Review in the light of scientific and technical progress of exemptions 8(e), 8(f)(b), 8(g) and 14 and re-evaluation of entry 8(j) of Annex II to Directive 2000/53/EC (ELV) (Pack 3) –

Draft Final

Under the Framework Contract: Assistance to the Commission on technical, socio-economic and cost-benefit assessments related to the implementation and further development of EU waste legislation

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Disclaimer

Oeko-Institut and Fraunhofer IZM have taken due care in the preparation of this report to ensure that all facts and analysis presented are as accurate as possible within the scope of the project. However, no guarantee is provided in respect of the information presented, and Oeko-Institut and Fraunhofer IZM are not responsible for decisions or actions taken on the basis of the content of this report.

EUROPEAN COMMISSION

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1. Executive summary – English

Under Framework Contract no. ENV.A.2/FRA/2015/0008, a consortium led by Oeko-Institut was requested by DG Environment of the European Commission to provide technical and scientific support for the evaluation of exemptions under the ELV Directive. The work has been undertaken by the Oeko-Institut and Fraunhofer Institute IZM, and has been peer reviewed by the two institutes.

1.1. Background and objectives

Directive 2000/53/EC on end-life-vehicles ("ELV" Directive) restricts the use of certain hazardous substances in vehicles. Annex II to the Directive includes a list of exemptions to the use of these restrictions, which is adapted regularly to scientific and technical progress according to the respective provisions in the Directive.

Following the requirements of Article 4(2)(a) of Directive 2000/53/EC on end-of-life vehicles, Member States of the European Union have to ensure that materials and components of vehicles put on the market since 1 July 2003 do not contain lead, mercury, hexavalent chromium and cadmium. A limited number of applications exempted from the provision of this article are listed in Annex II to the Directive as well as the scope and the expiry date of the exemption and the labelling requirement according to Article 4(2)(b)(iv) (if applicable).

Based on Article 4(2)(b), Annex II is to be adapted to scientific and technical progress by the Commission on a regular basis. This is done in order to check whether existing exemptions are still justified with regard to the requirements laid down in Article 4(2)(b)(ii), whether additional exemptions have been proposed on the basis of the same article and whether exemptions are no longer justified and need to be deleted from the Annex with regard to Article 4(2)(b)(iii). Furthermore, the adaptation procedure has to – as necessary – establish maximum concentration values up to which the restricted substances shall be tolerated (Article 4(2)(b)(i)) and designate those materials and components that need to be labelled.

With regard to this adaptation, Annex II has already been adapted 8 times (2002, 2005, 2008, 2010, 2011, 2013, 2016 and 2017).

1.2. Key findings – Overview of the evaluation results

The exemptions evaluate in this project 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 exemption evaluations (Ex. 8(e), 8(f)(b), 8(g), 8(j) and 14) were submitted to the EU Commission by Oeko-Institut and have already been published at the EU CIRCA website on 14 October 2019. The

Commission may take these recommendations into account in view of the amendment of Annex II Annex to Directive 2000/53/EC.

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

Ex. Req. No.	Current exemption wording	Recommendation	Recommended expiry date and scope
Ex. 8(e)	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead);	To be reviewed in 2024
Ex. 8(f)(b)	Lead in compliant pin connector systems other than the mating area of vehicle harness connectors	Lead in compliant pin connector systems other than the mating area of vehicle harness connectors	In vehicles type-approved before 1 January 2024 and after that date as spare parts for these vehicles
Ex. 8(g)	Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages	8(g)(I) Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages	In vehicles type-approved before 1 October 2022 and after that date as spare parts for these vehicles
		8(g)(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 b) A single die of 300 mm2 or larger in any semiconductor technology node c) Stacked die packages with dies of 300 mm² or larger, or silicon interposers of 300 mm2 or larger	Valid as of 1 October 2022 for vehicles type approved after 30 September 2022 Review in 2024
Ex. 8(j)	Lead in solders for soldering of laminated glazing	It is recommended not to renew the exemption	n.a

Ex. Req. No.	Current exemption wording	Recommendation	Recommended expiry date and scope
		validity. The Commission can grant the continuation with a narrowed scope. For details see section 8.8 on page 91.	
Ex. 14	As an anti-corrosion agent of the carbon steel cooling system in absorption refrigerators in motor caravans 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	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	
		(i) Designed to operate fully or partly with electrical heater, having an average utilised electrical power input < 75 W at constant running conditions.	Vehicles type-approved before 31 December 2019 and spare parts for these vehicles
		(ii) Designed to operate fully or partly with electrical heater, having an average utilised electrical power input ≥75 W at constant running conditions. (iii) Designed to fully operate with non-electrical heater	Vehicles type-approved before 31.12.2025 and spare parts for these vehicles

Note: As in the ELV legal text, commas are used as a decimal separator for exemption formulations appearing in this table, in contrast to the decimal point used throughout the rest of the report as a separator.

2. Executive summary: French - Note de synthèse: Français

To be updated.

3. Introduction

3.1. Project scope

Under Framework Contract no. ENV.A.2/FRA/2015/0008, a consortium led by Oeko-Institut e.V was requested by DG Environment of the European Commission to provide technical assistance for the evaluation of selected exemptions of the ELV Directive. The evaluation is to provide recommendations for a clear and un-ambiguous wording of the exemptions under review. The work has been undertaken by the Oeko-Institut, and by Fraunhofer IZM and has been peer reviewed by both institutions.

The evaluation includes consultation with stakeholders on the possible adaptation of the Annexes and the set-up of a website in order to keep stakeholders informed on the progress of work (http://elv.exemptions.oeko.info/index.php?id=64).

In the course of the project, a stakeholder consultation was conducted. The consultation was launched, on 29 May 2018. It ran for four weeks in relation to Ex. 8(j) and for eight weeks in relation to Ex. 8(e), Ex. 8(f(b), Ex. 8(g) and Ex. 14, thus ending on 26 June 2018 and 24 July 2018 respectively. The exemptions covered in this stakeholder consultation, specified in Table 4-1, were reviewed in agreement with the Commission:

- Some entries of Annex II include a mandatory review date. This is inter alia the case for exemptions 8(e), 8(f)(b) and 8(g) which need to be reviewed in 2019.
- Exemption 14 has no review date, but needs to be reviewed in order to align its formulation and duration with Directive 2011/65/EU (RoHS) and with Regulation 1907/2006 (REACH). In both of these legislations, the conditions of use of hexavalent chrome for applications addressed in Ex. 14 have changed. A review is necessary to ensure consistency of the ELV Directive with these other legislations.
- Exemption 8(j) bans the use of lead in solders for soldering of laminated glazing from 1 January 2020. However, evidence has been relayed to the European Commission on the difficulties of phasing-out lead from these applications by the end of 2019. A reassessment of this exemption is thus requested.

All non-confidential stakeholder contributions, submitted during the consultation, were made available on the ELV Exemptions website as well as on the EU CIRCABC website (Communication and Information Resource Centre for Administrations, Businesses and Citizens): https://circabc.europa.eu (Browse categories > European Commission > Environment > ELV exemptions, at top left, click on "Library").

3.2. Project set-up

Assignment of project tasks to Oeko-Institut, started 18 April 2018. The overall project has been led by Yifaat Baron. At Fraunhofer IZM the contact person is Otmar Deubzer.

4. Overview

In the course of the project, three existing ELV exemptions were reviewed. The exemptions covered in this project, together with the recommended expiration wording formulation and expiry dates, are summarised in Table 4-1. Please refer to the corresponding sections of this report for more details on the evaluation results and for more background on the rationale behind the recommendations.

Table 4-1: Overview Recommendations and Expiry Date

No.	Current wording	Recommended wording / action	Recommended expiration / review date
8(e)	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead);	To be reviewed in 2024
8(f)(b)	Lead in compliant pin connector systems other than the mating area of vehicle harness connectors	Lead in compliant pin connector systems other than the mating area of vehicle harness connectors	In vehicles type-approved before 1 January 2024 and after that date as spare parts for these vehicles
8(g)	Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages	8(g)(I) Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages	In vehicles type-approved before 1 October 2022 and after that date as spare parts for these vehicles
		8(g)(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 b) A single die of 300 mm2 or larger in any semiconductor technology node c) Stacked die packages with dies of 300 mm² or larger, or silicon interposers of 300 mm2 or larger	Valid as of 1 October 2022 for vehicles type approved after 30 September 2022 Review in 2024

<table>
<tr><th>No.</th><th>Current wording</th><th>Recommended wording / action</th><th>Recommended expiration / review date</th></tr>
<tr><td>8(j)</td><td>Lead in solders for soldering of laminated glazing</td><td>It is recommended not to renew the exemption validity.
The Commission can grant the continuation with a narrowed scope. For details see section 8.8 on page 91.</td><td>n.a</td></tr>
<tr><td rowspan="3">14</td><td rowspan="3">As an anti-corrosion agent of the carbon steel cooling system in absorption refrigerators in motor caravans 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</td><td colspan="2">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</td></tr>
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</table>

5. Exemption 8(e)

"Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)"

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.

Acronyms and definitions

ECB	automotive electronic circuit boards
HMPS	high melting point solders
LHMPS	lead-containing high melting point solders
OEM	original equipment manufacturer, original producer of a vehicle and/or component
Pb	lead

5.1. Description of Requested Exemption

Annex II of the ELV Directive lists the following exemption:

> *"Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)"*

Annex II further specifies that exemption 8(e) is to be reviewed in 2019, leading to the current evaluation. Antaya (2018 d); Saint-Gobain Sekurit (2019 a) and DA5 (2018) submitted information as to the unavoidability of lead use in high melting temperature type solders beyond 2019.

5.1.1. History of the exemption

The exemption was included in Annex II of the ELV Directive, when first published in 2000, and has not been changed since then. This exemption is one of the few material-specific exemptions in Annex II of the ELV Directive as it authorizes the use of lead in high-melting point solders (HMPS) without specifying the application in which these solders may be used. In the review for the 4th amendment of the ELV Directive (2008/2009), it was discussed whether the exemption should be restricted to applications where lead-free alternatives are not available. During that review, a list of applications was compiled for which the use of lead-containing HMPS was still unavoidable. However, the exemption could not be restricted to these applications for various reasons. The consultants recommended to continue the exemption.

In the review for the 7th amendment of the ELV Directive (2014/2015), the consultants arrived at the conclusion that the use of lead is still unavoidable in the applications identified in the 2008/2009 review and recommended to continue the exemption. The analogue exemption 7 (a) of Annex III of the RoHS Directive RoHS Directive (2011) was reviewed in 2015/2016. While the information provided clearly showed that the substitution or elimination of lead is still scientifically and technically impracticable in principle, it could not be clarified whether this was true for the attach of small dies.

5.1.2. Technical Background

ACEA et al. (2018 a) provide the below Table 5-1 to explain the basic applications of LHMPS and the functional requirements which it fulfils.

Table 5-1: Intended Use and Examples for Related Products in which HMP Lead-solders are utilized

Intended use	Examples of related products	Reasons for necessity
Solders used for internally combining: – a functional element with a functional element – and a functional element with wire/terminal/heat sink/substrate, etc. within an electronic component.	Resistors, capacitors, chip coil, resistor networks, capacitor networks, power semiconductors, discrete semiconductors, microcomputers, ICs, LSIs, chip EMI, chip beads, chip inductors, chip transformers, etc.	– Stress relaxation characteristic with materials and metal materials at the time of assembly is needed. – Stress absorption (ductility) is needed to prevent damage to jointed materials and components during lifetime. – 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, etc. – It is needed to gain high reliability for temperature cycles, power cycles, etc.*
Solders for mounting electronic components onto sub-assembled module or sub-circuit boards.	Hybrid IC, modules, optical modules, etc.	
Solders used as a sealing material between a ceramic package or plug and a metal case	SAW (Surface Acoustic Wave) filter, crystal resonators, crystal oscillators, crystal filters, etc.	

Source: ACEA et al. (2018 a)

** The long term reliability under the harsh environmental conditions of use in vehicles needs to be assessed and qualified according to automotive specifications (e.g. AEC-Q100)*

Gensch et al. (2015)[1] and Gensch et al. 2016[2] describe the technical background in more detail, which has not changed since these last reviews and is therefore not repeated here.

5.1.3. Amount of Lead Used under the Exemption

ACEA et al. (2018 a) estimated the amount of lead in lead-containing high melting point solders (LHMPS) in vehicles, based on the average numbers of automotive electronic circuit boards (ECBs) per vehicle and their lead content related to exemption 8(e).

- Average volume range of ECBs per vehicle: 1.5 to 3.0 kilograms per vehicle (source: ACEA)
- Amount of lead used under exemption 8(e) per ECB: 0.01 to 0.05 % (source: ZVEI)

Multiplying the above figures, the amount of lead used under exemption 8(e) per vehicle would be between 0.14 g (minimum) to 1.4 g (maximum).

Assuming that around 1 g of lead is used under exemption 8(e) per vehicle and that 15.65 million vehicles are newly registered in the EU 28 annually (status 2017), ACEA et al. (2018 a) calculate the total amount of lead used under the exemption to be around 16 tonnes per year.

5.2. Stakeholders' Justification for the Exemption

ACEA et al. (2018 a) explain that "*After ELV and RoHS enforcement, industry spent more than 10 years in research for alternative materials, considering the wide range of possibilities such as additive elements and electrically conductive resins. However, for three intended uses (Table* 5-1*), an alternative technology with similar ductility, strength and further physical properties as Lead is not yet available. Lead-free solders of metallic systems that have a solidus line temperature of 250°C or higher, as well as electrically conductive adhesive systems, have problems and thus cannot substitute Lead HMP solders. In addition, as a trend of vehicle components, further miniaturization of structures proceeds, and brings increase of thermal and mechanical load on components. Especially components requiring long term reliability (e.g. powertrain system components, high power applications such as generator diode etc.) and safety relevant components (Brake ECU, Steering ECU etc.) will be largely affected.*"

For lead-free die attach, the DA5 (2018) explain that "*[…] since till now no replacement material was identified by the DA5 consortium. Substantial development efforts have been running for more than 9 years involving leading international material suppliers on a global base. While the DA5 consortium has not yet found a*

1 For details, see page 5 et sqq.
2 For details, see page 373 et sqq.

reliable lead-free package technology for power semiconductor components, the research is promising for long-term solutions. The DA5 consortium expects that in the next decade more and more devices using newly available lead-free materials will enter the market for limited applications. The driving factor will be a dedicated performance upgrade for packages using lead-free materials already rather than the replacement of LHMPS. As already stated above, those same materials are promising candidates with a good evolution but not yet capable enough for the full scope of replacement of LHMPS with all its capabilities (e.g. reliability). Still, this trend will further enhance the development of die attach materials towards lead replacement for power devices."

For further details, refer to the last reviews of exemption 8(e) and RoHS exemption 7 (a)[3] and to the submissions of ACEA et al. (2018 a) and DA5 (2018).

5.3. Critical review

The consultants focused the critical review first on the status and progress achieved on component and material level since the last reviews in 2015/2016 (7th amendment of Annex II), in particular whether the substitution or elimination of lead is still scientifically and technically impracticable for attach of small dies. Secondly, available lead-free solutions were investigated as to whether and how far they can be or are already qualified for use in automotive applications.

5.3.1. Substitution or Elimination of Lead in LHMPS for Attach of Small Dies

ACEA et al. (2018 b) quote answers of the DA5 explaining that the die size is only one parameter for feasibility of lead substitution or elimination and cannot serve as a decision parameter on its own. A semiconductor product is a highly optimized system due to complex interactions, and the change to lead-free means comprehensive re-design of the whole system with the uncertainty that product performance, quality and reliability requirements cannot be fulfilled any longer at the same time. ACEA et al. (2018 b) give the below example from DA5:

- A change of die attach material to lead-free needs other metallizations on interfaces;
- Other interfaces impact the bill of materials in general (e.g. mold compound);
- Other materials bring other physical and chemical properties and have to be matched in a new way to re-gain quality, performance and reliability;
- Very often DA5 encounter incompatibilities that cannot be overcome;

The consultants are aware that die sizes alone are not the only criterion to be taken into account. An open question remains, however, whether there is a die size below which the adverse impacts of lead-free solutions can be reduced with available solutions to a degree that may allow to substitute the lead in LHMPS or to eliminate

[3] For details see Gensch et al. 2015; Gensch et al. 2016.

the use of LHMPS nevertheless. This question was discussed in the 2015/2016 review of the exemption 7(a) of RoHS Annex III without a final answer after a manufacturer had presented components where the use of LHMPS was eliminated.[4] DA5 (2019) state that future lead-free solutions would be limited to smaller die sizes at least in the beginning. The consultants understand this statement as a confirmation that there is a link between die size and the viability of lead-free solutions where the die size is the crucial parameter for the viability of lead substitution or elimination of LHMPS. Since the manufacturer of these LHMPS-free components did not participate in the online stakeholder consultation, no information is available to follow up on the issue. Additionally, it is an open question whether and how far all of these components would be qualified for use in automotive applications.

Upon request, ACEA et al. (2018 b) provide a general view on lead-free solutions in the market referencing information of the DA5:

- Lead-free solutions have been on the market since a long time already. Upcoming materials that are currently investigated will further enhance the market share of lead-free solutions.
- The DA5 consortium expects that in the next decade more and more devices using newly available lead-free materials will enter the market for limited applications. The driving factor will be a dedicated performance upgrade for new packages using lead-free materials rather than the replacement of LHMPS in existing packages. Nevertheless, it is mandatory for lead-free materials to fulfil the automotive requirement specs for all products in automotive applications. As already stated above, those same materials are promising candidates with a good evolution, but not yet capable enough for the full scope of replacement of LHMPS with all its capabilities (e.g. reliability). Still, this trend will further enhance the development of die attach materials towards lead replacement for power devices.
- Upcoming lead-free solutions for new products cannot be transferred to existing products in general.

DA5 were asked to provide more details about the above-mentioned lead-free die attach solutions. DA5 (2019) state that *"[…] there is no generic or common lead-free solution known in the market which might be applied as drop in replacement of LHMPS material for our products. That's why DA5 is still working on finding a generic solution. There are of course Pb free die-attach solutions available (already used by DA5 companies) but they can't be used as replacement of the LHMPS material!"* DA5 (2019) mention adhesives and conducting films (CDAF) in this context and explain that "*Pb-free die attach materials are not the same as Pb-solder replacement solutions. Low thermal glues have been used for semiconductor die attach over many decades by the entire semiconductor industry, incl. DA5. The reason for using Pb-solder in some applications instead of low thermal glues (which are organic in nature, with some Ag particle fillers) is determined by product requirements like high thermal or electrical conductivity. Low thermal glues, unlike Pb-solder, do not have high*

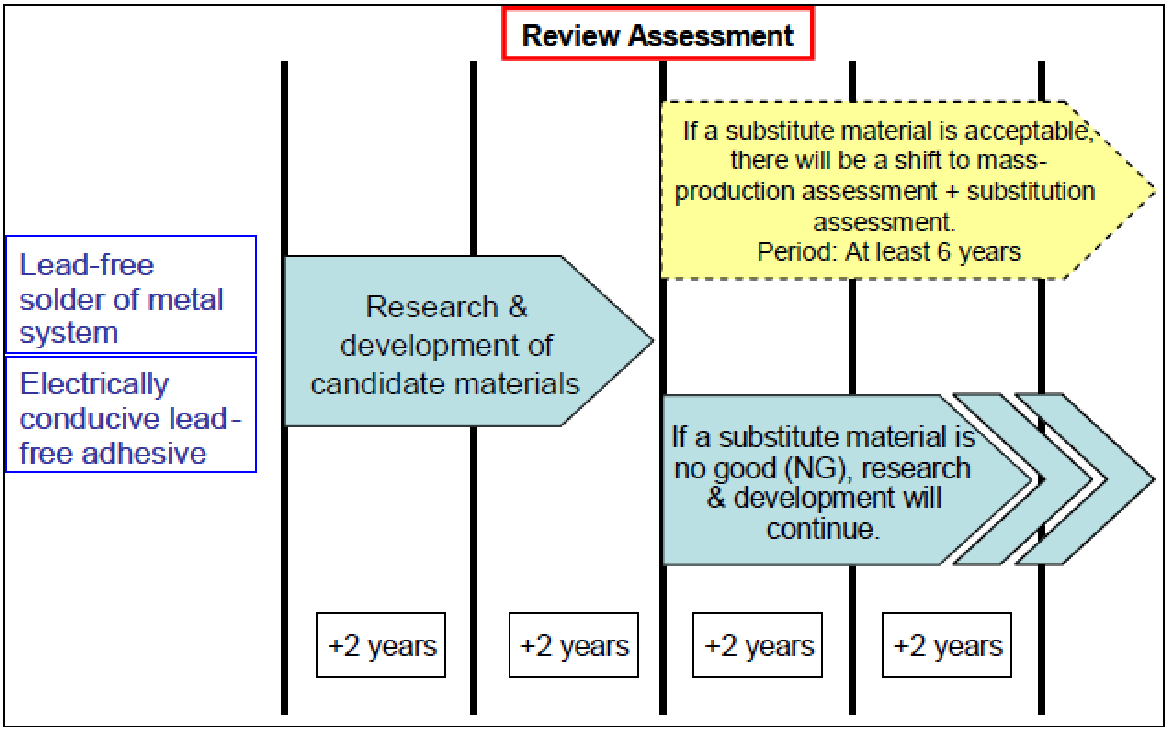
[4] C.f. Gensch et al. 2016.

thermal and electrical conductivities, without which the semiconductor product cannot function. This is the same reason why existing Pb-free low thermal glues are not Pb-solder replacement solutions."

The DA5 explanation is plausible, i.e., that the above-mentioned lead-free die attach solutions like for example adhesives are neither substitutes for LHMPS nor can they eliminate the use of LHMPS. Despite the above explanations, with a view to the still unclarified situation regarding LHMPS elimination for small die components, ACEA et al. and DA5 were asked whether any components with lead-free replacements for LHMPS are qualified for use in automotive applications. According to ACEA et al. (2019a), "*There is no generic lead-free solution known which can be applied qualified for automotive uses for lead-containing high melting point solders in die attach at this moment*." DA5 (2019) state that "*Adhesives are qualified for automotive usage and are already used (e.g. thermally uncritical applications; no vertical current flow).*" DA5 (2019) "*[…] expect some specific automotive-grade and soft solder equivalent applications to appear on the market in future, limited to small die dimension for the time being.*" Since the adhesives the DA5 mention cannot be considered as LHMPS replacements, components with lead-free LHMPS replacements for die attach are not available for automotive uses.

ACEA et al. (2018 a) provide the below time lines for the development and qualification of lead-free replacements for LHMPS.

Figure 5-1: Roadmap for development and qualification of lead-free replacements for LHMPS



Source: ACEA et al. (2018 a)

5.3.2. Substitution or Elimination of Lead in LHMPS for Applications other than Die Attach

Concerning applications of LHMPS other than die attach, ACEA et al. (2018 b) state upon request that there is no information about progress towards the substitution of lead in LHMPS.

5.4. Conclusions

The consultants cannot exclude that lead could possibly be substituted or eliminated for attach of small dies. The information the applicants made accessible, and in the absence of information suggesting the contrary, suggests that no components with lead-free substitutes of LHMPS in die attaches are qualified for automotive uses. The situation appears to be the same for the substitution or elimination of lead in LHMPS for applications others than die attach.

5.5. Recommendations

The information made available by the applicants suggests that the use of lead in LHMPS is still unavoidable. In line with Art. 4(2)(b)(II), the consultants can therefore recommend continuing exemption 8(e). The substitution or elimination of lead in LHMPS may become feasible, but it is explained to be unlikely that such solutions are available for automotive uses in the coming years. Given the time lines for the development and qualification of lead-free replacements for LHMPS (c.f. Figure 5-1), the consultants recommend continuing the exemption for five years beyond 2019 and to set a review date in 2024:

	Materials and Components	Scope and Expiry Date of the Exemption	Comments
	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead);	--	Review in 2024

5.6. References

ACEA et al. (2018 a): Answers to questionnaire 1 (clarification questionnaire) submitted to the public online stakeholder consultation. File "Contribution_ACEA_et_al_8e_consultation.pdf". Available online at http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2018-1/Contribution_ACEA_et_alt_8_e__questionnaire_20180718.pdf.

ACEA et al. (2018 b): Answers to questionnaire 2 sent by Jens Warsen, ACEA, via e-mail to Dr. Otmar Deubzer, Fraunhofer IZM, on 18 December 2018. File "Ex_8e_ACEA_Questionnaire-2.pdf".

ACEA et al. (2019): Answers to questionnaire 3 sent by Jens Warsen, ACEA, via e-mail to Dr. Otmar Deubzer, Fraunhofer IZM, on 30 January 2019. File "Ex_8e_ACEA_Questionnaire-3.pdf".

DA5 (2018): Answers to questionnaire 1 (clarification questionnaire) submitted to the public online stakeholder consultation. File "Contribution_DA5_Answers_8e_Consultation_2018_v1.00_DA5_230718.pdf". Available online at http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2018-1/Contribution_DA5_Answers_8e_Consultation_2018_v1.00_DA5_230718.pdf_20180718.pdf.

DA5 (2019): Answers to questionnaire 2 sent by Bodo Eilken, DA5, via e-mail to Dr. Otmar Deubzer, Fraunhofer IZM, on 29 January 2019. File "Ex_8e_DA5_Questionnaire-2.pdf".

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 (amended) for the European Commission DG Environment under Framework Contract No ENV.C.2/FRA/2011/0020, 1 July 2015. With assistance of Carl-Otto Gensch, Yifaat Baron, Oeko-Institut, Dr. Otmar Deubzer, Fraunhofer IZM (ELV IV). Available online at https://circabc.europa.eu/sd/a/86a233f1-93ce-41e7-b4f2-06609a144e1e/ELV-Exemptions_Amended_Final_2015-06-29.pdf.

Gensch et al. (2016): 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. Report, 7 June 2016. With assistance of Carl-Otto Gensch, Yifaat Baron, Markus Blepp, Katja Moch, Susanne Moritz, Oeko-Institut, Dr. Otmar Deubzer, Fraunhofer Institut Zuverlässigkeit und Mikrointegration IZM (Adaptation to Scientific and Technical Progress of Annexes III and IV of Directive 2011/65/EU, RoHS XIV). Available online at https://circabc.europa.eu/sd/a/eda9d68b-6ac9-4fb9-8667-5e561d8c957e/RoHS-Pack_9_Final_Full_report_Lamps_Alloys_Solders_June2016.pdf.

