the use of sodium chromate be limited to the high boiler temperature product range only after 2019.

As for the products with higher boiler temperatures, though the applicant has not requested a separate renewal for these articles, it is the opinion of the consultants that it is not conclusive if indeed all other articles are excluded from the scope of RoHS or not. From the additional information it is understood that substitution is underway in these articles, but expected to take a longer period. It would therefore be recommended to provide an exemption for a longer term for such applications, in order to reliably ensure substitution.

26.5.7 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

From the available information it is observed that a substitute has become available as such. However, redesign and testing of absorption refrigerators is still in process and shall require at least a few more years. The implementation of the substitute is expected to differ for various applications of the product range of absorption refrigerators (i.e., those operated only with electricly powered heaters and those operated with other sources sources of energy), depending over all on the boiler temperature. The consultants appreciate the applicant’s proposal of a shorter time frame of three years for low boiler temperature applications. However, as some products with higher boiler temperatures may fall under the scope of RoHS, a split of the exemption is proposed in order to differentiate the technical practicability of substitutes and to ensure its reliability in different applications, including where this is expected to take more than three years.

To conclude against the Article 5(1)(a) criteria:

[1521] Op. cit. ECHA RAC SEAC (2016)

- Research conducted by Dometic did not result in reliable possibilities via design changes, coatings or materials; however an alternative anti-corrosion agent has been developed.
- Establishing tThe reliability of the identified substitute needs additional time to complete further testing, the re-design of components in different models and the development of factory equipment for absorption refrigerators with a heater running exclusively on electricity in low boiler temperature applications (140-180°C).
  Substitution in other applications with a higher boiler temperature is expected to require a longer period. The time frame indicated by Dometic for these products to be launched on the market is 2025. However, exemptions for category 1 devices can only be granted for up to five years, at which time a revision of the further need of the exemption for these applications would allow evaluating whether inhibitor #7 has been successfully applied as a substitute or whether additional time would be needed.

26.6 Recommendation

It can be understood that a substitute has been discovered, however that additional time is needed to allow a phase-out of CrVI where used as anti-corrosion agent in absorption refrigerator units. This time shall allow necessary redesign of equipment and the completion of reliability testing and may differ for various units understood to be part of the product range. Assuming that the REACH authorisation requested by Dometic shall be granted and assuming that Entries 28-30 of REACH Annex XVII do not apply to sodium chromate when used as a cooling solution in the carbon steel structure of absorption refrigerator cooling units, the consultants conclude that the exemption is justified based on the Article 5(1)(a) criteria. In this case, the consultants recommend splitting the current exemption to differentiate between different products according to the time estimated to be required to complete substitution as follows:

Exemption 9	Duration*
Hexavalent chromium as an anticorrosion agent applied in carbon steel cooling systems of absorption refrigerators of applications:	
(I) designed to operate with electrical heater only, with up to 0,75 % by weight in the cooling solution; ***(II) designed to operate with variable energy sources;*** ***(III) designed to operate with other than an electrical heater***	*For Cat. 1: 21.7.2019 (three years)*

Should the REACH authorisation requested by Dometic not be granted, the RoHS exemption could only be granted until the 21.9.2017 (i.e. the sunset date specified in REACH Annex XIV) so as not to weaken the protection afforded by the REACH Regulation. In this case the consultants would recommend maintaining the current formulation as both product groups are expected to still need the exemption until this date.

Should Entries 28-30 of REACH Annex XVII apply in this case, the renewal of an exemption would weaken the protection afforded by the REACH Regulation and thus could not be granted according to Article 5(1)(a).

The consultants' do not see a need to grant the exemption to Cat. 8 and Cat. 9 equipment, as the exemption formulation clearly limits the applicability to products falling under Cat. 1. Nonetheless, as for exemptions listed in Annex III, for which an expiration date is not specified, it is understood that from a legal point of view, they shall be valid for applications of Cat. 8 and Cat. 9 for up to 7 years. This validity period is understood to start from the dates specified in Article 4(3), from when these categories come into the scope of the Directive. Thus, if from a formal-legal point of view the original formulation of the exemption needs to remain valid for these categories for the specified duration, the following formulation would be recommended:

Exemption 9	Duration*
***(III)* Hexavalent chromium as an anticorrosion agent of the carbon steel cooling system in absorption refrigerators up to 0,75 % by weight in the cooling solution**	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat 9 industrial: 21 July 2024

26.7 References Exemption 9

Dometic (2015a), Original Application for Exemption Renewal Request, submitted 20.01.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_9/9_150120_RoHS_V_Application_Form_Dometic.pdf

Dometic (2015b), Answers to Clarification Questions, submitted 13.08.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_9/20150813_Ex_9_Dometic_replay_on_questions.pdf

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27.0 Exemption 15“Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages”

Declaration

In the sections that precede the “Critical Review”, the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

ASIC	Application specific integrated circuit
BGA	Ball Grid Array
C4 wafer bumps	Controlled collapse chip connection wafer bumps
DNP	Distance from neutral point
DSP	Digital signal processing (or processor(s))
FCOL	Flip chip on lead (frame)
FCP	(Integrated) flip chip packages
FPGA	Field programmable gate array
FTEOS	Fluorinated tetraethyl orthosilicate
ILD	Interlayer dielectric
PC CPU	Personal computer central processing unit
RoHS 1	Directive 2002/95/EC
RoHS, RoHS 2	Directive 2011/65/EU (recast RoHS Directive)
UBM	Under bump metallization

27.1 Description of the Requested Exemption

Exemption 15 is currently listed in Annex I of the RoHS Directive with the following wording:

> *"Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages"*

Intel et al.[1522], a consortium including producers and users of semiconductors and their associations, apply for the continuation of exemption 15 with restricted scope for the maximum five year validity period with the following wording:

> *"Lead in solders to complete a viable electrical connection between active component(s) and the carrier within integrated circuit flip chip packages with at least one of the following characteristics:*
>
> - *Greater than or equal to 90 nm semiconductor technology node*
> - *Die size greater than or equal to 300 mm² in any semiconductor technology / node (including stacked die)*
> - *Stacked Die Packages using interposers greater than or equal to 300mm²*
> - *High current products (Rated at greater than or equal to 3amps) that use smaller package designs (With die sizes less than 300mm²) incorporating the flip chip on lead frame (FCOL) interconnect."*

27.1.1 Background and History of the Exemption

The exemption was added to the Annex of RoHS 1 in 2005 after a review of the related exemption request[1523] with an expiry date in 2010. The exemption was reviewed in 2008/2009 again, under RoHS 1. The consultants recommended to extend the exemption's validity until 2014, the maximum allowed validity period for exemptions under RoHS 1. Exemption 15 was transferred to Annex I of RoHS 2, and the maximum validity period was extended until July 2016. Since Intel et al.[1524] applied for the renewal of the exemption, it has become due for review again.

[1522] Intel et al. 2015a "Request for continuation of exemption 15, document "15_12-01-15_WG15_Exemption_Extension_Dossier_-_Final.pdf": Original exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_15/15_12-01-15_WG15_Exemption_Extension_Dossier_-_Final.pdf

[1523] (Paul Goodman December 2004) *Technical adaptation under Directive 2002/95/EC (RoHS) - Investigation of exemptions: Final Report*, with the assistance of Philip Strudwick, Robert Skipper, ERA Report 2004-0603, http://ec.europa.eu/environment/waste/weee/pdf/era_technology_study_12_2004.pdf

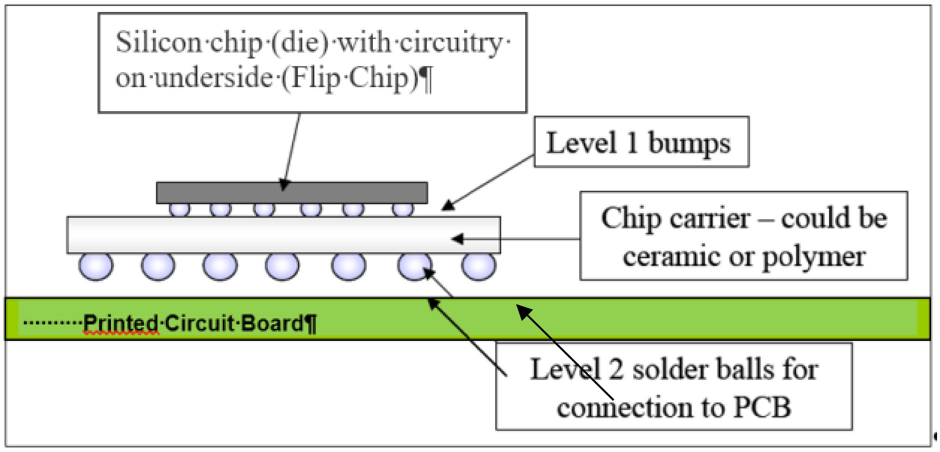
[1524] Op. cit. Intel et al. 2015a

27.1.2 Technical Description of the Requested Exemption

The technical background of the exemption was described in detail in the 2008/2009 review[1525], from which the most important aspects are copied below.

The exemption in its current wording allows the use of leaded solders for level 1 interconnects: the bumps and the solders used to attach the die to the chip carrier.

Figure 27-1: Outline of a flip chip package

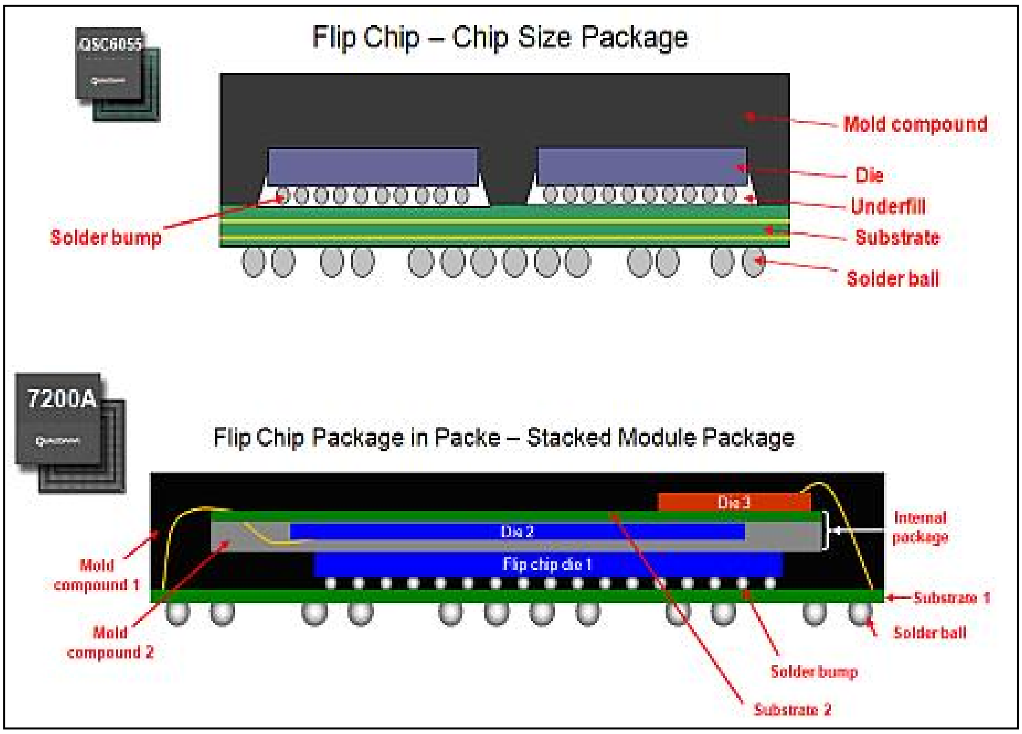


Source: Paul Goodman et al. in Gensch et al.[1526]*, modified*

[1525] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf

[1526] Ibid.

Figure 27-2: Schematic views of complex flip chip packages



Source: Qualcomm in Gensch et al.[1527]

The flip chip and the chip carrier together form the flip chip package (FCP), as shown in Figure 27-1. These FCPs can be very complex, as shown in Figure 27-2, with different die sizes and die thicknesses.

For the level 2 interconnects, lead-free solders can be used. For level 1 interconnects, different solders are applied:

- High melting point solders with 85% and more of lead (e. g. 97%Pb3Sn, 90%Pb10%Sn);
- Lead-free solders, such as SnAg, Sn3.5%Ag0.7%Cu (SAC);
- gold, copper or gold tin; or
- eutectic solder (63%Sn37%Pb).

The solders used on level 1 in the flip chip connections must be:

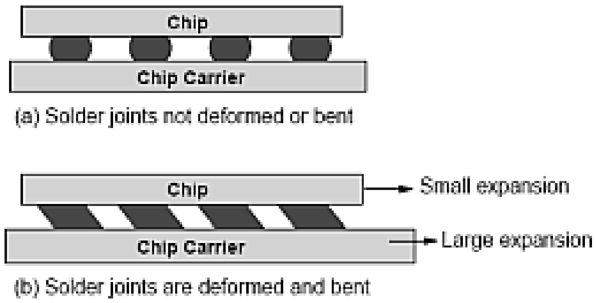
- resistant to electromigration failure at the extremely high current densities required;
- able to create a solder hierarchy that allows staged assembly and rework of components in the manufacture process; and

[1527] Ibid.

- have high ductility to reduce thermo-mechanical stress (Figure 27-3) in under bump metallurgy (UBM) structures in particular in larger dies.

Figure 27-3: Effects of thermomechanical stress in FCP

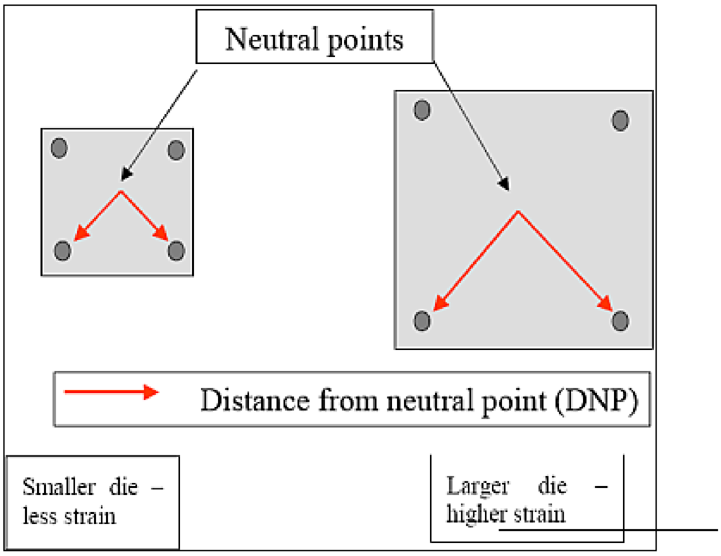
Material	TCE ppm/°C
Silicon	~ 2.5
Ceramics	~ 7
Polymer carriers and PCBs	~ 14



Source: Paul Goodman et al. in Gensch et al.[1528]

The thermal mismatch due to differences in the coefficient of thermal expansion (TCE) of the various materials increases with growing die diagonals. The effects of the TCE become more effective in larger packages. The thermal stress increases with increasing distance of the bumps from the centre of the die (distance to neutral point, DNP), and the most distant bumps thus contribute most to the mechanical stress on the die as illustrated in Figure 27-4.

Figure 27-4: Increasing thermomechanical stress with increasing DNP



Source: Intel et al.[1529]

[1528] Ibid.
[1529] Op. cit. Intel et al. 2015a

A more detailed technical description of the exemption is also available in the 2008/2009 review report[1530] and in the applicant's exemption request.[1531]

Intel et al.[1532] state that currently lead solders are still required for those FCP listed in their new wording proposal for exemption 15.

27.1.3 Amount of Lead Used Under Exemption 15

Intel et al.[1533] estimate the current amounts of lead entering the EU due to exemption 15 at around 900 kg per year. Table 27-1 details the type of devices, worldwide (WW) shipments, and calculated lead placed on the EU market in 2014. The 2008 lead usage estimates are included for reference.

Table 27-1: Shipments of FCP in various types of EEE

Device type	Average Bumps per device in 2014	WW shipments (Million Devices)		Mass of Pb(kg) into EU Markets	
		2008	2014	2008	2014
Server/ Mainframe	10,000	64	40	335	349
PC CPU	3,000	277	0	725	0
Games	3,500	53	0	162	0
DSP	450	23	2.5	10	1
ASIC/ Switch mix	2,000	162	22	353	38
FPGA	2,000	17	2.9	59	5
Graphics Processor	2,000	174	258	607	450
Routers	4000	36	15	63	52
TOTAL				**2315**	**896**

Source: Intel et al.[1534]

Intel et al.[1535] based the lead usage calculation on the following assumptions:

[1530] Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009), page 176 et sqq.
[1531] Op. cit. Intel et al. 2015a
[1532] Ibid.
[1533] Ibid.
[1534] Ibid.
[1535] Ibid.

14) An average bump pitch (distance between the bumps) of 150 um;
15) Eutectic tin/lead solder bumps (high Pb bumps, negligible volume);
16) Average bump diameter of 50um;
17) 30% of worldwide shipments are placed on the EU;
18) Volume estimates as obtained from Techsearch International.

Intel et al.[1536] claim that the overall lead usage for this exemption is estimated to have decreased by 61 % since 2008, and it can be seen that PC processors and gaming devices have successfully eliminated leaded solders. The predominant remaining uses of leaded flip chip devices are in servers and graphics processors. Within these devices there is a trend of decreasing dependence on the use of leaded solder. Graphics processor volume increased between 2008 to 2014 from 174 million to 258 million units, while lead usage decreased from 607 kg to 450 kg. The number of server devices using lead FCP is estimated to have decreased from 64 million devices to 40 million devices. Despite the decreased component count, there was a small increase in lead usage in server products due to a 67 % increase in the number of level 1 lead-containing bumps in these devices. The remaining devices using leaded flip chip attach are typically very large chips and/or long lived older integrated circuit technologies for which lead-free designs could not be reliably produced.

Intel et al.[1537] highlight that the electronics industry has demonstrated a strong commitment to develop new lead-free flip chip devices as new technologies with adequate reliability become available. The remaining devices manufactured with lead solders for flip chip attach are expected to continue to decline over the next five years as those products are replaced with newer technology.

Intel et al.[1538] add that, excluding the Flip Chips On Lead frame (FCOL), only a limited number of Pb containing components are in production today, and the volume is in a sharp decline. Even though exact numbers are proprietary, Table 27-2 lists total amounts of lead in 2012, and projected for 2014 and 2015, assuming 2012 volumes of 1,000,000 components containing in average 1.25 mg of lead in flip chips.

[1536] Ibid.
[1537] Ibid.
[1538] Ibid.

Table 27-2: Amount of Lead in FCP other than FCOL

Year	# of Units	Total Amount of Lead
2012	1,000,000	1.25 Kg
2014	200,000	0.25Kg
2015	150,000	0.19Kg

Source: Intel et al.[1539]

Intel et al.[1540] fully expect these volumes to continue to drop as the need to support legacy end products decreases to end of life. As can be seen from the indicative numbers in Table 27-2 the total amount of lead in kilogram for all components is very small. These products are only being supported to meet strict customer design and safety requirements already in place before 2016.[1541]

27.2 Stakeholders' Justification for the Continuation of the Exemption

According to Intel et al.[1542], the following flip chip products cannot meet the long-term reliability requirements with lead-free solder bumps on the dies and therefore need to remain in the scope of the continued exemption 15:

- Flip chip products with transistor gate lengths of 90 nm and longer (older FCP);
- Flip chip products with die sizes of 300 mm² or larger (large FCP);
- Flip chip products with interposers for stacked dies with sizes of 300 mm² or larger (large interposers);
- Flip chips on lead frame packages (FCOL) with rated currents of 3 A or more (high current FCP).

FCOL, according to Intel et al.[1543,1544], consist of products with leads[1545], leadless[1545] and laminate products. Leadless products can be built with lead frames, but the lead frame does not project outside of the package, similar to a ball grid array package.

1539 Ibid.
1540 Ibid.
1541 Ibid.
1542 Ibid.
1543 Ibid.
1544 Intel et al. 2016a "Answers to questionnaire 2, document "Exe-15_Questionnaire-2_Intel-et-al_2016-01-18 Final Response.docx", received by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel,

Intel et al.[1546] [1547] put forward that flip chips are commonly used in long life, high reliability applications that remain in the field for over 20 years and require continuous availability for replacement parts. Examples are server farms and telecommunication infrastructure. Legacy flip chip devices and many large die devices are older products that have declining volumes year-on-year making it difficult to justify an all-layer and material redesign. Removing these products from the market would create long supply gaps with minimal impact on the amount of lead in the EU market. Pin-for-pin compatibility replacements with devices on more recent silicon technology nodes are not available, potentially resulting in premature replacement of EEE due to lack of repair parts. The elimination of the flip chip lead solder exemption for the applications in this request would result in non-availability of mission critical components.

27.2.1 Lead in Solders of FCP with Large Technology Nodes

27.2.1.1 Technical Practicability of Lead-free Solder Use in FCP

Intel et al.[1548] present Figure 27-5 to explain the persisting problems with lead-free solders in FCP with technology nodes larger than 90 nm.

on 6 February 2016: Answers to second questionnaire" unpublished manuscript, Answers to second questionnaire

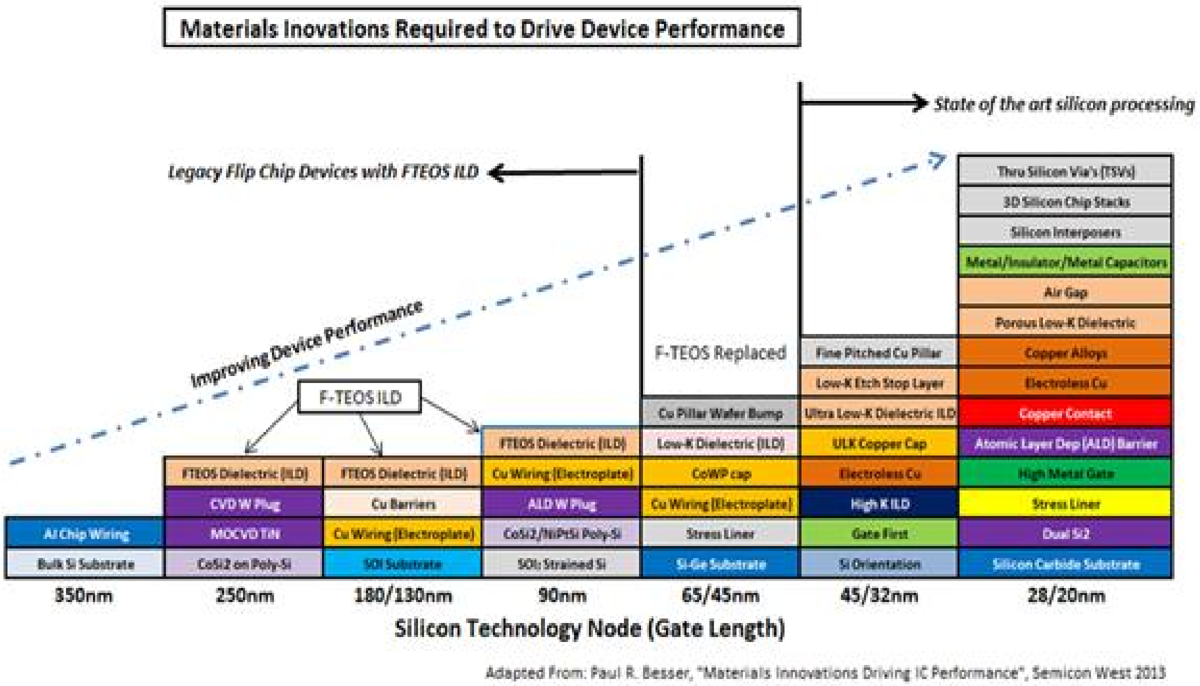
[1545] „lead" does not refer to the chemical element Pb, but to the carrying structure

[1546] Op. cit. Intel et al. 2015a

[1547] Op. cit. (Intel et al. 2016a)

[1548] Op. cit. Intel et al. 2015a

Figure 27-5: Overview of the development of FCP



Source: Intel et al.[1549]

Intel et al.[1550] report that silicon technology nodes with transistor gate lengths longer than 250 nm historically used aluminium interconnects in the wafer processing backend. With further technological advancement, industry had to migrate to copper interconnects due to device performance expectations and increased circuit densities. Devices on the 250 nm to 90 nm technology nodes converted to a common low dielectric constant film (low-k) fluorinated tetraethyl orthosilicate (FTEOS). FTEOS made copper interconnects possible. At the time, FTEOS was a breakthrough in materials engineering and from an electrical perspective it reduced capacitance in the silicon wafer backend dielectric stack. Reducing the resistance of interconnect wiring and the capacitance of the interlayer dielectric (ILD) allows for higher device clock speeds. Dielectric capacitance was significantly reduced with FTEOS when compared to the dielectrics used earlier in the semiconductor industry. The porous nature of the film is what reduces the capacitance. FTEOS offered improved electrical performance, however, at the expense of film mechanical strength.

Intel et al.[1551] state that the low mechanical strength of FTEOS makes it susceptible to dielectric fracturing beneath the under bump metallization (UBM) on the silicon chip

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[1549] Ibid.
[1550] Ibid.
[1551] Ibid.

(die) with lead-free wafer bumps. This does not occur with lead-containing C4 (controlled collapse chip connection) wafer bumps as illustrated in Table 27-3.

Table 27-3: Failure rates of lead-free and lead C4 bumps in tests

Accelerated Stress	Process	Cycles	Temp Range (°C)	Rate of Temp Change °C/Min (Arbitrary Units)	Control Group Leaded C4 White Bumps (% Fail Units)	Pb-free C4 White Bumps (% Fail Units)
Level 0	After Die Attach	1	STD Pb-free C4 Reflow Temp	2.0 x "Y"	0%	0%
Level 1	MSL3 Reflow	3	STD Pb-free C4 Reflow Temp	3.5 x "Y"	0%	15%
Level 2	Air-to-Air Temperature Cycling (AATC)	*5	Covers Industrial and Commercial Requirements	"Y"	0%	100%

Source: Intel et al. [1552]

Intel et al. [1553] explain that lead-free wafer bumps are significantly less ductile than those containing lead, and the observed failure mode mechanism is driven by mismatch in the coefficients of thermal expansion between the lead-free bump and the FTEOS dielectric. Fracturing of the dielectric with Pb-free wafer bumps is commonly referred to as "ghost" or "white" bumps due to the way they appear in acoustic imaging. Not only can the failure mode reduce assembly yields, it can also adversely impact product reliability. The failure mechanism may not be caught when a unit goes through component assembly and final test. Compromised units that ship are at high risk of failing during the customer's board level assembly process or in the field. This failure mode does not occur with wafer bumps that contain lead because leaded bumps can absorb the stress associated with the coefficient of thermal expansion mismatch between the silicon chip and the substrate to which the solder attaches.

Intel et al.[1554] explain that more advanced silicon technology nodes, with transistor gate lengths of 65 nm and smaller, completely replaced FTEOS. These replacement technologies are designed to address the stress levels associated with lead-free die solders so that lead solders are no longer required for those FCP unless they use large dies or large interposers of 300 mm² size or larger.

27.2.1.2 Redesign of Older FCP

Intel et al.[1555] focused their lead-free efforts on package redesigns that have increased the overall component's diameter, thickness and/or ultimate mass compared to the previous Pb containing packages. Since the newer package solutions cannot maintain the form, fit and function of these older FCP, they are not drop in replacements. To maintain form, fit and function, changes cannot be ones that:

- modify the devices height, width or length;

[1552] Ibid.
[1553] Ibid.
[1554] Ibid.
[1555] Ibid.

- change how the connections from the device to the printed circuit board fit together;
- imply significant material changes that can affect the functionality of the device in its current package design.

Going from lead to a non-lead solution is a major material change, and it would also have severe implications on the related processes. Intel et al.[1556] explain that replacing the FTEOS film with another dielectric film in older FCP to enable the substitution of lead would require the entire backend wafer process integration to be re-engineered (e.g. dry etch; photolithography; film deposition; dielectric and copper polishes). Any change in the existing process architecture and materials, however, would cause shifts in electrical characteristics that would force the device to have to be redesigned. Old FCP are, however, products that have declining volume year-on-year making it difficult to justify an all-layer and material redesign.

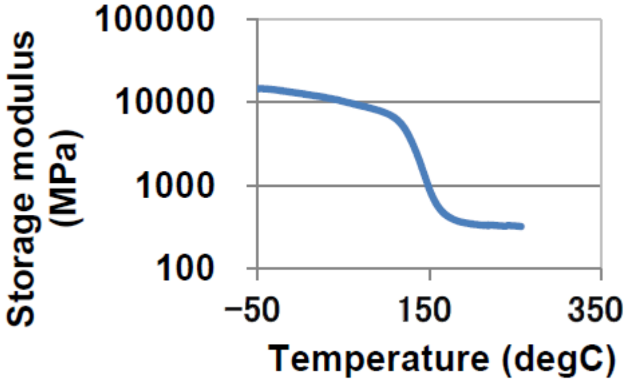
27.2.2 Use of Lead Solders in FCP with Large Dies and/or Large Interposers

27.2.2.1 Use of Lead Solders in FCP with Large Dies

Intel et al.[1557] state that even the advanced silicon technology nodes with 65 nm technology nodes and smaller cannot accommodate the stress levels associated with lead-free die solders when the die size is 300 mm² or larger. According to Intel et al. [1558] such large dies are also still used in the advanced technology nodes. Intel et al. [1559] explain that the package size increases with die size and larger packages impart significantly more strain energy onto the die and solder bump (c.f. Section 27.1.2 on page 585). Large dies with lead-free bumps require a high glass transition temperature (T_g > 120 °C) underfill to prevent solder bumps from cracking during stress tests. Figure 27-6 shows a typical high T_g underfill with a large modulus (> 10 GPa) at low temperature (< 0 °C).

[1556] Ibid.
[1557] Ibid.
[1558] Op. cit. (Intel et al. 2016a)
[1559] Op. cit. Intel et al. 2015a

Figure 27-6: Dynamic mechanical analyses of underfiller with high glass transition temperature



Source: Intel et al.[1560]

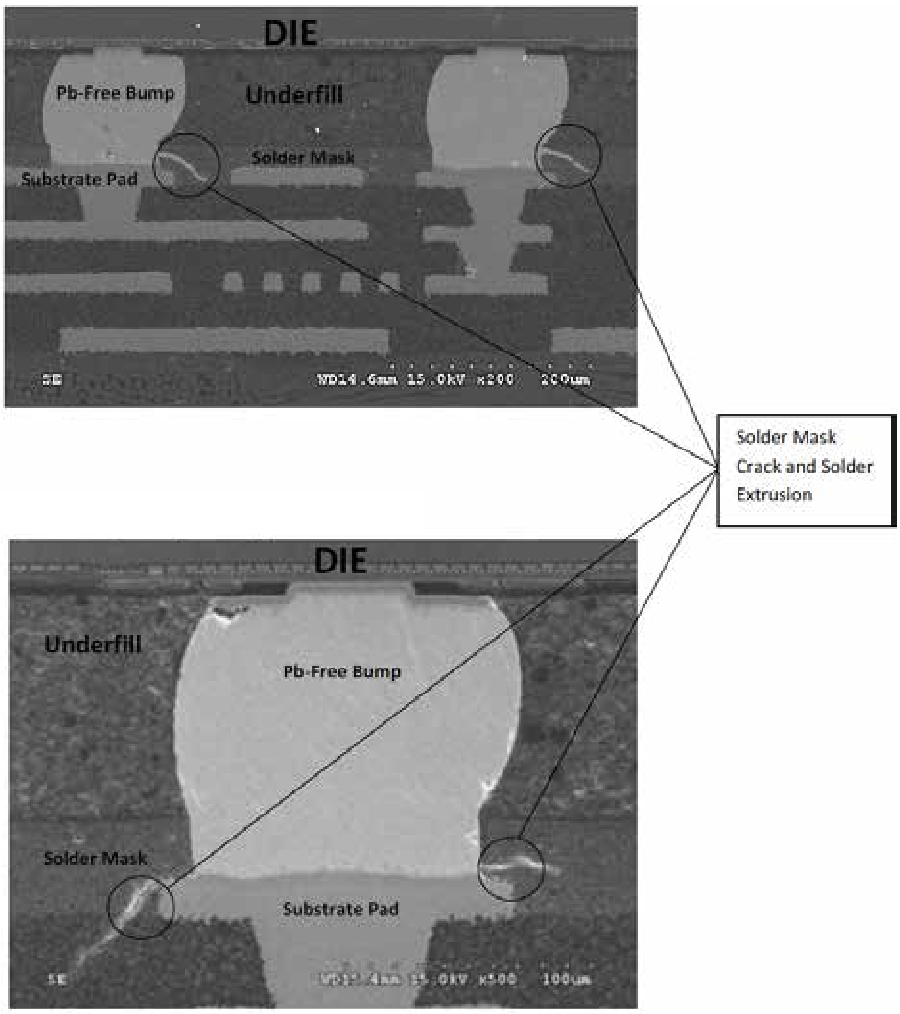
Intel et al. [1561] interpret from the Figure 27-6 stress-strain curve that the storage modulus increases as the temperature decreases, which means that the high Tg underfill becomes very rigid at lower temperatures. The loss of flexibility places strain on the substrate solder mask. The solder mask layer is an organic polymer used for its insulating properties to prevent solder migration. The solder mask ensures a proper connection is made between the solder bump and substrate pad. Figure 27-7 shows that during reliability temperature cycling from -40 °C to -50 °C for large die the solder mask will crack due to the high stress imposed by the high Tg underfill.

Intel et al[1562]. conclude that the failures shown in Figure 27-7 demonstrate that the additional strain from large die increased the failure rate for the solder mask, which adds another variable to the equation in developing a solution to use lead-free solders or any substitute interconnection technology for large dies. Research is still ongoing and more time is needed to find a reliable lead-free solution.

Consequently, lead-free die solder bumps are not compatible with large die sizes even in the most advanced silicon technologies. Large dies with lead-free die solder bumps near the edges and corners will deflect much more thermal and mechanical stress during fatigue cycling which can cause brittle fracture in lead-free bump alloys.

[1560] Ibid.
[1561] Ibid.
[1562] Ibid.

Figure 27-7: Solder mask cracks and solder extrusion in large die FCP



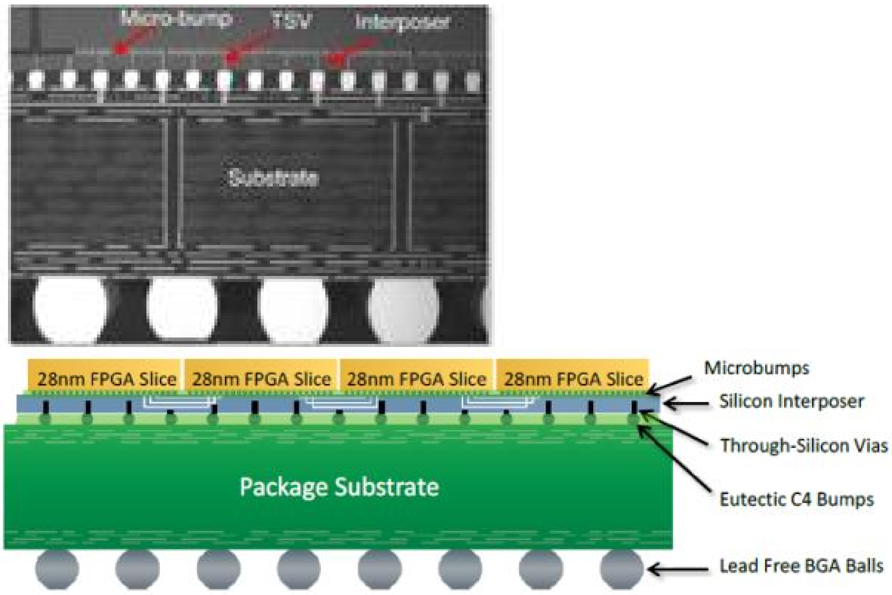
Source: Intel et al.[1563]

27.2.2.2 Use of Lead in Stacked Die Packages with Large Interposers

Interposers are used in stacked die flip chip packages as illustrated in Figure 27-8.

[1563] Ibid.

Figure 27-8: Stacked die FCP



Source: Intel et al.[1564]*; TSV: through silicon via*

Intel et al. [1565] explain that the schematic side view of a stacked silicon flip chip package, in Figure 27-8, contains four active silicon dies connected to each other through a passive interposer with through silicon via (TSV) using micro-bumps. In this type of package, any number of active dies can be assembled on the interposer and can then be connected to an organic package with C4 bumps. A capillary underfill is used to fill the gap between the micro-bumps and interposer, which helps in reducing the stress in micro-bumps. C4 bumps are created on the interposer backside, which are connected to a package substrate. A second layer of C4 bump capillary underfill is used to fill the gap between the interposer, C4 bumps and the organic package.

Intel et al.[1566] claim that lead-free solders cannot be used with interposers of 300 mm² size and larger. Upon further investigation whether the use of alternative interposers could solve or mitigate this problem, Intel et al.[1567] specify that there are two types of interposers in use:[1568]

- **Silicon interposers**: Silicon interposers are made with standard un-doped wafers, which have extremely high density of connectivity, i.e. more than

[1564] Ibid.
[1565] Intel et al. 2016d “Answers to questionnaire 4, document "Exe_15_Questionnaire-4_Intel-et-al_Answers_2016-02-29.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel, on 9 March 2016: Fourth questionnaire” unpublished manuscript,
[1566] Ibid.
[1567] Ibid.
[1568] Ibid.

200,000 connections across two adjacent dies. The silicon interposers are thinned and use through silicon vias (c.f. Figure 27-8).

- **Plastic interposers** of many types: Plastic interposers tend to be high density (few hundreds to thousand connections between the dies) and higher cost plastic packages or board technology. They are used as a space transformer to connect to a much lower density and lower cost package board material.

Intel et al.[1569] say that plastic interposers are not suitable for products that require high bandwidth and extremely large connectivity (>10,000 connections) between the two adjacent dies, like for example in flip chip grid array products. The use of interposer materials other than silicon is not feasible because only the silicon processing techniques enable such a high connectivity between the dies.

According to Intel et al.[1570], interposers other than silicon may be used to manage the mechanical stress risk from thermal expansion mismatches between a silicon die product and the plastic package. While lead solders may be used to mitigate the mechanical stress, there are alternative solutions as well. The comprehensive co-optimization of design, materials, assembly process, system integration, handling and assessment of the use environment facilitate the use of lead-free solders even with larger plastics interposers while silicon interposers of 300 mm² and more still require the use of lead solders like the larger silicon dies.

Intel et al.[1571] therefore confine that the exemption is only required for stacked die FCP with silicon interposers of 300 mm² and larger.

27.2.3 Lead in Solders of High Current FCOL

Intel et al.[1572] explain that FCP with high currents of 3 A and more may use dies smaller than 300 mm² incorporating the flip chip on the lead frame (FCOL). The FCOL design moved from traditional wire bond material sets to flip chip package types. Benefits according to Intel et al.[1573] are

1. Reduced package size;
2. Decreased package parasitic current, which is a direct gain in electrical performance;
3. Higher current capabilities.

The higher current capabilities of the FCOL packaged products expand the range of applications originally designed for cell phones and mobile devices to applications such

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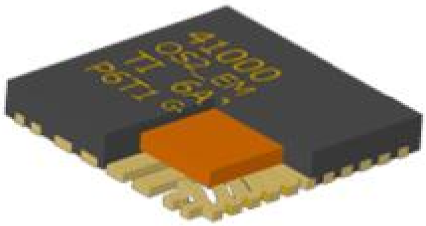
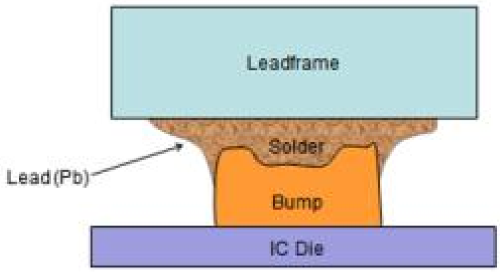
[1569] Ibid.
[1570] Ibid.
[1571] Intel et al. 2016e "Answers to questionnaire 5, document "Exe_15_Questionnaire-5_Intel-et-al_2016-03-13.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel et al., on 19 March 2016: Answers questionnaire 5" unpublished manuscript,
[1572] Op. cit. Intel et al. 2015a
[1573] Ibid.

as automotive and electronics in general. Figure 27-9 illustrates principle designs of FCOL.

Figure 27-9: Example of FCOL





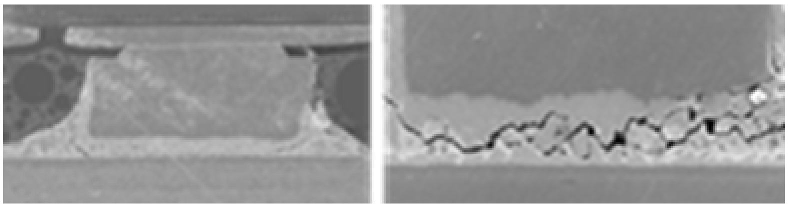
Source: Intel et al.1574

Intel et al.[1575] [1576] state that FCOL packages can be made with the lead[1577] in a ball grid array package or in a lead[1577] frame package. Both require lead (Pb) usage for the same technical reasons such as mechanical integrity, current carrying capability and stability during high temperature reflow. FCOL packages are assembled on a Pb-free profile and the Pb internal solder joint using a 60 % Pb solder does not melt during the secondary 260 °C assembly process. By using the Pb internal solder joint, fatigue resistance to thermal cycling is much greater and resists cracking where Pb-free solutions currently fail. The high current on the bumps that connect the die to the lead frame and the mechanical stress from the CTE mismatch between silicon and copper require the use of lead solders. Lead handles higher mechanical stress better than Pb-free solutions. For the mechanical stress induced within the FCOL package between the copper pillars and the lead frame, the Pb solder solution remains the one capable of meeting the minimal thermal stress requirements.

According to Intel et al.,[1578] working with Pb-free solutions in FCOL products with large copper posts results in fractured joints created during thermal cycling reliability testing, as shown in Figure 27-10.

[1574] Op. cit. (Intel et al. 2016a)
[1575] Ibid.
[1576] Op. cit. (Intel et al. 2016e)
[1577] The “lead” does not refer to the chemical element lead (Pb), but to the carrying and connecting structure in the FCP
[1578] Ibid.

Figure 27-10: Fractured solder joints in FCOL FCP



According to Bastow,[1579] tin, the main constituent of most solders and in particular in lead-free solders, has a strong affinity for alloying with precious metals such as gold. Studies indicate that 63Sn/37Pb at 200 °C (392°F) will dissolve one micron (~40 micro-inches) of gold. As tin reacts with gold, a brittle Au/Sn intermetallic forms. When the concentration is high enough, these intermetallics have a deleterious effect on the thermal fatigue characteristics of the joint, and make it susceptible to fracture during thermal cycling.

Bastow[1580] advises for tin-bearing solders in applications with gold-plated materials to keep the gold layer thin, < 0.38μ (15 micro-inches), thereby reducing the concentration of Au/Sn intermetallics that can form. However, many applications such as optoelectronics packages and defense/space electronics call for thicker gold metallizations. In such scenarios, in which the need for reliability is high, tin-bearing solders are not appropriate.

Bastow[1581] states that unlike tin, indium has a much lower affinity for precious metals and dissolves gold at a rate 13 to 14 times slower than tin. Also, in devices with operational temperatures below 125 °C (257°F), the intermetallic phase that forms between indium and gold is of a much more compliant and ductile nature, and is not susceptible to embrittlement. Therefore, the family of In/Pb solders is beneficial when soldering against thick gold film metallisations. The In/Pb alloys are a solid solution system in which the liquidus and solidus temperatures are close for all compositions (near-eutectic at all compositions). The indium-lead system offers alloys of varying melting points, with indium-rich compositions having a lower melting range, and the lead-rich compositions having a higher melting range. For example, 70In/30Pb has a melting range of 165 to 175 °C (329 to 347°F), and 81Pb/19In has a melting range of 260 to 275 °C (500 to 527°F).

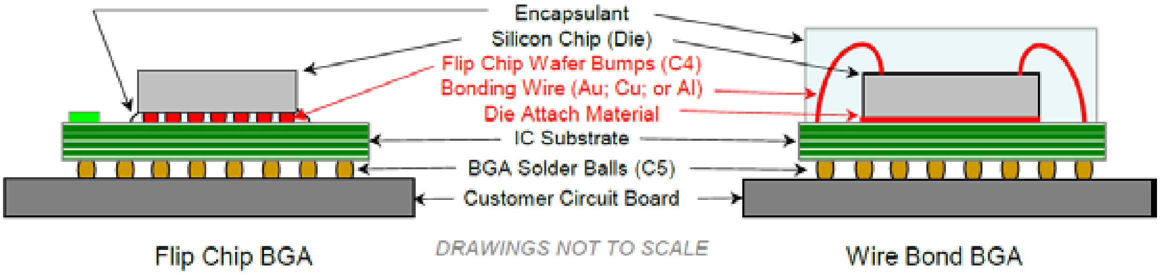
[1579] Eric Bastow, Indium Corp. of America, Utica, New York "Solder Families and How They Work, e-mail: ebastow@indium.com; document referenced by Intel et al. 2015e" unpublished manuscript,
[1580] Ibid.
[1581] Ibid.

Intel et al.[1582] conclude that Pb-based solders have both the creep properties with the highest ability to manage stress as well as achieving the needed current density in high current FCP.

27.2.4 Elimination of Lead in FCP

Intel et al.[1583] explain that FCP were developed from wire bonded BGA. Figure 27-11 shows a comparison between a FCP and a wire bonded BGA.

Figure 27-11: Comparison of FCP and wire-bonded BGA



Source: Intel et al.[1584]

According to Intel et al.,[1585] the lead-containing flip chip bumps replace the bonding wires, but also the die attach material, which is a lead-containing solder (high melting point solder with at least 85 % of lead as exempted in the current exemption 7a). Even if wired bonded components could replace FCP, such a replacement would actually not eliminate the requirement to use lead.

In terms of performance, Intel et al.[1586] state that consumers have expected improvements in both computing power and processing speed (i.e. higher clock rates) over time. Transistor miniaturization and reductions in electrical resistance within semiconductor chips were required to accomplish this. Reduced electrical resistance was achieved in part by minimizing the interconnect wire length between the chip and the package. A repercussion of higher clock rates is increased power consumption by the chip, which the packaged device must dissipate. Flip chip packaging was implemented to facilitate higher clock rates and heat dissipation. For instance, microprocessors that clock between 1.4 GHz and 3.8 GHz must dissipate between 50 and 165 Watts of power over a very small area. Achieving device performance like this is not possible with wire bonding.

[1582] Op. cit. Intel et al. 2015a
[1583] Ibid.
[1584] Ibid.
[1585] Ibid.
[1586] Ibid.

27.2.5 Other Stakeholder's Contribution

Infinera[1587], a provider of Intelligent Transport Networks (long life and high reliability infrastructure equipment, RoHS Cat. 3) contributed to the stakeholder consultation. Infinera states two key issues that challenge manufacturers of long-lived, high reliability Category 3 infrastructure equipment (like Infinera):

- Relatively short production lifecycles of leading edge semiconductor process technology; and
- Relatively low volume of semiconductor devices designed and built on such process technology.

Infinera's end-to-end packet-optical portfolio is designed for long haul, subsea, datacenter interconnect and metro applications. Infinera state that thier unique large-scale photonic integrated circuits enable innovative optical networking solutions for the most demanding networks.

Infinera[1587] would prefer to keep the current wording of Exemption 15 but, should the wording of Exemption 15 be changed, recommends the exemption expiration "grace period" be extended from the 12-18 months as defined in Directive 2011/65/EU, Article 5, paragraph 6, to a minimum of 36 months.

Ultimately, Infinera[1587] believes there will be little actual difference in terms of direct environmental impact between the original wording and the technically justifiable proposed revision as recommended by the dossier, given the amount of lead contained in typical application specific integrated circuits (ASICs). However, the financial and time impact on the customers of the semiconductor industry will be significant as manufacturers with end of life inventories are suddenly unable to use them unless the Commission extends the expiration date from 12 to 18 months after the date of the decision to at least 36 months after the date of the decision, as recommended above. This will enable a smoother ramp-down of volume production and enable customers to qualify and transition to replacement technologies.

Infinera[1587] believes that 36 months is a far more reasonable timeframe for manufacturers to assess, justify, and fund a project to re-design/re-engineer an ASIC, receive first silicon, test and evaluate it in products, evaluate its reliability, go through customer acceptance qualifications and cut it into volume production. Risk assessments of ASICs and other sole-sourced components always lead to extraordinary redesign costs or difficulties with resource allocation, and tend to result in timeline requirements as set forth here:[1587]

[1587] Infinera 2015 Corp. 2015 "Answer to consultation questionnaire, document "Ex_15_Infinera_Comments_on_Extension_10-15-2015.pdf": Answer to consultation questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_15/Ex_15_Infinera_Comments_on_Extension_10-15-2015.pdf

1) Assessment of alternatives: 2 months – this requires obtaining design engineering resources, taking them off current projects, and thereby delaying, new product development (which has a time-to-market cost to the manufacturer). It can therefore take longer than 2 months based on resource availability;
2) Developing and justifying a budget and resource allocation: 1 month;
3) Engineering to tape-out (i.e. design, design verification, sending the design to the foundry): 3-6 months;
4) Receipt of first Silicon: 3-4 months;
5) Functional evaluation and testing: 1-2 months;
6) Reliability evaluation: 3-4 months (may be simultaneous with functional evaluation and testing);
7) Customer review and acceptance: 3-5 months;
8) New component ramp to volume: 3-5 months;
9) Cut-in to revised finished good equipment, ramp to volume: 1-3 months.

Infinera[1587] believes [...] *"a minimum 36-month post-decision timeframe will enable an adequate reduction of business and reliability risks of either transitioning an ASIC or other active device from an existing technology to a replacement technology or customer transition from an existing product to a new product which does not incorporate components using Exemption 15."*

27.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

According to Intel et al.,[1588] the use of lead-free solder bumps in flip chip interconnects continues to be a challenge. Reliability concerns are well documented with the use of lead-free solders because they are less ductile than lead solders. This causes the lead-free solders to crack under stress and increases the likelihood for failures during the product life cycle. Preventing lead-free solder cracks requires additional engineering to improve the thermal and mechanical fatigue life of the solder joints. The primary solution is a load-transfer from the solder to an underfill encapsulant. The residual stress from the underfill can cause other material failures, which most commonly include dielectric crack, delamination, or die crack. Each component must be redesigned and tested several times to obtain the correct formulation needed to protect each layer and the solder joints.

Intel et al.[1589] state that alternatives are readily available for new silicon wafer fabrication technologies and small die sizes. These alternatives typically use copper studs on the die and tin-silver or tin-silver-copper solder on the substrate. These lead-free solders are more rigid than the lead-containing flip chip solder, introducing more stress on the

[1588] Ibid.
[1589] Ibid.

products. For older technologies, large die sizes, and large interposers for flip chip stacked die this additional stress ultimately results in an unacceptably high product failure rates. Also for FCOL, industry is working on lead-free solutions, but none have been able to pass the same form / fit / function requirements met by the current Pb flip chip solution.

27.4 Critical Review

27.4.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

The applicants mention indium-lead solders that may be used in the context with FCOL so that Annexes XIV and XVII need to be checked for entries regarding lead and indium.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as a directly added substance nor as a substance that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds and indium phosphide shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restriction for substances under Entry 28 and Entry 30 of Annex XVII does not apply to the use of lead and indium in this application. The use of lead and indium in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead and indium are part of an article and as such, Entry 28 and Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds…

- "shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight." This restriction, however, does not apply to internal components of watch timepieces inaccessible to consumers;
- "shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children." This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under Entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

No other entries, relevant for the use of lead or indium in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

27.4.2 Rewording of the Exemption

To simplify and specify the wording, the consultants and the applicant agreed on the below wording[1590] [1591] [1592] including a further restriction of the exemption to large silicon interposers by excluding plastics interposers:

15) Lead in solders to complete a viable electrical connection between the semiconductor die and the carrier within integrated circuit flip chip packages where one of the below criteria applies:

a) A semiconductor technology node of 90 nm or larger

b) A single die of 300 mm^2 or larger in any semiconductor technology node

c) Stacked die packages with a die of 300 mm^2 or larger, or silicon interposers of 300 mm^2 or larger

[1590] Op. cit. (Intel et al. 2016a)
[1591] Op. cit. (Intel et al. 2016d)
[1592] Intel et al. 2016f "E-mail communication, document "E-mail-Communication_Intel-et-al_2016-03-22.pdf", reveived via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel, until 22 March 2016: E-mail communication" unpublished manuscript,

d) *Flip chip on lead frame (FCOL) packages with a rated current of 3 A or higher and dies smaller than 300 mm²*

27.4.3 Substitution and Elimination of Lead

The applicants explain plausibly that the substitution or elimination of lead at the current state of the art is not viable for FCP in the scope of exemption parts a), b) and c) as listed in the rewording in Section 27.4.2. The root cause is the mechanical stress due to different coefficients of thermal expansion of the various materials in the FCP resulting in damages of the components. It is plausible that this effect is stronger for larger dies. The dies are made of silicon like the silicon interposers so that the same thermal mismatch issues apply. While larger plastic interposers can be used in combination with lead-free solders, they cannot replace the silicon interposers as only the silicon interposers facilitate very high connectivity rates. It is also plausible that the older FCP with technology nodes of 90 nm and larger cannot be redesigned in order to enable the use of lead-free solders in such FCP.

Differently from the justifications of the other exemption parts, Intel et al. did not provide a proper justification why the use of lead is still necessary in FCOL in part d) of the exemption. It was clearly pointed out to the stakeholders that the justification available in the original exemption request[1593] is not sufficient to justify the requested exemption. Intel et al. were asked three times to provide a sound justification[1594] [1595] [1596]. The applicants were requested to take into account in their answer that "*The justifications for the use of lead in parts 15 b) and c) of the exemption are based on the CTE issues related to large dies or interposers where 300 mm² are a critical size beyond which the use of lead-free solders is currently not possible. Exemption part 15d) would, however, explicitly allow the use of lead with smaller dies. Please justify the use of lead also with respect to the die size. It will otherwise raise questions concerning the plausibility of the technical justification.*"[1597]

"Please make sure you provide a sound overall explanation why lead is required in 15d) despite dies smaller than 300 mm², and take into account the current issue and any other relevant aspects. While the need for the use of lead is plausibly justified in detail for the other parts of exemption 15 related to die sizes, so far we only have a few lines of explanation with a few keywords like CTE, copper lead, current carrying capacity, for 15d). This is not sufficiently detailed and clear to justify the use of lead in 15d) […]. Should we have overlooked any more detailed information, we apologize, but still ask you to answer the above questions."[1598]

[1593] Op. cit. Intel et al. 2015a
[1594] Op. cit. (Intel et al. 2016a)
[1595] Op. cit. (Intel et al. 2016d)
[1596] Op. cit. (Intel et al. 2016e)
[1597] Ibid.
[1598] Ibid.

No information was provided besides what is described in Section 27.2.3 on page 598, which in the consultants' point of view is not sufficiently substantiated to justify the use of lead in this part of the requested exemption.

From the information provided, it is not clear why FCOL actually require the use of lead solders also with dies smaller than 300 mm². It can be concluded that it has to do with the lead frames which makes these components different from the other FCP, but the root causes and context are not further explained. Furthermore, the role of the high currents requiring the use of lead is not explained either. Overall, crucial information is missing that would allow understanding the technical background sufficiently to justify the use of lead in this part of the exemption.

27.4.4 Expiry Date for Older FCP

Based on the information submitted, FCP with technology nodes of 90 nm and larger cannot be designed to lead-free solder use and hence still need lead solders. However, the question arises why such older FCP are still applied in products and whether they cannot be replaced by modern lead-free FCP. On this basis, the extension of the exemption for older FCP is difficult to justify in line with RoHS Art. 5(1)(a) for another five years.

27.4.4.1 Applicants' Arguments for a Five Year Extension

Intel et al.[1599] report that the transition to lead-free on technology nodes of less than 90 nm has been realized between 2008 and 2014 by various suppliers they are aware of. As not all suppliers are on the same timetable for new technology introductions, it is impossible to pick a date that would denote complete conversion by all suppliers. That is not to say that some products did not transition beyond 2014 as well, but that increasing numbers of products were being produced on newer technology nodes by more and more suppliers, and these were being placed on the market with lead-free technology during that timeframe.

The applicants were asked when the big producers (e.g. Intel etc.) started placing lead-free FCP with technology nodes smaller than 90 nm on the market. Intel et al.[1600] replied that the better question is 'what' the companies converted. Just because a company offered Pb-free FC products, this does not equate to them offering replacement products for all existing Pb FC products. Companies had different dates for different die sizes, wafer fabrication processes, reliability requirements, sensitivity to stress, etc. The FC technology is typically used on complex chips that may each provide unique functions or sets of functions. Not all chips have alternatives available on the market – whether Pb or Pb-free.

[1599] Op. cit. (Intel et al. 2016f)
[1600] Ibid.

Intel et al.[1601] continue that it is very difficult to determine conversion timelines for, or among competitors. Companies often announce an initial market entry date for major products, but they tightly guard other roadmap information, such as the date that their very first product was qualified or that their last product converted or will convert from Pb to Pb-free. As part of an industry work-group they have been cautioned against asking these types of questions lest they are accused of collusion. Intel et al. can only ask whether a company is currently using an exemption. They can only assume that they know who will continue to use it based upon those interested in the extension.

According to Intel et al.,[1602, 1603] FCP are used in long life and high reliability products, and older FCP are used in various markets, categories of products listed in RoHS Annex I and component types:[1604]

- Markets:
  - Consumer;
  - Industrial;
  - Automotive and aerospace (out of scope for RoHS).
- Product Types In Scope (Categories 1-7 and 10):
  - Network infrastructure equipment;
  - Telecom equipment, older technology nodes, but with longer product life cycles;
  - Networking and communications equipment;
  - Communications systems;
  - Wireless infrastructure;
  - Storage array systems: both disk and tape systems;
  - Building Control and HVAC;
  - Digital imaging and data storage;
  - Factory automation and drives;
  - Televisual and multimedia equipment;
  - Other undetermined uses within end-products.
- Component types:
  - Microprocessors;
  - Integrated circuits;
  - Chips and memory devices;
  - Controllers.

Intel et al. state that lead-free FCP can provide *most* required electronic functions for *most* products, but put forward that the general availability of the newer technology

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[1601] Ibid.

[1602] Op. cit. Intel et al. 2015a

[1603] Intel et al. 2016c “Answers to questionnaire 3, document "Exe_15_Questionnaire-3_Intel-et-al_2016-02-18.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale on 26 February 2016” unpublished manuscript, Answers to third questionnaire

[1604] Ibid.

nodes does not necessarily line up with the design cycles required for many of the above products still utilizing the 90 nm and greater technology nodes. If in a particular application, e.g. the network infrastructure technology, modern FCP were not available until 2012 in the newer technology nodes, the companies providing those finished products into the market would already have been into at least two additional design cycles based on the older technology. This means those finished products (infrastructure equipment) would not be placed on the market until 2015 / 2016 and would continue to be sold for at least five to seven years and for some applications ten to fifteen years beyond introduction.

27.4.4.2 Critical Review of the Stakeholders' Arguments in Relation to Expiry Date

The applicants' above arguments need to be evaluated against the stipulations for exemptions in RoHS Art. 5(1)(a) and the review practices applied in the past in alignment with the European Commission.

- **Use of FCP in long life and high reliability electrical and electronic equipment**
  Intel et al. claim that FCP are used in long life and high reliability products. However, they mention products like mobile phones that use FCP, and consumer products as a general category of electrical and electronic equipment (EEE) that uses FCP. Consumer products can thus be assumed to at least be one part of the market for FCP, where most EEE are neither long life nor high reliability products. Concerning automotive applications, these are not in the scope of the RoHS Directive but are separately governed by the End of Life Vehicle Directive. Intel et al.[1605] insisted that there are many applications such as server farms and telecommunication infrastructure that utilize flip chip technologies and these are both long life and high reliability. Though the information submitted suggests that FCP certainly are also used in high reliability and long life products, it can also be understood that there are many other products with shorter life cycles that use FCP. It can be assumed that these markets are the mass markets for FCP not excluding that some specific FCP are mainly applied in long life and high reliability applications, which would, however, justify a specific extension of the exemption for certain products rather than a general renewal for all EEE in the scope of the RoHS Directive.

- **Technical practicability of using modern FCP to substitute old FCP**
  Intel et al.[1606] state that lead-free FCP can provide *most* required electronic functions for *most* products. In the consultants' point of view, this statement

[1605] Op. cit. (Intel et al. 2016a)
[1606] Ibid.

of Intel et al. is correct for the current product designs still using old FCP, but modern FCP must be applicable in all products, even though not as a drop-in solution, but after a redesign to accommodate the geometrical, mechanical, electronic requirements related to the use of such modern FCP. If modern FCP could not provide all required functions for all products, the volumes could not decline from year to year until they finally disappear from the market, but continuous further production of such old FCP would be required until the products they serve would no longer be needed.

- **Availability of Modern FCP and Redesign of EEE to Enable the Substitution of Lead**
The applicants indicate that the various FCP manufacturers transitioned to lead-free technology nodes of less than 90 nm between 2008 and 2014, and that some products might have transitioned beyond 2014 as well. In light of RoHS Art. 5(1)(a) and the past review practices, the crucial question is not when the last supplier had transitioned to lead-free FCP, but when the substitution of lead became scientifically and technically practicable. This had been the case from 2008 on. It is the applicants' obligation to provide all information substantiating the exemption request. The applicants did not provide any specific information on specific FCP that had not been available on the market. The reviewers therefore act on the assumption that after 2008 and before 2014 modern FCP were sufficiently available on the market to allow the replacement of older FCP, even though only after a redesign of the EEE into which they are applied.

