12th adaptation to scientific and technical progress of exemptions 2(c)(ii), 3, 8(e) and 8(g)(ii) of Annex II to Directive 2000/53/EC (ELV)

Final Report

Written by a consortium led by Bio Innovation Service, with the participation of Fraunhofer IZM and UNITAR

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1 Executive summary – English

The consortium for the Framework Contract "Assistance to the Commission on technological, socio-economic and cost benefit assessments related to the implementation and further development of EU waste legislation" (ENV.B.3/FRA/2019/0017) coordinated by Bio Innovation Service was requested by DG Environment of the European Commission to provide technical and scientific support for the evaluation of exemption requests under the "12th Adaptation to scientific and technical progress of exemptions 2(c)(ii), 3, 8(e) and 8(g)(ii) of Annex II to Directive 2000/53/EC (ELV)". The work has been undertaken by Fraunhofer Institute IZM, UNITAR and Bio Innovation Service.

1.1 Background and objectives

Directive 2000/53/EC on end-life-vehicles ("ELV" Directive) restricts the use of certain hazardous substances in vehicles. The Directive includes a list of exemptions to these use 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)[1] (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.

All non-confidential stakeholder comments submitted during the consultation are made available on the EU CIRCABC website (Communication and Information Resource Centre for Administrations, Businesses and Citizens):

[1] Article 4(2)(b)(iv) provides that designated materials and components of vehicles that can be stripped before further treatment have to be labelled or made identifiable by other appropriate means.

https://circabc.europa.eu (Browse categories > European Commission > Environment > ELV exemptions, at top left, click on "Library").

1.2 Key findings – Overview of the evaluation results

The exemption request covered in this project and the applicant concerned, as well as the final recommendation and proposed expiry date are depicted in Table 1-1. The reader is referred to the corresponding section of this report for more details on the evaluation result.

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

Ex. No.	Current exemption wording	Applicant	Recommendation	Proposed expiry date and scope
2(c)(iii)	Aluminium alloys not included in entry 2(c)(i) with a lead content up to 0,4 % by weight	ACEA et al., European Aluminium	Continue with modified wording: Lead in aluminium casting alloys containing up to 0.3 % lead by weight provided that the lead stems from lead-bearing aluminium scrap recycling	Vehicles type-approved after 31 December 2026 and spare parts for these vehicles
3	Copper alloys containing up to 4 % lead by weight	ACEA et al., Wieland	No recommendation possible. If continued, maintain current wording.	If continued: Review in [YEAR] ; See section 5.4 for details
8(e)	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)	ACEA et al.	No recommendation possible. If continued, maintain current wording.	If continued: Review in [YEAR] ; See section 6.4 for details)
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 that electrical connection consists of any of the following: (1) a semiconductor technology node of 90 nm or larger; (2) a single die of 300 mm² or larger in any semiconductor technology node; (3) stacked die packages with dies of 300 mm2 or larger, or silicon interposers of 300 mm² or larger	ACEA et al.	No recommendation possible. If continued, maintain current wording.	If continued: Vehicles type-approved before 1 January 2030 and spare parts for these vehicles.

2 Executive Summary: French - Note De Synthèse: Français

Le consortium pour le contrat cadre « Assistance en faveur de la Commission sur les évaluations techniques, socio-économiques, environnementales et coûts-avantages liées à l'exécution et au développement ultérieur de la législation UE sur les déchets » (ENV.B.3/FRA/2019/0017) coordonné par Bio Innovation Service a été mandaté par DG Environnement de la Commission Européenne pour fournir une assistance technique et scientifique pour l'évaluation des demandes d'exemptions suivant la « 11ème Adaptation aux progrès techniques et scientifiques des exemptions 2(c)(ii), 3, 8(e) et 8(g)(ii) de l'Annexe II à la Directive 2000/53/EC (ELV) ». Les travaux ont été réalisés par Fraunhofer Institute IZM, UNITAR et Bio Innovation Service.

2.1 Contexte et objectifs

La directive 2000/53/CE relative aux véhicules hors d'usage (directive "VHU") restreint l'utilisation de certaines substances dangereuses dans les véhicules. La directive comprend une liste de dérogations à ces restrictions d'utilisation, qui est régulièrement adaptée au progrès scientifique et technique conformément aux dispositions respectives de la directive.

Conformément aux exigences de l'article 4(2)(a) de la directive 2000/53/CE relative aux véhicules hors d'usage, les États membres de l'Union européenne doivent s'assurer que les matériaux et les composants des véhicules mis sur le marché depuis le 1er juillet 2003 ne contiennent pas de plomb, de mercure, de chrome hexavalent et de cadmium. Un nombre limité d'applications exemptées des dispositions de cet article sont énumérées à l'annexe II de la directive, ainsi que le champ d'application et la date d'expiration de l'exemption et l'exigence d'étiquetage conformément à l'article 4, paragraphe 2, point b) iv) (le cas échéant).

En vertu de l'article 4, paragraphe 2, point b), l'annexe II doit être régulièrement adaptée au progrès scientifique et technique par la Commission. Cela permet de vérifier si les exemptions existantes sont toujours justifiées au regard des exigences fixées à l'article 4, paragraphe 2, point b) ii), si des exemptions supplémentaires ont été proposées sur la base du même article et si des exemptions ne sont plus justifiées et doivent être supprimées de l'annexe au regard de l'article 4, paragraphe 2, point b) iii). En outre, la procédure d'adaptation doit - si nécessaire - établir des valeurs de concentration maximales jusqu'auxquelles les substances faisant l'objet de restrictions sont tolérées (article 4, paragraphe 2, point b) i)) et désigner les matériaux et composants qui doivent être étiquetés.

Tous les commentaires non confidentiels des parties prenantes soumis au cours de la consultation ont été mis à disposition sur le site web de l'UE CIRCABC (Communication and Information Resource Centre for Administrations, Businesses and Citizens) :

https://circabc.europa.eu (Naviguez) (Catégories > Commission européenne > Environnement > ELV exemptions, en haut à gauche, cliquez sur "Library").

2.2 Les principales conclusions – Synthèse des résultats de l'évaluation

La demande d'exemption couverte par ce projet, le demandeur concerné, ainsi que la recommandation finale et la date d'expiration proposée sont présentés dans le Table 2-1. Traduction en français fournie par souci de commodité. En cas de contradictions entre la traduction française et la version originale anglaise, cette dernière fait foi. Le lecteur est invité à se reporter à la section correspondante du présent rapport pour plus de détails sur le résultat de l'évaluation.

Table 2-1: Récapitulatif des demandes d'exemption, des recommandations associées et des dates d'expiration

Dem. ex. n°	Libellé actuel de l'exemption	Demandeur	Recommandation	Date d'expiration proposée et champ d'application
2(c)(ii)	Alliages d'aluminium non inclus dans la rubrique 2c)i) contenant jusqu'à 0,4 % de plomb en poids	ACEA et al., European Aluminium	Maintenir l'exemption avec le libellé suivant : Le plomb dans les alliages de fonderie d'aluminium contenant jusqu'à 0,3 % de plomb en poids, à condition que le plomb provienne du recyclage de déchets d'aluminium contenant du plomb.	Véhicules réceptionnés depuis le 31 décembre 2026 et pièces détachées pour ces véhicules
3	Alliages de cuivre avec une teneur en plombe allant jusqu'à 0,4 % en poids.	ACEA et al., Wieland	Recommandation n'est pas possible. S'il est décidé de maintenir l'exemption, maintenir le libellé actuel	En cas de maintien: réexamen en [année] ; Pour plus de détails, voir la section 5.4
8(e)	Plomb dans les soudures à haute température de fusion (alliages de plomb contenant au moins 85 % de plomb en poids)	ACEA et al., KEMI	Recommandation n'est pas possible. S'il est décidé de maintenir l'exemption, maintenir le libellé actuel	En cas de maintien : réexamen en [année] ; Pour plus de détails, voir la section 6.4

Dem. ex. n°	Libellé actuel de l'exemption	Demandeur	Recommandation	Date d'expiration proposée et champ d'application
8(g)(ii)	Plomb dans les soudures visant à réaliser une connexion électrique durable entre la puce semi-conductrice et le substrat dans les boîtiers de circuits intégrés à puces retournées lorsque la connexion électrique consiste en l'une des solutions suivantes : 1) un noeud technologique de semi-conducteur de 90 nm ou plus; 2) une puce unique de 300 mm^2 ou plus dans tout noeud technologique de semi-conducteur ; 3) des boîtiers à puces empilées avec des puces de 300 mm^2 ou plus, ou des interposeurs en silicium de 300 mm^2 ou plus.	ACEA et al.	Recommandation n'est pas possible. S'il est décidé de maintenir l'exemption, maintenir le libellé actuel	En cas de maintien: Véhicules réceptionnés avant le 1er janvier 2030 et pièces détachées pour ces véhicules.

3 Introduction

3.1 Background

The EU Directive 2000/53/EC on end-of-life vehicles ("ELV" Directive, hereafter referred to as "the Directive") bans the use of certain substances in vehicles. According to Article 4(2)(a), “Member States shall ensure that materials and components of vehicles put on the market after 1 July 2003 do not contain lead, mercury, cadmium or hexavalent chromium other than in cases listed in Annex II under the conditions specified therein.” Article 4(2)(b) provides a basis for excluding certain materials and components in Annex II and specifies the criteria on which such exemptions can be justified:

“Annex II shall be amended on a regular basis, according to technical and scientific progress, in order to:

(i) as necessary, establish maximum concentration values up to which the existence of the substances referred to in subparagraph (a) in specific materials and components of vehicles shall be tolerated;

(ii) exempt certain materials and components of vehicles from the provisions of subparagraph (a) if the use of these substances is unavoidable;

(iii) delete materials and components of vehicles from Annex II if the use of these substances is avoidable;”

(iv) under points (i) and (ii) designate those materials and components of vehicles that can be stripped before further treatment; they shall be labelled or made identifiable by other appropriate means.”

Annex II to the Directive has so far been adapted to scientific and technical progress 11 times, the last amendment of Annex II to the Directive being dated 5 March 2023 after a review in 2020 and 2021. Annex II also provides review dates for a number of exemptions.

3.2 Project scope and methodology

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 the current 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 not anymore 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.

Against this background, this study reviewed the following four exemptions of Annex II of the Directive, which approach their mandatory review dates in 2024/2025.

- 2(c)(ii): Aluminium alloys not included in entry 2(c)(i) with a lead content up to 0.4 % by weight
- 3: Copper alloys containing up to 4 % lead by weight
- 8(e): Lead in high melting temperature type solders (i.e., lead-based alloys containing 85 % by weight or more lead)
- 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 that electrical connection consists of any of the following:
  (1) a semiconductor technology node of 90 nm or larger;
  (2) a single die of 300 mm^2 or larger in any semiconductor technology node;
  (3) stacked die packages with dies of 300 mm^2 or larger, or silicon interposers of 300mm^2 or larger.

In the course of the study, a stakeholder consultation was performed, following the EC guidelines for consultation of interested parties. The stakeholder consultation was launched on the 8th of February 2024 and ended on the 2nd of May 2024. A dedicated website (https://elv.biois.eu) for the study was developed where all relevant documents related to the consultation were stored. It was also used as a channel to inform the stakeholders on the progress and provided links to the webpage of the public consultation. Stakeholders were also provided the opportunity to register, and registered stakeholders were kept informed through email. The answers to the consultation questionnaires and other contributions to the online consultation are made available at the study website.[2]

Following the stakeholder consultations, an in-depth evaluation of the exemption was conducted which is reflected in this report.

[2] Cf. https://elv.biois.eu/requests2.html

4 Exemption 2(c)(ii): Lead in aluminium alloys not included in entry 2(c)(i) with a lead content up to 0.4 % by weight

The below Table 4-1 shows the wording, scope and expiry dates of the exemption

Table 4-1: Current wording of the exemption 2(c)-series

No.	Current exemption wording	Current scope and dates of applicability
2(c)(i)	Aluminium alloys for machining purposes with a lead content up to 0,4 % by weight	Vehicles type-approved before 1 January 2028 and spare parts for these vehicles.
2(c)(ii)	Aluminium alloys not included in entry 2(c)(i) with a lead content up to 0,4 % by weight[3]	This exemption shall be reviewed in 2024

Declaration

In the sections preceding the "Critical review", the phrasings and wordings of applicants' and stakeholders' explanations and arguments have been adopted from the documents they provided as far as required and reasonable in the context of the evaluation at hand. In all sections, this information as well as information from other sources is described in italics. Formulations were altered or completed in cases where it was necessary to maintain the readability and comprehensibility of the text.

Acronyms and Definitions

Al	Aluminium [chem.]
COM	European Commission
EEA	European Economic Area
EEE	Electrical and electronic equipment
ELV	End-of-Life Vehicle Directive 2000/53/EC
Lead-free	Not containing lead in applications in the scope of the reviewed exemption
Pb	Lead [chem.]

[3] Applies to aluminium alloys where lead is not intentionally introduced, but is present due to the use of recycled aluminium.

RoHS	Directive 2011/65/EU, current RoHS Directive

4.1 Background and technical information

On 02 May 2024, ACEA, JAMA, JAPIA, CLEPA, and KAMA, henceforth addressed as "ACEA et al.", jointly requested the continuation of the above exemption 2(c)(ii) of Annex II in the online stakeholder consultation with the wording, scope and validity period shown in the table below. (European Aluminium 2024a) support an immediate reduction to 0.3 % of lead.

Table 4-2: Wording and scope of the requested exemption

No.	Requested exemption	Requested scope and dates of applicability
2(c)(ii)	Aluminium alloys not included in entry 2(c)(i) with a lead content up to 0.4 % by weight[4]	Vehicles type-approved before 1 January 2030 and spare parts for these vehicles.

4.1.1 History of the exemption

Annex II of the legal text of the ELV Directive (2000/53/EC) included an exemption for "Aluminium containing up to 0.4 % lead by weight". In 2003, the first revision of the Directive was published, and considering the need to exempt applications where lead is a constituent of aluminium alloys, exemption 2 of Annex II changed to "Aluminium for machining purposes containing…", and included a footnote specifying that "a maximum concentration value up to 0.4 % by weight of lead in aluminium shall also be tolerated provided it is not intentionally introduced", covering the use of recycled aluminium containing lead.

The second revision of the Directive was published in 2005, where the footnote did not appear. In the third revision of Annex II, in 2008, the exemption wording was changed, and "for machining purposes" was deleted. This allowed within the scope of the exemption, although it was not specifically mentioned, the presence of lead unintentionally introduced.

Exemption 2(c) last revision was published in 2017, where the exemption was divided into two, as can still be seen in the current wording (cf. Table 4-1) to allow addressing the different applications separately. Exemption 2(c)(i) addresses the lead content in aluminium used for machining purposes (primary aluminium), while exemption 2(c)(ii) addresses aluminium alloys not included in Exemption 2(c)(ii) (secondary aluminium). Exemption 2(c)(ii) was determined to be reviewed in 2024.

[4] Applies to aluminium alloys where lead is not intentionally introduced, but is present due to the use of recycled aluminium.

4.1.2 Summary of the request for the continuation of the exemption

(ACEA et al. 2024a) explain that the exemption is relevant for Aluminium alloys where Lead is not intentionally introduced, but is present due to the use of recycled Aluminium (secondary Aluminium). As Lead is sometimes present in Aluminium scrap, secondary Aluminium contains Lead as a tramp element. The Lead content depends on the available scrap.

(ACEA et al. 2024a) request to maintain the exemption wording for vehicles type-approved before 2030, and note the possibility of reducing the limit of Lead content by weight from 0.4 % to 0.3 % after 2030. In their opinion, this would allow them to adopt specifications for vehicles currently under development and validate the materials and components hereof accordingly.

4.1.3 Technical description of the exemption and use of the restricted substance

As (ACEA et al. 2024a) explained, the scope of exemption 2(c)(ii) is secondary aluminium, as lead is present in secondary aluminium as a trap element. The availability and quality of scrap differs between local markets.

(ACEA et al. 2024a) pointed out that in 2020 the European aluminium market (including primary and secondary aluminium) corresponded to around 15 % of the global market, and that the share of aluminium used in the transport sector was around 20 % of the global market.

In this context, (ACEA et al. 2024a) explained that the secondary aluminium market is a global market that absorbs nearly all aluminium scrap qualities. There is no vehicle-specific secondary aluminium market, and the aluminium scrap recovered from ELVs does not satisfy the current demand for aluminium in vehicles. To allow the use of different scrap grades, standards applied in the global automotive industry allow a lead content of up to 0.4 % by weight in secondary aluminium alloys. (ACEA et al. 2024a) explained that there is no known manufacturer specification which requires a minimum lead content in secondary aluminium alloys and, in many cases, the secondary aluminium alloys delivered to produce automotive components do not reach the lead concentration limit of 0.4 % by weight.

According to (ACEA et al. 2024a), the average amount of aluminium used in European cars has increased by 18 % from 174 kg in 2019 to 205 kg in 2022. This is due to the increase in new registered electric vehicles (EVs). A Battery Electric Vehicle (BEV) is estimated to have an average aluminium content of around 280 kg, compared to an average of 170 kg in an Internal Combustion Engine (ICE) vehicle. (ACEA et al. 2024a) conducted a data evaluation in 2024, and concluded that aluminium use ranges from around 100 kg to around 380 kg per vehicle, and lead use per vehicle covered by exemption 2 (c)(ii) ranges between 10 g to around 250 g Pb. Average lead content per vehicle has decreased since 2010, as can be seen in Table 4-3*, and currently, single concentration ranges of Pb are estimated to be between 0.1 % and 0.4 %.*

Table 4-3: Average lead content per vehicle in the EU under the scope of exemption 2(c)(ii) per year

Year	Average Pb/vehicle EU per entry 2(c)(ii)
2010	120 g
2014	80 g
2020	70 g
2024	60 g

Source: (ACEA et al. 2024a)

4.1.4 Amount(s) of restricted substance(s) used under the exemption

(ACEA et al. 2024a) stated that around 780 tonnes of Pb would enter the EU per year, in the scope of exemption 2(c)(ii). In 2022, 12.910.891 new vehicles were registered in the EU, with an average of 60 g Pb per vehicle (see Table 4-3) in the scope of exemption 2(c)(ii). Electrical vehicles have a higher share of aluminium in use but less Pb in aluminium. They estimate the Aluminium content in a BEV with around 280 kg on average compared to around 170 kg in a petrol or diesel ICE-only vehicle.