RoHS (2011): 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. Available online at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32011L0065, checked on 10/5/2012.

6. Exemption 8(f)(b)

"Lead in compliant pin connector systems other than the mating area of vehicle harness connectors"

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.

Acronyms and definitions

Ag	silver
Bi	bismuth
CoPiCS	compliant pin connector systems
ECU	electronic control units
EFTA	European Free Trade Association, i.e. Norway, Switzerland, Liechtenstein and Iceland
In	indium
Pb	lead
Sn	tin
SOP	start of production

6.1. Description of Requested Exemption

Annex II of the ELV Directive lists exemption 8 (f)(b) as:

> *"Lead in compliant pin connector systems other than the mating area of vehicle harness connectors"*

Annex II further specifies that exemption 8(f) (b) is to be reviewed in 2019, leading to the current evaluation.

ACEA et al. (2018 a) *„[…] ask to extend the exemption 8(f)(b) with commitment to further develop Lead-free alternatives and for a further revision in 2024."*

6.1.1. History of the exemption

The use of lead in the applications addressed under Ex. 8 (f) (b) was not explicitly listed in Annex II of the ELV Directive[5] when it was adopted. The use of lead solders in electronic parts of vehicles was at that time covered by the general exemption "Solder in electronic circuit boards and other applications" (no. 11). In the course of reviews of ELV Annex II by Lohse, Joachim; Gensch, Carl-Otto; Groß, Rita; Zangl, Stéphanie; [Öko-Institut e.V.]; Deubzer, Otmar, Fraunhofer IZM (2008) and Zangl, Stéphanie [Öko-Institut e.V.] et al. (2010), the former exemption 11 was specified. In 2010, it was assessed that lead-free solutions were not yet available for automotive compliant pin connector systems (CoPiCS), even though the substitution of lead in CoPiCS had been proved to be viable for applications in electrical and electronic equipment under the scope of the Directive 2002/95/EC (RoHS 1)[6]. The main difference was that automotive CoPiCS use insertion forces in the range of 120 to 150 N, while for CoPiCS used in EEE in the scope of RoHS, 20 to 50 N are sufficient.[7] The exemption was listed in Annex II with the following wording:

Lead in compliant pin connector systems

As the stakeholders had stated in 2010 that lead-free alternatives were under development, the exemption was scheduled for review in 2014. In this review, the stakeholders and Gensch et al. (2015) agreed on a rewording of the exemption, which resulted in the current wording of exemption 8 (f) (b) with a review date in 2019.

6.1.2. Technical Background

ACEA et al. (2018 a) say that press-fit connectors systems (CoPiCS) provide a method of attachment and electrical contact between a connector and printed circuit board (PCB) which does not require a soldering operation. The pin contacts are inserted into plated through holes (PTH) in the PCB (see figure 1) and the mechanical design of the pin provides reliable electrical contact. The compliant pins must be sufficiently flexible to deform as they are inserted into the holes without an excessively high force that might damage the plating in the holes. The press fit technology thus saves solder material and energy. CoPiCS are widely used in safety-related parts like anti-lock

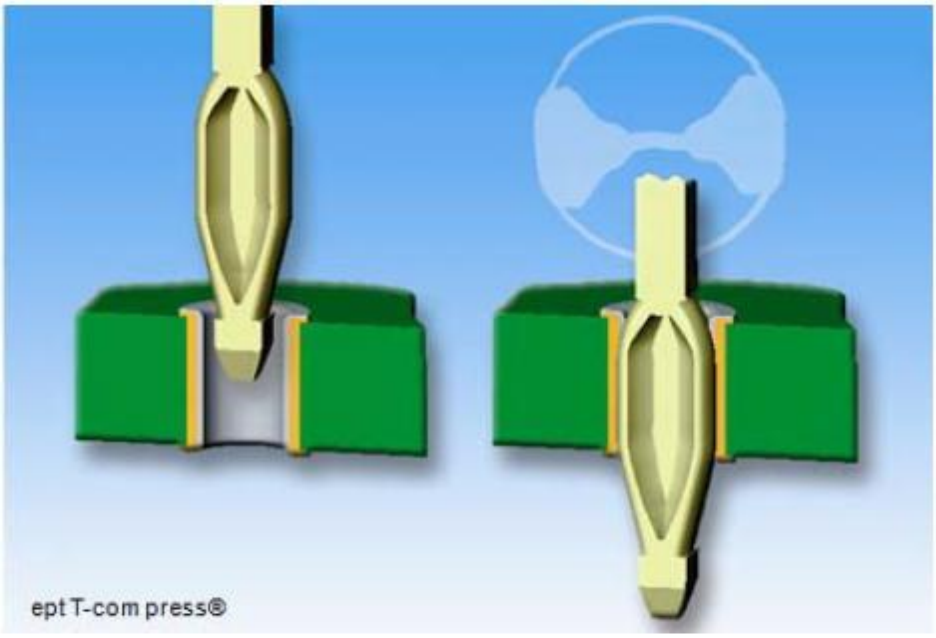
5 Cf. Directive 2000/53/EC (ELV Directive) from 21.10.2000, Annex II, exemption 11: https://eur-lex.europa.eu/resource.html?uri=cellar:02fa83cf-bf28-4afc-8f9f-eb201bd61813.0005.02/DOC_1&format=PDF

6 For details see pages 140 to 152: Oeko-Institut (2009) Gensch, C.; Zangl, S.; Groß, R.; Weber, A. (Oeko-Institut e.V.); Deubzer, O. (Fraunhofer IZM); Adaptation to scientific and technical progress under Directive 2002/95/EC, Final Report, February 2009, retrievable from http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf; last accessed 20.11.2011

7 For details see pages 109-118: Oeko-Institut (2010) Zangl, S.; Hendel, M.; Blepp, M.; Liu, R.; Gensch, C. (Oeko-Institut); Deubzer, O. (Fraunhofer Institute for Reliability and Microintegration IZM); 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), revised version of the final report, Freiburg, 28 July 2010, retrievable from https://circabc.europa.eu/sd/d/a4bca0a9-b6de-401d-beff-6d15bf423915/Corr_Final%20report_ELV_RoHS_28_07_2010.pdf; last accessed 5.09.2013

braking systems or airbag systems. In case of a failure, human life is directly endangered.

Figure 6-1: Insertion of pins of a compliant pin connector system



Source: ACEA et al. (2018b b)

To enable a smooth insertion process and prevent the growth of whiskers, ACEA et al. (2018 a) state that the CoPiCS are pre-coated for technical reasons in joining technology with thin layers which have been made from lead, which have to be replaced by lead-free solutions.

Further details about the technical background of the exemption are described in the report of the last review [8].

6.1.3. Amount of Lead Used under the Exemption

ACEA et al. (2018 a) estimate the amount of lead in applications in the scope of this exemption with around 150 kg per year in the EU28 + EFTA. The calculation is based on the below Table 6-1.

8 For details c.f. Gensch et al. 2015, page 29 sqq.

Table 6-1: Estimation of lead used per year under the exemption in the EU28+EFTA

Value	**Unit**	**Description**
3.2	mm	Circumference of pin
7.0	mm	Length of surface
0.8	µm	Thickness of layer
7%	Pb portion of layer	
0.0012544	mm^3	Volume of Pb per pin
0.011342	g/mm^3	Specific mass density of Pb
14.2274	µg	Weight of Pb per pin
7 – 10 – 16 Average: 10 *(2013: 14,2274)*	mg Pb/vehicle	Weight of Pb per vehicle Calculation, assuming all pins contain Pb, typical amounts: 1.600 (simple electronic equipped) – 2.200 (medium electronic equipped) – 3.500 (high electronic equipped) pins per wire harness in average (means per vehicle), thereof 90% contacts for ECU, thereof 70% press fit technology thereof max 50 % with leaded pins Multiplied with weight of Pb per pin (for details see table 2)
15.659.624 *(2013: 12.340.000[vii])*	vehicle	New vehicles in European Union 2017[viii]
0,15 *(2013: 0,19)*	**t**	Pb

	Vehicle Type		
	simple electronic equipped	Medium electronic equipped	high electronic equipped
pins per wire harness of a vehicle	1.600	2.200	3.500
thereof 90% contacts for ECUs, thereof 70% press fit technology	1008	1386	2205
thereof max. 50 % leaded pins: Max. Pb in mg / vehicle	7,2	9,8	15,7
Average market share	50%	30%	20%
Average Pb in vehicles on market in mg	10		

Source: ACEA et al. (2018 a)

ACEA et al. had calculated the use of around 200 kg in 2014 which is a 25 % reduction despite, according to ACEA et al. (2018 b), the number of CoPiCS used in the car as well as the amount of cars produced have been increasing in the range of 20 % in the same time. ACEA et al. (2018 b) explain this with the fact that after the last ELV revision in 2015, the OEM and Tier1 already avoid lead in those applications where this was possible. ACEA et al. (2018 b) expect that further reductions will be realized with more and more vehicles coming on the market with new type approvals and new developed components.

6.2. Stakeholders' Justification for the Exemption

6.2.1. Technical Arguments

ACEA et al. (2018 a) state that "[…] *Lead-containing coating of press fits is still unavoidable due to safety and reliability reasons in some cases. Overall the amount of Pb used by this exemption is very limited and we want to point out that since 2009 a significant reduction of Pb has already been achieved, despite an increase of electrification and vehicles put on the EU market.*" Based on data and calculations of ACEA et al. (2018 a), the lead use in this application has decreased from 800 kg in 2009 to 150 kg in 2018.

ACEA et al. (2018 a) further on summarize:

- Some major applications with lead-free CoPiCS have been successfully implemented.
- The implementation of lead-free CoPiCS has been promoted and new production capacities are being built up.
- Whisker growth elimination/reduction is a target of the new pin plating technologies in development. However, for high reliability and safety critical automotive applications, CoPiCS pins containing lead are still essentially required as a fallback solution.

In the past years, ACEA et al. (2018 a) conducted intensive research related to geometry, thickness, alternative surface materials and technologies. The mechanism of whisker formation and growth was thoroughly investigated so that there is now a high level of scientific based knowledge and understanding on the issue. However, due to the quantity and complexity of influencing factors, in practice unexpected whisker growth is still observed at times and cannot be fully eliminated. In the past this has impacted safety relevant applications. ACEA et al. (2018 a) say that new pin plating technologies in development target whisker growth elimination/reduction. However, for high reliability and safety critical automotive applications, CoPiCS pins containing lead are still required as a fallback solution.

In addition to tin (Sn), tin silver (SnAg) and tin lead (SnPb) surface finishes, ACEA et al. (2018 a) have indium (In) and bismuth (Bi) finishes under development and approval. As a result, promising new technologies have been developed and are being tested and validated for use in new applications and series production. These systems are demonstrating good results to date, however they are not yet completely verified, i.e., usable for all applications.

ACEA et al. (2018 a) describe a three step approach - design and product validation, long-term reliability tests and ramp-up production - for lead-free plated CoPiCS considering all available technologies, providing the following details on the process steps:

Step 1: Design and product validation

- Status of tin (Sn) platings;
  - Available on market as of 2003;

- Status of tin-silver (SnAg) platings;
  - Start of production (SOP) 2013;
  - Available on market as of 2013, multiple sources in evaluation;
- Status of indium (In) platings;
  - SOP 2018;
  - Available on market as of 2016;
- Status of bismuth (Bi) platings:
  - SOP 2019;
- Available on market as of 2018;

Step 2: Long-term reliability tests

- Status of Sn platings:
  - Field experience for specific products available e.g. electronic control units (ECUs) for Airbags;
  - Multiple pin families;
  - CuSn6, CuNiSi basematerial;
  - iSn (immersion tin), iAg (immersion silver), OSP (organic surface protection); PCB (printed circuit board) plating technology;
  - Several plating lines and production Design of Experiment series (DoE) in operation;

    Sn is not IP protected, free to use by everyone;

- Status of SnAg platings:
  - Field experience for specific products available, e.g. Airbag-ECU's;
  - Laboratory scale long time experience since 2011;
  - Long time field experience since 2014;
  - Multiple pin families;
  - CuSn6, CuNiSi Basematerial;
  - iSn, iAg and OSP PCB plating technology;
  - Several plating lines at different suppliers;

    Several SnAg solutions are available, partly IP protected;

- Status for In platings:
  - Limited field experience available (starting 2018) on Body Electronics;
  - Product validations on different product families (e.g. Body controller, Airbag ECUs);
  - Laboratory scale long time experience since 2011;
  - Multiple pin families tested, 2 different CoPiCs in production;
  - iSn and OSP PCB plating technologies tested, iSn in series production on first product;
  - High temperature long time reliability tested;
  - 2 plating lines at 1 location;

    In is not IP protected;

- Status for Bi platings:
  - No field experience;
  - Product validations on different product families ongoing;
  - Laboratory scale long time experience since 2013;
  - Multiple pin families tested;
  - iSn, iAg and OSP PCB plating technologies tested;
  - High temperature long time reliability tested;
  - 2 plating lines at 1 location available, extension planned;
  - Bi is not IP protected;

Step 3: Ramp-up production of lead-free CoPiCS:

Sn: no issues

- SnAg:
  - Available in Germany on several production lines at various suppliers;
  - There are 3 different plating technologies in production;
  - Roll out plan for Asia and NAFTA as of 2020;

  Overall capacity exceeds volume of current SnPb press-fit plating;
- In:
  - Available in Germany at one location;
  - Roll out plan for Europe (2018 ff), Asia (2019 ff) and NAFTA (2020 ff);
  - Roll out plan for multiple product groups (2019 - 2021);
  - Long term manufacturing and field experience is required to complete implementation;
- Bi:
  - Available in Germany;
  - Roll out plan for Asia and NAFTA as of 2020;

In general, ACEA et al. (2018 a) claim, production must be feasible in all regions, as supply chain is globally located. ACEA et al. (2018 a) claim that "*Industry is committed to use Pb free solutions for new developments, nevertheless SnPb is still required as fall-back due to whisker risk for existing legacy components*." Therefore, another review date for exemption 8(f)(b) in 2024 is suggested, to allow a transition time with commitment to further develop lead-free alternatives since field and global production experience for newly developed alternatives is still missing:

- for migration from one to another technology;
- for new vehicle type approvals;
- for carry-over parts to be allowed to use layers as specified when approved.

6.2.2. Non-technical Arguments

ACEA et al. (2018 a) point out that any kind of press fit applications are more material efficient than soldering. Small and medium sized companies might need more time to adopt and realize change. For end-of-life vehicles a clearly defined take back and recycling route is established in the EU. Exposition coming from Pb in this application therefore is unlikely due to the additional fact that the contained lead is part of the base metal of the pin, and is part of the metal recycling process. ACEA et al. (2018 a) should like to point out that the application of indium and bismuth as a substitute for Lead may interfere with the EU Report on Critical Raw Materials and the Circular Economy[9].

6.3. Critical review

6.3.1. Use of Lead in CoPiCS for Legacy Products

The consultants asked ACEA et al. to further elaborate their statement that lead is still required for legacy products. In the consultants' understanding, lead-containing CoPiCS can still be applied in the production of new vehicles with type approval prior to a potential restriction or repeal of the exemption scope as well as for the repair of those vehicles. ACEA et al. (2018 b) skipped their earlier argument that lead-containing CoPiCS are still required for legacy products answering that "*Legacy parts are out of focus for this request. The intent concerning the fall-back solution, is not to use lead-containing pins for repair. The fall-back solution is needed to cover unexpected emergency cases where newly developed alternative surface finishes show reliability issues in the field which have not been covered or detected by the environmental test plans.*"

The need expressed above for lead use in legacy products such as carry over parts and others is thus obsolete. ACEA et al. had explained in the report of Zangl, Stéphanie [Öko-Institut e.V.] et al. (2010) that a carry-over is an electrical or electronic system used in a new type approved vehicle without functional change, which was or still is used in a previous vehicle type with earlier type approval. ACEA et al. had requested the use of lead in solders of printed circuit boards of carry over parts in an earlier review already. Zangl, Stéphanie [Öko-Institut e.V.] et al. (2010) had recommended[10] to decline this request, and the Commission followed this recommendation. In line with the requirements of Art. 4(2)(b)(ii) and with the past exemption review practices agreed with the Commission, carry over parts do not justify an exemption. To accommodate the specific situation of vehicle manufacturers in terms of product redesign cycles and legal reliability requirements, the continued use of carry over parts and other legacy products using a certain exemption is limited to vehicles with type approval prior to the date when the exemption expired, was repealed or its scope restricted.

6.3.2. Substitution and Elimination of Lead

ACEA et al.'s remaining justification for the continued use of lead is thus the fall-back option in case lead-free CoPiCS fail in the field, in particular in applications that are relevant for safety.

9 https://ec.europa.eu/commission/publications/report-critical-raw-materials-and-circular-economy_en (source as referenced by ACEA et al.)

10 For details see Zangl, Stéphanie [Öko-Institut e.V.] et al. 2010, page 90 sqq.

ACEA et al. were requested to describe in more detail the major applications with successfully implemented lead-free CoPiCS. ACEA et al. (2018 a) explain that after "*[…] ELV exemption 8(f)(b) got effective, new generations of control units are developed pre-dominantly with new Lead-free surface finish alternatives. Since some years for example several airbag ECUs* [electronic control unites; note of the consultants] *are using such alternatives. Beginning 2018, a first body control unit has been designed using an alternative surface finish and several next generation engine control units as well are designed to use such alternative surface finishes. Upcoming future applications in general are targeted to avoid Lead-containing surfaces at CoPiCS.*"

ACEA et al. (2018 b) confirm that "*The fall-back solution is needed to cover unexpected emergency cases where newly developed alternative surface finishes show reliability issues in the field which have not been covered or detected by the environmental test plans.*" ACEA et al. (2018 a) had further narrowed down this need to high reliability and safety critical automotive applications without specifying these applications. ACEA et al. were therefore asked whether there is a clear and generally acknowledged definition of "safety critical parts" in the automotive context, or whether it would at least be possible to clearly identify applications/parts that are not safety-critical.

ACEA et al. (2019b) said that there is neither a standard defining safety critical parts nor any legally assured definition. In practice, it requires a case-to-case consideration to exclude personal injuries. The term could be interpreted based on the product safety regulation that the intended or foreseeable use of a product shall not endanger the safety and health of persons. ACEA et al. did not provide any information which parts using CoPiCS could be considered as not safety-critical.

The consultants understand that the reliability of components in particular in safety critical applications is essential, and the root causes and understanding of whisker growth as the main reason for potential reliability issues is a scientifically complex issue. At the same time, keeping open options for the use of lead in applications where lead-free solutions are available in the consultants' understanding of Art. 4(2)(b)(ii) can only be a temporarily limited solution, if at all.

The consultants therefore deem an expiry date appropriate since ACEA et al. could not deliver a clear picture as to which safety-critical applications are actually those that would require the fallback option, or at least which applications of CoPiCS are definitely not safety relevant.

Besides surfaces like tin and tin-silver, which are already in use and can be produced in large production capacities, indium and bismuth surfaces are to become available for use in the period between 2019 to 2021, as described in section 6.2.1 on page 30. Given the overall situation with risks for safety-critical applications on the one hand and available and soon available various lead-free pin surfaces for CoPiCS on the other, the consultants recommend continuing exemption 8(f)(b) for four years beyond 2019 and setting an expiry date in 31 December 2023. The additional two years after the indium and bismuth surfaces have become available in 2021 at latest can be used to collect field experience with these coatings as a further lead-free alternative.

Should the case arise that within this period emergencies occur requiring the use of lead in specific components as a fallback option beyond 2023, ACEA et al. can apply for a more specific exemption clearly nominating the cases where the use of lead is to be considered as unavoidable, e.g. in lack of sufficient reliability of the lead-free alternatives for these specific uses.

6.3.3. Non-Technical Arguments

ACEA et al. mention that only a minor amount of lead is used in CoPiCS, and that they have considerably reduced this amount of lead in the past years. Even though the consultants understand the concerns about the efficiency of avoiding minor amounts of lead, the European legislators have not foreseen a threshold of lead in applications that would allow exempting such applications in line with Art. 4(2)(b)(II). Further on, Art. 4(2)(b)(II) does not foresee to reward past efforts and merits in reducing restricted substances with granting exemptions. It is what producers are expected to do and shows that substitution of a restricted substance is viable.

The CRM-list (2017) actually lists bismuth and indium, two of the alternatives to lead in CoPiCS, as critical raw materials. Any decision whether and how far this constellation can justify continuing exemption 8(f)(b) is beyond the consultants' mandate. ACEA et al. should discuss this aspect with the Commission.

6.4. Conclusions

Technically, lead-free CoPiCS are increasingly available, and more experience could be collected with such lead-free solutions to a degree that ACEA et al. deem the exemption only to be needed for emergencies where lead-free solutions in safety critical applications fail and thus jeopardize human safety and lives. ACEA et al. do not specify which safety critical applications this would include, or at least which ones are not safety-critical ones. Based on the technical situation described by ACEA et al. and their arguments, the consultants' recommend continuing exemption 8(f)(b) for four years beyond 2019 for vehicles type approved before 1 January 2024. The current status of lead-free CoPiCS and the increasing availability of more lead-free alternatives in the consultants' understanding show that the complete substitution of lead is foreseeable and an expiry date at the end of 2024 therefore justified.

6.5. Recommendations

The consultants recommend to continue exemption 8(f)(b) to accommodate the automotive industry's responsibility for the safety of their products. Given the available and upcoming lead-free solutions and the time lines described in section 6.2.1 on page 30, the consultants further on plead for setting an expiry date on 31 December 2023. The expiry data appraises the fact that lead-free CoPiCS are already in use, and that further substitution is foreseeable so that the continuation of the exemption with its current broad scope after 2024 with a review date only, as requested by ACEA et al., in the consultants' understanding would infringe the stipulation in Art. 4(2)(b)(II) to restrict the use of lead unless its use is unavoidable.

The four years extension allows ACEA et al. a temporary fall back option should cases arise that lead-free CoPiCS, which successfully passed the reliability tests, nevertheless fail in the field. Should a further extension of the exemption be required beyond 2023, ACEA et al. can apply specifically for the continuation of the exemption for those cases where such emergencies actually occurred or for which the continuation of the exemption may be justified for other reasons in line with Art. 4(2)(b)(II), provided ACEA et al. can substantiate such claims, in particularly proving that none of the various lead-free solutions is viable.

The wording of the exemption is recommended as below:

	Materials and Components	Scope and Expiry Date of the Exemption	Comments
	Lead in compliant pin connector systems other than the mating area of vehicle harness connectors	In vehicles type-approved before 1 January 2024 and after that date as spare parts for these vehicles	--

6.6. References

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Klicken Sie hier, um Text einzugeben.

7. Exemption 8(g)

"Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages"

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.

Acronyms and definitions

EEE	electrical and electronic equipment
FCOL	flip chip on lead-frame
FCP	flip chip package
Pb	lead

7.1. Description of Requested Exemption

According to Annex II of the ELV Directive Exemption 8(g) is to be reviewed in 2019.

> *"8(g): Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages"*

ACEA et al. 2018 a request the continuation of the exemption until 2024.

7.2. History of the Exemption

The use of lead in the applications addressed under Ex. 8(g) was not explicitly listed in Annex II of the ELV Directive[11] when it was adopted. The use of lead solders in electronic parts of vehicles was covered at that time by the general exemption "*Solder in electronic circuit boards and other applications*" (no. 11). In the course of the 2010 review by Zangl, Stéphanie [Öko-Institut e.V.] et al. (2010), the former exemption 11 was specified, which resulted in the current exemption 8(g). Its wording was taken over from RoHS, where it was listed as exemption 15 from 2005 on.[12]

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[11] Cf. Directive 2000/53/EC (ELV Directive) from 21.10.2000, Annex II, exemption 11: https://eur-lex.europa.eu/resource.html?uri=cellar:02fa83cf-bf28-4afc-8f9f-eb201bd61813.0005.02/DOC_1&format=PDF

[12] C.f. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02002L0095-20051025

Gensch et al. (2015) reviewed the exemption again in 2014 in the ELV context. The Commission decided to continue the exemption with the same wording and set a review date in 2019.

In 2015/2016, Gensch et al. (2016b) reviewed exemption 15 of Annex III of RoHS Directive (2011) after industry had applied for its continuation beyond 2016 with a restricted scope reflecting the status of science and technology. The review resulted in the new wording as reflected in RoHS exemption 15(a):

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 mm² or larger in any semiconductor technology node
c) Stacked die packages with dies of 300 mm² or larger, or silicon interposers of 300 mm2 or larger

The review of ELV exemption 8(g) will thus focus on clarifying whether and how far the above wording is applicable for the future exemption 8(g).

7.3. Technical Background

The technical background of the exemption is described in the review report of Gensch et al. (2015) as well as in the report of Gensch et al. 2016.

7.3.1. Applications of FCP in Automotive Systems

According to ACEA et al. 2018 a, exemption 8(g) is relevant for all automotive models being designed, produced and currently on the market. Examples of applications used in vehicles are listed but not limited to the below:

- Electronic stability control systems
- Advanced emergency braking systems
- Distance control
- Lane departure warning systems
- Frontal projection systems
- Pedestrian protection
- Tire pressure monitoring systems to reduce rolling resistance and noise emissions
- Hydrogen and hybrid cars
- Car radio
- Vision systems
- Car-infotainment
- Traffic sign recognition
- Navigation
- Telematics
- Head-up displays

7.3.2. Amount of Lead Used under the Exemption

ACEA et al. 2018 a calculate the annual total amount of lead used under the exemption based on the data in Table 7-1.

Table 7-1: Basic data for calculation of lead use under exemption 8 (g)

EU Vehicle Sales in 2017 [viii]						
ACEA Report						
Vehicle Type	2017 Totals (Mio units)		Minimum amount of Pb per vehicle (mg)	Maximum amount of Pb per vehicle (mg)	Minimum total Pb (kg)	Maximum total Pb (kg)
All	15,659		2	35	31	548

Source: ACEA et al. (2018 a)

The annual total use of lead under exemption 8 (g) is between around 30 kg and around 550 kg per year in the EU. ACEA et al. (2018 a) assume an average value of 17 mg of lead per vehicle resulting in around 250 kg of lead per year in the around 15.7 million vehicles out on the EU market in 2017. This is in a similar range as the around 200 kg to 600 kg of lead contained in the around 13.4 million registered vehicles put on the 2015 EU market, specified in the review report of Gensch et al. (2015).