RoHS Art. 5(1)(a) requires producers to change product designs if this enables the substitution or elimination of lead, where this is scientifically or technically practicable. Two to eight years have passed since modern FCP have become available on the market. While the applicants argue that this time line does not fit their product cycles for some of their products, the question arising from the RoHS perspective is whether and how far manufacturers can adapt their product cycles to the availability of lead-free alternatives. FCP producers and their customers should exchange information about when lead-free alternatives become available and the EEE producer could, within certain limits, postpone the next redesign cycle accordingly. In case another supplier offers lead-free FCP earlier than their supplier, they can also be expected to change to the other supplier. Besides technical practicability, the substitution of lead in applications covered by exemptions is also a competitive issue. The example EEE producer mentioned by the applicants being in two product redesign circles already when lead-free FCP became available in 2012 could have possibly better aligned the timing of the redesign cycle and thus have avoided redesigning the EEE with FCP that have to rely on the renewal of exemption 15.

Furthermore, the applicants put forward that this example EEE producer would continue to sell this equipment with old FCP for at least five or seven years or even up to 15 years beyond introduction. In the past exemption review rounds, manufacturers of EEE were allowed sufficient transition time to implement RoHS-compliant solutions in their products once such solutions became available. This transition time is, however, aligned with the time to redesign products and to qualify such RoHS compliant solutions according to the state of the art standard qualification procedures of the respective sectors. Transition times have not been recommended to allow EEE producers to place EEE on the market benefitting from an exemption in the presence of RoHS-compliant solutions that show that the substitution or elimination of the restricted substance in the scope of the exemption is scientifically and technically practicable.

27.4.4.3 Expiry Date

The information available clearly suggests that modern FCP are available to replace old FCP. There has been sufficient time since at the latest 2014 and most probably much longer for most products to be redesigned and replaced with new products and thus to switch to lead-free FCP. In this situation, continuing the exemption for five years would not be in line with RoHS Art. 5(1)(a). Nevertheless, the consultants are aware that some products might require more time than others. The consultants therefore recommend the expiry of that part of the exemption covering the old FCP on 21 July 2019. Should there be need for specific products in the scope of the RoHS Directive to renew the exemption for older FCP beyond 21 July 2019, there is time until 20 January 2018 to request the renewal of the exemption for such specific cases.

Intel et al.[1607] say they understand this approach, but do not agree stating that there are too many variations of products across varying market segments that require this older technology so that the industry will most surely be requesting extensions for the broader industry and not on an application specific basis.

Intel et al.[1608] mention that since many FCP products are used in high reliability applications, even if the exemption is limited to large die size and older technologies, those FCP small die in new technology applications no longer under the exemption would need at least 36 months for customer qualification and supply chain transition. To eliminate this exemption for all devices prematurely would have significant socioeconomic risks associated with early retirement of critical technologies, placing EU countries at a competitive disadvantage. In the consultants' opinion, this early retirement of critical technologies cannot occur as on the one hand the old FCP can still be used for repair and upgrade of EEE placed on the market prior to the expiry of the

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[1607] Op. cit. (Intel et al. 2016c)
[1608] Op. cit. (Intel et al. 2015a)

exemption. On the other hand, granting an appropriate transition period should enable producers of EEE to prepare their products for the use of modern FCP.

Infinera[1609], a provider of Intelligent Transport Networks (long life and high reliability infrastructure equipment, RoHS Cat. 3) supports this 36 month transition period as described in Section 27.2.5 on page 602 stating that 36 months will enable the transition to RoHS compliant product.

The consultants conclude from these statements that a 36 month transition period until July 2019 is realistic and reasonable to accommodate the needs of long life high reliability equipment. Any longer period would require a sound justification taking into account why the producers that need more time have not started the transition earlier already when the modern lead-free FCP have become available.

27.4.5 Expiry Date for FCP with Large Dies and Large Silicon Interposers

Based on the information available, it is plausible that lead is still required in those FCP in the scope of parts b) and c) of the requested exemption. The applicants indicate that further research is needed to make the use of lead-free solders scientifically and technically practicable. The applicants' exemption request and the answers to the clarification questionnaire were made available through the online consultation to the public (i.e. to industry, governments, NGOs and other stakeholders) and a consultation questionnaire had been prepared with specific questions to stakeholders. No further information supporting or discrediting the technical application in question was received, and there were no hints that lead-free solutions would be foreseeable for the FCP with large dies and large interposers. It is therefore recommended to grant the exemption for another five years. Granting the exemption for another five years would therefore be in line with the requirements of Art. 5(1)(a).

27.4.6 Lead Solders in High Current FCOL

Despite several requests to do so, the applicants did not provide a substantiated justification why the use of lead is required for the high current FCOL in part d) of the proposed new exemption wording. The consultants can therefore not recommend to grant the requested exemption for these FCP. RoHS Art. 5(6) requires providing a transition period of 12 to 18 months in this case.

In the absence of a sound justification, the consultants cannot conclude that an exemption would be justified according to the criteria specified in Article 5(1)(a). The

[1609] Infinera 2015 Corp. 2015 "Answer to consultation questionnaire, document "Ex_15_Infinera_Comments_on_Extension_10-15-2015.pdf": Answer to consultation questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_15/Ex_15_Infinera_Comments_on_Extension_10-15-2015.pdf

transition period is left to the COMs decision. Should the exemption actually still be required, a 12 to 18 month transition period might not be sufficient.

27.4.7 Conclusions

The applicants showed that FCP with technology nodes of 90 nm and larger cannot be designed to accommodate the properties of lead-free solders. They can, however, be replaced by modern FCP with technology nodes of less than 90 nm, in which lead can be substituted. It is therefore recommended to renew the exemption until 21 July 2019 to allow industry time to adapt to using FCP with smaller nodes.

For FCP involving large dies or silicon interposers of 300 mm^2 and more, it is recommended to renew the exemption for the maximum period of five years as no alternatives are foreseeable to substitute or eliminate the use of lead.

For FCOL, the stakeholders did not adequately substantiate their exemption request to justify the continued use of lead despite several requests to do so. In the absence of a sound justification, the consultants cannot conclude that an exemption would be justified according to the criteria specified in Article 5(1)(a). In cases where exemptions are not renewed even though the renewal has been requested, RoHS Art. 5(6) foresees a transition period of 12 to 18 months. The transition period is left to the Commission's decision. Should the exemption actually still be required, a 12 to 18 month transition period might not be sufficient. The FCOL-related exemption is added to the below recommendation for exemption 15 with the wording as agreed upon with the stakeholders, but without an expiry date.

27.5 Recommendation

Based on the available information, the reviewers recommend the renewal of the exemption with an amended wording and with the following expiry dates:

Exemption 15	Expires on	Comments
I) Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages	*21 July 2021 for medical equipment in category 8 and monitoring and control instruments in category 9*	
	21 July 2023 for in vitro diagnostic medical devices in category 8	
	21 July 2024 for industrial monitoring and control instruments in category 9	
II) Lead in solders to complete a viable electrical connection between the semiconductor die and the carrier within integrated circuit flip chip packages where one of the below criteria applies:		
a) *A semiconductor technology node of 90 nm or larger*	*21 July 2019 for categories 1-7 and 10*	
b) *A single die of 300 mm^2 or larger in any semiconductor technology node*	*21 July 2021 for categories 1-7 and 10*	
c) *Stacked die packages with dies of 300 mm^2 or larger, or silicon interposers of 300 mm^2 or larger*	*21 July 2021 for categories 1-7 and 10*	
d) *Flip chip on lead frame (FCOL) packages with a rated current of 3 A or higher and dies smaller than 300 mm^2*		The exemption cannot be recommended but is added here in case the Commission would decide that it should be granted

27.6 References Exemption 15

Eric Bastow, Indium Corp. of America, Utica, New York Solder Families and How They Work, e-mail: ebastow@indium.com; document referenced by Intel et al. 2015e.

Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

Goodman, Paul 2004 Technical adaptation under Directive 2002/95/EC (RoHS) - Investigation of exemptions: Final Report. With the assistance of Philip Strudwick, Robert Skipper. ERA Report 2004-0603. http://ec.europa.eu/environment/waste/weee/pdf/era_technology_study_12_2004.pdf.

Infinera 2015 Corp. Answer to consultation questionnaire, document "Ex_15_Infinera_Comments_on_Extension_10-15-2015.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_15/Ex_15_Infinera_Comments_on_Extension_10-15-2015.pdf.

Intel et al. 2015a Request for continuation of exemption 15, document "15_12-01-15_WG15_Exemption_Extension_Dossier_-_Final.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_15/15_12-01-15_WG15_Exemption_Extension_Dossier_-_Final.pdf.

Intel et al. 2016a Answers to questionnaire 2, document "Exe-15_Questionnaire-2_Intel-et-al_2016-01-18 Final Response.docx", received by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel, on 6 February 2016.

Intel et al. 2016c Answers to questionnaire 3, document "Exe_15_Questionnaire-3_Intel-et-al_2016-02-18.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale on 26 February 2016.

Intel et al. 2016d Answers to questionnaire 4, document "Exe_15_Questionnaire-4_Intel-et-al_Answers_2016-02-29.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel, on 9 March 2016.

Intel et al. 2016e Answers to questionnaire 5, document "Exe_15_Questionnaire-5_Intel-et-al_2016-03-13.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel et al., on 19 March 2016.

Intel et al. 2016f E-mail communication, document "E-mail-Communication_Intel-et-al_2016-03-22.pdf, reveived via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel, until 22 March 2016.

28.0 Exemption 18b: "Lead as activator in the fluorescent powder (1 % lead by weight or less) of discharge lamps when used as sun tanning lamps containing phosphors such as BSP ($BaSi_2O_5$:Pb)”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

BSP	Barium silicate phosphor doped with lead, also known as $BaSi_2O_5$:Pb
CFL	Compact fluorescent lamp
EEE	Electrical and Electronic Equipment
Hg	Mercury
HID	High intensity discharge lamps
InGaN	Indium gallium nitride
LED	Light emitting diode
OLED	Organic LED
LEU	LightingEurope
NARVA	NARVA Lichtquellen GmbH + Co. KG
NMSC	Non-melanoma skin cancer
Pb	Lead
PUVA	Psoralen (P) and ultraviolet A (UVA) therapy

UV	Ultra violet
UVB	Ultra violet radiation in the range of 280-315 nm
UVC	Ultra violet radiation in the range of 100-280 nm
WEEE	Waste Electrical and Electronic Equipment
WPE	Wall plug efficiency
YPO	Yttrium phosphate phosphor

Declaration

The phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text.

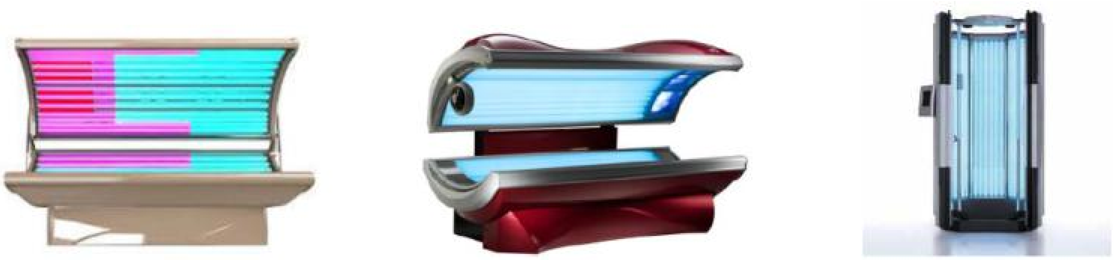
28.1 Background

NARVA Lichtquellen GmbH + Co. KG (NARVA) and LightingEurope (LEU) have applied for a renewal of exemption 18b of Annex III of the RoHS Directive.

According to LEU[1610], indoor tanning lamps are light sources that produce ultraviolet light in the regions of the UVA and UVB spectrums. Their intent is to produce artificial sunlight to replicate sunlight exposure (e.g., similar to that as emitted by the sun) for the human body, yet applied in calculated doses in line with European regulations. The lamps are installed in various commercial- and residential indoor tanning equipment. This can be in the form of a sun tanning bed or booth or a table top appliance for facial tanning. It is estimated that over 90% of indoor tanning lamps produced and used throughout Europe are manufactured with BSP ($BaSi_2O_5$:Pb) phosphors containing 1% or less lead as an activator).

[1610] LEU (2015a), LightingEurope, Request to renew Exemption 18b under the RoHS Directive 2011/65/EU Lead as activator in the fluorescent powder (1 % lead by weight or less) of discharge lamps when used as sun tanning lamps containing phosphors such as BSP ($BaSi_2O_5$:Pb), submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_18_b_/Lighting_EUrope/18b_LE_RoHS_Exemption__Req_Final_draft.pdf

Figure 28-1: Examples of indoor tanning equipment



Source: LEU (2015a)

NARVA[1611] explain that fluorescent lamps using barium silicate phosphor doped with lead (BSP lamps) are used in tanning equipment. Since the lamps contain lead, an exemption from the RoHS Directive is needed to allow further use in tanning equipment.

Both applicants request the renewal of the exemption for applications of category 5, with the current wording and for the maximum duration:

> "*Lead as activator in the fluorescent powder (1 % lead by weight or less) of discharge lamps when used as sun tanning lamps containing phosphors such as BSP (BaSi2O5 :Pb)*"

28.1.1 Amount of Lead Used under the Exemption

LEU[1612] explains that the phosphor coating represents the homogenous material used in the fluorescent lamps with respect to this exemption. The lead content of the phosphor is less than 1% of the total phosphor weight. There is no published data available for the quantity of tanning lamps entering the EU. However, based on market estimations of LightingEurope the lead content of tanning lamps is limited to 250 kg of lead in total entering the EU per annum[1613].

28.2 Description of Requested Exemption

According to LEU[1614] the exemption covers indoor sun tanning discharge lamps containing lead as activator in the fluorescent powder. The lamps produce UVA and UVB in predetermined dosages and ratios for the purpose of producing artificial sunlight. The lamps are installed in tanning equipment which is calibrated for the use of specific lamp

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[1611] NARVA (2014), NARVA Lichtquellen GmbH + Co. KG, exemption Request for Using Lead in fluorescent Lamps for Tanning, submitted 19.12.2014, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_18_b_/NARVA/18b.pdf

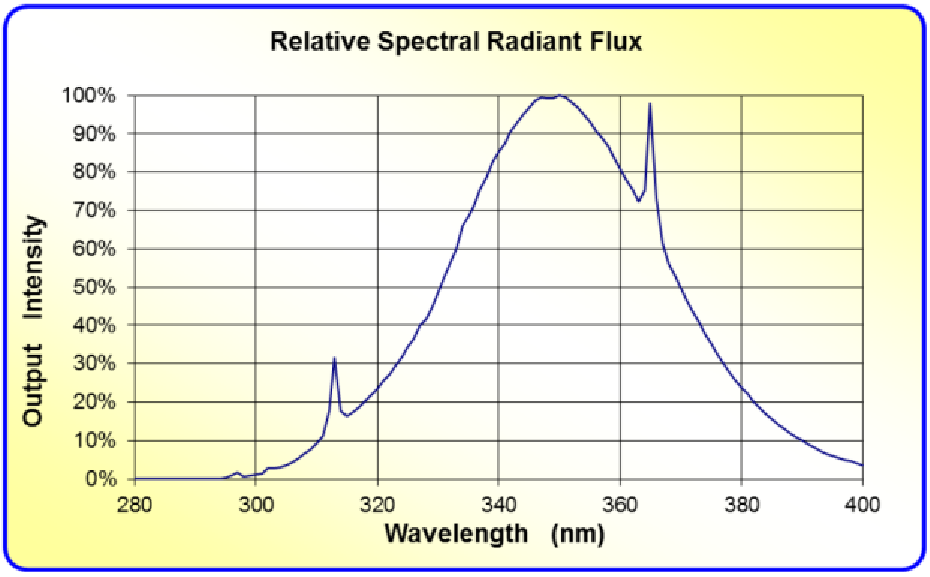
[1612] Op. cit. LEU (2015a)

[1613] According to LEU, lead is also used in similar lamp types for medical and phototherapy applications such as PUVA light therapy for skin conditions such as psoriasis. The mentioned figures are explained not to include estimated usage of lamps used in medical therapy, for which a separate exemption has been requested.

[1614] Op. cit. LEU (2015a)

types, marked in accordance with EU regulations for tanning lamps and equipment[1615]. Lamps are produced in T12, T8 and T5 diameters and compact fluorescent lamp (CFL) configurations. The phosphors contained in these lamps are manufactured from the same components but can vary in spectral discharge across the UVA and UVB spectrum as a result of the specified proportional phosphor mix (see typical example in Figure 28-2).

Figure 28-2: Example of a typical UVA/UVB spectrum



Source: LEU (2015a)

The typical lifetime of these lamps ranges from 600 to 1000 hours with a session or usage time that ranges approximately from 5-30 minutes. These lamps are not used for the production of visible light so general lighting efficacy standards do not apply. UV output efficacy (UVA radiation out vs electrical power in) is typically between 15% and 25%, but the real measure is with what power the desired effect is reached. This is governed by the equipment, lamp type, lamp power, UV output measured by standardized means, user skin type and other such factors.[1616]

The tanning industry is closely monitored and regulated by European authorities under regulations such as EN 60335-2-27 and EN 61228. EN 60335-2-27 is an international standard that deals with the safety of electrical equipment on exposing the skin to

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[1615] LEU (2015a) reference brochures and data about such lamps as follows:

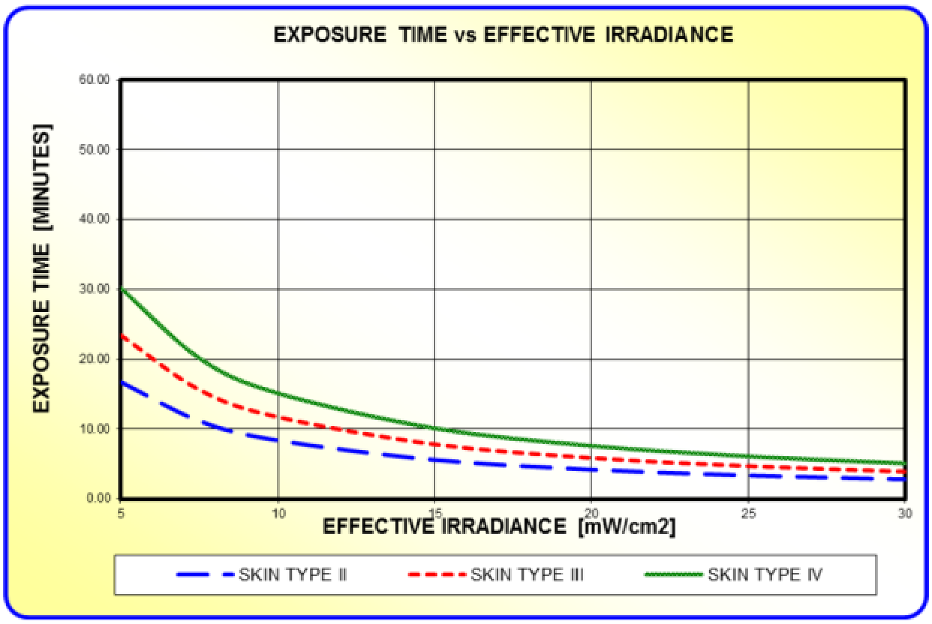
- Lighttech http://www.light-sources.com/tanning/tanning-lamp-products
- Cosmedico http://www.cosmedico.de/en/tubes.html
- Havells-Sylvania: http://www.havells-sylvania.com/media/Downloads/Sylvania%20Lamps%20Brochures/SPG/Suntanning/SY_Bodycare_Broschuere_2011_2012_ENGL_RZ_FINAL_ANSICHT.pdf

[1616] Op. cit. LEU (2015a)

ultraviolet or infrared radiation, for household and similar use in tanning salons, beauty parlours and similar buildings. EN 61228 includes requirements for measurement and details specification methods. Tanning and medical equipment in Europe is subject to unscheduled auditing and measurement of the lamps and equipment, which has been certified for use with lamps that are equivalent or the same as the lamps originally installed by the OEM. This equipment has undergone extensive testing to assure compliance with ultraviolet exposure schedules, and the use of non-equivalent lamps is restricted.

EU regulations govern the allowable output of ultraviolet radiation permitted within a determined exposure time (see Figure 28-3). The EU regulates and enforces tanning equipment and the installed lamps, which are marked on the lamps with a specific "X, Y" code system for the erythemally-weighed UV radiation in accordance with EN standard 61228 Ed.2 (2008-01). This EN standard forms the basis of lamp marking, and needs to be complied with. LEU claims that this limits the possibility of substitution with lead-free phosphors. The regulatory demands come from the LVD Administrative Co-operation working group (ADCO)[1617], which at its 18th meeting on the 14th of November 2006 decided among others that the maximum erythemal-weighted irradiance should not exceed 11 SED/h (0.3 W/m2).[1618]

Figure 28-3: Exposure time vs. effective irradiance



Source: LEU (2015a)

[1617] LEU (2015a) references the declaration of the LVD ADCO Group on the following website: http://ec.europa.eu/enterprise/electr_equipment/lv/guides/index.htm

[1618] Op. cit. LEU (2015a)

28.3 Applicant's Justification for Exemption

LEU[1619] explains that the lead activator is required to allow the barium silicate phosphor to fluoresce. It transforms the 254 nm radiation to the designed UV (290nm-400nm) radiation. A fluorescent lamp uses phosphors which, when activated, will produce light in different wavelengths. The primary wavelengths of "light" produced by indoor tanning lamps are in the UVA and UVB regions or 290-400nm. Lead is the primary activator for the barium silicate phosphors to fluoresce and is used in over 95%[1620] of the indoor low pressure mercury vapour fluorescent lamps used for tanning and certain medical applications, which are not covered by this exemption. The lead is evenly distributed throughout the phosphor coating of the lamps to radiate in the range of 290-400 nm when excited by radiation at 254 nm.

LEU[1621] further explains that UV intensity at the wavelength of 350 nm is crucial in order to get skin pigmentation (tanning result). The UV output of the lamps with narrow band UVA phosphor is negligible at that important wavelength so that they are insufficient for use for a wider range of tanning applications.

Tanning equipment is strictly regulated in the EU, and thus LEU[1622] explains that any possible alternative to lead in BSP type of phosphor would need to fulfil following criteria:

- "*Lamp specification must be the same with regard to:*
  - *UVA and UVB output, and with that Erythema*[1623]*;*
  - *Spectral power distribution*
  - *Compatibility (electrical/mechanical spec) must be OK*
  - *Reliability must be OK*
  - *Safety must be OK*
  - *Lamp operation must be the same in the different equipment in the market*
  - *Lamp start-up and time to peak intensity must be the same.*
  - *Lamp intensity must be the same.*

[1619] Op. cit. LEU (2015a)

[1620] LEU (2015b) explains that these non-BSP lamps emit only a narrow bandwidth of the UVA spectrum and no- UVB and do not produce the required action spectrum required for tanning response. As evidenced by the market size there is limited use of such lamps and when used it is always in conjunction with BSP phosphor lamps to generate the total UVA and UVB spectrums needed to initiate a tanning response.

[1621] LEU (2015b), LightingEurope, Answers to 1st Questionnaire Exemption No. 18b (renewal request), submitted 28.8.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_18_b_/Lighting_EUrope/Ex_18b_LightingEurope_1st_round_Clarification_LE_Answers_20150828.pdf

[1622] Op. cit. LEU (2015a)

[1623] In this respect LEU explains that the EU regulates tanning equipment (including lamps) with a specific "X, Y" code system for the erythemally-weighed UV radiation in accordance with EN standard 61228 Ed.2 (2008-01).

- *Lamp maintenance/depreciation must be the same,*
- *Tanning result on patients*
- *Compliance with CE regulations (X/Y coding system for tanning lamps according to EN 60335-2-27)*
- *No (negative) side effects*
- *Economically feasible. Equipment in use today is calibrated and requires lamps to meet output limits using X/Y coding system. Different lamps would need revalidation*."

28.3.1 Possible Alternatives for Substituting RoHS Substances

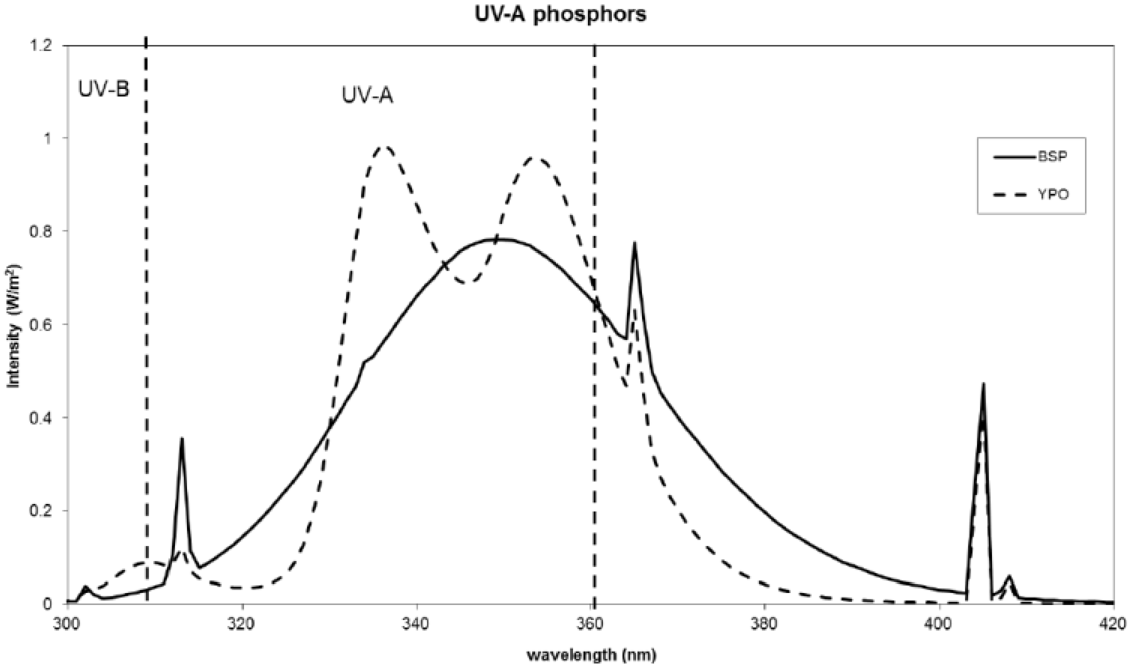
According to LEU[1624], only one alternative substance comes close to the performance of BSP phosphors - cerium (Ce) doped yttrium phosphate phosphor (YPO) phosphor. LEU explains that tanning lamp output is measured on a weighted distribution of UVA and UVB output measured by the output depending on the wavelength (nanometer). The lamps are coded using the X/Y system by lamp type which is then applied for use in each specific piece of equipment. Tests have been done using these phosphors for tanning lamps showing that the spread in UVA and UVB output is too high to be viable as a practically feasible alternative. Such phosphors would not be able to comply with CE regulations for tanning lamps (due to spectral incompatibility) and are thus not allowed for this application.

Figure 28-4 below shows the spectrum of Ce doped YPO phosphor in comparison to BSP. Based on the comparison, LEU concludes that:

- The spectral power distribution shows differences in the UVA and UVB range.
- The ratio for UVA and UVB output is different, which is an important factor for tanning applications and is governed by EU regulations due to the health risks.
- Therefore the cerium-based material has a lower expected treatment effectiveness, with regard to Erythema and NMSC (non-melanoma skin cancer).

[1624] Op. cit. LEU (2015a)

Figure 28-4: Emission spectrum of a cerium-doped phosphor – UV lamp



Source: LEU (2015a)

LEU[1625] raises a second point of relevance, with relation to the variations of the UV output along the lamp length [i.e. its surface area – consultants comment] due to coating thickness. When fluorescent lamps are coated with a phosphor the thickness of the coating varies over the length of the lamp. For current UV-fluorescent coatings used, like BSP, the thickness variations do not cause a severe inhomogeneous output. However, for cerium doped phosphor this thickness difference leads to unacceptable UV output variations, which will affect the skin treatment effectiveness (for further details see Appendix A.5.0).

LEU[1626] also explains why the BSP phosphor cannot be replaced in order to eliminate the need for lead as an activator: besides $BaSi_2O_5$:Pb, below lead doped phosphors are known as UV emitting phosphor.

- $SrBaMgSi_2O_7$:Pb 370nm
- $BaZn_2Si_2O_7$:Pb 303nm
- $BaMg_2Si_2O_7$:Pb 290nm

All above phosphors are doped with lead, but the emission wavelength depends on the chemical composition of the base substance. To get an efficient emission at 350nm, which is effective for sun tanning purpose, only $BaSi_2O_5$ can be used as a base substance. In parallel, though both lead (Pb) and europium can be used as a doper for BSP, barium

[1625] Op. cit. LEU (2015a)
[1626] Op. cit. LEU (2015b)

silicate emits 520nm when it is activated by europium, making $BaSi_2O_5$:Pb the only compound that achieves the 350nm output.

28.3.2 Possible Alternatives for Eliminating RoHS Substances

In relation to different designs of equipment (i.e. alternative technologies that could enable the elimination of lead in this application), LEU[1627] explains that other technologies could be evaluated for replacing fluorescent technology in tanning applications. These could be for example e.g. LED, OLED, HID, and incandescent or halogen technology. However, for any new technology there will be a need to address the replacement market (replacing lamps in existing fixtures) and the market for new equipment using the new technology. The criteria to determine whether a new technology can replace existing fluorescent technology using BSP (and Hg related to the discharge technology of the lamps) in existing equipment are detailed in Section 28.3 above. Since incandescent, halogen and OLED do not emit radiation in the UVA/UVB range, LEU only provides additional information as to the potential of LED technology as an alternative. The following obstacles are detailed in this regard:

- **Wall Plug Efficiency -** In contrast to general lighting lamps, (compact) fluorescent lamps for special purposes emit radiation in UV or blue wavelength bands. LEDs for general lighting purposes are made of indium gallium nitride (InGaN), a material that emits blue light, which with the help of phosphors is converted into the desired visible wavelengths. Theory says you can only convert from shorter wavelengths to longer. It is therefore impossible to create UV light with LED material as used for visible light LEDs. There are other materials available from which LEDs can be made that generate UV light (like AlGaN), however the efficiency (radiated power out / electrical power in) of LEDs with those materials is still very low. In the UVC (100-280 nm) and UVB (280-315 nm), the wall plug efficiency (WPE) of LEDs is below 1%, where the WPE of fluorescent lamps is close to 20% or even higher. There is currently no comparable WPE for LEDs with a spectral output below 380 nm. Therefore, LED lamps are not suitable at present as a practical alternative for tanning applications.
- **Effectiveness (i.e. same tanning effect) -** No tests results, from a comparative study of equipment using fluorescent lamps and equipment using LEDs, are available at present with regard to the effectiveness of alternative lamps to reach the desired effect in terms of tanning results. This is explained to be related to the lacking availability of LED candidates. Thus concluding as to possible effectiveness is not possible at present.
- **Regulation/approbation -** CE conformity and other European directives for special purpose applications (like for instance approbation of medical devices for phototherapy and CE regulations on tanning lamps (CE 60335-2-27)) are

[1627] Op. cit. LEU (2015a)

based on fluorescent discharge lamps (with respect to safety and system responsibility). No CE conformity is available for other lamp technologies.

28.3.3 Environmental Arguments

According to LEU[1628], there are no statistical data available specific to the Life Cycle Analysis of tanning lamps represented in this exemption request, however due to the relatively low market quantities for special lighting, the total environmental impact is expected to be limited.

Sun tanning lamps are further explained to be in the scope of EU Directives 2002/96/EC - WEEE and 2012/19/EU– WEEE Recast. Take back systems are installed in all EU Member States: end users and most commercial customers can bring back the lamps free of charge (see application for additional detail).[1629]

The limited wall-plug efficiency of LEDs currently available that produce light in the non-visible region is also understood to be of environmental relevance. Please see Section 28.3.2 and in 28.5.3 in this respect.

28.3.4 Socio-economic Impact of Substitution

LEU[1630] claims that the use of lead as an activator of the phosphor in these lamps allows the transmission of the specific wavelengths of light to be emitted in such a fashion to be the most effective form for its purpose, which is not achievable with other phosphor types or other technologies. Therefore efficacies of any alternative product types would not be an adequate comparison. The potential substitution or replacement with other wavelengths or ultraviolet dosages would require revalidation of all existing equipment in the EU market or could cause the elimination of such equipment causing great hardship to the small business owners of tanning salons throughout the EU. These current lamp types have been tested, studied and regulated in the EU and changes to these products would require a duplication of the clinical testing which has been compiled over years of study and regulation. LEU further explains that the effect of Ce doped phosphor may have considerable impact on health and safety of customers as the manufacturing tolerance in output and spectrum cannot be controlled to the extent required by EU regulations. For LED as an alternative technology, effects on health and safety will have to be investigated once candidates are developed.

According to LEU[1631], it can be expected that even if UVA LEDs become available with feasible specifications tanning equipment may become much more expensive. It will become therefore an economically unattractive solution and may have significant impact on the application. The possibility for lead-free technology for these lamps is not feasible

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[1628] Op. cit. LEU (2015a)
[1629] Op. cit. LEU (2015a)
[1630] Op. cit. LEU (2015a)
[1631] Op. cit. LEU (2015a)

for replacements lamps in existing equipment due to the scientific and clinical evaluations that would need to be done on every type of fixture or appliance that is in the field. The economic burden this would impose on the small business owners such as tanning salons and dermatologists would cause the closing of many businesses. It can be imagined that new equipment could be changed to non-lead phosphors. However over 90%, and it is estimated that it may be as much as 99%, of the tanning phosphors are lead activated. There are no alternative non-lead activated phosphors available today that provide the same or equivalent spectral radiation.

In a later communication, LEU[1632] however explains that the substitute candidate should have exactly the same spectral distribution curve and power effectiveness like BSP phosphor, because this is the only way to avoid needing to clinically retest all the tanning devices on the EU market.

In terms of social impacts, LEU[1633] explains that as there are no reliable substitutes if the renewal of the exemption is denied it would shut down the indoor tanning industry in Europe. LEU estimates that:

- Almost 100% of the BSP tanning lamps used in Europe are manufactured in Europe by fluorescent lamp companies;
- Almost 100% of the indoor tanning equipment sold in Europe is manufactured in Europe. Almost 100% of the tanning lamps sold as aftermarket lamps are sold by manufacturers or distributors located in Europe;
- Over 90% of the tanning lamps used in the US are manufactured in Europe;
- Over 75% of the tanning equipment sold in the United States is made in Europe.

28.3.5 Road Map to Substitution

LEU[1634] expects that given the market size in combination with strict regulations, efforts to substitute BSP containing lamps are extremely limited (to non-existent). There are no plans to replace Pb with Ce as earlier tests were unsuccessful. With regard to LEDs, other UVA applications are available in LEDs but tanning application development has been limited. At this moment it is impossible to predict if and when UVA LED based equipment will become feasible.

[1632] Op. cit. LEU (2015b)
[1633] Op. cit. LEU (2015a)
[1634] Op. cit. LEU (2015a)

28.4 Stakeholder Contributions

A single contribution was made in relation to Ex. 18b during the stakeholder consultation. The Test and Measurement Coalition (TMC)[1635] includes the seven leading companies in the sector representing roughly 60% of the global production of industrial test and measurement products. It is TMC's understanding that, according to the RoHS Directive, the exemptions listed in Annex III and Annex IV for which no expiry date has been specified, apply to sub-category 9 industrial with a validity period of 7 years, starting from 22 July 2017. This is also said to be explained in the RoHS FAQ, p. 26 http://ec.europa.eu/environment/waste/rohs_eee/pdf/faq.pdf. TMC, thus does not interpret the current exemption evaluation related to package 9 to concern category 9 industrial equipment and has not provided exemption specific information.

28.5 Critical Review

28.5.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists entry 28 and entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restriction for substances under entry 28 and entry 30 of Annex XVII does not apply to the use of lead in this application. Pb used as an activator of BSP phosphors applied in discharge lamps used for tanning, in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Pb is part of an article and as such, entry 28 and entry 30 of Annex XVII of the REACH Regulation would not apply.

In general, BSP, or silicic acid ($H_2Si_2O_5$), barium salt (1:1), lead-doped (CAS number 68784-75-8) has been addressed in an Annex XV dossier[1636] prepared by the European Chemicals Agency (ECHA), proposing its classification as a substance of very high concern (SVHC). The substance has been proposed to be identified as a substance meeting the criteria of Article 57 (c) of REACH, owing to its classification as toxic for reproduction category 1 A. Furthermore BSP is a registered substance[1637]. Nonetheless, at present,

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[1635] TMC (2015), Test & Measurement Coalition, General comments related to RoHS exemption package 9, submitted 16.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/General_Contribution_Test___Measurement_Coalition_package_9_exemptions_20151016.pdf

[1636] Available here: http://echa.europa.eu/documents/10162/13638/SVHC_AXVREP_EC_272-271-5_SilicicAcidBariumSaltLead-doped_en.pdf

[1637] Available information from REACH registration dossiers can be found under the following link:

there are no listings of this substance under Annexes XIV and XVII of REACH that restrict its use in products to be placed on the EU market. There are also currently no processes underway to evaluate the need for such listings (restriction / authorisation). Even if further processes should be embarked on, it is currently not possible to assume if this would result in legislation that would restrict the use of BSP in lamps used for tanning (or medical) applications. Though such proceedings should be observed in future evaluations of the RoHS exemption for lead in BSP lamps, the consultants do not think it would be appropriate at present to limit the current exemption or its duration in anticipation of results of such processes.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status January 2016).

Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

28.5.2 Scientific and Technical Practicability of Substitution

NARVA and LEU explain that lead in BSP lamp types used for tanning applications currently cannot be substituted or eliminated. Though a few candidate alternatives are elaborated on, it can be understood that none of these have reached a stage of maturity in terms of being used in articles to be placed on the market. In this sense, at least at present, it can be understood that substitutes are not available on the market for a number of reasons.

To begin with, an alternative light source providing the same function as BSP lamps using lead is yet to be found. Using an alternative activator to dope BSP instead of lead, such as europium, would not result in a comparable spectral output. Though the option of using YPO phosphors is elaborated on as a substance substitute, it can be understood that such lamps do not provide the same spectral output as BSP lamps either. The change of spectral output is explained to possibly result in larger negative health impacts such as erythema. It can be understood that the spectral output of BSP lamps may also cause such health impacts, however at a lower rate and thus holding lower risks for health effects on patients. From an earlier exemption request evaluation[1638] that led to Ex. 34 of Annex IV, it is also understood that other phosphor compositions that have

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http://apps.echa.europa.eu/registered/data/dossiers/DISS-9fdc6c5f-6d4c-29d1-e044-00144f67d031/AGGR-ec42affe-9178-4b25-911c-415860a9699a_DISS-9fdc6c5f-6d4c-29d1-e044-00144f67d031.html#section_3_5

[1638] Exemption request from Therakos Photopheresis to exempt BSP lamps in extracorporeal photopheresis applications. Application documents can be viewed here: http://rohs.exemptions.oeko.info/index.php?id=146 and final evaluation report here: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_VI/20130412_RoHS2_Evaluation_Proj2_Pack1_Ex_Requests_1-11_Final.pdf

been investigated in the past, would either lead to similar risks or to an ineffective treatment. In parallel, developing alternative light sources with technologies such as LED have also yet to mature. Though first UVA LED lamps may have started to become available, their efficiency (radiated power out ÷ electrical power in) is said to be very low in comparison with BSP lamps, and information predicting when UVA LEDs with acceptable output and efficiency shall become available is not publicly available. Though such lamps are currently not available for use in tanning equipment, it should be noted that differences in efficiency could have relevance to the environmental comparison of alternatives.

To conclude, as an alternative light source is a precondition for developing equipment which would be compatible with such new technologies, further evaluating the performance of such possible equipment is not yet possible, making substitution and elimination not practical at this time.

28.5.3 Environmental Arguments

LEU provides some information regarding environmental aspects of BSP lamps, mainly related to the treatment of waste. As the information does not allow a comparison with possible alternatives (which are in any case understood to not be applicable at present), the information is not further discussed.

As shortly explained above, though first UVA LED lamps may have started to become available, their efficiency is said to be very low in comparison with BSP lamps. This is understood to mean that even if their spectral output would be comparable to that of BSP lamps, their limited efficiency would result in a significantly higher energy consumption than that of BSP lamps.

28.5.4 Socio-Economic Arguments

LEU mentions a number of aspects related to socio-economic aspects.

Among others, information is provided regarding possible differences in health impacts of BSP lamps and of the current candidate alternatives; these have been discussed above in Section 28.5.2.

Furthermore, LEU claims that once an alternative is to be found, the development and implementation of such alternatives in equipment can be expected to result in heavier costs for business (tanning salons). In this respect LEU[1639] mentions that:

- **Even if UVA LEDs become available with feasible specifications, tanning equipment may become much more expensive** – in the consultants' view it is difficult to estimate what costs substitution could lead to. Alternatives may not necessarily be more expensive, especially if they are to be developed after most discharge lamp applications have been replaced with Hg-free

[1639] Op. cit. LEU (2015a)

alternatives. In the transformation of the lighting sector from Hg-based (discharge lamps) to Hg-free applications (other technologies), it can be expected that at some point the burden of manufacturing last Hg-based articles in relatively small quantities shall become an incentive for developing alternatives. In such a case, emerging alternatives could be viewed by businesses more as a blessing than as a burden. As the spectral function of alternative light sources cannot be anticipated at present, it cannot be predicted if in the long run the alternatives may have lower negative impacts on health and thus provide benefits for patients, regardless of the costs of a transformation.

- **Development of replacement lamps for existing equipment shall not to be feasible** as the recertification would need to be performed for every type of fixture or appliance, resulting in an economic burden for small business owners (e.g. tanning salons). The consultants are aware that different technologies may use different fixtures or require rewiring or changes to the interface of the lamp with equipment, however cannot follow that this is always the case. If the spectral out-put of alternatives is the same as well as its directionality and other characteristic properties of the light source, the consultants cannot follow that a change in light source would require extensive recertification of each type of equipment. In this sense, here too, it is difficult to say how costs of development, clinical studies and recertification shall add up. Though it can be expected that such processes for replacement lamps may be time consuming and less practical, it needs to be kept in mind that all equipment has a certain service life and is gradually replaced with new equipment, which has undergone at least some degree of redesign. In this sense, though ensuring replacement lamps for existing equipment with new technologies could justify keeping BSP lamps on the market in some cases, predicting this at present is not straightforward.

28.5.5 Stakeholder Contributions

The contribution submitted by TMC raises a legal question as to the availability of the current exemption to category 9 equipment. Regardless of TMCs claims as to the availability of Annex III exemptions to sub-category 9 industrial for 7 years starting in 22.7.2017, in the case of Ex. 18b the wording formulation limits its applicability to tanning applications. As tanning equipment is understood not to fall under Cat. 9, in the consultants' opinion, sub-category 9 industrial equipment would not benefit from the exemption. Should BSP lamps be in use in Cat. 9 equipment (general and industrial), relevant stakeholders would have been expected to come forward with such information, either in the past evaluations related to medical equipment or in the current one.

28.5.6 The Scope of the Exemption

LEU[1640] explains that technically there is no difference between BSP phosphors used for medical purposes and BSP phosphors used for tanning purposes. Both lamp categories may have the same diameter and same wattage range in principle. Medical lamps may also be used in smaller lengths, diameters and wattages for partial body or spot treatment. The phosphor types may use the same components with a very similar or different blend to produce a specific UV output. In medical applications these would be called PUVA[1641] lamps and produce broad band UVA output. These lamps would be marked accordingly. The differences are in the field of application, in marking of the lamps and in the way to market. The sizes and wattages of certain tanning lamps can be the same as PUVA type of medical lamps for which LightingEurope has submitted a separate application for the use of BSP phosphors in those medical lamps. The manufacturers of tanning lamps do not market tanning lamps for use in medical equipment and therefore do not request an exemption for the use of tanning lamps in medical equipment.

In the consultants view, in relation to the scope of the exemption, the question here is whether a distinction can be made between similar BSP lamps used in different types of equipment. If the same lamp can be used in equipment falling into different categories, there would be a justification to merge all applications to a single exemption with a single validity date, regardless of category. The aim of this would be, on the one side, to ensure that the need to renew exemptions for BSP lamps be evaluated in the future for all applications during the same review, i.e. for a single merged exemption. On the other hand, should all BSP lamps which are interchangeable be addressed by a single exemption, this would simplify the legislation.

LEU was thus asked to clarify the aspect of exclusivity related to the use of BSP lamps in tanning and medical equipment. LEU[1642] explains that differentiation between tanning and medical lamps is done via the following protocol: On each and every sunlamp there is a mandatory warning text which describes clearly that the lamp is made for tanning purposes. This applies for medical lamps as well where the warning text shows that the lamp is intended for use in medical applications. All lamps manufactured for tanning purposes are marked with a so-called ‘equivalency code’ which refers to the UV strength of the lamp. This code ensures that in the application the user applies the correct lamps to avoid over exposure. Such code (i.e. its significance - consultants comment) is well known and widely used by people who replace the lamps in the sunbeds. On each and every sunbed there is a sticker, which specifies what lamp with what ‘equivalency code’ should be used in the device. Such ‘equivalency codes’ are not etched on medical lamps.

[1640] Op. cit. LEU (2015b)

[1641] The name PUVA comes from a group of medical treatment practices that combine intake of a psoralen drug with exposure to UVA radiation.

[1642] LEU (2016a), LightingEurope, Answers to 2nd Questionnaire Exemption No. 18b (renewal request), submitted 19.01.2016 per email.

Each and every tanning lamp is marked accordingly and each and every medical lamp is marked according to legal and safety requirements for its intended use. LEU contends that this sufficiently prevents misuse of the lamps.

Figure 28-5: Warning text, equivalency code and marking examples for lamps

Tanning Lamps	**Medical Lamps**
Warning text	**Warning text**
Sunlamp - **DANGER**.Ultraviolet radiation. Follow instructions. Use **ONLY** in fixture equipped with a timer.	**WARNING: Medical UV lamp.** **Use only in certified medical devices!** **Use protective eyewear.**
Equivalency code	
180-R-36/2,4	
Marking	**Marking**
R 180W 2m Sunlamp - **DANGER**.Ultraviolet radiation. Follow instructions. Use **ONLY** in fixture equipped with a timer. USA Technology. 180-R-36/2,4	WIDE BAND PUVA 100W **WARNING: Medical UV lamp.** **Use only in certified medical devices!** **Use protective eyewear.**

Source: Op. cit. LEU (2016a)

Nonetheless, when asked whether some BSP lamps were sold on the open market (i.e. accessible to private consumers, LEU[1643] answered positively, explaining that they are sold through professional distribution networks. Regarding the possibility of using medical lamps in tanning applications and vice versa, LEU explained that as some medical lamps and tanning lamps are made to lighting industry standard dimensions and electrical characteristics (e.g. length, diameter, wattage, end fitting) it is mechanically possible that a lamp intended for medical use or tanning use or general lighting use can fit in the same luminaire or equipment. However, these lamps are absolutely not intended to be interchangeable for medical or tanning or general lighting applications and any such misuse could cause harm to the user. All tanning lamps are marked for sun tanning purposes and all medical lamps are marked for medical use in accordance with safety regulations and as demonstrated in our previous responses".

According to the above information, though the consultants can follow that BSP lamps of different types are manufactured for use in specific equipment, it cannot be concluded that tanning lamps and medical lamps would not be interchangeable. It is understood that lamps for other medical applications and lamps for tanning applications are sold as individual lamps. Though they are sold through professional distribution networks, LEU confirms that private consumers could have access to some lamps as is also apparent from searching the internet in this respect[1644]. This can also be followed as it is

[1643] LEU (2016b), LightingEurope, Answers to 3rd Questionnaire Exemption No. 18b (renewal request), submitted 27.01.2016 per email.
[1644] See for example: http://www.uvee.be/puva-uvb-lamps

understood that equipment both for tanning and for medical phototherapy can be purchased by private consumers. In this respect, even if this is not the intended use, lamps manufactured for one application could be implemented by users in the other application type.

The consultants, thus, cannot follow why there should be separate exemptions for sun-tanning lamps and for medical applications as this would mean double regulation of the same product, possibly leading to uncertainties in the future.

In this respect, it is also clear that should substitutes become available, that their applicability would need to be evaluated for all applications, further supporting formulating a single exemption for all BSP applications.

28.5.7 Exemption Wording Formulation

The aspect of lamp exclusivity has been discussed in the evaluation of Ex. 2015-3, evaluated in the course of an earlier project[1645]. In this earlier evaluation, a recommendation was made to merge the exemption for tanning applications and for medical applications (excluding at present applications covered under Ex. 34 of Annex VI, which is due to expire only on 22 July 2021). In this sense the wording recommended in this earlier exemption evaluation is also proposed below, as a means of merging the applications under one exemption.

28.5.8 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

In the consultants' opinion, in the case of BSP lamps it can be followed that there are currently no alternatives that would allow either a substance substitution in the existing technology or an elimination of the need for lead through the implementation of new technologies. In this sense, elimination and substitution are considered to be impractical at present.

Furthermore, though it can be understood that none of the named candidate alternatives have matured to the point of being subjected to clinical trials and testing, for some of these candidates negative health risks have been identified due to spectral

[1645] See Report for Pack 8, available under http://rohs.exemptions.oeko.info/index.php?id=164

output differences. Though in theory YPO alternatives could be used in lamps, the first research suggests that their spectrum would raise the risk for Erythema and non-melanoma skin cancer. In this sense such substitutes are understood to also have higher negative impacts on health in comparison with BSP lamps. Though the conclusion that the first criterion is fulfilled would suffice to justify an exemption, this aspect (if true) further strengthens the justification.

As there is currently no information to suggest that alternatives should become market ready in the next few years, setting a short duration for an exemption does not seem practical. As Ex. 34 currently has an expiration date in mid-2021, and addresses BSP lamps used for a different application, and as a positive evaluation of Ex. Request 2015-3 could result in the same expiration date, the consultants would recommend that should an exemption be approved for tanning applications, that its validity be aligned with this date, even if the date of the EU COMs decision would in theory allow extending the duration of the exemption beyond this point in time.

28.6 Recommendation

It is recommended to grant the requested exemption extending its applicability from tanning applications to medical applications. In the consultants' view an amendment of Ex. 34, which also covers a certain type of medical application, should be avoided at present though it should be consider in future reviews. It is thus recommended to amend exemption 18(B) of Annex III as follows:

Exemption 18b	Duration*
Lead as activator in the fluorescent powder (1 % lead by weight or less) of discharge lamps containing phosphors such as BSP (BaSi2O5 :Pb), when used: ***I. in tanning equipment; or*** ***II. in Annex I category 8 medical phototherapy equipment - excluding applications falling under point 34 of Annex IV***	*For Cat. 5: 21 July 2021*

The consultants' do not see a need to grant the exemption to Cat. 9 equipment, or to applications in the scope of Cat. 8 equipment not specifically addressed in the formulation above and in Ex. 34 of annex IV. The current Ex. 18b is restricted to tanning equipment, understood not to fall under Cat. 8 or Cat. 9. Furthermore, in the evaluation of the current request, the recent evaluation of Ex. Re. 2015-3 also applied for by LEU and the evaluation of the Therakos request, information has not become available to suggest that BSP lamps are used in Cat. 9 equipment or in other Cat. 8 equipment.

Nonetheless, as for exemptions listed in Annex III, for which an expiration date is not specified, it is understood that from a legal point of view, they shall be valid for applications of Cat. 8 and Cat. 9 for up to 7 years. This validity period is understood to start from the dates specified in Article 4(3), for when these categories come into the scope of the Directive. Thus if from a formal-legal point of view the original formulation of the exemption needs to remain valid for these categories for the specified duration, the following formulation would be recommended:

Exemption 18b	Duration*
(1) Lead as activator in the fluorescent powder (1 % lead by weight or less) of discharge lamps containing phosphors such as BSP (BaSi2O5 :Pb), when used: ***I. in tanning equipment; or*** ***II. in Annex I category 8 medical phototherapy equipment - excluding applications falling under point 34 of Annex IV***	For Cat. 5: 21 July 2021
(2) Lead as activator in the fluorescent powder (1% lead by weight or less) of discharge lamps when used as sun tanning lamps containing phosphors such as BSP ($BaSi_2O_5$: Pb)	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat 9 industrial: 21 July 2024

The consultants recommend the next review to be performed along with the review of all other exemptions for BSP applications (e.g. Annex IV Ex. 34), assuming applicants request the renewal of these exemptions.

28.7 References Exemption 18b

LEU (2015a) LightingEurope, Request to renew Exemption 18b under the RoHS Directive 2011/65/EU Lead as activator in the fluorescent powder (1 % lead by weight or less) of discharge lamps when used as sun tanning lamps containing phosphors such as BSP (BaSi2O5 :Pb), submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_18_b_/Lighting_EUrope/18b_LE_RoHS_Exemption__Req_Final_draft.pdf

LEU (2015b) LightingEurope, Answers to 1st Questionnaire Exemption No. 18b (renewal request), submitted 28.8.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_18_b_/Lighting_EUrope/Ex_18b_LightingEurope_1st_round_Clarification_LE_Answers_20150828.pdf

LEU (2016a) LightingEurope, Answers to 2nd Questionnaire Exemption No. 18b (renewal request), submitted 19.01.2016 per email.

LEU (2016b) LightingEurope, Answers to 3rd Questionnaire Exemption No. 18b (renewal request), submitted 27.01.2016 per email.

NARVA (2014) NARVA Lichtquellen GmbH + Co. KG, exemption Request for Using Lead in fluorescent Lamps for Tanning, submitted 19.12.2014, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_18_b_/NARVA/18b.pdf

TMC (2015) Test & Measurement Coalition, General comments related to RoHS exemption package 9, submitted 16.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/General_Contribution_Test___Measurement_Coalition_package_9_exemptions_20151016.pdf

29.0 Exemption 21: "Lead and cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

Cd	Cadmium
CMH	Ceramic Metal Halide
EEE	Electrical and Electronic Equipment
HGT	Hecker Glastechnik GmbH & Co KG
HID	High-intensity discharge [lamps]
HPS	High Pressure Sodium
IRL	Irlbacher Blickpunkt Glas GmbH (IRL)
LEU	Lighting Europe
PAR	Parabolic aluminized reflector
Pb	Lead
QMH	Quartz Metal Halide
TL(s)	Tubular lamps

29.1 Background

LightingEurope (LEU)[1646] has requested the renewal of Ex. 21 to ensure that lead and cadmium can further be used in printing inks applied as enamels to glass, such as borosilicate and soda lime glasses.

LEU[1647] explains that lead is used in printing inks applied to glass, and provides a durable product marking especially on the glass bulb of lamps. The durability is important to maintain the legibility of product markings throughout product-lifetime, as required by legislations and product safety standards.

Though lead-free ink solutions have been found, LEU claims that they cannot be effectively utilized in all situations with the required mark quality, and provide the following example (see Figure 29-1) to demonstrate the difference.

Figure 29-1: Examples of lead-containing and lead-free marking

Good marking with Pb containing ink | Marking with lead free ink in some applications

Source LEU (2015a)

Thus, LEU requests the exemption be renewed with the following wording and with the maximum duration, and further specify that the exemption renewal is requested for Category 5 articles on which the inks are used (e.g. lamps):

> "*Lead and cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses*"

LEU did not provide argumentation for the use of lead based inks in other applications aside from lamps, nor in relation to the need to renew the exemption for the use of Cd in

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[1646] LEU (2015a), LightingEurope, Request to renew Exemption 21 under the RoHS Directive 2011/65/EU Lead and cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_21/21_LE_RoHS_Exemption_Req_Final.pdf

[1647] Op. cit. LEU (2015a)

inks used for the application of enamels on glasses. In a later communication LEU[1648] thus agreed that the exemption could be limited to the use of Pb in ink, and proposed the following exemption formulation:

> *"Lead in printing inks for the application of enamels on glasses"*

LEU[1649] further explains that the exemption is relevant for use of lead in inks used on both mentioned types of glass, i.e. borosilicate and soda lime glass, and also on quartz glass.

29.1.1 Amount of Lead Used under the Exemption

LEU[1650] estimates the amount of lead placed on the EU market through lead based inks used for lamp marking in relation to some of the relevant lamp types:

- Double capped fluorescent lamps: the total amount of lead on the stamp in Tubular lamps (TLs) placed on the EU market is approximately 20 kg[1651] lead per annum.
- The total amount of lead in high-intensity discharge (HID) lamps and parabolic aluminized reflector (PAR) lamps placed on the market per annum in Europe is less than 0.5 kg.
- For other lamps mentioned, LEU states that the amounts of Pb are very low.

LEU explains these estimations to be calculated by multiplying the volumes of lamps placed on the market with lead-containing marking with the estimated average amount of lead used per stamp (depending on mark size and text).[1652]

29.2 Description of Requested Exemption

LEU[1653] explains that lead is used in inks, which are applied to lamp glass for marking purposes. Among others, such inks are used to mark fluorescent tubes, PAR lamps and HID lamps like High Pressure Sodium (HPS), Quartz Metal Halide (QMH) and Ceramic Metal Halide (CMH).

In a later communication LEU[1654] explains that the request concerns in general lamps where the lamp stamp is located on the glass material (e.g. tube or bulb) including: linear and (non) linear fluorescent lamps (e.g. T5, T8, T12), high pressure sodium lamps,

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1648 LEU (2015b), LightingEurope, Answers to 1st Questionnaire Exemption No. 21 (renewal request), submitted 10.8.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_21/20150810_Ex_21_LightingEurope_Answers_to_1st_Clarification-Questions.pdf
1649 Op. cit. LEU (2015b)
1650 Op. cit. LEU (2015a)
1651 This value was stated as 2 kg in LEU (2015a) but later corrected in LEU (2015b) to 20 kg.
1652 Op. cit. LEU (2015b)
1653 Op. cit. LEU (2015a)
1654 Op. cit. LEU (2015b)

ceramic metal halide lamps, quartz metal halide lamps, PAR lamps, incandescent lamps for special purposes (exempted from 244/2009) and halogen lamps (low and mains voltage). It is elaborated that there is currently no expectation that such lamps are to be phased out in the coming years. Nonetheless, LEU[1655] has mentioned that the focus of the current lighting industry is on the further development of LED technology and that an extension of the exemption will have no negative effect on the efforts to further innovate in LED.

Lead is needed to make a mark on the soda lime glass that durably stays on the lamp throughout the lifetime of the lamp. Lead helps the marking ink to fuse into the glass surface. The ink has to adhere to the glass within a few seconds without being damaged in the course of other manufacturing processes. In the black ink, a so called lead-containing glass frit is used as adhesion compound to the glass. In the green (lead-free) ink an aluminium phosphate is used for the adhesion to the glass. [1656]

In a later communication, LEU adds that "*Lead-containing ink is not only limited to the black colour inks, it is also used in silver/golden coloured stamps. The ink recipe is completely the same for the silver/golden stamp colours…The printing ink composition can be very much dependant on manufacturing and lamp marking process, hence not solely related to lamp stamp colour. Different lamp marking colours are also used to execute proper market communication and product positioning strategy by various manufacturers*".[1657]

Lead is one of the components in the low melting glass (enamel), which is in turn a component in the ink. This enamel has a very low softening point due to the presence of lead, which is needed to adhere the pigment particles in the ink to the bulb glass of the lamp, without affecting the lamp bulb glass itself, during the fixation process of the marking to the lamp bulb glass, which is carried out at elevated temperatures.[1658]

LightingEurope[1659] is of the opinion that the question whether glass marked with pigment particles embedded in enamel is considered as homogeneous material is not resolved completely. Hence, since the marking cannot be removed by mechanical abrasive means LightingEurope considers the marked glass as homogenous material. This was the position of ELC some years ago when the exemption was extended from borosilicate glass to all type of (lamp) glasses. This exemption gave legal certainty to manufacturers, supply chain and authorities.

According to LEU[1660], the marking has several functions, during the entire life cycle:

[1655] Op. cit. LEU (2015a)
[1656] Op. cit. LEU (2015a)
[1657] LEU (2016a), LightingEurope, Answers to 2nd round of clarification questions, submitted per email on 29.1.2016
[1658] Op. cit. LEU (2015b)
[1659] Op. cit. LEU (2015b)
[1660] Op. cit. LEU (2015b)

- To identify the producer (a.o. brand and “Made in …”);
- To identify lamp type and wattage, which is relevant for safety, correct lamp replacement and recycling;
- CE, WEEE marking.

LEU then elaborates:

> “*Product identification is legally required for CE Marking according to the LVD Directive (2006/95/EC). A list of harmonized standards falling under this directive is published in OJEU as 2015/C 125/02. For instance, the marking requirement for linear fluorescent lamps is given in safety standard EN61195 in clause 2.2.1. Moreover, marking of lamps at the end of life is also required by the WEEE Directive (2002/96/EC)… marking of lamps must fulfil criteria set by standards and regulations, among others related to safety directive, WEEE and information essential for lamp identification must be visible during the entire service life. For example on straight fluorescent lamps, the lamp glass is the only place where this labelling on the product itself is possible, due to limited space and regulated size on marking on any other visible component such as lamp base (cap).*
>
> *Product identification must be legible for the consumer or other stakeholders during the entire life cycle of the product (safety, replacement, recycling etc.). Intensive heat and light during lamp operations result in quality challenges for the marking of a lamp. Some luminaries state maximum wattage in order to avoid excessive heat. If a mark is not properly legible for the user, the user might place the wrong lamp into a luminaire with the consequence of a high safety risk. Maximum lamp temperatures may differ per lamp type and application. For example, clause 2.9.1 in EN61195 for linear fluorescent lamps states that maximum cap temperature rise can vary from 55 to 95K depending on the specific product type.*
>
> *It also has to be considered that a lamp can be used for a certain period of time, exchanged against another lamp in an existing application but still not at end of life. If this lamp is used again, packaging and other product description are no longer available, hence general product designations are important to be present on the lamp.*” [1661]

[1661] Op. cit. LEU (2015a)

29.3 Applicant's Justification for Exemption

29.3.1 Possible Alternatives for Substituting RoHS Substances

LEU[1662] claims that lead-free ink solutions (green ink using aluminium phosphate) have been found, but they cannot be effectively utilized in all situations with the required mark quality yet. Damaging of the marking (i.e. affecting legibility) can already appear during processing of the lamps. LEU provides examples of lamps marked with lead based and lead-free inks to demonstrate the difference in durability (see Figure 29-1). As it is explained that lamp marking is required by various legislations and standards, the phasing out of lead-based inks could hinder marking in some cases: "*some companies from LightingEurope cannot always apply the required stamp in all situations*".