4.2 Justification of the requested exemption

4.2.1 Substitution and elimination of the restricted substance

The use of secondary aluminium in the automotive industry contributes to saving resources and CO2 emissions as explained by (ACEA et al. 2024a). Lead in casting aluminium alloys is not intentionally introduced but it is present due to the use of secondary aluminium where lead is present as a tramp element. Currently, exemption 2(c)(ii) allows a lead content of up to 0.4 % by weight to allow the use of different scrap grades found in the secondary aluminium market. It is estimated that lead concentration per vehicle covered by this exemption ranges between 0.1 and 0.4 %.

As lead is not intentionally introduced, but an allowed contamination, the substitution of the substance does not apply in this case. Regarding the elimination of the substance, as stated by (Gensch et al. 2016), the unintentional content of lead in aluminium scrap will continue to decrease gradually within the coming years with a reduction in the lead content by weight in alloys using secondary aluminium.

4.2.2 Environmental, health, safety and socioeconomic impacts

(ACEA et al. 2024a) explained that the use of secondary aluminium supports the closed material loops for post-consumer aluminium. The use of secondary aluminium, instead of primary aluminium, saves resources and CO2 emissions significantly while contributing to a circular economy in Europe.

4.3 **Critical review**

4.3.1 Substitution and elimination of lead

Since the lead in the aluminium alloy in the scope of exemption 2(c)(ii) stems from recycled aluminium scrap, the lead is not added intentionally but is a constituent of the recycled aluminium as the heritage of past uses of lead in aluminium. Substitution or elimination are thus not relevant.

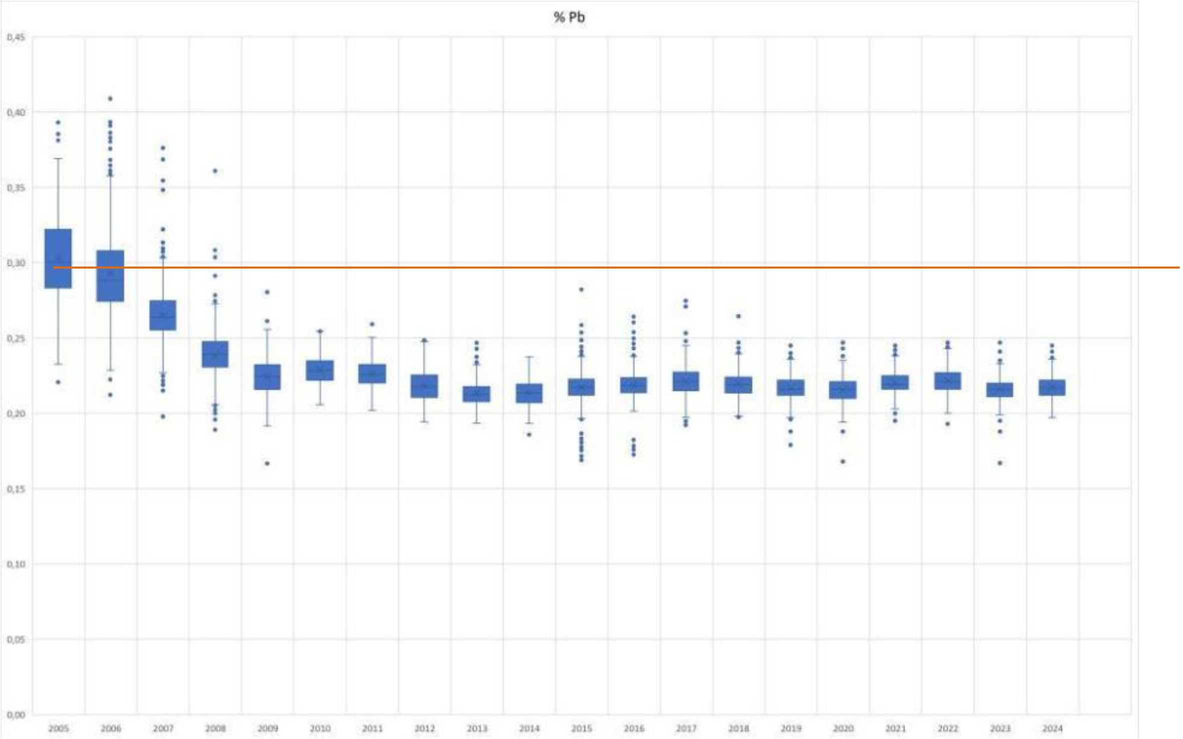
The focus of the review of this request for the continuation of the exemption is instead on whether and from when the decreasing lead content of aluminium scrap can be reflected in the lead threshold in exemption 2(c)(ii).

4.3.2 Reducing the lead content threshold

The lead content of aluminium in the exemption scope should reflect the development and current status of lead content in scrap aluminium and recycled aluminium respectively. The discussion on reducing the limit of lead content in aluminium under exemption 2(c)(ii) has brought forth different perspectives among stakeholders. While ACEA et al. request keeping the current 0.4 % lead content limit in the exemption until 2030, other stakeholders plead for an earlier reduction.

(European Aluminium 2024a) support an immediate reduction of the lead content allowed from the current 0.4 % to 0.3 %, citing the declining share of lead in aluminium scrap. This reduction is also supported by (Swedish Chemicals Agency 2024). (European Aluminium 2024b, 2024c) stated that in Europe their members have already reduced lead in cast alloys to 0.3 % and that the level was below 0.3 % already in 2020. They attached Figure 4-1 from one of their biggest members, a secondary aluminium smelter, illustrating the lead content of aluminium scrap intake batches (batches composed to process in the remelting oven) in the European market. The figure shows that the average lead content has been under 0.3 % since 2006 and that in 2024 the average lead content is around 0.22 %. The figure also shows the continuing trend of decreasing lead content.

Figure 4-1: Lead content of aluminium scrap intake batches in the European market



Source: (European Aluminium 2024c)

The consultants are aware that the statements of (European Aluminium 2024b, 2024c) on lead content below 0.3 % in their members' cast alloys and incoming secondary aluminium batches do not necessarily reflect the entirety of the secondary aluminium market. Other stakeholders did, however, not participate in the consultation to make their voices heard so the consultants focused on the EA information next to the arguments of ACEA et al.

In contrast, (ACEA et al. 2024a) see a possibility to reduce the lead limit of 0.4 % down to 0.3 % for vehicles type-approved after 1.1.2030 only. When asked why it could not be reduced before 2030, (ACEA et al. 2024b) replied that they estimate that the lead content of new-type approved vehicles is less than 0.3 % yet today, but at the moment exemption 2 (c)(II) enables the use of different scrap qualities. (ACEA et al. 2024b) further stated that many suppliers already promise 0.3 % lead by weight, but they, too, cannot foresee future developments. (ACEA et al. 2024b) are concerned that the lead content could increase again, e.g. if the aluminium content decreases due to evaporation as a result of repeated melting, but the lead remains.

Regarding the above arguments, (European Aluminium 2024c) stated that the oxidation of aluminium during remelting (maximum 5 %) has a minimal impact on the final lead content in the alloys and that they do not see any risk in the lead content increasing in *secondary aluminium.* Moreover, it is questionable whether the lead remains since it has a lower evaporation temperature[5] than aluminium and may therefore evaporate as well.

(ACEA et al. 2024a, 2024b) also stated that such a reduction might compel some recyclers on the global market to dilute their recycled alloys with primary material to stay below the exempted levels. (European Aluminium 2024b) argumented against this statement that the best way to reduce the high-lead content scrap is to dilute it with low-lead content scrap, and not with primary aluminium. (ACEA et al. 2024c) argued that this approach could be chosen, but it depends on low-lead scrap being available in sufficient volumes and economically affordable, especially for the regional acting refiners.

When questioned why the lead threshold should remain at a higher level than 0.3 % when standard EN1706 was amended in 2020 already to limit the value to 0.29 % lead by weight to reflect the lead content of aluminium scrap on the market, *(ACEA et al. 2024a) replied that standard EN1706 is only one of the standards applied in the EU, and argued that for example the ISRI standard for aluminium scrap specifies the minimum aluminium content and allowable contamination limits, but does not explicitly ban lead.*

The consultants consider that although the EN1706 standard is not legally binding, it was amended in 2020 to reflect the development of lead in secondary aluminium, confirming that lead alloys are available with a lead content below 0.29 % are available. The consultants understand that EN1706 would not have reduced the lead limit to 0.29 % without considering a safety margin in the timeline, such that the lead content would increase again above 0.3%. (European Aluminium 2024c) confirmed that *the lead level was below 0.3 % already in 2020*. Standards other than EN1706 that are applicable for cast aluminium produced from aluminium scrap but do not set a lead limit are not relevant in this argumentative context. These standards might be an obstacle against lower lead limits in cast aluminium alloys with relevance for automotive uses if they required a minimum lead content for cast aluminium alloys, which seems, however, not to be the case.

The above arguments put forward by (ACEA et al. 2024a) are in the consultants' opinion no compelling evidence to substantiate their request to maintain the current lead limit at 0.4 % until 2030. The information provided suggests that the lead level of recycling aluminium (cast alloys) is - and has been in the past years - already reliably at 0.3 % and probably below, taking into account that EN1706 was adapted in 2020 already with a limit of 0.29 % to reflect this situation. It can be assumed that the standard left some safety margin to the actual lead level. Both (ACEA et al. 2024a) and (European Aluminium 2024c) have shared figures that support the decreasing trend, and there is no apparent reason for the trend to change.

(ACEA et al. 2024a, 2024a, 2024b) argued that with more older vehicles remaining in use in the EU, the share of old scrap (with more lead) remains longer in the EU, which leads to the efforts of reducing the lead content in vehicle production taking longer than expected. (ACEA et al. 2024a) stated that the average age of vehicles in the EU market has increased (from around 7 years in the year 2000 to around 12 years in the year 2022) and that with more older vehicles remaining in use in the EU, the share of old scrap (with more lead) remains longer in the EU. At the same time, (ACEA et al. 2024a) emphasised that the European aluminium market for transportation applications is part of a much

[5] https://www.engineeringtoolbox.com/melting-boiling-temperatures-d_392.html

larger global market. (European Aluminium 2024c) were asked what the share of scrap aluminium is coming from vehicles in the scope of the ELV Directive in the total volumes of scrap aluminium in the European Economic Area and worldwide. *(European Aluminium 2024c) replied that they do not have global figures, but in Europe aluminium from ELVs represents between 4 % and 14 % of the total scrap used in aluminium recycling*. In the consultants' view, the two statements by (ACEA et al. 2024a, 2024b) are contradictory. If the aluminium market for transportation is part of a much larger global market, older vehicles reaching the end-of-life in Europe would have a small repercussion in the increase of lead concentration in aluminium globally if they contribute a maximum of 14 % of secondary aluminium to the EU/EEA market only.

(European Aluminium 2024c) figures support the conclusion that older vehicles reaching the end-of-life do not have a significant repercussion in the market and that there is no reason to not lower the lead content limit in secondary aluminium. *(European Aluminium 2024c) further stated that scrap with a high lead content from old cars is progressively mixed with scrap with a low lead content from less old cars, and with scrap from other sources with a low lead content, so the final lead content in the alloys will continue to decrease progressively over the years.* This shows that, as previously noted, the lead content in aluminium has a stable decreasing trend.

When considering a further reduction to a 0.2 % lead-by-weight threshold, *(European Aluminium 2024a) argued that reducing it to 0.2 % is not possible, as the recent extension of exemption 2(c)(i) allows for the use of wrought aluminium alloys with up to 0.4 % lead content in new vehicles type-approved before 1.1. 2028. As these vehicles will remain in use and require spare parts for many years, end-of-life recycling of these vehicles will continue to introduce lead into the aluminium scrap stream for an extended period, potentially delaying the achievement of a 0.2 % lead content for more than 15 years. (ACEA et al. 2024a) replied that market development is currently unforeseeable.* This is consistent with Figure 4-1, where a stable level of lead content in aluminium scrap is shown in the past years. The consultants understand that reducing the threshold to 0.2 % is not yet feasible. Any such reduction would have to be preceded by a EEA-wide – or beyond - reduction of lead-levels in primary aluminium alloys, e.g. in wrought alloys for machining purposes so that the lead levels in scrap aluminium go down.

4.3.3 Exemption wording

(European Aluminium 2024a) suggested modifying the exemption wording to "Lead as an alloying element in aluminium casting alloys containing up to 0.3 % lead by weight provided it stems from lead-bearing aluminium scrap recycling", aligning the wording with exemption III-6(b)(I) of the RoHS Directive and the proposed new exemption III-6(b)(III) reflecting the reduced 0.3 % lead limit.

Asked how can it be verified that the lead comes from aluminium scrap recycling, (European Aluminium 2024b) replied that their members who process scrap analyse samples from all incoming scrap lots and keep records of their chemical composition, including their lead content. Also, the producers of casting alloys have no reason to add lead intentionally.

(ACEA et al. 2024b) do not support the suggested formulation as it would require certified sorting of aluminium scrap into lead-containing and lead-free, and there are no adequate

and economic market capacities for such separation procedures. When asked to clarify why such scrap sorting would be necessary, (ACEA et al. 2024c) stated that with the suggested wording, it could be understood that the source of aluminium must be lead-bearing aluminium scrap only. (ACEA et al. 2024b) also argued that the proposed formulation could limit their supplier portfolio, as they would only be able to use aluminium scrap and no virgin aluminium, and suppliers must supply primarily material to meet the composition of a particular alloy. Concerning this statement, (European Aluminium 2024c) believed that the wording does not prevent a casting alloy containing virgin aluminium but it means that if lead is present in the alloy, this lead may exclusively come from recycled aluminium. (European Aluminium 2024c), taking this into account, proposed the following wording: "Lead as an alloying element in aluminium casting alloys containing up to 0.3 % lead by weight provided that the lead stems from lead-bearing aluminium scrap recycling".

(ACEA et al. 2024c) argued that including "as an alloying element" in the wording is not needed as lead in casting alloys is a tolerated contamination, and not added deliberately. They also believe that the restriction to casting alloys alone is dispensable. (ACEA et al. 2024c) proposed the following wording: "Lead as unintentional contaminant in aluminium alloys -not included in entry 2(c)(i)- up to 0.3 % by weight".

The consultants agree with the fact that the wording should be clear and not lead to confusion. The consultants do not consider that the first wording proposed by (European Aluminium 2024c) would limit the portfolio of suppliers. The consultants proposed to use the wording "Lead in aluminium containing up to 0.3 % lead by weight provided that the lead stems from lead-bearing aluminium scrap recycling". This wording would allow aligning with exemption III-6(b)(I) and its potential successor III-6(b)(III) of the RoHS Directive recommended by (Deubzer et al. 2024) with minimum deviations. Applying (European Aluminium 2024c) proposal, replacing "it" with "lead", addresses (ACEA et al. 2024b) concerns about the potential confusion of whether the aluminium or the lead would have to come from aluminium scrap recycling.

(ACEA et al. 2024d) disagree with including the terms scrap or waste in the exemption wording. In their view, the term scrap would not allow recycling or remelting complete parts without prior defragmenting, as scrap is defined as "a small piece of something that is left after you have used the main part" by the Brittanica Dictionary , and this could lead to unnecessary burdens. The Brittanica Dictionary also defines scrap as "things from an unwanted or broken object (such as a car) that are useful only in making or fixing something else", such that scrap aluminium also refers to aluminium coming from a vehicle in its end of life. *(ACEA et al. 2024d) disagree with the term "lead-bearing aluminium", as it could be misunderstood as referring to bearings where lead-containing aluminium is applied. Moreover, (ACEA et al. 2024d) do not consider aligning with RoHS exemptions as a reason to use the proposed wording, especially when the COM has not yet decided if the wording for RoHS exemption will be adopted. Nevertheless, (ACEA et al. 2024d) consider the wording proposed by the consultants feasible, although they would want their concerns to be addressed.*

(European Aluminium 2024d) consider important limiting the scope to casting alloys to avoid misuse by introducing lead in aluminium alloys for machining purposes (which are wrought alloys). (ACEA et al. 2024c) considered the restriction to casting alloys dispensable, but did otherwise not oppose it. The consultants believe that, even if it can be assumed that recycled aluminium is used in casting alloys, it is reasonable to specify it in the wording to clearly demark the scope of the exemption, and avoid misuse and misunderstandings.

The consultants propose to use the wording "*Lead in aluminium casting alloys containing up to 0.3 % lead by weight provided that the lead stems from lead-bearing aluminium scrap recycling*". This revised wording decouples the scope of exemption 2(c)(ii) from 2(c)(i) and aligns with the proposed wording by (Deubzer et al. 2024) for exemption III-6(b)(I) and its potential successor III-6(b)(III) of the RoHS Directive with minimum deviations, even if it is yet to be approved by the COM.

4.3.4 Scope and expiry of the exemption

Regarding the expiry date, *(European Aluminium 2024a) expressed that the lead content can be reduced to 0.3 %, while (ACEA et al. 2024a) expressed that it can only be reduced for vehicles type-approved after 1.1.2030. (ACEA et al. 2024b) defended this statement based on the arguments explained before, adding that the development process for new models and components takes 5-7 years, such that it could not be done before 2030. (ACEA et al. 2024b, 2024c) argue that standard EN 1706:2020 is not legally binding, and although it limits lead in aluminium to 0.29 %, various standards can be followed. Also, the fact that EN 1706 sets a limit of 0.29 % does not change local scrap qualities. Lead in EU vehicle aluminium is decreasing, and flexible scrap use aids global recycling and the automotive industry aims to lower the lead limit to 0.3 % by December 31, 2029. Keeping the current 0.4 % limit provides time to align with global environmental goals and minimize administrative burdens, while efficiently using secondary aluminium.*

The consultants understand that EN1706:2020 was adapted to reflect the state of the market. Producers are expected to reduce the content of restricted substances if the opportunities arise so that, with a 5-7 years development time, 2027 (2020 + 7) can be assumed as a feasible expiry date. Also, the core of exemption reviews is adapting exemption scopes to reflect the state of the art of lead reduction/avoidance. *(European Aluminium 2024d) would like to have the soonest possible date of applicability, which would be vehicles type-approved after 1 January 2026.* The consultants believe that considering the maximum development time (7 years) in this case is sensible, and recommend to maintain the expiry on 31 December 2026.

(ACEA et al. 2024d) disagree with the statement that producers are expected to reduce the content of restricted substances if the opportunity arises, as in that case only virgin aluminium would be used. This exemption supports the use of recycled aluminium in M1/N1 category vehicles. Additionally, the ELV Directive encourages increasing recycled material use, aligning with the Green Deal and circular economy goals to reduce CO_2 emissions and support UN Sustainable Development Goals. The consultants agree with the fact that recycled aluminium must be used to align with the European Green Deal and UN Sustainable Development Goals, and do not expect producers to use primary instead of secondary aluminium. Nevertheless, setting the expiry date in 2027 would not require the use of primary aluminium as secondary aluminium with a lead concentration of 0.3 % is already available in the market. ACEA et al. do not explain how the necessity might arise that vehicle manufacturers have to add primary aluminium. In case vehicles that are in the development phase now still use aluminium with more than 0.3 % lead content, lead would have to be added to compensate for the difference between the current market lead level and the required level of lead in vehicles. It cannot be followed how the 0.3 % lead level would be in contrast to the Green Deal, Circular Economy or even the UN Sustainable Development Goals.