7.4. Stakeholders' Justification for the Exemption

7.4.1. Substitution of Lead in FCPs in General

ACEA et al. 2018 a explain that high lead bumps in a semiconductor device are less rigid and can absorb a part of the stress induced during package assembly and during the board mounting process. Pb-free solutions are not able to meet these capabilities to date and fail standard qualification requirements. For vehicles, there are additional long-term reliability requirements under the harsh environmental conditions according to automotive specifications (e.g.AEC-Q100[2]) that need to be assessed and qualified according to automotive specifications.

ACEA et al. 2018 a are concerned that the review of this exemption by the Commission within the RoHS review process (c.f. Gensch et al. (2016b) likely did not provide every use case requiring the continuation of lead use in flip chip applications that were requested by the exemption extension technical team.

According to ACEA et al. 2018 a, lead-free efforts were focused 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 the legacy package technology, they are not drop in replacements. To achieve the basic 15-year service life of products in vehicles (post end of life for the vehicle's production), they must maintain form, fit and function. Minor changes affecting these parameters cannot be ones that:

- Modify the devices height, width or length.
- Change how the connections from the device to the printed circuit board fit together.
- 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.

ACEA et al. 2018 a state that if these devices were to be continually migrated to the latest IC fabrication process, the cost of designing new ICs and qualifying them in the systems would be prohibitive for many products. Where it has not been feasible to move old designs into new IC technologies, the remaining devices present minimal risk to the environment. The remaining devices manufactured in leaded flip chip attach are expected to decline steadily over the next 5 years as those products are replaced with newer technology.

According to ACEA et al. 2018 a, "*ELV is not directly comparable to RoHS due to different product scope, covered applications and product use profiles. They therefore ask to keep the current ELV Annex II wording as this covers following essentially required characteristics, at least:*

- Greater Than or Equal to 90nm semiconductor technology node;
- Die size greater than or equal to 300mm^2 in any semiconductor technology / node (including stacked die);
- Stacked Die Packages using interposers greater than or equal to 300mm^2;
- High current products (Rated at greater than or equal to 3amps) that use smaller package designs (With die sizes less than 300mm^2) incorporating the flip chip on leadframe (FCOL) interconnect."

For the reasons outlined, ACEA et al. (2018 a) feel "[…] *that an extension of at least 5 years is required for this exemption using the current wording. While the current form of the exemption is felt to be sufficient, the industry is willing to narrow the scope of the current exemption based to die size greater than 300 square millimeters or integrated circuit technologies greater than 90nm, and high current flip chip on leadframe (FCOL). 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."*

7.4.2. Substitution of Lead in FCOL

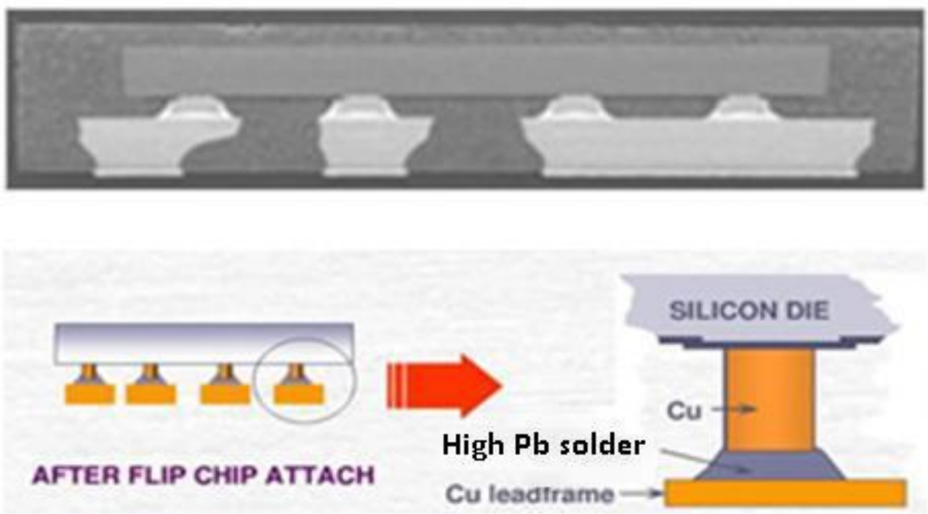
ACEA et al. 2018 a say that "*Currently it is not possible to retrofit older Lead solder based FCOL parts into Lead-free solders. A brittle solder joint may drive 2 fail modes:*

1. Strain transferred to the die may create cracked dielectric and metal lines

2. Solder joint is less robust and may crack, causing an electric open

Failure rates have exceeded 20 %. If pillar sizes are reduced to alleviate this stress, high current pillars will no longer meet electromigration limits."

Figure 7-1: Sample of a FCOL



Source: ACEA et al. 2018 a

ACEA et al. 2018 a explain that lead-free solder joints are more brittle and require a different set of design rules. The design rule changes would create a major change in package and die layout to convert from high-lead to lead-free. These types of major changes are not allowed for existing automotive products with expected long-term life requirements.

According to ACEA et al. 2018 a, 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 solutions. The packages are assembled on a Pb-free profile and the Pb internal solder joint using a 60 % Pb solution 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.

7.5. Critical Review

7.5.1. Substitution of Lead in FCPs for Automotive Uses

Table 7-2 compares the minimum requirements which ACEA et al. 2018 a need to have in the scope of exemption 8 (g) with the new wording of exemption 15(a) after the 2015/2016 revision.

Table 7-2: Comparison of ACEA et al.'s minimum scope requirements with wording of RoHS exemption 15 (a)

Item	Lead in solders to complete a viable electrical connection between the semiconductor die and carrier within integrated circuit flip chip packages (where at least one of the following criteria applies):	
	ACEA et al.'s minimum scope requirements	**Wording for RoHS Ex. 15 as Adopted by the Commission**
1	Greater than or equal to 90 nm semiconductor technology node;	A semiconductor technology node of 90 nm or larger;
2	Die size greater than or equal to 300 mm^2 in any semiconductor technology / node (including stacked die)	A single die of 300 mm^2 or larger in any semiconductor technology node; Stacked die packages with dies of 300 mm^2 or larger, or silicon interposers of 300 mm^2 or larger.
3	High current products (rated at greater than or equal to 3 A) that use smaller package designs (with die sizes less than 300 mm^2) incorporating the flip chip on lead frame (FCOL) interconnect.	***Requested, but not adopted by the Commission:*** *High current products (rated at greater than or equal to 3 A) that use smaller package designs (with die sizes less than 300mm^2) incorporating the flip chip on lead frame (FCOL) interconnect.*

Source of the left column requirements: ACEA et al. (2018 a)

In the review of RoHS exemption 15 in 2015/2016, the applicant had requested to include point 3 into the new wording as well, but could not substantiate their request. In the absence of clear evidence, Gensch et al. (2016b) could not recommend to grant this part of the exemption, and the Commission followed this recommendation.

In the consultants understanding, besides the FCOL under point 3 in Table 7-2, RoHS exemption 15(a) reflects the minimum requirements, which ACEA et al. need to be covered. To avoid misunderstandings, ACEA et al. (2018 b) were asked whether they share this point of view, but did not answer the question, which the consultants understand to mean that there are no technical objections. The comparison of points 1 and 2 in Table 7-2 shows a clear congruence of ACEA et al.'s minimum scope requirements with the wording of RoHS exemption 15(a). ACEA et al. did not present plausible technical facts proving the opposite, and ACEA et al. (2018 a) had shown willingness to narrow down the scope to these applications. The consultants recommend to adopt the wording under points 1 and 2 in RoHS exemption 15(a) for the future exemption 8 (g).

7.5.2. Substitution of Lead in FCOLs

Status of Lead Substitution in FCOLs on Component Level

ACEA et al. (2018 b) state that *"From our supply chain it is confirmed that FCOL high current products (… greater than or equal to 3A) …) are in use and need to be included in scope of an exemption."*

ACEA et al. were asked to provide the necessary evidence that the use of lead in these FCOLs is actually unavoidable and to answer the questions that had remained open for the use of lead in FCOL in the review of RoHS exemption 15 despite of several attempts to obtain a clear answer.

1) Why is the use of lead unavoidable in high current FCOLs despite of die sizes smaller than 300 mm^2, where lead-free solutions are available for other types of FCPs; and
2) How is the high current relevant in this context, taking into account that lead-free FCPs of other types may also have to stand the impacts of high currents?

Concerning the second question ACEA et al. (2018a c) stated that *"There is no information available from our supply chain beyond the yet provided submissions."*

The yet provided information from ACEA et al. (2018 a) as reflected in section 7.4.2 on page 41 says that (lead-free) pillar sizes cannot be reduced to alleviate stress since the high current will then exceed electromigration limits. The statement seems to refer to retrodesigned older FCOL. It is not clear whether and how far this applies to new high current FCOL. According to ACEA et al. (2018 b), examples for these FCOLs are those listed under number 3 in the above Table 7-2. The context with the lead frame is not explained. Beyond the statement that electromigration plays a role, the answer does not further illustrate and explain the technical reasons why high currents and resulting electromigration require the use of lead on FCOLs with chips of less than 300 mm^2 while it seems to be irrelevant for other FCPs.

Concerning question 1, ACEA et al. (2018b c) replied that *"[…] Lead-free vehicle-suitable and sufficient reliable substitutes which could cover production volume demands are not known. E.g Analog Devices (ADI) states in a document[13] released in November 2018, that "ADI continues to use Pb in die attach adhesives, glass, and flip chip interconnection where regulations allow an exemption* ***until reliable alternatives are available. "*** *This statement is shared with Texas Instruments and has included the latest test failures seen for a Pb-free vs Pb solution.*

These statements do not answer the above technical questions. Moreover, ADI's statement only refers to SOT23-FCOL and thus cannot justify why the use of lead is generally unavoidable. Additionally, it is not clear whether the statement refers to retrofit FCOLs or new type FCOLs.

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13 https://www.analog.com/media/en/quality/RoHS_Compliance_General_Info.pdf; last accessed Dec.16.2018 (as reference by ACEA et al. 2018a c)

To clarify the situation and to exclude principal misunderstandings, the consultants sent out another questionnaire to ACEA et al. and proposed a phone conference with a technical expert who could explain the technical background and then answer the technical questions in this questionnaire. In a phone conference with ACEA on 14 January 2019, the consultant explained the background of the question for technical details and again asked for an interview with a technical expert. Contrary to their announcement, ACEA et al. have not come back with a specific proposal as to such a phone conference.

ACEA et al. (2018a c) answered the last questionnaire explaining that "*FCP products other than FCOL are not typically designed to run at greater than 3 A on a single net/pin as is typical of the FCOL products. […] When delivering current greater than 3 A, very high density of copper must be used in the package to support that current. The difference in thermal coefficient between the copper (17ppm / degree C) in the package and the silicon chip (2.6 ppm /degree C) creates a very high stress interface. Lead ability to absorb this strain lends to a reliable package*."

This explanation gives some insights, but is not a coherent and sufficiently comprehensible explanation why the high current FCOLs need to use lead despite of die sizes smaller than 300 mm^2 where the use of lead is avoidable for such die sizes in other FCPs.

ACEA et al. (2018a c) further on state that "*While it is agreed that new devices designed for lead-free are available. For the older products that were designed with lead, these cannot be converted".* The consultants had additionally asked whether the use of lead is actually unavoidable for high current (3 A and more) FCOLs which are NOT retrofits but from the beginning are designed for use of lead-free solders. ACEA et al. (2018a c) answered this question with "*Yes*".

As for earlier questions concerning the substitution of lead in new type high current FCOLs, ACEA et al. (2018b c) had answered that "*There is some success in the research and development phase, but not in a manufacturing phase. Within the next 3 to 5 years it may be possible to have manufacturable solutions available for newer FCOL package designs."* Overall, the information provided is contradictory, confusing and not substantiated. After the efforts of four rounds of questionnaires and a phone call including a request to discuss the technical details with an expert, the consultants did not attempt further clarifications of the situation but decided to evaluate the request based on the information submitted so far.

The consultants understand that the use of lead is avoidable in high current FCPs - which, according to ACEA et al., should typically be FCOLs - that are not old, retrofit FCPs but are from the beginning designed to avoid the use of lead. Such new types of high current FCPs cannot be used in products to replace lead-containing FCPs due to, for example, different geometries. The products would have to be redesigned as well, to accommodate the geometrical and electrical properties of lead-free high current FCPs.

The fact that the use of lead is unavoidable in retrofit FCOLs in the consultants' understanding would not justify recommending an exemption if at the same time new type FCOLs or other types of FCPs can provide all electrical and electronic functionalities without using lead. This would apply even if these new type components require the redesign of electronic circuits and modules, which applicants are expected to do if it makes the use of lead unavoidable. Potential needs to use FCOLs in carry over and other legacy parts were accommodated in an earlier review in 2010 by using the type approval as deadline for restrictions in the course of narrowing exemption scopes and exemption expiries. Details are explained in Section 6.3.1 on page 33.

Availability of Lead-free High Current FCOLs for Use in Automotive Applications

Possibly, the lead-free new type high current FCPs may be available on component level, but not be appropriate and qualified for automotive uses. ACEA et al. (2018a c), (2018 a) reference the test results presented in the below Figure 7-2 as further evidence that lead-free FCOLs cannot be qualified and used in vehicles.

Figure 7-2: Test results of FCOL packages

Pb-free based packages			Pb-based packages		
Quantity	# failures	# cycles	Quantity	# failures	# cycles
55	17	500	240	0	500
50	38	750	240	0	750

Source: ACEA et al. (2018a c), (2018 a)

According to ACEA et al. (2018 b), "*[…] all failures were re conducted to the Lead free material. In general, statistical methods and established quality instruments for automotive electronic components are applied to make decisions, if a component may be used in volume production." […] The large-scale availability of Lead- free variants will still require additional development time for ensuring their long-term reliability. It is excluded to use insufficient tested components or to reduce reliability demands."*

To have a better frame for the interpretation of the above results, the consultants asked for more details. ACEA et al. (2018a c) detailed that "*The tested lead free parts are lead-free retrofits."* […] *Technology node tested is greater than 90 nm. The die areas are much smaller than the 300mm^2 exception currently stated in 8(g). Usually less than 25 mm^2. Current ranges from 2 – 15 amperes for the devices tested."*

Since the technology node of the tested FCOL is larger than 90 nm, part 1 of the new wording which the consultants propose for exemption 8 (g) (c.f. Table 7-2 on page 43) would allow the use of lead in the tested FCOL packages. The specific exemption for high current FCOLs (c.f. part 3 of Table 7-2) is not necessary to allow the use of lead in the tested components. To prove the unavoidability of lead use in components in the scope of this part of the exemption, the test samples would have to exhibit a technology node of less than 90 nm besides the small die (< 300 mm²). Adding to this, the test samples were retrofit FCOLs, which the large technology node had already implied.

The test results thus in the best case prove that retrofit FCOLs other than those in the scope of part 3 of the proposed new exemption wording do not qualify for use in automotive applications. There is no evidence that the use of lead is unavoidable in FCOLs that would fall in the scope of this part 3 which ACEA et al. consider a minimum requirement for the future exemption 8 (g).

The available information suggests that new types of high current FCPs seem to be available as lead-free versions. The presented test result is no evidence that these components are not appropriate for automotive uses and that the use of lead is unavoidable in high current FCOLs for automotive uses. Experience from a previous review oblige the consultants to apply increased diligence and to insist even more on clear and substantiated test results and information as base for positive recommendations.[14]

7.5.3. Objections of ACEA et al. against the Scope Refinement

ACEA et al. (2018 a) had applied for the continuation of exemption 8 (g) in its current wording, but declared their willingness to narrow the scope of the current exemption 8 (g) to the applications listed in the left column of Table 7-2. In the course of the evaluation, the consultants learned that ACEA et al. do not accept adopting the wording of RoHS exemption 15(a) to exemption 8 (g), even if the scope is extended to include FCOLs. In the opinion of ACEA et al. (2018 b) *"[…] the existing wording and scope, as it is, should be continued. If there is an explanation of the scope necessary, it could be specified in the consultant report at our opinion. As the report will be public available, the scope then will be defined in a public accessible document."*

The core objective of the exemption review and the consultants' mandate is, however, to adapt the scope of exemption 8 (g) in Annex II of the ELV Directive to the scientific and technical progress to ensure that the use of lead is restricted to those cases where its use is technically unavoidable. The consultants therefore cannot follow the above argument. A scope clarification in a publicly available document as a kind of an accessory to ELV Annex II is not legally binding. The consultants follow their mandate to adapt exemption 8 (g) to the scientific and technical progress and therefore recommend ACEA et al. to discuss their proposal with the Commission.

ACEA et al. (2018 b) request to "*Please understand that a different wording would cause high administrative burdens. Reporting and monitoring within the IT systems along the supply chain then needs to be changed and we will have a mixture of declarations because of different wordings and that would cause challenges in data assessment.*"

14 For details see Gensch et al. 2015, page 55 et seqq. (chapter 6.33 Conclusions)

It is not further explained why the automotive industry, different from the electrical and electronic (EEE) industry, cannot be expected to bear the burden of a rewording. Adding to this, adopting the new wording of RoHS exemption 15(a) may even reduce the overall administrative burden in the supply chain since most if not all manufacturers of FCPs supply the automotive as well as the EEE sector.

ACEA et al. (2018 b) further on put forward that "*We see that the draft text of the new entry "15 is identical to current entry 8(g) of ELV Annex II."*

The wording of exemption 15 is, however, not new. Due to the different maximum validity periods for exemptions used in medical equipment and industrial monitoring and control instruments, RoHS exemption 15 remains valid in its current official wording until 2021 for medical equipment, 2023 for in-vitro-diagnostic devices and 2024 for industrial monitoring and control instruments. RoHS exemption 15 was reviewed in 2015/2016 for all other types of EEE in the scope of the RoHS Directive, and industry proposed the rewording of exemption 15 including the FCOLs to reflect the scientific and technical progress, which in the end resulted in the new exemption 15(a). ACEA et al. did not provide scientific and technical evidence that it would be technically and scientifically not practicable to adopt this wording for exemption 8 (g) so that the scope reflects the state of the art of lead substitution in FCPs.

ACEA et al. (2018a c) finally argues that "*As there is an average usage of 17 mg of Lead in this application per car we doubt if there is re-ally further progress achievable by defining 5 new subentries." […] "The ELV Directive is based on Articles 174 and 175 of EU (Lisbon) Treaty. Article 174(3) third item states that "- the potential benefits and costs of action or lack of action" shall be taken into account. In combination with article 175 (5) we would like to dispute that further split of entry 8(g) contributes significantly to further Lead reduction respectively overall tar-gets. Therefore we don´t support any further split of the exemption*.

The ELV Directive does not foresee a minimum amount of lead as a justification for granting exemptions, or as hindrance to adapt the scope of exemptions, but stipulates in Art. 4(2)(b)(ii) that the use of restricted substances like lead shall only be possible if its use is unavoidable. Evaluating the ELV Directive and its legality and correct interpretation in the context of other EU treaties – ELV Directive is based on Art. 175(1) - and regulations is beyond the consultants' mandate. ACEA et al. are advised to address these concerns directly to the EU Commission.

7.6. Conclusions

The consultants�because evaluated whether and how far the new wording of RoHS exemption 15(a) of Annex III of RoHS Directive (2011) can be adopted for exemption 8(g). In the absence of substantiated technical arguments, the consultants conclude that this approach is viable so that the scope of the future exemption 8(g) can be specified as follows:

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 dies of 300 mm² or larger, or silicon interposers of 300 mm^2 or larger

ACEA et al. (2018a) claim that they would need a transition period of at least 36 months should the FCPs with smaller dies be excluded from the exemption. The consultants therefore recommend a transition period until 1 October 2022, which is around 36 months from the publication of this report. It is recommended to review the exemption in five years in 2024.

ACEA et al. requested that the following high current FCPS (FCOLs) must be included in the scope of the future exemption 8 (g) as a minimum requirement:

High current products (rated at greater than or equal to 3 A) that use smaller package designs (with die sizes less than 300 mm^2) incorporating the flip chip on lead frame (FCOL) interconnect.

However, ACEA et al. did not provide sufficiently substantiated evidence that the use of lead is unavoidable in these FCOLs so that the consultants cannot recommend an exemption for these applications without infringing Art. 4(2)(b)(II). Based on the available information, the consultants conclude that the wording adopted by the EU Commission for exemption 15 of RoHS Annex III can be applied for exemption 8(g) as well.

7.7. Recommendations

Based on the accessible evidence, granting an exemption with a more narrow scope, in alignment with Ex. 15 of RoHS Annex III, would be in line with Art. 4(2)(b)(ii) in the consultants' point of view. To allow the automotive industry to transition to the scope changes, it is recommended to introduce the exemption to Annex II of the ELV Directive on 1 October 2022. Until this time, the existing exemption should remain valid. The consultants thus recommend the below exemptions to be listed in annex II of ELV instead of the current exemption 8(g).

	Materials and Components	Scope and Expiry Date of the Exemption	Comments
8(g)(I)	Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages	In vehicles type-approved before 1 October 2022 and after that date as spare parts for these vehicles	
8(g)(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 b) A single die of 300 mm^2 or larger in any semiconductor technology node c) Stacked die packages with dies of 300 mm^2 or larger, or silicon interposers of 300 mm^2 or larger	Valid as of 1 October 2022 for vehicles type approved after 30 September 2022	Review in 2024

ACEA et al. had claimed as a minimum requirement the need to include certain high current flip chips on lead frames into the scope of the future exemption.

In the absence of evidence and of clear technical information that and why the use of lead is unavoidable in these components for automotive uses, Art. 4(2)(b)(II) does not allow the consultants to recommend including these components into the scope of the future exemption.

In case the Commission nevertheless wishes to follow the above claim of ACEA et al., the consultants recommend adding a part d) to the above recommended exemption 8(g)(II):

Materials and Components	Scope and Expiry Date of the Exemption	Comments
d) High current products (rated at greater than or equal to 3 A) that use smaller package designs (with die sizes less than 300mm^2) incorporating the flip chip on lead frame (FCOL) interconnect	Valid as of 1 October 2022 for vehicles type approved after 30 September 2022	

The above additional part of the exemption should be reviewed at the latest in 2024.

7.8. References

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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 (amended) for the European Commission DG Environment under Framework Contract No ENV.C.2/FRA/2011/0020. Unter Mitarbeit von Carl-Otto Gensch, Yifaat Baron, Oeko-Institut und Dr. Otmar Deubzer, Fraunhofer IZM (ELV IV). Online verfügbar unter https://circabc.europa.eu/sd/a/86a233f1-93ce-41e7-b4f2-06609a144e1e/ELV-Exemptions_Amended_Final_2015-06-29.pdf.

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Zangl, S.; Hendel, M.; Blepp, M.; Liu, R.; Gensch, C.-O.; Deubzer, O. (2010a): 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). Contract No.: 07.0307/2008/517348/SER/G4, Final report - revised version -. Hg. v. Oeko-Institut e.V. Online verfügbar unter http://elv.exemptions.oeko.info/fileadmin/user_upload/Final_Report/Corr_Final_report_ELV_RoHS_28_07_2010.pdf.

Zangl et al. (2010b): 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. Unter Mitarbeit von Stéphanie Zangl (Öko-Institut), Otmar Deubzer (Fraunhofer IZM), Markus Blepp, Carl-Otto Gensch, Ran Liu, Katja Moch (Öko-Institut e.V.). Öko-Institut e. V. und Fraunhofer IZM. Freiburg (Adaptation to scientific and technical progress of Directive 2000/53/EC and 2002/96/EC; ELV and RoHS exemption review, RoHS IV, ELV II).

8. Exemption 8(j)

"Lead in solders for soldering of laminated glazing"

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.

Acronyms

CTE	coefficient of thermal expansion
ICS	indium-containing solders
LG	laminated glazing
Pb	Lead
SGS	Saint-Gobain Sekurit

Definitions

Liquidus temperature	Temperature at which all components are molten in an alloy, e.g. a solder alloy
Solidus temperature	Temperature at which all components are solidified in an alloy, e.g. a solder alloy

8.1. Description of Requested Exemption

The current wording of exemption 8(j) is:

Exemption formulation	Validity
"Lead in solders for soldering of laminated glazing"	for Vehicles type-approved before 1 January 2020 and after that date as spare parts for these vehicles

ACEA et al. (2018 a) request the continuation of exemption 8(j) beyond 2019 with a slightly different scope:

> Lead in solders for soldering of laminated glazing, except embedded solder contacts in the intermediate polymer

for

vehicles type-approved before 1 January 2024 and spare parts for these vehicles.

Saint-Gobain Sekurit (2018 a) claim that they can offer lead free soldering solutions which are already used in mass production of the automotive industry today so that a continuation of exemption 8(j) is not required.

Antaya (2018 a) call for the immediate removal of exemption 8(j) as they claim to have viable solutions for removing lead in solders for any application, including laminated glazing. They state that their technology was a viable solution in 2013 when the exemption was previously reviewed, and has been further developed so that the use of lead in soldering for all laminated glazing applications, including in and on the glass, is avoidable.