As for the possibility of using lead-free inks in all applications (e.g., green ink) in a later communication, LEU[1663] states that "*The usage of lead in ink is very much related to the manufacturing process, especially where in this process lamp marking is located [i.e. at what stage of manufacture the marking is applied – consultants comment]. When the marking is executed at the beginning of the production process, marking has to survive all further process steps, before the lamp leaves manufacturing line. In most lamp production lines the lead-free marking does not survive these next process steps between marking and fixation of the ink and the mark is not readable anymore. Due to that reason in T8/T12 lamps … lead based inks are used. When lamp marking process is located at the end of production line (e.g. T5 manufacturing) and different printing technology is used (e.g. pad printing), opportunity to use lead-free black ink exists. Existing manufacturing lines cannot be easily switched from (older) printing method (at the beginning of the lamp). This is only possible with high investment costs for such machines. Complete new printing equipment has to be installed for T8 and T12 lamps*."

29.3.2 Possible Alternatives for Eliminating RoHS Substances

LEU[1664] explains that marking the glass with etching/engraving does not seem to be technically feasible due to cracks. Further alternatives of ink marking that would eliminate the need for using lead based inks were not mentioned.

29.3.3 Environmental Arguments

LEU[1665] explains that lamps are in the scope of EU Directives 2002/96/EC - WEEE and 2012/19/EU – WEEE Recast. All lamps need to be collected and recycled, regardless if they use lead-free or lead-based inks for the marking. Take back systems are installed in all EU Member States to facilitate the collection and the proper handling of lamps at end-of-life (further details are given in the exemption renewal application dossier, but

[1662] Op. cit. LEU (2015b)
[1663] Op. cit. LEU (2016a)
[1664] Op. cit. LEU (2015b)
[1665] Op. cit. LEU (2015a)

are not detailed here as they concern lamps in general and do not provide specific details as to the fate of Pb from ink markings of lamps).

29.3.4 Socio-economic Impact of Substitution

LEU[1666] claims that substitution of lead based inks would result in socio-economic costs including an increase in fixed costs and possible social impacts within and external to the EU. After being asked to detail such possible costs, LEU[1667] elaborated that the impact on fixed costs is related to development needs and consequently possible changes to production equipment and processes. The social impact however is related to potential job losses if proper alternatives cannot be secured and the exemption (at the same time) is not granted.

29.4 Stakeholder Contributions

Three contributions were made to the stakeholder consultation.

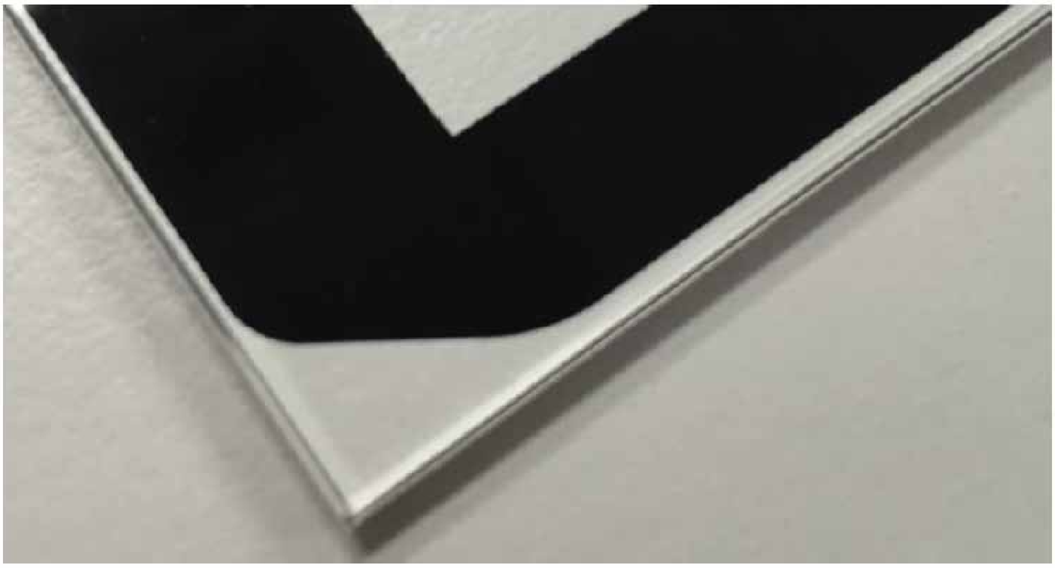
The Test and Measurement Coalition (TMC)[1668] includes the seven leading companies in the sector representing roughly 60% of the global production of industrial test and measurement products. It is TMC's understanding that according to the RoHS Directive, the exemptions listed in Annex III and Annex IV for which no expiry date has been specified, apply to sub-category 9 industrial with a validity period of 7 years, starting from 22 July 2017. This is also said to be explained in the RoHS FAQ, p. 26 http://ec.europa.eu/environment/waste/rohs_eee/pdf/faq.pdf. TMC, thus does not interpret the current exemption evaluation related to package 9 to concern category 9 industrial equipment and has not provided exemption specific information.

Irlbacher Blickpunkt Glas GmbH (IRL)[1669] is a manufacturer of technical glasses, e.g. control panels, for various applications (white goods, lightning, laboratory, medicine, sanitary industry, and others). IRL explains that among the manufacturing processes applied, the application of lead- and cadmium-containing inks on glasses like borosilicate, soda lime glasses and others are sometimes involved. Subsequently a high-temperature process is applied for enamelling. Inks used by IRL for enamelling glass may contain both lead and cadmium and thus the stakeholder suggests not changing the current exemption wording formulation. Inks for enamelling glasses are explained to contain glass frits, high temperature stable pigments and additives like solvents.

[1666] Op. cit. LEU (2015a)
[1667] Op. cit. LEU (2015b)
[1668] TMC (2015), Test & Measurement Coalition, General comments related to RoHS exemption package 9, submitted 16.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/General_Contribution_Test___Measurement_Coalition_package_9_exemptions_20151016.pdf
[1669] IRL (2015a), Irlbacher Blickpunkt Glas GmbH, Reply to Consultation Questionnaire Exemption No. 21 (renewal request), submitted 7.10.2915, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_21/Reply_to_Consultation_Questionnaire_Exemption_No._21_online.pdf

Whereas the latter will be removed[1670] during the enamelling process, glass frits and pigments will form a permanent connection with the glass, i.e. the substrate which was coated by the ink. Those inks may not only by used for marking lamps, but also for the decoration of (flat) glasses like soda-lime and borosilicate glasses (see Figure 29-2). In the latter case, inks will be applied on glasses for creating custom-built designs like logos or for the positioning of buttons, just to name a few examples. Glasses with lead- and cadmium-containing enamels are used in different fields of application, like household appliances, lighting equipment, medical devices, industrial instruments and others.

Figure 29-2: Example of decoration of borosilicate glass with black ink.

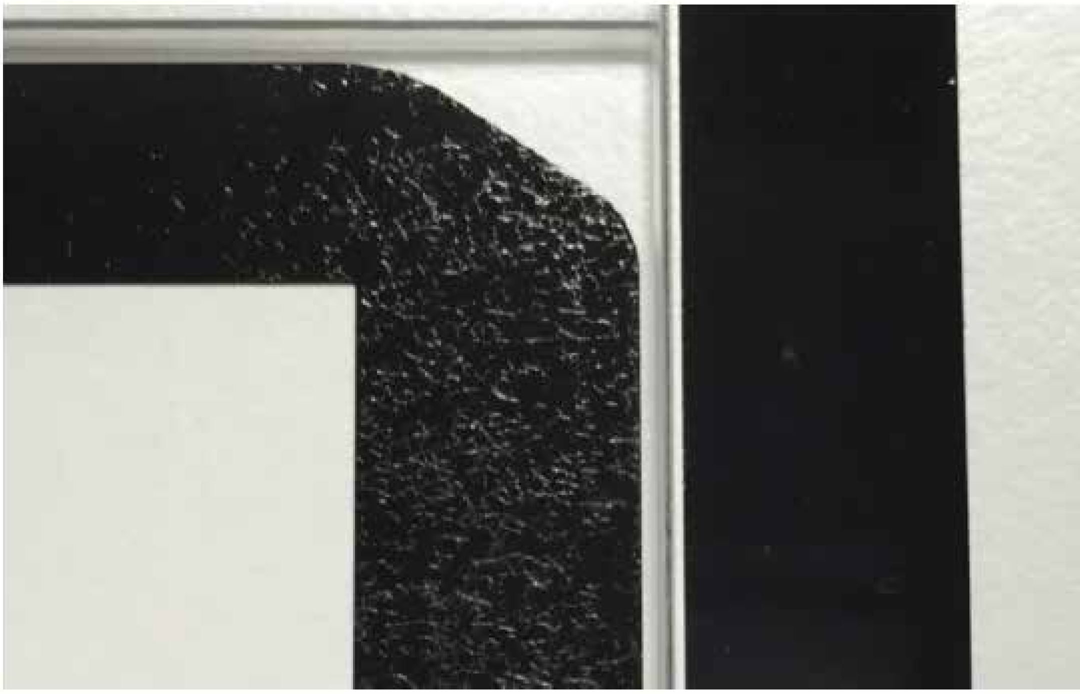


Source: IRL (2015a)

IRL[1671] confirm that lead-free alternatives are available on the market, but explain that they have some disadvantages which exclude their application for the decoration of (flat) glasses. First of all, and most crucial, the adhesion on the glass will be drastically reduced when using lead-free inks (Figure 29-3). Beside this there are some reasons, like higher enamelling temperature or reduced opacity, which contradict a stable and environmentally friendly process control. The opacity of lead-free inks is also explained to be too low to allow a replacement of lead-containing inks.

[1670] This is assumed to mean that the solvents evaporate during the process of application – consultant's comment.
[1671] Op. cit. IRL (2015a)

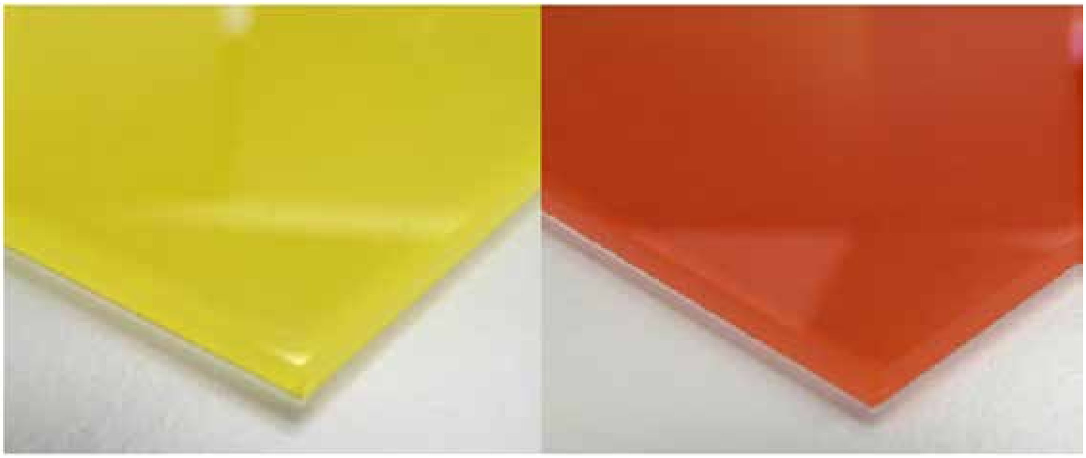
Figure 29-3: Comparison of lead-free (left) and lead-containing (right) ink. On the left side the ink shows a so called "chipping", i.e. peeling off from the substrate (borosilicate glass).



Source: (IRL (2015a)

IRL further explains that besides lead-containing glass frits, cadmium may be used in the pigment-component of inks. For the production of bright colourings, e.g. yellow, red or orange (see Figure 29-4) it is indispensable to use pigments with cadmium containing compounds. There are no alternatives available. Cadmium-free inks are not available for the production of bright colourings, thus cadmium-based pigments are essential. The stakeholder does not suppose the invention of cadmium-free equivalents in the future.

Figure 29-4: Enamels on borosilicate glass giving bright yellow (left) or orange (right) colourings



Source: (IRL (2015a)

IRL further contends that to the best of its knowledge, there are no ongoing research initiatives at present. In case of potential future research projects the adhesion as well as the opacity should be the major focus for the substitution of lead in inks. Lead-free inks could be used if significant improvement in adhesion and opacity can be obtained. Based on IRLs opinion cadmium cannot be removed from inks for enamelling glasses at present.

A second contribution was made by Hecker Glastechnik GmbH & Co KG (HGT)[1672], explained to be a specialist for heat-resistant and safety glass. HGT is a make-to-order supplier for the industry. HGT is a manufacturer of glass for lighting applications and technical products (e.g. glass for lighting, medical technologies, engineering and household and bath appliances as well as glass for automation). HGT's contribution outlines the same aspects raised in the IRL contribution, and are thus not repeated here. In short, HGT also support the renewal of the exemption with its current formulation, allowing the use of both lead and cadmium in printing inks applied as enamels to glass.

29.5 Critical Review

29.5.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead and cadmium in various articles and uses.

Entry 23 of Annex XVII of REACH restricts the use of Cd in application. Paragraph 1 regards various materials that can be summarised as plastic materials, thus not relevant for this exemption which relates to the use of Cd in ink enamels used on glass. Use in metal plating, in brazing fillers and in metal parts (jewellery, beads) is also restricted in later paragraphs, but understood not to be relevant to the application at hand.

However, according to Paragraph 2 of Entry 23, Cd:

> *"2. Shall not be used in paints [3208] [3209].*
>
> *For paints with a zinc content exceeding 10 % by weight of the paint, the concentration of cadmium (expressed as Cd metal) shall not be equal to or greater than 0,1 % by weight.*
>
> *Painted articles shall not be placed on the market if the concentration of cadmium (expressed as Cd metal) is equal to or greater than 0,1 % by weight of the paint on the painted article."*

This article is understood only to apply to paints with a zinc content above 10%. This is understood not to apply to the enamelling inks.

[1672] HGT (2015a), Hecker Glastechnik GmbH & Co KG, Reply to Consultation Questionnaire Exemption No. 21 (renewal request), submitted 13.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_21/HGT_Reply_to_Consultation_Questionnaire_Exemption_No__21.pdf

Entry 28 and entry 30 in Annex XVII of the REACH Regulation, stipulate that various cadmium compounds and lead compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. In the consultants' understanding, the restriction for substances under Entry 28 and Entry 30 of Annex XVII does not apply to the use of cadmium and lead in this application. Cd and Pb used in inks applied to glasses, in the consultants' point of view is not a supply of cadmium or lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Cd and/or Pb are encapsulated in a vitreous enamel material which is part of an article and as such, entry 28 and entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of REACH Annex XVII restricts the use of lead and its compounds in jewellery and also in "articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children". Though it is possible that some articles for which the current exemption is relevant may fall under this restriction, Paragraph 8(d) of Annex XVII excludes from the aforementioned restriction *"(d) enamels, defined as vitrifiable mixtures resulting from the fusion, vitrification or sintering of mineral melted at a temperature of* ***at least 500°C***;" from the restriction. As the enamels used in the applications relevant for the exemption are understood to be fused to the glass article, this exclusion would be understood to apply, as long as the application process occurs at a temperature which is above 500°C. In parallel, the lead restriction within REACH Annex XVII entry 63 provides, under Paragraph 8(k), for an exclusion of articles in the scope of various Directives, among others specifying Directive 2011/65/EU (RoHS 2). Thus, it is understood that regardless of the enamelling temperature that this restriction would not apply, leaving the regulatory process entirely to RoHS. This aligns with a communication from the European Commission on the relationship between RoHS and REACH:

> *"in those situations in which the RoHS restriction generally takes into account the protection of human health and the environment, at all stages, similarly to REACH restrictions, the latter should exclude EEE from their scope of application, indicating that the use of the substance in question in EEE is restricted by the RoHS Directive."*[1673]

No other entries, relevant for the use of cadmium and lead in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016).

Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection

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[1673] European Commission (date not specified) *REACH AND DIRECTIVE 2011/65/EU (RoHS): A COMMON UNDERSTANDING*, http://ec.europa.eu/DocsRoom/documents/5804/attachments/1/translations/en/renditions/native

afforded by the REACH Regulation. Where this is the case, an exemption could be granted for the use of Cd and for the use of Pb if other criteria of Art. 5(1)(a) apply.

29.5.2 Scientific and Technical Practicability of Substitution

LightingEurope explains that lead is present in printing inks applied in lamp marking as enamels to borosilicate, soda lime glass, and also to quartz glass, specifying that its presence is relevant in inks of black, silver and gold colour. LEU admits that other inks exist, such as green coloured inks, which are lead-free and which can be applied in some cases, however elaborates that this depends on the stage of lamp production at which the marking is applied. It can be understood that when the marking is applied towards the end of the lamp production process, green inks (lead-free) are suitable, making the use of lead-based inks unnecessary. In contrast however, when the marking is applied at the beginning of the production process, the lamp parts are still to go through the various production stages, and thus the durability of lead-free inks does not suffice. Though LEU does not expect the production of lamps using the lead-based marking to be phased out in the coming years, changing the printing methods used in the processes and/or their location at the beginning or end of the process is explained not to be practical; existing manufacturing lines cannot be easily switched from (older) printing methods located at the beginning of the lamp production process, as this would require high investment costs for such machines.

Two manufacturers, of technical glasses (IRL) and of heat-resistant and safety glasses (HGT) further explain that the exemption is also needed for applying lead- and cadmium-containing inks on glasses like borosilicate, soda lime glasses and others. Subsequent to application, they explain that a high-temperature process is applied for enamelling. Inks are understood to be used for decorative applications and in some cases also for applying safety warnings. For Cd based inks it is explained that the main function of the Cd is in enabling the production of inks of specific hues, e.g., of different tones of red, orange and yellow. Lead in contrast is explained to be important as an ingredient of printing inks of different colours, as it allows reducing the enamelling temperature, and further increases the adhesion of inks to glass, the durability and the opacity of markings.

In relation to Pb, HGT[1674] provides further detail as to the properties provided by lead, for which Pb-free inks are not yet comparable:

- **Adhesion** depends on the thermal expansion coefficient (α) of the substrate = glass. Pb-free inks do not adhere to substrates with a very low α.
- The **enamelling temperature** of the ink to the glass is approximately 50K higher for Pb-free versions (the exact value depends on various parameters like colour/hue, the kind of substrate, etc.). For some substrates the

[1674] Op. cit. HGT (2016a)

enamelling temperature cannot be increased arbitrarily as defects would be introduced [i.e. to the glass - consultant's addition].

- **Durability** of ink markings - according to HGT's experience, Pb-free versions are less stable towards hydrolytic weathering (hydrolytic class is reduced by approximately 1-2).
- **Opacity** of ink markings - the values depend on various parameters, but in one comparison (black Pb-containing ink vs. Pb-free ink) printed by HGT, the absorbance decreases from ~3 to <2 (values at 600nm).

IRL[1675] have also provided information supporting these statements. IRL further explains that the addition of Pb simultaneously affects all of the properties mentioned above. In contrast to the use of Cd, the use of Pb in inks is not related to colour, but it is a constituent (in terms of lead oxide) in the glassy component of the ink and thus affects the properties mentioned above. Consequently, it is not only used in black hues, although this is the most used colour. Generally Pb can be added independently of colour to improve the properties mentioned above. The following detail is given in relation to the properties above:

- **Adhesion** – "*the range of α is typically ~0 K^{-1} (so called glass ceramics, heat-resistant glass) to ~3 10^{-6} K^{-1} (borosilicate glass) to ~9 10^{-6} K^{-1} (sodalime glass).*
- *The **enamelling temperature** for Pb-free inks is ~700 °C; for Pb-containing inks it is ~650 °C[1676]. Temperatures above 650°C would damage the substrate, i.e. various errors like surface failures up to complete breakdown of the substrate can occur.*
- ***Durability** is a basic requirement which permits the use of an ink for the decoration of glass. In this case durability means all aspects of resistance against attacks like mechanical (abrasion) or chemical (hydrolysis, acidic or basic corrosion, all kinds of solvents, etc.) attacks*."
- In relation to **opacity, "***Absorbance (A) is defined as A = $-log_{10}$ T, where T is the transmission. A and T depend on wavelength, and 600 nm was meant as an example for a specific wavelength in the visible range of the electromagnetic spectrum. Absorbance is a measure for the opacity of an ink*."

In this sense it can be understood that where Pb is used in inks applied to glass for applications other than lamps, that the various properties that it enables in the applied enamel are of importance. The stakeholders explain that Pb-free enamels do not provide comparable performance where these properties are concerned, while also requiring enamelling at higher temperatures.

[1675] Op. cit. IRL (2016a)
[1676] In the original document the sentence referred in both instances to Pb-free inks. This was corrected in an email communication from 16.02.2016 sent by IRL and HGT.

In parallel, however, it can be understood that a substitute has been developed that would at least provide sufficient performance for some applications. Schott AG have registered patent number DE 102014101140 A1[1677] for a glass flux-based coating substrate, detailing the glass flux material and the method for coating a glass or glass ceramic substrate . It is explained that for the preparation of heat resistant transparent layers (as well as other components, e.g., bottles, pipes, etc.), glasses with low thermal expansion coefficients are used, particularly borosilicate glasses and aluminosilicate glasses. In some applications, such glasses are coated, at least in part, for example with black or white ink, used to create frame forms or for applying text to the glass. The use of conventional glass flow-based coatings on glasses with a low thermal expansion coefficient is not optimal in light of thermal expansion coefficient differences. In such cases a thin layer can be applied, but this does not suffice for producing a sufficiently opaque layer. This is particularly true for lead-free glass-flow materials. Lead-free examples are detailed, which have various disadvantages (an enamelling temperature above 750°C, which is too high for borosilicate glasses; high thermal expansion coefficients, which do not allow thicker and thus also opaque layers; resulting coatings are not sufficiently durable with regard to chemical resistance). For this reason a lead-free alternative was developed with a low thermal expansion coefficient that achieves an opaque application with a high abrasion and chemical resistance (durability). It can also be understood that the softening temperature of the developed substitute is below 680°C, and can be as low as 650°C in some cases.

Schott AG were thus contacted and asked for information to allow a comparison of the development with lead-based inks. Schott AG[1678] explains that the glass-flow coating has currently been developed with black, blue and white hues. The coating has been adapted for borofloat glasses, with an adhesion close to α=3.3. Schott AG states:

> "*Generally speaking we can say that we have (over)achieved same performance as enamels containing Pb, with regards to opacity, durability and adhesion, this was a clear target for the development of this enamel*."

The development is understood to already be applied in products made available on the EU market (2 home appliance customers in Europe with >50k pieces per annum). Schott AG has not yet decided if to make the glass-flow coating available to third parties, however it does not foresee a problem to fulfil the potential demand for such inks in applications on glasses in the EU, should the exemption not be renewed.

[1677] Schott AG (2015), Schott AG, Registered Patent DE 102014101140 A1 for "Mit einer glasflussbasierten Beschichtung versehenes Substrat, Glasflussmaterial sowie Verfahren zur Beschichtung eines Glas- oder Glaskeramiksubstrats, published 30.7.2015, available under: http://google.com/patents/DE102014101140A1?cl=de&hl=de

[1678] Schott AG (2016a), Schott AG, Answers to Questions Related to DE 102014101140 A1 in the Context of RoHS Annex III Exemption 21, submitted per email on 22.2.2016.

29.5.3 Environmental Arguments

LEU has provided some information related to the treatment of lamps with Pb-based markings at end of life. As this aspect is not understood to be directly related to the justification for the exemption, it is not discussed here.

29.5.4 Stakeholder Contributions

Three contributions were submitted to the stakeholder consultation. Contributions of HGT and IRL are discussed in the sections above as well as below.

The contribution submitted by TMC raises a legal question as to the availability of the current exemption to Category 9 equipment. The current exemption is not specific to a certain product or component, but only to the application of certain materials (enamels) on glass. Such applications may be used in Cat. 9 products (or in Cat. 8 products), and this is also raised by HGT and IRL who refer to medical and laboratory applications among others. In this sense the consultants interpret the contribution as support for the exemption, and note that a change in the wording formulation could affect articles falling under categories 8 and 9.

29.5.5 The Scope of the Exemption

LightingEurope originally applied for the exemption with a formulation as currently appears in Annex III of the RoHS Directive:

> "*Lead and cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses*"

In contrast, their provided argumentation only concerns the application of Pb in printing inks applied as enamel to certain glasses, and thus after being asked, it was confirmed that where lamp marking was concerned, that the exemption could be limited to Pb. In parallel, LEU specified that in lamps, Pb-based printing inks could be applied in markings on borosilicate and soda lime glass, as well as on quartz glass, which was not originally included in the exemption formulation. Prior to the stakeholder consultation, they thus proposed an adjusted formulation, which is understood to cover applications for which LEU has requested the exemption renewal:

> *"Lead in printing inks for the application of enamels on glasses"*

In this sense, where the exemption is needed for lamp marking applications, these changes could be taken into consideration in order to restrict a possible renewal of the exemption to lead and to certain glass types where it is needed for lamps.

In parallel, it is understood that the exemption is also needed for other types of applications. Since it can be understood that Cd is not needed for all printing ink colours and lead-free inks are available that could be applied in some cases, both HGT and IRL

were asked to further specify their information to allow a better understanding as to the scope of applications for which the exemption is needed.

In relation to Cd, HGT[1679] explains:

> "*Some worldwide introduced logos like the logo of AEG, 3M, Sparkasse, Vodafone, Shell, Coca Cola, and a lot of others are presented in colour tones which cannot be printed with ceramic colours without Cadmium-containing pigments. To be more specific, most of the RAL colour tones from 1000 to 3031 are affected. Besides those customer-specific needs there are some standards which define the use of RAL colours. For example DIN 4844-2 defines the colours for warning signs, where black triangles are to be printed on a yellow (RAL 1003 "Signalgelb") background. RAL 1003 can be printed by ceramic colours only by using Cadmium-containing inks*".

To summarize, HGT claims that specific hues, for example RAL 3020 ("Verkehrsrot") or RAL 1003 ("Signalgelb") are not available in Cadmium-free versions. IRL have also specified these aspects in their response.[1680]

When asked whether these applications types can be considered exhaustive, IRL[1681] stated that "there are plenty of other applications, for example printing of flags, the usage of a specific hue for filter glasses (i.e. the colour printed is opaque for a certain range of electromagnetic radiation) or any imaginable custom-specific design (e.g. a customer asks for colour which is identical to an existing housing etc.). Consequently IRL cannot give an exhaustive list of applications."

HGT[1682] and IRL[1683] further provide lists of hues (RAL specification) for which Cd-free alternatives are not available (See Appendix A.7.0). When requested to exhaustively detail standards specifying the use of Cd-based hues for certain applications (i.e. for safety related applications), HGT[1684] provided Table 29-1, explained to give a link between several colours and corresponding standards, which require that colour. HGT however notes that the list is not exhaustive and believes there are many more standards, which they are not aware of:

> "*Quite an important field of application, which is not regulated by any standard, is the realization of custom-specific designs: just to name two examples, RAL 2011 (dark-orange) is required for municipal vehicles and RAL 3003 (ruby red) for ambulance*."

[1679] HGT (2016a), Hecker Glass Technik GmbH & Co KG, Answers to 1st round of clarification questions, submitted per email 18.1.2016
[1680] IRL (2016a), Irlbacher Blickpunkt Glas GmbH, Answers to 1st round of clarification questions, submitted per email 18.1.2016
[1681] Op. cit. IRL (2016a)
[1682] Op. cit. HGT (2016a)
[1683] Op. cit. IRL (2016a)
[1684] Op. cit. HGT (2016a)

Table 29-1: Use of Cd-based printing inks on glass specified in standards:

RAL number (colour)	Standard in which colour referred to	Stated purpose of colour specification	Further comments
RAL 1003 (signal yellow), RAL 1004 (goldyellow), RAL 1007 (narcissusyellow)	*DIN 4844-2*	*Colours for warning signs, where black triangles are to be printed on a yellow background.*	*Only available as Cd based ink*
RAL 1003 (rape yellow), RAL 3000 (firered), RAL 3001 (signalred), RAL 2003 (pastel orange)	*DIN 2403*	*Identification of tubes*	*Only available as Cd based ink*
RAL 1023 (traffic yellow), RAL 2009 (trafficorange), RAL 3020 (traffic red)	*DIN 6171*	*Surface colours for traffic signs and traffic installations*	*Only available as Cd based ink*
RAL 2010 (signal orange), RAL 3001 (signalred) , RAL 3002 (chimney red)	*DIN 5381*	*Identification colours*	*Only available as Cd based ink*

HGT and IRL[1685] provide more detail on such applications in a later communication. They explain that the use of the colours/ink is not limited to a specific application, and that they may be used inside and outside of the vehicle. The range of applications is said to be huge, with typical examples including printed signs on side windows (outside) or control panels/displays for electronic devices (inside).

In the consultants' opinion, not all of these additional applications would be covered by exemption 21. Uses for municipal vehicles and for ambulances are not understood to be covered by the exemption as these vehicles are not regulated under RoHS. If the statement regards equipment installed in these vehicles, some equipment may be RoHS regulated, assuming it is installed as a later addition to the vehicle and in this respect is also available to consumers on the market as equipment. If equipment is specifically designed for and installed only within these vehicles, it could be that it is excluded from the scope of RoHS through article 2(4)(c).[1686] In any case, the consultants cannot follow why equipment within these vehicles would need to have a specific colour in order to

[1685] HGT & IRL (2016a), Hecker Glass Technik GmbH & Co KG & Irlbacher Blickpunkt Glass GmbH, Reply to 3rd Round of Clarification Exemption No. 21 (renewal request), submitted per email 16.2.2016.
[1686] Article 2(4)(c) of Directive 2011/65/EU (RoHS 2): "Equipment which is specifically designed, and is to be installed, as part of another type of equipment that is excluded or does not fall within the scope of this Directive, which can fulfil its function only if it is part of that equipment, and which can be replaced only by the same specifically designed equipment."

fulfil their function. Furthermore, it is not clear how relevant "printing of flags" or custom-specific design would be, as it is assumed that not in all of these cases is the glass part of an EEE, whereas, only printing on glasses, which are part of an EEE are of concern to this request. Finally, for the use of "Cd and lead in filter glasses" more detail was requested. Cd in filter glasses is addressed by Ex. 13b, which was also recently subject to evaluation. In this sense, it is important to understand if and how the use of these substances in filter glasses to be used in EEE would differ from the scope of articles falling under Ex. 13b. HGT and IRL were thus asked to provide further detail and explained the following:

> *"Such articles may fall under all categories of RoHS Annex I, depending on their application. Just to name a few examples filter glasses could be used in lighting applications and colour effect or food filter glasses."*[1687]

> *"Various inks, among others Cd-based ones are used to coat glasses to lend the glass filtering functions. Through the coating, the glass will then allow certain wavelengths to pass through, while blocking others, depending on its colour or tone. The coatings usually appear semi-transparent to the eye, however where a light source is concerned shall only let certain wavelengths pass through, and are thus considered opaque to these wavelengths. In certain cases, coatings may appear opaque to the human eye, where they are used to block the visible light wavelength range and to only let non-visible wavelengths pass through. Coated filter glass is used as a component of lighting applications installed in displays and control panels of various equipment."*[1688]

> *"From our point of view filter glasses covered by Ex. 13b throughout tinted glasses, i.e. Cd- or Pb-containing substances are added during the production of the glass itself. On the other hand "filter glasses" in our terminology are coated glasses (coating = ceramic ink, which may contain Cd or Pb)".*[1689]

HGT and IRL later agreed that the term "colour printed glass" would be more appropriate for such glasses, in order to distinct them from filter glasses addressed under Ex. 13(b).[1690]

In the consultants view, the justification for applications of this last group would be similar to the justifications given for Ex. 13b in relation to Cd in filter glasses. Cd is used as it allows a more accurate separation between the spectrum, which should pass through and that, which should be blocked. Alternative additives, as explained under the report for Ex. 13b, do not provide the same "sharp cut-off" accuracy. Use of organic pigments in various ways would also not be comparable as these are explained to fade

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[1687] Op. cit. HGT & IRL (2016a)
[1688] HGT & IRL (2016b), Hecker Glass Technik & Irlbacher Blickpunkt Glass, Reply to 4th Round of Clarification Questions Regarding Exemption No. 21 (renewal request), submitted per email 17.2.2016
[1689] Op. cit. HGT & IRL (2016a)
[1690] Op. cit. HGT & IRL (2016b)

with time and to be thermally unstable.[1691] The consultants can thus follow that substitutes are not yet available for such applications and that an exemption would be justified, however that it would be important to address such applications more clearly in order for them to be distinguished from filter glasses covered under Ex. 13(b). In the consultants opinion it would be possible to address such applications both in respect to the application of printed colour on glass and in respect of the components in which such colours are used, thus limiting the scope to:

> "*the use of Cd in colour printed glass with filtering functions, used as a component in lighting applications installed in displays and control panels of EEE*".

In theory, there are different approaches to applying filter applications and light conversion applications to lighting. For example, for down conversion with Cd-quantum dots, manufacturers mention three strategies: on-chip, on-edge, and on-surface.[1692] In the on-chip strategy it can be assumed that the converting element may be sold with the LED (the chip) and would thus be understood as a lighting application, falling under Cat. 5. In on-surface however, a down-converting layer is assembled as a sheet in the display and it is assumed that this would be sold separately from the light source and would thus be a display component but not necessarily a lighting component. Applications of filter coating could thus also be relevant in some cases. The Cd-coating could thus in some cases by considered part of the lighting application, falling under Cat. 5, but in others it could be a separate component, related to the display or control panel and falling under a different category. Displays and control panels are therefore understood to be in use in different equipment and thus the exemption should be available to all categories. An exemption for this application could be left in Ex. 21, in light of the printing aspect, however it may be beneficial to add this application to Ex. 13b, as the justification is the same and substitutes that may be developed in the future could be of relevance for both types of filter applications.

In applications other than lamp markings, explained to be in scope, Pb is understood to enable a number of properties, some of which can reduce the energy consumption of

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[1691] See Baron et al. (2016) Baron, Y.; Gensch, C.-O.; Moch, K. in collaboration with Gibbs, A. and Deubzer, O.; Eunomia Research and Consulting Ltd. in cooperation with Oeko-Institut e.V. & Fraunhofer IZM, Assistance to the Commission on technological, socio-economic and cost-benefit assessment related to exemptions from the substance restrictions in electrical and electronic equipment (RoHS Directive) – Pack 7, Commissioned by: EU Commission, DG Environment, Brussels, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/reports/20160129b_RoHS_Exemptions_Pack7_Final_Report.pdf

[1692] Baron et al. (2014), Baron, Y.; Blepp, M.; Gensch, C.-O.; Deubzer, O.; in collaboration with Hogg, D.; Eunomia Research & Consulting Ltd. in cooperation with Oeko-Institut e.V. & Fraunhofer IZM; Assistance to the Commission on technological, socio-economic and cost-benefit assessment related to exemptions from the substance restrictions in electrical and electronic equipment (RoHS Directive)-Pack 4, Commissioned by: European Commission, DG Environment, Brussels pg. 49-50, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IX/20140422_RoHS2_Evaluation_Ex_Requests_2013-1-5_final.pdf

manufacturing processes (enamelling temperature) and some of which influence the reliability of enamels created with such inks (adhesion, durability, opacity). In this respect Pb-based inks are understood to have advantages over most Pb-free inks, however, in parallel, it can be understood that a substitute has been developed which, based on the provided information, provides comparable performance when applied on borofloat glasses. The substitute is already applied on borofloat glasses used in products made available on the EU market, however, information was not available in sufficient detail to clarify that the substitute would provide the same reliability when applied on other types of glasses. It would also be of interest to understand if the substitute could be used in the lamp marking process to substitute lead-based inks when these are applied at the beginning of the manufacturing process.

29.5.6 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

The information provided by LEU specifies that inks of various colours are used in lamp marking, some of which are actually lead-free. In other words, it can be understood that some alternatives have become available. The application of such inks is explained only to be possible when the marking stage is at the end of the lamp production process. In cases where the marking stage is at the beginning of the process, the reliability of the lamp marking does not suffice to ensure durability and legibility throughout the lamp life-time, mainly as the following manufacture stages may damage the marking.

Though the consultants can follow that the reliability of Pb-based inks (black, silver, gold) may be higher than the reliability of Pb-free inks (green), it can also be understood that this added reliability is only needed to avoid damage during the manufacturing stages. This is confirmed as LEU admits that in cases where the marking is applied at the end, the green ink, which is lead free, can be used.

LEU specifies that:

> "*Existing manufacturing lines cannot be easily switched from (older) printing method (at the beginning of the lamp). This is only possible with high investment costs for such machines. Complete new printing equipment has to be installed for T8 and T12 lamps*".

In this sense it is understood that the reason for not switching to printing methods, that would allow the use of lead-free inks, is mainly an economical one. Article 5(1)(a) specifies that socio-economic aspects can be taken into consideration. However, as none

of the three primary criteria are fulfilled, the costs of substitution alone do not suffice to justify an exemption.

In relation to the use of Cd in printing inks used as enamels on glass, the consultants understand that Cd is used in printing inks to achieve certain hues of the enamel in various application areas. It can be followed that safety aspects and warning aspects may be required to be communicated with the use of certain hues, which are considered to increase visibility. This is assumed to be the reason why various standards, that regulate the safety of certain applications, specify certain colours for such purposes. It can also be followed that Cd is used for printing on glasses to create filtering functions, as substitutes for Cd in such applications would not provide comparable filtering accuracy or would be less reliable. Thus, where certain hues cannot be manufactured with Cd-free inks, the exemption could be renewed for all relevant applications. If this aspect however is not understood to be relevant as a technical aspect related to the availability of substitution, the EU Commission could limit the applicability of the exemption to Cd-based printing inks, where used to comply with standards and norms requiring the use of specific hues for safety applications and where used as a coating to produce filtering functions.

Where Pb inks are used on applications other than glass of lamps, it can be followed that Pb is necessary to provide various qualities of the marking. The presence of Pb allows reducing the enamelling temperature, which in turn would mean that less energy is consumed for this process in comparison with Pb-free leads where the enamelling temperature is higher. Pb also affects the durability and the opacity of the marking, as well as its adhesion to the glass. Though information available indeed supports that most Pb-free alternatives would not be comparable, a substitute is understood to have become available that can be applied on borofloat glasses and that provides comparable reliability. Though this alternative may be sufficient to allow substitution of all Pb-based inks used for enamel applications (i.e. in the full range of glass coating applications), the consultants can follow that some time would be needed to allow establishing that the alternative would be sufficiently reliable in [applications] other than borofloat glasses. A short termed exemption would thus be recommended for Pb-based inks used on other than borofloat glasses to allow establishing that the substitute is sufficiently reliable.

In the case of Cd-based inks, since information relating to the development of possible alternatives is currently not available, it can be followed that the exemption may be needed for at least 5 years, however as the applicant and the participating stakeholders did not provide any information to suggest that they are involved in research into substitutes, it could also be considered to provide the exemption for a shorter duration so as to create an incentive for stakeholders to develop a strategy for research and development of substitutes to allow substitution in the future.

29.6 Recommendation

As explained above, although lead-free substitutes exist for lamp markings, it can be understood that their application on lamp glass needs to be at the end of the lamp production process. In other words, when applied at the end of the process, substitutes exist and are understood to be reliable. Though implementing equipment changes to production lines may require significant investments, this is not understood to fulfil one of the three primary criteria for justifying an exemption. The consultants would thus recommend revoking this exemption. As the lighting industry is undergoing a transformation (from conventional technologies to LED) and as some lamp types can be expected to be phased-out within the next few years, the Commission may decide to renew the exemption despite the lacking technical justification, so as to avoid such costs for technologies approaching phase-out.

It can also be understood that substitutes for Pb in printing inks for the application of enamels on other than lamp glass applications are available in some cases, however that their reliability must be established for other than borofloat glasses. In their patent, Schott AG detail that borosilicate glasses include Borofloat33®, Borofloat40®, Fiolax®, Duran® oder Pyrex. Characteristic of borosilicate glasses is their significant share of silica (SiO_2) and boric acid (B_2O_3 > 8%) as glass constituents. The consultants' understand the various glass types to be trademark names and is of the opinion that the substitute would thus be applicable to all borosilicate glass types.

As for Cd in printing inks for the application of enamels on glasses, these are understood not to be available for all hues of red, orange and yellow tones. Such tones are particularly necessary to comply with standards where colours are specified in relation to safety aspects. It can also be understood that some customers specify a certain hue in custom products, for example where a logo is printed on glass or where a glass element is to correspond to colours of other elements to be adjacent to it in use. Furthermore, there are no comparable substitutes for Cd inks used in colour printed glass applied to obtain filtering functions, when these are used as a component in lighting applications installed in displays and control panels of EEE.

The justification for the exemption where Cd is used as an ink to provide certain hues and colours is that alternatives do not provide sufficient colour compatibility. If this property can be judged as indispensable, then Ex. 21 could be renewed for Cd-based inks in all applications. If this is not a valid justification, it would be recommended to restrict the exemption for Cd in enamels used for printing of safety warnings and signs, as prescribed in various harmonised standards and norms which are valid in the EU. It would also be recommended to renew the exemption for "the use of Cd in colour printed glass with filtering functions, used as a component in lighting applications installed in displays and control panels of EEE". However, it may be beneficial to add this as a further item to Ex. 13b, which is closely related to this application in terms of the applicability of substitutes.

The following exemptions could thus be granted / renewed:

Exemption n. 21	Duration*	Comments
I. *Cd when used in colour printed glass to provide filtering functions, used as a component in lighting applications installed in displays and control panels of EEE*	*For Cat. 1-7 and 10: 21 July 2021*	The EU Commission should consider if it would not be more beneficial to add this entry to Ex. 13b.
II. ***Alternative A:*** *Cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses, when used to comply with harmonised standards specifying the use of particular hues for safety applications.* ***Alternative B:*** *Cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses, excluding Cd used in colour printed glass to provide filtering functions.*	*For Cat. 1-7 and 10: 21 July 2021*	The EU Commission could consider providing a shorter validity period so as to promote the supply chain to develop a strategy for research and development of alternatives for Cd-based inks.
III. *Lead in printing inks for the application of enamels on other than borosilicate glasses.*	*For Cat. 1-4, 6,7 and 10: 21 July 2019*	The recommended period should suffice to establish the reliability of Pb-free substitutes in other than borosilicate glasses.
IV. *Lead and cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses*	*For Cat. 8 and Cat. 9: 21 July 2021* *For Sub-Cat. 8 in-vitro: 21 July 2023* *For Sub-Cat. 9 industrial: 21 July 2024*	As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.

29.7 References Exemption 21

Baron et al. (2014) Baron, Y.; Blepp, M.; Gensch, C.-O.; Deubzer, O.; in collaboration with Hogg, D.; Eunomia Research & Consulting Ltd. in cooperation with Oeko-Institut e.V. & Fraunhofer IZM, Assistance to the Commission on technological, socio-economic and cost-benefit assessment related to exemptions from the substance restrictions in electrical and electronic equipment (RoHS Directive) - Pack 4, Commissioned by: European Commission, DG Environment, Brussels pg. 49-50, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IX/20140422_RoHS2_Evaluation_Ex_Requests_2013-1-5_final.pdf

Baron et al. (2016) Baron, Y.; Gensch, C.-O.; Moch, K. in collaboration with Gibbs, A. and Deubzer, O.; Eunomia Research and Consulting Ltd. in cooperation with Oeko-Institut e.V. & Fraunhofer IZM, Assistance to the Commission on technological, socio-economic and cost-benefit assessment related to exemptions from the substance restrictions in electrical and electronic equipment (RoHS Directive) – Pack 7, Commissioned by: EU Commission, DG Environment, Brussels, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/reports/20160129b_RoHS_Exemptions_Pack7_Final_Report.pdf

HGT (2015a) Hecker Glastechnik GmbH & Co KG, Reply to Consultation Questionnaire Exemption No. 21 (renewal request), submitted 13.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_21/HGT_Reply_to_Consultation_Questionnaire_Exemption_No__21.pdf

HGT (2016a) Hecker Glass Technik GmbH & Co KG, Answers to 1st round of clarification questions, submitted per email 18.1.2016

IRL (2015a) Irlbacher Blickpunkt Glas GmbH, Reply to Consultation Questionnaire Exemption No. 21 (renewal request), submitted 7.10.2915, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_21/Reply_to_Consultation_Questionnaire_Exemption_No._21_online.pdf

IRL (2016a) Irlbacher Blickpunkt Glas GmbH, Answers to 1st round of clarification questions, submitted per email 18.1.2016

HGT & IRL (2016a) Hecker Glass Technik GmbH & Co KG & Irlbacher Blickpunkt Glass GmbH, Reply to 3rd Round of Clarification Exemption No. 21 (renewal request), submitted per email 16.2.2016

HGT & IRL (2016b) Hecker Glass Technik GmbH & Co KG & Irlbacher Blickpunkt Glass GmbH, Reply to 4th Round of Clarification Questions Regarding Exemption No. 21 (renewal request), submitted per email 17.2.2016

LEU (2015a) LightingEurope, Request to renew Exemption 21 under the RoHS Directive 2011/65/EU Lead and cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses, submitted 15.1.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_21/21_LE_RoHS_Exemption_Req_Final.pdf

LEU (2015b) LightingEurope, Answers to 1st Questionnaire Exemption No. 21 (renewal request), submitted 10.8.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_21/20150810_Ex_21_LightingEurope_Answers_to_1st_Clarification-Questions.pdf

LEU (2016a) LightingEurope, Answers to 2nd round of clarification questions, submitted per email on 29.1.2016

Schott AG (2015) Schott AG, Registered Patent DE 102014101140 A1 for "Mit einer glasflussbasierten Beschichtung versehenes Substrat, Glasflussmaterial sowie Verfahren zur Beschichtung eines Glas- oder Glaskeramiksubstrats, published 30.7.2015, avail. under http://google.com/patents/DE102014101140A1?cl=de&hl=de

Schott AG (2016a) Schott AG, Answers to Questions Related to DE 102014101140 A1 in the Context of RoHS Annex III Exemption 21, submitted per email on 22.2.2016.

TMC (2015) Test & Measurement Coalition, General comments related to RoHS exemption package 9, submitted 16.10.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/General_Contribution_Test___Measurement_Coalition_package_9_exemptions_20151016.pdf

30.0 Exemption 24 “Pb in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

CTE	coefficient of thermal expansion
CCTV	closed circuit television, video surveillance systems
EMI	electromagnetic interference
HMPS	high melting point solders
LHMPS	lead-containing high melting point solder(s)
MLCC	multi-layer ceramic capacitors

30.1 Description of the Requested Exemption

Knowles et al. [1693] apply for the continuation of Exemption 24 in its current wording and scope. The current wording of Exemption 24 is

> *“Lead in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors”*

[1693] Knowles Capacitors et al. 2015a: 2015 “Request for continuation of exemption 24, document "24_RoHS_V_Application_Form_E24_final_160115.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_24/24_RoHS_V_Application_Form_E24_final_160115.pdf

30.1.1 Background and History of the Exemption

The exemption was not yet listed in the Annex of RoHS 1 when it was published in 2003. The exemption was requested and reviewed in 2005/2006, and the Commission followed the reviewers' recommendation[1694] to grant the exemption with the same wording and scope as still valid in the current exemption. The exemption was renewed without changes after the next review in 2008/2009[1695], and was adopted into Annex III of RoHS 2 in 2011. Its foreseen expiry date would have been July 2016 if no requests for renewal had been submitted.

30.1.2 Technical Description of the Exemption

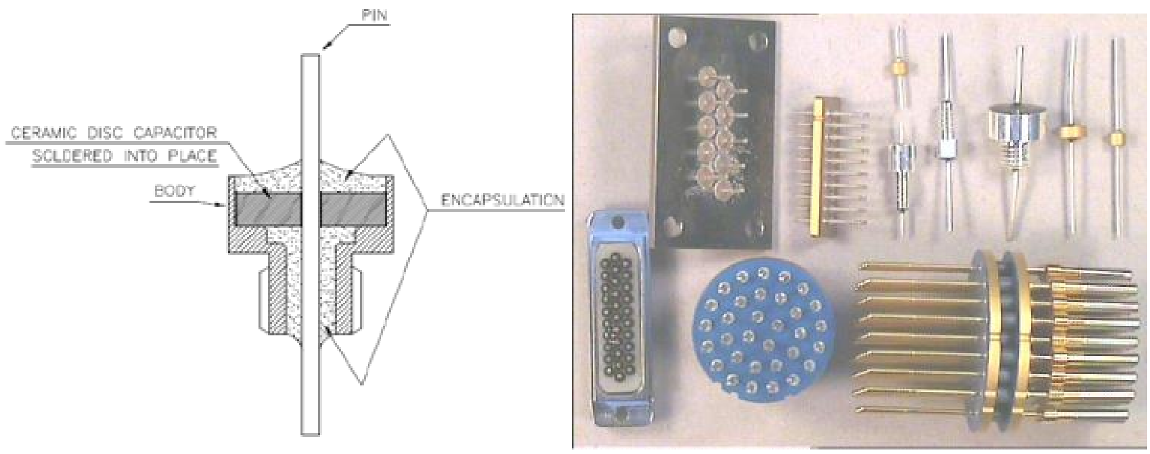
Knowles et al.[1696] use indium-lead solders with 40 % to 50 % lead content (In60Pb or In50Pb, the latter being the preferred alloy), which provides the combination of a suitable melting point and ductility. The ductility of this solder avoids cracking of the ceramic layer during and after soldering due to thermal mismatch between the ceramic capacitor and the copper pin.

Knowles et al.[1697] explain that discoidal and planar array capacitors are derivations of MLCC's (multi-layer ceramic capacitors) with the opposing terminations made to the outside periphery and the inside diameter of holes drilled through the ceramic body. They are specialist capacitors used in EMI (electromagnetic interference) filters and EMI filtered connectors for high end applications, where the elimination of electrical interference is critical. Typical applications for assemblies incorporating these components and covered by the RoHS directive include professional audio equipment, maritime monitoring (coastguard radar) and CCTV (closed circuit television, video surveillance) systems. In application, signal carrying feedthrough pins are passed through the ceramic element and connected to the internal bore to make a mechanical and electrical connection. This connection must have low electrical resistance and inductance for optimum performance, as high resistance / inductance will inhibit the high frequency electrical path to ground through the filtering capacitor. Traditionally this connection is made by lead solder, as lead-free solders cause cracks in the ceramic element.

[1694] Gensch, Carl-Otto [Oeko-Institut e.V.], et al. 2006 "Adaptation to scientific and Technical progress under Directive 2002/95/EC: Final Report - final version, RoHS I," http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf page 14 et sqq.
[1695] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009) Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, RoHS III, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM, http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf
[1696] Knowles Capacitors et al. 2016a "Answers to Second Questionnaire, document "Exe_24_Questionnaire-2_Knowles-et-al_Response_2016-02-09.pdf", received by Dr. Otmar Deubzer, Fraunhofer IZM, via e-mail from Stephen Hopwood, Knowles Capacitors, on 9 February 2016" unpublished manuscript,
[1697] Op. cit. Knowles Capacitors et al. 2015a, page 214 et sqq.

Knowles et al.[1698] as component suppliers are not aware of all applications where this product is used, but in general it is for high end applications where performance is more important than cost. They are not generally used in low cost consumer electronics. Knowles et al. include category 11 to cover unknown applications. Figure 30-1 shows EMI filters as one typical application in the scope of exemption 34.

Figure 30-1: EMI filter outline (left) and examples of EMI filters and assemblies



Source: Knowles et al.[1699]

A detailed description of the technical background can be found in the report of the last review in 2008/2009.[1700]

30.1.3 Amounts of Lead Used under the Exemption

According to Knowles et al.[1701], the lead content varies with filter design, but typically is 5 mg to 10 mg per solder joint, equating to ~1.0 % of the total component weight (maximum). More complex designs such as filter connectors will be proportionally less as a percentage of the total weight. The total amount of lead put on the EU market under the exemption is estimated to be less than 50 kg as quantified from the information in the following paragraphs.

[1698] Ibid.

[1699] Knowles Capacitors et al. 2015b: "Addendum to request for continuation of exemption 24, document "Application Note AN0011 Solder Alloy Choice for Through Hole Ceramic Discoidal & Planar Array Capacitors.pdf": Addendum to request for continuation of exemption 24," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_24/Application_Note_AN0011_Solder_Alloy_Choice_for_Through_Hole_Ceramic_Discoidal__Planar_Array_Capacitors.pdf

[1700] Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009)

[1701] Op. cit. Knowles Capacitors et al. 2015a

Knowles et al.[1702] have no accurate data available to indicate the amount of lead entering the EU in this type of application, however most applications of these components are not covered by the RoHS directive. There are two major players in the supply of planar arrays for EMI filtered connectors, and customers informed Knowles et al. that they account for ~60 % of the market. The average manufacturing of Knowles et al.[1703] is 357,000 capacitive holes per week, amounting to 18.6 million capacitive holes per year, indicating the market is around 31 million capacitive holes per year. The nature of these components is such that they are mainly used for high end applications such as aerospace and military, where technical performance outweighs cost. Knowles et al.[1704] estimate from feedback that only around 4 % of parts are supplied into applications covered by the RoHS directive, corresponding to around 1.25 million capacitive holes. Each hole takes up to 10 mg of lead in a typical solder joint, the total lead from filtered connectors entering RoHS applications per year thus being around 12.5kg maximum

With regard to EMI single line filters, Knowles et al.[1705] estimate the global market at $70 million with a typical selling price of $1.50 per line. From this, using the same 4 % estimate of parts shipping to RoHS applications, indicates the number of lines soldered would be ~1.9 million per year. Again, based on the same lead weight per solder joint of 10mg, this equates to around 19 kg of lead maximum.

Adding the two figures together gives the estimate of 32kg per year supplied into applications covered by the RoHS directive. Allowing for errors and assumptions, Knowles et al.[1706] apply a figure of less than 50 kg.

According to Knowles et al.[1707], these calculations take into account feedthrough lines (unsoldered) and filtered connectors making use of spring clip technology. They do not take into account filters manufactured using high melting point solders with a lead content of at least 85 % where the high melting point solder is needed to allow step soldering of the finished article or during final assembly of the finished article. This application is covered by exemption 7a.

Knowles et al. [1708] state that lead-containing high melting point solder (LHMPS) have the same ductility benefits as indium-lead alloys, but obviously the higher lead content and high processing temperatures (high energy usage) mean this is not a sensible substitution to make on the basis of environmental concerns.

Without exemption 24, the amount of lead used for soldering to machined through hole discoidal and planar array ceramic multilayer capacitors would increase, as the LHMPS

[1702] Ibid.
[1703] Ibid.
[1704] Ibid.
[1705] Ibid.
[1706] Ibid.
[1707] Ibid.
[1708] Ibid.

with at least 85 % of lead content would have to be used instead of the indium-lead solders used under exemption 24 which have a maximum weight share of 50 % lead.

30.2 Applicants' Justification for the Continuation of the Exemption

30.2.1 Elimination of Lead

According to Knowles et al.,[1709] [1710] where it is technically necessary to use solder, there are no known replacements for lead containing alloys. In some cases it has, however, been possible to replace solder with mechanical connections, i.e. spring clips and canted coil springs. Canted coil springs fulfil the same function as spring clips. There are no other purely mechanical methods of connecting to the smooth plated inside bore of the ceramic capacitor and the plated surface of the through lead. The spring clip/coil technology allows making solderless connections.

According to Knowles et al.[1711], the clips and coils have been used in EMI filtered connector applications to make the contact between the planar capacitor array and the through connector pin where they were suitable based on the product requirements. They are the ultimate in reducing stress on the ceramic, but there are limits to their use:[1712, 1713]

1) The technique takes up more physical space, reducing available capacitance and reducing the electrical performance of the device. For this reason the use is limited to larger size filtered connectors with wide contact pitch and lower filtering requirements.
2) The technique does not provide a 100 % grounding ring, so can reduce EMI performance and allow high frequency noise to pass through.

Knowles et al.[1714] claim that the usability of spring clips depends on many factors which may interact:

- Component size;
- Contact (pin) size;

[1709] Ibid.
[1710] Knowles Capacitors et al. 2015c: 2015 "Answers to first questionnaire (clarification questionnaire), document "Ex_24_Knowles-et-al_Questionnaire-1_2015-08-10_response.pdf": Clarification questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_24/Ex_24_Knowles-et-al_Questionnaire-1_2015-08-10_response.pdf
[1711] Knowles Capacitors et al. 2016c "E-mail communication, document "E-mail-communication_Knowles.pdf, received by Dr. Otmar Deubzer, Fraunhofer IZM, from Steve Hopwood, Knowles Capacitors, until 16 March 2016" unpublished manuscript,
[1712] Op. cit. Knowles Capacitors et al. 2015a
[1713] Op. cit. Knowles Capacitors et al. 2015c
[1714] Ibid.

- Working voltage;
- Pin pitch;
- Required capacitance / filtering performance; and
- Whether the clip can be isolated from any sealants, epoxies or coatings that are required to achieve the desired performance within the available size envelope.

Knowles et al.[1715] state that single line filters are not made using clips as the dimensions of the units do not allow it. Single line filters also do not allow for isolation of the clip from sealing resins and are too small to allow use of a clip whilst maintaining the necessary capacitance values. Larger filtered units, for example multiway filtered connectors, may use mechanical connections if the mechanical and electrical requirements allow it. However there is a general trend for smaller connectors with tighter pitches that precludes the use of mechanical connections due to the physical and electrical requirements. The clip technique takes up more physical space, reducing available capacitance and the electrical performance of the device. For this reason the use is limited to larger size filtered connectors with wide contact pitch and lower filtering requirements. Additionally, the clip technology can reduce EMI performance and allow high frequency noise to pass through.

Knowles et al.[1716] claim that the evaluation where clips/coils can be used is complex to a degree that it cannot be governed down to a set of rules as there are too many parameters that need to be considered.

Knowles et al. [1717] claim that the evaluation where clips/coils can be used is based on the many parameters listed above making it a complex task. For example, assuming a required level of filtering, it can easily be translated into a necessary capacitance value, and the voltage rating and diameter of the pin can also be defined. In a multi-element connector, the pin-pitch is also known. With this, the available mechanical area can be defined in which the capacitance must be achieved. In the available mechanical area allowance must be made for the joint area. A mechanical clip takes up much more of this area than does a solder joint. Solder has the ability to wet and flow into small gaps – typically 0.1 mm or so – between the pin and the inside bore of the capacitor. Clips will typically need to have around 0.35 mm gap between the capacitor and the pin, so around 0.7 mm per joint around the diameter of the pin. This can dramatically reduce the available area to achieve the capacitance required. In some cases it would make it impossible to fit a capacitor at all in the area that remains.

[1715] Knowles Capacitors et al. 2016b "Answers to third questionnaire, document "Exe_24_Questionnaire-3_Knowles-et-al_2016-03-01.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Hopwood, Knowles Capacitors, on 8 March 2016: Answers third questionnaire" unpublished manuscript,

[1716] Ibid.

[1717] Ibid.

Knowles et al.[1718] say that the spring/clip must be isolated from sealants or resins to prevent them breaking the electrical contact between the pin and the capacitor. Barrier boards are required which again increase the length of the unit so that it can be impossible to fit the required capacitance into the available space envelope.

Finally, according to Knowles et al.[1719] there is the issue of vibration resistance which can preclude the use of a clip as the contact can be lost increasing the resistance and adversely affecting the functionality of the device. A solder joint provides a guaranteed connection at all times.

Knowles et al.[1720] conclude that each case will be different, with so many variables as listed above so that they cannot provide general criteria to define where clips can replace the lead-containing solders.

30.2.2 Substitution of Lead by Lead-free Solders

Knowles et al.[1721] claim that when lead-free solder is used to connect the feedthrough pins to the internal bore to make a mechanical and electrical connection, the shrinkage of the solder and pin assembly within the bore exerts a tension force on the inside of the bore, sufficient to form micro-cracks in the ceramic element. These cracks have a recognisable shape and form. If the crack propagates through the electrically active portion of the design, where electrodes of opposing polarities overlap each other, then the result can be a low resistance path or an electrical short circuit, resulting in failure of the electrical system and potentially health and safety risks to operators. Knowles et al.[1722] tested the alloys listed in Table 30-1.

30.2.2.1 Tests of Lead-free Solders

According to Knowles et al.[1723], the tested solders specified in Table 30-1, represent the solders currently in use for the assembly of EMI filters, conventional tin lead solders and samples of proposed lead-free replacement solders. In each case, except for the two LHMPS alloys, two sample sets of filters were assembled and reflowed using a five zone hot air reflow furnace. Sample 1 had a standard solder profile with forced cooling by air blowers after zone 5. Sample 2 was reflowed using the same soldering profile but with the cooling air blowers turned off to allow gradual cooling, so as to reduce the stresses on the ceramic.