(ACEA et al. 2024d) believe setting the expiry date in 2027 would not contribute to a circular economy and reducing CO_2 emissions, and it would require renegotiating specifications and contracts. They advocate for an open-loop approach to secondary aluminium use in the automotive industry, focusing on actual lead concentrations that will naturally decrease over time. They consider that from a global standpoint, this measure would not have a tangible impact as it imposes restrictions on reuse and not on primary use.

If the average concentration of lead is already below 0.3 % and has been for years, the consultants do not believe that these aspects are a concern that would require the expiry date to be set in 2030. The consultants consider the reduction to 0.3 % of the lead content to be fully in line with *focusing on actual lead concentrations that will naturally decrease over time.* The consultants only propose to reflect the status of the natural decrease of the past far more than 10 years in the exemption scope.

(ACEA et al. 2024d) believe that even if European Aluminium members offer 0.3 % lead in aluminium, this does not necessarily reflect the market's state as many non-member SMEs' views were not considered. Moreover, the EU represents less than 20 % of the global aluminium market, leaving 80 % unaddressed.

The review process was open to all stakeholders. The consultants regret that other stakeholders did not participate to express their views during the consultation but the consultants have to focus on the available contributions. The applicants' market arguments were already discussed further above and found to be inconsistent.

(ACEA et al. 2024d) stated that EN1706 is not a binding element and only the COM could determine if a European standard is valid on the scope of the ELV Directive. Therefore, it does not justify setting the expiry date in 2027. It is unclear for (ACEA et al. 2024d) why the consultants have highlighted this standard and disregarded others, such as EN:573 (Aluminium and aluminium alloys – Chemical composition and form of wrought products – Part 3: Chemical composition and form of products), that also define lead limits. The consultants understand that EN 1706:2020 is not legally binding, but it reflects the state of the market as aluminium with 0.3 % lead content has been the average already before 2020, and the producers are expected to avoid (also in the sense of reducing) restricted substances as soon as they are avoidable. ACEA et al. state that the consultants disregarded other standards and mention EN:573 as an example. This standard seems to refer to wrought aluminium alloys that are used for machining to the consultants' best knowledge. These alloys are in the scope of exemption 2(c)(i), and the above argument is not relevant in the context of exemption 2(c)(ii).

With the lead concentration in the market being at 0.3 % and below already for years, the consultants disagree with the applicant's arguments that the expiry date earlier than 2030 would provoke any of the adverse effects discussed above. Vehicle models developed from 2020 on for entering the market from 2027 could have reflected the lower lead content already. The six to seven years that ACEA et al. indicate as the development time for new models of vehicles in the scope of the ELV Directive are thus no obstacle for the reduced lead content to be applicable after 31 December 2026.

4.3.5 Summary and conclusions

ACEA et al. request the continuation of exemption 2(c)(ii) with the current wording for vehicles type-approved before 2030, after which the lead content could be reduced from 0.4 % to 0.3 % by weight. This time frame would allow them to adopt specifications for vehicles under development and validate corresponding materials and components. European Aluminium support an immediate reduction to 0.3 % lead content, citing the declining lead share in aluminium scrap. The Swedish Chemical Agency also support the reduction.

ACEA et al. put forward various arguments which seem to reflect their doubts that the lead concentration in scrap/recycling aluminium will not rise again to more than 0.3 %. They argue with potential fluctuations in lead content resulting from varying scrap quality, recycling processes that evaporate aluminium and thus make the reduction in lead content take longer than expected, and the increasing average age of cars in the EU. In the consultants' opinion, there is no compelling evidence for a potential change in the secondary aluminium market that could turn around the trend of decreasing lead levels.

European Aluminium proposed to align the future wording of exemption 2(c)(ii) with the wording of the technically equivalent exemption in the RoHS Directive with slight clarifying modifications taking up concerns expressed by ACEA et al. The consultants see the advantages of this wording and recommend to adopt it.

The consultants noted that aluminium with 0.3 % lead has been available since before 2020 and producers are expected to reduce the content of restricted substances if the opportunity arises. Therefore, the 0.3 % lead concentration level could be adopted for vehicles type-approved after December 31 2026 already, not at first in 2030 as requested by ACEA et al. European Aluminium support adopting the 0.3 % reduction for vehicles type-approved even earlier, from January 1, 2026. ACEA et al. disagree with any earlier applicability date. The consultants do not follow the arguments and stick to their proposal considering the development time for new vehicle models from 2020 on.

4.4 **Recommendation**

The information made available by ACEA et al. and European Aluminium suggests that the use of 0.4 % of lead in aluminium in the scope of the exemption is still unavoidable until the end of 2026, but that it should be reduced to 0.3 % in 2027 in line with Article 4(2)(b)(II). The consultants recommend granting the continuation of exemption 2(c)(ii) with the below wording and expiry date. The development towards 0.2 % is not expected to be achieved within the next 15 years. The consultants therefore recommend a review of the exemption after the maximum validity period of ELV exemptions, usually five to seven years under the current ELV Directive, or alternatively to decided a different duration at the time of review of the ELV Regulation (ELVR) proposal[6] currently in ordinary legislative procedure as foreseen in Article 55 of the Commission proposal (8 years after entry into force)".

[6] Cf. the Commission proposal: https://eur-lex.europa.eu/resource.html?uri=cellar:8e016dde-215c-11ee-94cb-01aa75ed71a1.0001.02/DOC_1&format=PDF

Table 4-4: Recommendation of the exemption wording

No.	Exemption	Scope and dates of applicability
2(c)(i)	Aluminium alloys for machining purposes with a lead content up to 0.4 % by weight	Vehicles type-approved before 1 January 2028 and spare parts for these vehicles.
2(c)(ii)	Aluminium alloys not included in entry 2(c)(i) with a lead content up to 0,4 % by weight	Vehicles type-approved before 1 January 2027 and spare parts for these vehicles.
2(c)(iii)	Lead in aluminium casting alloys containing up to 0.3 % lead by weight provided that the lead stems from lead-bearing aluminium scrap recycling	Vehicles type-approved after 31 December 2026 and spare parts for these vehicles. The exemption shall be reviewed in [max. review period], or alternatively 8 years after entry into force of the ELVR.

4.5 References

ACEA et al. (2024a): Answers to Stakeholder Consultation Questionnaire on Exemption 2(c)(ii) of ELV Annex II. With assistance of CLEPA, JAMA, JAPIA, KAMA. Edited by ACEA. ACEA et al. Available online at https://elv.biois.eu/ACEA_et_al_2cii_submission.pdf.

ACEA et al. (2024b): Answers to Questionnaire 2 on Exemption 2(c)(ii) of ELV Annex II. With assistance of CLEPA, JAMA, JAPIA, KAMA. Edited by ACEA. ACEA et al.

ACEA et al. (2024c): Answers to Questionnaire 3 on Exemption 2(c)(ii) of ELV Annex II. With assistance of CLEPA, JAMA, JAPIA, KAMA. Edited by ACEA. ACEA et al.

ACEA et al. (2024d): Answers to Questionnaire 4 on Exemption 2(c)(ii) of ELV Annex II. With assistance of CLEPA, JAMA, JAPIA, KAMA. Edited by ACEA. ACEA et al.

Deubzer et al. (2024): RoHS Pack 27. Study to assess requests for 29 renewal requests concerning one specific EEE category and two (-2-) new exemption requests under the Directive 2011/65/EU. With assistance of Otmar Deubzer, Chris Eckstein, Alexandra Morozow, Christian Clemm, Elena D'angelo, Elena Fernandez, Vittoria Luda, Shailendra Mudgal. Available online at https://rohs.biois.eu/RoHS-Pack-27_Report_Final.pdf.

European Aluminium (2024a): Answers to Stakeholder Consultation Questionnaire on Exemption 2(c)(ii) of ELV Annex II. European Aluminium. Available online at https://elv.biois.eu/European_Aluminium2.pdf.

European Aluminium (2024b): Answers to Questionnaire 2 on Exemption 2(c)(ii) of ELV Annex II. European Aluminium.

European Aluminium (2024c): Answers to Questionnaire 3 on Exemption 2(c)(ii) of ELV Annex II. European Aluminium.

European Aluminium (2024d): Answers to Questionnaire 4 on Exemption 2(c)(ii) of ELV Annex II. European Aluminium.

Gensch et al. (2016): 8th Adaptation to scientific and technical progress of exemptions 2(c), 3 and 5 of Annex II to Directive 2000/53/EC (ELV). Final Report for the European Commission DG Environment under Framework Contract No ENV.C.2/FRA/2011/0020. ELV III.5. With assistance of Carl-Otto Gensch, Yifaat Baron, Katja Moch, Oeko-Institut. Available online at https://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/20160216_ELV_Final_Gen_Ex_2c__Ex_3_Ex_5.pdf.

Swedish Chemicals Agency (2024): Comments of the Swedish Chemicals Agency and the Swedish Environmental Protection Agency on the consultation of exemption 2(c)(ii) ELV Directive. Swedish Chemicals Agency. Available online at https://elv.biois.eu/kemi_2cii.pdf.

5 Exemption 3: Copper alloys containing up to 4 % lead by weight

The below Table 5-1 shows the current wording, scope and review dates of the exemption.

Table 5-1: Current wording of the exemption

No.	Current exemption wording	Current scope and dates of applicability
3	Copper alloys containing up to 4 % lead by weight	This exemption shall be reviewed in 2025

Declaration

In the sections preceding the "Critical review", the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents they provided as far as required and reasonable in the context of the evaluation at hand. In all sections, this information as well as information from other sources is described in italics. Formulations were altered or completed in cases where it was necessary to maintain the readability and comprehensibility of the text.

Acronyms and Definitions

Al	Aluminium [chem.]
COM	European Commission
Cu	Copper [chem.]
EEA	European Economic Area
EEE	Electrical and electronic equipment
ELV	End-of-Life Vehicle Directive 2000/53/EC
Lead-free	Not containing lead in the applications in scope of the exemption to be reviewed
Pb	Lead [chem.]
RoHS	Directive 2011/65/EU, current RoHS Directive

5.1 Background and technical information

On 2 May 2024, ACEA, CLEPA, JAMA, KAMA (ACEA et al. 2024b, 2024a) requested the renewal of the above exemption 3 of Annex II with the wording, scope and validity period shown in the table below.

Table 5-2: Wording and scope of the requested exemption

No.	Requested exemption	Requested scope and dates of applicability
3	Copper alloys containing up to 4 % lead by weight	This exemption shall be reviewed in 2032

(ACEA et al. 2024b, 2024a) submitted their request for the continuation of exemption 3 along with the expression of a stakeholder contribution by (Wieland 2024a).

5.1.1 History of the exemption

Exemption 3 has been listed in Annex II with the above mentioned wording since the publication of the ELV Directive.

It was reviewed in 2009/2010 by (Zangl et al. 2010) who recommended the continuation of the exemption for five years to leave the industry time to further develop lead-free solutions.

In the review in 2015/2016, (Gensch et al. 2016) concluded that despite the use of up to 4 % lead in copper alloys still being unavoidable in a number of components, starting points for substitution existed, especially for components with an already low lead content. However, it was concluded that the overall picture where substitution efforts were promising was not clear enough to narrow the exemption scope. Thus, (Gensch et al. 2016) recommended the continuation of the exemption with the current scope and wording for another five years to provide sufficient time to allow monitoring developments in the potential for substitution and to clarify that the increased use of electrical applications within vehicles does not lead to an unjustified increase in the use of leaded copper alloys, and to identify lists of components or categories of applications for lead reduction or substitution.

Similarly in 2021, (Deubzer et al. 2021) recommended an extension with the current wording for up to four years to provide sufficient time for application-centered and specific assessments of substitution possibilities or, in case, impossibilitites, so that in the next review, stakeholders can provide substantiated, sound and transparent evidence where the use of lead may still be unavoidable. The exemption has become due for review in 2024.

5.1.2 Summary of the stakeholder contributions

(ACEA et al. 2024a) comment that as this stakeholder consultation for entry 3 comes early in 2024, information expected to be available in 2025 is missing and may not be used here, due to competition respective antitrust guidelines to be met.

According to (ACEA et al. 2024a), copper and copper alloys have unique properties and are essential materials for the automotive industry. Most of the copper in vehicles is used in lead-free copper based materials. Increasing digitalisation up to autonomous driving might lead to an increase in the number of specialized small components made of leaded copper alloys. However, the quantity of Lead in Copper alloys per vehicle decreased, but there are still many small applications, where the use of Lead-containing Copper alloys *is still required due to technical reasons. Lead in copper alloys shows no interference with other alloying metals, it fills casting porosities, it provides emergency lubricating effects with sliding characteristics, it enhances machinability, it improves corrosion resistance and it exhibits a higher degree of conformity.*

(ACEA et al. 2024a) state that the industry approach, described in previous consultations, in principle continues. The step-by-step procedure for minimizing the essential use of Lead in Copper materials is ongoing. The efforts concentrate for efficiency reasons mainly to new developments. (ACEA et al. 2024b) request a continuation for this exemption of 8 years.

5.1.3 Technical description of the exemption and use of the restricted substance

Use of copper in vehicles - (ACEA et al. 2024a)

In the automotive industry, cost and weight are two important material characteristics. Copper and copper alloys are selected and used only when it is strictly necessary due to their high specific gravity and higher costs compared to e.g. aluminium and steel.

Around one fifth of the copper use can be allocated to the motor of an internal combustion engine (ICE) vehicle. This includes among other applications generator, starter, pumps, ventilator-/cooling system, injection systems, electric and control units and engine specific harness components. Due to specific requirements like elevated temperatures, impact of automotive fluids, conductivity and corrosion resistance, the use of copper materials is necessary (ACEA et al. 2024a).

Function of lead in copper alloys - (ACEA et al. 2024a)

Lead is present in the microstructure of some copper alloys in the form of finely dispersed particles, located at the grain boundaries of the alloy matrix. In addition, it has a grain fining impact. Lead, because of its low melting point, is able to fill any casting porosities that may arise due to volume deficit that occurs during solidification. This increases the pressure tightness of casted parts. Lead concentration above 1.5 % slightly reduces strength and elongation. Among other parameters, lead influences stress relaxation behaviour or mechanical deformation. Lead as alloying element has no interference with other alloying elements. This reduces complexity in alloy production and gives some robustness in alloy production.

The ability of the lead particles decreases the coefficient of friction. In the copper matrix, embedded lead particles give excellent sliding characteristics and can prevent fretting of sliding elements, e.g. in gear units and act as emergency lubricant, which is considered as important safety advantage viewed from engineering perspective.

Lead enhances the machinability of copper alloys. The most used free cutting Copper alloy is C36000 with the nominal composition 61,5 % Cu, 3 % Pb, and 35,5 % Zn. It is considered as a kind of reference standard material, if maximum machinability is desired. A good machinability is not only economically relevant, but also important from an environmental point of view, as a reduced machinability may increase the energy demand during the production process and increase the need for additional lubricant. Lead acts as a chip breaker and lubricant which provides manufacturing and *performance benefits and enables superior machinability required to achieve precise tolerances in tiny components. So miniaturisation of components and less material use is supported in addition by lower specific cutting forces level, e.g. for the alloy CuZn39Pb3. Moreover, the achievable resulting surface quality is excellent with low surface roughness values.*

Adding lead to the alloy affects the formation of short chips, instead of long ribbon and whirling chips, which often occur in machining of lead-free copper alloys. The short chips support efficient production procedures and minimize challenges of safety and production interrupts which may be associated with the formation of whirling chips.

Increasing lead content contributes to higher material corrosion resistance especially against sulphuric acids as well as for chlorine environment. The copper alloys used for vehicles need to be resistant against additives in lubricants, vehicle operating fluids and additives therein. Any change will require validation test on component and system level.

Adding additional elements in pure Copper, in general, decreases the electrical conductivity and increases the electrical resistivity. The impact is element specific. Compared to Lead, the conductivity decrease impact of the chemical elements Si, Fe or Al as alloying element in Copper is higher. Higher resistivity values mean more energy losses by heat.

Table 5-3: Resistivity increase per added element in copper

Element	Resistivity increase per 1 wt. % addition; [μ Ω · cm]
Au	0.185
Ag	0.355
Zn	0.286
Pb	1.02
Al	2.22
Mn	3.37
Te	4
Si	7
Fe	10.6
P	14.3
S	18.6

Source: (ACEA et al. 2024a)

It is well known that the electrical current flows through surface contact spots. The better these can be deformed, the higher the true contact surface is. Softer material like CuZn39Pb3 is therefore advantageous. Furthermore, the lead segregated on the surface fills partially the inter-spot regions. Citing (Welter 2014) they state that "Tests with terminals made with CuZn39Pb3 and CuZn42 at 125 °C have shown that even after 5,000 hours the leaded alloy relaxes less than the maximal allowed design value. For the design of connecting elements, especially for spring-loaded terminals, high mechanical relaxation is a drawback. It reflects the reduction of internal stress when the material is deformed elastically through an imposed strain. The elastic stresses are needed to insure that the female element, acting as a spring, closes well the connector".

Leaded Cu-alloys exhibit high degrees of conformability. That is, e.g. why bearings are getting more robust, as they may adjust its shape to allow for poor alignment or for vibration.