8.2. History of the exemption

The exemptions related to the use of lead in solders for soldering on or in automotive glazing have been reviewed several times since 2007. Until 2009, the use of lead in solders for soldering on glass and in laminated glazing (LG) fell under the scope of the former Exemption 8:

Lead in solder in electronic circuit boards and other applications

in Annex II of the ELV Directive[15], which was valid at that time. During the 2007/2008 review, a stakeholder, Antaya, claimed to have a solution for lead-free soldering on glass and applied for repealing the exemption. Glass makers and vehicle manufacturers opposed Antaya's arguments and views. During the review process, the available stakeholder comments did not provide a basis for a clear recommendation to repeal the exemption. The general exemption for lead in solders was thus further specified, and soldering on glass incl. soldering in laminated glazing was covered by Exemption 8(b)[16]:

Lead in solder in electric applications on glasses

The exemption was reviewed in 2009/2010 again[17], and thereupon was split into two parts:

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15 Cf. Directive 2000/53/EC (ELV Directive) from 21.10.2000, Annex II, exemption 11: https://eur-lex.europa.eu/resource.html?uri=cellar:02fa83cf-bf28-4afc-8f9f-eb201bd61813.0005.02/DOC_1&format=PDF

16 For details see page 45 ff of Oeko-Institut (2008) Stéphanie Zangl, Oeko-Institut e.V.; Otmar Deubzer, Fraunhofer IZM: Adaptation to Scientific and Technical Progress of Annex II Directive 2000/53/EC, final report from January 2008, Oeko-Institut e. V., Fraunhofer IZM; download from http://circa.europa.eu/Public/irc/env/elv/library?l=/stakeholder_consultation/evaluation_procedure/reports/final_report/report_revision/_EN_1.0_&a=d;

17 For details see page 151 ff of Oeko-Institut (2010) Zangl, S.; Hendel, M.; Blepp, M.; Liu, R.; Gensch, c: (Oeko-Institut); Deubzer, O. (Fraunhofer Institute for Reliability and Microintegration IZM); 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), revised version of the final report, Freiburg, 28 July 2010, retrievable rom https://circabc.europa.eu/sd/d/a4bca0a9-b6de-401d-beff-6d15bf423915/Corr_Final%20report_ELV_RoHS_28_07_2010.pdf; last accessed 24.01.2014

> 8(i) *Lead in solders in electrical glazing applications on glass except for soldering in laminated glazing in vehicles type approved before 1 January 2016*;

and

> 8(j) *Lead in solders for soldering in laminated glazing; review in 2014;*

There was no evidence at that time that the proposed indium-based lead-free solder may be viable for soldering in laminated glazing. Oeko-Institut[18] therefore recommended *"[…] to exclude soldering in laminated glass from the ban of lead until there is evidence that a solution is available. To promote the technical and scientific progress towards a lead-free solution, it is recommended to review this exemption in 2014. The stakeholders will then have to show that they have undertaken steps to achieve compliance with the material bans in the ELV Directive."*

The Commission followed the recommendation and set a review date for 2014. The 2014 review showed that the use of lead in applications covered by Exemption 8(j) was avoidable. Lead-free solutions were on the market already or foreseeable for the nearer future, even though adaptions to the individual vehicles and technologies or vehicle redesigns may have been required. A transition period was therefore recommended allowing also the option for case specific exemptions should the use of lead still be unavoidable after 2019. The Commission accepted the expiry date but decided to change the exemption wording to:

> *Lead in solders for soldering of laminated glazing for vehicles type approved before 1 January 2020 and spare parts for these vehicles.*

However, evidence was relayed to the European Commission on the difficulties of phasing-out lead from these applications by the end of 2019. A reassessment of this exemption has thus been performed.

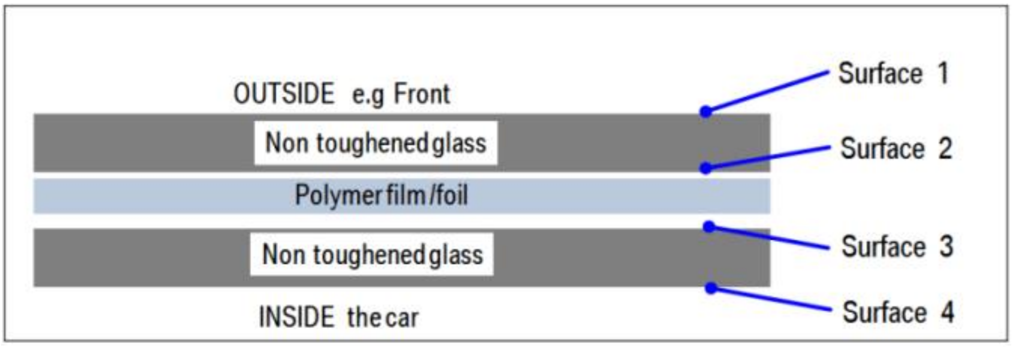
8.3. Technical Background

8.3.1. Use of Lead for Soldering to Glass Panes in Laminated Glazing

Gensch et al. (2015) described the technical background of the exemption in the 2013 review report. The technical facts are still valid, and the information below has therefore been copied from that report if not referenced otherwise. In laminated glazing structures, a polymer layer is embedded between two thinner panes of glass as illustrated in Figure 8-1.

[18] Ibid.

Figure 8-1: Schematic outline of laminated glazing structures



Source: BMW

Soldering of laminated glazing structures may be applied on a silver print on the non-toughened glass, or on a silver print on top of the black lead-free enamel print of the glass, or to wires/films inside/on the foil. Wire materials are tungsten or copper. For typical uses of lead containing solders within laminated glazing structures, ACEA et al. (2018 a), see reference to earlier submissions which are described in Gensch et al. (2015):

1. Heating Applications

a) Heated Wire Windshield or Backlight
The technology is used to defrost/defog the entire windshield or backlight. Thin tungsten wires are embedded onto the interlayer materials (e.g.: polyvinyl butyral (PVB)) with solder connections to copper strip busbars. All is assembled between two plies of glass.

b) Heated Coated Windshield
The technology is used to defrost/defog the entire windshield. A metallic coating is heated by an electrical current. The electricity is applied through connectors soldered/ welded on busbars in contact with the coating. All is assembled between two plies of glass including an interlayer material (e.g. PVB).

c) Heating pattern on backlight
The technology is used to defrost/defog the laminated backlight. A silver print conductive pattern is printed on the occupant compartment side surface. Connections are soldered to the silver print busbar on glass.

d) Heating Device Circuit on surface 4
The technology is used to defrost the windshield on a local surface, for instance a heating pattern for camera area on windshield. A silver print conductive pattern is printed on the occupant compartment side surface. A connector is soldered to the silver print pattern on glass.

e) Windshield Wiper De-icer Wire
The technology is used to defrost the windshield wiper area in rest position. Thin tungsten wires are embedded onto the interlayer materials (e.g. PVB). Connectors are

soldered to the busbar plate in a local area at the edge of the screen. Then connectors are covered by sealant.

f) Windshield Wiper De-icer Printed
The technology is used to defrost the windshield wiper area in rest position. Silver ceramic grid lines are printed on inner glass surface and heated up by an electrical current. Connectors are soldered to the silver ceramic busbar in a local area at the edge of the screen. Then connectors are covered by sealant.

2. Antenna Applications:

a) Wire Antenna
The technology is used for radio/TV reception system on windshield. A metallic wire (usually made of copper) is embedded on the surface of the interlayer material (e.g. PVB) that is between the two plies of glass. A connector is soldered to the metallic wire.

b) Antenna Printed
The technology is used for radio/TV reception system on windshield, laminated sidelight or laminated backlight. A silver print conductive pattern is printed on the occupant compartment side surface. A connector is soldered to the antenna on glass.

3. Capacitive Coupling Connectors Soldered on Position 4
Capacitive coupling connectors are soldered to side 4 but not directly connected with the silver structure reception inside the glass pair. The connector therefore interacts like a capacitor.

For laminated automotive glazing structures covered by Exemption entry 8(j), the technologies and demands are different from soldering on toughened glass, which is covered by Exemption 8(i).

8.3.2. Amount of Lead Used under the Exemption

ACEA et al. (2018 a) present the below Table 8-1 illustrating the annual use of lead in newly registered vehicles in the EU for applications in the scope of exemption 8(j).

Table 8-1: Lead in application groups put on the EU market in newly registered passenger cars in 2016

Quantity calculation; Europe 2016		
Application group	Use of Lead [kg], rounded	Use of Lead [t], rounded
Wire heated	1240	1,2
Coated heated	1205	1,2
Other /not specified	441	0,4
Total:	2886 kg	2,9 tons

Source: ACEA et al. (2018 a)

ACEA et al. (2018 a) and joint associations have requested the quantities, which were reported to ACEA as trustee and consolidated. In the last review in 2015, these lead amounts were indicated[19] with around 0.6 t to 1.4 t. The figures are different from the last application because of different designs in use, vehicle volume increase and technical progress, e.g. support functions for recognition of traffic situations. In total, ACEA et al. (2018 a) state a volume of around 2.9 tonnes of lead per year under exemption 8(j).

8.4. Stakeholders' Justification for Continuation of the Exemption

ACEA et al. (2018 a) claim that the continuation of the exemption beyond 2019 is required due to technical, material-based challenges and in addition new safety requirements for current and future vehicles in general. A break of the glass may occur due to too high mechanical stress in the area of the soldered contacts. The challenges are not generic, but seem to be oriented to technologies, processes, components (contacts, glass) geometry and individual vehicle. In specific applications, indium based solders are under consideration, if specifications of the car producers can be fulfilled. With more test experience, more knowledge has been gained on the challenges of fulfilling the specifications of the vehicle producers without entry 8(j) exemption after 1.1.2020.

8.4.1. Properties of LG and Solders

ACEA et al. (2018 a) describe the steps of LG production:

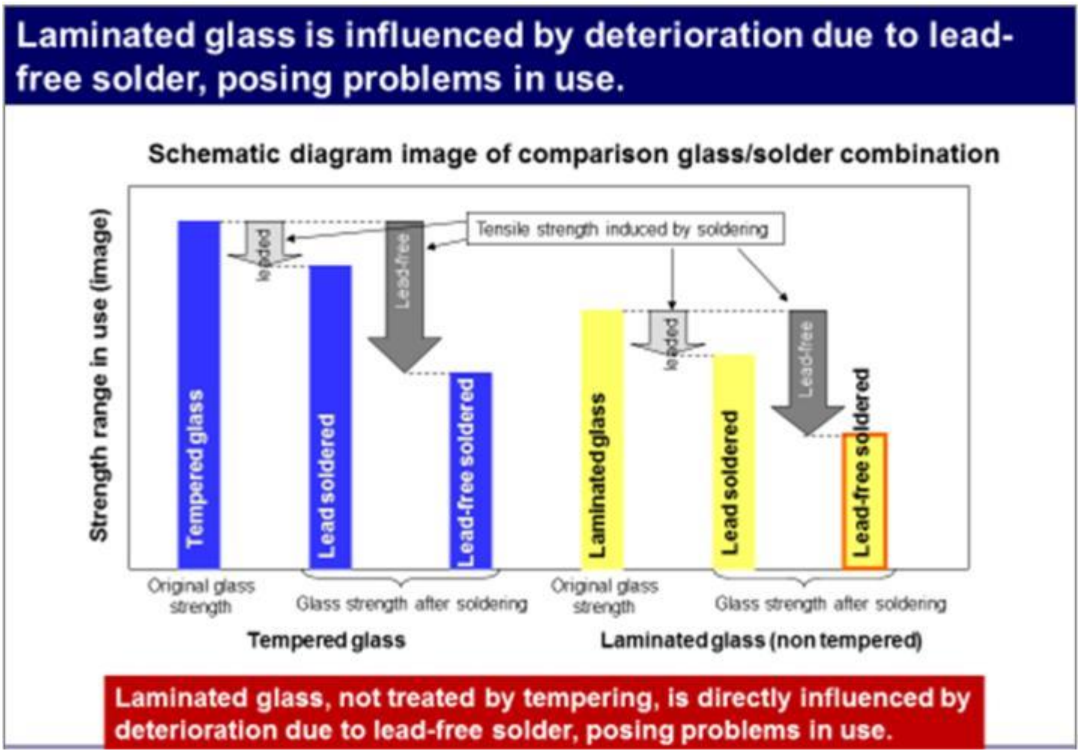
- Cutting of float glass panes in individual shapes and pre-treating (e.g.: edge grinding), application of lead-free black enamel layer, application of silver prints;
- Bending at around 650°C to 750°C to achieve the individual three-dimensional geometry (different technologies in use);
- Slow cooling to room temperature to minimize residual stress in the glass
- Application of surface 2 or surface 3 electrical contacts;
- Preparing laminate consisting of two bended glass panes and an inner layer of a polymer film;
- Finishing laminate via autoclave procedure for around 1h at pressure level around 15 bar and temperatures between 120 and 160 °C;
- Final assembly, if applicable, adding electrical contacts on surface 1 and 4,
- Final inspection.

Exemption 8g for "*Lead in solders in electrical glazing applications on glass except for soldering in laminated glazing*" expired already for vehicles type approved before 1 January 2016. ACEA et al. (2018 a) argue that lead-free soldering of laminated glazing in the scope of exemption 8(j) is more challenging than on tempered glass, which is in the scope of exemption 8g. LG is mechanically weaker than tempered glass due to micro-flaws in the surface and micro flaws migrating into and through the glass

[19] C.f. Gensch et al. 2015, page 74

matrix. Further presence of micro bubbles and impurities reduce the acceptable stress level. The flexural strength of bended float glass is different in centre surface from edge areas. The value in the edges area typically may be 30 % weaker. The tolerable bending stress of tempered glass is 2.5 to 4 x higher than for annealed float glass used for LG. Lead-free solders according to ACEA et al. (2018 a) reduce the strength compared to lead solders (c.f. Figure 8-2).

Figure 8-2: Reduction of glass strength by lead and lead-free solders



Source: ACEA et al. (2018 a)

ACEA et al. (2018 a) say that the tolerable mechanical strength decreases significantly further over time under steady load and in combination with humidity.

Lead-free solders based on tin such as e.g. 95.5Sn/3.8 Ag/0.7Cu have a higher melting point (typically 30 to 40 K) and a higher tensile strength (typically 50 % higher) compared to lead-based solders. The higher process temperature of tin-based lead-free solders increases the temperature difference between process temperature and room temperature and increases the stress level resulting from the CTE (coefficient of thermal expansion) mismatch.

Table 8-2: Physical properties of lead and SnAg-type lead-free solders

Property	Units	Sn60Pb40	SnAg3.8Cu0.7
Density	g/mm^3	8.5	7.5
Melting point	Deg C	183	217
CTE	$x\ 10^{-6}$	23.9	Similar (23.5]
Vol change on freezing	%	2.4	Larger (2.7)
Specific heat	$J\ kg^{-1}\ K^{-1}$	150	Higher (226)
Thermal Conductivity	$W\ m^{-1}\ K^{-1}$	50	Higher (73.2)
Young´s Modulus	GPa	30	Higher (48)

Source: ACEA et al. (2018 a)

Besides the data in the above table, ACEA et al. (2018 a) present more material data in the annex. ACEA et al. (2018 a) argue that lead-based solders are able to compensate higher mechanical stress levels by plastic deformation at significant lower stress levels compared to lead-free solders of SnAgCu type. This means that in the case of lead-based solders, mechanical stress is relieved at lower values while SnCuAg type solder only deform at higher mechanical stress levels and thus cannot mitigate the mechanical stress between the glass and the solder. If this higher mechanical stress impacts to the glass, the glass may break. In addition, technological aspects have to be considered which means the different behaviour of formation of intermetallic phases. Whereas the eutectic lead-based solders intend to form a fine grain structure, Lead-free SAC solder types intend to form hard intermetallic phases, even in interference with the silver print.

ACEA et al. (2018 a) explain that non-toughened glass used in LG has a reduced temperature cycle range compared to toughened glass (typically < 50 %). This is especially challenging for the heating functions. Typically small sector heating functions are powered with currents up to 10 A and full screen heating functions can require currents between 20 A and 50 A per screen.

ACEA et al. (2018 a) also put forward that for breaking of the glass there is superposition of CTE mismatch stress between solder and glass, glass residual stress from glass production, additional CTE mismatch of contact bridge and additional mechanical stress from vehicle and its operating conditions like wind load, car body torsion, temperature. ACEA et al. (2018 d) state that there is no ideal perfect glass for vehicle glass panes. The real glass has always imperfections (voids, flaws, point defects etc.). According fracture mechanics principles (Griffith's equation), a fracture starts at such imperfections. As a result, of the soldering process for electrical contacts of laminated glazing structures tensile stress is remaining. Micro voids can affect pile up of local mechanical stress and cause initial micro cracks. By constant or varying effective tensile stress a subcritical fracture growth may occur. Toughened glass has much higher levels of compression stress in the surface, so micro cracks are compressed and there is no fast fracture growth or glass rupture, resp. the velocity of growth is very low. The probability of a critical defect (failure) causing surface defect increases with area size. This gives also an indication why bigger contact areas can cause more trouble than small contact areas. To transfer higher heating power requires bigger contact areas.

ACEA et al. (2018 a) find it easy to understand that a thinner wall size of a material can bear less load than a higher wall size. The wall size of laminated glass panes is normally thinner than that of tempered single side glass. In order to reduce vehicle weight, during the last 10 years total thickness of laminated glass has been reduced by around 10 % and sometimes even more. If the structure is not symmetrical, it is the inner glass sheet that is thinner and this is in most cases the sheet that has soldered connections on printed products. Because panel bending stiffness is proportional to glass thickness with cube and moment of inertia proportional 4th power, this has significant impact on the mechanics of a laminated glass structure like torsional stiffness and operating elastic strains. Especially future E-vehicles may require integrated intelligent electric heating functions on thinner glass panes of laminating glazing structures. Weight reduction directly improves the operating distance. A ban of using lead-based solders for such applications should not block such developments. Details currently are not available for publication for competitive reasons and meeting antitrust rules.

8.4.2. Evidence for Technical Problems with Lead Substitution in Solders

Indium-based Solders

ACEA et al. (2018 a) say that in specific applications, indium based solders are under consideration as problem crunchers, if individual vehicle specs /demands package /size /available space can be met.

Known lead-free indium-based solders have a low melting temperature compared to the otherwise applied lead-based solders Because of process temperatures for autoclave procedure (typically 120 to 160 °C), soldering with available lead-free indium-based solders before autoclave procedure on surface 2 or 3 is not appropriate. Subsequently, application potential is limited to side 1 or side 4 application, if temperature load demands of the relevant vehicle and its production processes (e.g. paint refurbishing) allows such low melting temperatures. As reported in previous applications temperature load in a specific vehicle can significantly exceed 110 °C under severe climate conditions.

ACEA et al. (2018 a) further on describe that the shearing resistance of In52Sn48 at 100 °C is only 3.5 MPa. Together with a homologous temperature above 0.7, indium-based solders are challenging in mechanical properties at elevated temperatures. Indium-based solders are sensitive to corrosion by halides in presence of moisture.

Status of Lead-free Soldering

ACEA et al. (2018 a) state that some glass producers claim to have lead-free solutions for their product spectrum of laminated glass products available at least on laboratory level while other producers claim for their product spectrum that lead-free soldered solutions are not able to meet their customers' specifications today in volume production. To cover the demand of laminated glass with electric contacts and components the supply of all major suppliers is required. The challenges in lead-free soldering of contacts for laminated glass are reported unspecific and up to now no sufficient test results are available to identify clearly the reasons of component failure.

Whereas in several cases lead-free soldering seems to be feasible in laboratory scale, on the other hand component and vehicle tests end with negative and disappointing results.

ACEA et al. (2018 a) report one industrial stakeholder´s laboratory stage test results, which were performed on a large variety of connector designs, material composition and process conditions in a wide laboratory trial portfolio. According to ACEA et al. (2018 a), the following examples highlight the main concerns of "lead-free soldering for laminated" glazings.

Test example 1:

Laboratory sample:	10x10 cm
Glass structure:	2.1/PVB/1.6 mm
Siler print on glass:	No black enamel
Connector design:	Heating bridge for high current application > 30 A
Lead-free soldering:	tin-base solder alloy - high melting temperature > 200°C
Observations:	Glass cracks observed sometimes after soldering and before ageing due to stresses induced by lead-free soldering; while the lead allows to reduce the stresses transmitted to the glass substrate → Could generate glass breakages at different steps of its lifetime (stock, transport, mounting, on the road…) and reduce production yield

Figure 8-3 shows cracks in the glass sample. (ACEA et al. 2018 b)

Figure 8-3: Cracked laboratory glass samples with soldered contact on surface 4

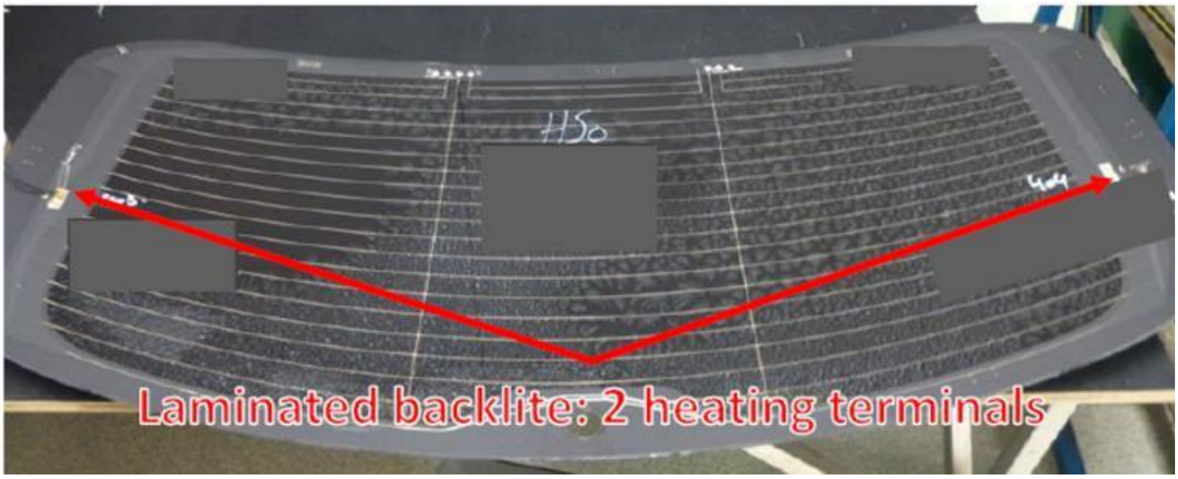
Source: ACEA et al. (2018 a)

Test example 2:

Laminated backlite:	Real part
Glass structure:	2.1/PVB/1.6 mm
Siler print on black enamel:	-
Connector design:	Heating bridge for high current application > 30 A
Lead-free soldering:	indium-base alloy with melting temperature > 130°C
2 ageing test of VDA AK2.1:	Thermal cycle test (TC) → -40 to 105°C, 480h, 14V Heat soak test (HSo) → 105°C, 96h, 14V power, 10N load
Observations	Lead-free soldering alloy melting during the ageing test generating a detachment of the connector from the glass → Impossible to survive such high temperature for this kind of low-melting temperature alloys

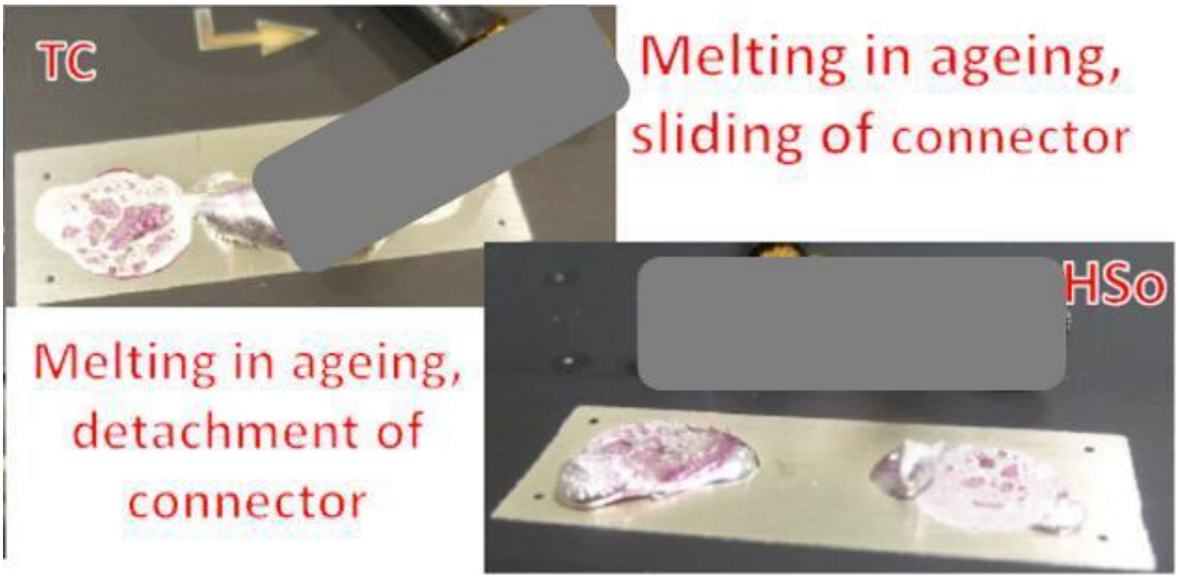
Figure 8-4 shows the laminated backlight with heating grid and the soldered contacts.

Figure 8-4: Laminated backlight with heating grid and soldered contacts on surface 4



Source: ACEA et al. (2018 a)

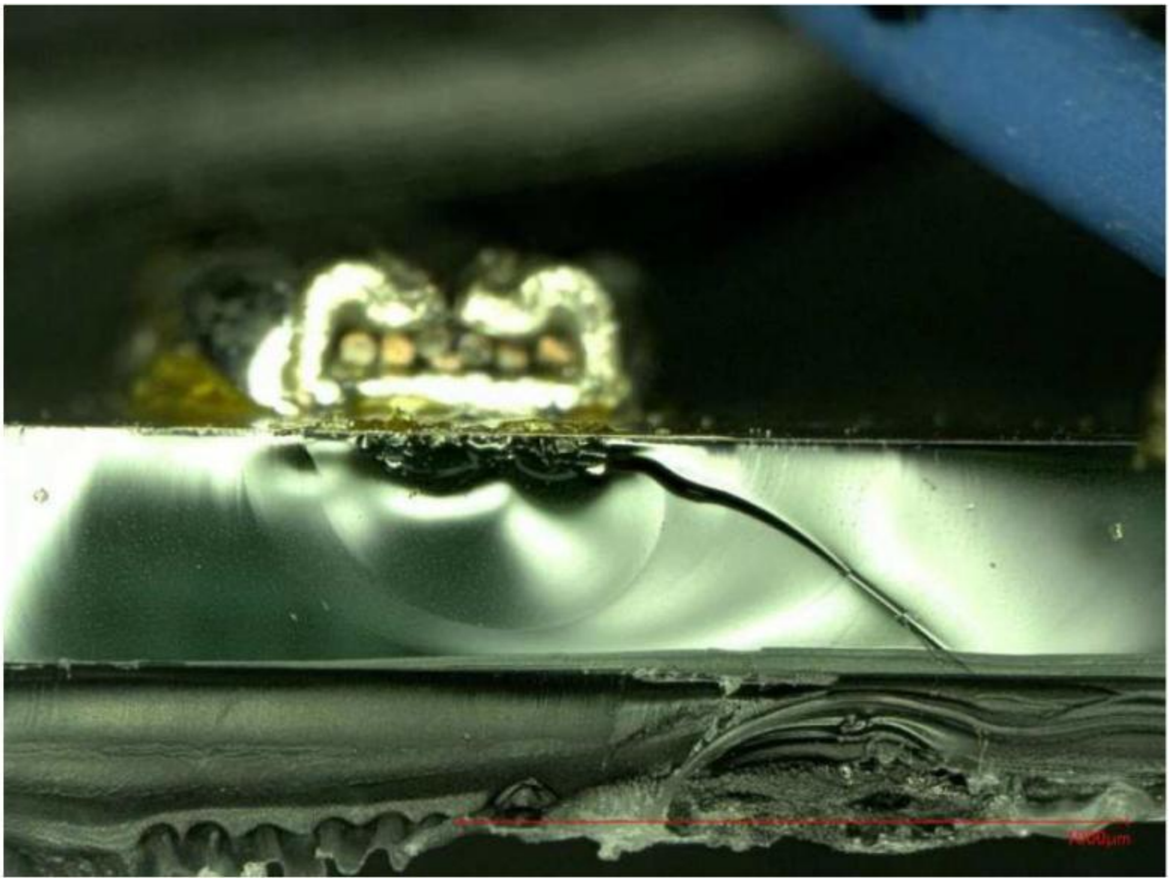
Figure 8-5: Melting of solder and connector detachment



Source: ACEA et al. (2018 a)

ACEA et al. (2018 a) also report about cases of in-field glass breaking in the rear screen with the fractures starting from lead-free solder joints in a vehicle to collect market experience (Figure 8-6). Because of the glass crack problem the lead-free solder used was changed to lead-based solder and the problem disappeared.