Knowles et al. [1724] explain that 95Pb/5In solder has a high melting point of between 300 °C and 313 °C, and 93.5Pb/5Sn/1.5Ag a high melting point of between 296 °C and

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[1718] Ibid.
[1719] Ibid.
[1720] Ibid.
[1721] Op. cit. Knowles Capacitors et al. 2015a
[1722] Knowles Capacitors et al. 2015b
[1723] Knowles Capacitors et al. 2015b
[1724] Knowles Capacitors et al. 2015b

301 °C, so neither could be soldered using the available hot air furnace. Instead samples of these were assembled using a hot plate at 425 °C. Preheat was not used. Sample 1 parts were force cooled by placing directly in front of a desk fan. Sample 2 parts were allowed to gradually cool. The samples were then sectioned, allowing the capacitor structure around the solder joints to be inspected for cracking.

Table 30-1: Tested solders and results

Alloy Type		Cooling	Defective 'Longbow' (%)	Defective Total (%)
62Sn/36Pb/2Ag	Traditional low melting point lead solder	forced	80	100
		gradual	20	60
60Sn/40Pb	Traditional low melting point lead solder	forced	100	100
		gradual	60	80
99.3Sn/0.7Cu	Lead free 'plumbers' solder	forced	100	100
		gradual	100	100
95.5Sn/3.8Ag/0.7	Lead free solder recommended for PCB assembly	forced	100	100
		gradual	40	80
50Pb/50In	Ductile stress relieving solder	forced	0	0
		gradual	0	0
95Pb/5In (LHMPS)	Ductile stress relieving high melting point solder	forced	0	0
		gradual	0	0
93.5Pb/5Sn/1.5Ag (LHMPS)	Ductile stress relieving high melting point solder	forced	10	10
		gradual	0	0

Source: Knowles et al.[1725]*, modified*

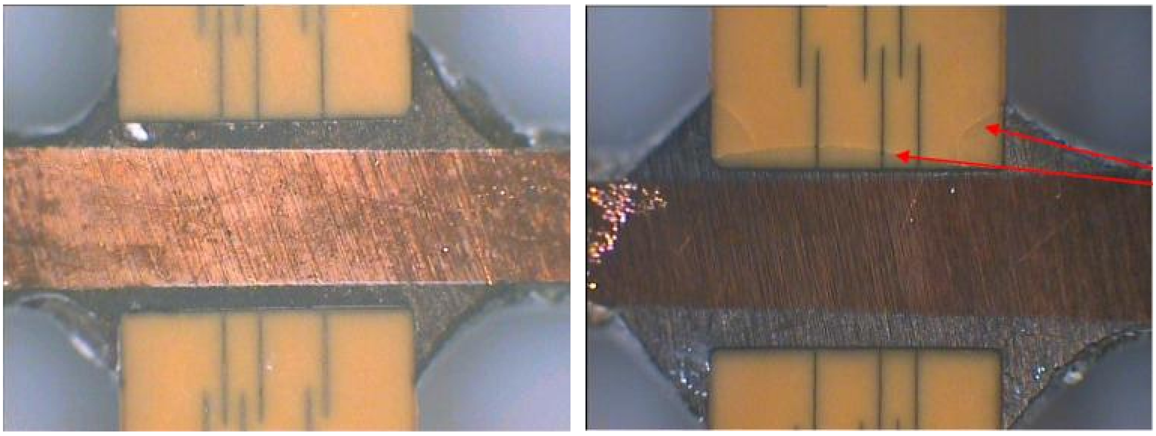
Knowles et al.[1726] that the LHMPS joints were made using capacitors without solder pads as available jigging did not allow padded parts to be assembled. This eliminated corner

[1725] Knowles Capacitors et al. 2015b

cracking and may have slightly shifted the results towards a too positive result for the LHMPS. However, the very low level of longbow cracking found in HMP-soldered parts (10% of force cooled 93.5Pb/5Sn/1.5Ag joints only) still indicates the improved performance of these alloys.

Figure 30-2 shows the example of a test sample without cracks (50Pb/50In with gradual cooling) and a gradually cooled test sample soldered with SnAgCu solder.

Figure 30-2: Test sample without cracks (50Pb/50In, left) and sample with long bow and corner cracks (SnAgCu, arrows, right)



Source: Knowles et al.[1727]

Knowles et al.[1728] conclude that lead containing solders, often in conjunction with other metals such as indium, impart a degree of ductility to the solder joint, allowing stress release within the joint and absorbing the forces applied to the ceramic. Alternative solder alloys, such as tin-based lead-free alloys and SnPb alloys, do not have sufficient ductility to prevent stress damage to the ceramic and can represent a reliability / safety risk during the operating life of the component.

30.2.2.2 Use of Alternative Materials with Less Difference in CTE

Knowles et al.[1729] explain that dielectric ceramic - the same material as used by chip capacitor MLCC - is a sintered brittle material selected primarily for its electrical properties. All ceramic dielectrics are liable to mechanical stress cracking. There are no ceramic dielectric materials currently available with sufficient ductility or crack resistance.

According to Knowles et al.,[1730] the pin material used in this type of component is copper, brass and very occasionally steel, chosen for its machinability and electrical

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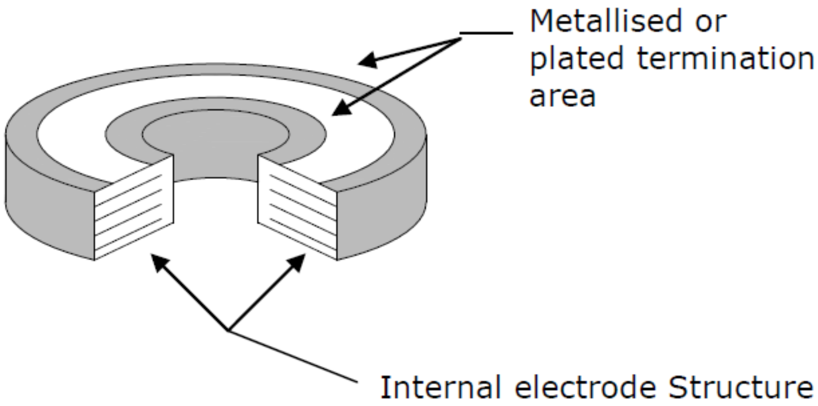
[1726] Knowles Capacitors et al. 2015b
[1727] Knowles Capacitors et al. 2015b
[1728] Ibid.
[1729] Op. cit. Knowles Capacitors et al. 2015c
[1730] Ibid.

conductivity. The lead-free soldering tests (c.f. Table 30-1) were conducted with silver-plated copper pins, which is the most malleable of the pin materials normally used. The use of other pins and platings would thus even aggravate the crack problem.

In combination with palladium-silver (PdAg) platings, as an alternative approach to enable lead-free soldering, lead-free solders cause failures as well, even though different ones.

Figure 30-3: Typical stray capacitor discoidal construction



Source: Knowles et al.[1731]

Knowles et al.[1732] describe that PdAg platings reduce the bond strength between the termination and the ceramic, compared to gold plating. The effect of this is that the contraction forces tend to stress relieve the assembly at the termination / ceramic interface rather than inside the ceramic structure in the form of a crack. Tests were carried out using capacitor arrays with the electrical design shown above and terminated with PdAg termination material. The advantage with this type of construction is that any failure of the internal termination or ceramic cracking is demonstrated by a drop in the capacitance. This is because of the introduction of an alternative dielectric material – air – in the area of the failure. Prior to assembly, the capacitance of the holes with this design was recorded. The assembly was soldered using 95.5Sn/3.8Ag/0.7Cu lead-free solder and hot air reflow. After assembly, the capacitance was re-measured. Table 30-2 shows the results of the tests undertaken. Knowles et al.[1733] state the drop in capacitance for both soldered arrays indicates failures in all assemblies. Details about the failure mechanism are explained in Knowles et al. 2015b.[1734]

[1731] Op. cit. Knowles Capacitors et al. 2015b
[1732] Ibid.
[1733] Ibid.
[1734] Ibid.

Table 30-2: Test results of PdAg-plated discoidal MLCC soldered with lead-free solders

Array No. 1			Array No. 2		
Start Capacitance (pF)	Capacitance after Soldering (pF)	Change (%)	Start Capacitance	Capacitance after Soldering	Change (%)
551	296	-46.3	539	331	-38.6
550	242	-56.0	540	256	-52.6
550	300	-45.5	535	196	-63.4
552	249	-54.9	536	189	-64.7
553	244	-55.9	532	323	-39.3
546	474	-13.2	538	151	-71.9
544	351	-35.5	536	91	-83.0
543	418	-23.0	539	175	-67.5
551	339	-38.5	544	353	-35.1
551	520	-5.6	536	168	-68.7
546	368	-32.6	536	176	-67.2
550	289	-47.5	534	317	-40.6
544	451	-17.1	544	173	-68.2
544	443	-18.6	543	153	-71.8
550	242	-56.0	543	285	-47.5

Source: Knowles et al.[1735]

Knowles et al. conclude that the use of lead solders is currently still required and ask for the continuation of exemption 24.

30.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

Knowles et al.[1736] see no scope for replacing solder as the primary method of making electrical and mechanical connection between the capacitor and the through conductor pin. They continue to monitor the solder industry through web searches and in conjunction with their partner solder supplier Indium Corporation, but they claim no viable alternatives to lead containing alloys to be available at the present time.

30.4 Critical Review

30.4.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead and cadmium in various articles and uses.

[1735] Ibid.
[1736] Op. cit. Knowles Capacitors et al. 2015a, page 17 et sqq.

The exemption reduces the amount of lead used in some of the applications in the scope of Exemption 24. Indium replaces part of the share of lead in the lead-containing solder so that Annexes XIV and XVII need to be checked for entries regarding lead and indium.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as a directly added substance nor as a substance that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds and indium phosphide shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restriction for substances under Entry 28 and Entry 30 of Annex XVII does not apply to the use of lead and indium in this application. The use of lead and indium in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead and indium are part of an article and as such, Entry 28 and Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds…

1) *"shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight."* This restriction, however, does not apply to internal components of watch timepieces inaccessible to consumers;
2) *"shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable*

conditions of use, be placed in the mouth by children." This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under Entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

30.4.2 Elimination of Lead

Knowles et al. explain that the usability of spring clips depends on multiple parameters. Neither during the stakeholder consultation, nor at a later stage of the review process, have other sources of information or contrary information become available disproving the statement of Knowles et al. While it is possible to eliminate the use of lead in some cases, the consultants conclude, based on the available information, that it is not possible to define an exemption wording with a clear-cut demarcation of applications where these clips can be used.

30.4.3 Substitution of Lead

30.4.3.1 Use of Lead-free Solders

The applicant plausibly shows that lead-free solders currently cannot replace the lead-containing solders. One key reason for this is the higher ductility of lead-solder, which thus can better balance the different coefficients of thermal expansion (CTE) between the pin and the ceramics.

One possible approach could thus be to use a different material for the pin with a CTE closer to the other materials involved. Knowles et al.[1737] claim that the pin materials are fixed as copper alloys by application. No other material is acceptable to the industry as offering the appropriate combination of physical and electrical characteristics. Alternative pin materials are thus not considered an option.

30.4.3.2 Replacement of Lead-containing High Melting Point Solders

In the 2008/2009 review[1738], Knowles – at that time named "Syfer" – said that some of its customers are tending towards using higher lead alloys typically containing 95 % of lead rather than 50 % as preferred by Syfer/Knowles to overcome the limitations of the RoHS Directive. Knowles/Syfer at that time considered this solution to represent a negative environmental impact. Lead-containing high melting point lead solders (LHMPS, as currently still exempted under Exemption 7a) with Pb content > 90 % also tend to

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[1737] Op. cit. Knowles Capacitors et al. 2015c: 2015

[1738] Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009)

have the ductility demanded, 92.5Pb/5In/2.5Ag or 95Pb/5In being the most likely solutions. However, alloys with this content of lead have much higher reflow temperatures - 92.5Pb/5In/2.5Ag has a liquidus temperature of 310 °C compared with 210 °C for 50Pb/50In alloy. This will demand new equipment capable of reaching much higher temperatures. Trials have shown that an inert atmosphere will also be necessary to prevent oxidisation problems. The use of these LHMPS would increase the use of lead as well as the energy consumption due to the higher soldering temperatures and for the production of the inert gas. Syfer/Knowles state, however, that some applications require the use of LHMPS in such capacitors.

The applicants were asked whether the above statement is still correct. Knowles et al.[1739] replied that they recommend their customers always to use indium-lead solders where possible, with LHMPS being used where the technical demands require a higher melting point alloy. They believe that customers they are in regular contact with generally follow this advice. The comments regarding the processing limitations for LHMPS, i.e. high process temperatures, higher energy consumption and inert atmospheres, still hold true.

Exemption 24 thus offers an alternative to LHMPS with less use of lead involved. Vice versa, the use of lead in this application would increase without exemption 24 because LHMPS with higher lead contents as exempted in the current exemption 7a may remain as the only alternative.

Exemption 24 thus offers an alternative to reduce the use of lead. LHMPS contains at least 85 % of lead and typically even more than 90 % in the application in the scope of exemption 24, while the alternative indium-based solders apply a maximum of 50 % of lead. The use of lead in this application would therefore increase without exemption 24 because LHMPS with higher lead contents as exempted in the current exemption 7a remains as the only alternative.

Knowles et al.[1740] use indium-lead solders with melting points of around 210 °C. This means that the components within existing designs would not survive a standard soldering process with the most frequently used lead-free solders, which have melting points above 210 °C. Knowles was therefore asked how they can use these indium-lead solders without problems in subsequent soldering processes, in which the component is, for example, bonded onto a printed circuit board.

Knowles et al.[1741] [1742] explain that the types of MLCC covered by exemption 24 are chiefly used in applications where subsequent assembly is by selective soldering, usually

[1739] Op. cit. (Knowles Capacitors et al. 2016a)
[1740] Op. cit. (Knowles Capacitors et al. 2015a)
[1741] Op. cit. (Knowles Capacitors et al. 2016a)
[1742] Knowles Capacitors et al. 2016d "Answers to questionnaire 2 related to exemption 7a, document "Exe_7a_Questionnaire-2_Knowles_2016-03-29.pdf", received from Steve Hopwood, Knowles, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016" unpublished manuscript

by hand and only to the end pin of the filter/connector. Where a low melting point alloy such as Pb50In50 is used for the assembly of the component, it is preferable from both a lead content and a process point of view. In such cases, the finished component or connector would not be expected to be processed through a standard reflow soldering practice. Otherwise, where a component is designed to be subsequently mounted using standard reflow soldering techniques, it will be assembled using LHMPS. This type of component would then be rated for assembly using conventional lead-free solders, in contrast to those assembled with for example with Pb50In50. The current scope of Exemption 24 covers both of these cases, thus allowing the use of high melting point solders with 85 % and more of lead as well as other solders with lower lead contents.

The consultants tried to clarify[1743] why not all capacitors in the scope of exemption 24 can be soldered selectively so that the use of LHMPS would no longer be required, but this information was not available until the end of the review process. Given the considerable efforts undertaken and the limited time and resources available, it was not possible to follow this technical discussion further.

30.4.4 Conclusions

30.4.4.1 Substitution and Elimination of Lead

The applicants plausibly explain that lead-solders are required to solder the pins into discoidal and planar array multilayer capacitors. Lead-free solders are not sufficiently reliable. Alternative approaches to enable the use of lead-free solders, i.e. the use of different pin materials with more appropriate coefficients of thermal expansion, and alternative plating's, in order to allow the use of lead-free solders, are not technically viable either.

Elimination of soldering via the use of spring clips is an option in some cases, but such cases cannot be clearly demarcated from those areas, which require the use of lead-solders as already determined in the 2008/2009 review[1744]. The situation remains that it is not possible to define a functional exemption wording with a clear-cut demarcation of applications where spring clips can be used.

In the absence of Exemption 24, LHMPS with at least 85 % of lead would have to replace the indium-lead solders with a maximum of 50 % of lead. Exemption 24 thus contributes to reduce the amount of lead as long as the situation persists that lead-free solutions are not available. Based on the available information, the reviewers conclude that renewing Exemption 24 would be in line with the requirements of Art. 5(1)(a).

The current scope of the exemption covers both the use of high melting point solders with 85 % and more of lead as well as other solders with lower lead contents such as Pb50In50. As it has not been possible to detail why the selective soldering of the components in the scope of Exemption 24 could not be generally applied to avoid the

[1743] Ibid.
[1744] Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009), page 214 et sqq.

use of LHMPS, a rewording targeting a reduction of the maximum content of lead in the solders to less than 85 % could not be proposed.

Even though lead cannot yet be fully substituted, restricting the scope of Exemption 24 to exclude the use of LHMPS would at least reduce the amounts of lead used. Granting the continuation for the maximum of five years would not be justified in line with the requirements of Art. 5(1)(a). To further clarify the scope of the exemption, the consultants recommend granting the exemption for 30 months. As a sound justification why selective soldering cannot be used for all capacitors in the scope of this exemption to avoid the use of LHMPS, in the consultants' opinion does not require further research and development, 30 months should be sufficient time to apply for the renewal of the exemption in time 18 months prior to its expiry.

30.4.4.2 Avoiding Overlaps with Exemption 7(a)

Exemption 7(a) currently covers the use of LHMPS in electrical and electronic equipment so that there is a scope overlap with Exemption 24. The use of LHMPS in the capacitors in the scope of Exemption 24 should therefore be excluded from the scope of Exemption 7(a) to avoid that the use of solders in these capacitors is covered by two different exemptions. In the course of a future scope refinement of Exemption 24, the lead-content of the solder used under Exemption 24 could be reduced to a level below 85 % thus excluding the use of LHMPS provided this is scientifically and technically practicable. In this case, the references to Exemption 24 could be removed from Exemption 7(a).

In principle, the use of LHMPS in the capacitors in the scope of Exemption 24 could also be exempted in Exemption 7(a), which would, however, require adding another entry under Exemption 7(a) for these capacitors. This part of Exemption 7(a) would then have to be revoked should it be practicable to exclude the use of LHMPS in Exemption 24, which generates an additional entry under exemption 7(a) that would have to be maintained to enable repair and reuse. Compliance may also become more difficult for industry if the soldering for a specific component is regulated in two different exemptions. Additionally, regulating the use of LHMPS in the MLCC capacitors would require restricting the lead content in the solders in Exemption 24 to a level below 85 % to avoid an overlap with Exemption 7(a). Such a restriction should be discussed with the applicants and stakeholders to ensure the concentration of lead is high enough to cover all uses of solders other than LHMPS.

Concerning the lead substitutes, the European Commission[1745] lists indium as one of 20 critical raw materials for the European Union, which calls for the substitution of indium, while in the case of Exemption 24, indium replaces lead, which the EU Commission has

[1745] European Commission: 2014 "On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions," http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0297&from=EN, page 5 et sqq.

not listed as a critical material. In this respect, Exemption 24 contravenes the strategy of the Critical Raw Materials Initiative to substitute critical materials and to reduce their use, while it is in line with the requirement of the RoHS Directive to substitute lead.

RoHS Art. 5(1)(a) stipulates that decisions on exemptions shall take into account the availability of substitutes, meaning *"[...] the ability of a substitute to be manufactured and delivered within a reasonable period of time as compared with the time required for manufacturing and delivering the substances listed in Annex II"*, i.e. the list of restricted substances. Hence, if the use of indium would cause delays in the manufacturing of components due to the limited availability of indium, Art. 5(1)(a) would allow cancelling the exemption based on the lacking availability of indium and thus moving industry to alternatively use high melting point solders with at least 85 % lead content under the current exemption 7a. Such indium shortages were not, however, identified by stakeholders, and the fact that the applicants plea for the renewal of Exemption 24 implying the use of indium can be seen as evidence that indium is sufficiently available for these applications.

It should be stressed that it is beyond the consultants' mandate to recommend the continuation or revocation of exemptions based on criteria other than those stipulated in RoHS Art. 5(1)(a). The consultants therefore recommend renewing the exemption based on Art. 5(1)(a). Any other recommendations on whether and how far to take into account strategies or requirements resulting from the Commission's Raw Material Initiative must be considered separately from this review, and such decisions should be made by the competent European Authorities.

Should the Commission prioritize the conservation of indium resources over the reduction of lead use, then Exemption 24 should not be renewed. This would require exempting the use of LHMPS as the substitution or elimination of lead in the capacitors in the scope of Exemption 24 is currently impracticable. In this case, the consultants recommend

A) to take no further action should the Commission decide to keep the current wording of Exemption 7(a).
B) adding a clause in the proposed rewording of Exemption 7(a) allowing the use of LHMPS in the capacitors in the scope of Exemption 24 with a validity period of five years. A validity period shorter than five years would not be justified as no lead-free solutions to replace LHMPS are foreseeable within the next five years.

The above option B will be addressed in an alternative rewording proposal for Exemption 7(a).

30.5 Recommendation

The applicants plausibly explain that neither the elimination nor the substitution of lead is viable to a degree that would allow the revocation or the restricting of scope of Exemption 24. Doing so would prevent the use of indium-lead solders with a maximum of 50 % of lead and instead require the use of high melting point solders with at least 85 % of lead content due to the absence of lead-free solutions.

Based on the available information, renewing the exemption with its current wording would be in line with Art. 5(1)(a). The consultants recommend granting the exemption for 30 months in order to clarify whether the scope of the exemption can be restricted to exclude the use of high melting point solders, which would reduce the amount of lead used under this exemption:

Exemption 24	**Expires on**
Lead in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors	*21 January 2019 for categories 1-7 and 10*
	21 July 2021 for · *medical equipment in category 8* · *monitoring and control instruments in category 9*
	21 July 2023 for in vitro diagnostic medical devices in category 8
	21 July 2024 for industrial monitoring and control instruments in category 9

The European Commission lists indium as a critical material for the European Union.[1746] Recommendations on exemptions taking into account criteria beyond Art. 5(1)(a), are beyond the consultants' mandate. Taking into consideration strategies and requirements resulting from the Commission's Raw Material Initiative in the context of this exemption should be made by the competent European Authorities.

30.6 References Exemption Request 24

European Commission: On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative 2014. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0297&from=EN.

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Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, RoHS III. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

[1746] Ibid., page 5 et sqq.

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Knowles Capacitors et al. 2016c E-mail communication, document "E-mail-communication_Knowles.pdf, received by Dr. Otmar Deubzer, Fraunhofer IZM, from Steve Hopwood, Knowles Capacitors, until 16 March 2016.

Knowles Capacitors et al. 2016d Answers to questionnaire 2 related to exemption 7a, document "Exe_7a_Questionnaire-2_Knowles_2016-03-29.pdf", received from Steve Hopwood, Knowles, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016.

31.0 Exemption 29: "Lead bound in crystal glass as defined in Annex I (Categories 1, 2, 3 and 4) of Council Directive 69/493/EEC (1)"

Declaration

In the sections that precede the "Critical Review" the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

EDG	European Domestic Glass
EEE	Electrical and Electronic Equipment
HCl	Hydrochloric acid
HF	Hydrofluoric acid
H_2SO_4	Sulfuric acid
LCG	Lead crystal glass
LEU	LightingEurope
Pb	Lead
UVCB	Substance of **U**nknown or **V**ariable **C**omposition, complex reaction products or **B**iological materials

31.1 Background

European Domestic Glass (EDG) and LightingEurope (LEU)[1747] have submitted a joint request for the renewal of exemption 29 of Annex III of the RoHS Directive to allow the use of lead in the manufacture of lead crystal glass to be applied in EEE.

Crystal is a substance characterized by a continuous and essentially non-crystalline or vitreous inorganic macromolecular structure, which is highly insoluble and inert. Obtained by a mineralogical process, resulting in a chemical network (matrix), crystal constituents are closely linked together and are in a specific chemical environment, different from the initial state of the raw materials.[1748]

It is explained by the applicants[1749] that lead oxides (PbO or Pb_3O_4), are used as an intermediate for the chemical synthesis of Lead Crystal Glass (LCG). LCG is used in EEE applications because their unique combinations of processing and optical/decorative properties and characteristics allow the manufacture of EEE articles which could not be produced otherwise. Substitutes are said to have been sought over the latest two decades without success. The performance of alternative materials is worse and does not allow the production of articles with comparable properties, notably because of the insufficient workability time made possible by the lead oxide component. Various articles are named as types of EEE in which LCG is used (see Figure 31-1 for examples):

- Fixed/portable luminaires;
- Lamps;
- Electrified mirrors;
- Horology (clocks, watches etc.);
- Display cases;
- Digital photo frames;
- Tablet and smart phone docking stations;
- Furniture and home décor items (carrousel, tables etc.);
- Building materials (illuminated bricks).

Thus EDG & LEU request the renewal of the exemption with the following wording:

“*Lead bound in crystal glass as defined in Directive 69/493/EEC*”

[1747] EDG & LEU (2015a), European Domestic Glass and LightingEurope, Original Dossier Requesting the Extension of Exemption 29 in Annex III of Directive 2011/65/EU, submitted by the European Domestic Glass Association and by LightingEurope on 16.1.2015 to the EU COM, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/29_EDG_LE_RoHS_Exemption_Req_final.pdf

[1748] EDG & LEU (2015b), European Domestic Glass and LightingEurope, Answers to 1st Clarification Questions regarding Exemption 29 in Annex III of Directive 2011/65/EU, submitted on 14.08.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/20150814_Ex_29_EDG___LEU_1st_round_of_Clarification-Answers_final-Public.pdf

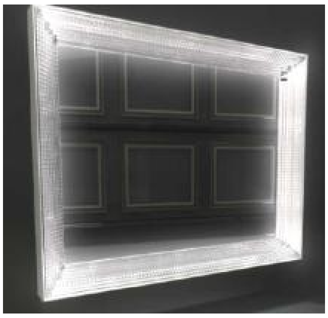
[1749] Op. cit. EDG and LEU (2015a)

The exemption has been requested for a period of 10 years. In this respect the applicants have specified that the exemption is requested for articles of categories 3 (IT and telecommunications equipment), 4 (consumer equipment), 5(lighting equipment) and 11(other EEE not covered by any of the categories above). Since Article 5(2) of the RoHS Directive limits the maximum duration of the validity of an exemption to 5 years in the case of EEE falling under Cat. 1-7, 10 and 11, the consultants interpret this to mean that the applicant requests the maximum applicable duration.

Figure 31-1: Example EEE in which lead crystal glass is used

Lighting applications (luminaires, chandelieres)

Building materials - illuminated bricks

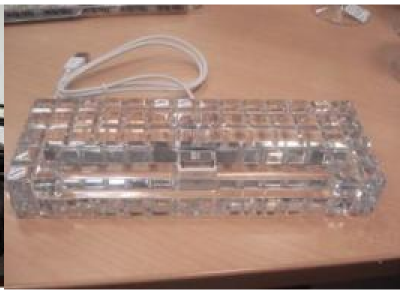


Electrified mirrors

Horology

Display cases

Digital photo frames



Tablet and smart phone docking stations

Furniture and home décor items

Source: EDG & LEU (2015a, 2015b)

31.2 Amount of Lead Used under the Exemption

EDG & LEU[1750] explain that the Crystal Glass Directive 69/493/EEC[1751] defines crystal glass into four categories along three criteria, among them its composition expressed notably as lead oxide up to over 30% by weight. Under the REACH Regulation, glass is considered as a UVCB substance (substance of **U**nknown or **V**ariable **C**omposition, complex reaction products or **B**iological materials). It is not a preparation and does not contain lead metal nor lead compounds as such. EDG and LEU explain that 130 tonnes[1752] of EEE using LCG are placed on the EU market per annum. From the combined declarations of members of EDG who are LCG manufacturers, representing 80% of the EU market share, it can be understood that 40 tons/annum of Pb_3O_4 and PbO are used as an intermediate for the manufacture of LCG applied to EEE applications manufactured for the EU market. Thus 40 tons/annum of Pb_3O_4 and PbO are used to manufacture 104 tonnes of lead crystal electric/electronic articles, representing 80% of the EU market share. On this basis, it is estimated that for the total EU market, 130 tonnes are manufactured, of which 50 tons/annum of Pb_3O_4 and PbO would be used for manufacture.[1753] The Pb comprised in 50 tonnes of Pb_3O_4 and PbO is estimated to amount to 46 tons.[1754]

31.3 Description of Requested Exemption

According to EDG & LEU[1755] lead oxides (PbO or Pb_3O_4), are used as an intermediate for the chemical synthesis of Lead Crystal Glass (LCG), as required by Council Directive 15 December 1969 on the approximation of the laws of the Member States relating to crystal glass (69/493/EEC). The amount of lead in the LCG has to be at a minimum of 24% expressed as PbO for the glass to be called “lead crystal” and above 30% for it to be called “full lead crystal”. EDG & LEU stress that it does not mean that there is PbO nor Pb as such in the articles. It is simply a convenient way to express the result of an elementary composition analysis. It is further explained that under REACH Regulation[1756], Crystal Glass is itself a substance of unknown or variable composition,

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[1750] Op. cit. EDG & LEU (2015a)

[1751] COUNCIL DIRECTIVE of 15 December 1969 on the approximation of the laws of the Member States relating to crystal glass (69/493/EEC), (OJ L 326, 29.12.1969, p.36), available under: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:01969L0493-20070101

[1752] In the application document, both tons and tonnes are referred to. A Uk ton represents 1016 kg and an American one 907 kg, whereas a tonne represents 1000 kg. The consultants assume that the inconsistency is a typo and that tonnes, representing 1000 kg are meant, as this would be consistent with the explained calculation.

[1753] It is further noted that the former submission (exemption renewal request from 2008) indicated 145 tonnes/year, most probably because there was a confusion between lead crystal glass EEE applications and Pb oxide components.

[1754] Op. cit. EDG & LEU (2015a)

[1755] Op. cit. EDG & LEU (2015a)

[1756] Cited as REACH Regulation, Annex V and Guidance for Annex V, Entry 11, pp.38-39

which by convention is expressed as oxides of the constituent elements (SiO_2, Na_2O, K_2O, PbO, etc.). The addition of lead oxide enables:

- The production of exceptional articles otherwise impossible to obtain, through the:
  - increased working time with the glass, via excellent thermal and viscosity properties (melting and forming);
  - unique optical properties needed for:
    - High refractive index nd > 1.56 (responsible for brilliance);
    - High dispersion nf – nc > 0.01, preferably 0.013 (responsible for the refraction and reflection performance);
    - High light transmission (L > 98; -0.5 < a < 0; -0.5 < b < 0.5 (100 mm thickness immersion, light C, 2°, CIELAB);
    - No grey, but sharp colour transition;
  - unique mechanical (cutting and polishing) process possibility;
  - unique refinement (sustainable surface) process possibility;
  - decorative aspects.
- A better energy efficiency. Measures demonstrate that from a same source (LED), the light flow transmitted through a crystal item is bigger by a factor of at least 10%, compared to the light flow transmitted by the same item in flint glass. The energy efficiency (lumen/watt) of crystal is therefore much better than in flint glass. In certain cases, the ranking Index of energy efficiency (IEE) of an electric lighting device can jump to category A (with crystal) from category B (with flint glass). In other words, less energy is required for lighting.

On this basis, EDG & LEU[1757] conclude the crystal glass is a component of high quality lighting and decoration applications (see Section 31.1), and is used for the very production of these articles otherwise impossible to manufacture, for enhancing light distribution or transparency thereof and for enabling specific decoration (shape and finishing).

In a later communication[1758] it is elaborated that in the hot process, the use of lead for the synthesis of crystal increases the working range. It reduces the viscosity of the melt for the same temperature, rendering it more fluid than ordinary glass. The viscosity of glass varies radically with temperature. This results in a few practical developments:

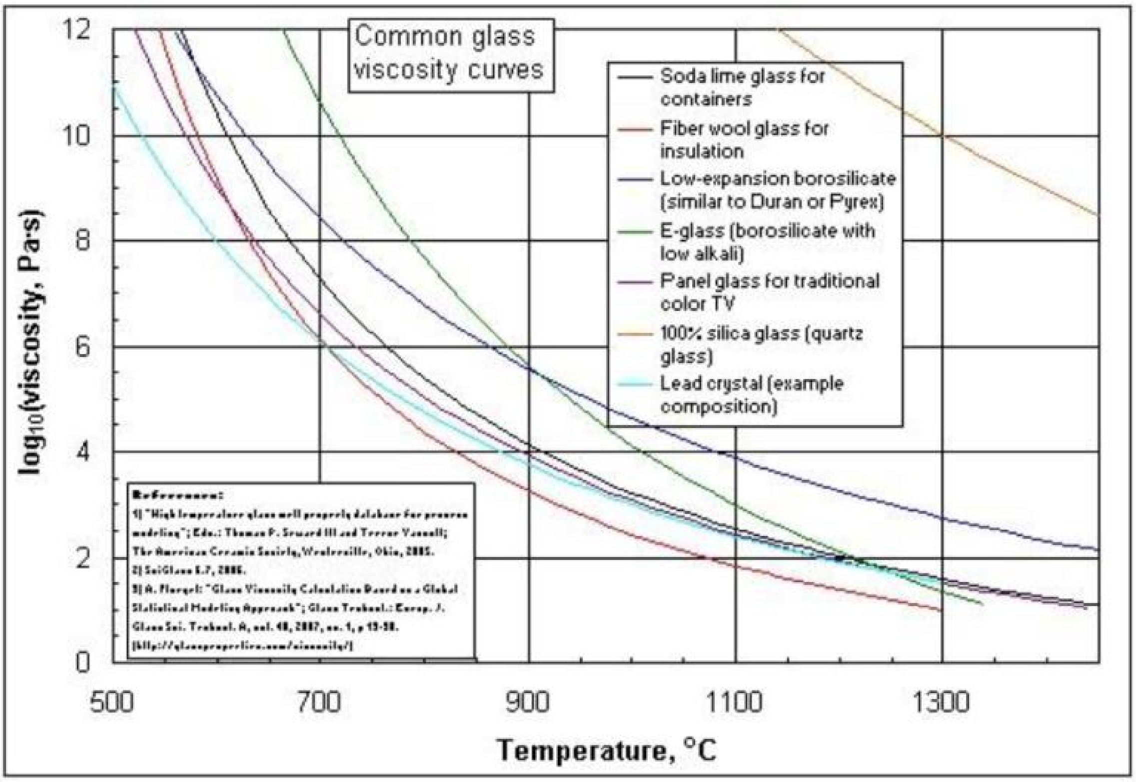
- Lead glass may be worked at a lower temperature, making possible the shaping of sophisticated items. Design is therefore determined by the cooling time: complex forms are not possible to produce in a glass (without lead) with a short working range – see Figure 31-2 representing viscosity as function of temperature for several types of glass. Simply stated, the working range of

1757 Op. cit. EDG and LEU (2015a)
1758 Op. cit. EDG and LEU (2015b)

glass is that range of temperatures that corresponds to the point where glass just begins to soften up to the point where glass is too soft to control. The ASTM and the American Ceramics Society committees on glass definitions summarize the definition now widely used in today's glass industries[1759]: WORKING RANGE: "The range of temperatures in which glass is formed into ware in a specific process. For comparison purposes, when no specific process is considered, the working range of glass is assumed to correspond to a viscosity range from the working point to the softening point. (4 to 7.6 Log10 Poise)". A LONG glass will have a significantly longer temperature range from the working point to the softening point than a SHORT glass. Since glass blowers hand work (or hand process) glasses in this range they are able to readily distinguish a long glass from a short glass.

- The working range also has a direct impact on manufacturing cost due to reheating requirements (additional energy consumption, timing and defective items).
- Properties of the crystal are also key-factors for tools design; therefore any change in the properties may lead to major change requirements for the associated tools.

Figure 31-2: Viscosity as a function of temperature for several glass types



[1759] EDG and LEU (2015b) refers to pp. 677-680 in The Handbook of Glass Manufacture by Tooley and pp. 72-74 in Technical Glasses by Volf

Source: EDG & LEU (2015b)

31.4 Applicant's Justification for Exemption

EDG & LEU[1760] provide more detail as to the function of lead in LCG, explaining that "*lead oxide or tetroxide is added to achieve the following characteristics:*

- *Refractive index: ratio of the speed of the light in vacuum in a dimensionless number that describes how light propagates through a medium. The higher the refractive index, the more lighting effects (rainbow).*
- *Abbe number: Abbe number is a measure of the variation of refractive index with wavelength so that the refractive index of a glass with a low Abbe number varies across the visible spectrum less than a glass with a high Abbe number. Lead crystal glass has a low Abbe number which reduces chromatic aberration in parallel to displaying a high refractive index.*
- *Dispersion: phenomenon in which the phase velocity of a wave depends on its frequency. The bigger the dispersion, the more visible spectrum of colours (rainbow).*
- *Cooling time: lapse of time between two viscosity states below and above which glass cannot be shaped. The more time is possible, the more specific (longer, thinner, and complex) shapes can be designed. This specificity enhances the skills of the craftsman to elaborate high end products.*
- *Working range: range of temperature with the same purpose of the cooling time, expressed in °C, instead of time.*
- *Vickers' Hardness: measure of hardness of the material. The lower the hardness, the more possibilities for cutting and engraving complex artistic designs on exceptional and prestigious items which can only be achieved by handcrafting.*
- *Better energy efficiency[1761] because of less energy consumption together with a better lighting effect*."

31.4.1 Possible Alternatives for Substituting RoHS Substances

EDG & LEU[1762] explain that research has been conducted for over two decades, but that no viable substance substitute exists. There are a limited number of elements in the periodic table available that can be combined to form certain kinds of crystal glass in EEE applications (BaO, ZnO, SrO, CaO, MgO). Combinations that exist form glasses only

[1760] Op. cit. EDG and LEU (2015a)
[1761] When asked to quantify this aspect, EDG replied that "A confidential study made by one of our stakeholders shows that for a light source of 30,9 lm/W, crystal gives 10% more light than glass leading to an 'A' category for crystal item and 'B' for some glass items." As it was not possible to understand how this study was performed from information in the public realm and as other argumentation was found to provide a relevant basis on which the review can be judged, this aspect has not been further pursued.
[1762] Op. cit. EDG & LEU (2015a)

within relatively small composition ranges. Many combinations have been tested but a viable alternative has not yet been found. Research has provided patterns achieving some of the Pb-bound in crystal properties, but none of these patterns achieve all of the same essential properties, especially the main one: thermo-mechanical-optical properties to elaborate the product. EDG & LEU provide a comparison as presented in Table 31-1 below. The results obtained show that the required properties are not provided by investigated candidates, which displayed inferior thermal, mechanical and optical properties (cooling time, Vickers hardness, Abbe number) and that would thus not allow the manufacture of the same applications.

Table 31-1: Comparison of properties of lead crystal to lead-free crystal and and sodalime crystal

	lead crystal	lead free crystal 1	lead free crystal 2	lead free crystal 3	sodalime glass
Refractive Index	1,559	1,555	1,547	1,554	1,521
	discrepancy	0%	-1%	0%	-2%
Abbe Number	43,8	55,7	53,6	55,4	59,4
	discrepancy	27%	22%	26%	36%
Dispersion (656,27nm-768,2nm) (10E-3)	4,2	na	3,2	3,2	3,1
	discrepancy		-24%	-24%	-27%
Dispersion (589,3nm-656,27nm) (10E-3)	3,7	na	2,7	2,7	2,6
	discrepancy		-26%	-26%	-29%
Dispersion (435,84nm-486,13nm) (10E-3)	7,3	na	5,1	5,1	4,8
	discrepancy		-30%	-31%	-34%
Dispersion (404,66nm-435,84nm) (10E-3)	6,3	na	4,3	4,2	4,0
	discrepancy		-32%	-32%	-36%
Working Range (T Log4 - T Log 7,65) (°C)	333	271	290	254	298
	discrepancy	-19%	-13%	-24%	-10%
Cooling time (s)	130	106	113	104	100
	discrepancy	-19%	-13%	-20%	-23%
Vickers' Hardness (MPa)	4799	5319	5038	5431	5586
	discrepancy	11%	5%	13%	16%

Source: EDG & LEU (2015a)
Notes: Lead-free crystal 1&2 : formulations investigated during R&D works (thesis conducted by Baccarat until 2003, confidential, references upon request), Lead-free crystal 3 : US patent 2007/003237A1, Lead-free is based on US Patent. Holder is Swarowski Sodalime glass: commercial formulation used for tableware production

On this basis EDG & LEU[1763] conclude that lead-free glass does not fit with the required combination of essential properties.

- "*Shorter cooling time/working range would not permit the production of complex items any more.*
- *Higher Vickers hardness will trigger musculo-skeletal disorders for the workers because the cutting difficulty will dramatically increase. In addition, quicker damage and need to replace industrial tools will drastically increase. It will*

[1763] Op. cit. EDG and LEU (2015a)

become impossible to make very intricately engraved articles as employers are required to protect the health of their workers.

- *The combination of optical properties (refractive index, Abbe number, dispersion) generated by the use of lead bound in crystal glass are unique and unmatched by other materials (the latter are unable to obtain the same low value of chromatic aberration).*"

According to EDG & LEU[1764] there are no industrial processable substitutes with comparable thermo-mechanical-optical properties enabling the manufacture of handmade high end articles. There is no single element or combination of elements known to substitute Pb in crystal glass in all its properties (workability, optical properties, chemical resistance, etc.). Tested combinations of elements such as Ti, B, Zn, Bi, Sb, Ba, Sr, Li, have only allowed reaching some of the above-mentioned properties. It is further explained that it is difficult to estimate if and when further research shall allow achieving the demanding combinations of essential characteristics. It is therefore not possible to predict how long this type of R&D would take or whether substitutes could be found for all the lead bound in crystal EEE applications.

31.4.2 Environmental Arguments

According to EDG & LEU[1765] **the hazard represented by glass depends** on the intrinsic properties of the substance glass and not on the intrinsic properties of the individual substances that went into the batch as intermediates for making the glass. By definition, glass is an amorphous, inorganic solid material made by fusing silica with basic oxides. Glass is called amorphous because it is neither a solid nor a liquid but exists in a vitreous (or glassy) state. From a chemical point of view, glass is both a unique material and a material state respectively. The chemical and physical material characteristics and behaviour cannot be derived from the properties of the raw materials (e.g., PbO or Pb_3O_4) used as intermediates. The melting process leads to a complete chemical transformation forming a new chemical compound: crystal glass. Lead bound in crystal glass waste is a non-hazardous waste according to EC Decision 2003/33/EC. Criteria for acceptance of non-hazardous waste at landfills have been introduced in Council Decision 2003/33/EC, also including leaching thresholds for various substances. According to EDG & LEU, LCG has been tested and lead bound in crystal complies with the leaching values of the landfill directive (see Appendix A.5.0) and is classified as non-hazardous material in the Waste Framework Directive (2008/98/EC).

It is further explained that lead crystal EEE applications are prestigious and expensive items which are kept, transferred, inherited or resold. The repairing or replacement of the broken parts, of these prestigious and expensive items (e.g. one branch or prism of a luminaire), prevents the discarding of the full EEE application. Crystal manufacturers provide inherent assistance via an after-sales service by which they collect and replace

[1764] Op. cit. EDG and LEU (2015a)
[1765] Op. cit. EDG&LEU (2015a)

the broken parts of EEE crystal items which have been brought back by the customer, sometimes via the distribution chain. In addition, there are second-hand shops and specialized repair workshops, privately collecting, repairing and replacing spare parts of EEE applications made of lead bound in crystal glass. In this sense EDF & LEU argue the **probability of LCG EEE articles to reach the waste stream** to be very small. The number of discarded spare parts is negligible, given that EEE applications made of lead crystal glass are prestigious and expensive items which the consumer has all interest to keep and repair.[1766]

Finally, during the visit at the Saint-Louis manufacturing facility (see Section 31.5), both representatives of Saint-Louis and of Baccarat explained that the use of lead in the glass affects its workability and subsequently the **energy consumption of various manufacturing stages**. Saint-Louis were asked to substantiate this aspect and provided the following detail as a follow-up to the visit:

Saint-Louis[1767] explains that lead oxide included in a glass recipe has a significant contribution towards lowering the melting temperature of the different oxides, and towards extending the working range. The time within this working range is critical for handmade work, because it corresponds to the temperatures where the thermal and viscosity behaviour of the glass is suitable for glass shaping. Typically the lead oxide glasses will have longer working range by about 60-80°C (about +30% longer)[1768] in comparison to lead-free glasses. Consequently workers have more time to shape the glass before heating it again. Moreover, the thermal behaviour of lead oxide glass is shifted towards lower temperature, which means a lesser high reheating process when needed. All in all a lead oxide recipe needs less energy than a lead-free one. Saint-Louis[1769], estimates that typically the orders of magnitude of energy consumption savings and advantages for lead-glass recipes versus lead-free recipes, in relation to various processing stages are as follows:

- **Fusion**: with a nominal temperature setting of at least 50°C less for fusion in pot & tank furnaces, this translates to at least 10% less energy consumption for lead glass vs lead-free glass.
- **Blowing/glass art**: during shaping processes, glass is regularly reheated in different side gas furnaces, to allow the completion of all the different shaping gestures (blow gestures +hand shaping gestures) to achieve the right

[1766] Op. cit. EDG&LEU (2015a)
[1767] Saint-Louis (2015a), Answers to clarification questions following visit at the Saint-Louis manufacturing facility, sent per email 15.1.2016
[1768] In this regard please note the reference in Section 31.3: "The range of temperatures in which glass is formed into ware in a specific process. For comparison purposes, when no specific process is considered, the working range of glass is assumed to correspond to a viscosity range from the working point to the softening point. (4 to 7.6 Log10 Poise)". See also Figure 31-2: Viscosity as a function of temperature for several glass types .
[1769] Saint-Louis (2015a), Answers to clarification questions following visit at the Saint-Louis manufacturing facility, sent per email 15.1.2016

design. Lead oxide glass recipes, which have a longer working time, do not need to be reheated as often, and the needed temperature (relevant for reheating) is lower. Though it is difficult to quantify the differences in light of the diversity in the various pieces typology, it is however clear that the energy consumption relevant for making the same amount of pieces per time unit is less (estimated as about 15%).

- **Annealing**:with a nominal temperature setting of at least 50°C less for annealing in belt furnaces (after glass shaping and cup removing), it is estimated that as a minimum 15% less energy is consumed for lead-glass in comparison to lead-free glass.
- Every **mechanical operation** is affected by the change of hardness of the glass. Lead-glass is less hard than lead-free glass. As a consequence, the needed effort to modify the surface of the material is lower:
    - Handmade cutting: 20-50% less time is needed for completing tasks (depending on product's typology), with non-evaluated impacts on skeleton & muscular diseases.
    - Machine cutting: 15% less power is needed for the completing the same tasks.
    - Flat surfacing & final polishing: surface polishing is highly dependent on the hardness; lead glass flat surfacing time as compared to lead-free recipes is estimated to be about 75% less energy intensive, and for final polishing and reparation this difference is estimated to be about 35% less. Consequently, energy saving is expected to greater in lead glass.
    - Etching - acid polishing: The acid polishing process is comprised of a succession of dipping into different baths of hydrofluoric (HF) & sulfuric (H_2SO_4) acids, enabling chemical attacks of the glass surface and cleaning ones. This process occurs at 50°C. The chemistry of a lead glass reacts differently to the acid attacks of lead-free glass because of the atoms network bonding and chemical affinities, which influences the chemical reactions at the surface. For lead-free glass, it has been observed that the cleaning of the chemical substances from the acid attack is favourable when hydrochloric (HCl) acid is added to the HF and H_2SO_4, which means higher costs and energy, not yet quantified. According to the tests carried out, for the global etching process, typically 60% less time is needed for lead glass as compared to lead-free glass, which means directly 60% less energy consumption.
- **Decoration**: the firing process of gold palladium coatings is done in batch furnaces at temperatures which are at least 50°C lower for lead-glass recipes in comparison to lead-free glass, which means about 15% less energy.

Saint-Louis[1770] concludes that all in all, the estimated energy saving along the production stages of crystal lead glass in comparison to lead-free glass is between 20-30%. Concerning possible differences in the maintenance of equipment, the frequency at which cutting wheels need to be sharpened and replaced is around twice less (Saint-Louis's terminology).

31.4.3 Socio-economic Impact of Substitution

EDG & LEU[1771] argue that the ban of lead crystal in electric and electronic equipment would lead to the disappearance of some mainly lead crystal manufacturing companies. In Europe there are many companies whose business is devoted entirely to the production and sale of lead crystal chandeliers and allied lighting products (e.g. in UK approximately 10). A larger group of companies have lead crystal products as part of a wider range of products (e.g. in UK approximately 25) and there are a number of specialist antique restoration companies that refurbish and restore lead crystal chandeliers and rely on the manufacture of spare parts made from the same quality of crystal glass (e.g. in UK approximately 5). LCG is manufactured mostly through artisanal work, requiring unique and specific knowledge, with some European companies benefitting in this respect from national recognition for this via a status of patrimonial knowledge. EEE applications represent about one third of the turnover for some of these companies. Should the exemption not be renewed, it would mean:

- Loss of economic and patrimonial wealth.
- Loss of circa one third of turnover of related manufacturing companies and in the medium/long term, their disappearance.
- Loss of 1,000 direct jobs and 3,000 indirect jobs[1772] in Europe.

If lead crystal were to be banned in the EU the high quality market for chandeliers and other allied lighting products would be severely affected as the distinction between high quality chandeliers (some costing 10s of thousands of EUR) and poorer quality items will not exist. As a result the market for high quality crystal lighting will be damaged and some companies may be forced out of business with a resulting loss of jobs. A similar damage will affect the restoration and refurbishment market as lead crystal parts matching the originals would not be available rendering their work as poor restorations (bearing in mind that refurbished lighting products need to comply with relevant regulations). If the market does not exist there would be no replacement part available.[1773]

[1770] Op. cit. Saint-Louis (2015a)
[1771] Op. cit. EDG & LEU (2015a)
[1772] Indirect jobs are understood to be related to enterprises which use lead crystal in their work, however which do not manufacture the lead crystal themselves. For example, manufacturers of articles who rely on lead crystal producers as suppliers, enterprises who repair items (e.g. through replacement of single items that have broken, etc.).
[1773] Op. cit. EDG & LEU (2015a)

In a later communication it is understood that a large share of the manufacture of LCG for EEE articles relies on hand crafting and manual processing. Chandeliers, floor lamps, candelabras, table lamps, wall sconces, luminaires are made in crystal glass. Those lead crystal glass items are mainly hand crafted even if some parts could be industrially processed. For example a chandelier requires from 500 to 1,750 worked hours.

Hand crafting is said to represent 85% of work time, of the cold processing parts, for chandeliers, floor lamps, candelabras, table lamps, wall sconces and luminaires, . The remaining 15% of the work time utilises an automated tool. Equivalent additional worked hours should be taken into account for forming the part – all these additional hours are hand-crafted. Even for items where the main blank shape is produced by machine (picture frames, clocks etc.), the manual work content is approximately 80% of the manufacturing cost. Besides, most of the items manufactured by EDG-Member factories and workshops are unique. Each of them is a creation or issued in a limited edition. There is no mass production: [1774]

- For horology, production is about hundreds per year per producer;
- For chandeliers, total production volume is a little more than a thousand per year in Europe.

31.4.4 Roadmap to Substitution

General statements were made by the applicant as to the lack of available substitutes despite the research efforts that had been carried out in this area over the years. Following the visit at the Saint-Louis manufacturing facility (see Section 31.5) and the understanding from both Saint-Louis and Baccarat that manufacturers were actively researching possible alternatives to the use of lead in lead-crystal handmade articles, Saint-Louis were asked to substantiate the various aspects of their research.

In this respect, Saint-Louis[1775] explains the production of a lead crystal piece to be a succession of different sub-processes, gathered in hot and cold areas. In total, this includes more than 20 sub-processes, with flows depending on the product typology. The table below illustrates 3 different production flows (in green) for 3 typical luminaire crystal parts.

The complexity (i.e. of the research of potential substitutes) takes place intrinsically in the different flows that need to be tested but also in the interactions between the different sub-processes. In other words, the evaluation/development of a sub-process n+1 may necessitate the modification of a sub-process n or of the glass recipe itself,

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[1774] EDG & LEU (2015b), European Domestic Glass and LightingEurope, Answers to 1st Clarification Questions regarding Exemption 29 in Annex III of Directive 2011/65/EU, submitted on 14.08.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/20150814_Ex_29_EDG___LEU_1st_round_of_Clarification-Answers_final-Public.pdf

[1775] Op. cit. Saint-Louis (2015a)

which would require to check / adjust again other sub-processes: setting the recipe is an iterative development which needs to be proved for repeatability and reproducibility regarding handmade and product diversities. [1776]

hot processes ability ← impacts glass recipe → cold processes ability

At each stage, on one hand the product parameters are evaluated according to Saint-Louis quality standards expected by customers (Norme de Choix), and on the other hand in respect to the process performances (reject levels, energy consumption, maintenance impacts). For instance, the thermal and viscosity behaviour of one recipe could be found suitable for blowing processes, but not for injection/pressing processes, which means a correction of the recipe and a new check of the blowing performance would be needed. However, a change of the recipe also affects the fusion properties, particularly the refining process, which is key aspect for producing a high quality glass without bubbles. Another example of interaction is the impact of a recipe modification on the chemical behaviour during the etching process (acid attack), and on the aptitude of gold or platinum decoration (decor adhesion on the glass substrate during the firing decoration process).[1777]

[1776] Op. cit. Saint-Louis (2015a)
[1777] Op. cit. Saint-Louis (2015a)

Table 31-2: Example of 3 different production flows (in green) for 3 luminaire pieces

	Fusion		Hot processes					Cold processes					
glass or hurricanes for luminair	composition raw material mixing	fusion tank furnace fusion pot furnaces	blowing injection pressing paperweight glass art	glass annealing tunnel oven glass annealing batch oven	cup removing laser cup removing saw	cut edges flame polishing	glass annealing	flat polishing handmade cuts machine cuts engraving drilling / neck tooling sand blasting	chemical engraving	acid polishing	final polishing reparation	Gold/palladium decoration application & firing	
colored hurricane holder for luminair	composition raw material mixing	fusion tank furnace fusion pot furnaces	blowing injection pressing paperweight glass art	glass annealing tunnel oven glass annealing batch oven	cup removing laser cup removing saw	cut edges flame polishing	glass annealing	flat polishing handmade cuts machine cuts engraving drilling / neck tooling sand blasting	chemical engraving	acid polishing	final polishing reparation	Gold/palladium decoration application & firing	
branch for luminair	composition raw material mixing	fusion tank furnace fusion pot furnaces	blowing injection pressing paperweight glass art	glass annealing tunnel oven glass annealing batch oven	cup removing laser cup removing saw	cut edges flame polishing	glass annealing	flat polishing handmade cuts machine cuts engraving drilling / neck tooling sand blasting	chemical engraving	acid polishing	final polishing reparation	Gold/palladium decoration application & firing	sealing to metal holder + electrification

Source: Saint-Louis (2015a)

Fusion is the key starting process, which cannot be tested directly with final production furnaces (tank or pots). Indeed recipes evaluation and pre-validation must start with crucibles at the laboratory and in small size pots with limited trials, enabling the production of some pieces for testing performance in respect to shaping and cutting and challenging their hot/cold processes ability, leading finally to real size pots and extensive validations. Consequently, the use of a tank furnace ought to be done at the end of the development of all the sub processes with the final glass recipe selected, with the help of the tank furnace supplier where designing of the right furnace is of relevance.[1778]

Colours development is also a key issue for the product portfolio in relation to expectations of customers and designers, for luminaires as well as for decoration and tableware. A dozen colours are currently made available by Saint-Louis on the market. Many coloured products are made of overlaid glass colours. The glass colours must be developed on the basis of the clear recipe, for dilatation coefficient and fusion compatibility reasons. Furthermore, the effect of the colorant oxides strongly depends

[1778] Op. cit. Saint-Louis (2015a)

on the glass matrix. Therefore the development of the different colours must be synchronized once the clear recipe is known, and this cannot be fully anticipated and induces a time shift as well in respect to the time needed for enabling substitution.[1779]

Saint-Louis[1780] explains that as indicated in the presentation held during the visit on 3 December 2015 (detailed in Section 31.5), the overall recipe development for a substitute is thus based on a progressive, iterative and focusing approach following several criteria which must be validated with each other. So far, after desk-research (of between 1 to 600 recipes) and experimental tests with crucibles (of between 1 to 20 recipes), between 1 and 10 recipes are currently being tested in small pots, and Saint-Louis has initiated real pot evaluation of between 1-5 recipes. It took about 5 years to arrive at the mapping of results for processes performance, shown in the presentation for the hot and cold areas. On this basis it is expected that at least 10 more years shall be needed to achieve the final focus on one recipe and its optimization, in order to cope with the different sub-processes relevant for producing the product portfolio of the luminaires and other pieces manufactured by Saint-Louis. Against this background, Saint-Louis however also notes that there is no guarantee of success at this stage.

31.5 Visit of LCG Manufacturing Facility

During the evaluation period EDG coordinated a visit of the consultants at the manufacturing facility Saint-Louis[1781], located in the Lorraine region of France. During the visit the various stages of the manufacturing process were observed, including:

- Manufacture of pots from special clay, used for the fusing of the lead crystal glass in the second stage in the “multi-pot” furnaces – the composition of the clay is specifically determined for the LCG composition and will need adaptions should the composition of the glass change;
- First fusion in furnace of the intermediate ingredients into clear lead crystal glass. Most facilities will have a unique glass composition making separation of manufacture to lead-free articles and lead-based articles impractical;
- Second fusion in multi-pot furnaces of the lead crystal glass as preparation for hot processing of articles. In this stage metal oxides can be added to the clear crystal glass to determine the colour of a specific batch of glass;
- Hot processing of lead crystal – glass blowing as well as glass pressing (manufacture of articles with moulds). In the process of forming, the articles are reheated as necessary to provide sufficient forming time – the working range of the glass determines how many times the article is to be reheated until the hot process forming is completed;

[1779] Op. cit. Saint-Louis (2015a)
[1780] Op. cit. Saint-Louis (2015a)
[1781] The visit at Saint-Loius (See http://www.saint-louis.com/en/ for details) took place on the 3.12.2015 and was also attended by representatives of EDG, the French Federation of crystal manufacturers and Baccarat (another French lead crystal manufacturer).

- Belt and static furnaces are used to anneal articles after they are blown/pressed to relieve inner tensions and "relax" the material;
- Cold processing of lead crystal articles - depending on the type of article being produced, this stage may include: cutting, engraving, polishing, etching and gold decoration. At this stage the hardness of the glass impacts the processing time, subsequently determining the wear of machinery.

It was explained that the refraction of lead glass plays an important role for lighting products and thus that engraving and cutting processes, which are easier when lead is present, are more common to create more intense refraction effects. From the current research it can already be seen that certain types of cutting processes are impossible to achieve with lead-free crystal, as lead-based crystal glass is softer.

Furthermore, Saint-Louis presented results of their on-going research efforts into alternatives. It is understood that the search for lead-free recipes was motivated years ago by the regulation of lead, e.g. under RoHS and by the ongoing discussions about food contact and REACH. According to Saint-Louis, the general goal is to find an alternative glass recipe which shall allow manufacturing products with the unique properties relevant both for manufacture and for the end product. A new composition needs to show similar properties throughout all stages of manufacture and processing while also resulting in articles with the same qualities as LCG (refraction of light, the clearness of the glass, etc.). To begin with, candidate substitutes need to have a similar density and to exhibit similar refraction properties. Furthermore, candidates will need to be tested to see their performance through the various production phases, to ensure that the same articles can be manufactured with comparable quality. Saint-Louis have identified over 20 sub-processes within the manufacture for which potential compositions need to be checked, as well as checking the internal relations between these processing stages. The need to use a single composition for manufacturing a relatively wide product portfolio further complicates the search for a suitable alternative, as a potential substitute composition shall need to enable manufacture of a wide variety of different products[1782]. Aside from ensuring the technical comparability of candidate substitutes, it is also necessary to ensure that negative health and environmental impacts shall not be a result of substitution. In this respect, if the weight or the hardness of the material

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[1782] In this respect, the consultants can follow that the use of both the first fusion furnace and of the multi-pot furnace in the manufacturing process may limit the practicability of manufacturing in separate batches. This is because for each batch, all furnaces would need to be cleaned from any residues, which may affect the recipe composition and thus the properties of the crystal in subsequent production stages and in the final products. Furthermore, Saint-Louis has also mentioned the need to optimise the composition of the clay used for the pots in the multi-pot furnace, should a new composition be found to be a practical substitute. It has also been communicated that possibly the machines used from cold processing would need to be adapted in light of differences in the hardness of the material. In this sense, it can be followed that batch production that may allow using a lead-free or lead-reduced formula for certain articles and lead based for others, would not be practical. Though theoretically it is possible that multiple production lines could be constructed, this would only be practical in facilities above a certain size of production.

change, this may influence the workability of articles for employees, as well as influencing the time needed for certain processes and thus the energy consumption or the wear of machinery. If the composition shall have a higher fusing temperature and/or a shorter work range, this would also increase the time needed for various process stages as well as the energy consumption. Furthermore, depending on the substances that shall compose the substitute, toxicity aspects may also need to be considered.