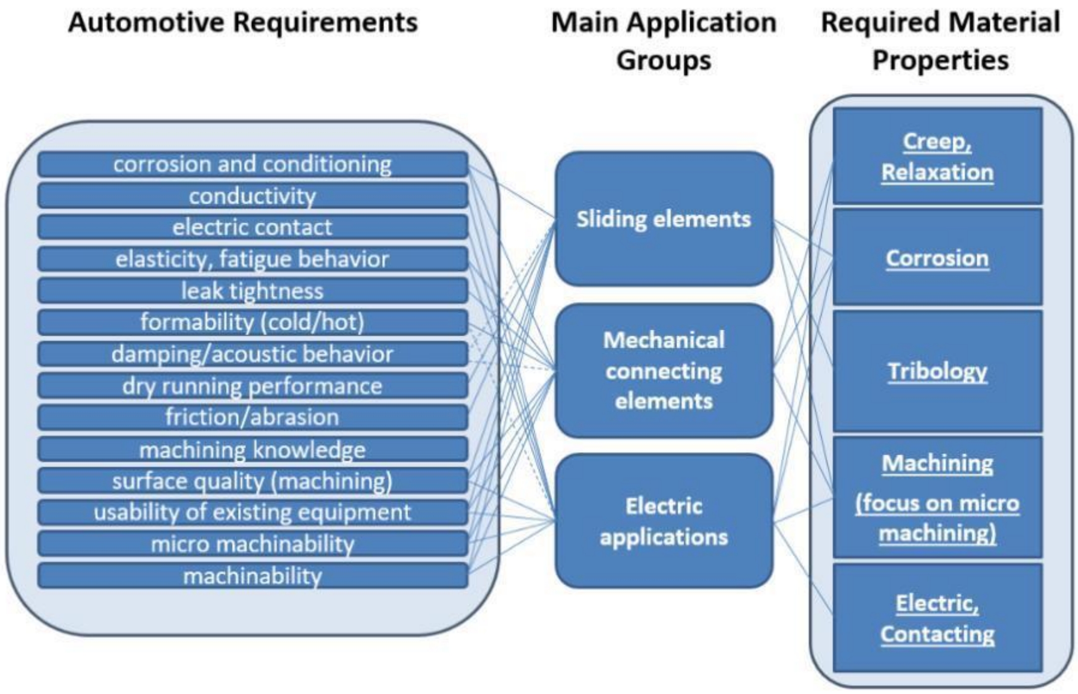
Demands to automotive lead-containing copper alloys parts - (ACEA et al. 2024a)

Along with fatigue resistance, strength, and ability to take a good finish, the main selection criteria for copper and copper alloys are: material costs, ease of fabrication, electrical conductivity, thermal (heat) conductivity, corrosion resistance, sliding behaviour, low wearing, service life, weight, (non)-magnetic properties.

The Pb-containing Cu-alloys have a proper balance between crack toughness, machinability, malleability, relaxation and strength. There is a broad long-term field experience with their use in automotive applications.

The complexity of automotive requirements to the copper materials and components produced thereof is outlined Figure 5-1. This graphic visualizes the manifold demands, which need to be addressed and considered in the development of components including scrutinizing the interaction with neighboured parts on system level.

Figure 5-1: Correlation between main application groups of Lead Copper brasses and automotive material requirements



Source: (ACEA et al. 2020) in (ACEA et al. 2024a)

5.1.4 Amount(s) of restricted substance(s) used under the exemption

(ACEA et al. 2024a) state that around 8.4 % of the global copper demand are allocated to automotive applications. The automotive industry is the estimated as the fifth most important copper user in the EU. The EU CRM 2023 report estimates the total 2022 demand for copper in the automotive sector with around 11 %. The European vehicle market currently is 19 % of the global market. So less than, or around 2 % of the global

refined copper produced in 2022 may be allocated to EU vehicles new registered in EU in the year 2022. Leaded copper alloys are a small part thereof.

(ACEA et al. 2024a) refer to the Copper Alliance in 2022 which specify copper in today´s conventional ICE car on a global level the following uses: wiring 85 %, alternator 5 %, starter motor 3.7 %, small motors 3,5 %, non-power train other 1.8 %, power train other 1.0 %. This sums up to an estimated quantity of 29.4 kg of copper per current vehicle on average.

(ACEA et al. 2024a)'s conclusions are based on current anonymised data samples provided by their members. In line with literature, they state that the total amount of copper materials per vehicle has increased. EV need more copper than ICE vehicles; EV have more electronics and electrical applications than ICE. As there is no unified naming of components and because of the high amounts of part numbers, a listing of examples for specific uses would always be incomplete. Instead, reference is made to the previous contributions of (ACEA et al. 2020) where application groups and use examples for components produced with lead-containing copper alloys are outlined.

(ACEA et al. 2024a) add that with EU decision in Regulation (EU) 2023/851, new registered passenger vehicles with fossil-fuel powered internal combustion engine from 2035 onwards will be banned. It can be assumed that within a decade the volume of corresponding copper applications in ICE´s and the number of annually new registered ICE powered vehicles will decrease significantly. This traffic turnaround in combination with the numbers reported above will cause a change in the number of parts currently made of leaded copper alloys.

Cables, copper windings in electrical engines and generators, are not made of leaded copper alloys. So, most of the around 30 kg of copper per vehicle is used in lead-free copper based materials. Electrical driven vehicles will usually not have a starter motor but will have more connectors and similar components in the power train and to the battery. In combination with the increasing digitalisation up to autonomous driving, the number of specialized small components made of leaded copper alloys can increase.

(ACEA et al. 2024a) note that the total copper content and the total Pb content covered by entry 3 are varying in a broad range of vehicle model. They see the range for Cu uses varying between about 21 kg up to around 100 kg and a varying range for entry 3 related Pb weight share per vehicle between around 4 and 20 g. As average value concerning entry 3 they estimate on average around 9 g Pb/vehicle. As the total copper share per vehicle increased and the number of electric and electronic systems increased, a slight further decrease compared to 2019 may be assumed.

With 10.5 million [7] newly registered passenger cars and around 1.5 million light commercial vehicles (vans)[8] in 2023, around 108 t of lead per year were incorporated in vehicles that are placed on the EU market.

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[7] Cf. ACEA, https://www.acea.auto/?mailpoet_router&endpoint=view_in_browser&action=view&data=WzUzMjExLCIxY2M4ZWI0NzI3ZjgiLDI2NjA2LCI1ODNkNGI2ZDIwYjg3MTgxMTM0ZDZhNzNlODFjMDAyZSIsNTI2MDksMF0

[8] Cf. ACEA, https://www.acea.auto/cv-registrations/new-commercial-vehicle-registrations-vans-14-6-trucks-16-3-buses-19-4-in-2023/

5.2 Justification of the requested exemption

5.2.1 Substitution and Elimination of the restricted substance

(ACEA et al. 2024a) put forward that the demands to components made of lead-containing copper alloys are multi-dimensional, so that a generic substitution would fail. A step-by-step, resp. part per part, approach is essential. Due to different material properties, it may be necessary to change the part geometry. Therefore, also, the system partners may need to be modified and the interferences between different components need to be tested. This causes high efforts.

In early stage of construction and design of new parts and systems, it is assessed if economic and also more environmentally compatible materials can replace the expensive material, where possible and feasible. As an outcome of this approach, the quantity of lead in copper alloys per vehicle decreased, but there are still many small applications, where the use of lead-containing copper alloys is still required due to technical reasons.

(ACEA et al. 2024a) further state that a new vehicle, in general, consists to a higher degree of well-known and intensively tested standard components (construction kits) and larger aggregates. These are applied in different vehicles and, e.g. like plugs and connectors, applied all over the automotive industry and beyond. Changing such industry standard components is more demanding than individual component design and a very complex and long-term task.

The introduction of new components or new materials are linked with missing related experience of vehicle service life. Therefore, OEMs often start carefully with pilot applications in smaller volume models to validate the collected experiences from component testing and many kilometers of tests on the road with prototype cars. Pilot applications may be screened over a complete vehicle cycle and if they performed well, they are an opener for large volume scale production. As this may be competitive sensitive information, it is very difficult to disclose such pilot applications within a stakeholder consultation.

In the last stakeholder consultation (ACEA et al. 2020), some substitute applications were addressed to be in use since recently. There are no failures reported up to now, but they should not have passed a complete life cycle yet. Therefore, no final assessment or conclusions can be made.

(ACEA et al. 2024a) present an unnamed supplier's opinion, stating that the more than 20 years of research done on lead-free copper alloys showed that up to now there is still a lack of drop-in replacement for leaded copper alloys, mainly CuZn39Pb3, with the same properties. So, a combination of adjustment of the production technology and perhaps of the products, as well as the development of materials with their critical properties at least similar to those of CuZn39Pb3 will be necessary. They continue that the substitution of leaded copper alloys in relevant amounts, so in series production, is only possible when the alternative alloy and its supply chain is mature enough. This includes that at least two reliable suppliers must exist, and the world market has to be able to provide the required amounts of material. Also, as far as possible, local sourcing has to be possible for robust supply and minimization of transport-related emissions.

(ACEA et al. 2024a) further state that it has to be ensured that the material is available in relatively constant quality, so that production of safe and functioning products can be ensured. The about 3 % lead in CuZn39Pb3 somehow smoothen the further properties, meaning that small deviations in the other properties of a specific batch that can be caused by small changes in the composition, or the manufacturing are outweighed by the effects lead gives to the alloy. It is an additional challenge in the substitution that this does usually not apply to the lead free alloys.

(ACEA et al. 2024a) continue to explain that two strategies exist that are usually applied in combination: To try to use established lead-free materials for new products and simultaneously to test upcoming new materials. The two existing families of alloys that are established at least in other industries (e.g. plumbing) are copper-zinc alloys with a higher zinc content and no additional chip breaker, as well as copper-zinc-silicon alloys. For these types of alloys the supply chain is usually developed, especially for industries that require higher amounts of brass as for example plumbing and construction. If substitution of leaded copper alloys is or will be possible in the nearer future for automotive parts, it is likely that it will happen via alloys of these two families. It is also very important to test and evaluate upcoming new alloys, but it is not likely that they can replace leaded copper alloys in the near future.

5.2.2 Environmental, health, safety and socioeconomic impacts

(ACEA et al. 2024a) refer to the Green Deal strategy of the European Commission, which calls for the reduction of CO_2 *resp. greenhouse gas emissions and enhancing the circularity of the automotive sector. Use of copper alloys resp. brass materials based on secondary raw materials contribute to this goal. (ACEA et al. 2024a) point to a functioning recycling system with around a 90 % efficiency by referencing (Welter 2014) reports on page 5 where ´Leaded brass rods for free machining and hot forging are fabricated almost exclusively with recycled brass (either old scrap coming from end of life systems or new scrap occurring during the manufacturing of components), low quality copper and zinc scrap. The intensive use of scrap has both financial and sustainable advantages within a circular economy.*

(ACEA et al. 2024a) continue that the direct use of scrap reduces the amount of energy needed for the production of alloys compared to production via primary material. If lead-containing scrap could not be processed directly, then an energy intensive metallurgical procedure needs to be applied to separate lead and zinc in order to obtain pure copper. This causes energy demand and related emissions.

All copper materials in a vehicle have an excellent recyclability. End-of-life vehicles within the EU have defined end-points (authorized treatment facilities). After pre-treatment, the remaining scrap vehicles go to shredders for material recovery. New developed shredder scrap separation technologies like TSR40 (REDERS Project) are able to reduce copper content in steel (e.g. < 0.1 %) and aluminium scrap and extracting even small copper particles for subsequent separate copper recycling. In addition, the efficiency to recover small copper particles increases and dissipation losses decrease. Such technologies however could not extract bismuth or silicon containing alloys. Bismuth especially is challenging the recycling of brass and production of pure copper.

Table 5-4: Recycling rates of selected copper alloy constituents

EU Recycling Indicators according JRC RMIS System[9] ***Element***	***EoL Recycling Input Rate***	***Recycling Input Rate***	***EU CRM***
Lead	*80 %*	*85 %*	*no*
Bismuth	*0 %*	*6 %*	*Yes 2023*
Indium	*No data assumed 0%*	*No data*	*Yes 2020*
Tellurium	*1 %*	*15 %*	*no*

Source: (ACEA et al. 2024a)

Table 5-4 provides data on recycling values for Pb, Bi, In and Te. Pb has the highest recyclability performance of all elements in scope here. Pb will enter the recycling loops.

5.2.3 Roadmap towards substitution or elimination of the restricted substance

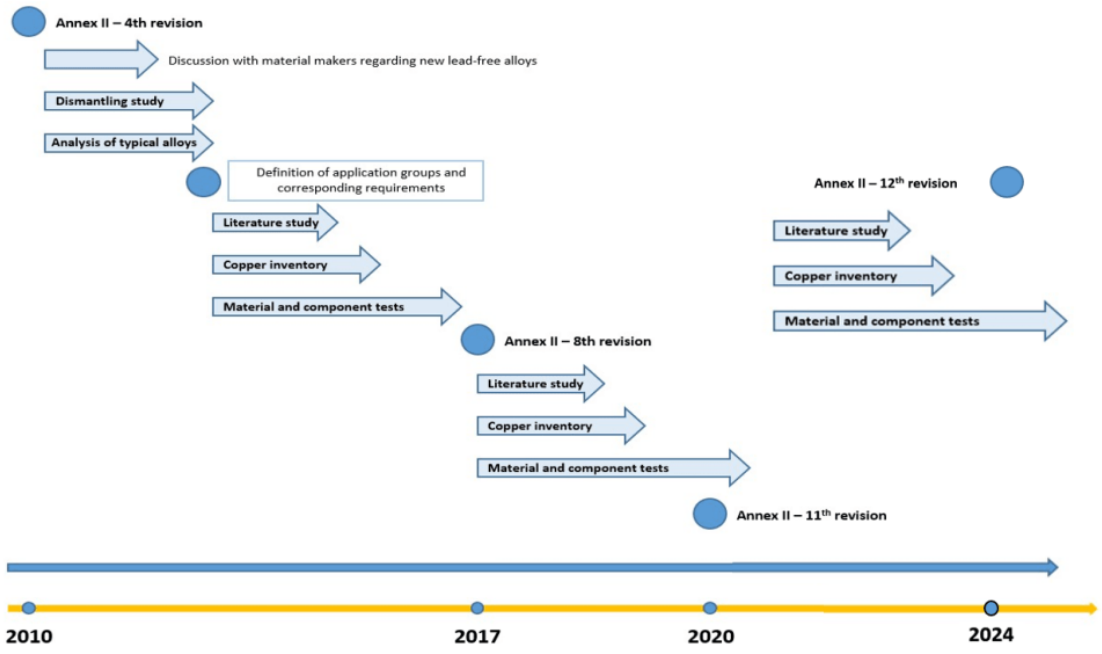
(ACEA et al. 2024a) comment that the step-by-step procedure for minimising the essential use of Lead in Copper materials is ongoing. The efforts concentrate for efficiency reasons mainly on new developments. Developing, testing and validation of a new vehicle model takes around seven years, considered that yet existing parts can be applied and not every part needs to be newly designed.

Furthermore, economic aspects of high copper prices and machining costs and technological changes, as well, trigger efforts for substitutions. E.g., DVD or CD players, which contained a significant amount of tiny CuZnPb alloy based parts, disappeared in new registered vehicles, or a substitution with steel or other suitable materials was realized.

The industry approach, described in previous consultations, in principle continues (see Figure 5-2).

[9] (https://rmis.jrc.ec.europa.eu/rmp/)

Figure 5-2: Activity model 2010 to 2024



Source: (ACEA et al. 2024a)

5.3 Critical review

5.3.1 Substitution and elimination of the restricted substance

Automotive evaluation and standards

(ACEA et al. 2024a) state that due to the large number of applications, each with specific requirements, a large number of specific tests are required. (ACEA et al. 2024c) further comment that the metals used in the automotive sector are validated by means of a large number of tests that are oriented towards their use profiles. Below they list some of the relevant parameters that are tested, followed by a selection of non-exhaustive standards, exluding company individual standards.

Mechanical Properties Evaluation (at different temperatures):

1) Tensile Strength (Measure the maximum stress a material can withstand without breaking)
2) Elongation (Determine how much the material can stretch before breaking.)
3) Fatigue Strength (Evaluate resistance to repeated loading.)
4) Impact Toughness (Measure the material's ability to absorb energy during impact)
5) Creeping (Evaluation on loss of tension under load and temperature)
6) Hardness (Assess the material's resistance to indentation or scratching.)
7) Coefficient of expansion

8) Density
9) Fatigue strength
10) Force/form deviation test

Tribological Properties Evaluation

11) Wear resistance (Assessing, how well the material withstands wear due to friction.)
12) Coefficient of Friction (Measuring the resistance to sliding motion.)
13) Lubrication Properties (Evaluation of performance under lubricated conditions.)

Corrosion Resistance Evaluation

14) Salt Spray Test (e.g. ASTM B117) (Exposing the material to a corrosive environment to assess its resistance.)
15) Electrochemical Tests (e.g., potentio-dynamic polarization)
16) Corrosion resistance to various agents

Electrical Conductivity Evaluation (at different temperatures)

17) Electrical Conductivity (% IACS) (Measuring the material's ability to conduct electricity.

Heat Conductivity Evaluation

18) Heat Conductivity (Ability of the material to transport heat; this is linked to electrical conductivity via the Wiedemann-Franz relationship)

Processing

19) Machinability
20) Hot forming
21) Cold forming
22) Solderability
23) Coatability

Metallurgy

24) Equilibrium diagram
25) Microstructure analysis (Measurement of grain distribution, structure with methods like optical microscopy, scanning electron microscopy (SEM), and X-ray diffraction (XRD))
26) Special treatment like hardening etc.