Figure 8-6: Lead-free soldered laminated backlights with glass breakages starting at the soldered bus bars



Source: ACEA et al. (2018 a)

ACEA et al. (2018 a) have identified the following applications and features as very challenging for lead-free soldering:

- Heating functions with high electric current (power) load up to several 10 A
- Temperatures > 100 °C for indium based solders
- Autoclave procedure process conditions
- Temperature loads in use
- Thin glass, sometimes also for reference lead-solders
- Curved glass is more demanding than flat glass panes
- High gradients of cooling and heating
- Transfer from lab solutions to car applications

ACEA et al. (2018 a) explain that there is no generic solution, and individual vehicle specific problems are to be considered. Even if some laboratory solutions and first applications are available today, according to ACEA et al. (2018 a) the transition to industrial solutions is very challenging and will probably not be ready in 2020 for the full laminated application portfolio. Furthermore, laminated glazing is in constant evolution: thinner structures, more and more heating applications being under consideration for future vehicles with even more efficient heating systems, new antenna functions or sensors.

In addition, ACEA et al. (2018 a) mention that the competitive situation, and confidentiality agreements for new developments sharpen the problem to outline and to report the negative test results. Last but not least, ACEA et al. (2018 a) add, windshields are safety relevant.

ACEA et al. (2018 a) conclude that the overall thermomechanical stress level for lead-free soldered laminated glazing structures exceeds the level for the breaking tension of the glass. A sufficient safety margin to ensure reliable mass production and long-lasting component function is still missing. Further research and development is necessary to enable lead-free soldering of laminated glass in mass production for all applications. ACEA et al. (2018 a) therefore apply to extend the exemption by four years until 1 January 2024.

8.4.3. Potential Alternatives to Solders for the Elimination of Lead

According to ACEA et al. (2018 a), conductive glues are, among other criteria, restricted to specific cases and have a poor electrical conductivity. Conductive adhesives are based on silver in an organic matrix. Silver tends to migrate under voltage and humidity, and higher power densities increase the risk of electro-migration. Above 175 °C, the organic based matrix begins to degrade. Electrical heating of laminated glass requires high electric current density application. There is an inevitable compromise between mechanical resistance and conductivity. There are no new developments known for conductive adhesives for high current applications.

8.4.4. Critical Raw Material and Environmental Aspects

ACEA et al. (2018 a) put forward that the EU Commission has put indium on the list[20] of critical raw materials since 2014. In 2017, also bismuth has been listed as critical raw material. ACEA et al. (2018 a) state that use of critical raw materials should be avoided because of high supply risks.

Further on, ACEA et al. (2018 a) state that "Indium (CAS 7440-74-6) was registered by industry under REACH recently. There are also some hazard classifications for Indium listed (https://echa.europa.eu/de/brief-profile/-/briefprofile/100.028.345) but no harmonized classification yet. There is no data on neurotoxicity and immunotoxicity provided yet and the registration dossier and/or substance is not evaluated yet by authorities."

ACEA et al. (2018 a) also reference their life cycle analysis for indium provided in the course of the last application, which claims the need to reflect overall environmental benefits of substituting Lead in a specific application by indium.

[20] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS on the 2017 list of Critical Raw Materials for the EU ;13.9.2017 COM(2017) 490 final https://ec.europa.eu/transparency/regdoc/rep/1/2017/EN/COM-2017-490-F1-EN-MAIN-PART-1.PDF (source as referenced by ACEA et al. 2018 a)

8.4.5. Challenges for Future Developments

ACEA et al. (2018 a) put forward that future automated assisted driving pushes ideas to integrate sensor and camera functions in windshields or other laminated glazing structures. E-driven vehicles have no waste heat from combustion processes. So as yet outlined above, future vehicles may require even more efficient integrated electric de-icing systems for light weight front screens instead of conventional heating systems with a fan and hot air. The heat generated by the engine is not available anymore for E-vehicles.

ACEA et al. (2018 a) worry about potential interferences between lead-free soldering of laminated glass components and future technical progress for more safety and for weight reduction targets (thinner glass, function integration). Moreover, especially electric vehicles are requiring thinner glazing for weight reduction and higher efficient embedded electrical functions. These two requirements being already challenging today with lead solders.

Furthermore, ACEA et al. (2018 a) put forward that with proposal COM (2018) 286 8 from 17.05.2018 on General Safety Regulation the Commission is mandating integration of advanced safety features that could contribute to reduce further road fatalities and injuries. The integration of intelligent speed assistance, lane-keeping systems, emergency stop signals or attention monitoring systems will also address challenges for implementation of reliable electrical contacts of laminated glass. As of today, it is open, if this can be realized with lead-free solders, or if the use of lead-containing solders is essential. It is clear that use of lead-free solders is the default for the new developments.

8.5. Stakeholders' Arguments for the Revocation of the Exemption

SGS and Antaya both claim to have lead-free solutions available for lead-free soldering on LG.

8.5.1. Antaya's Comments on the ACEA Request for Continuation of the Exemption

Lead-free Soldering Process Optimization

(Antaya 2018 b) highlight with reference to the submission of ACEA et al. (2018 a) that there are factors contributing to the success of any soldering application, whether lead or lead-free solder is used in the soldering process for both tempered and laminated glass. They agree that the need for thinner glass is a trend that will continue in the automotive glazing industry. As the automotive market makes the transition from traditional combustion engines to electric vehicles with more autonomous capabilities and technologies, the opportunity for on-glass electrical connections also increases. Antaya have optimized their lead-free solder alloys specifically for these types of glass conditions and observes favourable results with these alloys where even lead-based alloys fail to perform.

ACEA et al. (2018 a) and Antaya (2018 b) agree that thermomechanical stress related to soldering on laminated glass is a key factor to consider when optimizing a soldering process. (Antaya 2018 b) agree that high-tin lead-free solder causes unfavourable stress on the glass due to a higher coefficient of thermal expansion (CTE) mismatch. This is one of the reasons that Antaya utilizes a range of indium alloys where the malleability of the indium creates a more favourable CTE match resulting in less thermomechanical stress.

Antaya (2018 b) also want to note that the In52Sn48 alloy mentioned in the submission of ACEA et al. (2018 a)[21] is not an indium-based alloy which Antaya provides. (Antaya 2018 b) have identified an optimized range of indium content for their alloys and this specific alloy (In52-Sn48) does not meet this range.

Test Data Presented by ACEA et al. (2018 a)

Antaya (2018 b) questions the test data provided by ACEA et al. (2018 a)[22] The information provided in the *Test 1 details* section that, *"[lead-free solder] could generate glass breakages at different steps of its lifetime…"* is quite broad and the exact same statement could be made for lead-based solder or for tempered glass. Without details and data on the specific lead-free alloy and its corresponding soldering process parameters or the statistics that resulted from the test, no reliable conclusions can be drawn. Also, the statement that glass cracks were observed "sometimes" tells us nothing about the performance of the lead-free solder, nor does it relate or compare those results to the outcomes that would be achieved if leaded solder were used.

Additionally, Antaya questions the composition of the alloy and the soldering process parameters used for Test 2 as they are not explicitly stated or disclosed[23]. As mentioned above, Antaya recognizes that not all indium-based alloys are optimal for soldering to laminated glazing.

In real world scenarios, (Antaya 2018 b) is able to adjust process inputs such as specific time and temperature of heat delivery as well as to identify a specific cooling time to optimize the entire soldering process. Without any of these details for either test presented in the ACEA et al. (2018 a) submission, Antaya challenges the stated results.

In fact, there are no examples where Antaya has not been technically capable of launching a program with lead-free solder for laminated glass. In every instance when requested, Antaya is able to optimize a part and process solution for any individual application without the use of lead-based solder. Additionally, there are programs where an Antaya indium-based lead-free alloy replaced a lead-based solder alloy. In these cases, the leaded solder was causing too much of thermomechanical stress and

[21] See section "Indium-based Solders" on page 26

[22] C.f. section "Status of Lead-free Soldering" on page 27

[23] C.f. section "Status of Lead-free Soldering" on page 27

microcracks either in pre-launch testing or in the field. By switching to an Antaya lead-free alloy, the cracking problems were solved. As previously noted, this is the specific reason the Antaya indium-based alloys were developed. In 1998 (Antaya 2018 b) developed first lead-free indium alloys specifically for soldering to laminated glass. After successful validation of these alloys, these on-glass connectors were launched into series production and have been in continuous production use ever since.

Physical and Technical Parameters Presented by ACEA et al. (2018 a)

(Antaya 2018 b) are concerned that tin-based lead-free solder causes a higher stress on glass due to coefficient of thermal expansion (CTE) mismatch. ACEA et al. (2018 a) highlight that tin-based lead-free solders have higher melting points and higher tensile strengths than lead-based solders. Antaya (2018 b) agree with these assertions, which is why they do not utilize tin-based lead-free alloys for laminated applications. However, what the submission fails to take into consideration is that Antaya indium-based lead-free solders have a lower melting point than traditional lead-based solders. The melting point of Antaya's indium-based alloys are within a range that allows for optimal processing conditions. This property effectively lowers the temperature difference during the soldering process and reduces the thermomechanical stress induced onto the glass more effectively than lead-based solder. These are key properties of these lead-free indium-based alloys that enable them to perform better than high-tin lead-free alloys and the currently used lead-based alloys as well.

Conclusion

(Antaya 2018 b) maintain their position that continuing exemption 8(j) is unnecessary as there are multiple solutions already available for lead-free soldering for laminated glazing, which makes the use of lead for laminated applications avoidable. The Amended Final Report published by Gensch et al. (2015) acknowledges that *"lead-free solutions are on the market already, or in a status that allows for their implementation."* Now, more than three years later, the case for allowing this exemption to expire is even stronger as there are documented examples by at least two stakeholders, Antaya Technologies and Saint Gobain Sekurit, of lead-free applications in series production.

Additionally, the 2018-06-25 submission by ACEA et al. did not provide any specific examples where the use of leaded solder was unavoidable. Instead, the submission discussed general challenges that are unchanged since the previous review. The Amended Final Report by the Öko-Institut e.V. states that,

> *"ACEA et al. would, however, have to prove that the use of lead is still unavoidable in these cases in spite of efforts to adapt the design to the requirements of lead-free soldering, and that the continuation of the exemption is hence justified beyond 2019 for such specific applications."*

(Antaya 2018 b) state that ACEA et al. (2018 a) did not provide such applications and therefore see no evidence to justify the further continuation of exemption 8(j) or to change the wording of the current exemption again.

8.5.2. Antaya: Status of Lead-free Soldering

Antaya (2018 c) supplies three different types of indium-containing solders (ICS) referred to as "65," "B601," and "B604" differing in the indium content:

- In65: contains 65 % indium as well as other metals.
- B6: either B601 or B604 alloy
  - B601: contains 75 % indium as well as other metals.
  - B604: contains 90 % indium as well as other metals.
- Any other acronyms/compositions:
  When comparing the performance of one of the Antaya Indium-based solders, Antaya (2018 b) often reference a high tin alloy commonly known as SAC305. SAC305 contains 96.5 % tin, 3 % silver, and 0.5 % copper.

Table 8-3 lists liquidus and solidus temperatures of Antaya's indium-based lead-free solders.

Table 8-3: Liquidus and solidus temperatures of Antaya's lead-free indium solders

Alloy	Liquidus	Solidus
65	127°C	109°C
B601	135°C	125°C
B604	140°C	135°C
SAC305*	220°C	217°C

*Source: Antaya (2018 d), *tin-silver-copper (SAC) solder listed as reference only*

Antaya (2018 a), (2018 b), (2018 c) present examples of applications in vehicles for American and the EU market, which used the above ICS for soldering of LG, c.f. section A.1.1 in the appendix.

8.5.3. Saint-Gobain Sekurit: Status of Lead-free Soldering

Saint-Gobain Sekurit (2019 a) have developed a tin-based lead-free solder with a melting point of 217 °C. The compliance with the specified parameters must be ensured throughout the entire soldering process to avoid failures and glass cracks.

Saint-Gobain Sekurit (2018 a) claim their lead-free soldering solutions to be drop-in solutions in the sense that they do not require any adaptation of existing interfaces in vehicles and changes of wiring, devices or functionalities.
On this basis, Saint-Gobain Sekurit (2019 b) state that they offer lead-free solutions for soldering on laminated glazing for all heating applications including higher currents, as well as for antenna connectors. They agree that lead-free soldering of foil connectors on LG is challenging, but claim to have developed and to offer lead-free solutions for these connectors, which meet the demanding customer specifications. Saint-Gobain Sekurit (2019 b) also confirm that lead-free soldering of rigid ("bridge" type) connectors on laminated glazing is critical, but they have developed solutions to overcome this design related issue.

Saint-Gobain Sekurit (2018 a) say to have industrialized technologies for lead-free soldering of laminated glass for conventional, hybrid and electrical vehicles, which are already used in mass production of the automotive industry today. They have brought the first serial solution to the market in 2013 already. According to Saint-Gobain Sekurit (2018 b), these technological solutions can be adapted to the specific needs of its customers, covering the full range of applications known today. They say that based on current knowledge these solutions do not have special restrictions, which might exclude certain customers, and they are viable for new customers not known today as well. To secure the supply of lead-free LG, Saint-Gobain Sekurit (2018 b) is willing to give access to its lead free soldering technologies to other automotive glazing suppliers within the framework of licensing.

Saint-Gobain Sekurit (2018 a) state that Volvo has conducted and finalized lead-free soldering testing programs for LG, all of which have been brought to serial production. Other lead-free soldering programs are covered by confidentiality agreements and can therefore not be used in the exemption review process.

Consequently, Saint-Gobain Sekurit (2018 a) state that the continuation of exemption No. 8(j) is not required.

8.6. Critical review

8.6.1. Scope and Wording of the Requested Exemption

ACEA et al. (2018 a) propose the following wording for the requested exemption:

> *Lead in solders for soldering of laminated glazing, except embedded solder contacts in the intermediate polymer.*

The added clause "except embedded …" invites the question whether this wording would in principle allow the use of lead solders for soldering on glass surfaces 2 and 3 (c.f. Figure 8-1 on page 55.

Upon request, ACEA et al. (2018 a) clarified that *"Lead free soldering of printed laminated glazing structures […] is causing the actual challenge. For soldering of "in the intermediate polymer embedded contacts", lead-free joining solutions are available at our best knowledge for all vehicles with a type approval from 1.1.2020 onwards."*

The proposed exemption formulation therefore principally allows the use of lead solders on all 4 surfaces of LGs (see Figure 9-1 on page 55) like the current wording in Annex II of the ELV Directive, excluding only "embedded solder contacts in the intermediate polymer". Since soldering to such structures is not related to soldering on glass – which is the core justification for the use of lead- the add-on "*[…] except embedded solder contacts in the intermediate polymer"* clarifies the exemption scope.

8.6.2. Status of Lead-free Soldering

In the last review of exemption 8(j), Gensch et al. (2015) had already assessed that lead-free solutions for soldering on LG were available, based on solutions of Antaya and SGS. It was stated in the 2014/2015 review that in the light of the findings and conclusions in that review, ACEA et al. would have to provide substantiated evidence that the use of lead is actually still unavoidable. Glass and other suppliers can only demonstrate their capabilities for lead-free soldering on industrial scale if the vehicle manufacturers start lead-free soldering programs with them. It is therefore in the vehicle manufacturers hands whether and how far the viability of lead-free solutions can actually be tested in practice.

The consultants therefore tried to obtain a clearer picture about the progress made since 2015. Section 8.5.2 and 8.5.3 present lead-free solder examples from Antaya. Application examples are listed in sections A.1.1 (Antaya).

ACEA et al. (2018 d) comment the Antaya applications listed in section A.1.1.1 that these references are basically true, but it is important to look at the details:

None of the models must fulfil the requirements of the Asian and German Automotive manufacturers having stronger specifications than the American ones and for which indium alloys are not suitable, as put in evidence in the trial 2 (c.f. Figure 8-5).

- Most of the models seem to be developed for the American market for which the thickness of the laminated structure is, most of the time, higher than the other worldwide market configurations
- Lead-free soldering for North American (NA) vehicles only used for partially heated windscreens, as standard or as option (camera heating area & wiper rest area). In general: fully heated windscreens are quite uncommon in NA vehicles with low take rate / poor interest of NA vehicle owners.
- The referenced Ford Transit Connect model in Europe only has a partially heated windscreen "mini-application" for camera window it is lead-free, but low volume / low take rate. In contrast fully heated windscreen has high volume / high take rate in Europe and can NOT use lead-free soldering.
- None of the models refers to the applications requiring the higher current as the defrosting of the rear window, so requiring the bigger connector size (for some car manufacturer, such big connector are mandatory also for applications with lower current load, even antenna for which other solutions could be used.

In the consultants' opinion, the examples in sections A.1.1.1 through to A.1.1.3 for the use of ICS show that

- several vehicle manufacturers successfully ran or still run lead-free soldering programs on LG.
- indium-based solders are used for soldering to glass surface 2 despite of the autoclave process.
- lead-free solders have been applied to antenna and several heating elements such as heated wiper rests and heated camera windows, even though no backlight heatings. ACEA et al. do, however, not ask for an exemption for soldering of high current backlight heatings, but for all applications on all glass panes regardless of thickness in their original exemption request, and later on restrict it to components and glass thicknesses which are not common. The comment of ACEA et al. is therefore misleading in the context of the requested exemption.

- lead-free solders have been applied on glass panes thinner than 2.1 mm.

The information presented in Figure 8-5 on page 63 is not an evidence that indium-based lead-free solders are principally not viable, even though they may not appropriate for all applications, as already assessed by Gensch et al. (2015).

One of the vehicles – the Opel Sinatra – seems to be produced for the European market as well. Beyond that and more important, the fact that vehicles are used or produced for other markets than the EU without having passed European and Asian manufacturers' tests in general is not an argument that the use of lead-free solders is not viable. This could only be different if ACEA et al. could prove that these vehicles actually have higher failure rates in use related to the faults of lead-free solders in LG. Such evidence is not available. It is not the tests that should count, but the proven applicability in the field. ACEA et al. at least concede that indium-based solders are used as "problem cruncher".

Saint-Gobain Sekurit (2018 a) state that Volvo has conducted and finalized lead-free soldering testing programs for LG, all of which have been brought to serial production. Further details and other SGS lead-free soldering programs are covered by confidentiality agreements and can therefore not be used in this exemption review process.

8.6.3. Initial Evidence Provided by ACEA et al. as to the Non-practicability of Lead-free Soldering of LG

Material Properties as Evidence for the Unavoidability of Lead Use

ACEA et al. repeatedly refer to the material properties (c.f. section 8.4.1 on page 58) in their submissions and answers as evidence for the unavoidability of lead use for soldering of LG. The comparison of lead and lead-free solders in Figure 8-2 shows that the use of lead-free solders reduces the glass strength. It is, however, unclear which lead-free solder was used for this comparison, or whether the lead solder was simply replaced by a lead-free one without taking into account the specific properties of lead-free soldering, e.g. in the soldering profile, the geometries, materials and placement of the connectors on the glass, etc.

In Table 8-2 ACEA et al. (2018 a) present specific material properties of tin-based lead-free solders versus lead-containing solders. These data show that on a material level, properties of tin-silver lead-free solders actually are less favourable for use on LG compared to lead solders. ACEA et al. (2018 a) present more material properties in the annex of their exemption request. The data collection focuses on comparing mostly tin-silver-based solders with tin-lead based ones. Indium-containing solders seem to be mentioned only in those cases where they have known weaknesses compared to lead and in part also to tin-silver based lead-free solders.

Soldering on LG requires a system approach rather than a mere exchange of solders. As ACEA et al. themselves point out, the soldering profiles, connector materials and geometries, their location on the glass, the glass geometry and other parameters play a vital role as well. If properly adjusted to the material properties of the applied lead-free solder, adverse material properties of lead-free solders can at least be mitigated.

Further, various tin-silver based lead-free solders can have similar, but still different material properties, and indium based solders are an alternative with quite different material properties, which are not taken into account in the table.

Upon request to provide clear evidence that lead-free soldering on LG is scientifically and essentially impracticable ACEA et al. (2018 d) presented results of a measurement with SCALP 05 equipment which enables non-destructive measurements of residual stress. In experiments with lead-free soldered screens, a stress difference of around up to 20 MPa was measured in the area of the connectors. Non-tempered/non-toughened glass used for LG according to ACEA et al. (2018 d) can only take 25 to 34 MPa of tensile stress. Toughened/ tempered glass is around 2 times stronger. Superposing of all single stress elements can easily exceed glass performance - and the glass breaks.

ACEA et al. neither present reference values for those connectors when lead-soldered nor do they explain, for example, which lead-free solder was used, which connector – in particular which size – was soldered, how thick the soldered glass pane was, and which soldering profile had been applied. They do not explain either whether or how different lead-free solders and variations of the soldering profiles and other parameters like connector geometries etc. would have impacted the residual stress in the glass panes of the LG.

Overall, the presented material properties show that lead-free solders have properties that are partially less favourable for soldering on LG compared to lead solders. In practice, mitigation possibilities through system approaches and an application-specific selection of lead-free solders can at least partially compensate adverse material properties. The presented material data are thus neither a general evidence that lead-free soldering on LG is scientifically and technically impracticable, nor can these general material data be seen as specific evidence that lead-free solders cannot be applied on the presented test samples. Lead-free soldering on LG is actually applied successfully as the examples in section 8.5.2 and 8.5.3 on page 71 et sqq. show, even on glass panes thinner than 2.1 mm. Further on, ACEA et al. (2018 b) "*[…] don't deny that SGS has Lead-free solutions for entry 8(i) (and assumedly 8(j)) applications […]*",and ACEA et al. (2018 a) admit that "*In specific cases In- based solders could be used as problem cruncher, if individual vehicle specs /demands package /size /available space can be met.*" If the material parameters principally exclude the viability of lead-free soldering on laminated glazing, there is no reason to assume that lead-free solutions might be available or even be used as problem cruncher.

Substantiation of Provided Evidence

Gensch et al. (2015) already concluded that "*The Antaya and Sekurit* [Saint-Gobain Sekurit; note of the authors*] lead-free soldering programs show that lead-free solutions can be achieved already, and ACEA et al. confirmed that other suppliers are working on lead-free solutions as well. […] lead-free solutions are even on the market already* […] *even though they may have to be adapted for the individual vehicles and technologies on the one hand, or they may require vehicle design and technology adaptations on the other hand. A transition period until the end of 2019 is therefore justified in the consultants' opinion. In case specific applications require the continued* *use of lead after 2019, the transition period until the end of 2019 is long enough to apply for specific exemptions in due time. ACEA et al. would, however, have to prove that the use of lead is still unavoidable in these cases in spite of efforts to adapt the design to the requirements of lead-free soldering, and that the continuation of the exemption is hence justified beyond 2019 for such specific applications.*" It was thus stated in the 2015 review already, that ACEA et al. would have to substantiate a request for the continuation of exemption 8(j) with sound evidence.

ACEA et al. (2018 a) actually present two results of laboratory trials that "*[…] were performed on a large variety of connector designs, material composition and process conditions.*" They explain that the main concerns of "*Lead-free soldering for laminated glazings observed on this wide laboratory trial portfolio can be highlighted by the failures presented in […]*" Figure 8-3 and Figure 8-4 on page 63 et sqq.

ACEA et al. were asked to present details of this large and wide laboratory test program, e.g. the statistical test result, which (Antaya 2018b) demand as well. Antaya (2018 b) state that in the tests results provided by ACEA et al. (2018 a) a larger number of lead-free solder joints should have been tested for various lead-free solders against lead-containing solder joints on the same glass type with various connector types and process conditions. An example of such test statistics was presented in the last review report of this exemption by Gensch et al. (2015).[24] This evaluation showed that solder joints produced with lead-free as well as those produced with lead-containing solders exhibited a certain rate of failures in the test, even though in different quantities, which then allowed drawing conclusions regarding the usability of the solders. A single photo of a failed lead-free solder joint on a certain LG alone therefore does not prove that the lead-free solder is not appropriate in this application.

ACEA et al. (2018 c) confirmed that "*The trials are including a lot of the parameters playing a role in lead-free soldering: connector material and design, solder alloys, soldering process*", but did not provide further details and results. ACEA et al. (2018 c) instead "*In general […] would like to state that at our opinion material properties (of glass, solders and connectors) in this application are at its technical limits. This is the main reason for failures.*" "*Material parameters and fundamental principles of solid state physics are giving sufficient evidence.*" In the opinion of ACEA et al. (2018 c) "*[..] it does not make sense to go in details if elemental test do not indicate any chance for positive results.*"

The consultants had, however, not asked for the reasons of failures and for physical evidence, but for substantial details of the test program behind the submitted evidence in Figure 8-3 and Figure 8-4 on page 63 et sqq. According to ACEA et al. (2018 c) "*The trial examples aim to show that, in summary, with indium alloy the industry could face a functional risk of connector disconnection while with other alloys the industry could face a quality risk of glass breakage.*" ACEA et al. (2018 c) concede

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24 C.f. page 105

that "*We understand that showing only some failure examples is probably not representative of all potential solutions in order to demonstrate that it is not working but, at the opposite to have some positive success results for some specific samples, doesn't ensure that a solution is available today for an industrial mass production in multiple different conditions. The limits presented in the trials are giving real issues of lead-free potential solutions as today, which explains that lead-free industrial solutions are not ready industrially today for the whole market diversity, even more for future configuration and application requirements as detailed in our document. As safety is a general key goal, vehicle producers are concerned about this situation.*"

The consultants agree that single test results do not prove the general viability of lead-free soldering for all applications on LG. The applicants were therefore requested again to present details and comprehensive results of this wide and detailed test program, and/or to let the consultants know which of the above-mentioned elemental tests resulted in their conclusion that further tests did not make sense.