31.6 Stakeholder Contributions

The following stakeholders contributed to the stakeholder consultation regarding Ex. 29 and all support the renewal of the exemption:

- Academie de Clermont- Ferrand, Lycée Jean Monnett (Academie de C-F);[1783]
- Assemblée Nationale, Jacques Lamblin, Député de Meurthe et Moselle, Maire de Lunéville (Maire de Lunéville);[1784]
- Assemblée Nationale, Céleste Lett, Député de la Moselle, Maire de Sarreguemines (Maire de Sarreguemines);[1785]
- Assemblée Nationale, Gérard Cherpion, Member of the French Parliament, Member of the regional Council of the region Lorraine (Gérard Cherpion);[1786]
- Association of the Glass and Ceramic Industry of the Czech Republic (ASKPCR);[1787]
- Canning Design Ltd (Canning Design);[1788]
- Cerfav, CRT- Verre (Cerfav);[1789]

[1783] Academie de CF (2015), Academie de Clermont-Ferrand, Lycée Jean Monnett, submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Ex_29_lycee_Jean_Monnet_zusammengefuegt.pdf

[1784] Maire de Lunéville (2015), Assemblée Nationale, Jacques Lamblin, Député de Meurthe et Moselle, Maire de Lunéville, General comments related to RoHS exemption package 9, submitted 12.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Courrier_RoHS_anglais.pdf

[1785] Maire de Sarreguemines (2015), Assemblée Nationale, Céleste Lett, Député de la Moselle, General comments related to RoHS exemption package 9, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/contribution_by_celeste_LETT.pdf

[1786] Gérard Cherpion (2015), Assemblée Nationale, Gérard Cherpion, Member of the French Parliament, Member of the regional Council of the region Lorraine, General comments related to RoHS exemption package 9, submitted 15.10.2015, available under: • Assemblée Nationale, Gérard Cherpion, Member of the French Parliament, Member of the regional Council of the region Lorraine

[1787] ASKPCR (2015), Association of the Glass and Ceramic Industry of the Czech Republic, submitted 16.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Ex_29_ASKPCR_16102015.pdf

[1788] Canning Design (2015), Canning Design Ltd., submitted 16.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Ex_29_CanningDesign_Consultation_Document151015.pdf

[1789] Cerfav (2015), CRT- Verre, submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Ex_29_Cerfav_20151016.pdf

- CFE-CGC Chimie (CFE- CGC);[1790]
- Confédération française des métiers d'art de l'exellence et du luxe- French Confederation of Arts and Crafts (CFMA);[1791]
- Fédération CFTC Chimie Mies Textile Energie (CFTC- CMTE);[1792]
- Institut Universitaire de France, Ecole Nationale Supérieure de Chimie de Clermont- Ferrand (Institut Universitaire de France);[1793]
- John Rocha, CBE (John Rocha);[1794]
- José Lévy, Design expert (José Lévy);[1795]
- Parlament Européen, Députée Européene ADLE/ Grand Est- France (Députée au Parlament européen);[1796]
- Direction de l'Economie Solidaire et de l'Insertion, Conseil Départemental de Meurthe-et-Moselle (Meurthe et Mosselle)[1797];
- La Région Lorraine, Le Président du Conseil Régional de Lorraine, Sénateur de la Moselle (Région Lorraine);[1798]

[1790] CFE- CGC (2015), CFE- CGC Chimie, French trade union, submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Ex_29_CFE-CGC_Chimie_reponses_questions_20151016.pdf

[1791] CFMA(2015), Confédération française des métiers d'art de l'exellence et du luxe- French Confederation of Arts and Crafts, Application to exemption No 29 of crystal glass a part of the directive RoHS 69/493/EEC, submitted 13.10.2015, available under:http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Contribution_by_confederation_francaise.pdf

[1792] CFTC- CMTE (2015), Fédération CFTC Chimie Mies Textile Energie, submitted 19.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Ex_29_FEDERATION_CFTC-CMTE_Position_20151016_ENG.pdf

[1793] Institut Universitaire de France (2015), Ecole Nationale Supérieure de Chimie de Clermont- Ferrand, submitted 15.10.2015, available under:http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Contribution_Exe_29.pdf

[1794] John Rocha (2015), Designer, CBE, 10 Ely Place, Dublin, Ireland, submitted 16.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Ex_29_John_Rocha_Contribution__20151016.pdf

[1795] José Lévy (2015), Design expert, General comments to RoHS exemption package 9, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Lettre_Jos_Levy_V2__2_.pdf

[1796] Députée au Parlament européen (2015), Parlament Européen, Députée Européene ADLE/ Grand Est- France (Députée au Parlament européen, Renouvellement d'exemption- Référence Exemption No 29, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/20151012_-Consultation_publique_-_Exemption_Request_For_Exemption_no._29_ROHS.pdf

[1797] Meurthe et Mosselle (2015), Direction de l'Economie Solidaire et de l'Insertion, Conseil Départemental de Meurthe-et-Moselle, Application to exempt No 29 of Crystal Glass as a Part of the Directive RoHS 69/493/EEC, submitted 29.9.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Contribution_by_Direction_de_l_Economie_Solidaire_et_de_l_Insertion.pdf

[1798] Région Lorraine(2015), Le Président du Conseil Régional de Lorraine, Sénateur de la Moselle, General comments to RoHS exemption package 9, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/translation.pdf

- La Fédération Chemistry - Energy of the CFDT Group (Cfdt);[1799]
- Lyceé Dominique Labroise, The Headmaster, F. Vignola (Lyceé Dominique Labroise);[1800]
- Ministry of Industry and Trade of Czech Republic, Vice Minister, Ing. Eduard Muricky (Ministry of Industry/ Trade of Czech Republic);[1801]
- Moselle Department Council, Le president (Moselle Department);[1802]
- Noé Duchaufour Lawrance, pour Néonata S.A.R.L. (Noé Duchaufour Lawrance);[1803]
- Test and Measurement Coalition (TMC);[1804]
- Jackie Pierre, Senat (Le Senateur de Vosges);[1805]
- Philippe Leroy, Senat (Le Senateur de la Moselle);[1806]
- PRECIOSA- LUSTRY, a.s., President of Managing Board (PRECIOSA).[1807]

[1799] Cfdt (2015), La Fédération Chemistry - Energy of the CFDT Group, Consultation Questionnaire Exemption no. 29, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Ex_29_CFDT_ROHS_20151015_.pdf

[1800] Lyceé Dominique Labroise (2015), The Headmaster, F. Vignola, General comments to RoHS exemption package 9, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/20151015094719390.pdf

[1801] Ministry of Industry / Trade of Czech Republic (2015), Vice Minister, Ing. Eduard Muricky, General Comments to RoHS exemption package 9, submitted 16.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Ex_29_Ministry_of_Industry_and_Trade_of_the_Czech_Republic_contribution_20151016.pdf

[1802] Moselle Department (2015), Moselle Department Council, Le president, General comments to RoHS exemption package 9, submitted 14.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Ex_29_Department_Moselle_Council_14102015_Oko-Institut.pdf

[1803] Noé Duchaufour Lawrance (2015) pour Néonata S.A.R.L., General comments to RoHS exemption package 9, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Ex_29_NOEDUCHAUFOURLAWRANCE_20151015.pdf

[1804] TMC (2015), Test and Measurement Coalition, General comments related to RoHS exemption package 9, submitted 16.10.2016, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_1_a-e_/General_Contribution_Test___Measurement_Coalition_package_9_exemptions_20151016.pdf

[1805] Le Senateur des Vosges (2015), Jackie Pierre, Senat, Exemption Request for Exemption No 29 (renewal request), submitted 07.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/051015_Directive_ROHS_-_CONSULTATION_CE_cabinet_Oeko_exemption_29.pdf

[1806] Le Senateur de la Moselle(2015), Philippe Leroy, Senat, Application to exemption No 29 of crystal glass a part of the directive RoHS 69/493/EEC, submitted 13.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/contribution_by_philippe_leroy.pdf

[1807] PRECIOSA (2015), PRECIOSA- LUSTRY, a.s., Lucie Karlova, President of Managing Board, submitted 15.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_29/Contribution-Preciosa_EN-ws___2_.pdf

A short summary of the aspects raised by the various stakeholders is provided in Table 31-3.

Table 31-3: Summary of aspects related to Ex. 29 raised in stakeholder contributions

Aspect	Stakeholders
Lack of substitutes for lead oxides in the manufacture of LCG, despite research efforts of manufacturers.	Meurthe et Mosselle; Senateur des Vosges; Maire de Lunéville Senateur de la Moselle; CFMA; Moselle Department; Maire de Sarreguemines; Institut Universitaire de France; PRECIOSA, Cfdt; Ministry of Industry/ Trade of Czech Republic. ASKPCR; Cerfav; CFTC- CMTE
Unique properties obtained through the use of lead in LCG – optical properties, aesthetic properties, improved working properties (increase of the viscosity of the material), allows the production of specific articles.	Meurthe et Mosselle; Maire de Lunéville; CFMA; Région Lorraine; Maire de Sarreguemines; PRECIOSA; José Lévy; Lyceé Dominique Labroise; Noé Duchaufour Lawrance; Cfdt; Ministry of Industry/ Trade of Czech Republic; John Rocha; Canning Design; Cerfav; CFTC- CMTE; Academie de CF
Properties that enable energy savings in the manufacture of LCG related to the use of lead as an intermediate.	Meurthe et Mosselle; Maire de Lunéville; PRECIOSA; Lyceé Dominique Labroise; Cfdt; CFTC- CMTE
Low probability of articles to reach the waste stream (i.e. to reach end-of-life). Subsequently, no significant environmental impact expected related to collection, replacement, repairing.	Meurthe et Mosselle; Senateur des Vosges; Senateur de la Moselle; CFMA; Moselle Department; Députée au Parlament européen; Maire de Sarreguemines; PRECIOSA; José Lévy; Lyceé Dominique Labroise; Noé Duchaufour Lawrance; Cfdt; ASKPCR; Cerfav; CFE- CGC; CFTC- CMTE; Academie de CF
Lead crystal used in EEE is handcrafted (artisanal) and comprises a cultural heritage of importance in various EU countries; the exemption does not relate to articles in mass production.	Meurthe et Mosselle; Senateur des Vosges; Assemblée Nationale; Moselle Department; Région Lorraine; Députée au Parlament européen; PRECIOSA; Lyceé Dominique Labroise; Gérard Cherpion; Cfdt; Ministry of Industry/ Trade of Czech Republic; John Rocha; ASKPCR; CFE- CGC; CFTC- CMTE; Academie de CF
Many individuals depend on the further manufacture of EEE containing lead crystal items for their livelihood – should the exemption be revoked, this could have a high social impact on such individuals, of particular concern in certain peripheral areas where the local population depends on such manufacturing establishments for employment (e.g. Lorraine in France, North of Bohemia (Kamenicky Senov), etc.).	Meurthe et Mosselle; Senateur des Vosges; Maire de Lunéville; Senateur de la Moselle; Moselle Department; Région Lorraine; Députée au Parlament européen; Maire de Sarreguemines; PRECIOSA; Lyceé Dominique Labroise; Gérard Cherpion; Cfdt; Ministry of Industry/ Trade of Czech Republic; ASKPCR; CFTC- CMTE
The validity period of Ex. 29 in relation to articles in sub-category 9, industrial monitoring and control instruments.	TMC

31.7 Critical Review

31.7.1 REACH Compliance – Relation to the REACH Regulation

Appendix A.1.0 of this report lists Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. Entry 63 restricts the presence of lead and its compounds in various articles. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restriction for lead compounds under Entry 30 of Annex XVII does not apply to the use of lead in this application. Pb used in lead crystal glass, in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. The lead oxides used to form the glass undergo a change of form when the ingredients are fused together. As the applicants explain, though its constituents are closely linked together, lead crystal is different from the initial state of its raw materials. In this sense lead is encapsulated in the vitreous material and thus not accessible to the public as such. Pb is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII restricts the use of lead and its compounds in various articles. Paragraph 1 specifies jewellery in this respect, however paragraph 4(a) specifically excludes "crystal glass as defined in Annex I (categories 1, 2, 3 and 4) to Council Directive 69/493/EEC (*)" in relation to paragraph 1. Paragraph 6 does not allow placing articles on the market which, contain Pb concentrations above 0.05% by weight, where during normal use these could be placed in the mouth by children. Nonetheless, paragraph 7(b) specifically excludes "crystal glass as defined in Annex I (categories 1, 2, 3 and 4) to Directive 69/493/ EEC"; It is thus concluded that this entry would not apply to Pb in lead crystal glass used in EEE. Paragraph 8(k) also further excludes equipment in the scope of RoHS from the paragraph 7 restriction.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status December 2015).

Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

31.7.2 Scientific and Technical Practicability of Substitution

EDG and LEU have requested the renewal of exemption 29 to allow the use of Pb in lead crystal glass when used in EEE. The applicants argue that lead provides unique properties to the crystal glass, which are of importance both in the manufacture of articles as well as in the performance of the product through its use.

The properties of the lead crystal glass are explained to be of importance for the end product, as the addition of lead affects optical properties and thus the aesthetic properties of the glass, such as the refractive index and the dispersion of light. This is explained to be important, as it allows designers of articles to create unique products, and is also of importance to consumers judging by the demand for such products on the market.

EDG and LEU argue that there are no comparable substitutes for lead crystal glass that would provide the same properties and performance both in the manufacture and in the products themselves. The production of lead crystal glass used in EEE includes a large degree of hand crafting, both in the manufacturing stages, such as blowing and pressing and in the later stages of cold processing such as cutting and polishing. Even when automation is involved in the manufacture, EDG & LEU claim that up to ~80% of the production costs are related to further handcrafting of the articles. The properties of the material are understood to have a large effect on the ability to perform the various stages of the production, particularly in the manual processing stages, and it can be understood that substitutes that have been tested up until now would not allow creating articles of the same complexity. This would also affect the time needed for production and thus respectively the energy consumption (estimated by Saint-Louis to be at least 20-30% lower than were lead-free glass to be applied).

It can be understood that the various lead crystal manufacturers have been researching substitutes for many years, and results of this research also show certain progress in this respect. However, it is also understood that an alternative to lead in the glass which is applicable to all stages of the production, is not yet available and that lead crystal glass is at present still the only material that would allow retaining the diverse product range. Where first attempts (production of articles in small scale and testing of their suitability in various processing stages) have been performed with lead-free glasses, it can be followed that results are not yet sufficiently comparable to allow the substitution of lead, and that such results also suggest that substitution at this stage would result in a significant increase of energy costs and use of resources.

Though one could argue that for the various EEE articles, in which lead crystal is used, that various alternatives exist – e.g. alternative luminaires – the consultants can follow that such articles would not provide a one-to-one replacement in terms of the appearance of the products. Though this aspect is understood to be of aesthetic nature, being difficult to assess in technical terms, some data has been provided to show that should other types of glass be used to create articles of similar appearance, that the optical properties of importance for the aesthetic properties of the products would not be comparable on the crystal level. Alternative types of glass, regardless of their ability to be used for creating products of the same complexity, show inferior levels in terms of e.g. refractive index, abbe number, dispersion, etc.

It is understood that in manufacture, the addition of lead increases the working time of the glass through its impact on the viscosity of the glass and its thermal properties. This facilitates the melting and forming of crystal articles in hot-processing, and more importantly has an impact on the energy consumption related to these production

stages as the glass does not need to be reheated (re-melted) as often, and as the temperature for reheating is significantly lower than for lead-free glass types.

It is also understood that the addition of lead results in a glass that is not as hard, and in this respect the glass crystal also facilitates cold processing of the articles such as cutting, engraving, polishing, etc. Since the glass is softer, it can be processed more easily and in less time for the same amount of units, therefore also reducing the energy consumption related to these stages. Another important aspect in this respect is understood to relate to the softer lead-based glass also resulting in less frequent maintenance and replacement of equipment, which would translate to a lower use of resources where equipment or equipment components need to be replaced.

31.7.3 Environmental Arguments

The applicants, as well as some of the stakeholders, who participated in the consultation, explain that in LCG articles, lead is encapsulated within the material and a risk of emissions to the environment during the use and the end-of-life phases is not expected. The risk related to the end-of-life stage is further assessed to be irrelevant, claiming that practices of repair or replacement of the broken parts, of these prestigious and expensive items (e.g. one branch or prism of a luminaire), prevents the discarding of the full EEE application at end-of-life. EDF & LEU thus argue that the probability of LCG EEE articles to reach the waste stream is very small. EDF & LEU have furthermore submitted lead crystal leaching testing results (one report can be viewed in Appendix A.5.0) showing that the risk of lead emissions from such articles is negligible. In the consultants' view, submitted test results sufficiently show that (under normal use/ environmental conditions) emissions from lead crystal during use and during end-of-life are not expected. As long as not treated with strong acids, release of lead from the vitreous matrix would not be expected. The consultants can also follow that lead crystal articles would typically not reach the waste stream in light of their value. Small parts may become waste when broken and repaired; however it can be followed that typically articles will not be disposed of, but rather sold to antique shops and the likes. This is particularly understood to be the case for EEE articles, which as opposed to tableware are less at risk to break during use (chandeliers and luminaires shall usually be fixed to walls and ceilings, etc.). This means that possible emissions at this stage would be less significant in light of the amount of lead crystal potentially disposed of. Possible emissions of lead at these life cycle stages are thus understood to be sufficiently controlled.

A further important aspect raised in relation to environmental impacts is related to the consumption of energy and resources during the manufacture of articles. It is further expected that lower energy consumption would subsequently mean lower emissions related to energy such as greenhouse gases. These aspects have been summarised in Section 31.7.2 and are not discussed here again.

31.7.4 Socio-Economic Impacts

The applicants and the various stakeholders who participated in the consultation also argue that to revoke the exemption could result in significant social costs, as the production of hand-crafted lead crystal is considered a cultural heritage in many areas of the EU (e.g. Alsace Lorraine in France, Bohemia in the Czech Republic, etc.). Furthermore, it is explained that in areas where this traditional form of hand crafting of LCG is performed, that facilities employ a large number of individuals, whose livelihood would be at risk should the use of LCG in EEE be prohibited. Manufacturers claim that respective market shares of LCG articles used for tableware and for EEE are changing, with a growing importance of EEE in the product portfolio. This would further support that a change to the current exemption could have a significant impact on the LCG sector. The consultants can follow that the artisan manufacture of lead crystal articles has importance both as a cultural heritage and as a source of employment for many individuals. However, it is also possible that a reduced manufacture of lead crystal (i.e., LCG applied in EEE) would in parallel lead to increased manufacture of alternative equipment (alternative luminaires, etc.) and thus to an increase of employment in other sub-sectors. Nonetheless it is difficult to estimate the total possible impacts of a revocation of the exemption, and thus the consultants cannot conclude as to the range of such impacts and their severity in terms of costs for society.

31.7.5 Stakeholder Contributions

The stakeholder contributions generally support the request, raising various aspects related to the properties of lead crystal and the unavailability of comparable substitutes. As these aspects are addressed in the summary of information provided by the applicants and by Saint-Louis, further detail is not provided here.

The contribution submitted by TMC raises a legal question as to the availability of the current exemption to category 9 equipment. Regardless of TMCs claims as to the availability of Annex III exemptions to sub-category 9 industrial for 7 years starting in 22.7.2017, in the case of Ex. 29 the wording formulation limits its applicability to crystal glass. Though in theory, such glass could be used in Cat. 9 products, this aspect has not been raised by the applicant or other stakeholders to be an area of application. Furthermore, should such glass be used as a component in such EEE, it would still benefit from the exemption as long as it is valid. Should substitutes become available however, it would be of importance to evaluate their applicability in all possible applications at the same time. In this sense, in the consultants opinion, though some Cat. 9 products could enjoy a validity period of the current exemption up till 2024 (Cat. 9 industrial), it would still be considered beneficial to align the exemption validity of all categories. Further supporting this view is the fact that the applicants who represent manufacturers of the relevant articles have not specified Cat. 9 as a category into which their articles fall.

31.7.6 The Scope of the Exemption

The consultants can follow that the search for lead-free crystal glass alternatives is still on-going. Furthermore, despite the fact that alternatives are not yet sufficiently

developed, it can be understood that where tested in small scale, such alternatives would also increase energy and resource consumption related to various production stages. The information made available to support these understandings is, however, based on practices of the artisanal manufacture of lead crystal glass, which involves a large degree of hand-crafting, as practiced for example by Saint-Louis. It is not clear if lead crystal glass articles for which the exemption is needed would also be produced through automated manufacture, nor whether the same argumentation would apply. Furthermore it is currently unclear whether in such articles the same concentration or lower concentrations of lead are present. In this sense, the question arises, whether the exemption should be limited to articles produced through artisanal manufacturing or if different concentrations of lead could be specified.

From the information provided, it can be followed that the various benefits related to the addition of lead would be equally relevant as long as similar glass formulas are used. Though the ease of processing related to glasses with a longer working range and glasses that are softer can be understood to be more relevant to hand-crafting, in light of such processes not being "controlled through automation", the reduced energy and resource consumption are understood to be relevant for both types of manufacture as the production stages would be similar in this respect (fusing temperatures of glass, cold processing with equipment). In this sense if automated production uses similar glass formulas, it can be assumed that the argumentation would apply similarly to such articles. However, if similar formulas are not used and the exemption is not needed for such production, the consultants do not think that it would be practical to exclude such articles from the exemption. The consultants are not aware of a mechanism for differentiating between articles that are hand crafted and articles that are made with automation that could be used by market surveillance to ensure enforcement.

In this sense, though it is difficult to determine to what degree the justification is relevant to articles produced with automation, limiting the exemption to hand-crafted articles would not be considered to be practical in terms of its enforcement. It could also limit the ability of manufacturers to combine automated components in some cases in order to increase competitiveness through the reduction of production costs related to hand crafting where this is possible. The consultants thus do not recommend a change of the current exemption wording formulation.

31.7.7 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- their **elimination or substitution** via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable;
- the **reliability** of substitutes is not ensured;
- the total negative **environmental, health and consumer safety impacts** caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.

In the consultants' opinion, it can be followed that substance substitutes for lead in glass are currently not available. Though changes in the ingredients of the glass have been the subject of research for many years, it can be followed that at present such a substitute would not allow sufficient replication of the product portfolio in terms of production of articles with comparable properties. Such a substitute is currently not considered available, early phase-in of a substitution candidate still under investigation would limit both the complexity of articles that could be produced as well as resulting in a significant rise in energy consumption and use of resources related to manufacture. Such a substitution is also not understood to provide comparable products in terms of their optical properties, of importance for the consumer.

In parallel, one could argue that the need for lead could be eliminated through the shift to other articles, i.e. other luminaires (possibly not from glass and of different shape and form). If for example the function of a luminaire is only to provide light or also to provide a certain appearance. In the case of crystal luminaires, the applicants have communicated that certain optical properties of the glass are established in the luminaire through the use of lead: a high refractive index, a high dispersion and transmission of light and sharp colour transition. In this sense, for an alternative luminaire to be considered as a one-to-one replacement, it would need to have similar properties and to perform on a comparable level. Where alternative glass types are used to produce crystals for use in the assembly of similar luminaires, it can be understood from the applicant that such products do not provide similar performance. It has also been communicated that the processing of lead crystal glass further allows creating items of higher complexity in this respect.

31.8 Recommendation

The justification for the renewal of Ex. 29 is based on the observation that alternatives for EEE articles with lead crystal glass do not meet the technical criteria representing the specific optical properties. If these properties can be judged as indispensable, then an exemption would be considered to be justified, as possible (substance) substitutes for lead in glass currently do not allow manufacturing comparable articles and would also result in a higher consumption of energy and other resources. Such alternatives would not compare in terms of optical properties and complexity of design should they be manufactured with lead-free glass. Using lead-free alternatives in the actual hand-crafted manufacture stages of LCG would not allow completing all manufacture stages at sufficient quality, while also resulting in an additional impact in terms of energy consumption and resource use. In this case, other EEE articles fulfilling similar functions (e.g., a luminaire which functions in providing light) would not be considered as one-to-one replacements and thus also not as alternatives. On this basis, it is recommended to grant the exemption renewal for the maximum duration according to Article 5(2), as information suggests that a period of at least 10 years could be needed before substitutes may become available. In this case, the following formulation and duration would be recommended for the exemption.

Exemption n. 29	Duration*
Lead bound in crystal glass as defined in Directive 69/493/EEC	For Cat. 1-10: 21 July 2021
	For Sub-Cat. 8 in-vitro: 21 July 2023**
	For Sub-Cat. industrial: 21 July 2024**

*Note: *As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here for all categories either on the basis of the requested duration in the exemption request which the consultants perceive to be justified, or on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.*

*** In contrast, the applicants have not specified the exemption to be relevant for EEE of categories 8 and 9, and in the consultants view it would be recommended to align the exemption duration for all EEE, including Sub. Cat. in-vitro and Sub-Cat. 9 industrial, should EEE in these categories make use of the exemption despite lacking evidence thereof.*

31.9 References Exemption 29

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32.0 Exemption 32 “Lead oxide in seal frit used for making window assemblies for Argon and Krypton laser tubes”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

Ion lasers	Gas lasers, i.e. argon and krypton lasers
SSL	Solid state laser(s)

32.1 Description of the Requested Exemption

Coherent[1808] and Lumentum[1809] (formerly JDSU) requested the renewal of Exemption 32 without changes for another five years:

> *Lead oxide in seal frit used for making window assemblies for Argon and Krypton laser tubes*

32.1.1 Background and History of the Exemption

The exemption was first reviewed[1810] in 2006, whereupon the Commission granted the exemption, and once again[1811] in 2010/2011. The exemption was renewed for the

[1808] Coherent 2015a “Request for continuation of exemption 32, document "BR-_9849983-v3-Coherent_Exemption_request_form_update_after_comments___PG_with_redaction.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/Coherent/BR-_9849983-v3-Coherent_Exemption_request_form_update_after_comments___PG_with_redaction.pdf

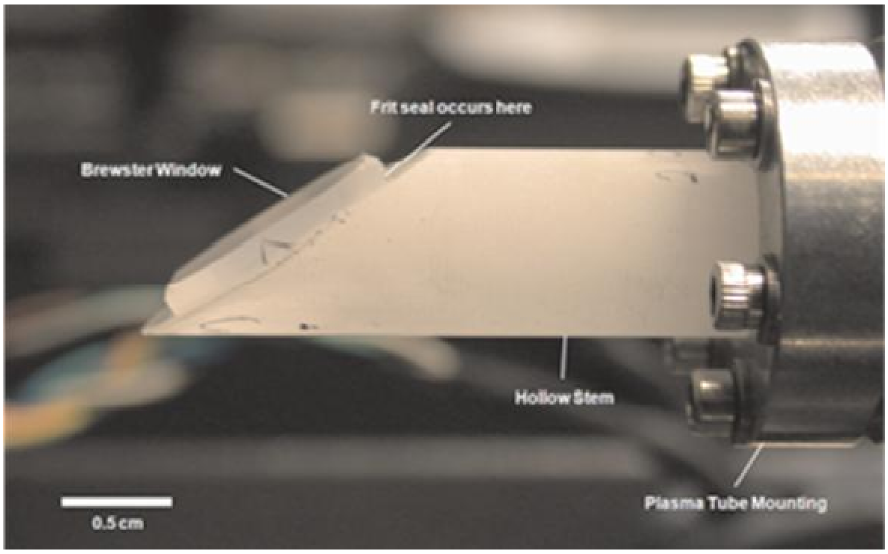
[1809] Lumentum 2015a 2015 “Request for continuation of exemption 32, document "32_JDSU_RoHS_Application_Exemption_32.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/JDSU/32_JDSU_RoHS_Application_Exemption_32.pdf

maximum four years allowed under Directive 2002/95/EC (RoHS 1) until 31 July 2014. This expiry date was systematically postponed to July 2016 when the exemption was transferred to Annex III of the recast Directive 2011/65/EU (RoHS 2).

32.1.2 Technical Description of the Exemption

According to Coherent[1812], as illustrated in Figure 32-1 the lead oxide in the seal frit is located in a Brewster window assembly, i.e. an optomechanical assembly that provides a vacuum-tight seal and is optically transparent to the laser radiation.

Figure 32-1: Location of the seal frit in the laser tube assembly



Source: Coherent[1813]

Coherent[1814] classifies the Brewster window with the lead-containing seal frits as a critical optical interface that significantly affects the performance of the laser. A plasma tube can have either one or two of these assemblies based on its type. Lumentum[1815] explains that the lead oxide-based material in Argon and Krypton laser products provides a critical thermo-mechanically-stable and vacuum-tight seal between the optics and

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[1810] Gensch, Carl-Otto [Oeko-Institut e.V.], et al. 2006 "Adaptation to scientific and Technical progress under Directive 2002/95/EC: Final Report - final version,"; http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf; page 127 et seqq.

[1811] For details see report of Zangl, Stéphanie, Oeko-Institut e.V. 30 May 2011 Adaptation to Scientific and Technical Progress under Directive 2002/95/EC: Evaluation of New Requests for Exemptions and/or Review of Existing Exemptions. With the assistance of Otmar Deubzer, Fraunhofer IZM, and Ran Liu, Katja Moch, Oeko-Institut e.V., page 83 et sqq.

[1812] Op. cit. Lumentum 2015a

[1813] Op. cit. Coherent 2015a

[1814] Op. cit. Coherent 2015a

[1815] Op. cit. Lumentum 2015a

laser tube. The softening point of the lead-oxide material occurs at a narrow temperature range around 420 °C, and does not thermally damage the nearby fragile components being joined. Additionally the material has a coefficient of thermal expansion closely matched to the components for stress-free sealing. Lead-free glasses are not available for this application, and the continuation of exemption 32 is therefore required.

Coherent [1816] states that ion lasers are unique in that they generate a variety of wavelengths in the ultraviolet, visible and infrared regions of the electromagnetic spectrum. These lasers are capable of producing ultrapure spatial and temporal output. Lumentum[1817] explains that its Argon laser products are used as coherent light sources in a broad range of critical applications, a majority of which are in research, bioinstrumentation and semiconductor manufacturing. Coherent[1818] lists the following primarily scientific and light industrial applications for Argon and Krypton ion lasers in use in the EU today:

- Spectroscopy, e.g. examination of molecules or atoms by measuring effects of laser beam exposure;
- Microscopy, e.g. magnification of samples and objects using laser as light source; non-medical uses include examination of geologic materials; and
- Holography, e.g. using lasers to record and/or view optically stored information for applications such as data storage, security, art, engineering and communications.

Lumentum[1819] states that leading manufacturers of flow cytometers, DNA sequencers, and haematology equipment, incorporate Argon lasers into their products in both new production and in service of a large worldwide installed base. Instruments are used internationally by both government and private sector agencies for health care, drug discovery, and research applications. In semiconductor manufacturing, Argon lasers are used in inspection equipment, again for both new installations and service business.

Further technical details related to Exemption 32 are available in the reports of the previous reviews.[1820, 1821]

[1816] Op. cit. Coherent 2015a
[1817] Op. cit. Lumentum 2015a
[1818] Op. cit. Coherent 2015a
[1819] Op. cit. Lumentum 2015a
[1820] Op. cit. Gensch, Carl-Otto [Oeko-Institut e.V.], et al. 2006; http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf; page 127 et seqq.

[1821] For details see report of (Zangl, Stéphanie, Oeko-Institut e.V. 30 May 2011) Adaptation to Scientific and Technical Progress under Directive 2002/95/EC: Evaluation of New Requests for Exemptions and/or Review of Existing Exemptions. With the assistance of Otmar Deubzer, Fraunhofer IZM, and Ran Liu and Katja Moch, Oeko-Institut e.V., page 83 et sqq.

32.1.3 Amount of Lead Used Under the Exemption

Coherent's[1822] 2014 shipments of replacement plasma tubes and new systems containing plasma tubes, in all non-exempt applications, EU-wide, contain less than 1g of lead, and the number of ion lasers in use for all applications is flat to declining, both in the EU and globally. There is no potential for emerging applications that would employ ion laser technology, and thus, the amount of Pb introduced per annum would be generally flat to declining in subsequent years. Lumentum[1823] indicates its total annual usage of PbO in the sealing glass in its lasers to be 230g, and with only 17g of PbO thereof entering the EU market direct shipments of argon lasers.

Even though exact figures concerning the total amount of lead used under this exemption are not available, the consultants assume it is safe to say that less than 1 kg of lead is used in the EU under this exemption.

32.2 Applicants' Justification for the Continuation of the Exemption

32.2.1 Substitution of Lead

Lumentum[1824] mentions bismuth-based glass as an alternative to the lead-based sealing glass. The bismuth-based glasses have a significantly higher (540°C) melting temperatures than the lead-based glass (420°C). Lumentum has tested the initial suitability of bismuth-based alternatives. While the published melting temperature is 540°C, in trial builds processing temperatures in excess of 560°C did not produce good flow of the frit material. The coverage of the frit material should be complete as in the photo on the left in Figure 32-2. As seen in the photo on the right, the lead-free material did not flow to provide a complete seal (red arrow).

[1822] Op. cit. Coherent 2015a
[1823] Op. cit. Lumentum 2015a
[1824] Ibid.

Figure 32-2: Lead-based (left) and bismuth-based frit (right) after processing

Source: Lumentum[1825]

Lumentum[1826] says the potential of damage to the components, primarily the optics, restricts the processing temperatures. Because the optics utilize complex multilayer coatings (> 30 layers), the suppliers of the optics discourage the use of higher temperatures or longer processing times. The coating fabrication process only allows for stabilization of the key optical properties up to 500°C. Processing at temperatures above 500°C will cause failure of the coatings.

Lumentum[1827] concludes that bismuth oxide material is not considered a viable alternative at this time. The optics are not designed to be subjected to temperatures beyond 500°C. Testing of the bismuth oxide material even above the specified sealing times and temperatures did not provide the complete sealing needed.

Coherent[1828] as well considers bismuth- or phosphorous-based glasses as potential substitutes, which are, however, not sufficiently developed technically or commercially to be viable for Coherent; there is no experience or working history in industry with those materials and Coherentdoes not believe that such materials satisfy the exact technical requirements to form the window bonds. Coherent believes there are a

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[1825] Ibid.
[1826] Ibid.
[1827] Lumentum 2015b 2015 "Answers to clarification questionnaire, document "Exe_32_Questionnaire-1_JDSU_2015-08-31.pdf": Clarification questionnaire (questionnaire 1)," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/JDSU/Exe_32_Questionnaire-1_JDSU_2015-08-31.pdf
[1828] Coherent 2015b "Answers to questionnaire 1, document "Coherent_Resp_August_2015_Exem_32_NC.pdf"," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/Coherent/Coherent_Resp_August_2015_Exem_32_NC.pdf

number of fundamental unresolved difficulties with respect to the viability of lead-free alternatives for the fabrication of Brewster window assemblies: [1829]

- **<u>Yield</u>**

  The manufacturing process of the window bonds is multifaceted and complex. It has evolved incrementally over 40 years. There are extraordinarily stringent requirements for mechanical and optical performance. Despite Coherent's experience with the established process, current yields are only borderline acceptable. Any change to the established process will drive yield even lower. No lead-free frit exists that would allow Coherent to utilise its established processing envelope. Alternative frit materials have melting temperatures of 550°C. This is 125°C higher than the material used in the current processes with lead glass. These higher temperatures will place extreme stresses on both raw materials in the assembly, and the production tooling. A reduction in yield will severely compromise Coherent's ability to provide sufficient product for mission-critical applications in the semiconductor and microelectronics markets.

- **<u>Performance</u>**

  The performance of Coherent's plasma tubes are determined to a significant extent by their capability to resist optical degradation by vacuum ultraviolet (VUV) radiation emanating from the gas plasma. A proprietary optical coating on the vacuum side of the Brewster window confers this distinguishing characteristic. Deposition of this unique optical coating on the Brewster window occurs prior to fritting the window to the stem. The dimensions of the assembly and limitations of the coating process preclude the application of the coating after the window fritting process. Because of this process limitation, the coating must endure the high temperatures required to bring the frit to liquid state. The higher temperatures required by the lead-free material will compromise the integrity of this coating. Manifestations of this degradation are yield loss and premature field failure. Coherent is not aware of a coating that provides the required performance and confers resistance to the higher processing temperatures.

- **<u>Usable lifetime</u>**

  In highly accelerated testing, lead-free alternatives performed very poorly when compared to the currently used process. Figure 32-3 is illustrative of the significant differences Coherent encountered. The yellow data points represent the lead-free test. The blue line is the current process. (Due to the

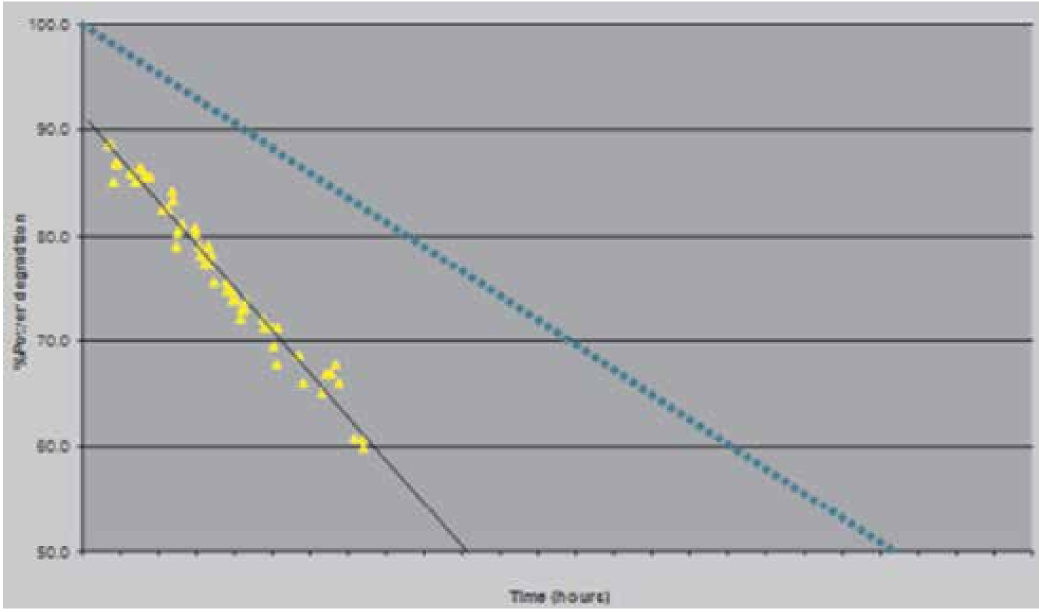
[1829] Coherent 2015b "Answers to questionnaire 1, document "Coherent_Resp_August_2015_Exem_32_NC.pdf","
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/Coherent/Coherent_Resp_August_2015_Exem_32_NC.pdf

sensitive nature of the data, Coherent has removed the x-axis (hours) values). Coherent[1830] finds two things in the lead-free sample remarkable:

- there was an output power (usable light) reduction at the onset, and;
- it takes less than half the time to a 50 % drop in output.

The 10 % initial output loss notwithstanding, just a 10 % reduction in performance would be significant to Coherent's end-users. A 50 % reduction would be catastrophic. Coherent has neither a clear technology path nor a projected timetable that would allow to mitigate performance gaps of this magnitude.

Figure 32-3: Power degradation of lead-free plasma tubes (yellow) vs. historical average with lead (blue dotted line)



Source: Coherent[1831]

Coherent[1832] and Lumentum[1833] conclude that krypton and argon lasers cannot be manufactured without the use of lead oxide in seal frit of the window assembly, and without these lasers many applications would not be possible. That includes instruments used in healthcare and research like flow cytometers, DNA sequencers, haematology equipment as well as equipment for bioinstrumentation and semiconductor manufacturing.

[1830] Ibid.
[1831] Op. cit. Coherent 2015a
[1832] Ibid.
[1833] Op. cit. Lumentum 2015a

32.2.2 Elimination of Lead

Coherent[1834] explains that solid state laser technologies are replacing the argon and krypton type of lasers (ion lasers) that require the above requested exemption. New system shipments of such ion lasers have been in steady decline for five years. Ion lasers are, however, unique in that they generate a variety of wavelengths in the ultraviolet, visible and infrared regions of the electromagnetic spectrum. These lasers are capable of producing ultrapure spatial and temporal output. According to Coherent1835, the use of argon and krypton ion lasers will therefore persist only in those applications where their unique multi-wavelength performance is a necessity.

Lumentum[1836] adds that solid-state lasers are usually well suited for modern instrumentation designed specifically to accommodate their characteristic electrical and optical performance. For some applications, modern solid-state lasers do not provide the required optical characteristics necessary to achieve required results, e.g. specific wavelengths or groups of wavelengths combined with narrow linewidth. As an example, for some DNA sequencing and flow cytometry applications, three or more exotic (uncommon) wavelengths, often ultraviolet, are necessary. Solid-state sources may not be available for these wavelengths or are otherwise unreliable. Substituting solid-state sources for these applications would require several solid state lasers in place of a single gas laser and thus significantly increase the use of natural resources and the environmental impact of the equipment manufacturing in order to perform the same analyses with solid state lasers.

Coherent[1837] states that the use of ion lasers has been in steady and quite significant decline since well before the inception of RoHS. New installations of ion lasers came to a zenith in 2000, after which the markets for ion lasers collapsed rapidly and nearly completely. The applications declined, among others due to alternative laser technologies becoming available. Coherent[1838] thinks it is safe to say that ion lasers are in use today only in those applications that cannot apply a substitute, based on one or more of the following requirements:

- A specific, process-driven wavelength;
- Continuous wave radiation;
- Deep UV, 257 nm and less;
- Single longitudinal mode;
- Transverse mode quality that is not available in an alternative;
- Discrete tuning at a number of visible and/or UV wavelengths;
- Higher output power than is available with a substitute;

[1834] Op. cit. Coherent 2015a
[1835] Ibid.
[1836] Op. cit. Lumentum 2015b
[1837] Op. cit. Coherent 2015b
[1838] Ibid.

- Low output noise which is not available in an alternative;
- Known cost in an established market—in other words, the alternative is more than the market will bear; or
- A ‘copy-exactly’ process where the cost of risk retirement for any substitute would be prohibitive.

Coherent[1839] lists the following applications where, among others, ion lasers are still used due to the above described unique properties of ion lasers compared to alternatives (Coherent notes this is not a complete list):

- Photomask direct imaging;
- Flat panel display direct imaging;
- Photomask inspection;
- Patterned wafer inspection;
- Spectroscopy;
- Holography;
- Some types of computer-to-plate imaging;
- Some types of particle imaging velocimetry.

Coherent[1840] states there is no market growth today for ion lasers of any type. Many more ion lasers come out of service each year than go into service. The global market for ion lasers with an output of more than 500 mW is less than 75 per year, with nearly all of the demand in Asia. There is no market scenario, real or imagined, which will alter this trajectory. New installations in the EU are rare, and as is the case globally, many more ion lasers come out of service each year than are installed in the EU.

32.2.3 Environmental Arguments

Coherent[1841] claims that in the full calendar year 2014, ion lasers introduced less than 1 g of lead in all shipments to the EU, new devices or serviced devices, exempt, or non-exempt. The amount of new ion laser installations will continue to drop worldwide. Every year, the Pb mass shipped globally under Exemption 32 will decrease.

Coherent[1842] concludes that ion lasers make only a miniscule contribution to lead contamination, as the atmospheric Pb contamination in the EU already stood at around 1,200 tonnes/year in 2012, for industrial sources alone. Other sources such as transport, commercial, institutional, and household fuel combustion accounted for at least as much on top of that.[1843]

[1839] Ibid.
[1840] Ibid.
[1841] Ibid.
[1842] Ibid.
[1843] “Air Quality in Europe, 2014 Report”, EEA Report No5/2014, ESSN 1977-8499; source as referenced by Coherent

32.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

32.4 Critical Review

32.4.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

The exemption allows the use of lead.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as directly added substance nor as substance that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under Entry 28 and Entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds

- shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight. This restriction does not apply to internal components of watch timepieces inaccessible to consumers

- shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children. This restriction does, however, not apply to articles within the scope of Directive 2011/65/EU (RoHS 2)

The restrictions of lead and its compounds listed under Entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

32.4.2 Environmental Arguments

The stakeholders' environmental arguments focus on the very small amounts of lead used under this exemption. Since the RoHS Directive does not specify minimum amounts of restricted substances as a criterion for an exemption, granting an exemption based on these environmental arguments would not be in line with RoHS Art. 5(1)(a).

32.4.3 Substitution and Elimination of Lead

The information submitted to the reviewers suggests that lead cannot be substituted in the seal frit used for making window assemblies for Argon and Krypton laser tubes. Solid state lasers can, however, replace krypton and argon lasers unless their unique characteristics are required. This would eliminate the use of lead. The applicants were therefore asked whether the scope of the exemption cannot be restricted to those applications where these ion lasers' unique properties are required so that solid state lasers cannot replace them.

Coherent[1844] answered that ion lasers are by their very nature the technology of last resort. They are most certainly powerful tools, but they are dinosaurs of the laser industry. They are bulky, inefficient at conversion of electrical energy to light output, and require dedicated infrastructure. Further, because they are relatively complex electro-optical devices, they typically require specialized training to install, maintain, and operate. That they remain in use today is a testament not only to their unique characteristics, and to the variety of performance improvements incorporated over four decades of use in science and industry, but more importantly, the lack of a complete suite of alternative technologies that sufficiently supplant the ion laser solution.

[1844] Ibid.

As a result, Coherent[1845] claims nobody buys an ion laser unless it is necessary. Ion lasers are massive, bulky, inefficient, and generally somewhat troublesome to operate relative to their solid-state alternatives. Moreover, they are expensive. The only customers for ion lasers today are those that require one or more of the unique attributes of the ion laser that are unavailable in a substitute, such as:[1846]

- One or more of the unique wavelengths that can only be obtained from Argon or Krypton plasma;
- The ability to tune between several of these unique wavelengths in a single laser platform;
- Continuous wave radiation;
- Many watts of output light;
- Spectral purity which cannot be matched by the alternative;
- Extreme coherence on the order of 10s of meters, which cannot be achieved by the alternative;
- Spatial characteristics of the output beam to deliver a nearly perfect circular beam cross-section, with a near perfect Gaussian distribution of intensity across the beam diameter (TEM_{00}, M_2<1.2);
- Extremely low output noise, typically <1%;
- Accessibility into the 351 to 413.1 nm range with multiple watts of output;
- Accessibility into the deep UV, specifically the wavelengths between 299nm and 257nm, that are provided by frequency-doubling of argon lasers;
- Proven longevity in commercial applications of more than 10,000 operating hours.

Lumentum[1847] confirms that due to the specific characteristics of ion lasers, it is unmanageable to replace them by solid state lasers where their characteristic properties are required. For example, most of diode laser-based products exhibit a linewidth that is substantially broader than a linewidth of a gas laser. Narrow linewidth is needed to achieve the required sensitivity of the equipment. Another example is the ability of one gas laser source to generate several specific wavelengths at the same time (i.e. 488 nm, 514 nm and 558 nm) critical for some applications. Equipment that requires a multi-line ion laser cannot be replaced with a single solid state laser. Several solid state lasers would be required to perform the same function.

[1845] Coherent Inc. 2016: "Stakeholder document "Letter to O_Deubzer02092016.pdf", received by Dr. Otmar Deubzer, Fraunhofer IZM, via e-mail from Paul Ginouves, Coherent Inc., on 10 February 2016" unpublished manuscript,
[1846] Ibid.
[1847] Lumentum 2016 "Answers to questionnaire 2, document "Exe_32_Questionnaire-2_Lumentum_2016-02-01.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Gabriela Janusz-Renault, Lumentum Inc., on 13 February 2016"

According to Coherent[1848], some of the strongest incentives to choose any alternative to an ion laser are electrical and water consumption. The average mid-power ion laser consumes 25 kW and three gallons (around 11.4 liters) of water per minute for cooling. A high-output device consumes 50 kW and 6 gallons (around 22.7 liters) of cooling water per minute. Ion lasers are inefficient. They convert just 0.1 % of the incoming power to light. The rest is converted to waste heat. A solid-state alternative will be roughly two orders of magnitude more efficient.

Coherent states[1849] that with every passing year, there are more varied alternatives for ion lasers. In addition, every year, the sales of ion lasers decline as a result. The ion laser has become, by its very nature, the laser of last resort. The few remaining customers resign themselves to the purchase, knowing that they truly have no alternative, while hoping for a different solution in the future.

32.4.4 Conclusions

Solid state lasers can in principle replace ion lasers. The above information suggests that for economic and technological reasons, krypton and argon lasers are only used where their unique properties are required, whereas otherwise solid state lasers will be used.

Working out the characteristic features of ion lasers that require their use instead of solid state lasers would result in a complex exemption wording with more than 10 criteria due to the various unique properties of ion lasers, which may have to be further specified and quantified to clearly demarcate the application fields of ion lasers from those of solid state lasers.

In this situation, the reviewers recommend to renew exemption 32 without changes for another five years.

32.5 Recommendation

The information submitted by the stakeholders suggests that substitution of lead in exemption 32 is technically impracticable. While the elimination using solid state lasers instead of ion lasers is possible in some cases, the applicants plausibly explain that argon and krypton lasers for technical and economic reasons are only used where their unique properties are required so that solid state lasers cannot replace them. In this situation, RoHS Art. 5(1)(a) in the reviewers opinion justifies the renewal of the exemption.

The reviewers therefore recommend continuing the exemption for another five years with its current scope and wording:

1848 Op. cit. (Coherent Inc. 2016)
1849 Ibid.

Exemption n. 32	Expires on
Lead oxide in seal frit used for making window assemblies for Argon and Krypton laser tubes	*21 July 2021 for* · *EEE of categories 1-7 and 10* · *medical equipment in category 8, and* · *monitoring and control instruments in category 9 of Annex I*
	21 July 2023 for in vitro diagnostic medical devices in category 8 of Annex I
	21 July 2024 for industrial monitoring and control instruments in category 9 of Annex I

32.6 References Exemption 32

Coherent 2015a Request for continuation of exemption 32, document "BR-_9849983-v3-Coherent_Exemption_request_form_update_after_comments___PG_with_redaction.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/Coherent/BR-_9849983-v3-Coherent_Exemption_request_form_update_after_comments___PG_with_redaction.pdf.

Coherent 2015b Answers to questionnaire 1, document "Coherent_Resp_August_2015_Exem_32_NC.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/Coherent/Coherent_Resp_August_2015_Exem_32_NC.pdf.

Coherent Inc. 2016: Stakeholder document "Letter to O_Deubzer02092016.pdf", received by Dr. Otmar Deubzer, Fraunhofer IZM, via e-mail from Paul Ginouves, Coherent Inc., on 10 February 2016.

Gensch, Carl-Otto [Oeko-Institut e.V.], et al. Adaptation to scientific and Technical progress under Directive 2002/95/EC 2006.

Lumentum 2015a Request for continuation of exemption 32, document "32_JDSU_RoHS_Application_Exemption_32.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/JDSU/32_JDSU_RoHS_Application_Exemption_32.pdf.

Lumentum 2015b Answers to clarification questionnaire, document "Exe_32_Questionnaire-1_JDSU_2015-08-31.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/JDSU/Exe_32_Questionnaire-1_JDSU_2015-08-31.pdf.

Lumentum 2016 Answers to questionnaire 2, document "Exe_32_Questionnaire-2_Lumentum_2016-02-01.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Gabriela Janusz-Renault, Lumentum Inc., on 13 February 2016.

33.0 Exemption 34 “Pb in cermet-based trimmer potentiometer elements”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

Cermet	Heat resistant material made of ceramic and sintered metal; here the resistive layer and the ceramic body onto which it is sintered
EEE	Electrical and Electronic Equipment
GE	General Electric

33.1 Description of the Requested Exemption

GE et al.[1850] request the renewal of exemption 34 in RoHS Annex I with its current wording:

“Lead in cermet-based trimmer potentiometer elements”

In the course of the review of exemption 7(c)-I, it was found that Bourns’ application[1851] for renewal of exemption 7(c)-I covers aspects that are relevant for cermet-based trimmer potentiometer elements as well, in particular concerning the status of lead-free alternatives.

[1850] General Electric et al. 2015a “Request for continuation of exemption 34, document "34_RoHS_V_Application_Form_-_Exemption_34_lead_in_trimmer_potentiometers-final.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_34/34_RoHS_V_Application_Form_-_Exemption_34_lead_in_trimmer_potentiometers-final.pdf

[1851] Bourns Inc. 2015 “Answers to first questionnaire (clarification questionnaire), document "20150818_Ex_7(c)-I_Bourns_Questionnaire-1_2015-07-28.pdf": First questionnaire (clarification questionnaire),” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/20150818_Ex_7(c)-I_Bourns_Questionnaire-1_2015-07-28.pdf

33.1.1 Background and History of the Exemption

The exemption was reviewed once in 2007[1852]. The applicant requested this exemption claiming that exemptions 5 and 7 listed in the annex of directive 2002/95/EC (RoHS 1) as they were formulated in 2006/2007 did not cover the use of lead in these cermet-based trimmer potentiometers:

- *"No. 5: Lead in glass of cathode ray tubes, electronic components and fluorescent tubes",*
  and
- *"No. 7: Lead in electronic ceramic parts (e.g. piezoelectronic devices)"*

The manufacturer said that this resistive layer in the cermet-based trimmer potentiometer is a homogeneous material, as it can be mechanically separated from the ceramic base. This homogeneous material, the thick film layer containing the lead, is neither a glass nor a ceramic material and thus would not be covered by the above exemptions. As a consequence, exemption 34 was adopted to the annex of RoHS 1 with its current wording:

"Lead in cermet-based trimmer potentiometer elements"

Exemption 34 was transferred to annex II of RoHS 2 with an expiry date in July 2016.

To avoid confusion about the scope of exemption 5 and 7, and to make sure these exemptions actually cover those uses of lead where it cannot be substituted or eliminated, the consultants aspired to improve exemptions 5 and 7, and to align them with the exemption wording of parallel exemptions within the ELV Directive as far as possible.

Exemption 11 of annex II in directive 2000/53/EC (ELV Directive[1853]), the equivalent to exemption 7(c)-I of RoHS Annex III, was reviewed in 2007/2008[1854]. The stakeholders decided that the wording in the ELV Directive covers applications like lead in cermet-based trimmer potentiometers.

[1852] Carl-Otto Gensch, Stéphanie Zangl, and Otmar Deubzer 2007 "Adaptation to scientific and technical progress under Directive 2002/95/EC: Final report," Oeko-Institut e.V., http://ec.europa.eu/environment/waste/weee/pdf/rohs.pdf, page 18 et sqq.

[1853] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles, ELV Directive, European Union (21 October 2000), http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0053:EN:NOT

[1854] Lohse, Joachim; Gensch, Carl-Otto; Groß, Rita; Zangl, Stéphanie; [Oeko-Institut e.V.]; Deubzer, Otmar, Fraunhofer IZM (2008): Adaptation to Scientific and Technical Progress of Annex II Directive 2000/53/EC. Final Report - Amended Final. Oeko-Institut e. V., Fraunhofer IZM. https://circabc.europa.eu/sd/a/f5d79a51-2e5a-47eb-85d3-7b491ae6a4b3/Final_report_ELV_2008_Annex_II_revision.pdf; page 65 et seqq.

In the subsequent review[1855] of RoHS exemption 7c in 2008/2009, it was therefore decided to adopt the wording formulation of ELV exemption 11 with some slight adaptations, which are reflected in the current wording of RoHS exemption 7(c)-I:

> *"Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound"*

Exemptions 5 and 7 were integrated into the above new exemption, and in principle the use of lead in trimmer potentiometers in the scope of exemption 34 is now already covered by exemption 7(c)-I.

33.1.2 Technical Description of the Exemption

The technical background of the exemption was described in detail in the last review report[1856] from 2007.

33.1.3 Amount of Lead Used Under the Exemption

GE et al.[1857] quantify the content of lead in homogeneous material (% weight) with around 40 to 50 % of PbO in glass. The amount of lead entering the EU market annually through applications for which the exemption is requested is, according to GE et al.[1858], a small fraction of the ~ 350 tonnes related to exemption 7(c)-I.

GE et al.[1859] base their estimations on 2013 data from the companies listed below, who represent the major players on the EU market:

- Ceram Tec;
- Emerson;
- EPCOS;
- Freescale;
- Johnson;
- Matthey Catalysts (Germany);
- Meggitt DK;
- Morgan Advanced Materials;
- Murata; and
- PI Ceramic.

[1855] Carl-Otto Gensch, Oeko-Institut e. V., et al. (2009): Adaptation to scientific and technical progress under Directive 2002/95/EC. Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. und Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf; page 98 et seqq.
[1856] Op. cit. Gensch, Zangl and Deubzer 2007, page 18 et sqq.
[1857] Op. cit. General Electric et al. 2015a
[1858] Ibid.
[1859] Ibid.

GE et al.[1860] note that the list is not exhaustive. Electrical and electronic components are used in a wide range of final products and markets, it is impossible to provide a precise figure of the amount of lead included in glass and ceramic components in the EU for electrical and electronic equipment (EEE). For this reason, although the estimates were done in good faith with the data resources available, the values shown here are provided strictly for reference purposes, and GE et al. do not want to bear responsibility concerning their accuracy or enforceability.

GE et al. were asked to provide a more detailed estimate or calculation for the use of lead in exemption 34. GE et al.[1861] stated that their figures are based on one company's estimate of 5.5kg/annum lead used in their products annually. They claim that the overall amount should not exceed 46 kg/annum.

In the 2007 review[1862] of this exemption, the amount of lead-oxide (PbO) used in cermet-based trimmer potentiometers worldwide was indicated to be around 1,600 kg. Around 93 % of the total weight of PbO being lead, the total amount of lead would be around 1,500 kg. The consultants therefore cannot exclude that the share used in the EU, which the applicant could not calculate in 2007, would be much higher than around 50 kg indicated by GE et al.

The actual lead consumption is thus not clear, but in the consultants view it could well be considerably more than 50 kg per year in the EU.

33.2 Applicants' Justification for the Continuation of the Exemption

33.2.1 Substitution of Lead

GE et al.[1863] state that this exemption follows the same justification criteria as exemption 7(c)-I "*Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound*". Alternative technologies have been evaluated, but so far no substitution technology is available for resistive inks in glass which ensures the needed properties such as mechanical endurance and contact resistance variation. Therefore they apply for the renewal of the exemption.

Stated already in the first review[1864] of this exemption in 2007, lead-free solutions were available for certain resistance ranges and applications, but it was at that time not

[1860] Ibid.

[1861] General Electric et al. 2015b "Answers to first questionnaire (clarification questionnaire, document "Exe_34_Questionnaire-1_GE-Health-et-al_2015-09-15 - reply.pdf", received via e-mail by Otmar Deubzer, Fraunhofer IZM, from James Vetro, GE Healthcare, on 15 September 2015,"

[1862] Op. cit. Gensch, Zangl and Deubzer 2007, page 19

[1863] Op. cit. General Electric et al. 2015a

[1864] Carl-Otto Gensch, Oeko-Institut e. V., et al. (2009): Adaptation to scientific and technical progress under Directive 2002/95/EC. Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber,

possible to clearly define resistance ranges and detailed performance parameters of these products, nor the applications where these trimmer potentiometers would be suitable.

GE et al.[1865] claim that since the 2007 review[1866] of the exemption, they analysed several different lead-free cermet inks from several manufacturers. According to GE et al.[1867] there are no dedicated lead-free inks available for potentiometers but it is the target to qualify available inks for resistors applications. GE et al.[1868] mention boron, phosphorus, zinc, tin, bismuth glass/inks, etc. as potential principal lead-free alternatives. GE et al.[1869] tested mainly two types of lead-free inks from vendor A with sheet resistance from 15mΩ/sq to 5Ω/sq and vendor B with sheet resistance from 10 Ω/sq to 100 MΩ/sq. GE et al.[1870, 1871] say they were processed and their performances were measured by running qualification tests. At present no alternative solutions have similar or acceptable results compared to the leaded inks, especially in life tests. The critical point is the surface roughness of the ink after firing, degrading quickly the sliding contact (wiper) or creating unacceptable electric noise. The experiments showed a more rapid wear on the sliding contact as well as electrical noise, resulting in a life expectancy of only 50 % compared to the lead bearing paste.

GE et al.[1872] et al. conclude that based on these results, a continuation of the exemption is necessary to keep the performances of the products.

Within its trimming potentiometer product line, Bourns'[1873] research team has developed lead-free inks for low to mid-range resistance values for some cermet-based trimmer potentiometers. These proprietary lead-free substitutes are a form of calcium silicate borate glass. These ink systems are used on the trimming potentiometer products only. They work for some specific Bourns' parts, but are not a solution for all Bourns' trimming potentiometers, depending on the specific potentiometer models. Another remaining challenge is the higher end resistance values for which the company is still trying to find a suitable solution.

Oeko-Institut e. V. und Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf; page 98 et seqq.

1865 Op. cit. General Electric et al. 2015b

1866 Carl-Otto Gensch, Oeko-Institut e. V., et al. (2009): Adaptation to scientific and technical progress under Directive 2002/95/EC. Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. und Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf; page 98 et seqq.

1867 General Electric et al. 2016a "Answers to second questionnaire, document "Exe_34_Questionnaire-2_GE-Health-et-al_2016-3-11 reply.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, on 12 March 2016: Second questionnaire" unpublished manuscript,

1868 Op. cit. (General Electric et al. 2015a)

1869 Op. cit. (General Electric et al. 2016a)

1870 Op. cit. (General Electric et al. 2015b)

1871 Op. cit. (General Electric et al. 2016a)

1872 Op. cit. (General Electric et al. 2015a)

1873 Op. cit. (Bourns Inc. 2015)

With respect to a quantification of the resistance range in which lead can be substituted, Bourns[1874] state that the resistance range varies in relation to specific potentiometer models and their applications. Some of the inks developed are specifically for a certain model. Currently, a typical upper limit for one specific lead-free ink model is 24 kΩ, and 51 kΩ for another one. Bourns[1875] highlights, however, that these models are examples of successful substitutions only. Bourns[1876] still has many models where the substitution of lead in the ead-containing glasses in all resistances – low, mid and high ranges – is scientifically and technically not yet practicable. So for many other models, there has not yet been a successful resolution, and a lot of research is still to be done as it is not a one-size fits all solution.

Bourns[1877] explain that the lead-free trimmer potentiometers can potentially be used in a variety of applications, but does not claim they can be used in all applications. Their usability depends on the end user's need and the form, fit and function of their end products. Bourns[1878] continues to work with its suppliers, to explore possible solutions through experimenting with possible alternatives. It is a slow process with research, experimentation, testing, scale-up, qualification and reliability testing. If there is a failure along the way, the process has to be started over.