Table 5-5: Examples of public standards for copper and components produced of copper alloys

Standard	*Designation / Name*
ASTM B30	*Standard specification for copper-base alloys in ingot form.*
ASTM B248	*Standard specification for general requirements for wrought copper and copper-alloy plate, sheet, strip, and rolled bar.*
ISO 1338	*Copper and copper alloys - Determination of lead content - Electrolytic determination.*
ISO 6507	*Metallic materials - Vickers hardness test.*
ISO 6508	*Metallic materials - Rockwell hardness test.*
ISO 6509	*Corrosion of metals and alloys - Determination of dezincification resistance of copper alloys with zinc.*
ASTM Vol. 02.01	*Copper and Copper Alloys Edition 2024-05 (book)*
CSA ANSI LNG 3.12	*Road vehicles - Liquefied natural gas (LNG) fuel system components - Part 12: Rigid fuel line in copper and its alloys Edition 2022-09-01*
CSA C22.2 No. 60947-7-4	*Low-voltage switchgear and controlgear - Part 7-4: Ancillary equipment - PCB terminal blocks for copper conductors Edition 2018-04-01*
UNE-EN 1976	*Copper and copper alloys - Cast unwrought copper products; Edition 2013-06-01*
JIS H 3250	*Copper and copper alloy rods and bars Edition 2021-01-20*
JIS H 5120	*Copper and copper alloy castings Edition 2016-03-22*
UNE-EN 1173	*Copper and copper alloys - Material condition designation; Edition 2009-09-16*
UNE-EN 12164	*Copper and copper alloys - Rod for free machining purposes; Edition 2017-04-19*
JIS H 2109	*Classification standard of copper and copper alloy recycle materials Edition 2006-02-20*
JIS H 0501	*Methods for estimating average grain size of wrought copper and copper alloys Edition 1986-04-30*
JIS C 3001	*Resistance of copper materials for electrical purposes; Edition 1981-06-30*
JIS C 3102	*Annealed copper wires for electrical purposes; Edition 1984-04-30*
UNE-EN 1654	*Copper and copper alloys. Strips for springs and connectors. Edition 1999-02-08*
UNE-EN 12288	*Industrial valves - Copper alloy gate valves Edition 2010-09-22*
SAE AS 81824E	*Splice, Electric, Crimp, Copper, Environment Resistant Edition 2018-08-13*
UNE-EN ISO 2624	*Copper and copper alloys. Estimation of Average grain size. (ISO 2624:1990). Edition 1996-04-29*
UNE-EN ISO 2626	*Copper. Hydrogen Embrittlement Test. (ISO 2626:1973). Edition 1996-05-23*

NF A06-707	*Chemical analysis of copper and its alloys. Electrolytic determination of lead Edition 1967-02-01*
DIN EN 12164	*Copper and copper alloys – rods for machining*
DIN EN ISO 16701	*Corrosion of metals and alloys - Corrosion in artificial atmosphere - Accelerated corrosion test involving exposure under controlled conditions of humidity cycling and intermittent spraying of a salt solution (ISO 16701:2015); German version EN ISO 16701:2015 Edition 2015-10*
DIN EN 624	*Specification for dedicated LPG appliances - Room sealed LPG space heating equipment for installation in vehicles and boats; German version EN 624:2011 Edition 2011-10*
DIN EN ISO 14469	*Road vehicles - Compressed natural gas (CNG) refueling connector (ISO 14469:2017); German version EN ISO 14469:2017 Edition 2018-10*
DIN EN IEC 61189-5-502	*Test methods for electrical materials, printed board and other interconnection structures and assemblies - Part 5-502: General test methods for materials and assemblies - Surface insulation resistance (SIR) testing of assemblies (IEC 61189-5-502:2021); German version EN IEC 61189-5-502:2021 Edition 2022-05*
DIN CEN/TR 17144;	*Resistance of metallic materials to liquid biogenic and alternative fuels and their blends; English version CEN/TR 17144:2017 Edition 2017-12*
DIN EN 3155-003 (example for a bundle of standards for connectors)	*Aerospace series - Electrical contacts used in elements of connection - Part 003: Contacts, electrical, female, type A, crimp, class S - Product standard; German & English version EN 3155-003:2019 Edition 2020-04*

Source: (ACEA et al. 2024c)

These standards mainly reflect static requirements. As parts made from a new metal alloy always have to be tested in conjunction with other parts and further under impact of surrounding specific fluids, tests on component or vehicle level are needed to evaluate corrosion and long-term reliability. The specific requirements for components in service under driving conditions (like prove of water resistance) are the subject of B2B agreements in individual company specifications. As these are considered as competitive sensitive, examples are unavailable.

The consultants understand the restrictive nature of B2B confidentiality in publicly providing competitive sensititve information. However, the consultants must emphasize the responsibility of applicants requesting the continuation of an exemption, ensuring they provide the necessary technical insights for the consultants to fully understand the technical and scientific aspects relevant to the substitution and elimination of lead. The consultants believe it is indispensable to expect that stakeholders prepare themselves to answer technical questions effectively. Given the substantial set of evaluations and standardisations listed above, the applicants were asked to kindly provide specific examples of the tests listed in Table 5-5 above that have been carried out on lead-free copper alloys in the holistic approaches ACEA et al. describe to be necessary since the last revision. They should present their respective findings towards the applicability or lack of applicability for automotive applications of the aforementioned lead-free, reduced lead content Cu-alloys and other potentially promising lead-free Cu-alloys not previously addressed.

(ACEA et al. 2024d) responded that the elemental material properties, such as mechanical properties (e.g. shear /elasticity modulus, fatigue strength, creep), electrical properties, or corrosion material behavior, are normally determined by the material producers for their customers. Such provided data are used in the design phase for the preselection of materials and for calculations and can be found in material databases such as totalmateria (CH), Cambridge Engineering Material Selector (UK), NIMS database (JP), Material Center Databanks (US), IMA (DE) and others. The supplier or OEM must ensure that the product meets the necessary standards for manufacturability, workability and functional fulfilment. Tests are carried out according to company specifications, including specifications, drawing entries and company standards.

The consultants consider the presented explanation of the above data collection and publication scheme as generic which does not provide the requested information, e.g. whether and which lead-free copper-alloys would potentially qualify for which applications, actual test results for these alloys under evaluation for relevant automotive applications etc. However, some further information towards tested material properties were provided in the applicants initial submission and are summarized in the following section below.

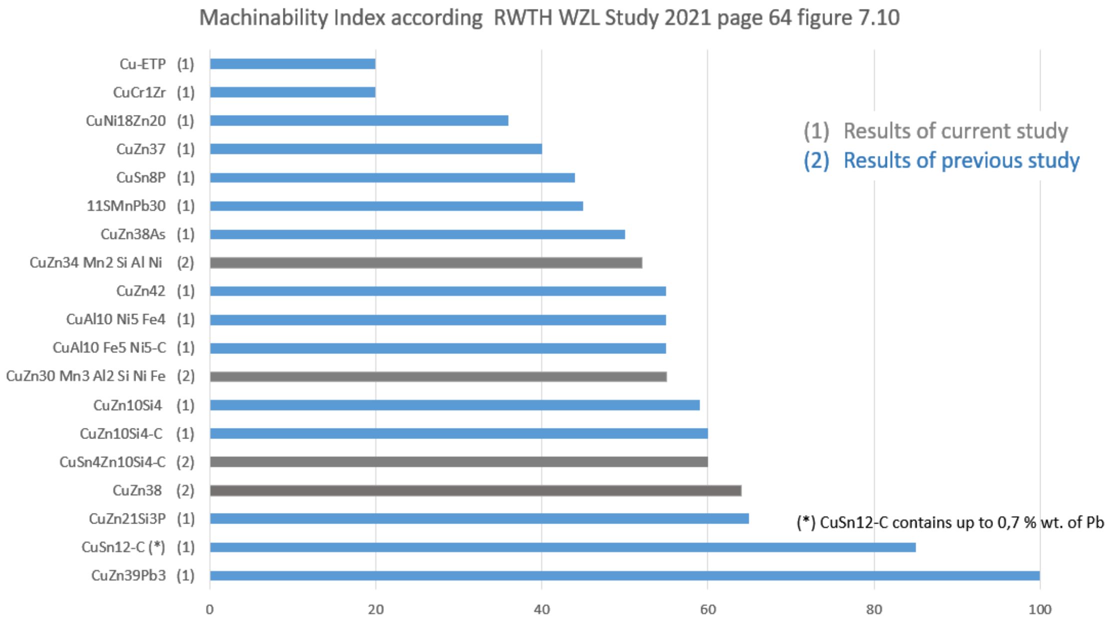
Materials processability assessment (machining, milling)

(ACEA et al. 2024a) report on a German research project at RWTH Aachen[10], supported by more than 20 industry partners, on improved milling parameters for new lead-free copper alloys, which was completed in June 2021. In the project, further lead-free copper alloys were assessed in continuation of a prior project (IGF 16867 N), the outcome of which was similarly described in previous contributions.

Assessing the machinability index, none of the tested up to now twenty different materials could demonstrate a better machining resp. milling performance than the reference alloy CuZn39Pb3. The latter alloy is still the benchmark with distance for machinability and for low cutting forces. Figure 5-3 shows the results of machinability assessment of different copper materials according RWTH WZL, with new assessed materials coloured in grey and results from the previous study are coloured in blue.

[10] Bergs T., Schraknepper D., Baier S.: Entwicklung angepasster Werkzeuge u. Prozesse zur Steigerung der Produktivität und Prozesssicherheit beim Fräsen innovativer bleifreier Kupferwerkstoffe; AIF Research Report, IGF-Vorhaben Nr. 20029 N RWTH Aachen University Werkzeugmaschinenlabor WZL Lehrstuhl für Technologie der Fertigungsverfahren; Aachen 16.06.2021; https://www.wvmetalle.de/index.php?eID=dumpFile&t=f&f=323697&token=dec537d866eb1656c2b97462d7cea8ff21a212b5

Figure 5-3: Results of machinability assessment of different Copper materials



Source: (ACEA et al. 2024a)

According to (ACEA et al. 2024a), the findings of this report are considered resp. disseminated in an updated industry guideline from 2023 on machining of copper and copper alloys[11]. This will support well manufacturability tests for future component production and ease efforts to apply the most suitable parameters for each of listed alloys. The guideline is provided by the copper industry as part of their engagement for copper materials and gives evidence for efforts to support the application of new materials.

The consultants acknowledge the effort of the copper industry to the set industry guidelines, but point out that out of the presented 19 alloys in Figure 5-3, only 4 are new to the present exemption review, whereas the remainder had already been available during previous revisions of this exemption since the referenced previous study, which was completed in June of 2013 (Lung 2013).

In addition, (ACEA et al. 2024a) state that the efforts for substitutions in the supply chain continue. This becomes evident by the constant amount of lead for articles in scope of entry 3, despite an increasing total copper use and more installed electrical and electronic systems per new registered vehicle (see section 5.1.4).

The consultants consider these findings unsubstantiated, since compared to their contribution to the previous 11th review of the exemption (ACEA et al. 2020) with an extensive copper inventory, in the current revision a comprehensive comparison of the numbers of lead-containing parts since the last review of the exemption in 2021 is not

[11] Richtwerte für die spanende Bearbeitung von Kupfer und Kupferlegierungen; Informationsdruck i 18: edited by Kupferverband e.V. Düsseldorf 2023; www.kupfer.de

presented. This information should be available despite the review being conducted in 2024 already instead of 2025 as ACEA et al. should have a reference for their above statement.

(Wieland 2024b) provided the information in Table 5-6 as an overview of which lead-free alloys are available to replace which lead-containing alloys.

Table 5-6: Alloys by Wieland Werke AG designated for the automotive sector

ecoline®	eco SW1®	eco SZ2®	eco SZ3®	eco SZ4®	eco SZ5®	eco SD4®	eco SX1®
Alloy type	Wrought alloy – special brass	Wrought alloy – Brass	Wrought alloy – Brass	Wrought alloy – Brass	Wrought alloy – Brass	Wrought alloy - special brass	Wrought alloy - special brass
EN designation	CuZn21Si3P	CuZn36Si1P	CuZn40SiP	CuZn42	CuZn40	CuZn37Mn3Al2Si	CuZn31Mn2SiAl
EN designation no.	CW724R	CW726R	N/A	CW510L	CW509L		
ASTM/UNS no.	C69300	C68370	C68330	N/A	C27450		
EN alternative		CW614N; CW617N	CW614N; CW617N	CW614N; CW617N	CW612N	CW713R	CW713R
UNS alternative		C38500	C38500	C38500	C37700	C67420	C67420
Note	Focus for high tensile applications						
Machining index	90%	90%	90%	85%	75%	45%	70%
Cold forming	good	poor	poor	poor	fair	poor	good
Hot forming	excellent	excellent	excellent	excellent	good	excellent	excellent
Dezinc-ification resistant	ISO 6509	N/A	N/A	N/A	N/A	N/A	N/A

Source: (Wieland 2024b)

(Wieland 2024b) claim that for components manufactured from the listed lead-containing alloys (Table 5-6), there is a corresponding substitution option regardless of the application. Despite the promising claim that a substitution with the presented alloys is possible regardless of the application, substantiated evidence supporting these claims in the form of evaluations of different automotive applications and test results was not provided.

(Wieland 2024b) explain that the information on machinability is based on internal tests and customer feedback. Machinability is not a material property but a system property. The assessment may vary depending on the machining operation. As there is no uniform evaluation standard for this, they are involved in the Copper Processing Innovation Network at RWTH Aachen University, which also includes numerous component manufacturers.

(Wieland 2024b) contributed to the machinability results by RWTH Aachen study (Figure 5-3), but also produced machinability indexes themselves (Table 5-6). For instance, Wieland report a machinability index for CuZn21Si3P (eco SW1 ®) of 90 %, in contrast to the 65 % reported by RWTH Aachen.

(ACEA et al. 2024c) add that a machinability index gives some hints but to decide if a specific material works, the machining must be tested in-house on existing production equipment. The complexity of factors that decide if a specific material works for a specific company is just too high to derive it from more abstract research. Each company has different products, different kinds of machines and knowledge.

The consultants conclude that the same part made of different alloys machined on the same machine will produce different machinability indexes. Further, the same part made of the same alloy machined on different machines will also produce different machinability indexes. For a parts manufacturer the machinability has a direct effect on the economic feasibility of the production of parts. The consultants therefore conclude that more results of machinability tests and results produced on different sets of machining systems by different manufacturers could have been relevant contributions that are missing for the current review of the exemption.

Promising materials presented for further evaluation in the previous review of the exemption

Around 20 lead-free alloys were reported by the primary stakeholders in 2020 to be available, including new ones just having entered the market which they claimed to have potential for further substitutions if application-specific and systematic tests are applied. The below lead-free copper alloys were explicitly mentioned as new and for further assessment in the time after the last review of this exemption by (Deubzer et al. 2021):

- AquaNordic lead-free copper alloy that might be a substitute of leaded brass from machinability point of view.
- Novel lead-free copper alloys for oil-hydraulic applications as bushings, slippers or distributor plates, by the company Otto-Fuchs[12] aimed to substitute leaded-alloys with a lead-content not exceeding 0.8 % by weight.
- The Aviva Model 3 alloy offering very good machinability, high conductivity and excellent dezincification-resistance properties.
- CuSi4Zn9MnP (wrought alloy) and CuSn4Zn2PS-C (casting alloy).

[12] B. Reetz, T. Münch, Challenges for novel lead-free alloys in hydraulics, 12th International Fluid Power Conference, Dresden, 2020.

ACEA et al. were requested to report about the tests announced in the last review and their results.

(ACEA et al. 2024a) report that CW511L Aqua Nordic® - Rod (CuZn38As modified) has received a qualification from the Swedish certification body Kiwa stating that the alloy is for the manufacturing of components for fixtures, appliances, fittings and pumps in contact with drinking water. (ACEA et al. 2024a) further present results of RWTH Aachen showing a machinability index for this alloy of 50 % compared to the 100 % of the reference alloy CuZn39Pb3. There are no test results known yet for automotive applications. (ACEA et al. 2024a) further present the machinability index of CW510L Aqua Nordic® (CuZn42).

The consultants consider the above mentioned reception of a qualification for components in contact with drinking water as a promising development for the wider adoption of this alloy in various other industries. However, when questionned about the transferrability of findings in the plumbing sector to the automotive sector (ACEA et al. 2024c) responded that *developments in the plumbing sector, which constitutes the primary market for brass, are generally of less significance in the context of automotive applications, these developments are projected to have a profound impact upon the substitution of Lead-containing Copper alloys within the plumbing sector. In the long term this will reduce the Lead content in EU Copper scrap significantly*. In the light of this answer, it remains unclear why ACEA et al. mention the qualifcation for plumbing.

Since the machinability studies for Aqua Nordic alloys CuZn38As and CuZn42 have already been available since 2013 (Lung 2013), the consultants consider the evidence brought forward as unsubstantiated towards the applicability or lack thereof of these alloys for automotive applications as set out in the last review by (Deubzer et al. 2021).

For the Otto Fuchs alloys, (ACEA et al. 2024a) refer to a corresponding paper of Otto Fuchs[13] in 2020, where bushings and slippers in axial piston pumps and distributor plates were assessed using CuZn30Al2Mn2Ni1FeSiSn (OF 2299). The alloy CuZn34Mn2SiAlNi was in scope of the RWTH 2021 machinability assessment and its machinability index was determined with around 52 %. The Otto Fuchs alloys CuZn28Al4Ni3Si1Mn (OF 2290) and CuZn35Mn2Ni2FeSi (OF 2297) were not part of the RWTH study 2021.

In the opinion of the consultants, the applicants refer to a research assessment conducted by Otto Fuchs, however, fail to actually present substantiated evidence or conclusions for the applicability or lack thereof of OF 2299 for automotive applications. The machinability index provided for CuZn34Mn2SiAlNi was indeed part of the most recent assessment by RWTH Aachen and can be considered as effort in the light of material characterisation. However, the consultants were not provided with the automotive sector's interpretation of these results and follow-up specific assessments towards automotive applications of this alloy. The alloys OF 2290 and OF 2297 are mentioned without any specific reference towards conducted assessments or findings for their applicability in the automotive industries.

(ACEA et al. 2024a) further add that Otto Fuchs is a supplier of the automotive industry and member of the VDA. The efforts of Otto Fuchs give evidence for the committed

[13] https://tud.qucosa.de/api/qucosa%3A71055/attachment/ATT-0/

engagement of the automotive industry to find lead-free solutions in a step-by-step approach. Otto Fuchs conducted research as material producer and as component manufacturer and developed a promising lead-free solution for applications in oil-hydraulics systems. (ACEA et al. 2024a) have no information if the release for volume production for this material and in this application was yet given.

The presented arguments above are, in the eyes of the consultants, rather anecdotal without the presentation of evidence-based findings. The promising lead-free solution for applications in oil-hydraulics systems has been subject to discussion in the previous review of the exemption, and the consultants are not provided with novel substantiated evidence towards its applicability or lack thereof in automotive applications.

(ACEA et al. 2024a) continue presenting the Aviva Model 3™ (Cu Zn14,5 Te) lead-free machining alloy, which was mentioned also in the last contribution of ACEA et al. According to its developer, it contains less than 15 % by weight of zinc and tellurium in an amount between 0.3 % and 0.9 % by weight, offers very good machinability, high conductivity and excellent dezincification-resistance properties. ACEA and the joint automotive associations do not currently have specific experience or knowledge about this alloy and are not aware of any automotive applications for which the Aviva Model 3 ™ alloy is in use or for which its use has been considered in the meantime. They further add that Tellurium is a quite limited resource and being associated with health risks and is therefore not favoured as substitute for lead. They further add that according to ECHA[14] the classification provided by companies to ECHA in REACH registrations identifies that this substance may damage fertility of the unborn child, is harmful if inhaled, may cause long lasting harmful effects to aquatic life and may cause an allergic skin reaction. (Classifications Danger; GHS07, GHS08 H360D, H317, H332, H413).