ACEA et al. (2018 d) did not allow the consultants any insights either into these elemental tests nor in the wide range laboratory test program. ACEA et al. (2018 d) stated that details of this test program cannot be made available since they are confidential.

In Figure 8-6 on page 65 ACEA et al. (2018 a) additionally present a photo of a lead-free soldered LG that broke in a field test. They claim that the glass did not break after the manufacturer returned to lead solder. There is no information on the thickness of the glass panes, it is not discussed whether and how far the failure could have been avoided with different soldering profiles for lead-free solders, adapted connector geometries, or a different type of lead-free solder.

The information ACEA et al. present as evidence thus is incomplete, in parts inconclusive, and the argumentation line is inconsistent and contradictory. ACEA et al. on the one hand claim to have conducted a large test program, then, upon request for more detailed information about this program, refer to elemental tests that indicate that it does not make sense to go into details. Neither the details of the test program nor these elemental tests have been made available. If ACEA et al. completed a comprehensive test program, the statement that elemental tests already showed that going into more details does not make sense is not plausible. Vice versa, if elemental tests actually prove that lead-free soldering in general or on the glass samples presented in Figure 8-3 and Figure 8-4 is not viable, it is not clear why they further performed a comprehensive test program as claimed.

Other Observations Related to the Presented Tests

The tests presented in Figure 8-3 and Figure 8-4 on page 63 et sqq. were both conducted on surface 4 of thin glass panes with only 1.6 mm thickness. Table 8-4gives an overview of glass pane thicknesses used for LG.

Table 8-4: Thicknesses of glass panes for LGs

Thicknesses	Outer Glass Pane (mm)	Inner Glass Pane (mm)	Status of Use
Combination 1	2.1	2.1	Standard
Combination 2*	2.1	1.8	Standard
Combination 3	2.1	1.6	Standard
Combination 4	1.8	1.4	Hardly used
Combination 5	1.6	1.6	Preferred for laminated backlights, so far in few car models only
Combination 6*	1.1	1.1	Not standard

*Source: Saint-Gobain Sekurit (2019 a), *Antaya (2018 e); this list is not complete, there may be other combinations as well.*

Inner glass panes with 2.1 mm and 1.6 mm are currently a standard glass thickness. According to ACEA et al., thinner glass like 1.6 mm panes is weaker and thus more prone to breakages with lead and even more with lead-free solders than thicker glass, e.g. standard glass panes with 2.1 mm.

The 2.1 mm/1.6 mm glass used in test 1 is, according to ACEA et al. (2018 d), a thin standard glass. For test 2, ACEA et al. (2018 a) ask (c.f. section 8.4.2 on page 61) to "*Please note that this is a relatively new type of light-weight front screen with 2.1 mm/PVB/1.6 mm structure.*"

Information for lead-free soldering on less challenging glass with 2.1 mm is thus missing completely. Adding to this, the thin glass in test 2 is a relatively new type of glass which further reduces the represenatativeness of the provided information, and where it can be reasonably assumed that glass makers still have less experience than with other glass.

Further on, the tests were all conducted with heating bridges for high current applications with more than 30 A. ACEA et al. (2018 a) explain that heating functions are particularly challenging for lead-free soldering on LG, i.e. small sector heating functions powered with currents up to 10 A and full screen heating functions which can require currents between 20 A and 50 A per screen. ACEA et al. were asked how these most challenging components can be representative for other, less demanding applications. ACEA et al. (2018 d) replied that "*[…] a high electric current load requires big connectors. But not only the current load is defining the design of the connector, but also the automotive market requirements, as the adhesion specification after dedicated climatic tests. If the test requires to reach a high adhesion value, the* *connector soldered surface must be large even if not necessary for the electrical current transmission. So, it is not because an application requires a small electrical current that a small connector will be suitable in regards to the Automotive market requirements."* ACEA et al. (2018 d) additionally referenced section 4 on page 10 of their first questionnaire (ACEA et al. (2018 a) for more information, in particular the section *"Applications assessed as very challenging for Lead-free soldering*".

This reference lists several challenges for lead-free soldering, among these only the high current heating functions as specific application. The reference does not explain which other applications would require larger contact areas for mechanical reasons.

ACEA et al. state that lead-free soldering of LG may be viable in certain cases, but contend that there is no generic solution, and individual vehicle specific problems are to be considered. They state that there is no pattern that would allow to define areas where lead-free soldering on LG is practicable since there is no clear pattern of where it works and where it fails.

The statements of ACEA et al. do not answer the question how failures with most demanding components - additionally applied on the currently thinnest standard glass - shall justify the continuation of the exemption in its current scope for all glass thicknesses and all applications. Additionally, the argument that currently no generic solutions are available for lead-free soldering on LG, requiring a case by case consideration, raises further questions. Even lead-soldering of any types of connectors on laminated glazing as well as on tempered glass is developed in programs and tests for each car model including a range of reliability tests. So there is no generic solution for lead soldering on laminated glass and hence its absence for lead-free soldering cannot justify the requested exemption.

Overall, the information submitted is not sufficient as evidence to a degree that would justify the continuation of the general exemption 8(j) in the requested scope.[25]

Restriction of the Exemption

Given the above-described situation, ACEA et al. were asked whether the exemption could be restricted to high current heating applications, possibly on glass panes thinner than 2.1 mm. ACEA et al. (2018 d) explained that "*Applications for which some solution could be available without requiring a large rigid connector are antenna applications with very low electrical current and less adhesion strength requirements from the automotive market. So yes, the exemption could be restricted for vehicles* with new type EU approval after 1.1. 2020 to:

- single pane wall thickness not exceeding 2,1 mm
- Heating applications of 0.5 A or more of heat current over related solder joint

[25] Note: The consultants do not consider the add-on to the exemption proposed by ACEA et al. as a scope restriction, but as a scope clarification.

Meaning, requiring Lead-free soldering for antenna application or heating applications (< 0.5 amperes Heat current over related solder joint) on laminated structure with a thickness higher 2.1/2.1 mm."

ACEA et al. (2018 e) agreed to the following potential wording for the exemption in case the consultants can recommend to continue the exemption in line with Art. 4(2)(b)(II):

> *Soldering of applications with 0.5 A or more of current per related solder joint to single panes of laminated glazings not exceeding wall thicknesses of 2.1 mm. This exemption does not cover soldering to contacts embedded in the intermediate polymer.*

The consultants asked ACEA et al. to clarify whether heating applications with less than 0.5 A of current per solder joint actually exist. ACEA et al. (2018 e) stated that "*One OEM has yet reported a heating application for defogging of a camera window. In general we assume that further similar application for sensor and camera windows are in scope of R&D efforts.*"

According to Antaya (2018 f), *[…] the most common heating applications for laminated glazings are the heated camera area and the windshield heated wiper rest area. […] We ran two tests in our lab today to demonstrate the required current for both the camera and wiper rest areas on a sample windshield. The heated camera area drew 1 A, and the heated wiper rest drew 4.8 A. Both these current values were measured with an applied voltage of 14V. […] The […] range is generally 1-10 A for heating applications on laminated glazing products. As a point of reference, tempered rear windshield heating applications typically draw up to 35 A. Considering all heating applications, the camera area is the smallest heated grid in the vehicle. Based on this information, we infer that 1 A is the least possible current required for heating applications.*" According to Saint-Gobain Sekurit (2019 a), camera heatings on wind shields are low current applications, the smallest current of last year's models having been 0.7 A.

Antenna will have to be soldered with lead-free solders because they are not heating applications, and the related current per solder joint is less than 0.5 A. The above information provided by ACEA et al., Antaya and Saint Gobain suggests that all current heating applications are out of scope of the proposed exemption.

8.6.4. Criticial Review of Further Test Results Provided by ACEA et al.

In light of the insufficient evidence to support that lead-free soldering on LG is not an option to avoid the use of lead for soldering of heating applications to LGs, ACEA et al. (2019 a) provided further tests for three connector types on two glass panes.

They gave the below details of the test program:

- Conductive silver ink printed onto laminated glass products –silver print on glass on surface 4.
- Screens were then bent using typical processes for making laminated automotive glass.

- Three types of typical electrical connectors (flexible foil connector, rigid connector, antenna connector) soldered to the silver print –between 50 and 60 connectors of each type soldered to the printed products.
- Soldering method was hot iron –common method for laminated glass products.
- All samples were then subjected to the AK2.1 thermal cycle test.
- After the test the samples were inspected for glass cracks.

Figure 8-7: Connectors

Source: ACEA et al. (2019 a)

Tested connector types (left to right):

1) Rigid connector
    a) with indium solder as commonly requested by customers for printed heated circuits;
    b) with tin solder –commonly requested by customer for printed heated circuits;
2) Flexible foil connector as commonly used on printed heated circuits on laminated glass;
3) Antenna connector –commonly used on printed antenna circuits on laminated glass;

The above elements were soldered to laminated glass.

- 2.1 mm inner glass[26] with the silver print connectors soldered to this surface;
- Glass bent using standard technology for making laminated automotive products;

Table 8-5 shows the results.

[26] In the original submission by ACEA et al. 2019 a, the glass thickness was indicated with 1.6 mm. Upon request for evidence that lead-free soldering is not viable on thicker glass (2.1 mm) even though lead-free soldering is less challenging on such glass, ACEA et al. 2019 b stated that the above test 1 was actually conducted on 2.1 mm glass.

Table 8-5: Results of test 1

Connector Type	Solder Type	% glass cracks after AK 2.1 thermal cycle test
Flexible Foil Connector	Indium Solder 1	0%
	Sn solder 1	55%
	Sn solder 2	98%
	Sn solder 3	95%
	Sn solder 4	95%
	Sn solder 5	38%
	Sn solder 6	25%
Rigid Connector	Sn solder 5	15%
	Indium solder 1	0%
Antenna Wire	Indium solder 1	0%

Source: ACEA et al. (2019 b)

A second test was conducted as follows:

- 1.6 mm inner glass (confirmed) with the silver print -connectors soldered to this surface
- Glass bent using standard technology for making laminated automotive products

Table 8-6: Results of test 2

Connector Type	Solder Type	% glass cracks after thermal cycle test
Rigid Connector	Indium solder 1	5%
	Sn solder 5	65% (before thermal cycle test)
Antenna Wire	Indium solder 1	0%

Source: ACEA et al. (2019 b)

ACEA et al. (2019 b) interpret the results as follows:

- The results show that the antenna wire connectors with an indium solder seem to give positive results in the thermal cycle test on laminated glass.
- The heating connector with indium solder gave positive results on glass representative of one model type but some glass cracks on glass representative of another model type. Indicates influence of the glass on the results. No certainty that all glass products will give positive results.
- The heating connector with tin based solder gave glass cracks on glass whenever tested. The percentage of glass cracks varied.
- The foil connectors with various tin based solders all gave glass cracks on glass tested.

ACEA et al. (2019 b) conclude:

- Antenna wires seem feasible with indium solder. Heating connectors (rigid connectors and foil connectors) have some risk of glass cracks which can be influenced by the glass/model type.

Critical Review of Test 1 and Test 2

Table 8-7 shows the evaluation of the completeness of the above tests against what ACEA et al. (2018 c) had mentioned as parts of their test program, assuming that this is what ACEA et al. would deem appropriate as minimum to produce sound evidence: "*The trials are including a lot of the parameters playing a role in lead-free soldering: connector material and design, solder alloys, soldering process".* The consultants added the variation of connector positions on glass panes, the large number of solder joints, the glass types and the bending process as further important and/or influencing test factors. Since antenna are out of scope of the potential future exemption, the antenna wire connector is not taken into account in the below table.

Table 8-7: Required and actually conducted test variations

Required Test Parameters	Actually Tested
Large variety of connector geometries	1 geometry per connector type, no variation
Large variety of connector materials	1 sample of each connector type, no material variation
Variation of glass type	1 glass type per test, no variation
Variation of soldering profiles/process conditions	1 soldering profile per soldered LG, possibly same profile for both glass samples, no variation
Variation/adaptation of the bending process	Probably no variation
Variation of solders	Several solders tested for flexible foils, only 2 for the rigid heating connector in test 1, limited variation
Large number of solder joints	50 to 60 per connector type in test 1; probably the same amount for test 2
Variation of connector position on glass panes	Variation possibly by soldering of larger number of solder joints on glass panes to different positions, not specified

Lead-free soldering on LG is a multi-parameter optimization issue. Table 8-7 shows that the tests fall short of what can reasonably be expected as minimum evidence for the unavoidability of lead use. Further on, both Antaya and SGS offer lead-free solutions for soldering in LG since 2015, including for heating applications, while no supplier in the consortium of ACEA et al. supports such a claim. Nevertheless, a supplier from this consortium conducted the above tests according to ACEA et al. (2019 c) without any involvement of SGS. ACEA et al. (2019 d) did not reveal whether materials and knowhow of Antaya were involved because "*[…] brand names and materials origin are no relevant parameters for technical aspects. Besides this […] with regard to antitrust rules even the names of suppliers for sub components are considered business sensitive information and may not be disclosed.*"

Glass and other suppliers can only demonstrate their capabilities for lead-free soldering on industrial scale if the vehicle manufacturers start lead-free soldering programs with them. It is therefore in the vehicle manufacturers hands whether and how far the viability of lead-free solutions can actually be tested. Since the last review there were more than four years' time, which ACEA et al. should have used to clarify whether there are actually applications on LG for which neither SGS nor Antaya lead-free solutions can qualify taking into account the multi-parameter optimization

(Table 8-7) and including design adaptations in vehicle design as far as other design requirements allow.

ACEA et al. (2018 a) say that "*To cover the demand of laminated glass with electric contacts components the supply of all major suppliers is required.*"

While the consultants understand that a single producer situation may have adverse implications, the consultants do not agree with the above claim since this implies that exemption 8(j) could only be revoked once all major suppliers are capable of supplying the vehicle manufacturers with lead-free soldered LGs. This would erect a high protective fence around each supplier instead of promoting competition for lead-free solutions rewarding those with more lead-free soldering development efforts and better solutions. Successful lead-free solutions can be licensed to other suppliers to maintain sufficient supply of LG. Saint-Gobain Sekurit (2018 b) for example is willing to give access to its lead free soldering technologies to other automotive glazing suppliers within the framework of licensing.

8.6.5. Technical and Legislative Trends as Justification for the Continuation of the Exemption by ACEA et al.

ACEA et al. (2018 a) point out that the use of lead in solders for LG may be required due to upcoming future requirements. They mention the use of thinner glass, e-mobility and automated assisted driving as future requirements should the proposal COM (2018) 286 8 from 17.05.2018 on General Safety Regulation be enacted and enforced.

Thinner Glass

It is technically plausible that generally thinner glass poses higher challenges and risks of failure for soldering on such LG. Vice versa, such a trend cannot justify a general exemption for the use of lead in LG on all glass thicknesses. The automotive industry uses glass panes with defined thicknesses, e.g. 2.1 mm, 1.8 mm, 1.6 mm and 1.4 mm for inner glass panes, and 2.1 mm and thinner for the outer glass panes. Saint-Gobain Sekurit (2018 d) consider glass panes thinner than 1.6 mm for the inner glass pane as thin glass, which may, however, differ from glass maker to glass maker.

Challenges in the context with thinner glass in the consultant's understanding do not justify a general exemption, since soldering of LG is conducted on thicker glass as well. The same applies to future challenges. In the consultants' view point, exemptions cannot be granted as reserve for future challenges unless these challenges and requirements can be clearly detailed and evidence is provided that the use of lead is unavoidable according to ELV Art. 4(2)(b)(ii).

Automated Driving and e-Mobility

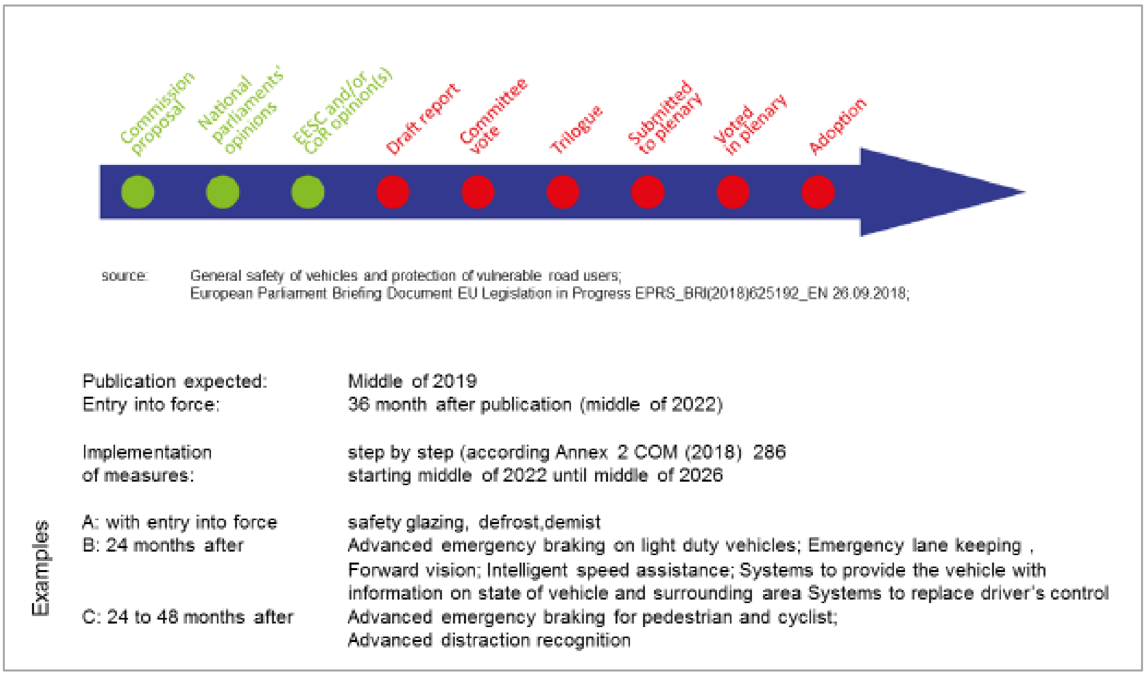
ACEA et al. (2018 a) put forward new requirements in the context of automated driving and e-mobility. In case such requirements actually are or become relevant, a specific exemption request could be submitted for such specific requirements. The future actual or potential needs of automated driving and e-mobility cannot be taken into account in the evaluation of this request to generally exempt the use of lead in

LG. In case the use of lead is unavoidable in such specific applications, an exemption can be requested specifically for those cases.

Upcoming Requirements Arising from the Future General Safety Regulation

ACEA et al. (2018 a) state that the proposal COM (2018) 286 8 from 17.05.2018 on General Safety Regulation (GSR) may entitle the Commission to mandate the integration of advanced safety features that could contribute to reduce further road fatalities and injuries, and that it is open whether this can be realized with lead-free solders. According to ACEA et al. (2018 c), the regulation would enter into force 20 days after its publication in the Official Journal, expected first half year of 2019 between January and June, and would apply from 36 months later, i.e. in the first two quarters of 2022. Deadlines for the application of various requirements to approval of new types of vehicles and to registration and placement on the market of new vehicles vary between 2022 and 2026 for new type approved cars as outlined in Figure 8-8.

Figure 8-8: Estimated timeline for implementation and requirements emerging from the future European GSR regulation



Source: ACEA et al. (2018 c)

According to ACEA et al. (2018 c), more cameras and sensor systems may have to be integrated into safety glazing structures for the purposes indicated in A, B and C of the above Figure 8-8. ACEA et al. (2018 a) claim that it is not yet clear whether these requirements can be accommodated with lead-free solders or not.

Art. 4 (2) (b) (II) allows granting exemptions if the use of lead is unavoidable. Granting exemptions for upcoming requirements for which it is not yet clear whether the use of lead can be avoided would infringe Art. 4 (2) (b) (II). In case the requirements resulting from the GSR cannot be met with lead-free solders, ACEA et al.

can ask for specific exemptions when they have clear evidence that and where lead-free solutions are not viable.

Reference to the Exclusion of Photovoltaic Panels from the Scope of the RoHS Directive

ACEA et al. (2018 a) reference literature about soldering to photovoltaic panels, where "Lead-based solders are still in use, because similar to laminated automotive glazing, thermomechanical stress is seen challenging for alternatives." As further evidence, ACEA et al. (2018 d) "*[…] referenced solar panels having an exemption from lead restriction, because of missing alternatives*".

Actually, legislators excluded photovoltaic panels from the scope of the RoHS Directive because "*The development of renewable forms of energy is one of the Union's key objectives, and the contribution made by renewable energy sources to environmental and climate objectives is crucial. […] there should be coherence between those objectives and other Union environmental legislation. Consequently, this Directive should not prevent the development of renewable energy technologies that have no negative impact on health and the environment and that are sustainable and economically viable.*" RoHS Directive (2011)

The exclusion of photovoltaic panels from the scope of the RoHS Directive was a political decision giving priority to the further development of renewable energies over the restriction of substances. It is beyond the consultants' mandate to evaluate exemption requests in the light of such decisions. ACEA et al. should convince legislators that soldering on LG is technically the same like soldering in photovoltaic panels and ask for a scope exclusion. As long as this situation is not achieved, the consultants have to evaluate the exemption request in line with the criteria of ELV Art. 4(2)(b)(ii).

8.6.6. Environmental and Critical Raw Material Aspects

Critical Raw Material Arguments

ACEA et al. (2018 a) point out that the CRM-list (2017) has identified indium as well as bismuth as critical raw materials (CRM) which should better be substituted and their use avoided. The consultants understand their mandate to evaluate whether the use of lead in the requested exemption is still unavoidable according to Art. 4(2)(b)(ii). Any decision whether and how far the fact that lead substitutes like the CRMs indium and bismuth may justify the use of lead in the requested exemption are beyond the consultants' mandate and must be decided by the Commission. To enable an informed decision, the amounts of indium required for replacing lead solders in soldering of laminated glazings is calculated.

It is assumed that the lead solder will be replaced volume-equivalently, meaning that 1 cm^3 of indium-containing solder will replace 1 cm^3 of lead solder. Based on this assumption, the below basic data are used to calculate the required amounts of indium to substitute the lead solders.

Table 8-8: Volume-equivalent substitution of solders

	Lead-solder	Indium-solder
Density of solders (g/cm³)	8.5 to 10.5	7.54
Content in solder (%)	40 % to 70 % lead	65 % indium

Source: Deubzer et al. (2012)

ACEA et al. calculated 2.9 t of lead used in laminated glazing in the EU. Assuming a lead content of 40 %, the total amount of lead solder would be 7.3 t. Taking into account the different densities, a volume-equivalent substitution of these 7.3 t of lead solder would require around 6.4 t of indium solder with 65 % of indium content. This corresponds to 4.2 t of indium required to substitute the lead solder. Assuming the content of lead in the lead solder with 70 %, the total amount of lead solder to be replaced would be 4.1 t. This would require 3.0 t of indium solder, resulting in 1.9 t of indium in the EU.

The figures need to be put into the perspective that the indium solder will not replace 100 % of all lead solder uses in laminated glazings. On the other hand, indium solders can contain more than 65 % of indium, up to 90 %. Overall, the required amount of indium can be assumed to be less than 5 tonnes per year in the EU, with a high probability that the actual consumption is much lower. USGS (2019) estimate the worldwide refinery production of indium with 750 t so that the need of indium in the EU for laminated glazing can be assumed to be less than 0.67 % of the annual indium world production.

ACEA et al. did not provide figures for lead use outside the EU. The actual need for indium might therefore be higher in case lead is substituted in laminated glazing in vehicles outside the EU as well.

Environmental and Health Arguments

ACEA et al. (2018 a) also mention that indium has been registered under REACH and exhibits some hazard properties. The ECHA-web-page they reference[27] shows no entries in the section "Properties of Concern", but in the section "Hazard classification & labelling":

- *Danger! According to the classification provided by companies to ECHA in **REACH registrations** this substance causes damage to organs through prolonged or repeated exposure and is toxic to aquatic life with long lasting effects.*
- ***Additionally**, the classification provided by companies to ECHA in **CLP notifications** identifies that this substance is harmful if swallowed, causes*

[27] For details see https://echa.europa.eu/de/brief-profile/-/briefprofile/100.028.345

serious eye irritation, is harmful in contact with skin, is harmful if inhaled, is a flammable solid, may cause respiratory irritation and causes skin irritation.

Indium, as an element, currently does not have a harmonised classification. Based on the list of classifications notified by companies, in a joint classification it is specified as causing damage to lungs as a result of repeated exposure (through inhalation) (STOT RE 1: 372) and toxic to aquatic life with long lasting effects (Aquatic chronic 2: H411).[28]

As for lead, under "Hazard classification and labelling" the ECHA-web-page specifies[29]:

- *Danger! According to the classification provided by companies to ECHA in CLP notifications this substance is very toxic to aquatic life with long lasting effects, may damage fertility or the unborn child, causes damage to organs through prolonged or repeated exposure, is very toxic to aquatic life, is harmful if inhaled, is harmful if swallowed, may cause harm to breast-fed children and is suspected of causing cancer.*
- *This substance is covered by several Harmonised Classifications and Labelling's (CLH) entries approved by the European Union. Differentiating between the different CLH's entries requires manual verification.*

The "Properties of Concerns" [30] field lists the following:

- *R: toxic for reproductivity;*
- *PBT: persistent, bioaccumulative, toxic* [this is specified with a dashed line, meaning that less than 90 % of notifiers specified this critical property].