33.2.2 Elimination of Lead

Bakelite-based potentiometers were identified in the 2007 review[1879] of the exemption as a potential way to eliminate the use of lead, but have proven to be no adequate replacement at that time.

GE et al.[1880] report that there are several alternative technologies to cermet trimmer potentiometers, for example:

- Conductive plastic inks;
- Other technologies (optic, magnetic, digital).

GE et al.[1881] say that for replacement the following issues have to be taken into account, as cermet trimmers:

1874 Bourns Inc. 2016a "Answers to second questionnaire, document "Exe_7(c)-I_Questionnaire-2_Bourns_2015-12-21.pdf", sent via e-mail to Otmar Deubzer, Fraunhofer IZM, by Cathy Godfrey, Bourns Inc., on 4 January 2016: Second questionnaire" unpublished manuscript,

1875 Bourns Inc. 2016b "Answer to second questionnaire, document "Exe_34_Questionnaire-2_Bourns_2016-03-16.pdf, received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Cathy Godfrey, Bourns, on 22 March 2016: Second questionnaire" unpublished manuscript,

1876 Ibid.

1877 Op. cit. (Bourns Inc. 2016a)

1878 Ibid.

1879 Carl-Otto Gensch, Oeko-Institut e. V., et al. (2009): Adaptation to scientific and technical progress under Directive 2002/95/EC. Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf; page 98 et seqq.

1880 Op. cit. (General Electric et al. 2016a)

- Can be of a very small size;
- Are not sensitive to electrostatical discharge (ESD);
- Do not need reverse polarity or surge protections;
- Can work at high temperature without Ohm value drift, contrarily to bakelite.

Bourns[1882] explain that bakelite is a phenolic resin material typically blended with a carbon powder to create a carbon-based film. Bourns screen prints this conductive plastic ink on a ceramic substrate. It is used for potentiometers, but not trimming potentiometers. Conductive plastic potentiometers are generally lower cost, less precise, used in environments where moisture or humidity is not a factor and resistance drift is not a concern.

GE et al.[1883] detail that cermet-based trimmer potentiometers have no drift for hundreds of hours at 150 °C. With Bakelite inks, several percentages of drift for every 96 hours of testing at 125°C were observed. Cermet is robust enough to support the force of the wiper. In small dimensions, the control of the force is not easy. For cermet wipers a force from 10 cN up to 150 cN can be used. Bakelite pots are of a poorer quality than cermet. The wear of the inks used on Bakelite is quicker than the Cermet ones. Cermet potentiometers can work up to 125 °C and some up to 210 °C.

Bourns[1884] confirm that for more precision in more demanding environmental conditions, where drift is not acceptable, cermets are used. These materials do not include phenolic resins or carbon. They generally have a precious metal-based ink (e.g. silver or gold for conductors; palladium, platinum, ruthenium for resistors). The cermet material is used for trimming potentiometers. One example is a trimming potentiometer used in medical equipment. The demand is for a precise potentiometer that will not drift from the desired setting. The choice here would be a cermet-based trimmer.

33.2.3 Roadmap towards Substitution or Elimination of Lead

GE et al. were asked about their plans and ideas for the future to achieve RoHS compliance. GE et al.[1885] answered that a possible time frame would be at least 3 years: one year for evaluation, one for internal qualification, and one for qualification at customers especially for specific applications.

Still there are some trimming potentiometers that no solution has yet been found for all resistance values. It varies based on the application of the part. Some termination inks still use lead-containing glass.

[1881] Op. cit. (General Electric et al. 2016a)
[1882] Op. cit. (Bourns Inc. 2016b)
[1883] Op. cit. (General Electric et al. 2016a)
[1884] Op. cit. (Bourns Inc. 2016b)
[1885] Op. cit. (General Electric et al. 2016a)

Bourns[1886] states it will continue work with its suppliers, explore possible solutions, and experiment with possible alternatives. It is a slow process with research, experimentation, testing, scale-up, qualification & reliability testing. If there is a failure along the way, the process starts over. Each product line using lead-based thick film inks is unique so a one-size-fits-all application does not work.

33.3 Critical Review

33.3.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

The exemption allows the use of lead.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as directly added substances nor as substances that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under Entry 28 and Entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance,

[1886] Op. cit. Bourns Inc. 2015

mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds

1) *"shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight."* This restriction does not apply to internal components of watch timepieces inaccessible to consumers;
2) *"shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children."* This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

33.3.2 Substitution and Elimination of Lead

Potentiometers can be made from bakelite with lead-free plastic inks and could be a potential means to eliminate the use of lead. The applicants both explain that the performance as well as the endurance of such bakelite potentiometers is inferior to the cermet-based trimmer potentiometers so that they cannot replace them.

Bourns mention that they have lead-free alternatives for cermet-based trimmer potentiometers; however, these are said to be applicable on a case by case basis and for some low to mid resistance range trimmer potentiometers only. On request, Bourns[1887, 1888] explained that it is not possible to classify and demarcate resistance and application areas where such lead-free alternatives can be applied from others where the use of lead is still indispensable.

GE et al.[1889] mention optic, magnetic, and digital technologies as approaches to eliminate the use of lead. However, they do not provide further information so it remains an open question whether and how far such technologies could eliminate the use of lead.

[1887] Op. cit. (Bourns Inc. 2016a)
[1888] Op. cit. (Bourns Inc. 2016b)
[1889] Op. cit. (General Electric et al. 2016a)

In order to substitute lead, GE et al. report about various experiments in Section 33.2.1 (from page 727). The consultants asked GE et al. who conducted these tests, and when, in order to obtain insights into the applicants' activities since the last review of this exemption in 2007. GE et al.[1890] answered that for potentiometers it is difficult to answer this question, as typically commercially available standard resistor inks are being used. They are printed and then tested regarding their performances to specification and limits.

The consultants consider that it is not plausible for GE et al. on the one hand to present these results, and on the other hand not to know who did these experiments and when.

While Bourns shows clear efforts and successful substitutions, the information provided and the way it is presented raise concerns about the motivation and willingness of GE et al. to actually research for and find alternatives to substitute or eliminate the use of lead. The answer of GE et al. to the question about their future ideas and plans to achieve RoHS compliance in the last questionnaire[1891] fuels these concerns:

> *"A possible time frame would be at least 3 years, one for evaluation, one for internal qualification, one for qualification at customers especially for specific applications."*[1892]

The applicants' exemption requests and the answers to the clarification questionnaire were made available through the online public consultation, i.e. to industry, governments, NGOs and other stakeholders, and a consultation questionnaire had been prepared with specific questions to stakeholders. No further information supporting or discrediting the technical application in question was received.

33.3.3 Conclusions

Overall, the information submitted suggests that lead is actually still required in cermet-based trimmer potentiometers, even though for some low and mid range resistance applications lead-free trimmer potentiometers are available. At this current time, these alternatives are not able to be clearly demarcated and specified in order to restrict the exemption's scope. No information is available concerning the status of optic, magnetic, and digital technologies mentioned by GE et al. as approaches to eliminate the use of lead in the application in the scope of Exemption 24.

Granting an exemption would thus be in line with the requirements of RoHS Art. 5(1)(b). The exemption should, however, be granted for a maximum of three years until 21 July 2019 only. Given the fact that the applicants did not provide information, whether lead could at least partially be eliminated within less than five years, a maximum of five years validity period in the consultants' understanding of Art. 5(1)(a) would not be justified. In

[1890] Ibid.
[1891] Ibid.
[1892] Op. cit. (Bourns Inc. 2016a)

case the exemption is still required, the applicants can apply for its renewal prior to 21 January 2018.

33.3.4 Integration of Exemption 34 into Exemption 7(c)-I

Technically, exemption 7(c)-I covers the use of lead in cermet-based trimmer potentiometers so that exemption 34 could in principle be included into the scope of exemption 7(c)-I. As exemption 7(c)-I is, however, recommended to be continued with the current wording without further specifications of the scope, the consultants recommend maintaining exemption 34 as a specific exemption for the time being so as to avoid any possible confusion, but to consider its integration into a future exemption 7(c)-I should the specification of that exemption 7(c)-I be successful in the next review.

Vice versa, the use of lead in cermet-based trimmer potentiometers in the scope of Exemption 34 should be excluded from the scope of exemption 7(c)-I to avoid that exempted uses of lead are covered by more than one exemption.

33.4 Recommendation

The information available to the consultants suggests that the substitution and elimination of lead is scientifically and technically impracticable to a degree that justifies the renewal of the exemption in line with the criteria for exemptions in Art. 5(1)(a). The exemption should, however, only be granted for a maximum of three years since the information provided and the way it is presented does not clearly demonstrate that lead cannot be eliminated within the next five years.

The reviewers recommend the renewal of exemption 34 with the identical wording, but an expiry date latest on 21 July 2019.

Exemption 34	Expires on
	21 July 2019 for categories 1-7 and 10
Lead in cermet-based trimmer potentiometers	*21 July 2021 for* · *medical equipment in category 8* · *monitoring and control instruments in category 9*
	21 July 2023 for in vitro diagnostic medical devices in category 8
	21 July 2024 for industrial monitoring and control instruments in category 9

33.5 References Exemption Request 34

Bourns Inc. 2015 Answers to first questionnaire (clarification questionnaire), document "20150818_Ex_7(c)-I_Bourns_Questionnaire-1_2015-07-28.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/20150818_Ex_7(c)-I_Bourns_Questionnaire-1_2015-07-28.pdf.

Bourns Inc. 2016a Answers to second questionnaire, document "Exe_7(c)-I_Questionnaire-2_Bourns_2015-12-21.pdf", sent via e-mail to Otmar Deubzer, Fraunhofer IZM, by Cathy Godfrey, Bourns Inc., on 4 January 2016.

Bourns Inc. 2016b Answer to second questionnaire, document "Exe_34_Questionnaire-2_Bourns_2016-03-16.pdf, received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Cathy Godfrey, Bourns, on 22 March 2016.

Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles. ELV DirectiveEuropean Union. October 21, 2000. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0053:EN:NOT.

General Electric et al. 2015a Request for continuation of exemption 34, document "34_RoHS_V_Application_Form_-_Exemption_34_lead_in_trimmer_potentiometers-final.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_34/34_RoHS_V_Application_Form_-_Exemption_34_lead_in_trimmer_potentiometers-final.pdf.

General Electric et al. 2015b Answers to first questionnaire (clarification questionnaire, document "Exe_34_Questionnaire-1_GE-Health-et-al_2015-09-15 - reply.pdf", received via e-mail by Otmar Deubzer, Fraunhofer IZM, from James Vetro, GE Healthcare, on 15 September 2015.

General Electric et al. 2016a Answers to second questionnaire, document "Exe_34_Questionnaire-2_GE-Health-et-al_2016-3-11 reply.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, on 12 March 2016.

General Electric et al. 2016b E-mail communication, document "E-Mail-Communication_GE-et-al_2016-03-01.pdf" sent via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, to James Vetro, General Electric, on 1 March 2016.

Gensch, Carl-Otto, Stéphanie Zangl, and Otmar Deubzer Adaptation to scientific and technical progress under Directive 2002/95/EC 2007. http://ec.europa.eu/environment/waste/weee/pdf/rohs.pdf.

JEITA and JBMIA 2015 Contribution to stakeholder consultation, document "Ex_34_Jeita_et_al_Japan_4EEE_Answers_to_Public_Consultation20151015.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_34/Ex_34_Jeita_et_al_Japan_4EEE_Answers_to_Public_Consultation20151015.pdf.

34.0 Exemption 37 “Pb in the plating of high voltage diodes on the basis of a zinc borate glass body”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

AC	alternate current
DC	direct current
HVD	high voltage diode(s)

34.1 Description of the Requested Exemption

IXYS[1893] and GE et al.[1894] apply for the continuation of Exemption 37 in its current wording:

> *“Lead in the plating layer of high voltage diodes on the basis of a zinc borate glass body”*

In the course of the review, it became clear that IXYS actually applies for the use of lead in glass, which is covered by exemption 7c-I, and not for the continuation of Exemption 37, which exempts lead in the plating layer of zinc-borate glass high voltage diodes

[1893] IXYS Semiconductor GmbH 2014 2014 “Request for continuation of exemption 37, document "37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/IXYS/37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf

[1894] General Electric et al. 2015a 2015b “Request for continuation of exemption 37, document "37_RoHS_V_Application_Form_-_Exemption_37_lead_in_high_voltage_diodes_final.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/general_elcetric/37_RoHS_V_Application_Form_-_Exemption_37_lead_in_high_voltage_diodes_final.pdf

(HVD). It was thus agreed with the applicant[1895] to take its exemption application into account in the review of Exemption 7c-I.

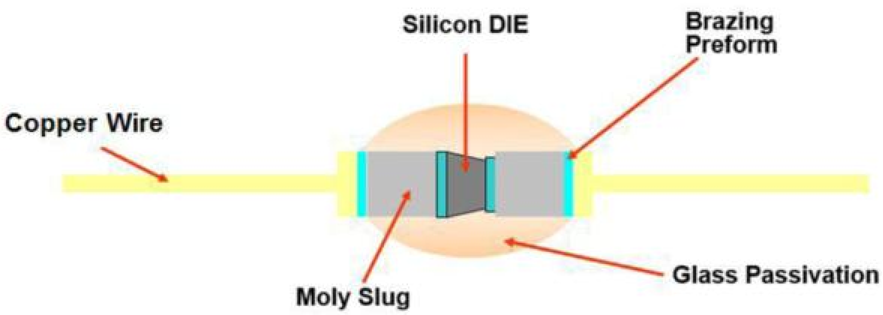
34.1.1 Background and History of the Exemption

The exemption was applied for and reviewed[1896] once in 2007. It was adopted as Exemption 37 to the annex of RoHS 1 and later transferred to Annex III of RoHS 2. The exemption would have expired in July 2016 if no applications for renewal had been submitted.

34.1.2 Technical Description of the Exemption

Figure 34-1 shows an outline of a HVD.

Figure 34-1: Sketch of a high voltage diode based on zinc borate glass



Source: GE et al.[1897]

GE et al.[1898] explain that the difference that sets HVD apart from "conventional" diodes is the special "glass bead design". The glass bead serves as both package and passivation. "Conventional" diode layout is a diode chip soldered between plugs or lead frames embedded in a moulded package.

GE et al.[1899] describe the major features of such HVD:

[1895] IXYS Semiconductor GmbH 2016b "Agreement to shift exemption request to exemption 7c-I, document "IXYS_Shift-to-exe.-7c-I.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Markus Bickel, IXYS Semiconductor GmbH, on 5 February 2016" unpublished manuscript,

[1896] Carl-Otto Gensch, Stéphanie Zangl, and Otmar Deubzer 2007 "Adaptation to scientific and technical progress under Directive 2002/95/EC: Final report," RoHS II Oeko-Institut e.V., http://ec.europa.eu/environment/waste/weee/pdf/rohs.pdf, page 58 et sqq.

[1898] General Electric et al. 2015b 2015 "Answers to first questionnaire (clarification questionnaire, document "Exe_34_Questionnaire-1_GE-Health-et-al_2015-09-15 - reply.pdf", received via e-mail by Otmar Deubzer, Fraunhofer IZM, from James Vetro, GE Healthcare, on 15 September 2015,"

[1899] Ibid.

- They can be built up to breakdown voltages of several kilovolts which cannot be achieved using “conventional” diode packages;
- The special “glass bead” design of those diodes provides hermetical sealing of the chip i.e. that package;

According to the GE et al.[1900], the diodes are used in all categories of electrical and electronic equipment in the scope of RoHS 2. Their main uses are in external power supplies of IT and telecommunication equipment and for automotive applications. The total number of HVD accounts for 100,000,000 pieces per year.

GE et al.[1901] explain that the manufacturing process starts with a silicon chip that is alloyed between two molybdenum (moly) slugs, which are brazed to copper wires. A glass bead is formed around the chip and the moly slugs. Finally the wires are plated. According to GE et al.[1902], during the terminal plating process of the sintered glass diodes, lead from the glass dissolves into the plating solution, which results in around 2.5 % of lead content in the plating layer. Thus, the lead glass is the root cause of the lead content in the wire plating. As such the lead is not added intentionally to the plating layer but is the result of contamination from the lead-containing glass in the manufacturing process.

34.1.3 Amount of Lead Used Under the Exemption

GE et al. [1903] state that the plating layer of the HVD contains 2.5 % of lead and claim that the total amount of lead is a small fraction of the around 350 tonnes of lead that is estimated to be used under exemption 7c-I.

Upon request, GE et al.[1904] present a more substantiated estimate stating that the weight of the plating of HVD is about 3 mg and the lead content in this plating around 2,000 ppm. According to GE et al.[1905] this accounts for about $6x10^{-3}$ mg of lead, equal to $6x10^{-9}$ kg lead in the terminal finish per diode.

[1900] General Electric et al. 2015a 2015a “Request for continuation of exemption 34, document "34_RoHS_V_Application_Form_-_Exemption_34_lead_in_trimmer_potentiometers-final.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_34/34_RoHS_V_Application_Form_-_Exemption_34_lead_in_trimmer_potentiometers-final.pdf

[1901] Op. cit. General Electric et al. 2015b

[1902] Op. cit. General Electric et al. 2015a

[1903] Op. cit. General Electric et al. 2015a

[1904] General Electric et al. 2015b “Answers to first questionnaire (clarification questionnaire): Clarification questionnaire,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/Exe_37_GE_et_al_Questionnaire-1_2015-09-15_reply.pdf

[1905] Ibid.

Based on the known run-rate of a component manufacturer and its estimated share of world market, GE et al.[1906] assume 60 million pieces of HVD annually and present the following overall calculation:

$$60{,}000{,}000 \times 6 \times 10^{-9} \sim 0.36 \text{ kg}$$

As a result of this calculation, GE et al.[1907] estimate the overall amount of lead in the plating of HVD in the scope of Exemption 37 to be less than 0.4 kg per year worldwide.

The 2,000 ppm GE et al.[1908] indicate as the lead content in the plating layer of the HVD are equal to 0.2 %, which contradicts the 2.5 % of lead GE et al. [1909] had initially indicated in their exemption request. Assuming a lead content of 2.5 % in the platings of the HVD, the total amount of lead under Exemption 37 would be 4.5 kg. The source of the discrepancy is not known, however the total amount of lead in both cases can be assumed to be in the lower kilogram range.

GE et al.[1910] state that electrical and electronic components are used in a wide range of final products and markets, it is impossible to provide a precise figure of the amount of lead included in glass and ceramic components in the EU for Electrical and Electronic Equipment [EEE]. The electronic equipment industry is engaged in the reduction of lead and environmental burdens within its powers, although it is impossible to completely cease the use of lead under the scope of exemption 37.

The results presented above are an estimate based on company figures. It is possible that there are companies, which are not included in this estimation. It should thus be noted, that the values presented are for reference purposes only.

34.2 Applicants' Justification for the Continuation of the Exemption

GE et al.[1911] state their exemption request follows the same justification criteria as exemption 7(c)-I "Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound". GE et al.[1912] request to keep the numbering and wording the same to avoid confusion and maintain the initial intention of scope of Exemption 37. They claim that alternative technologies are under evaluation but so far

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[1906] Ibid.
[1907] Ibid.
[1908] Ibid.
[1909] Op. cit. General Electric et al. 2015a
[1910] Ibid.
[1911] Op. cit. General Electric et al. 2015a
[1912] Ibid.

no substitution technology is available and therefore the renewal of the exemption is requested.

34.2.1 Substitution of Lead in the Glass Bead

The use of lead-free glass in the zinc borat HVD would at the same time solve the lead contamination of the plating layer.

According to GE et al.[1913], lead in zinc borate glass (Exemption 7c-I) is needed to reach similar thermal expansion as the touched metal pins. In addition, the change of the glass type is technically not possible, as the electrical loading of the glass type must be identical with the silicon-type being used within the die (p-Si). Also, with the distance between the Si-blocks only amounting to 180 µm, materials other than glass do not fulfill the specific surface conditions necessary to avoid flashovers at 1,800 V. Furthermore, the expansion of all other materials within the diode (such as the molybdenum slug etc.) is adjusted to this zinc borate glass. Only this kind of glass fulfils all of the technical/physical requirements.

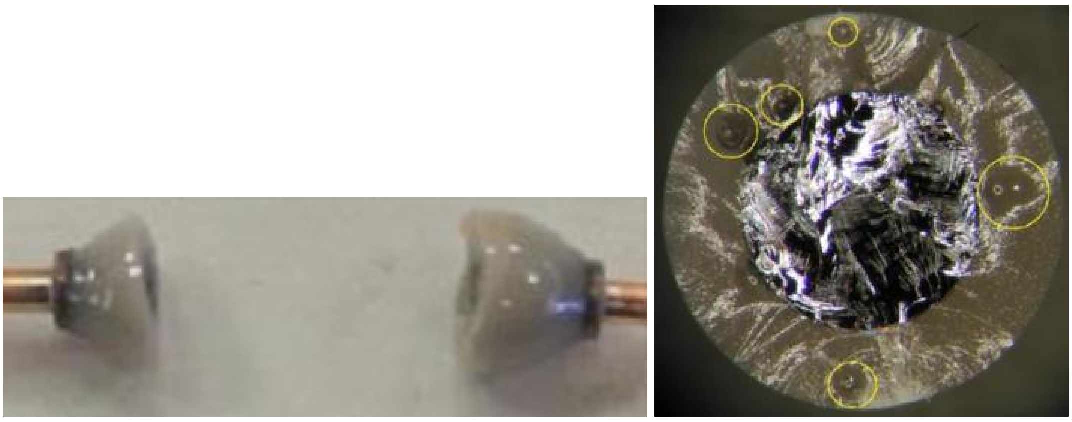
GE et al.[1914] report that latest experiments representing the current technical status have been conducted in 2014 and throughout 2015. Lead-free glass powders from suppliers Schott and NEG were used; precise specifications cannot be provided , with GE et al. citing company-confidential reasons. GE et al.[1915] claim that all attempts failed. Major problems that occurred when using glass types without lead were:

- Bubbles and voids in the glass which can lead to sparks, i.e. shorts along the chip junction;
- Cracks in the glass;
- Poor electrical characteristics due to high leakage currents.

Figure 34-2 shows a HVD with lead-free glass that was cut for optical analysis of the glass, and a cross section of that diode. GE et al.[1916] explain that the silicon chip can be seen in the centre, which is embedded in the Pb-free glass. The yellow circles indicate bubbles as one of the problems with Pb-free glasses. If such bubbles are located at the pn-junction, sparking can occur with high voltages.

[1913] Ibid.
[1914] General Electric et al. 2016a "Answers to questionnaire 2, document "Exe_37_Questionnaire-2_GE-et-al_2016-02-11_reply.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, on 11 February 2016" unpublished manuscript,
[1915] Op. cit. General Electric et al. 2015a 2015a
[1916] Op. cit. (General Electric et al. 2016a)

Figure 34-2: Cross-cut HVD (left) and analysis of the glass (right, bubbles marked with yellow circles)



Source: GE et al.[1917]

GE et al.[1918] think the root cause of the mechanism leading to bubbles in the glass is most probably a chemical redox reaction between ingredients of the Pb-free glass and chemicals from the chip. The most critical bubbles are those at the interface of the glass and the chip.

GE et al.[1919] admit that with some of the evaluated glasses in combination with optimized process parameters (sintering temperature profile, sintering atmosphere and pressure, viscosity of the glass slurry, etc.), it was possible to significantly reduce the occurrence of bubbles but claim that electrical characteristics like high leakage, "round" current-voltage curves, and sometimes reduced breakdown voltages are still poor.

GE et al.[1920] [1921] report about such experiments conducted at Vishay with lead-free glasses. HVD with typical 1,600 V breakdown voltage and less than 1 µA leakage current measured at reverse bias of 1,350 V were manufactured with the Pb free glasses under evaluation, electrically tested and compared to the reference control group using Pb-glass. The evaluated Pb-free glasses are labelled as "A" and "B" in Table 34-1.

[1917] Ibid.
[1918] General Electric et al. 2016b "Answer to third questionnaire, document "Exe_37_Questionnaire-3_GE-et-al_2016-03-11_reply.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, on 12 March 2016: Answers to third questionnaire" unpublished manuscript,
[1919] General Electric et al. 2016a
[1920] Op. cit. (General Electric et al. 2016a)
[1921] Op. cit. (General Electric et al. 2016b)

Table 34-1: Chemical composition of the tested Pb-free ZnB glasses

		Pb-free "A": ZnB	*Pb-free "B": ZnB*
PbO	wt%	0	0
B2O3	wt%	10-50	12,1
Al2O3	wt%	0	5,4
SiO2	wt%	1-10	23,4
ZnO	wt%	>50	58,1
Sb2O3	wt%	0,1-1	
CeO2	wt%	0,1-1	
Bi2O3	wt%	1-10	
MnO			0,91
Na2O	ppm	48	
Li2O	ppm		<0,005
Fe	ppm	33	

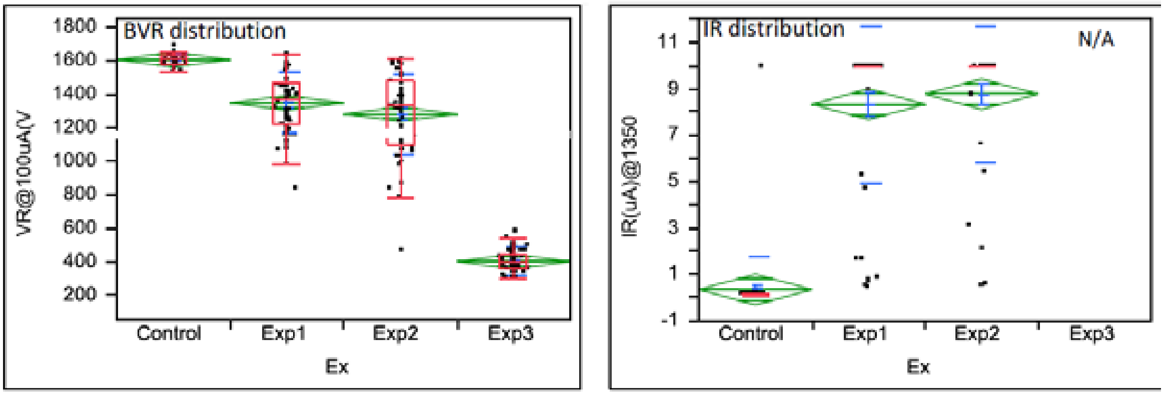
Source: GE et al.[1922]

GE et al. [1923] explain that the sintering profile is an important parameter in optimising and influencing mechanical and electrical characteristics. Glass "A" was therefore processed with two different sintering profiles in order to show the related process influence (EXP1 and EXP2 in the below figures and table).

Figure 34-3 shows the measured breakdown voltage (VBR). The control group (zinc-borate (ZnB) glass with 1-10 weight percent Pb) has a narrow VBR distribution around 1,600 V. Use of the Pb-free glasses A and B reduced the mean value of the breakdown voltage to about 1,300V (EXP1, EXP2) for glass "A" and to less than 400 V for glass "B" (EXP3). All groups have an extremely broad VBR distribution. The measured leakage current (IR) of the control group is less than 0.5 mA. Use of Pb-free glasses (EXP1-3) increased the leakage by a factor more than 20 to about 8-9 mA with broad IR distribution.

[1922] Ibid.
[1923] Ibid.

Figure 34-3: Distribution of breakdown voltage (BVR) and leakage current (IR)



Source: GE et al.[1924]

Table 34-2 lists the electrical yields at final testing regarding internally defined test limits for VBR and IR. Those yields are a direct consequence of the VBR and IR data shown in Figure 34-3. For the control group with Pb-glass, 9,368 out of 11,263 tested diodes passed the given VBR and IR limits, which results in 83,2% electrical yield. Equivalent evaluation for EXP1-3 is summarized in Table 34-2. Due to the very broad distributions of VBR and IR some devices from EXP1 and EXP2 even passed the limits. The yield for EXP3 was 0% because of the stronger degradation of VBR down to 400 V.

Table 34-2: Experimental electrical test results of lead-free glasses

Type	PN	Supplier	EXP NO	TMTT Yield(100% electric testing)		
				Input(ea)	Output(ea)	Yield(%)
Pb-Glass	Pb-glass	SUPPL. 1	Control	11,263	9,368	83.2%
Pb-Free Glass	Pb-free A	SUPPL. 1	EXP1	11,493	1,108	9.6%
	Pb-free A	SUPPL. 1	EXP2	11,399	2,130	18.7%
	Pb-free B	SUPPL. 2	EXP3	11,276	-	0.0%

Source: GE et al.[1925]

GE et al.[1926] highlight that the above evaluation only provides information on IR and VBR. These tests were, however, chosen in order to select first select the lead-free glass devices with the best electrical properties, which were then subjected to high reliability testing according to standard AEC-Q101. One important test which is crucial to proper chip and passivation quality is the High Temperature Reverse Bias (HTRB) test. In this

[1924] Ibid.
[1925] Ibid.
[1926] Ibid.

test, 77 diodes are biased at 100% rated reverse voltage at elevated (maximum data sheet specs) ambient temperature. The electrical device characteristics before and after testing are compared. Table 34-3 shows the results.

Table 34-3: Result of high reliability testing results of the lead-free samples

Hi-Rel No. :							
Test Item & Condition	Lot No.	EXP1¶			EXP2¶		
	Duration	Sample Size	Parametric failure (P)	Catastrophic failure (C)	Sample Size	Parametric failure (P)	Catastrophic failure (C)
H.T.R.B--(Tj=175°C)	168 Hrs	77	9	0	77	6	1
	500 Hrs	77	11	1	77	10	1
	1000 Hrs	77	11	3	77	12	2

Source: GE et al.[1927]

Table 34-4 presents the results of the control lot manufactured with lead-containing glass, which shows no failures.

Table 34-4: High reliability testing results of the lead control

Test Item & Conditions	Lot No.	Control Lot		
	Duration	Sample Size	Parametric failure (P)	Catastrophic failure (C)
H.T.R.B (Tj=175°C)	168 Hrs	77	0	0
	500 Hrs	77	0	0
	1000 Hrs	77	0	0

Source: GE et al.[1928]

GE et al.[1929] summarize that the use of Pb-free glasses results in degradation of the electrical characteristics (premature breakdown, increased leakage current, “round” current-voltage curves). Even the selected devices with the best electrical properties dramatically fail the high reliability test.

GE et al.[1930] explain that for good electrical characteristics of a chip embedded in glass, a number of properties need to be ensured:

1927 Ibid.

1928 General Electric et al. 2016c “E-mail communication, document "E-Mail-Communication_GE-et-al_2016-03-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, until 16 March 2016” unpublished manuscript,

1929 Op. cit. (General Electric et al. 2016b)

1930 Ibid.

- Proper charge balance in the glass to reduce the electrical field at the interface silicon-glass;
- Low mechanical strain, i.e. good match of thermal expansion between silicon and glass. The glass transition temperature TG of Pb-free glass types is significantly higher compared to Pb-glasses which generates higher mechanical strain during cooling after the sintering process;
- Good wettability of the silicon by the glass to avoid delamination etc.

According to GE et al.,[1931] so far none of the evaluated glass types ensured the combination of all those features, which results on device level in electrical characteristics ranging from shorts (worst case) to high leakage currents, “round” current-voltage curves, reduced breakdown voltage and also parametric drifts and thermal runaway of selected “acceptable” devices during HTRB testing.

GE et al.[1932] conclude that the tested lead-free glass materials are not yet mature for use in zinc-borate glass HVD.

34.2.2 Elimination of Lead

Besides substitution, elimination (i.e. the use of alternative technologies) is a principal way to avoid the use of lead, e.g. via a redesign of electronic circuits so that these HVD are no longer required.

GE et al.[1933] [1934] claim that HVD are used in high voltage power supplies, inverters, converters and freewheeling diode applications where their use is indispensable. GE et al.[1935] roughly group the uses of HVD as follows:

- Automotive applications (classical use: ignition);
- Lighting (classical use: electronic ballast);
- Industrial (classical use: Switch mode power supply - SMPS, inverters, freewheeling, etc.);
- Medical (often used in circuits for X-ray and CT (computer tomography). Use in high voltage power supply (i.e. where > 100 000V needs to be generated).

GE et al.[1936] give examples for applications in the scope of the RoHS Directive and of this review as follows.

34.2.2.1 HVD in Lighting Application (Electronic Ballasts)

A classical use of HVD in lighting applications is in electronic ballast of neon glow lamps. HVD are used in several positions of the ballast circuit:

[1931] Ibid.
[1932] Op. cit. (General Electric et al. 2016a)
[1933] Op. cit. (General Electric et al. 2015b)
[1934] Op. cit. (General Electric et al. 2016b)
[1935] Ibid.
[1936] Ibid.

- Bridge input rectification circuit;
- Power factor correction circuit;
- Others.

GE et al.[1937] claim that according to their knowledge and according to customers' inputs, HVD are inevitable devices for such circuits.

34.2.2.2 HVD in Industrial Electronics

According to GE et al.[1938], HVD are used in Switch Mode Power Supplies (SMPS). Their basic functions are:

- First step: the conversion of incoming alternate current (AC) to direct current (DC);
- Second step: the transformation to various DC voltage levels (including HV) dependent on final application.

GE et al.[1939] state that HVD among others must block main voltage spikes. GE et al. say that to their best knowledge and also according to customers' inputs HVD cannot be omitted in such circuits.

34.2.3 Avoidance of the Lead Contamination of the Plating Layer

34.2.3.1 Alternative Manufacturing Process

GE et al.[1940] [1941] explain that the leads of the HVD are plated in an electroplating process at typically 25 °C to 50 °C. Major process steps are:

- Pre-cleaning to remove oxides from the copper leads to be plated. The main component used of this pre-cleaning is H_2SO_4 (sulphuric acid);
- Electroplating in a galvanic bath with metasulfonic acid (MSA) and a tin chemical solution (SN chemical) as main components;
- Post cleaning with the main component (Na_3PO_4) (sodium phosphate).

GE et al.[1942] say that the lead contaminates the galvanic bath because the bath chemistry slightly etches the glass so that traces of lead dissolve and deposit onto the plating layer.

Reversing the order of processing, i.e. applying the tin plating prior to the glass bead, could in principle avoid the lead contamination of the plating layer. GE et al.[1943] explain that the glass bead is sintered at temperatures in the range of 700 °C. Tin has a melting

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[1937] Ibid.
[1938] Ibid.
[1939] Ibid.
[1940] Op. cit. (General Electric et al. 2016a)
[1941] Op. cit. (General Electric et al. 2016b)
[1942] Ibid.
[1943] Op. cit. (General Electric et al. 2016a)

point of around 231 °C so that the tin plating would not survive this high temperature process and hence needs to be applied after the glass bead.

34.2.3.2 Inhibition of Lead Contamination

The presence of lead in the plating layer could be avoided by inhibiting the lead in the bath to penetrate into the plating layer, e.g. by protective layers, or additives to the plating bath. GE et al.[1944] say that additives to the plating bath will not help because PbO is dissolved in the galvanic bath. Additives to the bath would not prevent dissolution. However, protecting the glass during immersion in the galvanic bath to prevent the contact of the glass with the acids in the bath might be a potential way to solve the lead contamination issue. GE et al.[1945] embedded the glass body into a protective compound, which then will remain on the final product so that the product will change and that way prevented dissolving of PbO in the galvanic acid. GE et al.[1946] will further pursue related activities, but have to investigate the consequences of the product modification and to understand whether so far unidentified barriers will be encountered.

34.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

According to GE et al.,[1947] there is no suitable substance for substituting lead. They claim that significant efforts are undertaken to eliminate lead in the glass body of the diode, but that so far no technical mature solution is available. Once lead can be eliminated in the glass body, it will also solve the contamination of the tinning. There are no prospects concerning the technical scope of Exemption 37 for a comprehensive substitution in the foreseeable future. Therefore such information and analysis required for a roadmap are not applicable in this case.

34.4 Critical Review

34.4.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

The exemption allows the use of lead.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate

[1944] Op. cit. (General Electric et al. 2016b)
[1945] Ibid.
[1946] Ibid.
[1947] Op. cit. (General Electric et al. 2015a 2015a)

- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as directly added substances nor as substances that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under Entry 28 and Entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds

- "shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight." This restriction does not apply to internal components of watch timepieces inaccessible to consumers;
- "shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children." This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

34.4.2 Substitution and Elimination of Lead

The stakeholders' justification and other information provided may have created the impression that Exemption 7c-I would allow the presence of lead in the plating layer, which is addressed in the scope of Exemption 37. On request, GE et al.[1948] confirm that this is not the case. Exemption 7c-I covers the use of lead in the glass of the HVD only. Exemption 37, however, only allows the occurrence of lead in the tin wire plating as a result of lead diffusion into the metal (tin) plating from the lead-containing glass during the plating process. While Exemption 7c-I covers the use of lead in the glass, Exemption 37 covers the lead in the tin plating of the HVD. Exemption 37 can therefore not be integrated into exemption 7c-I.

The occurrence of lead in the platings of zinc-borate glass HVD is the consequence of the use of lead-containing glass in the glass bead of such HVD as covered by Exemption 7c-I. There are three principle ways to overcome the problem:

- To use lead-free glass; or
- Eliminate the lead problem by applying alternative technologies that can replace HVD; or
- Change the process, in particular by applying the plating before the glass bead; or
- Inhibiting the diffusion of lead out of the lead glass bead of the HVD.

GE et al.[1949] [1950] claimed to have made considerable efforts to solve the problem, but the information GE et al. had provided in the exemption request and in the clarification questionnaire was highly insufficient to justify the renewal of the requested exemption. Only upon repeated requests[1951] [1952] [1953] [1954] did GE et al. present step by step more detailed and more specific information.

Based on the information available, the use of HVD must be considered to be indispensable so that the elimination of the lead problem by alternative technologies replacing HVD is technically impracticable at the current state of technology.

GE et al. present tests of lead-free materials for the HVD glass beads, the latest from 2015, to prove that lead-free glass materials are not yet mature for use in zinc-borate glass HVD. These tests are plausible and show some efforts by GE et al. to find lead-free alternatives to the lead glass that is used in HVD. Based on these tests, it can be concluded that currently lead-free glasses are not appropriate to prevent the lead contamination of the HVD plating layer.

[1948] Op. cit. (General Electric et al. 2015b 2015)
[1949] Op. cit. (General Electric et al. 2015a 2015a)
[1950] Op. cit. (General Electric et al. 2015b 2015)
[1951] Op. cit. (General Electric et al. 2015b)
[1952] Op. cit. (General Electric et al. 2016a)
[1953] Op. cit. (General Electric et al. 2016b)
[1954] Op. cit. (General Electric et al. 2016c)

The same applies to changing the process order, i.e. applying the lead glass bead prior to the plating process so that lead from the glass bead cannot contaminate the plating layer. The lower melting tin layer would not survive the high process temperature for the sintering of the glass bead onto the HVD so that a reverse process order is not a solution to the lead contamination problem.

The inhibition of lead diffusion out of the lead glass seems to be a promising approach. A protective layer around the glass bead could prevent its contact with the acids in the plating bath so that lead can no longer contaminate the bath and thus the plating layer. GE et al. had only mentioned this aspect very late within the review process for this exemption in response to the last submitted questionnaire[1955] after the reviewers had previously specifically asked for the viability of alternative approaches to solve the lead contamination problem. GE et al.[1956] then claimed they had conducted tests already and intend to further pursue this possibility, but also have to investigate the consequences of such a protective layer on the electrical and mechanical properties of the component. GE et al. did not indicate any time frame or present further details on this approach. Given the limited timeframe of the evaluation and the fact that GE et al. were given several possibilities already to present detailed information substantiating their exemption request, the consultants did not ask for further details.

The applicants' exemption request and the answers to the clarification questionnaire were made available through the public online consultation (i.e. to industry, governments, NGOs and other stakeholders). A questionnaire had been prepared for the public stakeholder consultation with specific questions to stakeholders. No further information supporting or discrediting the technical application in question was received.

34.4.3 Conclusions

Based on the information available, the reviewers conclude that the avoidance of lead in the plating layers of zinc borate HVD is currently scientifically and technically impracticable. The approach to apply a protective layer to the glass bead during the plating process to prevent the lead contamination of the plating layer should, however, be further investigated.

The available information allows concluding that avoiding the contamination of the plating layer of HVD currently is technically impracticable. RoHS Art. 5(1)(a) would allow the renewal of the exemption. As the applicants did not provide details about the status and timing of research to avoid the lead contaminations, it cannot be excluded that substitution or elimination of lead becomes scientifically and technically practicable within less than five years so that Art. 5(1)(a) would not allow granting the exemption for the maximum validity period. The consultants therefore recommend to renew the

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[1955] Op. cit. (General Electric et al. 2016b)
[1956] Ibid.

exemption for three years only, until 21 July 2019, which would allow to restrict the scope of the exemption and still leave sufficient time for industry to apply for the continuation of the exemption should it still be required by then.

34.5 Recommendation

Based on the presented information, the reviewers conclude that currently avoiding the lead in the plating layer of zinc-borate glass high voltage diodes is scientifically and technically impracticable. Art. 5(1)(a) in this situation would justify the continuation of the exemption in its current scope and wording. Protective coatings of the glass bead to prevent lead from the glass bead contaminating the plating layer are, however, discussed as a possible approach. It is therefore recommended to renew exemption 37, but to set an expiry date on 21 July 2019 as the applicants' information does not allow excluding that the substitution or elimination of lead shall become scientifically and technically practicable in less than five years.

<table>
<tr><th>Exemption 37</th><th>Expires on</th></tr>
<tr><td rowspan="4">Lead in the plating layer of high voltage diodes on the basis of a zinc borate glass body</td><td>21 July 2019 for categories 1-7 and 10</td></tr>
<tr><td>21 July 2021 for
· medical equipment in category 8
· monitoring and control instruments in category 9</td></tr>
<tr><td>21 July 2023 for in vitro diagnostic medical devices in category 8</td></tr>
<tr><td>21 July 2024 for industrial monitoring and control instruments in category 9</td></tr>
</table>

34.6 References Exemption 37

General Electric et al. 2015a Request for continuation of exemption 37, document "37_RoHS_V_Application_Form_-_Exemption_37_lead_in_high_voltage_diodes_final.pdf" 2015b. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/general_elcetric/37_RoHS_V_Application_Form_-_Exemption_37_lead_in_high_voltage_diodes_final.pdf.

General Electric et al. 2015b Answers to first questionnaire (clarification questionnaire). http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/Exe_37_GE_et_al_Questionnaire-1_2015-09-15_reply.pdf.

General Electric et al. 2016a Answers to questionnaire 2, document "Exe_37_Questionnaire-2_GE-et-al_2016-02-11_reply.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, on 11 February 2016.

General Electric et al. 2016b Answer to third questionnaire, document "Exe_37_Questionnaire-3_GE-et-al_2016-03-11_reply.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, on 12 March 2016.

General Electric et al. 2016c E-mail communication, document "E-Mail-Communication_GE-et-al_2016-03-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, until 16 March 2016.

Gensch, Carl-Otto, Stéphanie Zangl, and Otmar Deubzer Adaptation to scientific and technical progress under Directive 2002/95/EC 2007. http://ec.europa.eu/environment/waste/weee/pdf/rohs.pdf.

IXYS Semiconductor GmbH 2014 Request for continuation of exemption 37, document "37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf" 2014. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/IXYS/37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf.

IXYS Semiconductor GmbH 2016b Agreement to shift exemption request to exemption 7c-I, document "IXYS_Shift-to-exe.-7c-I.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Markus Bickel, IXYS Semiconductor GmbH, on 5 February 2016.

APPENDICES

A.1.0 Appendix 1: Relevant REACH Regulation Entries

Relevant annexes and processes related to the REACH Regulation have been cross-checked to clarify:

- In what cases granting an exemption could "weaken the environmental and health protection afforded by Regulation (EC) No 1907/2006" (Article 5(1)(a), pg.1)
- Where processes related to the REACH regulation should be followed to understand where such cases may become relevant in the future;

The last consolidated version has been consulted in this respect, published on 2 February 2016. Compiled information in this respect has been included, with short clarifications where relevant, in the following tables: Table A. 1 lists those substances appearing in Annex XIV, subject to Authorisation, which are relevant to the RoHS substances dealt with in the requests evaluated in this project. As can be seen, at present, exemptions have not been granted for the use of these substances.

Table A. 1: Relevant Entries from Annex XIV: The List of Substances Subject to Authorization

Designation of the substance, of the group of substances, or of the mixture	Transitional arrangements		Exempted (categories of) uses
	Latest application date (1)	Sunset date (2)	
4. Bis(2-ethylhexyl) phthalate (DEHP) **EC No: 204-211-0** **CAS No: 117-81-7**	21 August 2013	21 February 2015	Uses in the immediate packaging of medicinal products covered under Regulation (EC) No 726/2004, Directive 2001/82/EC, and/or Directive 2001/83/EC.
5. Benzyl butyl phthalate (BBP) **EC No: 201-622-7** **CAS No: 85-68-7**	21 August 2013	21 February 2015	Uses in the immediate packaging of medicinal products covered under Regulation (EC) No 726/2004, Directive 2001/82/EC, and/or Directive 2001/83/EC.
6. Dibutyl phthalate (DBP) **EC No: 201-557-4** **CAS No: 84-74-2**	21 August 2013	21 February 2015	Uses in the immediate packaging of medicinal products covered under Regulation (EC) No 726/2004, Directive 2001/82/EC, and/or Directive 2001/83/EC.
7. Diisobutyl phthalate (DIBP) **EC No: 201-553-2** **CAS No: 84-69-5**	21 August 2013	21 February 2015	
10. Lead chromate **EC No: 231-846-0**	21 Nov 2013	21 May 2015	-

Designation of the substance, of the group of substances, or of the mixture	Transitional arrangements		Exempted (categories of) uses
	Latest application date (1)	Sunset date (2)	
CAS No: 7758-97-6			
11. Lead sulfochromate yellow (C.I. Pigment Yellow 34) EC No: 215-693-7 CAS No: 1344-37-2	21 Nov 2013	21 May 2015	-
12. Lead chromate molybdate sulphate red (C.I. Pigment Red 104) EC No: 235-759-9 CAS No: 12656-85-8	21 Nov 2013	21 May 2015	-
16. Chromium trioxide EC No: 215-607-8 CAS No: 1333-82-0	21 Mar 2016	21 Sep 2017	-
17. Acids generated from chromium trioxide and their oligomers Group containing: Chromic acid EC No: 231-801-5 CAS No: 7738-94-5 Dichromic acid EC No: 236-881-5 CAS No: 13530-68-2 Oligomers of chromic acid and dichromic acid EC No: not yet assigned CAS No: not yet assigned	21 Mar 2016	21 Sep 2017	-
18. Sodium dichromate EC No: 234-190-3 CAS No: 7789-12-0 10588-01-9	21 Mar 2016	21 Sep 2017	-
19. Potassium dichromate EC No: 231-906-6 CAS No: 7778-50-9	21 Mar 2016	21 Sep 2017	-
20. Ammonium dichromate EC No: 232-143-1 CAS No: 7789-09-5	21 Mar 2016	21 Sep 2017	-
21. Potassium chromate EC No: 232-140-5 CAS No: 7789-00-6	21 Mar 2016	21 Sep 2017	
22. Sodium chromate EC No: 231-889-5 CAS No: 7775-11-3	21 Mar 2016	21 Sep 2017	
28. Dichromium tris(-chromate) EC No: 246-356-2 CAS No: 24613-89-6	22. July 2017	22 January 2019	
29. Strontium chromate EC No: 232-142-6 CAS No: 7789-06-2	22 July 2017	22 January 2019	
30. Potassium hydroxyoctaoxodizincatedichromate EC No: 234-329-8 CAS No: 11103-86-9	22 July 2017	22 January 2019	
31. Pentazinc chromate octahydroxide EC No: 256-418-0 CAS No: 49663-84-5	22 July 2017	22 January 2019	

For the substances currently restricted according to RoHS Annex II: cadmium, hexavalent chromium, lead, mercury, polybrominated biphenyls and polybrominated diphenyl ethers and their compounds, we have found that some relevant entries are listed in Annex XVII of the REACH Regulation. The conditions of restriction are presented in Table A. 2 below. Additionally, some amendments have been decided upon, and are still to be included in the concise version. These may be seen in Table A. 3.

Table A. 2: Conditions of Restriction in REACH Annex XVII for RoHS Substances and Compounds

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
8. Polybromobiphenyls; Polybrominatedbiphenyls (PBB) CAS No 59536-65-1	1. Shall not be used in textile articles, such as garments, undergarments and linen, intended to come into contact with the skin. 2. Articles not complying with paragraph 1 shall not be placed on the market.
16. Lead carbonates: **(a) Neutral anhydrous carbonate ($PbCO_3$)** **CAS No 598-63-0** **EC No 209-943-4** **(b) Trilead-bis(carbonate)-dihydroxide $2PbCO_3$-$Pb(OH)_2$** **CAS No 1319-46-6** **EC No 215-290-6**	Shall not be placed on the market, or used, as substances or in mixtures, where the substance or mixture is intended for use as paint. However, Member States may, in accordance with the provisions of International Labour Organization (ILO) Convention 13, permit the use on their territory of the substance or mixture for the restoration and maintenance of works of art and historic buildings and their interiors, as well as the placing on the market for such use. Where a Member State makes use of this derogation, it shall inform the Commission thereof.
17. Lead sulphates: **(a) $PbSO_4$** **CAS No 7446-14-2** **EC No 231-198-9** **(b) Pb_xSO_4** **CAS No 15739-80-7** **EC No 239-831-0**	Shall not be placed on the market, or used, as substances or in mixtures, where the substance or mixture is intended for use as paint. However, Member States may, in accordance with the provisions of International Labour Organization (ILO) Convention 13, permit the use on their territory of the substance or mixture for the restoration and maintenance of works of art and historic buildings and their interiors, as well as the placing on the market for such use. Where a Member State makes use of this derogation, it shall inform the Commission thereof.
18. Mercury compounds	Shall not be placed on the market, or used, as substances or in mixtures where the substance or mixture is intended for use: (a) to prevent the fouling by micro-organisms, plants or animals of: — the hulls of boats, — cages, floats, nets and any other appliances or equipment used for fish or shellfish farming, — any totally or partly submerged appliances or equipment; (b) in the preservation of wood; (c) in the impregnation of heavy-duty industrial textiles and yarn intended for their manufacture; (d) in the treatment of industrial waters, irrespective of their use.
18a. Mercury **CAS No 7439-97-6** **EC No 231-106-7**	1. Shall not be placed on the market: (a) in fever thermometers; (b) in other measuring devices intended for sale to the general public (such as manometers, barometers, sphygmomanometers, thermometers other than fever thermometers). 2. The restriction in paragraph 1 shall not apply to measuring devices that were in use in the Community before 3 April 2009. However Member States may restrict or prohibit the placing on the market of such measuring devices.

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
	3. The restriction in paragraph 1(b) shall not apply to: (a) measuring devices more than 50 years old on 3 October 2007; (b) barometers (except barometers within point (a)) until 3 October 2009. 5. The following mercury-containing measuring devices intended for industrial and professional uses shall not be placed on the market after 10 April 2014: (a) barometers; (b) hygrometers; (c) manometers; (d) sphygmomanometers; (e) strain gauges to be used with plethysmographs; (f) tensiometers; (g) thermometers and other non-electrical thermometric applications. The restriction shall also apply to measuring devices under points (a) to (g) which are placed on the market empty if intended to be filled with mercury. 6. The restriction in paragraph 5 shall not apply to: (a) sphygmomanometers to be used: (i) in epidemiological studies which are ongoing on 10 October 2012; (ii) as reference standards in clinical validation studies of mercury-free sphygmomanometers; (b) thermometers exclusively intended to perform tests according to standards that require the use of mercury thermometers until 10 October 2017; (c) mercury triple point cells which are used for the calibration of platinum resistance thermometers. 7. The following mercury-using measuring devices intended for professional and industrial uses shall not be placed on the market after 10 April 2014: (a) mercury pycnometers; (b) mercury metering devices for determination of the softening point. 8. The restrictions in paragraphs 5 and 7 shall not apply to: (a) measuring devices more than 50 years old on 3 October 2007; (b) measuring devices which are to be displayed in public exhibitions for cultural and historical purposes.
23. Cadmium and its compounds **CAS No 7440-43-9** **EC No 231-152-8**	For the purpose of this entry, the codes and chapters indicated in square brackets are the codes and chapters of the tariff and statistical nomenclature of Common Customs Tariff as established by Council Regulation (EEC) No 2658/87 (1). 1. Shall not be used in mixtures and articles produced from the following synthetic organic polymers (hereafter referred to as plastic material): — polymers or copolymers of vinyl chloride (PVC) [3904 10] [3904 21] — polyurethane (PUR) [3909 50] — low-density polyethylene (LDPE), with the exception of low-density polyethylene used for the production of coloured masterbatch [3901 10] — cellulose acetate (CA) [3912 11] — cellulose acetate butyrate (CAB) [3912 11] — epoxy resins [3907 30] — melamine-formaldehyde (MF) resins [3909 20] — urea-formaldehyde (UF) resins [3909 10] — unsaturated polyesters (UP) [3907 91] — polyethylene terephthalate (PET) [3907 60] — polybutylene terephthalate (PBT) — transparent/general-purpose polystyrene [3903 11] — acrylonitrile methylmethacrylate (AMMA)

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
	— cross-linked polyethylene (VPE) — high-impact polystyrene — polypropylene (PP) [3902 10] Mixtures and articles produced from plastic material as listed above shall not be placed on the market if the concentration of cadmium (expressed as Cd metal) is equal to or greater than 0,01 % by weight of the plastic material. By way of derogation, the second subparagraph shall not apply to articles placed on the market before 10 December 2011. The first and second subparagraphs apply without prejudice to Council Directive 94/62/EC (13) and acts adopted on its basis. By 19 November 2012, in accordance with Article 69, the Commission shall ask the European Chemicals Agency to prepare a dossier conforming to the requirements of Annex XV in order to assess whether the use of cadmium and its compounds in plastic material, other than that listed in subparagraph 1, should be restricted. 2. Shall not be used in paints [3208] [3209]. For paints with a zinc content exceeding 10 % by weight of the paint, the concentration of cadmium (expressed as Cd metal) shall not be equal to or greater than 0,1 % by weight. Painted articles shall not be placed on the market if the concentration of cadmium (expressed as Cd metal) is equal to or greater than 0,1 % by weight of the paint on the painted article. 3. By way of derogation, paragraphs 1 and 2 shall not apply to articles coloured with mixtures containing cadmium for safety reasons. 4. By way of derogation, paragraph 1, second subparagraph shall not apply to: — mixtures produced from PVC waste, hereinafter referred to as 'recovered PVC', — mixtures and articles containing recovered PVC if their concentration of cadmium (expressed as Cd metal) does not exceed 0,1 % by weight of the plastic material in the following rigid PVC applications: — (a) profiles and rigid sheets for building applications; (b) doors, windows, shutters, walls, blinds, fences, and roof gutters; (c) decks and terraces; (d) cable ducts; (e) pipes for non-drinking water if the recovered PVC is used in the middle layer of a multilayer pipe and is entirely covered with a layer of newly produced PVC in compliance with paragraph 1 above. Suppliers shall ensure, before the placing on the market of mixtures and articles containing recovered PVC for the first time, that these are visibly, legibly and indelibly marked as follows: '*Contains recovered PVC*' or with the following pictogram:  In accordance with Article 69 of this Regulation, the derogation granted in paragraph 4 will be reviewed, in particular with a view to reducing the limit

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
	value for cadmium and to reassess the derogation for the applications listed in points (a) to (e), by 31 December 2017. 5. For the purpose of this entry, ‘cadmium plating’ means any deposit or coating of metallic cadmium on a metallic surface. Shall not be used for cadmium plating metallic articles or components of the articles used in the following sectors/applications: (a) equipment and machinery for: — food production [8210] [8417 20] [8419 81] [8421 11] [8421 22] [8422] [8435] [8437] [8438] [8476 11] — agriculture [8419 31] [8424 81] [8432] [8433] [8434] [8436] — cooling and freezing [8418] — printing and book-binding [8440] [8442] [8443] (b) equipment and machinery for the production of: — household goods [7321] [8421 12] [8450] [8509] [8516] — furniture [8465] [8466] [9401] [9402] [9403] [9404] — sanitary ware [7324] — central heating and air conditioning plant [7322] [8403] [8404] [8415] In any case, whatever their use or intended final purpose, the placing on the market of cadmium-plated articles or components of such articles used in the sectors/applications listed in points (a) and (b) above and of articles manufactured in the sectors listed in point (b) above is prohibited. 6. The provisions referred to in paragraph 5 shall also be applicable to cadmium-plated articles or components of such articles when used in the sectors/applications listed in points (a) and (b) below and to articles manufactured in the sectors listed in (b) below: (a) equipment and machinery for the production of: — paper and board [8419 32] [8439] [8441] textiles and clothing [8444] [8445] [8447] [8448] [8449] [8451] [8452] (b) equipment and machinery for the production of: — industrial handling equipment and machinery [8425] [8426] [8427] [8428] [8429] [8430] [8431] — road and agricultural vehicles [chapter 87] — rolling stock [chapter 86] — vessels [chapter 89] 7. However, the restrictions in paragraphs 5 and 6 shall not apply to: — articles and components of the articles used in the aeronautical, aerospace, mining, offshore and nuclear sectors whose applications require high safety standards and in safety devices in road and agricultural vehicles, rolling stock and vessels, — electrical contacts in any sector of use, where that is necessary to ensure the reliability required of the apparatus on which they are installed. 8. Shall not be used in brazing fillers in concentration equal to or greater than 0,01 % by weight. Brazing fillers shall not be placed on the market if the concentration of cadmium (expressed as Cd metal) is equal to or greater than 0,01 % by weight. For the purpose of this paragraph brazing shall mean a joining technique using alloys and undertaken at temperatures above 450 °C. 9. By way of derogation, paragraph 8 shall not apply to brazing fillers used in defence and aerospace applications and to brazing fillers used for safety reasons. 10. Shall not be used or placed on the market if the concentration is equal to or

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
	greater than 0,01 % by weight of the metal in: (i) metal beads and other metal components for jewellery making; (ii) metal parts of jewellery and imitation jewellery articles and hair accessories, including: — bracelets, necklaces and rings, — piercing jewellery, — wrist-watches and wrist-wear, — brooches and cufflinks. 11. By way of derogation, paragraph 10 shall not apply to articles placed on the market before 10 December 2011 and jewellery more than 50 years old on 10 December 2011.
28. **Substances which appear in Part 3 of Annex VI to Regulation (EC) No 1272/2008 classified as carcinogen category 1A or 1B (Table 3.1) or carcinogen category 1 or 2 (Table 3.2) and listed as follows:** **— Carcinogen category 1A (Table 3.1)/carcinogen category 1 (Table 3.2) listed in Appendix 1** **— Carcinogen category 1B (Table 3.1)/carcinogen category 2 (Table 3.2) listed in Appendix 2:** **Chromium (VI) trioxide** **Zinc chromates including zinc potassium chromate** **Nickel chromate** **Nickel dichromate** **Potassium dichromate** **Ammonium dichromate** **Sodium dichromate** **Chromyl dichloride; chromic oxychloride** **Potassium chromate** **Calcium chromate** **Strontium chromate** **Chromium (VI) compounds, with the exception of barium chromate and of compounds specified elsewhere in Annex VI to Regulation (EC) No 1272/2008** **Chromium III chromate; chromic chromate** **Sodium chromate** **Cadmium oxide** **Cadmium chloride** **Cadmium fluoride** **Cadmium Sulphate**	Without prejudice to the other parts of this Annex the following shall apply to entries 28 to 30: 1. Shall not be placed on the market, or used, — as substances, — as constituents of other substances, or, — in mixtures, for supply to the general public when the individual concentration in the substance or mixture is equal to or greater than: — either the relevant specific concentration limit specified in Part 3 of Annex VI to Regulation (EC) No 1272/2008, or, — the relevant generic concentration limit specified in Part 3 of Annex I of Regulation (EC) No 1272/2008. Without prejudice to the implementation of other Community provisions relating to the classification, packaging and labelling of substances and mixtures, suppliers shall ensure before the placing on the market that the packaging of such substances and mixtures is marked visibly, legibly and indelibly as follows: 2. By way of derogation, paragraph 1 shall not apply to: (a) medicinal or veterinary products as defined by Directive 2001/82/EC and Directive 2001/83/EC; (b) cosmetic products as defined by Directive 76/768/EEC; (c) the following fuels and oil products: — motor fuels which are covered by Directive 98/70/EC, — mineral oil products intended for use as fuel in mobile or fixed combustion plants, — fuels sold in closed systems (e.g. liquid gas bottles); (d) artists' paints covered by Regulation (EC) No 1272/2008; (e) the substances listed in Appendix 11, column 1, for the applications or uses listed in Appendix 11, column 2. Where a date is specified in column 2 of Appendix 11, the derogation shall apply until the said date.