The presented information is in essence identical to the information provided in the 11th adaptation report by (Deubzer et al. 2021), and does therefore not harbour any new findings since the last review. The consultants agree that health and environmental concerns are to be accounted for, however, consulting safety datasheets, the toxicological implications upon exposure are less stringent for tellurium compared to lead[15,16]. The provided information on health and environmental concerns of tellurium indicate uncertainties of the current state of knowledge, which requires further assessments, particularly in direct comparison to the already certain adverse effects of lead. The consultants therefore deem the concerns brought forward as not justifying a halt of the exploration of this alloy for potential automotive applications in the future

[14] ECHA https://echa.europa.eu/substance-information/-/substanceinfo/100.033.452

[15] Roth – Safety Data Sheet Tellurium. Available at https://www.carlroth.com/medias/SDB-1L5N-GB-EN.pdf?context=bWFzdGVyfHNlY3VyaXR5RGF0YXNoZWV0c3wyMzUwODl8YXBwbGljYXRpb24vcGRmfGhhMy9oNWYvOTE0MTIwOTk1NjM4Mi9TREJfMUw1Tl9HQl9FTi5wZGZ8MjU0MDk1YzAyZTczYjUzM2IwNmM3YzQyOGEwODUxMDUyNjc5YTExYjExZjMyYmViMDM5OGI5MjRiNzkwOGNhOQ

[16] Roth – Safety Data Sheet Lead. Available at https://www.carlroth.com/medias/SDB-2734-GB-EN.pdf?context=bWFzdGVyfHNlY3VyaXR5RGF0YXNoZWV0c3wyNzU4OTN8YXBwbGljYXRpb24vcGRmfGFERTJMMmcyWXk4NU1UVXlPVGc0TlRFeU1qZzJMMU5FUWw4eU56TTBYMGRDWDBWT0xuQmtaZ3w1NzM2YTZiMGJhYzAwMDBhZGNjOWZhZTkxNGI2YTMyMjA0OWYzYmNkNjRhZmRlYjUzYjVjYWE0OGY5ODk0ZTNh

without further explanation than the above. The consultants conclude that the information provided does not reflect what could have been expected upon the presentation of these promising alloys by ACEA et al.

(ACEA et al. 2024a) state that the alloys CuSi4Zn9MnP and CuSn4Zn2PS-C have a much higher Cu content than CuZn39Pb3, both alloys are economically less favourable than CuZn39Pb3 and also than CuZn42 and similar alloys. A significant difference in technical properties is assumed. Taking further refernce towards the previously presented CuSn4Zn2PS-C (casting alloy) *(ACEA et al. 2024a) further state that the development of new lead-free Cu alloys is ongoing and material producers e.g. like Wieland (eco GS1 CuSn4Zn2PS-C-GC), Mitsubishi Materials (Glo Brass, Si based) and Diehl (ezee brass CuZn41Mg) have presented new developments. The challenge to achieve substitutions in a step-by-step approach remains, as there are part-specific demands like hot /cold formability, precise machinability, conductivity over service life etc. to consider, in principle for each component. Once and if new lead-free alternatives, able to effectively substitute leaded-copper alloys for all their current automotive applications and from all points of view, will be commercially available, a long time might still be needed for the large scale implementation, re-design and validation of the automotive components made out of them.*

The consultants agree on the usefulness of a step-by-step approach since the improbability of a „one size fits all" solution had already been discussed in previous stakeholder contributions, which is further discussed in the subsection below. The above answer of ACEA et al. also leaves open how they want to decide that new alloys can effectively substitute leaded-copper alloys for all their current automotive applications and from all points of view, and whether they consider the mentioned alloys as such. In this respect, the consultants do not see substantiated novel evidence-based results on the applicability of the claimed promising lead-free copper alloys since the last review of the exemption.

When confronted with the lack of novel evidence based substantiation of the applicability of the materials presented in previous revisions of the exemption, (ACEA et al. 2024c) responded that *in the submission dated December 2020, the automotive sector requested an eighth-year follow-up review. This request is based on the observation that the path from the availability of a new material to the implementation of its use in automotive applications often takes a considerable time. This is a conclusion that can be derived from previous submissions by ACEA and others, which were made in 2010, 2014, and 2020, respectively.*

The consultants continued to ask for any further active developments for these previously mentioned alloys and for test results underlining their applicability for the intended use in specific automotive applications since the last revision. If the overall process is announced to take eight years, it could be expected that work on finding lead-free alternatives is ongoing and profound and findings should be available since 2020.

(ACEA et al. 2024c) generically take reference to the previous submission of ACEA et al. from 8.December 2020 and to the new machinability test results, released in June 2021 (see Figure 5-3), which had been part of their original submission. None of these alloys achieved a comparable machinability index to that of the reference material CuZn39Pb3. Materials with lower machinability performance may result in significant investments in the supply chain. In such instances, it may be necessary to utilize additional tools and process aid media, which may in turn necessitate the purchase of

new machinery with greater capacity, resulting in increased energy consumption per produced part.

The situation changed in the last few years as more promising lead-free alloys got available, at least in the developing state. Accordingly, also tests of the alloys and research at the part manufacturer had to go an iterative way because some of the alloys seemed more promising than others and for at least one alloy it turned out that a continuously stable quality could not be guaranteed. The results of these iterative tests are not yet publishable.

As discussed above, the machinability depends on the individual machining system in operation. Presenting manufacturer specific machinability results or some form of factual results underlining the challenges of establishing production processes based on new alloys with reduced machinability could have been brought forward to provide a more transparent picture of the ongoing developments.

Promising materials presented for further evaluation in the current review of the exemption

The applicants were asked to explain the efforts their organisations have undertaken to find and implement the use of lead-free alternatives for automotive uses, which at least reduce the amount of lead applied or eliminate its necessity altogether.

<u>New copper alloys presented by ACEA et al.</u>

(ACEA et al. 2024c) point to a statement of a part manufacturer stating that major brass producers developed several new lead-free alloys. In many cases these are alloys of the type CuZn40 to CuZn42 with small additions of further alloying elements. As these alloys often have a complex microscopic structure, a lot of testing was required at the site of the material manufacturers and the part manufacturers. As these alloys have been in the developing state, publishable test results are not yet available.

The above part manufacturer explained that these developments challenged his former approach to substitute lead-containing copper alloys. In the past, it seemed that the alloys [presented as promising in the previous revision of the exemption] *are all more or less hard to machine and many parts with specific requirements could not be made from these alloys. Further developments in production technology would be required. It seems more promising to first follow the development of the new alloys* based on CuZn40, CuZn42 with small additions of further alloying elements.

(ACEA et al. 2024c) provided information from the supply chain where for one part tests to use another copper alloy with max. 0.1 % lead instead of higher content 2.5 % – 3.5 % were done. Checks are nearly finished and results until now show that change might be possible with increasing costs per part. Every use case has to be checked one by one and needs testing according to the customer requirements. Due to capacity, no further checks were done until now. (ACEA et al. 2024c) state that to date, no further related information from their members was received.

The consultants consider the presented activities towards reducing the maximum lead content in leaded copper parts as promising, though unsubstantiated in nature since no information on the parts tested, the particular alloy in question, test conditions or factual evidence on the reduction of lead, or consistent and sound follow-up activities are specified. In the opinion of the consultants the provided information does not justify reducing the maximum lead content of the exemption from 4 %.

(ACEA et al. 2024c) comment that in their initial submission, they projected that some relevant applications would be available in new vehicles launched towards the end of 2024 and 2025. However, this information will not be available until the start of production of these vehicles. It has been observed that the required timeframes for the evaluation of new materials are frequently unknown and underestimated. In the submission from December 2020, the automotive industry requested a follow-up review after a period of eight years. In the submissions from 2010, 2014 and 2020, ACEA et al. have yet outlined that the path from the availability of a new material until its volume-scale automotive applications is long. It is important to note that the assumption of responsibility for or acceptance of risks that could be caused by the use of inadequately tested materials is not acceptable.

The consultants acknowledge extensive testing timeframes until volume-scale production, however, emphasize that according to the step-by-step (or part-by-part) process proposed by the applicants, interim testing and results are of significance towards the assessment of potentially lead-free copper alloy substitutes. Therefore, the consultants assume that parts have to be tried and tested before launching the start of production of new vehicles. The consultants further assume that test results for lead-free copper alloy parts to be included in these productions must be well under way or near completion due to the proximity of the beginning of the production in the end of 2024. The consultants inquired in what components and functional parts lead-containing Cu-alloy could be replaced by lead-free Cu-alloys and how were these parts tested a priori.

(ACEA et al. 2024d) must respectfully inform that this question will require input from the original equipment manufacturers (OEMs) and their supply chains. It is at the discretion of each company as to what information may be disclosed before volume production. Regrettably, this will take much more time than the granted seven working days to provide answers.

The collection of the aforementioned test results may require more time than seven working days. However, since it was part of the conclusion of (Deubzer et al. 2021) that *"application-centred and specific assessments of substitution possibilities or, in case, impossibilities, so that in the next review, applicants can provide substantiated, sound and transparent evidence where the use of lead may still be unavoidable must be provided",* the applicants have been well aware of the format of the requested information since at least 2021 and should be able to bring forward at lest part of the relevant information during this current revision process. The consultants consider information as to the status of lead substitution or elimination as essential for the exemption request. It should be collected during the preparation phase or, in this case, since the review started earlier than expected, during the consultation period.

<u>Patent and literature screening by ACEA et al.</u>

(ACEA et al. 2024a) conducted a patent and literature screening but found only very limited number of hits on new lead-free copper materials.

(ACEA et al. 2024a) presented five lead-free copper alloy patents and one technical paper filed in the time span from 2015 to 2020, which cannot be regarded as novel contribution to the current revision of the exemption. One patent filed in 2024 was presented without further specific detail about the applicability of the alloy. Findings on conducted test results for automotive applications or plans therefore were not provided.

(ACEA et al. 2024a) further present results from conference proceedings of the Kupfersymposium 2021, copper-alloys 2022 conference, Kupfer Symposium 2023. The focus of these studies is mainly on plumbing applications and machinability assessments, however, no conclusions, test results or future plans on the implementation of the presented alloys in the automotive sector were provided.

(ACEA et al. 2024a) further conduct a generic assessment of the major elements proposed as lead substitutes, including Bismuth, Silicon, Tellurium, Indium, Sulphur, in the form of a summary of previous revision findings of alloying elements. No new application specific test results were presented.

<u>New copper alloys presented by Wieland</u>

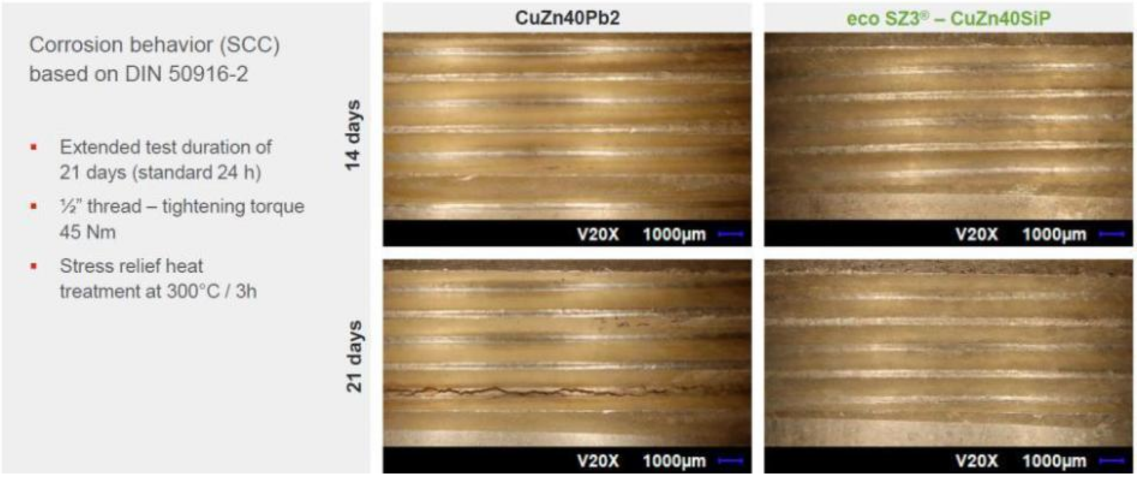
(Wieland 2024b) present a range of lead-free copper alloys designated for the automotive industry in Table 5-6. They newly introduced the eco SZ3® alloys which close the range of applications for electrical connecting parts (e.g., battery clamps; connectors; etc.). They declare these alloys to have an electrical conductivity on a level with the lead-containing alloys used today. These alloys can also be used for applications without requirements for electrical conductivity, such as tire valves, threaded inserts, etc. They compared the mechanical properties, corrosion resistance, corrosion behaviour, dezincification and hot formability on the basis of automotive customer trials. The results are presented in Table 5-7 and Figure 5-4 through Figure 5-6.

Table 5-7: ECO SZ3 mechanical properties (ISO 6892-1)

Material	Lead-free (max. 0,1 %)	Lead-containing	
Wieland	eco SZ3®	Z41/Z48	Z33
ISO	CuZn40SiP	CuZn40Pb2	CuZn39Pb3
EN	-	CW617N	CW614N
UNS	-	C38000	C38500
Processing properties (indication values)			
Machinability	● 90%	● 95%	● 100%
Cold forming properties	◑ 50%	◑ 50%	◑ 60%
Hot forming properties	● 100%	● 100%	● 90%
Mechanical and physical properties (reference values) dia. 20 mm			
Tensile strength R_m [MPa]	530	520	500
Yield strength $R_{p0.2}$ [MPa]	400	380	360
Elongation [%]	20	20	20
Electrical conductivity [%IACS]	23	25	25
Thermal conductivity [W/m*K]	104	113	113
Density [g/cm³]	8.21	8.43	8.46
Corrosion resistance			
Stress corrosion resistance	yes**	yes**	yes**
Dezincification resistance ISO 6509	no	no	no
Hygienic approval drinking water (product class B)			
	Expected end of 2024	Sunset dates: GER: January 2028 Other EU countries: December 2032	no

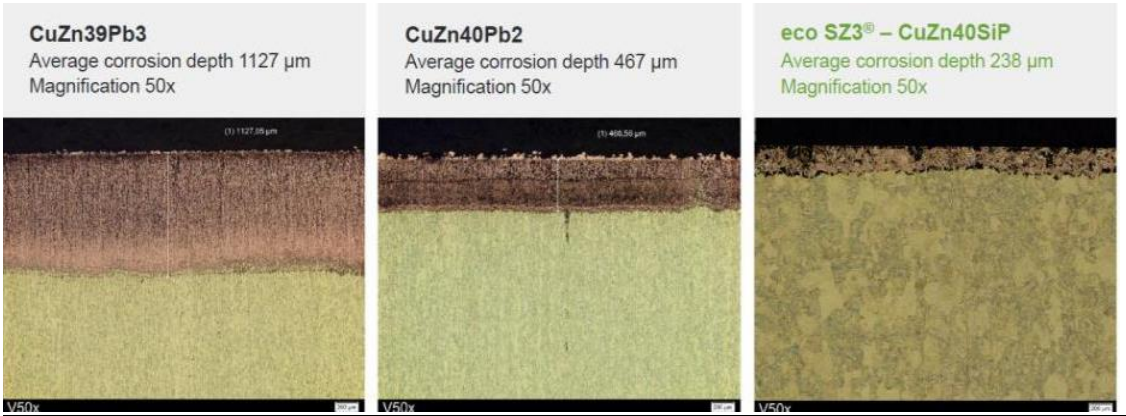
Source: (Wieland 2024b)

Figure 5-4: ECO SZ3 stress corrosion cracking test (DIN 50916-2) and dezincification (ISO 6509)



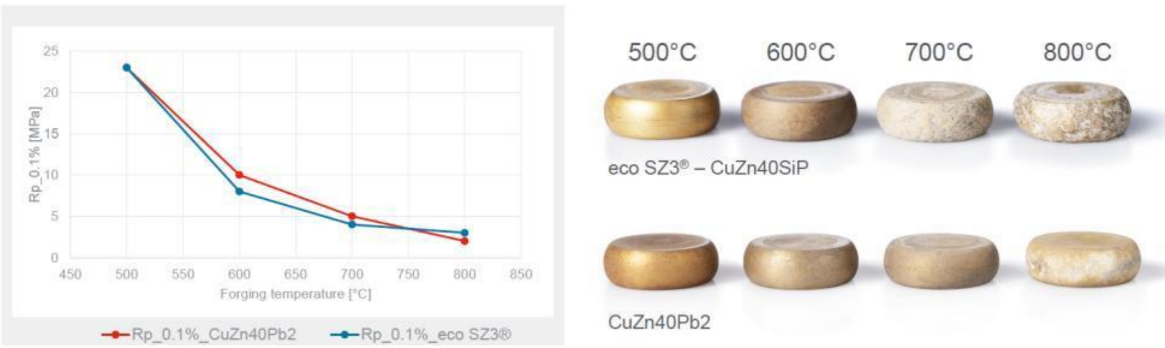
Source: (Wieland 2024b)

Figure 5-5: ECO SZ3 corrosion behaviour (EN ISO 6509)(CuCl2 / 75 °C / 24 h)



Source: (Wieland 2024b)

Figure 5-6: ECO SZ3 hot forming test by means of hot compression tests



Source: (Wieland 2024b)

Considering the addressed parameters, the lead free alloy showed similar, in parts superior performances compared to standard lead containing copper alloy references. Despite these promising results, Wieland's claim that these alloys can be used in battery clamps and connectors is not substantiated. Conclusions of the above test results towards these or other automotive applications were not provided, and evidence is missing that they can actually be used for these applications in the automotive sector. The claimed electrical conductivity comparable to lead-containing alloys, which can be assumed to be a core parameter for these uses, was not substantiated by supporting evidence.

Application specific testing of components

(ACEA et al. 2024a) have the opinion that the potentials of "one size fits for all purposes" substitution approaches are consumed and based on their experiences and test results of the last years, they are sceptical to a further success of generic substitution approaches.

This had already been discussed similarly in the stakeholder contribution to the 11th adaptation report, where (ACEA et al. 2020) state *that even though several potentially lead-free brass and copper alloys have been recently developed and in some cases even commercialized, it appears clear that none of them is able to substitute leaded-copper alloys in all applications and fields where they are currently used. Most likely, the future substitution of leaded-copper alloys will not be achievable through only a single type of lead-free copper alloy. Rather, different varieties of lead-free alloys will be likely needed to cover the whole spectrum of properties and possible applications that leaded-copper alloys are able to offer. The challenges to face in the upcoming years to succeed in the complete substitution of leaded-copper alloys include the development of new alloys, their full characterization, as well as the deep study of the promising alternative alloys already available and the re-design, production and test of real components made of these new alloys. (ACEA et al. 2024a) state that the challenge to achieve substitutions in a step-by-step approach remains, as there are part specific demands like hot /cold formability, precise machinability, conductivity over service life etc. to consider, in principle for each component.*

(Deubzer et al. 2021) also propose a less anecdotal, more systematic, transparent and substitution-oriented approach. This should imply to stop testing properties of lead-free copper alloys with the requirement that they either can substitute leaded copper alloys in all applications, or to otherwise disqualify the lead-free copper alloys. Examples of a successful lead substitution show that a lead-free alloy which failed tests of ACEA et al. can be applied successfully in specific applications. Hence, the consultants suggest an application-specific approach. This would require, next to characterizing materials, to first of all characterise applications, for example setting up basic requirement profiles for copper alloy parts in each of the three main application groups[17], which could then be further specified for the various applications within each of these groups. It could be a step to allow systematic assessments, enable application-specific substitution and provide sound evidence where exemption 3 is still needed.