Lead has a harmonized classification specifying it as hazardous in terms of "may damage fertility, may damage the unborn child" (Repr. 1A - H360FD) and "may cause harm to breast fed child" (Lact. - H362). Additional classifications are specified by companies in the list of notified classifications. [31]

The European Chemicals Agency (ECHA) adopted lead to the list of substances of very high concern[32] (SVHC). Lead has thus become a potential candidate for adoption to REACH Annex XIV (List of Substances for Authorization). Whether and how far this may affect the use of lead in the automotive industry generally or for use in solders for LG is currently unclear.

ACEA et al. (2019 c) "*[…] reemphasize the fact, that the use of Indium is basically driven by substitution pressure for Lead. From our point of view it is however*

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28 For details see: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/28369

29 Source: ECHA, https://echa.europa.eu/de/brief-profile/-/briefprofile/100.028.273

30 Source: ECHA, https://echa.europa.eu/de/brief-profile/-/briefprofile/100.028.273

31 For details see: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/14116

32 Source: ECHA, https://www.echa.europa.eu/web/guest/candidate-list-table/-/dislist/details/0b0236e182607ea6

questionable, whether the use of Indium in this specific application provides overall environmental benefits, as e.g. the total carbon foot print of Indium production is much higher as for lead and more knowledge of health and environmental risks of Indium is published. Consequently, the use of Indium may be a useful measure to fulfill the lead ban, but in terms of sustainability it seems to be counterproductive."

ACEA et al. (2018 a) refer to the life cycle assessment (LCA) submitted in the course of the last review of exemption 8(j) in 2015 to prove that the use of lead is favourable over the use of indium in solders for LG. Gensch et al. (2015) had assessed this LCA and found that it's use in the context with exemption evaluations is not conform with ISO requirements.

SGS has been stating since 2015 to offer lead-free solutions based on tin solders for antenna and other applications on LG. Indium-based solders are thus not the only alternative to lead-solders.

8.7. Conclusion

ACEA et al. request the continuation of exemption 8(j) beyond 2019, initially without scope restrictions[33]. In the course of the review, the scope of the requested exemption was narrowed to heating applications with at least 0.5 A or more of heating current per related solder joint on single glass panes not exceeding 2.1 mm thickness.

Gensch et al. (2015) stated in the last review report for exemption 8(j) that "*Lead-free solutions are on the market already, or are in a status that allows their implementation, even though they may have to be adapted for the individual vehicles and technologies on the one hand, or they may require vehicle design and technology adaptations on the other hand. […] In case specific applications require the continued use of lead after 2019 […] ACEA et al. would, however, have to prove that the use of lead is still unavoidable in these cases in spite of efforts to adapt the design to the requirements of lead-free soldering.*"

The submitted information and the arguments of ACEA et al. are, however, incomplete and in parts inconsistent and contradictory.[34] Further on, SGS as well as Antaya are the only suppliers who have attested as early as 2015 to offer lead-free soldering solutions for LG. ACEA et al., however, base their exemption request on information as to the unavoidability of lead use from other suppliers in their consortium. SGS solutions were not assessed by these suppliers, and ACEA et al. did not reveal whether Antaya solutions were involved in the testing of the indium-based lead-free solutions.

[33] ACEA et al. from the beginning excluded soldering of contacts embedded in the polymer layer, which the consultants consider as a scope clarification rather than a restriction.

[34] Past experience shows that due diligence with submitted information is especially advisable. For details see Gensch et al. 2015, page 55 et seqq. (chapter 6.33 Conclusions)

Indium has entries in ECHA's hazard classification and labelling, though it currently does not have a harmonized classification in the CLP Regulation. [35] Indium-based solders are, however, not the only current substitute for lead-solders for soldering of laminated glazing.[36] The European Commission has listed Indium as a critical raw material on its CRM-list (2017). Lead also has entries in this hazard classification and labelling system as well as being specified with additional "Properties of Concern" [37]. Lead also has a harmonized classification in the CLP Regulation with regards to toxicity for reproduction and toxicity for breast fed children. Lead is also listed as a substance of very high concern (SVHC)[38] due to its severe toxicity and other adverse health and environmental impacts. The further use of lead in automotive glazing could thus require authorization in the future under the REACH Regulation should lead be adopted to REACH Annex XIV. It is beyond the consultants' mandate to decide whether and how far the listing as CRM or toxic properties of indium vs. those of lead might have the potential to override the requirements of the ELV Directive to avoid the use of lead.

ACEA et al. (2018 a) argue that "*Whereas some glass producers claim to have Lead-free solutions for their product spectrum of laminated glass products available at least on laboratory level, other producers claim for their product spectrum that Lead-free soldered solutions are not able to meet their customer's specifications today in volume production. To cover the demand of laminated glass with electric contacts components the supply of all major suppliers is required.*"

While the consultants understand that a single supplier situation may have adverse implications, the consultants do not agree with the above claim since it implies that exemption 8(j) could only be revoked once all major suppliers are capable of supplying the vehicle manufacturers with lead-free soldered LGs. This would erect high protective fences around each supplier instead of promoting competition for lead-free solutions rewarding those who come up with better solutions earlier than others. Successful lead-free solutions can be licensed to other suppliers to maintain sufficient supply of LG. Saint-Gobain Sekurit (2018 b) for example is willing to give access to its lead free soldering technologies to other automotive glazing suppliers within the framework of licensing.

There is thus a lack of sound evidence that the use of lead is unavoidable for the heating applications remaining in the scope of the exemption request. Recommending the continuation of exemption 8(j) under these circumstances would infringe Art. 4(2)(b)(ii).

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35 ECHA, https://echa.europa.eu/de/brief-profile/-/briefprofile/100.028.345, also see section Environmental and Health Arguments on page 53 et sq.

36 For volumes of lead and indium see section "Critical Raw Material " on page 83

37 Source: ECHA, https://echa.europa.eu/de/brief-profile/-/briefprofile/100.028.273, also see section Environmental and Health Arguments on page 53 et sq.

38 C.f. List of Substances of Very High Concern (https://echa.europa.eu/candidate-list-table)

8.8. Recommendation

It is recommended not to grant the exemption.

ACEA et al. requested the continuation of the current exemption 8(j) [39] beyond 2019. In the course of the evaluation, ACEA et al. agreed to narrow the scope of the exemption to heating elements with at least 0.5 A heating current per related solder joint on single glass panes of laminated glazing not exceeding 2.1 mm thickness. ACEA et al. did, however, not provide substantiated evidence that the use of lead is actually unavoidable for the heating elements in the scope of this exemption. In the absence of sound evidence to be provided by applicants, the consultants cannot recommend to grant an exemption in line with Art. 4(2)(b)(ii).

All the more so as Gensch et al. (2015) stated in the last review report for exemption 8(j) that SGS and Antaya – and possibly other suppliers – offer lead-free solutions and that ACEA et al. would have to provide sound evidence that these solutions are not viable in case they request the continuation of the exemption after 2019. In the test results provided as evidence, ACEA et al. neither took into account the lead-free solutions for laminated glazing offered by Saint-Gobain Sekurit (SGS, tin-based), nor did they allow insights whether Antaya or Antaya materials and knowhow were involved in the presented tests. The tests and test results presented by ACEA et al. as evidence were conducted by other suppliers of laminated glazing. None of those suppliers, contrary to SGS and Antaya, had claimed in this or the 2015 exemption review to have lead-free solutions available for soldering on laminated glazing, which further undermines the evidentiary value of the presented tests as to the unavoidability of lead use in soldering of laminated glazing.

ACEA et al. argue that all major suppliers must be able to supply lead-free solutions for heating elements on LG before the exemption can be revoked. In the consultants' understanding, this argument does not justify that ACEA et al. do not even take into account the offered lead-free solutions. The situation is thus still unchanged compared to the last review around five years ago with two parties offering lead-free solutions for industrial use and ACEA et al. stating that such solutions are not yet available.

The consultants understand that a single supplier situation would not be adequate but do not agree to the above claim of ACEA et al. since it would eradicate the competition for better solutions among suppliers of LG. Successful lead-free solutions can be licensed to other suppliers to secure sufficient supply of LG. With the SGS tin-based and the Antaya indium-based lead-free solutions, two options are offered for lead-free soldering on LG. Given the large variety of LG for various vehicles and applications on the one hand, and material specific properties of these lead-free solders in combination with material properties of LG, and the strain they are exposed to during the vehicle life time, the consultants cannot exclude that there may be cases where the use of lead is actually unavoidable at the current status. The consultants can,

[39] ACEA et al. from the beginning excluded soldering of contacts embedded in the polymer layer, which the consultants consider, however, as a scope clarification rather than a scope restriction.

however, not recommend granting an exemption in the absence of sound evidence as to the unavoidability of lead use without infringing the stipulations of ELV Art. 4(2)(b)(ii).

Lead has well-known severely hazardous properties and as a consequence is classified as Substance of Very High Concern.[40] Indium has entries in ECHA's hazard classification and labelling[41] and is listed as critical raw material on the Commission's CRM-list (2017).It is beyond the consultants' mandate to decide whether and how far the listing as CRM or the toxic properties of indium versus those of lead might have the potential to override the requirements of the ELV Directive to avoid the use of lead. Indium-based solders are, however, not the only current substitute for lead-solders for soldering of laminated glazing.[42]

Should the Commission decide to continue the exemption, the following wording could be used, which has been aligned with ACEA et al. in the course of the evaluation:

	Materials and Components	Scope and Expiry Date of the Exemption	Comments
8(k)	Soldering of heating applications with 0.5 A or more of heat current per related solder joint to single panes of laminated glazings not exceeding wall thicknesses of 2.1 mm. This exemption does not cover soldering to contacts embedded in the intermediate polymer	Vehicles type-approved before XXX and spare parts for these vehicles	--

The above wording excludes all non-heating applications such as antenna from the exemption scope, but includes almost all heating applications due to the low current threshold of 0.5 A on glass panes 2.1 mm thickness at maximum, which is the upper threshold for standard pane thicknesses in LG.

8.9. References

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ACEA et al. (2018 b): Answers to questionnaire 2 sent by Jens Warsen, ACEA, via e-mail to Dr. Otmar Deubzer, Fraunhofer IZM, on 30 July 2018. File "Exe_8j_ACEA_Questionnaire_2_2018-07-14.pdf".

40 C.f. List of Substances of Very High Concern (https://echa.europa.eu/candidate-list-table)

41 ECHA, https://echa.europa.eu/de/brief-profile/-/briefprofile/100.028.345, also see section Environmental and Health Arguments on page 53 et sq.

42 For volumes of lead and indium see section "Critical Raw Material " on page 83

ACEA et al. (2018 c): Answers to questionnaire 4, sent by Jens Warsen, ACEA, via e-mail to Dr. Otmar Deubzer, Fraunhofer IZM, on 25 October 2018. File "Exe_8j_ACEA_Questionnaire-4_2018-10-11.docx".

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ACEA et al. (2018 e): Answers to questionnaire 6 sent by Dr. Jens Warsen, ACEA, to Dr. Otmar Deubzer, Fraunhofer IZM, on 18 December 2018. File "Exe_8j_ACEA_Questionnaire-6_2018-12-18.pdf".

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ACEA et al. (2019 c): Answers to questionnaire 7, received by Dr. Otmar Deubzer, Fraunhofer IZM, from Jens Warsen, ACEA, via e-mail on 1 August 2019. File "Questionnaire-7_ACEA_et_al.pdf".

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9. Exemption 14

"As an anti-corrosion agent of the carbon steel cooling system in absorption refrigerators in motor caravans 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"

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.

Acronyms and definitions

CrIII	Trivalent Chromium
CrVI	Hexavalent chromium
ECHA	European Chemicals Agency
ELV	Directive 2000/53/EC on End-Life-Vehicles
EU COM	European Commission
RAC	Risk Assessment Committee
REACH	Regulation 1907/2006/EC of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals
RoHS	Directive 2011/65/EU on the Restriction of Hazardous Substances in Electric and Electronic Equipment
RV	Recreational vehicle
SEAC	Socio-Economic Analysis Committee
SVHC	Substances of Very High Concern according to REACH

9.1. Description of Requested Exemption

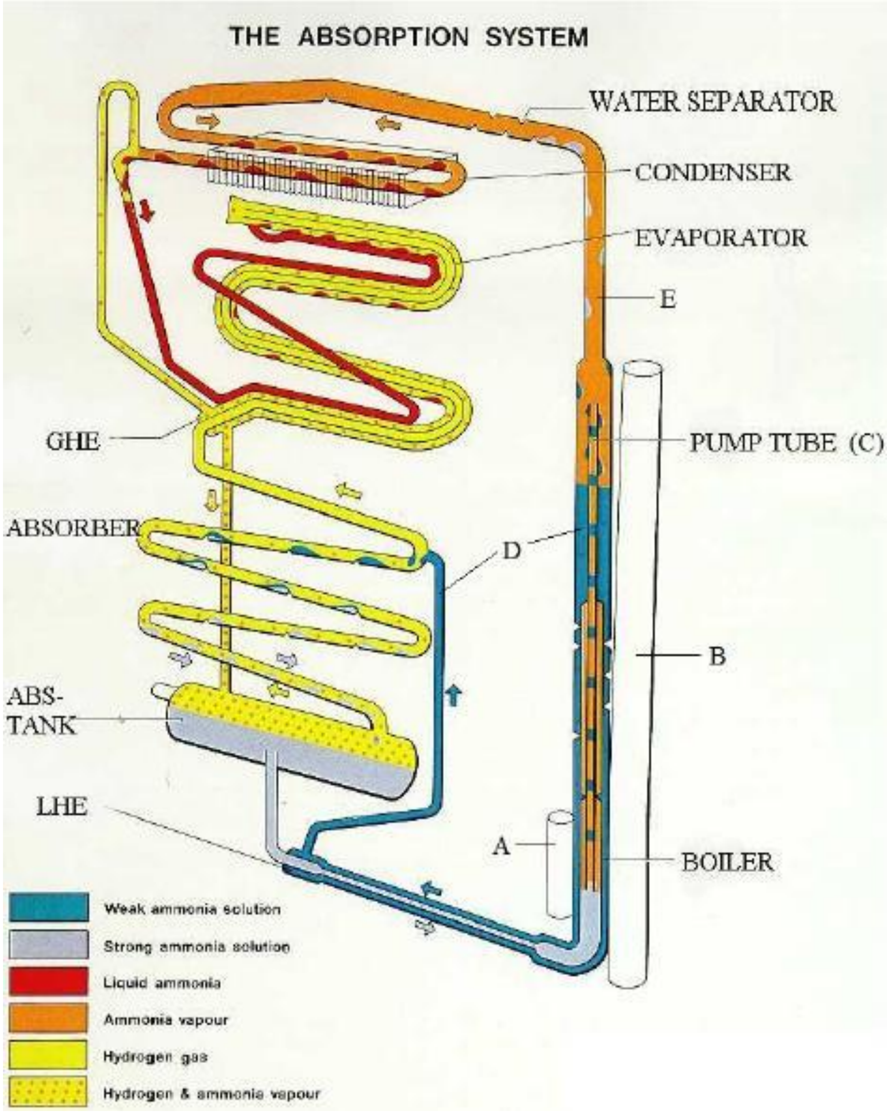
According to information summarized in previous evaluations (Gensch et al. 2016a), hexavalent chromium (CrVI) is used as a corrosion inhibitor in the cooling solution of absorption refrigerators that are operated with a heat source, e.g. gas, electricity or variable heat sources. On the interior tube surface of the cooling system, there is a thin corrosion protective layer of chromium oxide (Cr_2O_3). If this layer is damaged during operation, it is subsequently replenished by the sodium dichromate (CrVI) available in the cooling solution within the tube. Thereby, CrVI is reduced to the less toxic trivalent chromium (CrIII) (Gensch et al. 2016a).

Absorption refrigerators in which CrVI is applied are among others used in motor caravans and thus so as to allow the use of CrVI in this application, an exemption was approved in the past and currently appears in Annex II of the ELV Directive listed as exemption 14 (see Section 9.1).Following the regulation of similar applications under other legislation, an alignment of the ELV exemption has become necessary with Directive 2011/65/EU (RoHS) and Regulation 1907/2006/EC. As stated in the terms of references to this project, this has triggered the current review, through which a stakeholder consultation was held to clarify the need for the exemptions further validity. Dometic (2018a) submitted a contribution to the stakeholder consultation requesting a prolongation of Exemption 14 in the ELV Directive until the end of 2025 and proposes to align the wording of the exemption with the proposed wording of exemption 9 of the RoHS Directive.

9.2. Technical Background

In absorption refrigeration, a heat source (e.g. gas or electricity) is used to separate the ammonia, which acts as refrigerant, from the water. The ammonia 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. This is schematically shown in the following figure.

Figure 9-1: Scheme of the absorption cooling system



Source: Dometic (2015)

The cooling system is comprised from carbon steel (tubes) because of its strength and its good welding- and cold-working properties. The cooling solution consists of ammonia, water, sodium chromate (CrVI) and hydrogen gas, retained at a sufficient pressure to condense ammonia at the ambient temperature. Sodium chromate functions as a corrosion inhibitor to protect the carbon steel structure of the cooling unit in absorption refrigerators from the corrosive ammonia. According to Dometic, the CrVI creates a thin and tight layer on the interior surface to prevent inner corrosion of the steel tubes in order to allow a long service life of the sealed cooling system.

9.2.1. Amount of CrVI Used under the Exemption

Dometic (2018a) states that they use approximately 520 kg of CrVI for absorption refrigerators in motor caravans for the EU market.

Dometic (2018a) explains that "*the total amount of hexavalent chromium in absorption cooling system is depending on the size of the cooling unit. At time being we have a number of different cooling units with a sodium chromate quantity ranging from 5 to 15 grams. This corresponds to 1.6 to 4.8 grams of hexavalent chromium. Absorption refrigerators for vehicles placed on the EU market contain on average approximately 3.5 grams of hexavalent chromium.*"

Dometic (2018a) stresses that "*the hexavalent chromate used in the cooling system is gradually converted to Cr(III) during operation. This is a central part of the corrosion inhibitor function where Cr(VI) is reduced to Cr(III) while oxidizing F(0) to Fe(III). This reaction is fast during the initial period of use thus rapidly reducing the amount of Cr(VI) in the filling solution.*"

It is noted from past evaluations of the exemption and of the parallel Ex. 9 of Annex III of the RoHS Directive (see Gensch et al. (2016a)), that the consultants are aware of additional manufacturers such as Thetford who manufacture similar equipment outside of Europe. However, despite pursuing contact with some of these manufacturers, contributions were not made on their side. The consultants assume that the data provided by Dometic in relation to the amount of Cr VI in the form of sodium chromate placed on the market through this application only represents Dometic's manufacture. It cannot be estimated if the actual amount may be higher, or if the opposite is true.

9.3. History of the exemption

9.3.1. History of the exemption under ELV

This exemption was last reviewed in 2009/2010. At the time it appeared in the ELV annex as exemption no. 13 for "*Absorption refrigerators in motor caravans*" (see Zangl et al. (2010). During the last review, the wording was aligned to the corresponding RoHS exemption. Additionally, the second part of the exemption was added arguing that "*a high performance refrigerator with a freezer compartment while being in a secluded area can be viewed as expendable and thus avoidable in the sense of the ELV Directive*" (Zangl et al. 2010). This resulted in the following exemption being added under item 14 of Annex II of the ELV Directive:

> "*Hexavalent chromium [...]*
>
> *14. As an anti-corrosion agent of the carbon steel cooling system in absorption refrigerators in motor caravans 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*"

The ELV exemption 14 was included in this present 9th adaptation to scientific and technical progress of the exemptions of Annex II to Directive 2000/53/EC (ELV) in order to be aligned with inter alia the RoHS Directive and the REACH Regulation.

9.3.2. Sodium chromate and its use in absorption refrigerators under the REACH Regulation

Sodium chromate (CAS 7775-11-3; EC 231-889-5) is listed in REACH Annex XIV in light of its being identified as carcinogenic (category 1B), mutagenic (category 1B) and toxic for reproduction (category 1B). It thus cannot be placed on the market or used in the EU without an authorisation after the sunset date of this substance specified in Annex XIV as 21 September 2017.[43]

Dometic GmbH and Dometic Hűtőgépgyártó és Kereskedelmi Zrt. produce absorption refrigerators in Europe and therefore had 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 (Cr^{6+}) in the cooling solution*"[44].

During the REACH authorization process, Dometic (2015) grouped the wide range of absorption refrigerator products based on boiler temperature because the internal corrosion increases significantly with the boiling temperature. Dometic (2015) described two product groups with low and with high boiler temperature. Dometic (2015) described the road map for substitution in the context of the REACH authorization application, explaining that it planned to phase out sodium chromate beginning with the electrically operated refrigerators which are described as having a low boiler temperature. It is understood from the information provided by Dometic (2015) that the products with low boiler temperature are exclusively run on electrical heater.

According to Dometic (2015), absorption refrigerators that operate with gas have higher boiler temperatures. These products need more technical development before the new inhibitor can replace sodium chromate (e.g. re-design of the cooling units, new safety equipment).

During the REACH authorization application, the phase out was envisaged by Dometic (2015) to be completed with the substitution in high boiler temperature products in 2029.

On 15 February 2017, the European Commission (EU COM) published a decision concerning the Dometic request for a REACH authorisation (EU COM 2017). The decision authorises Dometic's use of sodium chromate in absorption refrigerator

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43 Entry No 22 in Annex XIV, sunset date 21/09/2017, latest application date 21/03/2016; https://echa.europa.eu/authorisation-list, last viewed 10.12.2018.

44 European Chemicals Agency ECHA, Adopted opinions and previous consultations on applications for authorisation on sodium chromate at: https://echa.europa.eu/applications-for-authorisation-previous-consultations/-/substance-rev/10106/term, last viewed 10.12.2018.

products, making a differentiation in the authorisation duration between high and between low boiler temperature products in this respect:

- The "*use in 'low boiler temperature products' (minibars)*" is allowed until 31 December 2019.[45]
- The "*use in 'high boiler temperature products' (recreational vehicles refrigerators and medical cold equipment)*" is allowed until 21 September2029.

9.3.3. The exemption under RoHS and its alignment with REACH

The corresponding RoHS exemption exists as exemption 9 of Annex III of the RoHS Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment. A review of the RoHS exemption was performed in 2015-2016 (Gensch et al. 2016a). In its recommendation for exemption 9, Oeko-Institut (Gensch et al. 2016a) took notice of the parallel REACH process, which had not been finalised at the time of publication of the RoHS evaluation report. A differentiation of the exemption was proposed in light of the different timelines needed to substitute CrVI in the form of sodium chromate in low and high boiler temperature products communicated by Dometic in the REACH authorization process. As a criterion to distinguish the different applications, it was discussed with Dometic if the boiling temperature could be used as e.g. proposed in Dometic's application for authorization under REACH because the internal corrosion increases correlating to boiler temperature. Dometic argued 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. Therefore, Oeko-Institut proposed to describe different items of the exemption specifying the energy source, i.e. absorption refrigerators designed to operate with electrical heater only, with variable energy sources or with other than electrical heater. This was also understood to be a practicable solution from a market surveillance perspective. (Gensch et al. 2016a)

The final formulation recommended by Oeko-Institut e.V. differentiated between products based on energy source in light of the correlation of this aspect with the time estimated to be required to complete substitution and referred to three distinct product groups (Gensch et al. 2016a) as follows:

> "*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*"

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[45] Since Dometic has not submitted a review report for this authorised use 18 months before 31 December 2019 in order to ask for its prolongation, the authorisation for this use will end on 31 December 2019.

Against the background that Article 5(1)(a) of the RoHS Directive does not allow approving exemptions (their renewal or amendment), where this could weaken the protection afforded by the REACH Regulation, it was recommended to align any future exemption formulations with the REACH authorisation should the process be finalised before the decision on the renewal request under RoHS was published.

After the publication of the European Commission (EU COM) Decision concerning the Dometic request for a REACH authorisation (EU COM 2017), Oeko-Institut revised the initial recommendation made for the RoHS exemption in the 2016 report and proposed a change to the formulation of this exemption Oeko-Institut e.V. (2018). A further specification with additional parameters mentioned in the context of the REACH Authorisation, namely the electrical power input, was proposed. This proposal is shown in the following table.

Table 9-1: Additional proposed formulation for exemption 9 of Annex III of Directive 2011/65/EU (RoHS 2), aligned with REACH

Exemption 9	Duration
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	Expires on: 21 July 2021 for categories 8 and 9 other than in vitro diagnostic medical devices and industrial monitoring and control instruments; 21 July 2023 for category 8 in vitro diagnostic medical devices; 21 July 2024 for category 9 industrial monitoring and control instruments, and for category 11.
Designed to operate fully or partly with electrical heater, having an average utilised electrical power input < 75 W at constant running conditions.	Expires on 31.12.2019 for Cat. 1-7 and 10 (*date aligned with REACH authorization REACH/17/7/0)
Designed to operate fully or partly with electrical heater, having an average utilised electrical power input ≥75 W at constant running conditions. Designed to fully operate with non-electrical heater	Expires on 21.7.2021 for Cat. 1-7 and 10 (five years)

Source: Oeko-Institut e.V. (2018)

As explained in Oeko-Institut e.V. (2018), the average utilised heat input of 75 W during constant running conditions, is understood by Dometic to comprise a possible threshold for separating between low and high boiler temperatures. Dometic explains that the electrical heating power can easily be measured and is also often specified on the data label of the product. The addition of this aspect to the formulation of exemption 9 of the RoHS Directive was meant to allow differentiating between low and high boiler temperature products by market surveillance.

The amendment of the exemption 9 under RoHS is still pending.

9.4. Stakeholders' Justification for the Exemption

During the stakeholder consultation held in the course of this study, Dometic (2018a) submitted a contribution requesting a prolongation of Exemption 14 in the ELV Directive. Dometic (2018a) explains that they have found an alternative corrosion inhibitor, called "*inhibitor 7*",[46] which they will gradually introduce to the whole portfolio of absorption refrigeration products:

> "*As laid out in the most recent application for RoHS exemption and REACH authorization we have identified one inhibitor (Inhibitor 7) that after extensive investigations has shown acceptable results. That is also why we have started the exchange of Cr(VI)*"

Dometic (2018a) states that they are now introducing the first products with the alternative corrosion inhibitors to the market "*by end of 2019 following the timeline in the RoHS application*". These are products running on electrical heat source only and therefore having a low boiler temperature.