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
Cadmium sulphide Cadmium (pyrophoric) Chromium (VI) trioxide Lead Chromate Lead hydrogen arsenate Silicic acid, lead nickel salt Lead sulfochromate yellow; C.I. Pigment Yellow 34; Lead chromate molybdate sulfate red; C.I. Pigment Red 104;	
29. Substances which appear in Part 3 of Annex VI to Regulation (EC) No 1272/2008 classified as germ cell mutagen category 1A or 1B (Table 3.1) or mutagen category 1 or 2 (Table 3.2) and listed as follows: — Mutagen category 1A (Table 3.1)/mutagen category 1 (Table 3.2) listed in Appendix 3 — Mutagen category 1B (Table 3.1)/mutagen category 2 (Table 3.2) listed in Appendix 4 Cadmium chloride Cadmium fluoride Cadmium Sulphate Chromium (VI) trioxide Potassium dichromate Ammonium dichromate Sodium dichromate Chromyl dichloride; chromic oxychloride Potassium chromate Sodium chromate	
30. Substances which appear in Part 3 of Annex VI to Regulation (EC) No 1272/2008 classified as toxic to reproduction category 1A or 1B (Table 3.1) or toxic to reproduction category 1 or 2 (Table 3.2) and listed as follows: — Reproductive toxicant category 1A adverse effects on sexual function and fertility or on development (Table 3.1) or reproductive toxicant category 1 with R60 (May impair fertility) or R61 (May cause harm to the unborn child) (Table 3.2) listed in Appendix 5	

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
— Reproductive toxicant category 1B adverse effects on sexual function and fertility or on development (Table 3.1) or reproductive toxicant category 2 with R60 (May impair fertility) or R61 (May cause harm to the unborn child) (Table 3.2) listed in Appendix 6: **Bis(2-ethylhexyl) phthalate; di-(2-ethylhexyl) phthalate; DEHP** **Benzyl butyl phthalate; BBP** **Dibutyl phthalate; DBP** **Diisobutyl phthalate** **Cadmium chloride** **Cadmium fluoride** **Cadmium Sulphate** **Potassium dichromate** **Ammonium dichromate** **Sodium dichromate** **Sodium chromate** **Nickel dichromate** **Lead compounds with the exception of those specified elsewhere in this Annex** **Lead hydrogen arsenate** **Lead acetate** **Lead alkyls** **Lead azide** **Lead Chromate** **Lead di(acetate)** **Lead hydrogen arsenate** **Lead 2,4,6-trinitroresorcinoxide, lead styphnate** **Lead(II) methane- sulphonate** **Trilead bis- (orthophosphate)** **Lead hexa-fluorosilicate** **Mercury** **Silicic acid, lead nickel salt**	
47. Chromium VI compounds	1. Cement and cement-containing mixtures shall not be placed on the market, or used, if they contain, when hydrated, more than 2 mg/kg (0,0002 %) soluble chromium VI of the total dry weight of the cement. 2. If reducing agents are used, then without prejudice to the application of other Community provisions on the classification, packaging and labelling of substances and mixtures, suppliers shall ensure before the placing on the market that the packaging of cement or cement-containing mixtures is visibly, legibly and indelibly marked with information on the packing date, as well as on the storage conditions and the storage period appropriate to maintaining the activity of the reducing agent and to keeping the content of soluble chromium VI below the limit indicated in paragraph 1. 3. By way of derogation, paragraphs 1 and 2 shall not apply to the placing on the market for, and use in, controlled closed and totally automated processes in which cement and cement-containing mixtures are handled solely by machines

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
	and in which there is no possibility of contact with the skin. 4. The standard adopted by the European Committee for Standardization (CEN) for testing the water-soluble chromium (VI) content of cement and cement-containing mixtures shall be used as the test method for demonstrating conformity with paragraph 1. 5. Leather articles coming into contact with the skin shall not be placed on the market where they contain chromium VI in concentrations equal to or greater than 3 mg/kg (0,0003 % by weight) of the total dry weight of the leather. 6. Articles containing leather parts coming into contact with the skin shall not be placed on the market where any of those leather parts contains chromium VI in concentrations equal to or greater than 3 mg/kg (0,0003 % by weight) of the total dry weight of that leather part. 7. Paragraphs 5 and 6 shall not apply to the placing on the market of second-hand articles which were in end-use in the Union before 1 May 2015.
51. The following phthalates (or other CAS and EC numbers covering the substance): **(a) Bis (2-ethylhexyl) phthalate (DEHP)** **CAS No 117-81-7** **EC No 204-211-0** **(b) Dibutyl phthalate (DBP)** **CAS No 84-74-2** **EC No 201-557-4** **(c) Benzyl butyl phthalate (BBP)** **CAS No 85-68-7** **EC No 201-622-7**	1. Shall not be used as substances or in mixtures, in concentrations greater than 0,1 % by weight of the plasticised material, in toys and childcare articles. 2. Toys and childcare articles containing these phthalates in a concentration greater than 0,1 % by weight of the plasticised material shall not be placed on the market. 4. For the purpose of this entry 'childcare article' shall mean any product intended to facilitate sleep, relaxation, hygiene, the feeding of children or sucking on the part of children.
63. Lead and its compounds **CAS No 7439-92-1 EC No 231-100-4**	1. Shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0,05 % by weight. 2. For the purposes of paragraph 1: (i) 'jewellery articles' shall include jewellery and imitation jewellery articles and hair accessories, including: (a) bracelets, necklaces and rings; (b) piercing jewellery; (c) wrist watches and wrist-wear; (d) brooches and cufflinks; (ii) 'any individual part' shall include the materials from which the jewellery is made, as well as the individual components of the jewellery articles. 3. Paragraph 1 shall also apply to individual parts when placed on the market or used for jewellery-making. 4. By way of derogation, paragraph 1 shall not apply to: (a) crystal glass as defined in Annex I (categories 1, 2, 3 and 4) to Council Directive 69/493/EEC (*); (b) internal components of watch timepieces inaccessible to consumers; (c) non-synthetic or reconstructed precious and semiprecious stones (CN code 7103, as established by Regulation (EEC) No 2658/87), unless they have been treated with lead or its compounds or mixtures containing these substances; (d) enamels, defined as vitrifiable mixtures resulting from the fusion, vitrification or sintering of minerals melted at a temperature of at least 500 °C. 5. By way of derogation, paragraph 1 shall not apply to jewellery articles placed

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
	on the market for the first time before 9 October 2013 and jewellery articles articles produced before 10 December 1961. 6. By 9 October 2017, the Commission shall re-evaluate paragraphs 1 to 5 of this entry in the light of new scientific information, including the availability of alternatives and the migration of lead from the articles referred to in paragraph 1 and, if appropriate, modify this entry accordingly. 7. Shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0,05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children. That limit shall not apply where it can be demonstrated that the rate of lead release from such an article or any such accessible part of an article, whether coated or uncoated, does not exceed 0,05 µg/cm 2 per hour (equivalent to 0,05 µg/g/h), and, for coated articles, that the coating is sufficient to ensure that this release rate is not exceeded for a period of at least two years of normal or reasonably foreseeable conditions of use of the article. For the purposes of this paragraph, it is considered that an article or accessible part of an article may be placed in the mouth by children if it is smaller than 5 cm in one dimension or has a detachable or protruding part of that size. 8. By way of derogation, paragraph 7 shall not apply to: (a) jewellery articles covered by paragraph 1; (b) crystal glass as defined in Annex I (categories 1, 2, 3 and 4) to Directive 69/493/ EEC; (c) non-synthetic or reconstructed precious and semi-precious stones (CN code 7103 as established by Regulation (EEC) No 2658/ 87) unless they have been treated with lead or its compounds or mixtures containing these substances; (d) enamels, defined as vitrifiable mixtures resulting from the fusion, vitrification or sintering of mineral melted at a temperature of at least 500 ° C; (e) keys and locks, including padlocks; (f) musical instruments; (g) articles and parts of articles comprising brass alloys, if the concentration of lead (expressed as metal) in the brass alloy does not exceed 0,5 % by weight; (h) the tips of writing instruments (i) religious articles; (j) portable zinc-carbon batteries and button cell batteries; (k) articles within the scope of: (i) Directive 94/62/EC; (ii) Regulation (EC) No 1935/2004; (iii) Directive 2009/48/EC of the European Parliament and of the Council (**); (iv) Directive 2011/65/EU of the European Parliament and of the Council (***) 9. By 1 July 2019, the Commission shall re-evaluate paragraphs 7 and 8(e), (f), (i) and (j) of this entry in the light of new scientific information, including the availability of alternatives and the migration of lead from the articles referred to in paragraph 7, including the requirement on coating integrity, and, if appropriate, modify this entry accordingly. 10. By way of derogation paragraph 7 shall not apply to articles placed on the market for the first time before 1 June 2016. (*) OJ L 326, 29.12.1969, p. 36. (**) Directive 2009/48/EC of the European Parliament and of the Council of 18 June 2009 on the safety of toys (OJ L 170, 30.6.2009, p. 1). (***) Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (OJ L 174, 1.7.2011, p. 88).

Table A. 3: Summary of Relevant Amendments to Annexes Not Updated in the Last Concise Version of the REACH Regulation

Designation of the substance, of the group of substances, or of the mixture	Conditions of restriction	Amended Annex	Amendment date
Addition of Entry 62 concerning: **(a) Phenylmercury acetate** **EC No: 200-532-5** **CAS No: 62-38-4** **(b) Phenylmercury propionate** **EC No: 203-094-3** **CAS No: 103-27-5** **(c) Phenylmercury 2-ethylhexanoate** **EC No: 236-326-7** **CAS No: 13302-00-6** **(d) Phenylmercury octanoate** **EC No: -** **CAS No: 13864-38-5** **(e) Phenylmercury neodecanoate** **EC No: 247-783-7** **CAS No: 26545-49-3**	1. Shall not be manufactured, placed on the market or used as substances or in mixtures after 10 October 2017 if the concentration of mercury in the mixtures is equal to or greater than 0,01% by weight. 2. Articles or any parts thereof containing one or more of these substances shall not be placed on the market after 10 October 2017 if the concentration of mercury in the articles or any part thereof is equal to or greater than 0,01% by weight.'	Annex XVII, entry 62	20 Sep 2012

As of 28 September 2015, the REACH Regulation Candidate list includes those substances relevant for RoHS listed in Table A. 4 (i.e., proceedings concerning the addition of these substances to the Authorisation list (Annex XIV) have begun and shall be followed by the evaluation team to determine possible discrepancies with future requests of exemption from RoHS (new exemptions, renewals and revocations))[1957]:

Table A. 4: Summary of Relevant Substances Currently on the REACH Candidate List

Substance Name	EC No.	CAS No.	Date of Inclusion	Reason for inclusion
Cadmium fluoride	232-222-0	7790-79-6	17 December 2014	Carcinogenic (Article 57 a); Mutagenic (Article 57 b); Toxic for reproduction (Article 57 c); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Cadmium sulphate	233-331-6	10124-36-4 31119-53-6	17 December 2014	Carcinogenic (Article 57 a); Mutagenic (Article 57 b); Toxic for reproduction (Article 57 c); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Cadmium chloride	233-296-7	10108-64-2	16 June 2014	Carcinogenic (Article 57a);

[1957] Updated according to http://echa.europa.eu/web/guest/candidate-list-table

Substance Name	EC No.	CAS No.	Date of Inclusion	Reason for inclusion
Cadmium sulphide	215-147-8	1306-23-6	16 Dec 2013	Carcinogenic (Article 57a); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Lead di(acetate)	206-104-4	301-04-2	16 Dec 2013	Toxic for reproduction (Article 57 c);
Cadmium	231-152-8	7440-43-9	20 Jun 2013	Carcinogenic (Article 57a); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Cadmium oxide	215-146-2	1306-19-0	20 Jun 2013	Carcinogenic (Article 57a); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Pyrochlore, antimony lead yellow	232-382-1	8012-00-8	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead bis(tetrafluoroborate)	237-486-0	13814-96-5	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead dinitrate	233-245-9	10099-74-8	19 Dec 2012	Toxic for reproduction (Article 57 c)
Silicic acid, lead salt	234-363-3	11120-22-2	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead titanium zirconium oxide	235-727-4	12626-81-2	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead monoxide (lead oxide)	215-267-0	1317-36-8	19 Dec 2012	Toxic for reproduction (Article 57 c)
Silicic acid ($H_2Si_2O_5$), barium salt (1:1), lead-doped ***[with lead (Pb) content above the applicable generic concentration limit for 'toxicity for reproduction' Repr. 1A (CLP) or category 1 (DSD); the substance is a member of the group entry of lead compounds, with index number 082-001-00-6 in Regulation (EC) No 1272/2008]***	272-271-5	68784-75-8	19 Dec 2012	Toxic for reproduction (Article 57 c)
Trilead bis(carbonate)dihydroxide	215-290-6	1319-46-6	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead oxide sulfate	234-853-7	12036-76-9	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead titanium trioxide	235-038-9	12060-00-3	19 Dec 2012	Toxic for reproduction (Article 57 c)
Acetic acid, lead salt, basic	257-175-3	51404-69-4	19 Dec 2012	Toxic for reproduction (Article 57 c)
[Phthalato(2-)]dioxotrilead	273-688-5	69011-06-9	19 Dec 2012	Toxic for reproduction (Article 57 c)
Tetralead trioxide sulphate	235-380-9	12202-17-4	19 Dec 2012	Toxic for reproduction (Article 57 c)
Dioxobis(stearato)trilead	235-702-8	12578-12-0	19 Dec 2012	Toxic for reproduction (Article 57 c)
Tetraethyllead	201-075-4	78-00-2	19 Dec 2012	Toxic for reproduction (Article 57 c)
Pentalead tetraoxide sulphate	235-067-7	12065-90-6	19 Dec 2012	Toxic for reproduction (Article 57 c)
Trilead dioxide phosphonate	235-252-2	12141-20-7	19 Dec 2012	Toxic for reproduction (Article 57 c)
Orange lead (lead tetroxide)	215-235-6	1314-41-6	19 Dec 2012	Toxic for reproduction (Article 57

Substance Name	EC No.	CAS No.	Date of Inclusion	Reason for inclusion
				c)
Sulfurous acid, lead salt, dibasic	263-467-1	62229-08-7	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead cyanamidate	244-073-9	20837-86-9	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead(II) bis(methanesulfonate)	401-750-5	17570-76-2	18 Jun 2012	Toxic for reproduction (Article 57 c)
Lead diazide, Lead azide	236-542-1	13424-46-9	19 Dec 2011	Toxic for reproduction (article 57 c),
Lead dipicrate	229-335-2	6477-64-1	19 Dec 2011	Toxic for reproduction (article 57 c)
Dichromium tris(chromate)	246-356-2	24613-89-6	19 Dec 2011	Carcinogenic (article 57 a)
Pentazinc chromate octahydroxide	256-418-0	49663-84-5	19 Dec 2011	Carcinogenic (article 57 a)
Potassium hydroxyoctaoxodizincatedichromate	234-329-8	11103-86-9	19 Dec 2011	Carcinogenic (article 57 a)
Lead styphnate	239-290-0	15245-44-0	19 Dec 2011	Toxic for reproduction (article 57 c)
Trilead diarsenate	222-979-5	3687-31-8	19 Dec 2011	Carcinogenic and toxic for reproduction (articles 57 a and 57 c)
Strontium chromate	232-142-6	7789-06-2	20 Jun 2011	Carcinogenic (article 57a)
Acids generated from chromium trioxide and their oligomers. Names of the acids and their oligomers: Chromic acid, Dichromic acid, Oligomers of chromic acid and dichromic acid.	231-801-5, 236-881-5	7738-94-5, 13530-68-2	15 Dec 2010	Carcinogenic (article 57a)
Chromium trioxide	215-607-8	1333-82-0	15 Dec 2010	Carcinogenic and mutagenic (articles 57 a and 57 b)
Potassium dichromate	231-906-6	7778-50-9	18 Jun 2010	Carcinogenic, mutagenic and toxic for reproduction (articles 57 a, 57 b and 57 c)
Ammonium dichromate	232-143-1	7789-09-5	18 Jun 2010	Carcinogenic, mutagenic and toxic for reproducetion (articles 57 a, 57 b and 57 c)
Sodium chromate	231-889-5	7775-11-3	18 Jun 2010	Carcinogenic, mutagenic and toxic for reproduction (articles 57 a, 57 b and 57 c)
Potassium chromate	232-140-5	7789-00-6	18 Jun 2010	Carcinogenic and mutagenic (articles 57 a and 57 b).
Lead sulfochromate yellow (C.I. Pigment Yellow 34)	215-693-7	1344-37-2	13 Jan 2010	Carcinogenic and toxic for reproduction (articles 57 a and 57 c))
Lead chromate molybdate sulphate red (C.I. Pigment Red 104)	235-759-9	12656-85-8	13 Jan 2010	Carcinogenic and toxic for reproduction (articles 57 a and 57 c)
Lead chromate	231-846-0	7758-97-6	13 Jan 2010	Carcinogenic and toxic for reproduction (articles 57 a and 57 c)
Lead hydrogen arsenate	232-064-2	7784-40-9	28 Oct 2008	Carcinogenic and toxic for reproduction (articles 57 a and 57 c)
Sodium dichromate	234-190-3	7789-12-0, 10588-01-9	28 Oct 2008	Carcinogenic, mutagenic and toxic for reproduction (articles 57a, 57b and 57c)

Additionally, Member States can register intentions to propose restrictions or to classify substances as SVHC. The first step is to announce such an intention. Once the respective dossier is submitted, it is reviewed and it is decided if the restriction or authorisation process should be further pursued or if the intention should be withdrawn.

As at the time of writing (Fall 2015), it cannot yet be foreseen how these procedures will conclude. It is thus not yet possible to determine if the protection afforded by REACH Regulation would in these cases consequently be weakened by approving the exemption requests dealt with in this report. For this reason, the implications of these decisions have not been considered in the review of the exemption requests dealt with in this report. However for the sake of future reviews, the latest authorisation or restriction process results shall be followed and carefully considered where relevant.[1958]

As for registries of intentions to identify substances as SVHC, as of 28 September 2015, Sweden has submitted intentions regarding the classification of cadmium fluoride and cadmium sulphate as CMR, intending to submit dossiers in August 2014.None of the current registries of intentions to propose restrictions apply to RoHs regulated substances.[1959]

As for prior registrations of intention, dossiers have been submitted for the substances listed in Table A. 5.

Table A. 5: Summary of Substances for which a Dossier has been submitted, following the initial registration of intention

Restriction / SVHC Classification	Substance Name	Submission Date	Submitted by	Comments
Restriction	Cadmium and its compounds	17 Jan 2014	Sweden	Artist paints
	Cadmium and its compounds	17 Oct 2013	ECHA	Amendment of the current restriction (entry 23) on use of paints with TARIC codes [3208] & [3209] containing cadmium and cadmium compounds to include placing on the market of such paints and a concentration limit.
	Lead and lead compounds	18 Jan 2013	Sweden	Placing on the market of consumer articles containing Lead and its compounds
	Chromium VI	20 Jan 2012	Denmark	Placing on the market of leather articles containing

[1958] European Chemicals Agency (ECHA), Registry of intentions to propose restrictions: http://echa.europa.eu/registry-of-current-restriction-proposal-intentions/-/substance/1402/search/+/term (28.09.2015)

[1959] ECHA website, accessed 28.09.2015: http://echa.europa.eu/web/guest/addressing-chemicals-of-concern/registry-of-intentions

Restriction / SVHC Classification	Substance Name	Submission Date	Submitted by	Comments
				Chromium VI
	Phenylmercuric octanoate; Phenylmercury propionate; Phenylmercury 2-ethylhexanoate; Phenylmercury acetate; Phenylmercury	15 Jun 2010	Norway	Mercury compounds
	Mercury in measuring devices	15 Jun 2010	ECHA	Mercury compounds
	Lead and its compounds in jewellery	15 Apr 2010	France	Substances containing lead
SVHC Classification	Cadmium chloride	03 Feb 2014	Sweden	CMR; other;
	Cadmium sulphide	05 Aug 2013	Sweden	CMR; other;
	Lead di(acetate)	05 Aug 2013	Netherlands	CMR
	Cadmium	04 Feb 2013	Sweden	CMR; other; Substances containing Cd
	Cadmium oxide	04 Feb 2013	Sweden	CMR; other; Substances Containing Cd
	Trilead dioxide Phosphonate; Lead Monoxide (Lead Oxide); Trilead bis(carbonate)di-hydroxide; Lead Dinitrate; Lead Oxide Sulphate; Acetic acid, lead salt, basic; Dioxobis(stearato)trilead; Lead bis(tetrafluoroborate); Tetraethyllead; Pentalead tetraoxide sulphate; Lead cyanamidate; Lead titanium trioxide; Silicic acid ($H_2Si_2O_5$), barium salt (1:1), lead-doped; Silicic acid, lead salt; Sulfurous acid, lead salt, dibasic; Tetralead trioxide sulphate; [Phthalato(2-)]dioxotrilead; Orange lead (lead tetroxide); Fatty acids, C16-18, lead salts; Lead titanium zirconium oxide	30 Aug 2012	ECHA	CMR; substances Containing Lead
	Lead(II) bis(methanesulfonate)	30 Jan 2012	Netherlands	CMR; Amides
	Lead styphnate; Lead diazide; Lead azide; Lead dipicrate	01 Aug 2011	ECHA	CMR; Substances containing lead
	Trilead diarsenate			CMR; Arsenic compounds
	Strontium Chromate	24 Jan 2011	France	CMR; Substances containing chromate
	Acids generated from chromium trioxide and their oligomers: Chromic acid; Dichromic acid; Oligomers of chromic acid and dichromic acid	27 Aug 2010	Germany	CMR; Substances containing chromate
	Chromium Trioxide	02 Aug 2010	Germany	CMR; Substances containing chromate
	Sodium chromate; Potassium chromate; Potassium Dichromate	10 Feb 2010	France	CMR; Substances containing chromate

Restriction / SVHC Classification	Substance Name	Submission Date	Submitted by	Comments
	Lead chromate molybdate sulfate red (C.I. Pigment Red 104); Lead sulfochromate yellow (C.I. Pigment Yellow 34)	03 Aug 2009	France	CMR; substances Containing Lead
	Lead Chromate	03 Aug 2009	France	CMR; Substances containing chromate
	Lead hydrogen arsenate	27 Jun 2008	Norway	CMR; Arsenic compounds
	Sodium dichromate	26 Jun 2008	France	CMR; Substances containing chromate

Concerning the above mentioned processes, as at present, it cannot be foreseen if, or when, new restrictions or identification as SVHC might be implemented as a result of this proposal; its implications have not been considered in the review of the exemption requests dealt with in this report. In future reviews, however, on-going research into restriction and identification as SVHC processes and the results of on-going proceedings shall be followed and carefully considered where relevant.

A.2.0 Appendix 2: Data as to the Average Number and Type of Light Sources per Household

The information is copied from Annex C of the VHK & VITO 2015 Task 3 Report and is available with additional detail under the following link:

http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources%20Task3%20Final%2020151031.pdf

Data is presented only for the the three most recent studies. Additional information for each data and additional studies are presented in the original source.

C.1 United Kingdom 2012, lighting measurements in households

The reference [211] presents the results of a survey of 251 households in England that was undertaken to monitor the electrical power demand and energy consumption over the period May 2010 to July 2011. Of the 251 households surveyed, 26 were monitored for a period of one year and the rest were monitored for periods of one month at intervals throughout the year. Different types of houses (terraced, flat, stand-alone) with different types of households (pensioners, workers, with or without children) were involved. Lighting energy consumption was part of the measurements.

A seasonality lighting curve was calculated using the 26 households that were monitored for one year [212]. This curve was used to calculate the annual consumption for the lights monitored for one month.

The average **number of light sources per household**, all types taken together, was **33.6**. As reported in the reference, this value is between the numbers for the ECL100 project in France (28.3) and the SWE400 project in Sweden (42.0). Subdivision over the lamp types:

Lamp type	Number per household	Share of lamps
Incandescent	12.9	38%
halogen MV	5.1	15%
halogen LV	5.4	16%
CFL	7.9	24%
LFL	2.0	6%
LED	0.2	1%
Total	**33.6**	100%

Table 55 Number of lamps per household, United Kingdom, 2012

C.2 Sweden 2009, lighting measurements in households

The reference [213] reports the results of the measurement campaigns that took place in Sweden in cooperation between the Swedish Energy Agency, Enertech (France) and YIT Sverige AB. The campaign went from August 2005 to December 2008. A total of 40 households were measured for one year. Additional 360 households were monitored for one month. The lodgings were approximately 50% apartments and 50% houses. On average, houses had a useful area of 127 m^2 and apartments 76 m^2. The households had a differing number of persons.

The **average total number of light sources [214] per household**, all types taken together, is **42.** For houses this value is 55.2 and for apartments 31.2.

Lamp type	Number per household	Share of lamps
incandescent	25.4	60%
halogen MV	0.7	2%
halogen LV	6.1	15%
CFL	5.5	13%
LFL	4.3	10%
LED	0	0%
Total	42	100%

Table 57 Number of lamps per household, Sweden, 2009 [215].

C.3 REMODECE 2008, lighting survey and measurements in households

REMODECE is an abbreviation for "Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe". This project of Intelligent Energy Europe was performed in the years 2006-2008. The project also considered energy use for lighting. The information presented below derives from different reports [217].

Data were gathered in the REMODECE project by means of a combination of measurements and of survey's (questionnaires), in the following countries: Belgium, Bulgaria, Czech Republic, Denmark, France, Germany, Greece (Hellas), Hungary, Italy, Norway, Portugal and Romania.

The measurement campaigns were performed in at least 100 households per country, using equipment capable to monitor the energy demand every 1 or 10 minutes. The measurement period has been approximately two weeks per household.

On average, the electric energy consumption for **lighting** was found to be **18% of the total household consumption of electricity** (excluding electric space heating and electric water heating.

The **average number of lamps per household was 26** [218]. As shown in Table 60, this number varied considerably from country to country, from 11 in Romania to 34 in Norway. On average there were 4 compact fluorescent lamps per household. The largest share was incandescent lighting, representing about 50% of the total number of lights installed. Low wattage halogen lamps were the second most used lamps. This is explained in the references by the fact that this type of lighting is used in false ceilings with a high number of light points. Fluorescent and compact fluorescent lamps had small percentages (only in Belgium these two combined were more than 30% of the total lighting lamps). Figure 40 and Figure 41 show the subdivision of lamp types per country and per room-type.

total of lamps by type	Pt	Be	Dk	Gr	Bu	It	No	Ro	Fr	Cz	De	Hu	Average
Incandescent	13	9	14	10	9	15	14	8	14	12	13	8	13
Low wattage Halogen	4	10	9	3	4	7	11	1	4	5	7	2	6
Halogen 230V	1	1	2	1	0	2	0,5	0	1	0	1	0	1
Fluorescent	3	3	3	1	1	3	4,2	1	2	2	2	0	2
Compact Fluorescent (CFL)	4	7	6	4	2	6	4,5	1	4	6	3	3	4
Total	26	31	33	20	16	33	34	11	24	25	25	14	26

Table 60 Number of lamps per household in various European countries (REMODECE project, 2006-200

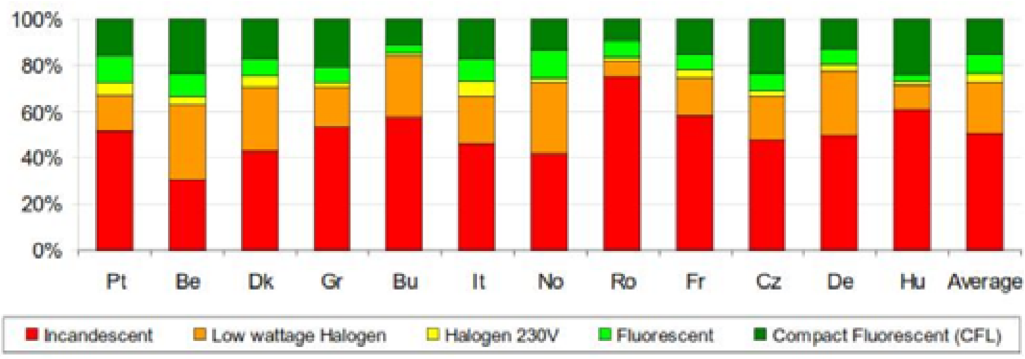


Figure 40 Types of lamps installed in various European countries (REMODECE project, 2006-2008)

A.3.0 Appendix 3: Applications of Ex. 4(f) UV Curing Lamps

According to LEU Ex. 4f(2015a): LightingEurope (LEU), Request to renew Exemption 4(f) under the RoHS Directive 2011/65/EU Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex, submitted 15.1.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_4_f_/Lighting_Europe/4f_LE_RoHS_Exemption_Req_Final.pdf

"*Currently medium pressure lamps containing mercury are used a wide range of manufacturing applications – including amongst others; printing, wood finishing, PCB manufacture, glass bottle decoration, metal container decoration, sewer rehabilitation, contact lens manufacture, plastic bottle decoration, optical fiber coating, ink jet printing, coating plastic parts etc. These applications are used in a wide range of well-known markets and industries, e.g.:-*

- *Coating of polycarbonate headlamp lenses for all the major European (and global) automotive manufacturers*
- *Coating of wide range of plastic components for the automotive industry, cosmetic and consumer goods for international companies*
- *Coating of wood and MDF products for furniture companies*
- *Coating of beverage cans for all the European (and global) can manufacturers*
- *Coating optical fibers for telecommunication*
- *Pressure sensitive adhesives manufactured by well-known, international companies*
- *used in tapes and label products*
- *Wide web, high speed printing and coating packaging for many well-known companies*
- *across Europe and beyond.*"

A.4.0 Appendix 4: Exemption 6b

Figure A - 34-1: Material Data Sheet for Al Alloy 6026 provided by EURAL, 1st Page

6026 by EURAL

Colour code
EU orange

Lead Free (Pb) (Sn)

EURAL GNUTTI S.p.A.

According to EU directives:
2000/53/EC (ELV) – 2011/65/EU (RoHS II)

PRODUCTION PROGRAM

Unit: mm	Round	Square	Flat	Hexagon
Drawn	6 ÷ 76,2	12 ÷ 65	Thick. 12 ÷ 55	12 ÷ 60
Extruded	30 ÷ 254	50 ÷ 165	Thick. 30 ÷ 157	–

PRESENTATION

This innovative alloy has been conceived and developed in Eural Gnutti SpA's research laboratories, in order to meet the most recent standards for the protection of the environment. It is particularly suitable for being machined on high speed automatic lathes. It has good resistance to corrosion, medium-high mechanical properties, good suitability for decorative and industrial hard anodizing. It is also used for hot forging purposes. Eural 6026 alloy does not contain tin (Sn) which, as it has been proved, causes weakness and cracking of the machined parts when submitted to stress and high temperature. Due to its brittle nature, tin has the dangerous tendency to sudden brakes without significant previous deformation (strain).

It can replace 2007, 2011, 2015, 2028, 2030, 2044, 6012, 6012A, 6020, 6021, 6023, 6028, 6033, 6040, 6041, 6042, 6061, 6065, 6082, 6262, 6064A, 6262A, 6351, 7020 alloys.

Main applications: automotive industry, electric and electronic industry, hot forging, screws, bolts, nuts, threaded parts.

Properties	T6	T8/T9
Machinability	Good	Good
Protective anodizing	Good	Good
Decorative anodizing	Good	Good
Hard anodizing	Excellent	Excellent
Resistance to atmospheric corrosion	Good	Good
Resistance to marine corrosion	Acceptable	Acceptable
MIG-TIG weldability	Good	Good
At resistance weldability	Good	Good
Brazing weldability	Acceptable	Acceptable
Plastic formability when cold	Acceptable	Not recommended
Plastic formability when hot	Good	Good

Legend: Excellent, Good, Acceptable, Not recommended

Samples of finished products made of Eural bars

Chemical composition	
Si	0,60 ÷ 1,40
Fe	≤ 0,70
Cu	0,20 ÷ 0,50
Mn	0,20 ÷ 1,00
Mg	0,60 ÷ 1,20
Cr	≤ 0,30
Ni	
Zn	≤ 0,30
Ti	≤ 0,20
Sn	
Pb	
Bi	0,50 ÷ 1,50
Al	Remainder

Physical properties		
Density	Kg/dm³	2,72
Modulus of elasticity	MPa	69.000
Coefficient of thermal expansion	x10⁻⁶/°C	23,4
Thermal conductivity at 20°C	W/mK	172
Electrical resistivity at 20°C	Ω mm²/m	0,039

Mechanical properties	Temper	Rm MPa	Rp 0,2 MPa	A%	HBW
Extruded	T6	370	300	8	95
	T6 *	400	370	10	110
Drawn	T6	370	300	8	95
	T6 *	390	350	10	115
	T8	345	315	4	95
	T8 *	370	360	10	105
	T9	360	330	4	95
	T9 *	400	380	8	110

* *Typical Eural properties*

Figure A - 34-2: Material Data Sheet for Al Alloy 6026 provided by EURAL, 2nd Page

6026 Lead Free EURAL

by EURAL

According to
RoHS II, ELV, REACH
directives
actual and future revisions

GNUTTI S.p.A.

Aluminium with technology

Application fields
6026 by EURAL is extremely versatile, due to its medium-high mechanical properties, good attitude to anodizing, good weldability, good attitude to forging, good corrosion resistance.
6026 by EURAL is suitable for components used in several industries as automotive, electric and electronic, valves, oleohydraulic, pneumatic, defence.

Ecological choice
Since many years, the European Community is working on reducing the content of hazardous substances.
Actual revisions of RoHS, ELV, REACH directives limit the content of Pb to max 0,40% on aluminium alloys, and the tendency for the future is to revise this limit to be lead free.
Eural Gnutti has anticipated the future restrictions of such directives creating the 6026 by EURAL Lead Free.

The born of 6026 by EURAL
6026 by EURAL is an innovative alloy designed and developed by Eural Gnutti S.p.A. R&D laboratories in order to meet the strictest requirements in critical automotive applications such as brake systems.

High machinability
6026 by EURAL is particularly suitable for being machined on high speed automatic lathes due to **extremely good chip forming.**

No tin
On many alloys of 6000 series lead (Pb) has been replaced with tin (Sn) which, as it has been proved, causes weakness and cracking of the machined parts when submitted to stress and high temperature (>140°C, 284°F).
Due to its brittle nature, tin has the dangerous tendency to sudden brakes without significant previous deformation (strain).
6026 by EURAL does not contain tin.

Ultrasonic tested billets
All semi-finished products in 6026 by EURAL are made of 100% ultrasonic tested billets according to **SAE AMS-STD-2154 class A.**

Production program
6026 by EURAL is available in drawn or extruded conditions.
Drawn round bars from 7,94 to 76,2 mm (0,236"-3"), temper T6, T8 or T9.
Extruded round bars from 30 to 254 mm (1,181"-10"), temper T6.
Square, rectangular, hexagonal bars are available.
A wide range of drawn bars are also available in h9 tolerance.

Alternative to:
6026 by EURAL is the best alternative to several aluminium alloys such as 2007, 2011, 2015, 2028, 2030, 2044, 6012, 6012A, 6020, 6021, 6023, 6028, 6033, 6040, 6041, 6042, 6061, 6065, 6082, 6262, 6064A, 6262A, 6351, 7020.
6026 by EURAL is an excellent replacement of brass, due to its good machinability, good attitude to forging, medium-high mechanical properties. Moreover, since 6026 by EURAL has a specific gravity of 1/3 compared to brass, it results extremely convenient costwise.

Compatibility in drawings
6026 by EURAL was born on 2002, and it has been registered to the Aluminum Association and to EN standards with a lead content of Pb ≤ 0,40.
6026 by EURAL lead free therefore does not need any variations in drawings where 6026 is already indicated.

Figure A - 34-3: Technical Laboratory Report of EURAL GNUTTE SpA. on the Manufacture of Brake Pistons

	EURAL GNUTTI SpA. Rovato	M 1203.03	Rev. 00	Pag. 1 di 6
			16/02/96	N° 3009

TECHNICAL LABORATORY REPORT / RAPPORTO TECNICO DI LABORATORIO

CUSTOMER/ CLIENTE: **Eural Gnutti Spa**	Report No / Rapporto n° **3009**
	Date/In data: 14/01/2015

Subject: Brake pistons made of drawn round bars Ø23 mm completely machined, in alloy 6026 lead free T9 belonging to batch 1510150027 (confirm 487127/01 cast 1536H15) and anodized. Two samples have been identified by #1 and #2	**Oggetto:** Pistoncini per freni realizzati mediante lavorazione meccanica di barre tonde Ø23 mm, trafilate in lega 6026 senza piombo T9, appartenenti al lotto di produzione 1510150027 (conferma 487127/01, colata 1536H15), e anodizzati. Due campioni sono stati identificati con i n°1 e n°2
Kind of analysis required by customer: Check the pistons made of 6026 lead free	**Tipo di analisi richieste dal cliente:** Verifica pistoncini prodotti con 6026 senza piombo

CONCLUSIONS: The analyzed samples have been made of bars in subject. The visual inspection, chemical composition test, hardness test and macrographical test did not emphasize anomalies. The micrographical test performed on the samples emphasizes that: • The samples have oxide layer with thickness between 13 and 18 µm • The samples have a good distribution of the low-melting element type Bi • Oxide microhardness test emphasizes values between 424 and 435 HV	**CONCLUSIONI:** I campioni analizzati sono stati ricavati da barre in oggetto. Al controllo visivo, della composizione chimica, della durezza e al controllo macrografico non sono state riscontrate anomalie. Al controllo micrografico eseguito sui campioni è stato riscontrato che: • i campioni hanno spessore dell'ossido con valori compresi tra 13 e 18 µm • i campioni hanno una buona distribuzione dell'elemento bassofondente tipo Bi • Al controllo della microdurezza dell'ossido sono stati riscontrati valori compresi tra 424 e 435 HV.

Made/Compilato		Date/Data	15/02/2016
Verified/Verificato		Date/Data	15/02/2016
Approved/Approvato		Date/Data	15/02/2016

SURFACE APPEARANCE (see following	ASPETTO SUPERFICIALE (vedi fotografie):
Brake pistons made of machining and anodizing of bars	Pistoncini per freni ottenuti mediante lavorazione meccanica ed anodizzazione di barre

DIMENSIONS mm (see pictures) /DIMENSIONI mm (vedi fotografie):

Required/ Richiesto: 23 +0/-0.13

Found/Riscontrato:

1) 22.16÷22.17

2) 22.16÷22.17

CHEMICAL ANALYSIS /ANALISI CHIMICA %:

Sample No n°camp.		Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Ni	Pb	Bi	Sn
Required Richiesto	min	0.600		0.200	0.200	0.600						0.500	
	Max	1.400	0.700	0.500	1.000	1.200	0.300	0.200	0.300		0.400	1.500	0.050
1		0977	0.588	0.409	0.660	0.789	0.071	0.020	0.073		0.015	1.221	0.001
2		0.981	0.593	0.413	0.660	0.794	0.070	0.020	0.073		0.015	1.297	0.001

MECHANICAL PROPERTIES / CARATTERISTICHE MECCANICHE:

Sample No n° camp.	Rm MPa	$Rp_{0.2}$ MPa	A	Rec.	Striction Strizione	Hardness Durezza	Position of hardness measurement Schema di rilievo della durezza
1						116	
2						116	

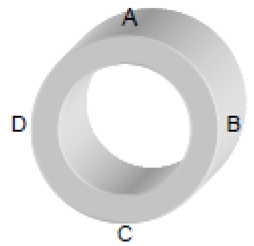
Macrographs (see following pictures) / **Macrografie (vedi fotografie)**

Etching: NaOH 20% solution at 50°C x 60 sec. / **Attacco NaOH 20% a 50°C per 60 secondi:**

1,2) No defect. Structure with fine and homogeneous grain

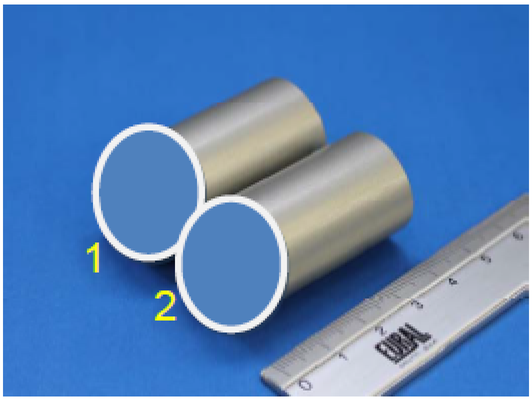
1,2) Nessun difetto. Struttura a grano fine ed omogeneo

Microhardness oxyde / Mirodurezza ossido (HV)				
Sample/ campione	Zone/ Zona			
	A	B	C	D
1	424	435	435	435
2	435	435	435	424



Made/Compilato	[signature]	Date/Data	15/02/2016
Verified/Verificato	[signature]	Date/Data	15/02/2016

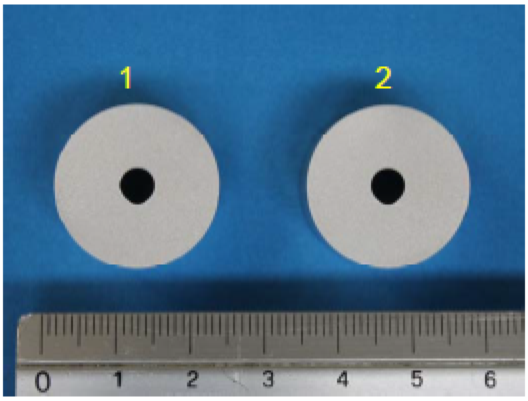
PICTURES OF SAMPLE AS DELIVERED BY THE CUSTOMER
FOTOGRAFIE DEL CAMPIONE COME CONSEGNATOCI DAL CLIENTE



Samples #1 and #2 as delivered by the customer

Campioni n°1 e n°2 come consegnatici dal cliente.

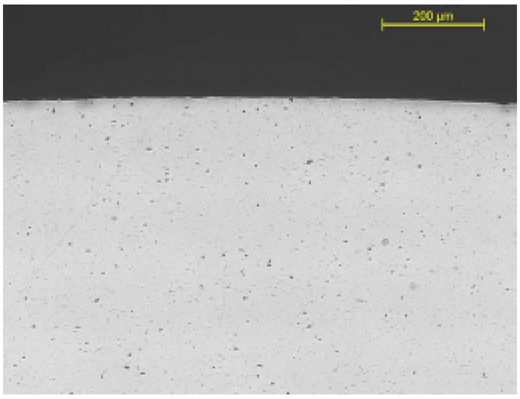
MACROGRAPHICAL PICTURES MADE ON THE SAMPLES
MACROGRAFIE ESEGUITE SUI CAMPIONI

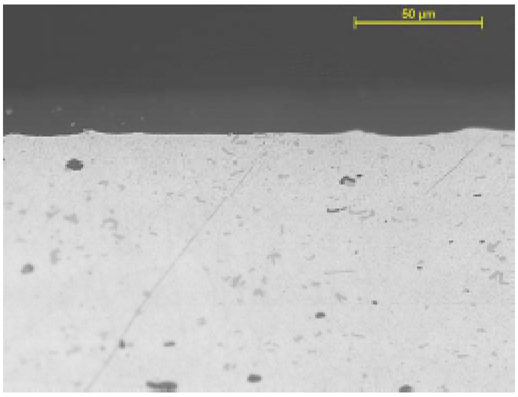


Macrograph:	Macrografia:
Etching: NaOH 20%a 50°C per 60 sec.	Attacco: NaOH 20% a 50°C per 60 sec
Transversal section	Sezione trasversale

Made/Compilato	[signature]	Date/Data	15/02/2016
Verified/Verificato	[signature]	Date/Data	15/02/2016

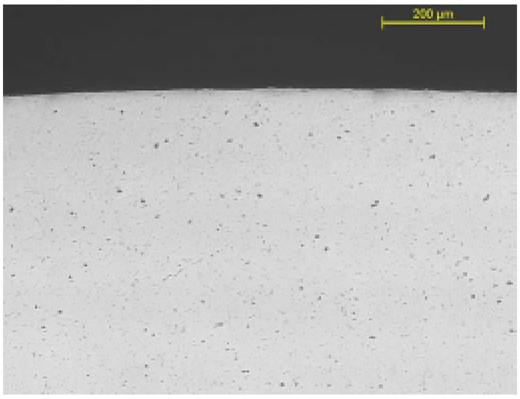
MICROGRAPHICAL PICTURES PERFORMED ON SAMPLE No 1
MICROGRAFIE ESEGUITE SUL CAMPIONE N°1

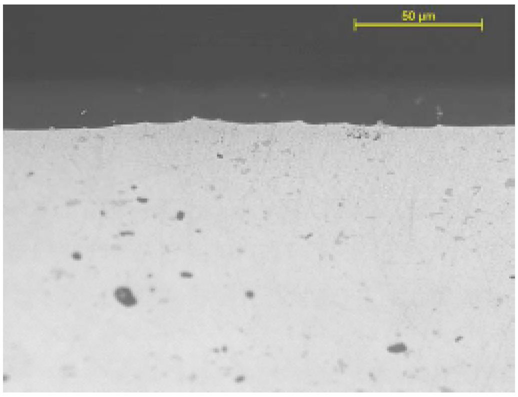




Micrograph X100	Micrografia X100	Micrograph X500	Micrografia X500
Etching: Not etched	Attacco: Non attaccato	Etching: Not etched	Attacco: Non attaccato
Transversal section	Sezione trasversale.	Transversal section	Sezione trasversale.
		Oxide layer: 15÷18 µm	Spessore dell'ossido: 15÷18µm

MICROGRAPHICAL PICTURES PERFORMED ON SAMPLE No 2
MICROGRAFIE ESEGUITE SUL CAMPIONE N°2

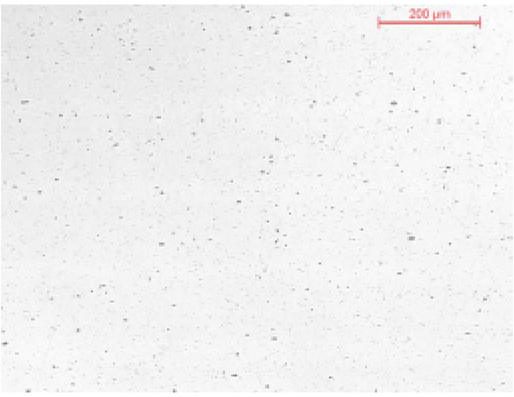


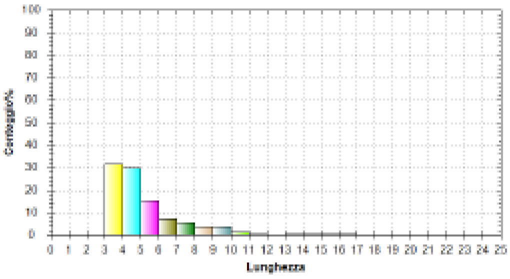


Micrograph X100	Micrografia X100	Micrograph X500	Micrografia X500
Etching: Not etched	Attacco: Non attaccato	Etching: Not etched	Attacco: Non attaccato
Transversal section	Sezione trasversale.	Transversal section	Sezione trasversale.
		Oxide layer: 13÷18 µm	Spessore dell'ossido: 13÷18µm

Made/Compilato	[signature]	Date/Data	15/02/2016
Verified/Verificato	[signature]	Date/Data	15/02/2016

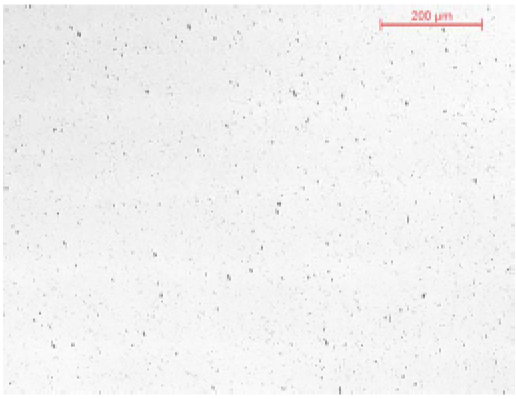
MICROGRAPHICAL PICTURES PERFORMED ON SAMPLE No 1
MICROGRAFIE ESEGUITE SUL CAMPIONE N°1

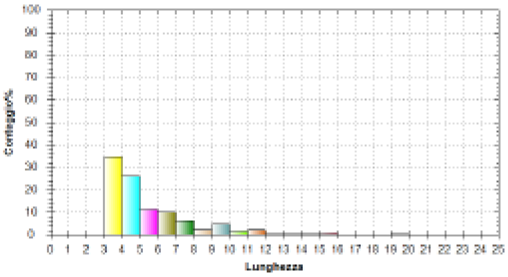




Micrograph X100.	Micrografia X100.	Length Bi µm/ Lunghezza Bi µm		
Etching: Not etched.	Attacco: Non attaccato.		Mean	5.200
Transversal section	Sezione trasversale		Min	3.299
Cortical zone	Zona corticale		Max	16.496

MICROGRAPHICAL PICTURES PERFORMED ON SAMPLE No 2
MICROGRAFIE ESEGUITE SUL CAMPIONE N°2

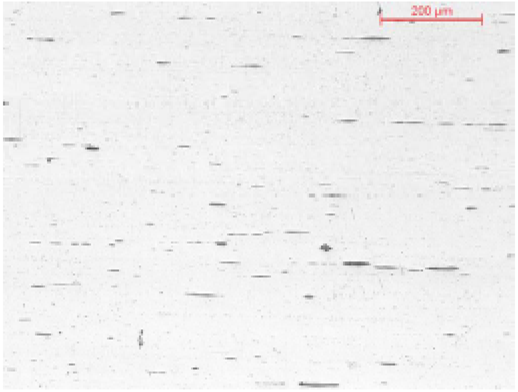


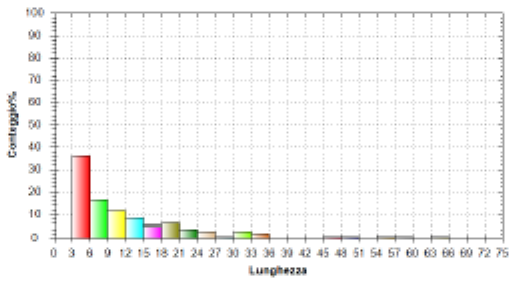


Micrograph X100.	Micrografia X100.	Length Bi µm/ Lunghezza Bi µm		
Etching: Not etched.	Attacco: Non attaccato.		Mean	5.333
Transversal section	Sezione trasversale		Min	3.299
Cortical zone	Zona corticale		Max	19.795

Made/Compilato	[signature]	Date/Data	15/02/2016
Verified/Verificato	[signature]	Date/Data	15/02/2016

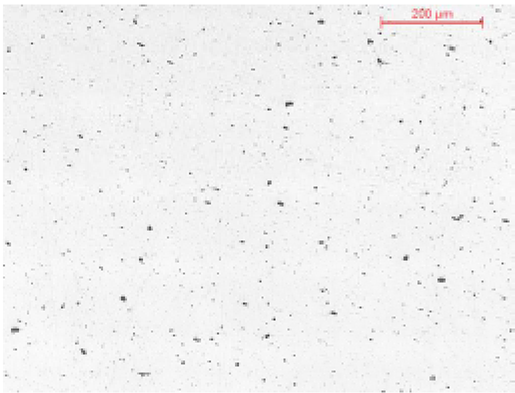
MICROGRAPHICAL PICTURES PERFORMED ON SAMPLE No 1
MICROGRAFIE ESEGUITE SUL CAMPIONE N°1





Micrograph X100.	Micrografia X100.	Length Bl µm/ Lunghezza Bl µm		
Etching: Not etched.	Attacco: Non attaccato.		Mean	12.188
Longitudinal section	Sezione longitudinale		Min	3.299
Cortical zone	Zona corticale		Max	65.158

MICROGRAPHICAL PICTURES PERFORMED ON TRANSVERSAL SECTION OF SAMPLE #1
MICROGRAFIE ESEGUITE SULLA SEZIONE TRASVERSALE DEL CAMPIONE N°1



Micrograph X100.	Micrografia X100.
Etching: n°1 per 10 sec.	Attacco: n°1 per 10 sec.
Cortical zone	Zona corticale

Made/Compilato	[signature]	Date/Data	15/02/2016
Verified/Verificato	[signature]	Date/Data	15/02/2016

A.5.0 Appendix 5: Exemption 7(a)

A.5.1 DA5 Research for Alternatives to LHMPS Die Attach

All information provided in this chapter is taken from the exemption request of Freescale/NXP et al.[1960] The numbering of the figures starts with "Chart2" like in the original document.

"Looking specifically at high-lead solder for attaching die to semiconductor packages, in 2Q 2010, Bosch (Division Automotive Electronics), Freescale Semiconductor, Infineon Technologies, NXP Semiconductors and STMicroelectronics formed a consortium to jointly investigate and standardize the acceptance of alternatives for high-lead solder during manufacturing. The five company consortium is known as the DA5 (Die Attach 5), and is actively supporting the demands of the European Union towards reduced lead in electronics.

Evaluations of different materials have been performed within the DA5 consortium together with several material suppliers specific to the die-attach application. This includes four main classes of materials:

- High Thermal Conductive Adhesives,
- Silver-sintering materials,
- TLPS (Transient Liquid Phase Sintering) materials, and
- Alternative solders.

At present, no material has been identified that fulfils the required properties of a replacement material. The slide images below provide a summary of results for the different material classes.

[1960] Op. cit. Freescale Semiconductors/NXP et al. 2015a

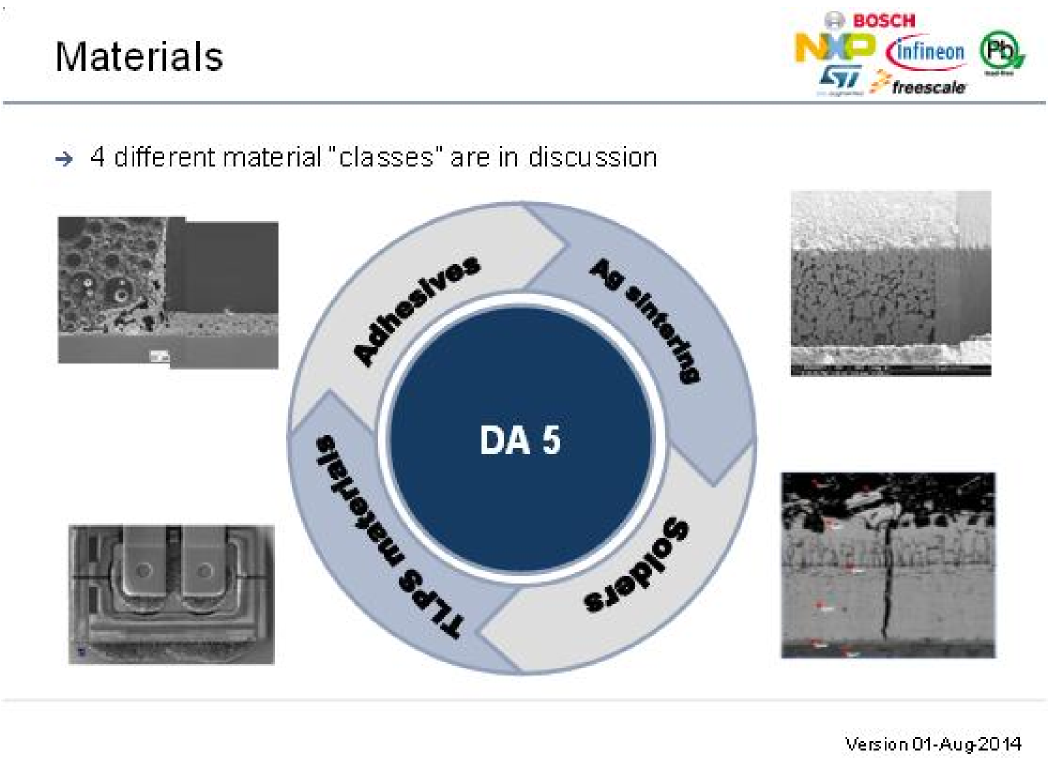


Chart 2: Potential alternative materials

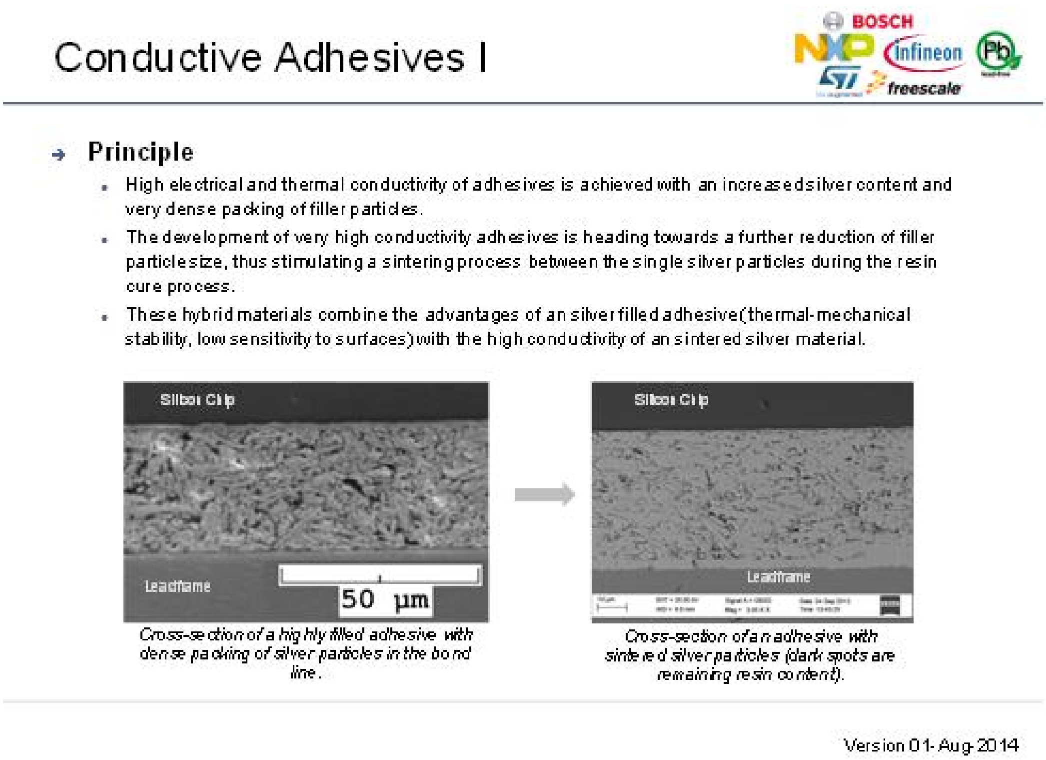
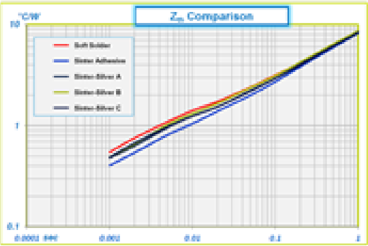


Chart 3: High Thermal Conductive Adhesives I

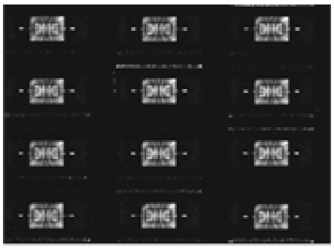
Conductive Adhesives II

Advantages

- Good adhesion to different types of chip backside and leadframe plating.
- Good thermal and electrical performance.
- Common production methods and equipment can be used for the application of the material and placement of the chip.
- Curing in box ovens under usual conditions in air or Nitrogen atmosphere.
- Pass automotive environment stress test conditions.



Comparison of transient thermal resistance of highly silver filled adhesive vs. high-lead soft solder and sintered silver materials.



Scanning acoustic microscopy shows no delamination of die attach after 2000cycles TC -50°C / +150°C.

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Chart 4: High Thermal Conductive Adhesives II

Conductive Adhesives III

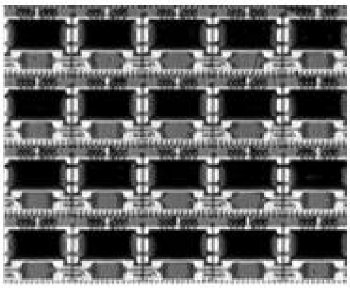
Limitations

- Adhesive can contain solvents to improve rheology. This requires more careful handling and control of the manufacturing process. It also bears a risk of leadframe and die surface contamination.
- Material cost is higher compared to standard adhesives and solder.
- Application is limited to low and medium power devices and packages with moisture sensitivity level of MSL3/260°C.

Visible solvent bleed out

Dispense Patterns

No solvent bleed out



Scanning acoustic microscopy shows delamination of large power transistor die attach after 1000cycles TC -50°C / +150°C

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Chart 5: High Thermal Conductive Adhesives III

In general, high thermal conductive adhesives have some favourable properties that may be acceptable for many applications within industry. Adhesives can be a solution for packages which don't need to be exposed to the higher soldering temperature (~400°C soldering temperature versus ~150°C glue curing temperature). E.g. Ball Grid Array (BGA) packages with organic substrates use adhesives for die attach. Adhesives are the typical solution for very thin lead frames (~200µm) due to unacceptable lead frame bending after a high temperature soldering process. In general adhesives have a bigger process window as compared to solder and can be used also for non-metalized chip backsides.

Nevertheless adhesives have severe limitations, especially in terms of performance, that justify the continued use of HMP lead (Pb) solders.

An overview in terms of key performance indicators of high performance adhesives in comparison with HMP lead (Pb) solder shows a significant gap that is still present with solutions available today. Especially for power devices there are major restrictions for the usage of adhesives. The bulk electrical and thermal conductivity of an adhesive is much smaller (<1*10^6 S/m and max. 25W/mK) as compared to a HMP lead (Pb) solder (~5*10^6 S/m and ~50W/mK). This keeps products that are covered with HMP lead (Pb) solder today from converting to conductive adhesives.

- Existing adhesives can only be used for chip thickness >120µm due to glue creepage on the side walls of the chips. Due to performance reasons, new chip technologies tend to go for 60µm or even thinner thickness è HMP lead (Pb) solder required
- Also the chip size for adhesive is limited to ~30 mm^2. This is due to the shrinkage of the glue during curing and thermo-mechanical instability. Mechanical strength is lower compared to HMP lead (Pb) solder (reliability issue).
- Another issue is the worse humidity behaviour of glue during reliability. Moisture uptake of adhesives can lead to moisture-induced failure during reflow soldering (MSL).
- Adhesives can't be used for products with a high junction temperature (>175°C). At such high temperatures the organic components of the glue tend to degrade.
- Conductive adhesives are based on an Ag/organic matrix. Ag tends to migrate under voltage and humidity. Higher power density increases the risk of electro migration.