The consultants want to add the aspect pointed out by (ACEA et al. 2024a), which is to scrutinise the interaction of a component/part produced from copper alloy with

[17] ACEA et al. group copper alloy parts into sliding elements, mechanical connecting elements, and
electric applications.

neighbouring parts on a system level, i.e. the other materials used in parts that interact with the component, the design of the module/appliance in which the copper alloy is used. The objective could be the holistic redesign of the entire module to enable the use of lead-free copper alloys, or to eliminate the use of copper alloys. (ACEA et al. 2024c) report such eliminations by use of stamped copper parts instead of turned ones (see further below), or possibly by substituting copper alloy by lead-free steel parts, etc.

Application and component profiling for alloy evaluation

(ACEA et al. 2024a) comment that they have received one feedback. In the area of aggregates, components have been converted to lead-free with a high level of testing. When further asked to provide more detail on the types of components, the proceedings towards the accomplishment of the conversion and the level of testing (ACEA et al. 2024c) provided the following information: *It was reported that the substitution in question pertained to bushings for an engine of an internal combustion engine (ICE) vehicle. Two different technical solutions were employed. One involved a redesign with other materials and the application of a special high-tech coating for the parts, which made the lead-containing copper obsolete. The second technical solution was the use of a lead-free copper alloy specified according to ISO 4382-2. (ACEA et al. 2024d) further add that this was a part specific solution, customized to interfering surrounding parts, dynamic load, temperatures and lubrication resp. tribological conditions.*

The consultants regard the presented findings as in line with the proposed step-by-step and holistic approach and consider the provided follow-up information as promising, however, also somewhat unsubstantiated. More application centered detail on the types of components, the proceedings torwards the accomplishment of the elimination and substitution or the level of testing could have provided the consultants with a better understanding of these elimination and substitution successes. The consultants expect, while welcoming such activities, that more details about conditions, circumstances, design approaches etc. were applied. It can be assumed that such information can be provided in more detail without revealing proprietary and competitive-edge knowledge which to disclose manufacturers are not expected to do.

Component grouping according to geometry or properties

(Deubzer et al. 2021) and (Baron et al. 2022) during the revision of the equivalent RoHS exemption III-6c stated: *"In principle, lead-free alloys are available, but their applicability is limited to specific cases and does not allow a demarcation of applications that could be excluded from the exemption. Furthermore, the substitutes that are so far available cannot be used as simple" drop-in" but need further adaptations in the alloy composition and/or in the machining processes to allow their successful implementation. Though industry agrees to a differentiation between two big application groups, this does not allow narrowing down the exemption's scope in a way that would exclude applications from the exemption where substitutes are available. It is further suggested that "A future possibility might be to base a grouping on geometry or properties of the final component (for components with electrical function this could be e.g. transfer of power versus transfer of data)."*

The applicants were asked if such a grouping adapted to automotive applications with a stronger focus on geometries and component properties similar to the proposition of

(Baron et al. 2022) could be a possibility to narrow down the scope of entry 3, and in what time frame the applicants would be able to come up with a grouping scheme for automotive applications and components.

(ACEA et al. 2024c) support targeted adaptations of the exemption where warranted from a practicability, reliability and environmental, health and consumer safety impacts standpoint. In such case grouping would be a good approach to check if it is possible to identify applications that share properties that are relevant for the use of Leaded Copper alloys. As the exemption is applied very broadly, it is currently unlikely that it is possible to define clearly enough specific application groups that do not require the exemption anymore.

It may be a useful approach to consider the currently available possibilities to reduce the use of Lead-containing Copper alloys to see to which properties or applications they may fit more closely. In the past the discussions on narrowing the scope have ended without significant results. Component development in the automotive industry is less standardized than in appliance applications such as plugs. Automotive OEMs have often own specifications which they consider as the best solution. So e.g. for water tightness individual requirements are given and for loading of electrical vehicles different plugs are in use. Finally, it is important to note that in the past, the main substitutes have been other materials and that the high price of Copper materials is a driving force.

The consultants understand the challenges of a less standardised development process for components in the automotive industry and the difficulties that come along with it in evaluating potentially lead-free substitutes. In the consultants' view, vehicle producers should, however, consider whether and how far their past and obviously also current practices will enable them justifying the continuation of exemption 3. A more systematic and organised approach was appealed for in the past review by (Deubzer et al. 2021) already. The members of ACEA et al. should have organised their efforts accordingly.

In the view of (Wieland 2024b), the grouping described by (Baron et al. 2022) also appears to present difficulties. The switch to lead-free materials is also very dependent on the individual circumstances of the processors (e.g., machinability as a system property). It may be that a functionally identical product can be converted by one producer with little effort, whereas for another this may mean that it can no longer be produced economically without investment. Considering the different applications of copper alloys in the automotive industry, the geometries and properties are overlapping. Accordingly, such a differentiation is not target oriented. If any differentiation needs to be done, we rather see a differentiation between components in combustion engines and other components used in vehicles – independent of the drive system. However, they believe that a reliable exit scenario with fixed deadlines is the most promising way to create a level and predictable playing field for the whole industry.

The consultants welcome this critical feedback on their proposals. The choice of the best-performing processor was considered to be part of the proposal rather than performing a single machinability test at one processor and disqualify the copper-alloy based on this. The consultants do not exclude that the flexibility of changing part processors may be limited but some flexibility would boost competition among processors for the best lead-free alloy processing, potentially with a specialisation of processors on specific alloy types and geometries. Concerning the best approach to avoid the use of lead, should it be grouping along material or application profiles or any other, the consultants trust the expertise available in the automotive industry including its suppliers. The consultants welcome good approaches and examples for implementation to be pesented in the next review.

To (Wieland 2024b), the above-mentioned obstacles to switching to lead-free materials are clear, but are also reflected in other areas of application, such as the sanitary sector, electrical engineering (RoHS), etc. It must also be taken into account that many of today's highly productive processes (equipment; tools; parameters; etc.) with lead-containing alloys have been optimized over years and decades for the specific alloy properties. In order to exploit economies of scale, we consider a complete switch to lead-free in these areas of application to be positive (material on stock, scrap cycles, reduced complexity, etc.).

The consultants understand this remark to express that there is a large potential for adaptation and optimisation of the current processing which is still characterised from decades of processing leaded copper alloys. Tests of lead-free copper alloys should therefore include the best lead-free processing experience and equipment to achieve progress in the avoidance of lead.

Elimination / substitution through changing production technologies

(ACEA et al. 2024c) report that a manufacturer compared the amount of Lead used per part for its hundred most sold parts for the years 2018 until 2023, respectively. These parts represent by number between 65 % and 72 % of all sold automotive parts of this manufacturer. It is a very promising result that the amount of lead per part was continuously reduced year by year and dropped by more than 50 % from 2018 to 2023. Interestingly a main reason for this drop in the amount of Lead is not the substitution of machined Leaded Copper alloys by machined Lead-free Copper alloys but the elimination of Leaded Copper alloys by the change from turned Copper parts to stamped Copper parts.

(ACEA et al. 2024d) continue that in general for metal parts produced in large volumes, it is advantageous to replace the production method of machining with other production methods like stemming or forming variants, if possible. Such production methods require specific machines and tools for forming and materials with sufficient plasticity. They further estimate that this substitution approach will gain increasing momentum soon, provided that questions of patents do not impede its progress. It is reasonable to anticipate that the number of parts produced using the described method will increase over time. This will result in a further contribution to the reduction in the number of applications requiring ELV exemption 3.

The consultants welcome the possibility to replace lead-containing with lead-free copper alloys in the conjunction with changing the manufacturing technologies from machining to stamping where operation processes allow. However, transparent and systemic information allowing the consultants to better comprehend the specific detail of this particular substitution, the component or the evaluation process towards this substitution was not provided.

5.3.2 Environmental, health, safety and socioeconomic impacts

(ACEA et al. 2024a) state that a reduced machinability may increase the energy demand during the production process.The machining of lead-containing copper alloys allows lower cutting forces and therefore less production expenditures.

If ACEA et al. assume that the additional energy consumption might cause environmental impacts that are likely to outweigh the benefits of lead substitution, substantiated evidence would be needed to comprehensibly assess these impacts from machining of lead-free against lead-containing copper alloys. It should also be kept in mind that, besides energy consumption, other environmental burdens and their impacts must be considered, and that the processing of copper alloys is not the only life cycle stage.

As presented in section 5.2.2 above, (ACEA et al. 2024a) point out the 90 % effciency for copper in recycling loops and circular economy so that copper based scraps derived from end-of-life-vehicles are a valuable resource for secondary copper or brass applications due to their excellent recyclability. But energy costs increase when zinc and lead have to be separated from copper scrap. They also state that some brass parts are fabricated almost exclusively from recycled brass which reduces the amount of energy and related emissions for the production of alloys compared to production via primary materials causing energy demand.

Recycling of copper and brass contribute to circular economy. Art. 4(2)(b)(II) requires, however, that lead shall only be used if unavoidable. Recyclability is in this context only a criterion as part of a larger consideration whether the continued use of lead is likely to be more beneficial for environment, health and safety than its substitution in a life cycle perspective, and considering all relevant environmental impacts. Further on, (Deubzer et al. 2021) showed in the previous review of this exemption that brass parts are not separated from ELVs so that they end up to a large degree in the copper fraction which is treated in smelters to recycle copper and lead. Recycling of brass from ELVs is thus impossible. The automotive industry does not contribute to brass recycling but consumes the recycled brass derived from other sources than ELVs.(ACEA et al. 2024a) comment that stakeholders further stated that alloys containing bismuth were also more difficult to recycle. Recycling must be done separately since separation of bismuth by pyrometallurgical or electrometallurgical methods is not possible so far. The tolerated Bismuth concentration limit is 5 ppm in pure Cu and 20 ppm in brass. A mixture may end up in a loss of recyclability.

If bismuth-containing copper alloys from automotive uses can and are actually separated from the copper waste stream, they may be used to directly produce new copper alloys for automotive or other uses instead of producing these alloys by mixing primary bismuth with primary copper. Whether and how far this is feasible, is not addressed above.

The reported global primary production volume for Bismuth in 2021 was 11 000 tonnes (JRC RMIS [29]). Bismuth is classified as CRM in the EU. In addition, the complete replacement of lead by bismuth would result in a tenfold increase in the demand of bismuth. For each tonne of bismuth, 30– 200 tonnes of lead would have to be produced.

In the consultants' opinion bismuth will only be a substitute for lead in applications where the resulting characteristics of the alloy due to the substitution are favourable for the application under assessment. Not all lead in all lead-containing copper alloys will be substituted by bismuth, therefore the total amounts of required bismuth will probably be much smaller than stated by the applicants. The consultants would require a more comprehensive and quantitative assessment of the arising environmental implications and potential supply chain dependencies to formulate an opinion on the practicability of bismuth as a substitute. Should this consideration result in a situation of conflicting policy objectives, it will be at the COM's discretion to decide which policy objective should be prioritised over the other.

5.3.3 Summary and conclusions

ACEA et al. request the continuation of exemption 3 for eight more years since according to them the use of lead is unavoidable in copper alloys.

In the consultants' opinion, new alloys presented in the present revision and the alloys presented in the previous revision harbour further potential of application-centered and systematic evaluations for possible substitutions.

No further substantiated evidence for the applicability or lack thereoff in automotive applications has been brought forward for the lead-free copper alloys explicitly mentioned as new and promising for further assessment in the previous revision of the exemption.

ACEA et al. further presented several new developments as promising, with currently not yet publishable results, but ongoing active developments suggesting novel findings:

- several new lead CuZn40 and CuZn42 alloys with small additions of further alloying elements
- for one tested part it might be possible to use a copper alloy with max. 0.1 % lead instead of higher content 2.5 % – 3.5 %
- some relevant applications projected to be available in new vehicles launched towards the end of 2024 and 2025

Wieland Werke presented a promising new lead free copper alloy eco SZ3® for electrical connecting parts, demonstrating good mechanical properties, corrosion resistance, corrosion behaviour, dezincification and hot formability. However further substantiating evidence towards the applicability in automotive applications is required.

ACEA et al. had previously stated that *"the challenges to face include the development of new alloys, their full characterization, the deep study of alternative alloys already available and the re-design, production and test of real components made of these new alloys."* However, the examples of the evaluation of lead-free copper alloys and their respective assessment results provided by ACEA et al. are mostly anecdotal, seem not to follow the above approach, and lack a structured, substantiated, evidence-based foundation. Explanations to why there is a lack of evidence primarily relate to the lack of time and confidentiality. The provision of unsatisfying evidence had already been criticized in previous reviews of this exemption by (Gensch et al. 2016) and (Deubzer et al. 2021) and in the eyes of the consultants has deteriorated during the current revision.

Considering the large number of applications using leaded copper alloys in the automotive industry and the even larger number of possible evaluation scenarios, it is likely that evidence supporting the necessity of using leaded-copper alloy parts will to some degree always be somewhat anecdotal. However, the evidence provided should be systematic, transparent, comprehensive, and conclusive with respect to the applicability, or non-applicability in automotive uses as it has already been pointed out in previous revisions.

ACEA et al. present a more than 50 % decrease of the amount of lead per part used in copper alloys from 2018 to 2023 via moving production technologies from machining to stemming and forming. Due to a lack of transparancy and detail a reflection of this substitution into narrowing down the scope of exemption 3 was not possible, and the base of this calculation was not presented so that the numbers are intransparent.

Examples of successful lead substitutions in the previous review by (Deubzer et al. 2021) show that a lead-free alloy which failed tests of ACEA et al. can be applied successfully in other automotive applications. (Deubzer et al. 2021) therefore suggested an application-specific approach where next to characterizing materials, applications should be characterized. In one example, ACEA et al. can be considered following this approach where they demonstrated a successful substitution and elimination of leaded copper alloys in bushings for an internal combustion engine of a vehicle via a system approach including the redesign with other materials with a high-tech coating (elimination) and the use of a lead-free copper alloy (substitution). However, the information provided by the applicants that this approach has been followed to allow systematic assessments, enable application-specific substitution and provide sound evidence where exemption 3 is still needed, was somewhat lacking transparency.

In the consultants' overall perspective, it appears that the applicants pointed out in the previous review of this exemption lead-free copper alloys which they consider as promising. In the subsequent review like in the current one, however, they do not report substantial efforts to assess whether the promising nature of these alloys would qualify them for automotive uses.

ACEA et al. highlight their step-by-step approach but cannot report with sufficient detail and substance about specific steps having been taken by their members in the past years. Given the number of vehicle producers and the large number of parts produced from lead-containing copper alloys in many different models of vehicles, there should be a large potential for such step-by-step approaches and their outcomes could be expected to be reported since the last review as evidence of compliance efforts.

The information provided appears as fragmented and anecdotal rather than the result of stringent and coordinated compliance activities. ACEA et al. put forward antitrust regulations and confidentiality agreements as obstacles, whereas it should be expected that applicants are organised in a way that supports compliance activities like the generation, collection and processing of sound evidence required for an exemption review process. In this review specifically, ACEA et al. face the situation that the review was initiated one year earlier than expected. The consultants cannot exclude that this may have affected the quality of the presented information to some degree but doubt that the earlier review is the root cause for the situation described above.

5.4 Recommendation

The applicants do not provide substantiated information on the tests they had announced to perform on several alloys in the previous review of the exemption. The earlier onset of the review of the exemption in 2024 cannot explain this gap as such tests cannot be performed within one year without adequate planning and preparation. Most of the other information presented lacks substance and conclusiveness with view to applicability in specific automotive applications. The applicants fail to provide substantiated evidence concerning their efforts and progress to substitute and eliminate the use of lead and to explain the status and prospects thereof. It remains unclear in which applications the use of lead is unavoidable. In the absence of clear evidence, the consultants cannot give a recommendation as to the continuation of the exemption according to Art. 4(2)(b)(II).

If the COM decides to continue the exemption, the consultants recommend the current wording. Reducing the maximum lead content from 4 % or narrowing the scope of the exemption cannot be justified based on the provided information and findings.

As to the review date, it is considered useful to align the next review with the review[18] of RoHS exemption III-6(c), which may result in a specification of that exemption. A parallel review, or, if this is not feasible, a review in timely proximity after the renewal of the corresponding RoHS exemption would allow exploiting possible industry spanning synergies for the previously proposed approach of characterising application/component profiles and possibly grouping of components, and ensure that the wordings of the technically similar exemptions remain aligned. While a certain share of copper-alloy applications can be expected to be different from those in electrical and electronic equipment regulated under the RoHS Directive, a large part of overlapping copper-alloy applications can be expected. Applicants are welcome to propose alternative approaches as long as they put them in a position to adequately respond and contribute sound information in future reviews of these exemptions.

Table 5-8: Recommended wording and scope of the exemption

No.	Exemption	Scope and dates of applicability
3	Copper alloys containing up to 4 % lead by weight	This exemption shall be reviewed in [YEAR]* * Remark (not part of the final exemption text): Since the COM has not yet decided the renewal of exemption III-6(c), the date should be adapted to the actual expiry date of that exemption, or with the earliest possible date in timely proximity to the review date of RoHS-exemption III-6(c). In this context, the COM might also consider setting the expiry of the exemption at a date that enables the next review of this exemption to be conducted under the revised ELV Regulation after its entry into force.[19]

If thereafter no new application-centered evaluations, providing factual, systematic, comprehensive and transparent evidence can be brought forward that demonstrate successful substitutions or comprehensibly show the unavoidability of leaded-copper alloys in automotive applications, the COM could consider a fixed sunset date for the expiration of the exemption to create a level and predictable playing field for the whole industry.

[18] (Baron et al. 2022) recommend the expiry of RoHS-exemption III-6(c) on 21 July 2026; the COM's decision is pending.

[19] Cf. the Commission proposal: https://eur-lex.europa.eu/resource.html?uri=cellar:8e016dde-215c-11ee-94cb-01aa75ed71a1.0001.02/DOC_1&format=PDF

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6 Exemption 8(e): Lead in high melting point solders

The below table shows the current wording of the exemption.

Table 6-1: Current wording of the exemption 8(e)

No.	Exemption	Scope and dates of applicability
8(e)	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)	This exemption shall be reviewed in 2024

Declarations

In the sections preceding the "Critical review", the phrasings and wordings of applicants' and stakeholders' explanations and arguments have been adopted from the documents they provided as far as required and reasonable in the context of the evaluation at hand. In all sections, this information as well as information from other sources is described in italics. Formulations were altered or completed in cases where it was necessary to maintain the readability and comprehensibility of the text.