Dometic (2018b) states that absorption refrigerators with only electrical heaters are not relevant for motor caravans and that products in motor caravans have high boiler temperatures as they operate, fully or partly, with gas burners. According to Dometic (2018a), the risk of corrosion is higher with a high boiler temperature. Furthermore, in motor caravans, absorption refrigerators are exposed "*to vibrations, uneven terrain etc. all things that can increase boiler temperature further*" Dometic (2018a). Dometic (2018a) explains that therefore the application of the alternative corrosion inhibitor requires design changes of the cooling units. Dometic (2019) explains that for high boiler temperature they have approximately 12 to 15 different cooling units. A further step in the substitution process according to Dometic (2019) comprises an adaptation of the manufacturing factory equipment for the re-designed cooling units. Dometic (2019) further explains that a subsequent working step consists of a re-design of a range of products to ensure the energy performance and cooling capacity.

It has to be noted that Dometic does not specify a timeline for each step; Dometic (2019) argues that "*it is rather difficult to set a precise time plan for the several actions required, as steps are depending on results in testing. Furthermore, the detailed steps of the time plan has not been set yet, as we are still in the phase of converting our low temperature range.*"

Dometic (2018c) explains the experience from the introduction of the new inhibitor in low boiler application to be useful also for products with higher boiler temperature. However, Dometic also points out that "*for the products with high boiling temperature no explicit field test has started yet. In order to keep 2-3 years field tests before final decision on the tests will be initiated during next year (2019).*" The consultant

[46] The identity of the possible substitute is not revealed by Dometic. During the last RoHS evaluation, Dometic indicates that the alternative corrosion inhibitor "inhibitor #7" is a mixture containing an inorganic salt and stabilisers Gensch et al. 2016a.

understands this to mean that field tests to start in 2019 shall need to run for at least 2-3 years.

Dometic (2018c) states that during in-house testing, several tests have been performed with extended pressure and temperature that are also representative for high boiler temperature absorption refrigerators. Tests have also been conducted with increased vibration to simulate expected road conditions. The field tests are aimed according to Dometic (2018c) *"at capturing events that could require us to reconsider safety systems for the electronics, e.g. user behaviour that would falsely trip the safety system. Furthermore, we aim at confirming that the behaviour during first years in the field corresponds to the experience we have in our laboratory investigations to confirm that the laboratory investigations are relevant in our assumptions of service life. We consider that field test of minimum 2-3 years should be conducted for the relevant cooling units before taking the required decisions. To get additional information from these tests we always pick products for examination to study the internal tubing surface after a certain time in use."*

As one safety feature of the re-designed products, Dometic (2019) develops a temperature monitoring system: *"A similar system is developed for our low temperature range of products, but an adoption to the new products will be required. We estimate that the adaptation would take 9-12 months for the RV range, but this task cannot start before the cooling units have been re-designed."*

As for a **wording**, Dometic (2018b) proposes to shorten the wording by deleting the last part of the current ELV exemption "*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*." Dometic (2018b) argues that "*this part is creating a significant legal uncertainty, as the parameters are difficult to confirm, monitor and follow up by authorities. Furthermore, we question if eco-design aspects like this one should at all be handled by the ELV Directive. The wording according to our proposal will also harmonize the legal text with the proposed wording of the corresponding exemption in the RoHS Directive.*"

9.5. Critical review

9.5.1. Elimination of Cr VI in adsorption coolers

In principle, absorption refrigerators could be replaced by an alternative technology like standard electrical refrigerators that use other refrigerants than ammonia. This would allow eliminating the use of ammonia and hexavalent chromium. The consultants understand, however, that absorption coolers with a variable or with a non-electric power source may be installed in motor caravans for two main reasons:

- They can be operated independently of electrical power, i.e. when a power grid connection is not available, so as not to deplete the vehicle battery;
- They produce less noise, which can be an advantage when the "cooking area" is difficult to separate from "sleeping area", as usually the case of motor caravans.

In this context the consultants thus views the use of adsorption refrigerators as unavoidable and thus the evaluation further focuses on the availability of substance substitutes for Cr VI in this application.

9.5.2. Substitution of Cr VI in adsorption coolers

Dometic has found a candidate for substituting Cr VI in the cooling units of adsorption refrigerators and it can be understood that development of this candidate is underway. It is understood from information provided by Dometic that field tests with the high boiler temperature products that are used in motor caravans have not started yet but will start in 2019 and need to be run for at least two to three years. This is explained to be because they are finishing the substitution process of the low boiler temperature products where the substitution is explained to be technically less demanding. Dometic explains that products with higher boiler temperatures, used in motor caravans, are exposed to harsher conditions than products with low boiler temperature (minibars), such as vibration, varying outside temperature and discontinuous running. Such parameters would need to be taken into account for field test conditions in order to ensure that the CrVI-free products have an equivalent product lifetime as those produced currently with sodium chromate as inhibitor.

From 2019 on, Dometic (2018b) estimates that a "*6 year transition period for the products to the EU market is reasonable, taken into consideration complications we have seen on the low boiler temperature range*" but states not being able to specify a timeline for the different steps. Thus, substitution would be completed end of 2025 which is somewhat earlier than envisaged by Dometic during the REACH authorization application Dometic (2015). It is understood from the information provided by Dometic that this is due to the fact that they have identified "*the critical technical parameters*" and found design and engineering solutions from the experiences and tests performed with the low boiler temperature products. Further on, they have also conducted certain in house tests that indicate a good reliability Dometic (2015).

Dometic benefits from some results gained during the substitution in low boiler temperature refrigerators, but products with higher boiler temperature still need some basic evaluation and technical development such as the re-design of the cooling unit in different models, the field tests, the adaptation of factory equipment and the re-design of various product models including the introduction of the temperature monitoring system.

Against this background, the consultants can follow that in light of the still to be performed testing (2-3 years starting 2019) and further time needed for adaptation of manufacturing and adaptations of the refrigerator product, that the substitution in high boiler temperature products shall still requires additional time. Dometic proposes a validity until 2025, which is somewhat earlier than estimated in the REACH authorization process (2029).

Other manufacturers of absorption refrigerators for recreational vehicles were urged to provide a contribution. However no statements were submitted. In the 2015/2016 evaluation of Ex. 9 of Annex III of RoHS Thetford[47] stated that "*All absorption refrigerators currently on the market use sodium chromate as a corrosion inhibitor as far as we are aware*". However, the status of products placed on the market in 2019 may differ from those placed on the market in 2016 and is not known.

9.5.3. Relation to REACH Authorisation and spare parts

As background for the following section, it should be kept in mind that the REACH Authorisation is only applicable for the use of CrVI in the form of sodium chromate in adsorption refrigerator devices and parts manufactured in the EU. As Dometic is currently the only manufacturer who has submitted and received an authorisation for use of sodium chromate in this equipment, it stands to reason that Dometic is the only manufacturer of cooling units using Cr VI in the EU for this purpose. As explained above, the granted authorisation allows use in low boiler temperature products until 31.12.2019 and in high boiler temperature products until 21.9.2029.

For the ELV exemption, Dometic (2018a) requests a shorter duration for the exemption than would be expected from the road map for substitution as presented during the REACH authorization process. Dometic (2018a) argues that "*with an exemption terminated by end of 2025 Dometic still has the possibility to produce refrigerators for a few years more, in accordance to the REACH authorization, this time period can be used for transition of the last products for outside of Europe and also for spare part production.*"

Based on the following information, the consultants conclude that Dometic had assumed that once the ELV exemption expires, as in the case of RoHS, it shall still be possible to put spare parts containing Cr VI (i.e. cooling units) on the market for repair of equipment put on the market prior to the expiration date:

Dometic (2018a) explains that "*for the spare parts market it is important that we could continue using pre-charged cooling units containing hexavalent chromium also after 2025. As the new inhibitor cannot be used for old product without significant re-build we would need this possibility.*" Failures of cooling units are related to leakages, although according to Dometic (2018c) "*on a very low level*".

As for warranty cases, Dometic prefers the spare part solution (Dometic 2018c) because exchanging the whole products might be limited depending on model and availability. Dometic (2018c) explains that "*during the warranty period <0.5 % of the products need replacement of the cooling unit.*" For the after-warranty service, Dometic (2018c) lists cases like:

[47] 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.

- *„The customer would probably not get a single replacement product for the same price as our product cost as in warranty period[48].*
- *A costly re-build of the RV[49] might be necessary to adopt to the new product. This could also include modification of the gas supply and would then require professional support.*
- *The replacement of the cooling unit in after-warranty could often be performed by less expensive service personal than our warranty service network. In many cases the replacement could be performed by the customer himself."*

From the consultants' general experience, at least in Germany, vehicle licencing requires acquiring authorisation for certain equipment types that can be built into the vehicle (so called "TÜV Zulassung"). This is for example understood to be the case for adsorption coolers in light of the use of gas (safety issues) and in some cases the connection to the electric system of the vehicle (impacts the vehicle safety). Such authorisations are checked each time the vehicle licence is renewed (e.g. 1-2 years, depending on vehicle) and must be renewed if the equipment is replaced at a cost (hundreds of Euros). Thus for example for the refrigerators, it can be followed that in some cases the consumer will prefer the replacement of the cooling unit instead of the complete equipment, so as not to need to renew the product authorisation which adds to the total expenses in such cases.

Seeing as such equipment may furthermore be built into the vehicle interface in the case of mobile homes (true all around the EU and not just in Germany), the consultants can also follow that replacement of the equipment with a product with differing dimensions can also result in higher replacement costs, driving a decision to replace the cooler unit.

These two aspects would suggest that the duration of the exemption may need to take account of availability of spare parts.

In this context, it is noted that there is currently not a general provision for further use of the ELV restricted substances in the manufacture of spare parts under the Directive. At present, spare parts provisions are only addressed specifically in relation to exemptions for which an expiration date has been set. Such provisions are specified for "*spare parts for vehicles type approved before*" a specified date. Dometic have requested the exemption to remain valid until the end of 2025. However, the spare parts are needed for repair of adsorption coolers to be put on the market prior to 2025, regardless of the type approval of the vehicle in which they are installed. It is not clear if amending the exemption duration with a reference to spare parts for vehicles placed on the market before 2025 would be pragmatic, i.e.:

48 The consultants assume that Dometic refers here to the case where the replacement of a faulty unit with a new one would have higher costs for the user than having the manufacturer replace the part at a certain cost, seeing as additional costs may entail from a product replacement, e.g. TÜV licensing process in Germany described further on.

49 RV: Recreational Vehicle, also referred to as motor caravan.

- some devices are installed by the vehicle manufacturer and can be assumed to comply with type approval; however
- where installed by the user it could not be controlled in what vehicle the device is installed or reinstalled, i.e. if the device needing repair is in a vehicle type approved prior to the expiration date.

To provide for spare parts, an exemption formulation referring to "*spare parts for adsorption coolers placed on the market before 2025*" may be more pragmatic to ensure availability.

It has to be taken into account that the provision of spare parts of Dometic is limited due to the REACH authorization; however, this might not be the case for other manufacturers producing outside the EU. In that respect Dometic (2018b) argues that *"our competitors are all producing outside EU and hence do not need to consider REACH in terms of products or spare parts and can continue to place products on the market until the ELV exemption expires. For Dometic however, the production limitation through REACH effectively means that we need to transfer the products in advance."* It is however not clear whether other manufacturers prefer spare part solutions in cases of warranty as well[50].

9.5.4. Environmental considerations on disposal of cooling units exchanged during service life

In parallel, to the need for spare parts, it also needs to be kept in mind that replacement of the cooler unit in case of a leak may be performed by either the manufacturer/dealer (e.g. in cases of warranty), but is also performed in some cases by the private consumer. Though in the former case, it can be expected that professionals are aware of possible impacts related to the CrVI solution still in the cooler unit and take care to prevent emissions, this may not be the case when private consumers perform the replacement ("do it yourself" replacements).

Dometic (2018d) estimates that *"in total approximately 900 cooling units per year are exchanged in service in Europe. We estimate that far less than 5 % are replaced by private customers (but we will use 5 % as a conservative number)."*

In cases that the replacement of the cooling unit is performed by the customer him-/herself, the customer is so far not informed on how to safely dispose of the defect cooling unit as Dometic (2018d) explains: "*At time being we are not informing private customer specifically about how to handle defective cooling units. Nor is there any specific take-back system for such units. For professional customers we are informing about the sodium chromate content according to REACH Article 33, and consequently*

[50] In relation to REACH, it is the consultants understanding that a repair which would include e.g. a refilling of the sodium chromate solution, would require an authorisation for the use of the substance for such purposes, i.e., where the repair takes place in the EU. For repairs as understood to be performed by Dometic, the cooling unit is completely replaced, whereas sodium chromate is already in the unit and is not made use of as a substance during the repair. Where such units are used for repair they would need to be manufactured in the EU under a valid authorisation or otherwise imported from outside the EU, where the REACH authorisation obligation does not apply.

we are able to do so for private customers as well on request." REACH Article 33 stipulates the duty to communicate information on substances of very high concern (SVHC) in articles in the supply chain; however, the customer has only to be informed on request. Due to this loophole in the ELV waste scheme as well as a limitation of REACH Article 33, an impact for human health and the environment may arise, which is not in line with the general ELV intentions of substance restriction.

With regards to potential CrVI emissions to the environment due to leakages, Dometic (2018d) estimates that on average, 30 % of the cooling solution is emitted. Taking into account a CrVI reduction due to the formation of the protective layer ("*[…] 25-30 % of the Cr(VI) is reduced during the first year. At the end of life it can be assumed (also partly through experimental verifications) that the Cr(VI) content is reduced with more than 75 %.*"; Dometic 2018d). Dometic (2018d) estimates a total of 315 grams CrVI per year with the figures from 2017 that leaks and is emitted into the environment. For a leaking cooling unit, the emitted amount of Cr(VI) is estimated by Dometic (2018d) at 0.15 grams Cr(VI) on average.

During the REACH authorization process, for this scenario for consumer exposure the Risk Assessment Committee and Socio-Economic Analysis Committee followed the explanation given by the applicant Dometic (RAC / SEAC 2016): *"The only potential exposure would be if the cooling unit starts leaking. As the cooling liquid in the cooling unit is under pressure all cooling liquid would be released at once producing noise and an unpleasant ammonia smell. Consumers would have the reflex to run away from the fridge and ventilate the room before re-entering, especially to remove the ammonia smell."* Based on this explanation and based on the reduction of CrVI in the cooling solution as explained above, RAC / SEAC (2016) concluded that *"a consumer would never be exposed to the full Cr(VI) concentration originally included in the cooling unit. Therefore, the applicants consider oral and inhalation exposure of consumers as not relevant."* As for environmental releases, RAC / SEAC (2016) did not consider local releases within this scenario to water, soil, and to air (RAC / SEAC 2016). The consultant assumes that this might be due to the emissions taking place at separated point sources.

Though it is not completely clear what the actual risk of exposure and environmental impacts may be in such cases, from a waste perspective, the consultant notes that in such cases a safe disposal of the article is not necessarily achieved.

9.5.5. Exemption Wording

Dometic (2018b) states that absorption refrigerators "*designed to operate with electrical heater only*" are not relevant for recreational vehicles and can therefore be excluded from the ELV exemption.

However, the consultant cannot rule out that products operating on electrical heater only may have been put on the market as a product for motor caravans in the past, which would mean that such applications used in ELVs should be addressed as under RoHS in terms of expiration date. Particularly in the "do it yourself" segment it cannot be ruled out that such equipment was not sold in some cases for use in vehicles.

Though this case might be theoretical, the interface between the products falling under RoHS was discussed in Gensch et al. (2016a). Gensch et al. (2016a) conclude that a wide 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.

In order to ensure coherence between the RoHS and the ELV Directive, the consultant recommends that the exemption wording be identical in order to avoid misuse of a possible loophole, despite the possibility that the sub-group of equipment with electrical power only may be an "empty group".

Substitution and elimination of hexavalent chromium

As for the last part of the current wording that refers to alternative cooling technologies ("*except where 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*"), it was argued during the last revision (Zangl et al. 2010) that *"the presence of a refrigerator in a motor caravan isolated from the electricity grid could be considered as "avoidable" in the sense that a motor caravan also fulfils its function without a built-in low-noise and electricity-independent refrigerator."*

Though it can be argued whether the function provided by absorption coolers in motor caravans is necessary for such vehicles to fulfil their function (i.e. avoidable), in the consultant's perspective, this aspect is beyond the mandate of the evaluation according to the ELV criteria. ELV Directive Article 4(2)(b) requires exemptions to be amended according to whether substances have become avoidable in terms of scientific and technical progress. The consultant understands the mandate of the ELV Directive to assess whether it is technically and scientifically feasible to avoid the restricted substance in an application or not.

In this context the consultant currently views the use of CrVI in such applications as unavoidable, seeing as adsorption refrigerators provide certain properties that limit their exchangeability with other cooling technologies, i.e. in relation to noise and non-dependability on electricity. If the EU COM agrees with these considerations, we recommend deleting this formulation from the exemption. If the EU COM thinks that it is of importance to stress that the use of other cooling technologies should be mentioned, this part should be retained.

9.6. Conclusions

Since the previous evaluation of this ELV exemption, a substitute for CrVI as an anticorrosion agent in the cooling solution of absorption refrigerators has become available. However, redesign and testing of absorption refrigerators using this substance is still in process and shall require at least a few more years. The implementation of the substitute is understood to differ for various applications of the product range of absorption refrigerators (i.e., those operated only with electricity powered heaters and those operated with other sources of energy), depending over all on the boiler temperature.

Following the information provided by Dometic, a renewal of the ELV exemption until end of 2025 is needed in order to complete the following tasks that are inevitable to ensure performance and safety level over the long service life of the absorption refrigerators:

- Re-design of cooling unit models operating with high boiler temperature to minimize the risk of corrosion inside the tubes and re-design of the products; Conduct field tests with the high boiler temperature products of minimum 2-3 years that are planned to be initiated during 2019.
- Adaptation of the manufacturing lines for the re-designed cooling unit models;
- Re-design of product models that includes the introduction of a temperature monitoring system.

To achieve an alignment with the RoHS Directive the formulation proposed for exemption 9 of RoHS should be used as a basis for the ELV formulation. The consultants propose the wording specified below:

Table 9-2: Additional proposed formulation for exemption 9 of Annex III of Directive 2011/65/EU (RoHS 2), aligned with REACH

Exemption 9	Duration
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	
Designed to operate fully or partly with electrical heater, having an average utilised electrical power input < 75 W at constant running conditions.	Vehicles type-approved before 31 December 2019 and spare parts for these vehicles
Designed to operate fully or partly with electrical heater, having an average utilised electrical power input ≥75 W at constant running conditions. Designed to fully operate with non-electrical heater	Vehicles type-approved before 31.12.2025 and spare parts for these vehicles

Source: Oeko-Institut e.V. (2018)

Whereas the exact formulation is still pending due to the processes under RoHS, a final alignment should be ensured once the process concludes. As the RoHS Directive could be expected to propose a shorter period for item ii and iii of the exemption in light of the maximum exemption duration (2021)[51] it should also be kept in mind that the exemption may become due for review if during the next RoHS review expected towards 2021, a change in the wording is proposed, i.e. should this happen, the Commission should consider the need for a further alignment between ELV and RoHS.

As the RoHS formulations have been aligned with REACH (EU COM 2017), the above formulations can be understood to also comply in this respect. In contrast, the proposed time line for substitution in the high boiler temperature products is somewhat shorter than proposed in the REACH authorization process. As it is however not clear if spare parts would be covered by the current formulation or not, neither if this is beneficial, the Commission could consider if to further align the expiry date of items ii and iii with the duration provided for the high boiler temperature products in the REACH authorization process.

9.7. Recommendations

Based on the information at hand, the consultant recommends extending the validity of exemption 14 with revised wording until the end of 2025. An alternative corrosion inhibitor has been identified, but is not yet available in products installed in motor caravans placed on the EU market; its application in absorption refrigerators installed in motor caravans still requires technical adaptations and field tests in order to reliably ensure corrosion inhibition over the long product life time and under harsh and varying conditions, thus justifying the renewal of the exemption until this can be accomplished.

Beyond this date, the use of hexavalent chromium as an anticorrosion agent of the carbon steel cooling system in absorption refrigerators is expected to be avoidable and not in line with the stipulations of Art. 4(2)(b)(ii).

The following recommendation provides an alignment with the corresponding exemption under the RoHS Directive as well as with the REACH Regulation.

Recommendation	Scope and expiry date of the exemption
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	
Designed to operate fully or partly with electrical heater, having an average utilised electrical power input < 75 W at constant running conditions.	Vehicles type-approved before 31 December 2019 and spare parts for these vehicles
Designed to operate fully or partly with electrical heater, having an average utilised electrical power input ≥75 W	Vehicles type-approved before 31.12.2025 and

51 The exemption was reviewed under the RoHS Directive in 2015-2016. At the time the duration of the exemption was proposed on the basis of the maximum duration that can be granted to exemptions for such equipment, which is five years. The duration in this case is not to be understood to reflect the technical ability of Dometic to substitute CrVI in products under the scope of RoHS.

Recommendation	Scope and expiry date of the exemption
at constant running conditions.* Designed to fully operate with non-electrical heater	spare parts for these vehicles

If the EU COM views that the provision of spare parts has to be explicitly listed, a formulation for "*spare parts for adsorption coolers placed on the market before 2025*" with an expiry date could be specified for the end of 2029.

9.8. References

Dometic, 2015, 'ANALYSIS OF ALTERNATIVES and SOCIO-ECONOMIC ANALYSIS'.

Dometic, 2018a, 'Contribution to the stakeholder consultation by Dometic submitted 27 June 2018, available under'.

Dometic, 2018b, 'Answers to 1st Questionnaire Exemption 14 provided 23.10.2018'.

Dometic, 2018c, 'Answers to 2nd Questionnaire Exemption 14 provided 21.11.2018'.

Dometic, 2018d, 'Answers to 3rd Questionnaire Exemption 14 provided 10.12.2018'.

Dometic, 2019, 'Answers to 4th Questionnaire Exemption 14 provided 10.02.2019'.

EU COM, 2017, Summary of European Commission Decisions on authorisations for the placing on the market for the use and/or for use of substances listed in Annex XIV to Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) (Published pursuant to Article 64(9) of Regulation (EC) No 1907/2006)(2017/C 48/10)**,** 2017).

Gensch, C.-O., Baron, Y., Blepp, M., Moch, K., Moritz, S. and Deubzer, O., 2016, *Assistance to the Commission on Technological Socio-Economic and Cost-Benefit Assessment Related to Exemptions from the Substance Restrictions in Electrical and Electronic Equipment.*

Oeko-Institut e.V., 2018, 'Proposed amendment for the recommended formulation of exemption 9 of Annex III of Directive 2011/65/EU (RoHS 2) for reasons of alignment with the REACH regulation'.

RAC / SEAC, 2016, *Committee for Risk Assessment (RAC) Committee for Socio-economic Analysis (SEAC) Opinion on an Application for Authorisation for Sodium chromate: 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.*

Zangl, S., Hendel, M., Blepp, M., Liu, R., Gensch, C.-O. and Deubzer, O., 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).*

A.1.0 Appendix 1

A.1.1 Antaya Lead-free Soldering Programs

Antaya (2018 b) submitted the following information on the use of indium-containing lead-free solders in vehicles:

A.1.1.1 Vehicles with Antaya ICS in Successfully Closed Series Production Towards End of Life of the Car

1) Car model: Ford Thunderbird

a. Application: Antenna
b. Soldered surface: 4
c. Type of ICS used: 65 % Indium alloy
d. Production dates: 2000 – 2005

2) Car model: GM U Vans (North America – Chevrolet Venture, Oldsmobile Silhouette, Pontiac Trans Sport; Europe – Opel/Vauxhall Sinatra)

a. Application: Antenna
b. Soldered surface: 4
c. Type of ICS used: 65 % Indium alloy
d. Production dates: 2000 – 2008

3) Car model: GM Chevrolet Volt (D1JCI)

a. Application: Antenna
b. Soldered surface: 4
c. Type of ICS used: 65 % Indium alloy
d. Production dates: 2010 – 2015

A.1.1.2 Vehicles with Antaya ICS on Surface 2 in Series Production

4) Car model: FCA Jeep Cherokee (KL)

a. Application: Printed heated wiper rest
b. Soldered surface in LG: Surface 2
c. Thickness of LG: 2.1 mm + 1.8 mm with polymer layer in between
d. Type of ICS used: 65 % Indium
e. Start and end year of series production, or ongoing: This program started production in 2013.

A.1.1.3 Vehicles with Antaya ICS on Surface 4 in Series Production

5) Car model: FCA Jeep Cherokee (KL)

a. Application: Heated wiper rest area
b. Soldered surface: 4
c. Type of ICS used: 65 % Indium alloy
d. Production dates: 2013 – ongoing

6) Car model: Ford Escape/Kuga (C520)

a. Application: Heated wiper rest area
b. Soldered surface: 4
c. Type of ICS used: 65 % Indium alloy & B604 alloy
d. Production dates: 2015 – ongoing

7) Car model: Tesla Model X & Model S

a. Application: Heated wiper rest area & heated camera window
b. Soldered surface: 4
c. Type of ICS used: B604 alloy
d. Production dates: 2015 – ongoing

8) Car model: Ford Edge (CD539)

a. Application: Heated camera window
b. Soldered surface: 4
c. Type of ICS used: 65 % Indium alloy
d. Production dates: 2015 – ongoing

9) Car model: Ford Lincoln MKC (C489)

a. Application: Heated camera window
b. Soldered surface: 4
c. Type of ICS used: 65 % Indium alloy
d. Production dates: 2016 – ongoing

10) Car model: Ford F-150, F-250 (P552, P558)

a. Application: Heated wiper rest area and heated camera window
b. Soldered surface: 4
c. Type of ICS used: 65 % Indium alloy & B604 alloy
d. Production dates: 2017 – ongoing

11) Car model: Ford Transit Connect (V408)

a. Application: Heated camera window
b. Soldered surface: 4
c. Type of ICS used: B601 alloy and B604 alloy
d. Production dates: 2017 – ongoing

12) Car model: Ford Expedition, Lincoln Navigator (U553, U554)

a. Application: Heated wiper rest area and heated camera window
b. Soldered surface: 4
c. Type of ICS used: 65 % Indium alloy & B604 alloy
d. Production dates: 2017 – ongoing

13) Car model: Volvo XC60 (V426)

a. Application: Antenna
b. Soldered surface: 4
c. Type of ICS used: B601 alloy
d. Production dates: 2018 – ongoing