As of mid 2014, the DA5 are not aware of any solution (glue or other materials) that can replace HMP lead (Pb) solder at the moment. The limitations of adhesives are detailed above. HMP solders and adhesives belong to completely different material classes and perform very differently.

The electronics industry naturally works toward eliminating HMP high-lead (Pb) solder because alternatives (e.g. conductive adhesive) are typically easier to manufacture; the HMP lead (Pb) solders are only used when no other options are available that enable the required product reliability and functionality.

The necessary uses for the exemption are outlined within Table 2, above. These applications require HMP lead (Pb) solder to reduce stress, to maintain reliability when subsequent temperatures after initial application exceed 250°C to 260°C, to achieve special electrical or thermal characteristics during operation due to electrical or heat conductivity, or to achieve reliability in temperature and power cycles.

Pb free adhesive alternatives that are available on the market today are not feasible for the types of products and applications where HMP solders are used.

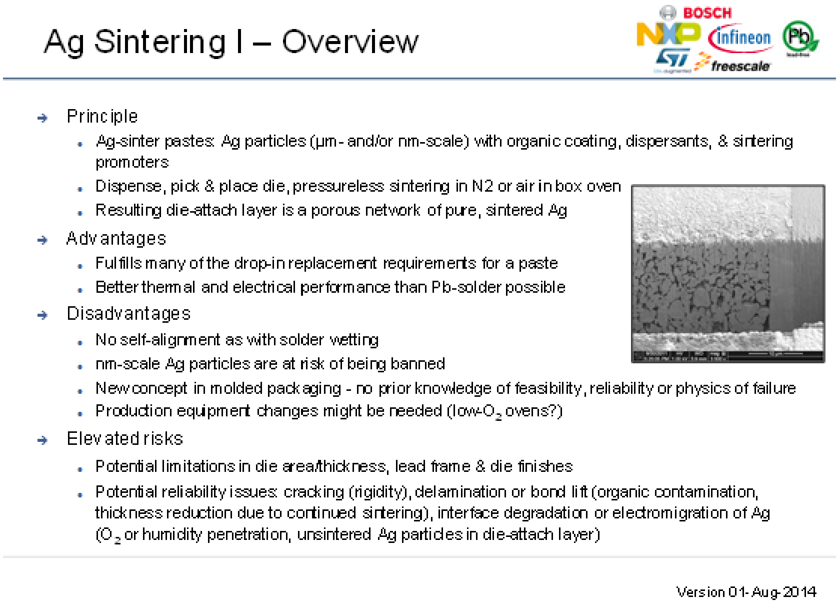

Chart 6: Silver Sintering I – Overview

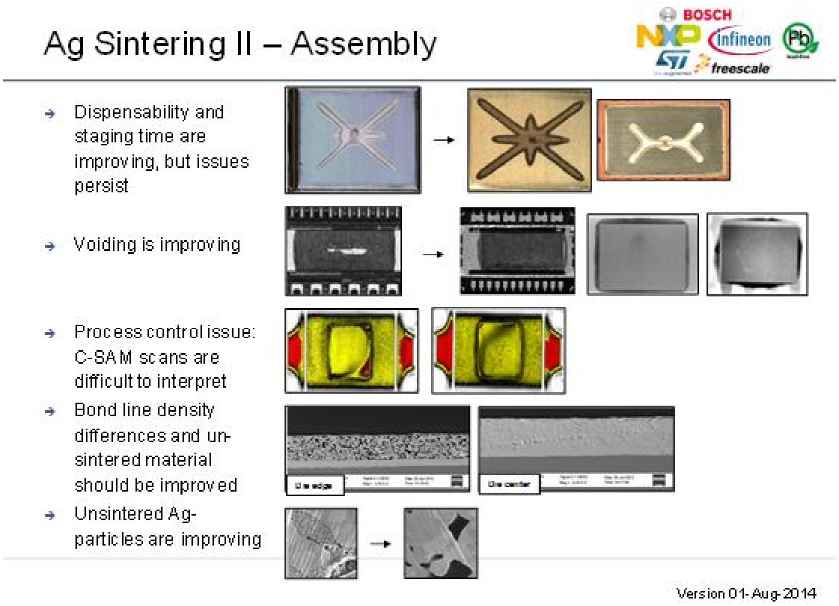

Chart 7: Silver Sintering II – Assembly

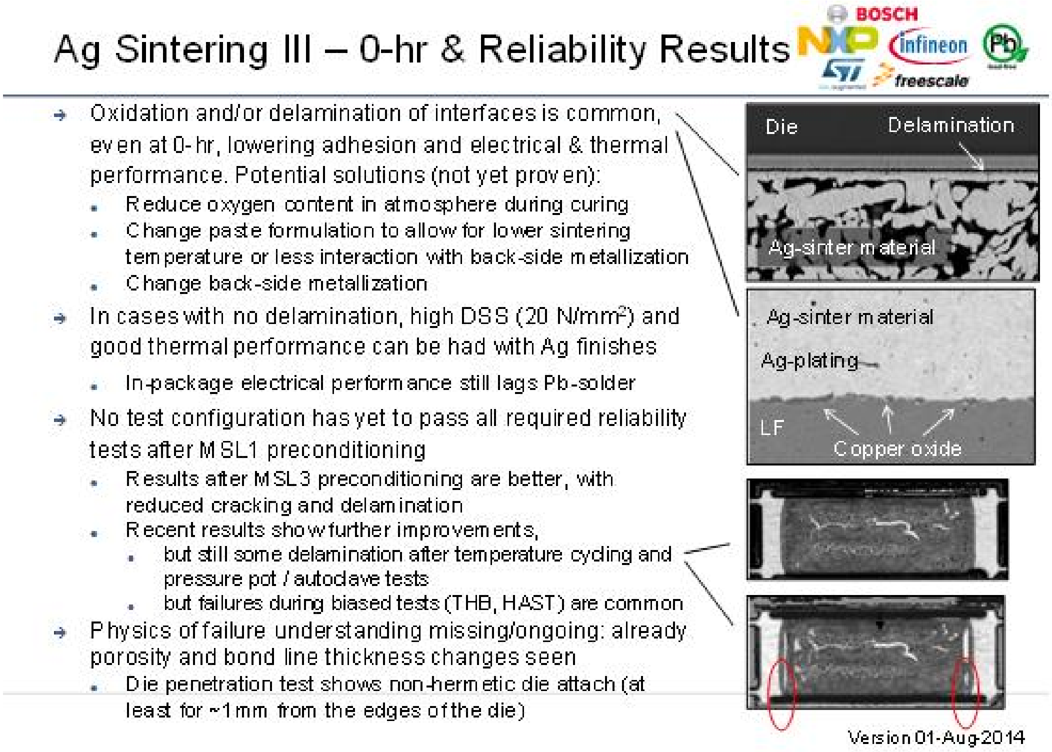

Chart 8: Silver Sintering III – 0-hr & Reliability Results

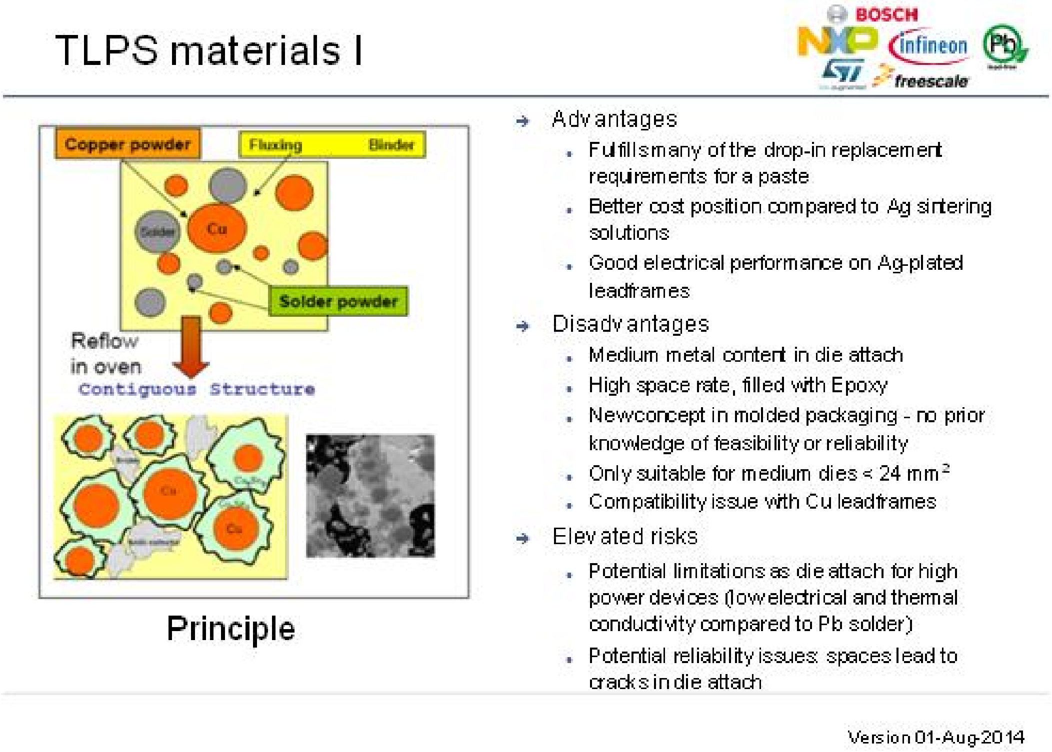

Chart 9: TLPS Materials I

TLPS material II

- The hybrid material showed a very high space rate. The spaces are filled with epoxy material
- The reflow process is very critical and has to be further optimized, the reflow profile seems to be product specific
- Reliability results are contradictory. Results are package/leadframe material dependant. A low space rate is mandatory to survive reliability
- Shear values at 260°C are low, barely above the minimum needed value (5N/mm²)
- Strong brittle intermetallic phase growth with Cu

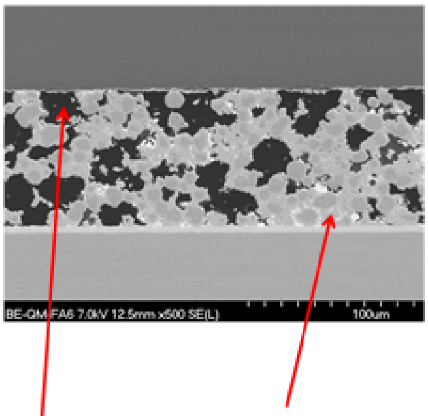

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Chart 10: TLPS Materials II

Alternative Solders I

Properties to be considered

- Robust manufacturing process
  - Repeatable solder application
  - Stable wetting angle
  - Surface compatibility (chip backside, lf finish)
- Reliability
  - Voiding / cracking / disruption after stress
  - Growth of brittle intermetallics at high temperature
  - Disruption during temperature cycling

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Chart 11: Alternative Solders I

Alternative Solders II

- Zn-based Alloys
  - Improved workability demonstrated
  - New formulations demonstrate lower mechanical stress and reduced die cracking, still further improvement required
  - Limited experience on reliability
  - Risk of Zn re-deposition can only be falsified in high-volume manufacturing
  - Material currently only available in wire form
- Bi-based Alloys
  - Low thermal conductivity & low melting point
  - Performance minor to high lead solder
- SnSb-based Alloys
  - Low melting point (new formulations show possible increase)
  - Workability challenging (increased voiding)
  - Limited surface compatibility (chip backside, leadframe finish)
  - Limited experience on reliability
  - Material currently only available in paste form

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Chart 12: Alternative Solders II

DA5 Conclusion on Alternative Solders: Although we find no mass market alternatives to HMP lead (Pb) solder, there are a few candidate materials in initial production as part of the long term manufacturability development efforts.

The DA5 customer presentation listed two potential alternative candidate materials based solely upon melting temperature evaluations in Chart 17 (below): Sn25Ag10Sb and Au20Sn. Considering only the brittleness and melting temperature, these alternative solders might be technically feasible – but only for very small die size when constraining die thickness, package geometry and surface materials.

KPI for Alternatives to HMP lead (Pb) Solders: As seen in the preceding charts, the DA5 evaluated the likely alternatives to HMP lead (Pb) solder against the required capabilities. The DA5 documented the suppliers and technical details for various alternatives within each alternative material category. The material suppliers prevent disclosure of this information due to their NDA with each DA5 company. The comparative strengths and weaknesses of the best tested material in each class are show in the following Key Performance Indicator charts.

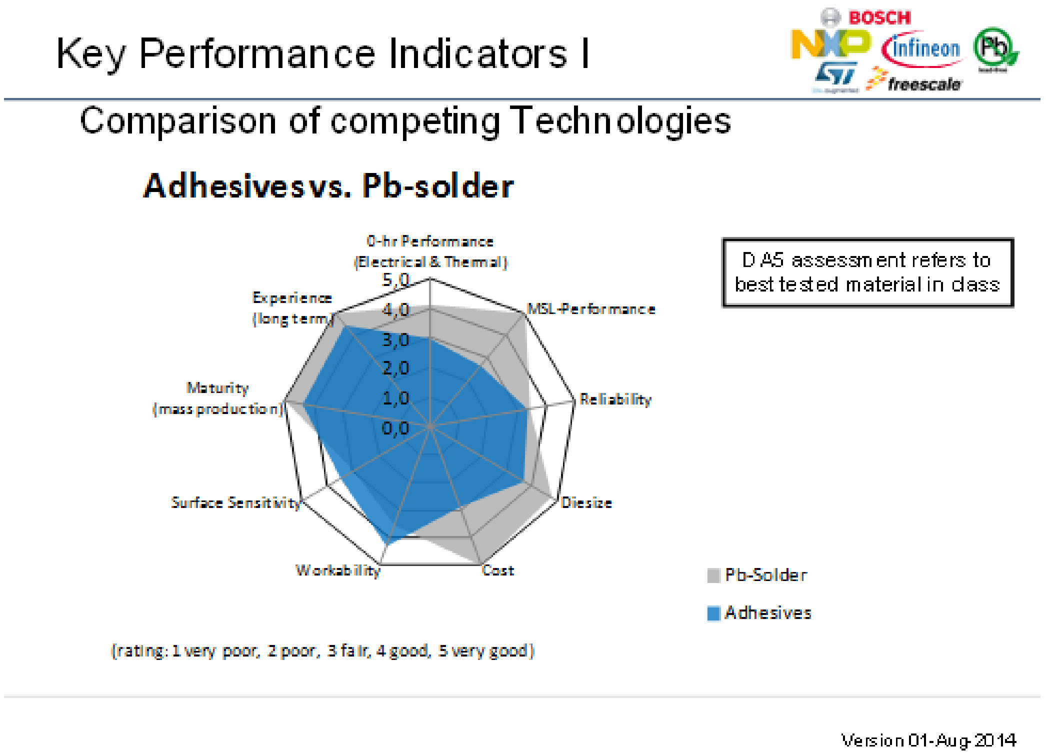


Chart 13: KPI-1 for Adhesives vs. Pb-solder

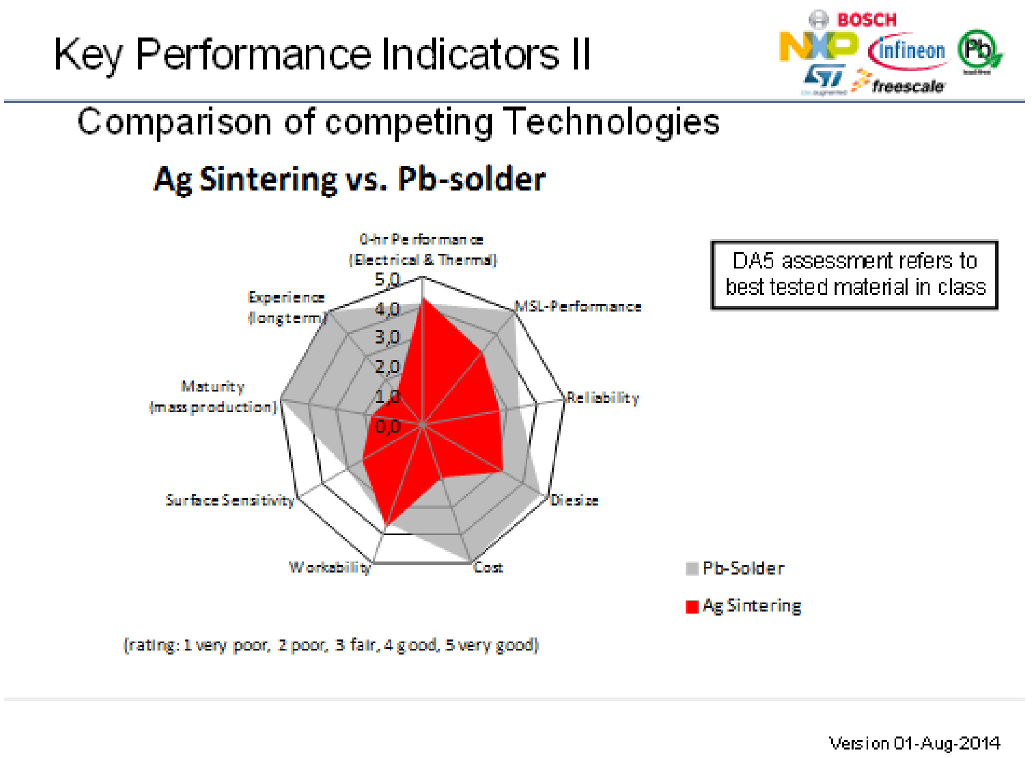


Chart 14: KPI-2 for Silver Sintering vs. Pb-solder

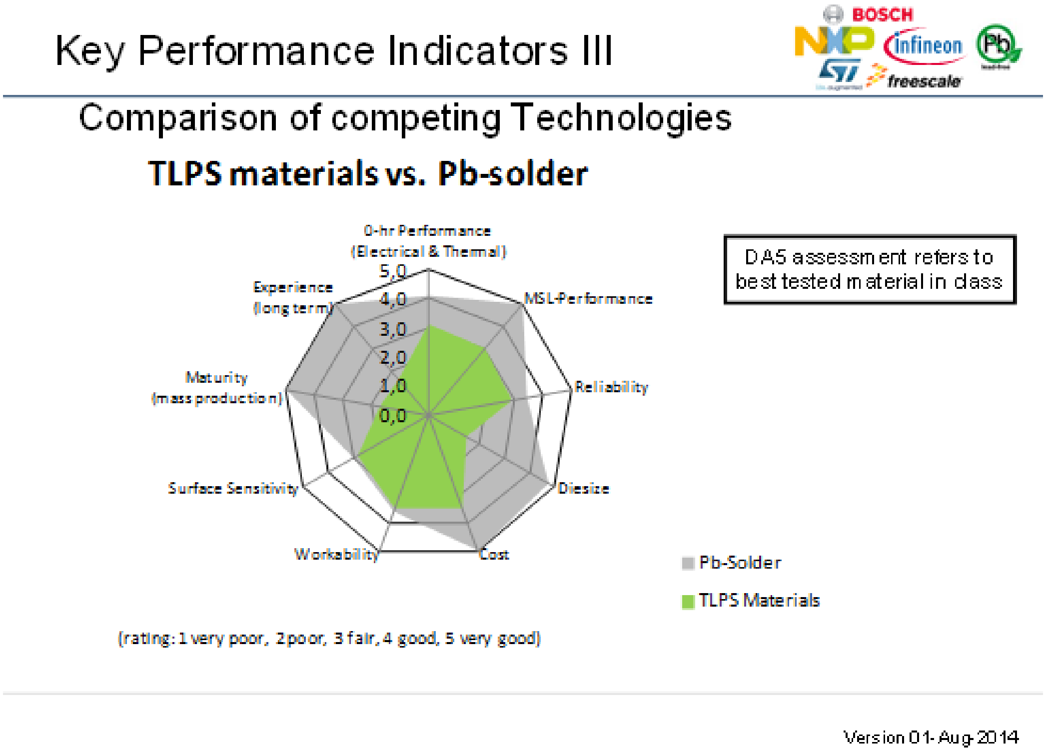


Chart 15: KPI-3 for Transient Liquid Phase Sintering (TLPS) vs. Pb-solder

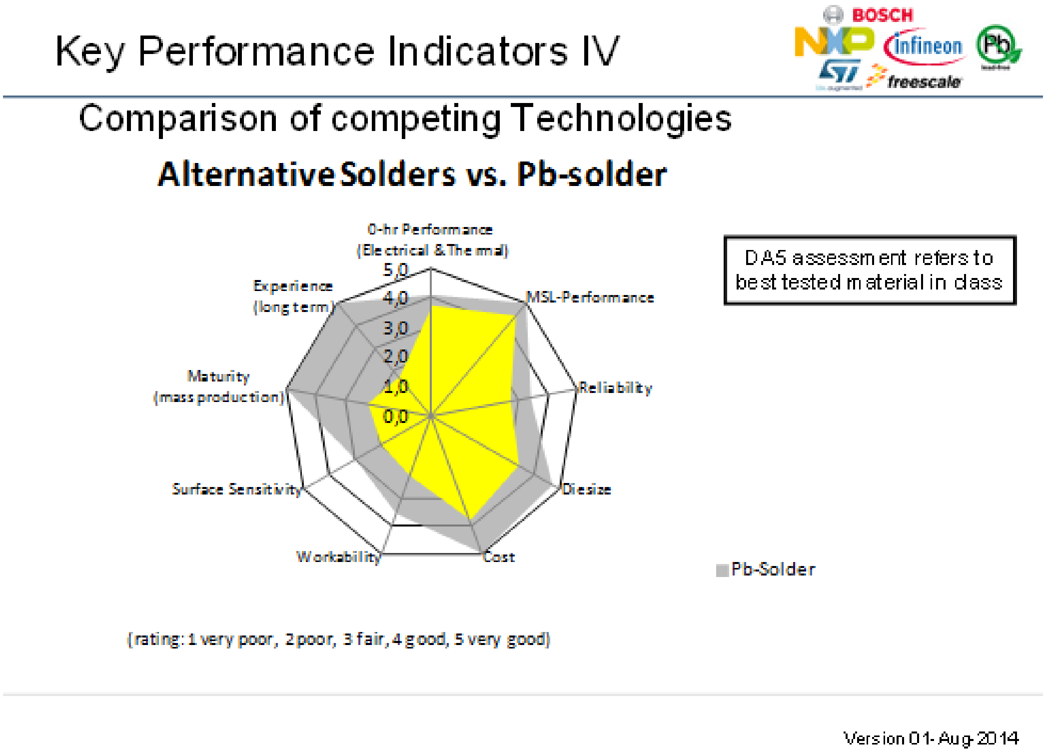


Chart 16: KPI-4 for Alternative Solders vs. Pb-solder

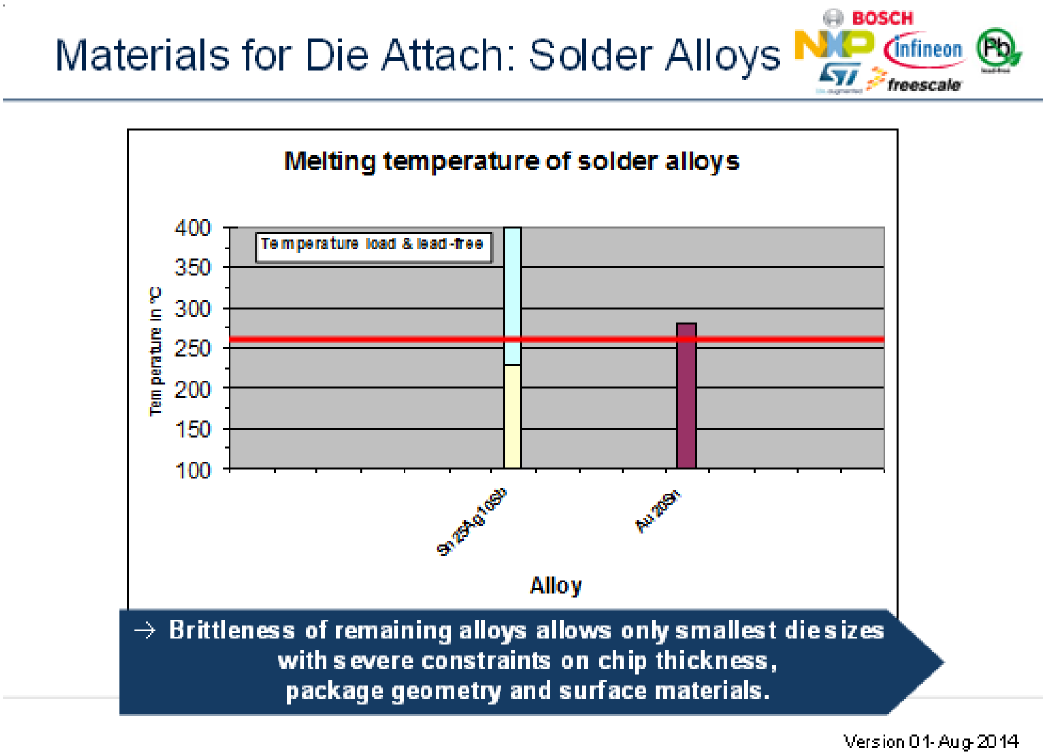


Chart 17: Melting Temperature of Solder Alloys

As noted in Chart 17, DA5 experience has shown that die size and melting temperatures are not the only requirements for alternative Pb-free solders. Additional design restrictions on chip thickness, package geometry and surfaces have to be carefully optimized to make such materials work at all. Optimization is difficult due to unfavorable mechanical properties of the die attach materials, like brittleness. Conversion would only be possible for new semiconductor products:

(1) that are specifically designed for these materials,

(2) where manufacturing processes and equipment have been designed and developed to support the change, and

(3) where the application can accept the material related limitations (e.g. design, functionality, reliability and/or manufacturability).

The resulting new semiconductor design will not be compatible with all customer applications.

In summary, the DA5 evaluation of alternatives to HMP lead (Pb) solder die attach materials determined that no current alternative solder materials can maintain product system performance and pass all qualification tests.

DA5 Note and Conclusion about Conductive Die Attach Films (CDAF): This alternative has not been mentioned in the DA5 evaluations above as an alternative for HMP lead (Pb) solder in die attach, although it is used as a die attach material in some products. Conductive Die Attach Films (CDAF, conductive glue prepared as a tape) are used to replace conductive glue but not to replace HMP lead (Pb) solder.

These conductive tapes are mainly used where clearance between die dimensions and die pad is very small and glue cannot be used due to bleeding which causes some glue constituents to start to migrate on the leadframe. Today, conductive tape is a potential improvement for products that use standard conductive glues. It cannot replace HMP lead (Pb) solder.

The thermal and electrical performance of available tapes is not comparable with HMP lead (Pb) solder. High power devices, particularly the so called "vertical current" devices where significant current flow is driven through the die attach material, would not work with conductive tape. The tape is too resistive and the maximum current that can pass through the tape is much lower than the current capability of HMP lead (Pb) solder.

So for the products which use HMP lead (Pb) solder today, a further exemption is still required. The DA5 evaluations have determined that no feasible alternative is available in the market."

DA5 References:

Latest DA5 Customer Presentation:

http://www.infineon.com/dgdl/DA5_customer_presentation_200813.pdf?folderId=db3a30433162923a013176306140071a&fileId=db3a30433fa9412f013fbd2aed4779a2

DA5 Material Requirement Specification can be provided on request:

Speaker of the DA5 consortium:

Bodo Eilken

Infineon Technologies AG

A.5.2 Efforts of International Rectifier (IR) for LHMPS Substitution

All information in this chapter was taken from Freescale/NXP et al.[1961]

International Rectifier Corporation (IR®) is a world leader in power management technology. Leading manufacturers of computers, energy efficient appliances, lighting, automobiles, satellites, aircraft and defense systems rely on IR's power management

[1961] Ibid.

benchmarks to power their next-generation products. Products range from discrete MOSFETs and IGBTs and high-performance analog, digital and mixed-signal ICs to integrated power systems, IR's innovative technologies.

IR has evaluated numerous suppliers and alternative Pb free high melting point materials to replace HMP lead (Pb) solder. This documentation recently became available to the industry organizations submitting this exemption extension proposal and provides more evidence of difficulties in identifying and qualifying alternative materials to replace HMP lead (Pb) solder. This includes the following Pb-free solders:

SnSb solders: The solidus temperature of SnSb is 235°C and the liquidus is 240°C which is still too low to stop the solder from completely melting during a customer's 260°C reflow process. We did look at solder variants that include SnSb such as J-alloy (SnAg25Sb10) that still have a solidus BELOW 260°C but a liquidus ABOVE 260°C which meant that they would be pastey or partially melted during a customer reflow. This was not successful as the resultant board attach process window was not large enough to allow customers to reliably board mount the components without seeing degradation of the die attach joint internal to the package. IR frequently saw 'solder squirt' with the die attach solder being forced out of the package during board attach.

BiAg solder: Processability and application is limited as it does not form good intermetallics with Cu or Ni. Additionally any intermetallics formed are brittle and weak resulting in reliability fails. The electrical and thermal performance of the BiAg solder is worse than that of the existing solder options containing Pb. The electrical resistivity is 4.5X worse and the thermal performance is 4X worse. On very low rds(on) MOSFETs this can greatly reduce the current rating of a given part resulting in customers having to go for much larger solutions. There are BiAg solders currently being evaluated in the industry which include additives to improve wetting; however, these additives need to remain separate from the BiAg alloy prior to melting, which means that it is only available in a solder paste form. It would not be possible to use on packages that require solder wire or preforms for die attach. The combination of poor electrical and thermal performance and the solder-paste 'only' option means that these newer BiAg versions could be used on is limited and very niche products. The materials are still under investigation at this time.

AuSn solder: This has been around for quite some time in the industry but with limited use. The alloy is over 4X harder than Pb solders which results in a lot more stress being transferred to the die. The hardness causes die cracking problems on larger die sizes and has meant that the application of this material for die attach has been limited to die sizes smaller than many power semiconductors.

At present, no identified Pb-free materials pass reliability tests, especially moisture sensitivity preconditioning. See the detailed analysis slides below.

Introduction

IR

- International Rectifier has been evaluating replacement materials for high lead die attach solder for over five years
- Our internal packaging R&D teams and our Operations teams have worked in collaboration with material vendors and our assembly subcontractors to evaluate all viable options
- We are all working based on an RoHS directive that currently would see an exemption for high Pb die attach solders dropped in June 2016
- Replacement material candidates are evaluated with respect to:
  - Performance
  - Cost
  - Reliability
  - CapEx requirements

Solder	Solidus / Liquidus temp	Thermal conductivity	Electrical resistivity (uOhm.m)	Elastic Modulus
Pb5Sn	308'C/312'C	35W/m'K	0.19	9GPa

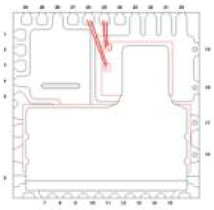
IR International Rectifier 2

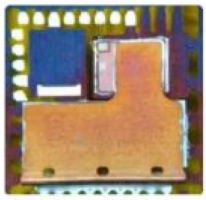
Slide 1: Pb Free Evaluation Introduction

Project Test Vehicle

IR

- **Test vehicle is IR3550MPBF**
  - 6x6 PQFN
  - Includes 2 FETs (Q1 and Q2) and 1 IC (U1)
  - Q1 mounted face up on leadframe, Q2 mounted face down
  - Cu clip connects source of Q1 to drain of Q2
  - Exclude IC from test parts as simplifies test process
- **Reliability Test**
  - MSL3
  - AC 121°C, 100%RH, 96hrs
  - TC -55°C to +150°C, 1000cyc
  - IOL 100°C ΔT_j, 12,000cyc
    - with RDSon shift data gathering





IR International Rectifier 3

Slide 2: IR Project Test Vehicle

Partial Melt Solders

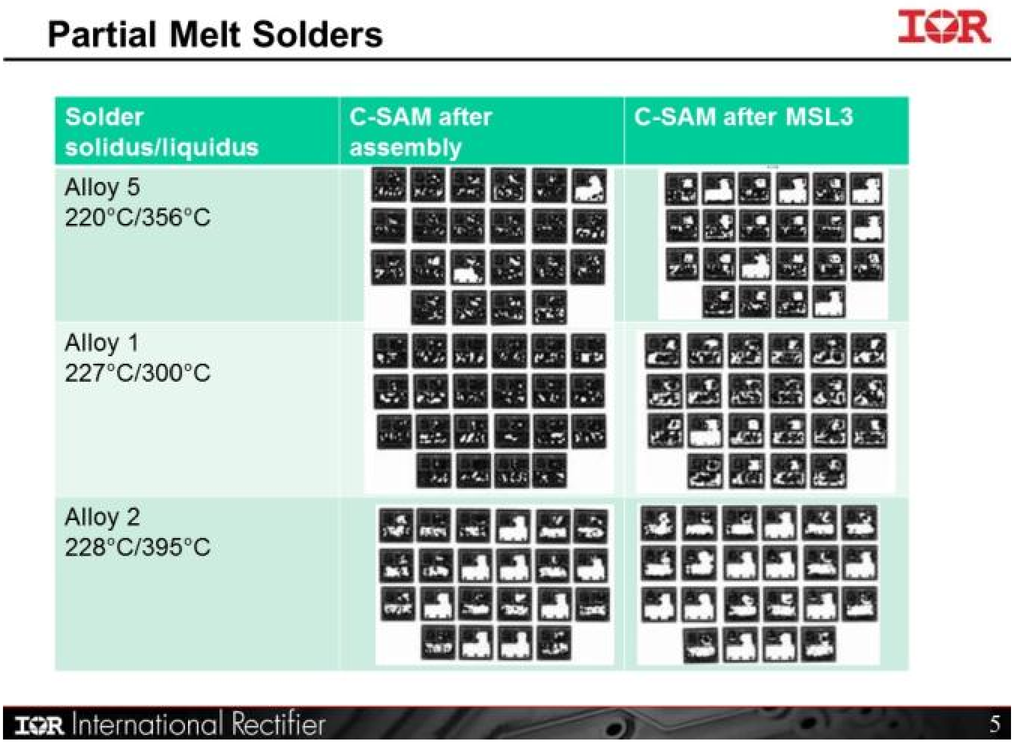
- **5 new Pb free solder materials evaluated**
  - Evaluate performance of high liquidus temp solder vs. MSL @ 260°C
  - All materials have solidus less than 260°C
  - Electrical and thermal performance similar to Hi Pb solder

Solder	Solidus / Liquidus temp	Thermal conductivity	Electrical resistivity (uOhm.m)	Elastic Modulus
Pb5Sn	308°C/312°C	35W/m°K	0.19	9GPa
Alloy 1	227°C/300°C	65W/m°K	0.12	47GPa
Alloy 2	228°C/395°C	55W/m°K	0.15	25GPa
Alloy 3	217°C/353°C	55W/m°K	0.13	48GPa
Alloy 4	222°C/384°C	50-55W/mK	0.135	46-50Gpa
Alloy 5	220°C/356°C	50-55W/mK	0.135	46-50Gpa

- Samples assembled using all material options
  - Process optimisation required due to increased solder voids and insufficient solder coverage
  - Test yields all good with Rds(on) in line with existing product
- Samples submitted to reliability testing including MSL3 preconditioning

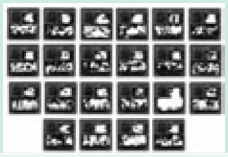
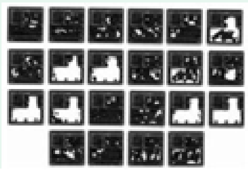
IOR International Rectifier 4

Slide 3: Partial Melt Solders (1)

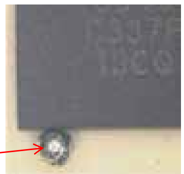


Slide 4: Partial Melt Solders (2)

Partial Melt Solders

Solder solidus/liquidus	C-SAM after assembly	C-SAM after MSL3
Alloy 4 222°C/384°C		
Alloy 3 217°C/353°C		

- In all cases significant die attach paddle and clip delamination observed after MSL3 preconditioning
- Visual inspection of parts show solder squirt from the edge of the package



Die and clip attach solder has squirted out of the side of the package after 3x 260 ° C reflows

International Rectifier 6

Slide 5: Partial Melt Solders (3)

Partial melt solders- Conclusions

- **All materials are unsuitable due to failure in MSL preconditioning prior to reliability testing**
  - **Solders partially melt during 260°C reflow causing massive package delamination and solder squirt**
- Materials could be used to replace Pb based solders with little change in process or equipment set used today.
- Final test electrical performance looks acceptable with Rds(on) comparable with Pb based solder.

International Rectifier 7

Slide 6: Partial Melt Solders – Conclusions

Ag Epoxy Materials

IOR

- **4 Ag Epoxy Materials evaluated**
  - Electrical and thermal performance comparable with Pb based solders – bulk properties to be confirmed in application

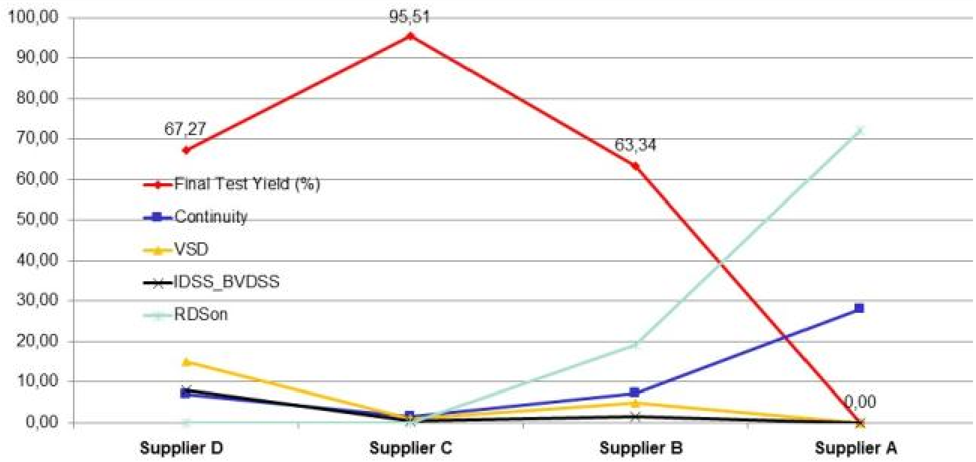
Epoxy	Cure Temp/Time	Thermal conductivity	Electrical Resistivity	Elastic Modulus	Tg	CTE1	CTE2
Supplier A	200°C/30min ramping + 200°C/60min cure	24W/m°K	50µOhm-cm	4.3GPA(25°C) / 1.4GPa(250°C)	44°C	60ppm	150ppm
Supplier B	150°C/30min ramping + 150°C/30min cure + 250°C/40min ramping + 250°C/90min cure	50W/m°K	30µOhm-cm	6.8GPa(25°C) / 5.4GPa(260°C)	63°C	25ppm	45ppm
Supplier C	180°C/50min ramping + 180°C/30min cure + 215°C/15min ramping + 215°C/60min cure	10W/m°K	100µOhm-cm	7.7GPa(25°C) / 0.45GPa(250°C)	-	35	-
Supplier D	230°C/40min raming + 230°C/90min cure	125W/m°K	5µOhm-cm	14.7GPa(25°C) / 8.9GPa(260°C)	100°C	20	50

IOR International Rectifier 8

Slide 7: Ag Epoxy Materials

Ag Epoxy Materials – Final Test

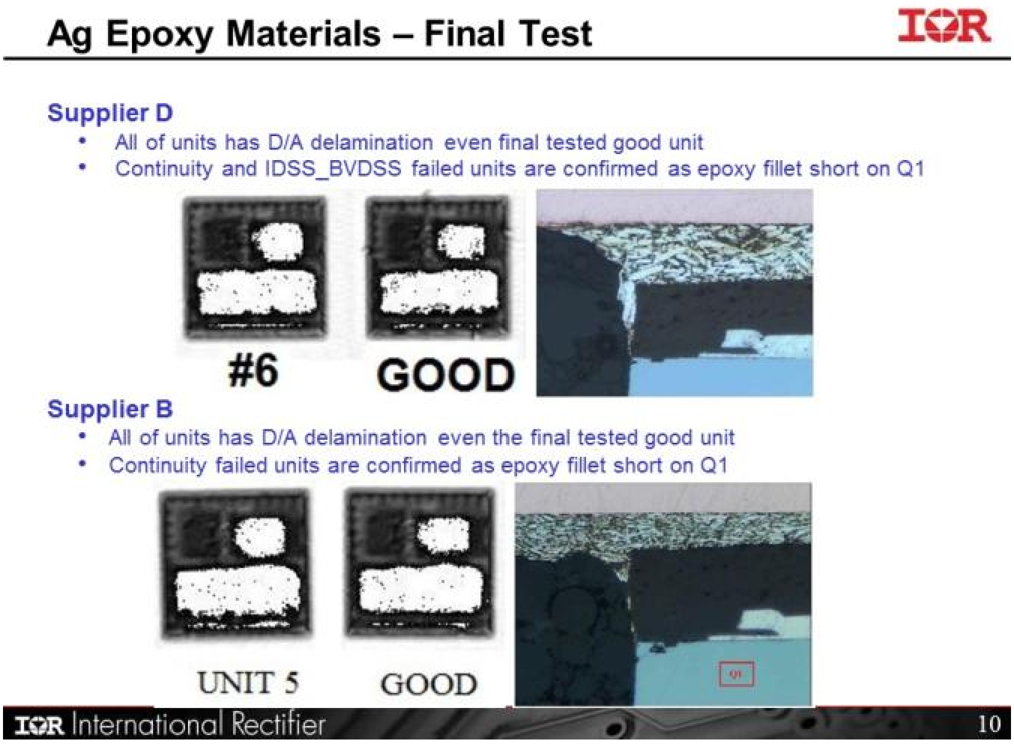
IOR



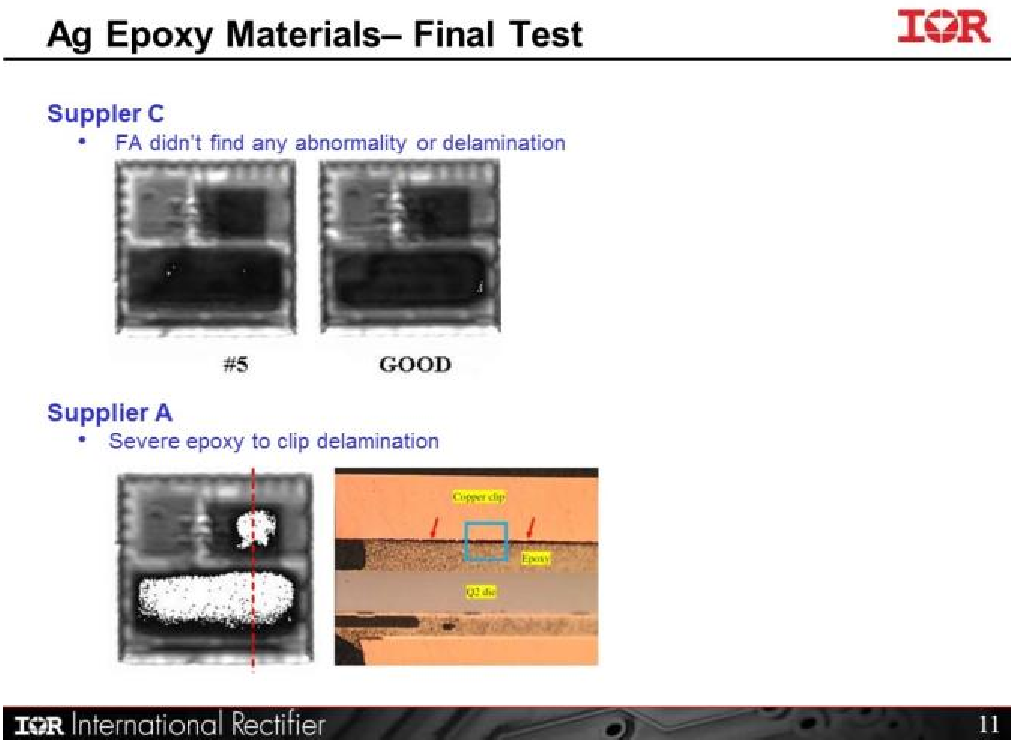
- **Severe Final test yield loss detected except Supplier C material**
  - FA confirmed
    - Continuity and IDSS_BVDSS failure as "Excessive epoxy on Q1 die"
    - RDSon failure as "D/A and Clip Delamination"

IOR International Rectifier 9

Slide 8: Ag Epoxy Materials – Final Test (1)



Slide 9: Ag Epoxy Materials – Final Test (2)



Slide 10: Ag Epoxy Materials – Final Test (3)

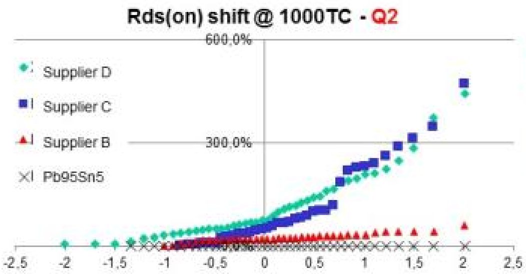
Ag Epoxy Materials– Reliability Test

Reliability

- Supplier D : Pass MSL3, failed TC250 and AC96hr by RDSon
- Supplier C : Pass MSL3, failed TC250 and AC96hr by RDSon
- Supplier B : Pass MSL3, TC1000, AC96hr
- Supplier A : Pass MSL3, no other test submitted as time zero severe delamination

RDSon Shift post TC1k cyc

- Supplier B material passed RDSon limit but Rdson shift = 23% avg, 61% max
- POR 95/5 high lead solder max Rds(on) shift 0.3%



Rds(on) Shift	Supl B	Supl C	Supl D	Pb95Sn5
Max	61%	472%	444%	0.3%
Avg	23%	95%	112%	0.1%

IOR International Rectifier 12

Slide 11: Ag Epoxy Materials – Reliability Test

Ag Epoxy Materials - Conclusions

- Materials are difficult to process for Cu clip products where material needs to be contained to contacts without overspill
  - Assembly yield adversely affected material overspill
- Final test electrical performance looks acceptable with Rds(on) comparable with Pb based solder
- **Reliability severely affected by package delamination causing unacceptable shifts in Rds(on)**

IOR International Rectifier 13

Slide 12: IR Ag Epoxy Materials - Conclusions

A.5.3 Timing devices, which are quartz crystals and components including these, like oscillators of all kinds and real time clock modules (RTCs)

According to Freescale et al.[1962], quartz crystal resonators are available in metal cans not using any Pb, but these devices can withstand only lower process and storage temperatures. They require manual soldering due to the lower heat resistance caused by the use of Pb-free low melting solder for the cylinder sealing. However, it has been shown in the past 10 years that this lead-free sealing still bears the risk of tin whisker growth. Tin whisker growth can potentially short parts and has been found in "lead-free" sealed crystals of all manufacturers.

Freescale et al.[1963] explain that manual assembly soldering processes are used in some dedicated industries like in the watch industry. Nearly all other industries however cannot use this manual process due to process compatibility, meaning the compatibility with mounting processes for other components on the complex modules, and reliability reasons as machine soldered joints are more reliable and consistent than manual joints.

According to Freescale et al.[1964], the wider temperature range of SMD assembly/reflow soldering however requires the use of higher solder temperatures which would cause the sealing of low melting solders to leak. These processes require the use of higher temperature cylinder seals based on LHMPS. While manual soldering was quite common many years ago, it is not compatible with modern PCB production machines and would require a manual and thus labor intensive and expensive mounting process not compatible with the process and quality requirements for all other components on conventional PCBs.

Freescale et al.[1965] say that reflow solder processes run on higher temperatures and SMD-mounting requires the cylinder crystals commonly to be mounted on a lead frame by means of a first soldering process before this combination is molded into a plastic and undergoing a final reflow process for mounting onto customers printed circuit board. Due to the fact that the cylinder sealing is exposed to multiple soldering processes including reflow soldering with higher temperatures than manual soldering, the components are thermally more stressed during assembly and thus it is necessary to increase the melting point of the cylinder capsulation (hermetic sealing of the metal cylinder with a plug) in this cases compared to the one where the cylinder is directly hand-soldered onto the PCB. For these cases the use of LHMPS is needed, as no other material has been found so far which combines the high melting point and the mechanical characteristics (i.e. softness and ductility) required to assure prolonged

[1962] Ibid.
[1963] Ibid.
[1964] Ibid.
[1965] Ibid.

reliable hermetic sealing between the metal cylinder and the plug over a wide temperature range during storage and operation.

Even more, Freescale et al.[1966] state, many applications can't work with a pure crystal, but need an oscillator of some type, i.e. Temperature-Compensated-Oscillators (TCXOs) for GNSS (Global Navigation Satellite System) applications or real time clock modules). In these cases, the hermetically sealed crystal resonator has to be mounted together onto a kind of module with an IC. So the same basic structure and arguments about the multiple soldering processes as mentioned above are valid in this case, as the cylinder crystal (where used) has to be mounted onto a PCB, lead-frame or similar together with the semiconductor before molding.

In other words, Freescale et al.[1967] put forward, LHMPS as sealing material is not only required for cylinder crystals to enable SMD soldering, but as well in widely spread components like RTC modules and others, where an IC and hermetically sealed quartz crystal have to be combined together inside one package/module to achieve desired specifications (e.g. accuracy).

Freescale et al.[1968] claim that metal can crystals with LHMPS cannot be completely replaced by crystals packed into ceramic packages, as the characteristics and covered frequencies are vastly different. The most remarkable differences are (Freescale et al.[1969]):

- Due to the different dimensions (fitting into the packages), the smaller crystals have a significantly different "pullability". This is the capability to change the frequency when external circuit parameters, namely the load capacitance of the oscillation circuit, are changed. This is a feature used to correct the initial tolerance and frequency drift over temperature as well as aging of the crystal and is required to meet standards for wireless and wired communication as well as GNSS applications. The high pullability of larger cylinder crystals is especially important in wide temperature applications like in automotive use, as the frequency temperature tolerance is far larger due to the wider temperature range which has to be covered which consequently needs a wider pulling range (so range in which the frequency can be changed).
- Due to the physical sizes of applicable ceramic packages, the crystals inside ceramic packaged quartzes are smaller compared to the ones inside metal cylinders. The smaller size of the quartz crystal however increases its internal loss (so called "ESR"; electrical serial resistance), thus requires oscillator circuits which can drive significantly more current and thus require more

[1966] Ibid.
[1967] Ibid.
[1968] Ibid.
[1969] Ibid.

electrical energy in operation. As many of this cylinder crystals are used for so called "clock" applications, so using a 32.768 kHz crystal to derive a time signal out of it, these oscillators have to be operated all the time, even while the application is not in use, which would impact the standby and "off" current of applications as required by applicable EU regulations. Power consumption is for several reasons (legislations, enviro nmental, operation time on batteries) very important for nearly all applications. For this reason, nearly all Semiconductor Manufacturers are putting technologies in place to reduce the power consumption of their ICs. As a result, the available energy for the oscillator is going down as well so that many of the latest ICs require extremely low ESR crystals which can use today's technologies and can only be achieved with crystals packed into a metal cylinder due to size reasons as mentioned above.

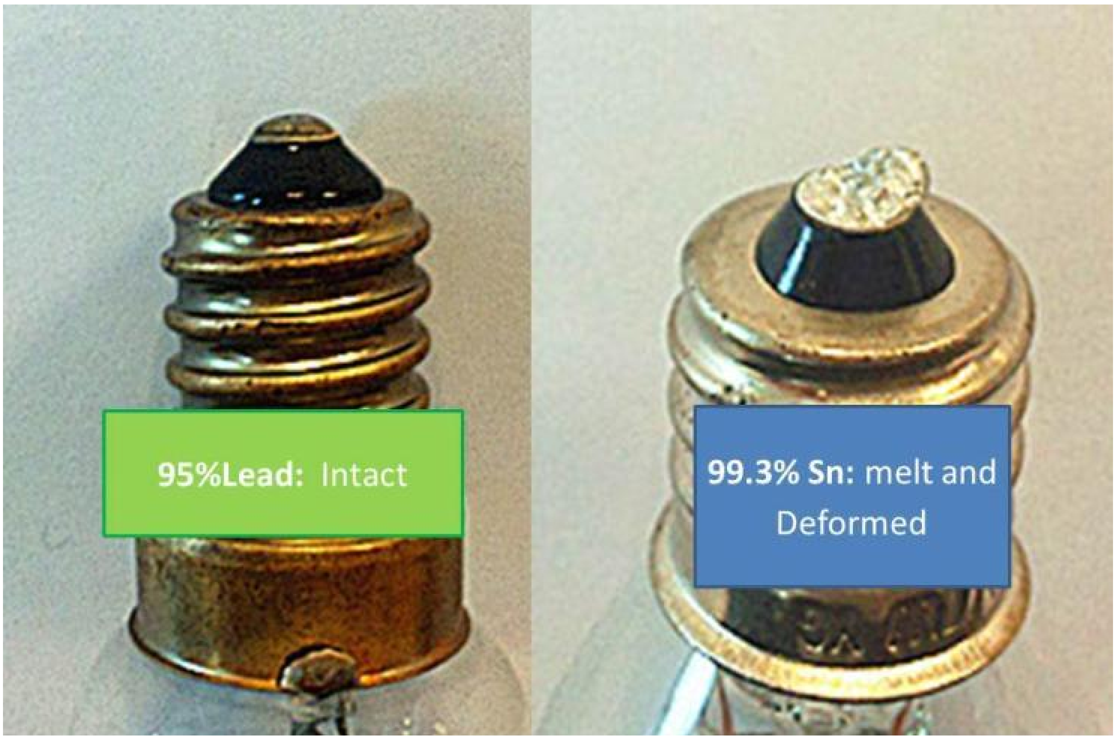
- Since the outer dimensions of the quartz crystal define its resonance frequency, the smaller ceramic packages do not allow to generate rather low frequencies like 4MHz, 6MHz or 8MHz, which however are often used to clock CPUs. Increasing this frequency would require different CPU chips and increase the power consumption in use unnecessarily.

A.5.4 Oven Lamps

Oven lamps are commonly used in many household ovens. Freescale et al.[1970] say that the temperature of the lamp during the baking process can reach 300 ^{C}. Alternative lead-free solders will 'melt' under these conditions. When the solder melts, the lamp fails and the consumer expects to replace the lamp. Lack of compatible replacement bulbs could result in premature oven replacement. The current technology (Incandescent, CFL, LED lamps) has no reliable alternative replacement light source available without LHMPS.

[1970] Ibid.

Figure 34-4: Oven lamp failure



Source: Freescale et al.[1971]

[1971] Ibid.

A.6.0 Appendix 6: Ce-doped Phosphor Coating Variations

Copied from LEU (2015b), LightingEurope, Answers to 1st Clarification Questions, submitted 27.3.2015, available under:
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_7/2015-3/Oko_Ex_Re_2015_3_Answers_2_Clarification_Questions_20150327_final.pdf

"A second problem for the Ce doped phosphors is the variations of the UV output over the lamp length due to coating thickness. When fluorescent lamps are coated with a phosphor the thickness of the coating varies over the length of the lamp. For current UV-fluorescent coatings used, like BSP, the thickness variations do not lead to a severe inhomogeneous output. However, for Cerium doped phosphor this thickness difference leads to unacceptable UV output variations which will affect the skin treatment effectiveness (see table below).

	thin coated side		thick coated side	
	UVB		UVB	
1 P	594		325	
2 P	567		313	
3 P	614		322	
4 P	614		322	
5 P	604		350	
6 P	600		325	
7 P	595		301	
8 P	615		265	
9 P	599		283	
10 P	622		409	
AVG	602,4		321,5	
STDV	14,87	2%	36,96	11%
MAX	622,00		409,00	
MIN	567,00		265,00	
Range	55,00	9%	144,00	45%

Table: Thickness variations of Ce-doped coatings and the impact on UV output

A.7.0 Appendix 7: Cd-based Ink Printing Colours that do not Exist in Cadmium-Free Versions (Ex. 21)

Lists of specific hues submitted by IRL and HGT are both copied below in light of small differences:

Source: HGT (2016a), Hecker Glass Technik, Answers to 1st round of clarification questions, submitted per email 18.1.2016

1002 sandyellow	*2000 yelloworange*	*3000 firered*	*4007 purpleviolet*
1003 signalyellow	*2001 redorange*	*3001 signalred*	*6010 grasgreen*
1004 goldyellow	*2002 bloodorange*	*3002 chimney red*	*8012 redbrown*
1007 narcissusyellow	*2003 pastel orange*	*3003 ruby red*	
1017 saffron yellow	*2004 orange*	*3004 purple red*	
1021 rape yellow	*2008 lightredorange*	*3005 wine red*	
1023 traffic yellow	*2009 trafficorange*	*3007 blackred*	
1027 curry yellow	*2010 signalorange*	*3009 Oxired*	
1028 melone yellow	*2011 darkorange*	*3011 brownred*	
1032 broom yellow	*2012 pollack orange*	*3012 beigered*	
1034 pastel yellow		*3013 tomato red*	
1037 Sunyellow		*3014 old pink*	
		3016 coral red	
		3018 strawberry red	
		3020 traffic red	
		3022 pollack red	
		3031 orientred	

Source: IRL (2016a), Irlbacher Blickpunkt Glas GmbH, Answers to 1st round of clarification questions, submitted per email 18.1.2016

1002	sandyellow	2000	yelloworange	3000	firered	4007	purpleviolet
1003	signalyellow	2001	redorange	3001	signalred	6010	grasgreen
1004	goldyellow	2002	bloodorange	3002	chimney red	8012	redbrown
1007	narcissusyellow	2003	pastel orange	3003	ruby red		
1017	saffron yellow	2004	orange	3004	purple red		
1021	rape yellow	2008	lightredorange	3005	wine red		
1023	traffic yellow	2009	trafficorange	3007	blackred		
1027	curry yellow	2010	signalorange	3009	Oxired		
1028	melone yellow	2011	darkorange	3011	brownred		
1032	broom yellow	2012	pollack orange	3012	beigered		
1034	pastel yellow			3013	tomato red		
1037	Sunyellow			3014	old pink		
				3016	coral red		
				3018	strawberry red		
				3020	traffic red		
				3022	pollack red		

A.8.0 Appendix 8: Leaching Test Results Related to Ex. 29

Test results sent on 26.6.2015 to by EDG to the European Commission, related to the possible leaching of lead from lead crystal.

Stazione Sperimentale del Vetro S.c.p.A.
Venezia - Murano, Via Briati 10
Venezia - Marghera, Via delle Industrie 13 - c/o VEGA Edificio Pegaso

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RAPPORTO DI PROVA / TEST REPORT N. 126760   pag. 1 di 1

Murano	23/04/2015	*rif.*	Yr/mail of confirmation dated 11.03.2015
richiedente proposer	FEDERATION DES CRISTALLERIES - VERRERIES A LA MAIN ET MIXTE 112-114 RUE LA BOETIE - 75008 PARIS		
campione sample	GLASS	*prova eseguita dal* / from test date *al* / to	30/03/2015 2/04/2015
contrassegnato reference	CRYSTAL GLASS CHANDELIER Sampling performed by the client		
ricevuto il received	18/03/2015 by carrier		

UNI EN 12457-2: 2004 (Charaterization of waste : Leaching- Compliance test for leaching of granular waste materials and sludges Part2: One stage batch test at liquid to solid ratio of 10 L/kg for materials with particle size below 4 mm without or with size reduction)

Principle

A sample of glass cullet was crushed and sieved to a grain size between 0.5 and 4 mm and then immersed in water with a liquid to solid ratio of 10 L/kg for 24 h at room temperature (20°C ± 5° C) under agitation. After this treatment the eluate was filtered and analysed using the ENV 12506:2004 and ENV 13370:2004 methods and others.

Results:

Parameters:		
pH	Start	8.8
	End	9.8
Temperature (°C)		22.0
Conductivity (μS/cm)	Start	3.4
	End	18.0

Moisture content (% w/w)		< 0.10
Volume of leachant	(l)	0.900
Mass of test portion	(kg)	0.090
Method of liquid solid separation:		filtering over 0.45 μm membrane

Costituents		Limit of determination (mg/l)	Blank (mg/l)	Eluate concentration (mg/l)	Amount leached (mg/kg)
Arsenic,	As	0.002	< 0.002	0.003	0.03
Cadmium,	Cd	0.0002	< 0.0002	< 0.0002	< 0.002
Chromium,	Cr	0.002	< 0.002	< 0.002	< 0.02
Lead,	Pb	0.002	< 0.002	0.249	2.49
Selenium,	Se	0.002	< 0.002	0.0043	0.043
Antimony,	Sb	0.002	< 0.002	0.060	0.600

Test carried out at Murano Laboratories

THE ANALYST
Dr.ssa Martina Scarpa

THE LABORATORIES DIRECTOR
Dr. Nicola Favaro

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Mod.: PG3-06 REV. 7 02.5.2013

EVALUATION OF THE GLASS SAMPLE

Sample

Crystal Glass obtained from two different pieces of a Chandelier: arm and candle cap

General Classification

Crystal glass: "Glass, oxide, chemicals" (CAS 65997-17-3)

Release of Pb on landfill due to leaching of metal from glass after the disposal in landfill

Leaching test carried out according to EN 12457-2 and TC13 protocol; comparison with limit values set out in Chapter 2.2 "Criteria for landfills for non-hazardous waste" in Council Decision 2003/33/EC

Constituent	Concentration mg/kg	limit value for non-hazardous waste mg/kg
Pb	2,49	10

Evaluation

Pb concentration is below the limit values set out in Chapter 2.2 "Criteria for landfills for non-hazardous waste" in Council Decision 2003/33/EC".

Stazione Sperimentale del Vetro S.c.p.A. – The Glass Research Center
Via Briati, 10 – 30141 Murano (VE) • P.I. 04176390278 • T.+39 041.2737011 • F.+39 041.2737048 • www.spevetro.it • mail@spevetro.it
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