Acronyms

Ag	Silver [chem.]
COM	European Commission
DCB	Direct copper bonding, or direct copper bonded (substrates)
EEE	Electrical and electronic equipment
HMPS	High melting point solders, i.e. solders with 85 % of lead and more
Lead-free	Not containing lead in the application in scope of exemption 8(e), also LHMPS-free
LHMPS	Lead-containing high melting point solder, i.e. solder with 85 % of lead and more
LFPAK	Loss-free package
MOSFET	Metal-oxide-semiconductor field-effect transistor
Pb	Lead [chem.]
SMA	Sub-miniature-A connector
SMB	Sub-miniature-B connector
SMC	Sub-miniature-C connector
TVS	Transient voltage suppressor
UP	Umbrella Project Working Group 7(a)

VDA Verband der Automobilindustrie (German Association of the Automotive Industry)

6.1 Background and technical information

ACEA et al. (2024b) request the continuation of the exemption in its current wording without specifying a review date.

Table 6-2:Requested wording and review date

No.	Exemption	Scope and dates of applicability
8(e)	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)	This exemption shall be reviewed in XXX

The Swedish Chemicals Agency, KEMI (2024), contributed to the stakeholder consultation expressing their support for a new wording of the exemption which specifies in what applications the exemption can be used like for example suggested by Baron et al. (2022).

6.1.1 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 by Gensch et al. (2016).

Gensch et al. (2019) reviewed ELV-exemption 8(e) and recommended to continue the exemption with the same wording. The information provided showed that the substitution or elimination of lead is still scientifically and technically impracticable in principle, but it could not be clarified whether this was true for the attach of small dies. The exemption has become due for review in 2024 and the COM had a consultation conducted,[20] and

[20] Cf. BIO IS, https://elv.biois.eu/requests2.html

ACEA et al. (2024a) answered the questions in the consultation questionnaire expressing the continued need for this exemption.

6.1.2 Summary of the stakeholder contributions

ACEA et al. (2024a) report that the automotive industry has been engaged in research on alternative materials for lead-contining high melting point solders (LHMPS), however, for three intended uses alternative technology with similar properties like lead are not yet available. Lead-free solders of metallic systems with solidus line temperature of 250°C or higher and electrically conductive adhesive systems have important disadvantages and cannot substitute for LHMPS but miniaturization of structures proceeds and brings increase of thermal and mechanical load on components, especially for components requiring long-term reliability. ACEA et al. (2024a) therefore ask to keep wording for exemption 8(e) and in addition avoid any further split of the entry into new subentries, especially if there is no technical solution for the subentries.

6.1.3 Technical description of the exemption and use of the restricted substance

ACEA et al. (2024a) list typical types and melting temperatures of solders currently (as of April 2024) used in applications falling under this exemption. As refence, it also lists types and melting temperatures of solders containing 85 % or less lead, the use of which is prohibited under the ELV Directive.

Table 6-3: Composition and melting points of lead-containing solders

Category	Solder Type	Alloy Composition (wt. %)	Melting Temperatures (Solidus Line-Liquidus Line) [C]
Lead-containing Solder	High temperature type Lead-containing solder (Falling under exemption under ELV Directive)	Sn-85Pb	226~290 C
		Sn-90Pb	268~302 C
		Sn-95Pb	300~314 C
	<Reference> Lead-containing solder Use thereof prohibited under ELV Directive	Sn-37Pb (Conventionally used)	183 C
		Sn-60Pb	183~238 C
		Sn-70Pb	183~255 C
		Sn-80Pb	183~280 C

Source: ACEA et al. (2024a)

The high melting point sof LHMPS enables, for example, their use inside components which have to survive subsequent soldering processes. Their melting point is higher than the temperatures of up to around 260 °C used in lead-free soldering processes. Their ductility makes them suitable to connect different materials with different coefficients of thermal expansion as the LHMPS can compensate part of the thermalmechanical stress *generate by temperature changes. They are ressistant against corrosion, have a good thermal and electrical conductivity, and their excellent wettability supports the soldering process resulting in reliable, high quality solder joints. (Gensch et al. (2015)).*

LHMPS with 85 % are used in several applications, typical examples being according to Gensch et al. (2015):

- *Internal electrical interconnections in components;*
- *Die attach;*
- *Plastic overmoulding;*
- *Ceramic ball grid arrays (BGAs);*
- *High power applications;*
- *Hermetic sealings;*

The below table summarises the uses and properties of lead-containing high melting point solders (LHMPS).

Table 6-4: Uses and properties of LHMPS

<table>
<tr><th>Intended use</th><th>Examples of related products</th><th>Reasons for necessity</th></tr>
<tr><td>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.</td><td>Resistors, capacitors, chip coil, resistor networks, capacitor networks, power semiconductors, discrete semiconductors, microcomputers, ICs, LSIs, chip EMI, chip beads, chip inductors, chip transformers, etc.</td><td rowspan="3">– 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.*</td></tr>
<tr><td>Solders for mounting electronic components onto sub-assembled module or sub-circuit boards.</td><td>Hybrid IC, modules, optical modules, etc.</td></tr>
<tr><td>Solders used as a sealing material between a ceramic package or plug and a metal case</td><td>SAW (Surface Acoustic Wave) filter, crystal resonators, crystal oscillators, crystal filters, etc.</td></tr>
</table>

Source: Gensch et al. (2019), ACEA et al. (2024a);

Further details as to the technical background of exemption 8(e) are provided in the review report of Gensch et al. (2015).

6.1.4 Amount(s) of restricted substance(s) used under the exemption

Based on a volume of 12.910.891 new registered vehicles in 2022 of category M1/N1 the total amount of Lead would be below 12.91 million x 1.6 g = ~ 21 t of Lead in LHMPS solder per year. The figures are based on samples currently provided (anonymized investigation) and mean value calculation.

For the last review of the exemption by Deubzer et al. (2021); Gensch et al. (2019), ACEA et al. assumed around 1 g of lead under exemption 8(e) per vehicle and 15.65 million newly registered vehicles (status 2017), resulting in around 16 tonnes of lead per year.

As reason for the increase in the volume per vehicle from 2018 to 2024, ACEA et al. (2024a) see the intensified use of electronic systems. With more electronic systems and sensors in a modern vehicle, the ongoing miniaturisation of electronics cannot completely compensate the increased demand for electronic components and use of LHMPS therein.

6.2 Justification of the requested exemption

6.2.1 Justification of the exemption by ACEA et al.

*ACEA et al. (2024a) report that since the last review of exemption 8(e) in 2018, the automotive industry has been engaged in research on alternative materials that take into account a wide range of possibilities, including additive elements in solder, conductive adhesives, and silver sintering. However, for three intended uses (*Table 6-4 *above), an alternative technology with similar ductility, strength and further physical properties as Lead is not yet available.*

ACEA et al. (2024a) provide further information as to the unavoidability of lead use which in its essence is identical to their submission for the review[21] of exemption 8(e) by Gensch et al. (2015) with an update of the link to the DA5 (Die Attach 5) activities[22], a consortium working to develop a Pb-free die-attach solution since around 2010. Die attach is just one of the uses of LHMPS under one of the intended uses specified in the above table.

ACEA et al. (2024a) report that the DA5 evaluated a variety of new materials from leading global suppliers of solders, adhesives, Ag sintering and transient liquid phase sintering (TLPS) materials. The DA5 evaluations recognize continuous improvement in the evaluated materials from 175 materials from more than 17 suppliers over the past 13 years. About 50 of those materials were selected for extensive testing by DA5 member companies. But even the best of these materials do not meet the DA5 requirements for quality, reliability and manufacturability. This research has shown that the substitute bonding technologies are not at least as good as the traditional high melting Pb solders. ACEA et al. (2024a) refer to the DA5 presentation[22] for more information. Many solutions are still under development, constantly being revised and strictly guarded by suppliers under non-disclosure agreements. They are not available yet for mass production.

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[21] Cf. Sections 4.1.2 and 4.2.1 (page 8 et sqq.)

[22] Cf. DA5, https://www.infineon.com/dgdl/DA5+Customer+Presentation+23112023.pdf?fileId=5546d4616102d26701610905cfde0005

ACEA et al. (2024a) conclude from the above information that the use of lead in the application addressed under exemption 8(e) is still unavoidable. As far as they know, there is no promising material or alternative technological approach to substitute or eliminate the use of lead. Therefore, the automobile industry request the continuation of the current exemption.

6.2.2 Stakeholder contribution of KEMI

KEMI (2024) do not know when lead is required in solders in vehicles. However, to avoid any unclarities they support a new wording of the exemption which specifies in what applications the exemption can be used. With such a wording of the exemption, for example the suggestion by the consultant for the exemption in the RoHS Directive[23], the enforcement authorities will be able to stop products with more than 85 % lead that should not benefit from the exemption, from being placed on the market.

The Swedish Chemicals Agency has many years of experience as a market surveillance authority to conduct enforcement activities on the RoHS Directive and especially on the exemption 7a "Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)". With the current wording they cannot stop products with more than 85 % lead from being placed on the market even though it is obvious that there is no need for high melting temperature type solders.

The products that they have this problem with are typically cheap non-complex products with a short lifespan. Only in 2023 they have analysed seven products that contain more than 85 % lead in solders and to their knowledge should not benefit from this exemption.

6.2.3 Environmental, health and safety, and socioeconomic impacts

ACEA et al. (2024a) point out that the solder in most cases is encapsulated in the components and that during component use in vehicle a release of lead can be excluded. In ELV utilization procedures, they expect that most of the lead will enter metal recovery routes. They claim that any substitute and the processing chemicals, needed for their application, should have clear evidence for reducing environmental loads. In this sense the lead-free criterion should align with further targets of the European chemical policy and best available technology approach.

ACEA et al. (2024a) state that, if a new applicable substitute for LHMPS will be found, the economic implications of changing designs and validation will be very high and time consuming.

[23] Cf. Baron et al. 2022, and Deubzer et al. 2024.

6.2.4 Roadmap towards substitution or elimination of the restricted substance

ACEA et al. (2024a) put forward that technology development and production technologies for semiconductors and electronic components are not a core competence of the automotive industry. As an end user, the automotive industry and OEMs specify the demands that electronics components and systems have to fulfil in a vehicle over service life. The requirement of availability of electronic components validated for automotive uses over such a long time, limits the offer by their producers. Suitable materials or technologies which could be used as generic alternatives are missing.

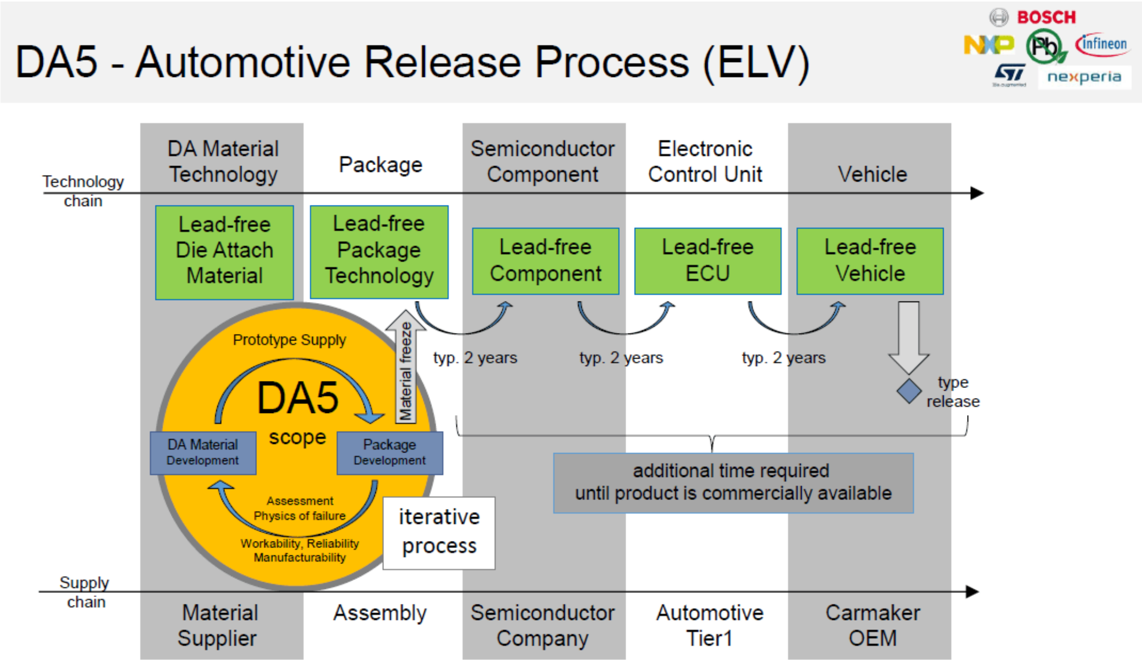
They claim the automotive industry is continuously researching alternatives, however currently no lead-free alternative technology can be predicted accurately for the short term. If they will be available in the future, they estimate that validation and industrialisation into volume production of vehicles takes at least around 6 years. Conversions cannot begin until lead-free alternatives are developed and perfected by material producers, processes and equipment are installed and implemented within component manufacturing lines, components are qualified, and those components are made available to automotive Tier1s and OEMs for:

- *development of*
- *assessment of, and*
- *replacement with alternative products.*

ACEA et al. (2024a) express the appreciation of the automotive industry of the DA5 initiative and its high engagement to find solutions. The DA5 consortium is working with selected material suppliers on the development of an appropriate replacement for lead solder (DA5 scope). The properties of the needed die-attach material are specified by the DA5 (material requirement specification) and provided to the material suppliers. Selected material suppliers offer their materials, which are evaluated by one of the DA5 companies together with the supplier. The detailed results are discussed with the material suppliers and all DA5 companies on a regular basis in face-to-face meetings. The results lead to further optimizations of the materials (development loop). The combined results are published by DA5 in their customer presentation. Based on current status, DA5 cannot predict a date for customer sampling as no suitable materials have yet been identified.

ACEA et al. (2024a) take reference to the generic DA5 automotive release process scheme displayed in the below figure.

Figure 6-1: DA5 Automotive Release Process (ELV)



Source: DA5 referenced in ACEA et al. (2024a)

6.3 Critical review

6.3.1 General aspects

Time available for answering to questions

ACEA et al. state in their answers that the granted time periods for answering questionnaires made it very challenging to inform all participating automotive industry stakeholders along the global supply chain. Dissemination, translation into national languages and retranslation and company internal distribution and discussions as well as the consolidation of answers or clarifications of misunderstandings are time consuming.

ACEA et al. (2024d) state that they are continuing to gather all necessary information and insights so that additional information may follow in the weeks after their initial response.

The consultants welcomed this approach for all questionnaires and encouraged the applicants to submit further relevant information after the submission of answered questionnaires. No additional information was received in the following weeks – although only four working days in case of the last questionnaire - until the finalisation of the review.

Confidentiality of crucial information

ACEA et al. approach the review with presenting DA5 activities as only more detailed application-specific LHMPS substitution/elimination research (die attach), while all other application-specific research is claimed to be organised on a business-to-business research which is covered by non-disclosure agreements and thus confidential, or could not be collected and discussed due to antitrust rules.

As a basic rule, applicants for exemptions need to provide substantiated and detailed evidence that the use of lead is still unavoidable, which implies information of where and how the restricted substance still needs to be used in the coming years. If confidentiality and other agreements prevent any insights into the current status or upcoming developments, applicants must find ways to be in the position that they can substantiate their exemption requests. The review process relies on transparent and sound evidence on which the consultants build their recommendations. Information about ongoing activities or results that are not sufficiently detailed to allow their assessment with respect to the unavoidability of lead use with reference to confidentiality agreements cannot be considered for the recommendation as to the continuation of the exemption.

6.3.2 Substitution and elimination of lead: Research and development efforts

Compliance activities since the last review

*ACEA et al. (2024a) claim that since the last review of exemption 8(e) in 2018 by Gensch et al. (2019), the automotive industry has been engaged in research on alternative materials but that three "intended uses" remain (*cf Table 6-4*) for which the use of lead is still unavoidable*.

ACEA et al. had submitted this table already in the review of this exemption by Gensch et al. (2015). The number and character of "intended uses" has not decreased or changed since 2013, when the table was introduced into the review process. The applicants were requested to provide more information about this research conducted by the automotive industry since 2018, i.e. for which uses of LHMPS, what kind of tests they applied, their outcomes, what they concluded and learned from it and what the next steps will be as follow-up of their findings.

ACEA et al. (2024c) regret having given the impression to the consultants that the automotive industry is the same as vehicle producers and take the opportunity to inform the consultants that the term automotive industry is not limited to vehicle producers only. The submission consigning associations CLEPA and JAPIA directly represent the automotive supply chain and as the VDA is associated to ACEA even VDA[24] *members like BOSCH, Siemens, Infineon or ST microelectronics are participating. The majority of the DA5 consortium members are also members of automotive associations so that it is comprehensible that the DA5 results are used in the submission.*

ACEA et al. (2024c) also suspect that there is a difference in the understanding of the term research in this context. They ask to consider the term "research" in this context as

[24] VDA: German Association of the Automotive Industry

investigation on activities of their partners in the automotive supply chain, especially the DA5 consortium members and especially in order to discover new information.

The applicants notice that, besides the DA5 activities to avoid the use of lead in die attach, the applicants do not report any research efforts as to finding lead-free alternatives to LHMPS. There is no evidence either that lead-free solutions for die attach, once available, would be viable for all other uses of LHMPS listed in Table 6-4 on page 68. Even though the properties of LHMPS accommodate all these needs, with variations in the lead content, the other LHMPS uses would not require all these properties to the same degree. Still, ACEA et al. seem to follow the drop-in replacement[25] and 1:1 substitution approach[26] that has been practiced in the past 20 years. *ACEA et al. (2024a) confirm that as far as they know, there is no promising material or alternative technological approach.*

It seems that a solution is not foreseeable yet even though, for die attach, the DA5 had announced in the 2018 review of exemption 8(e) by Gensch et al. (2019) that *in the next decade, more and more devices using newly available lead-free materials will enter the market for limited applications.* Meanwhile, 50 % of this decade have already passed. The applicants were requested to provide an update on the status of the DA5 activities in the light of their 2018 statement.

ACEA et al. (2024e) point out that the current status and the progress achieved is periodically reported by the DA-5 consortium. They are pleased to have received from their partners the information that the DA-5 information should be considered in its full context and refer to the Conclusion II of the latest DA5 project customer information displayed in Figure 6-2*.*

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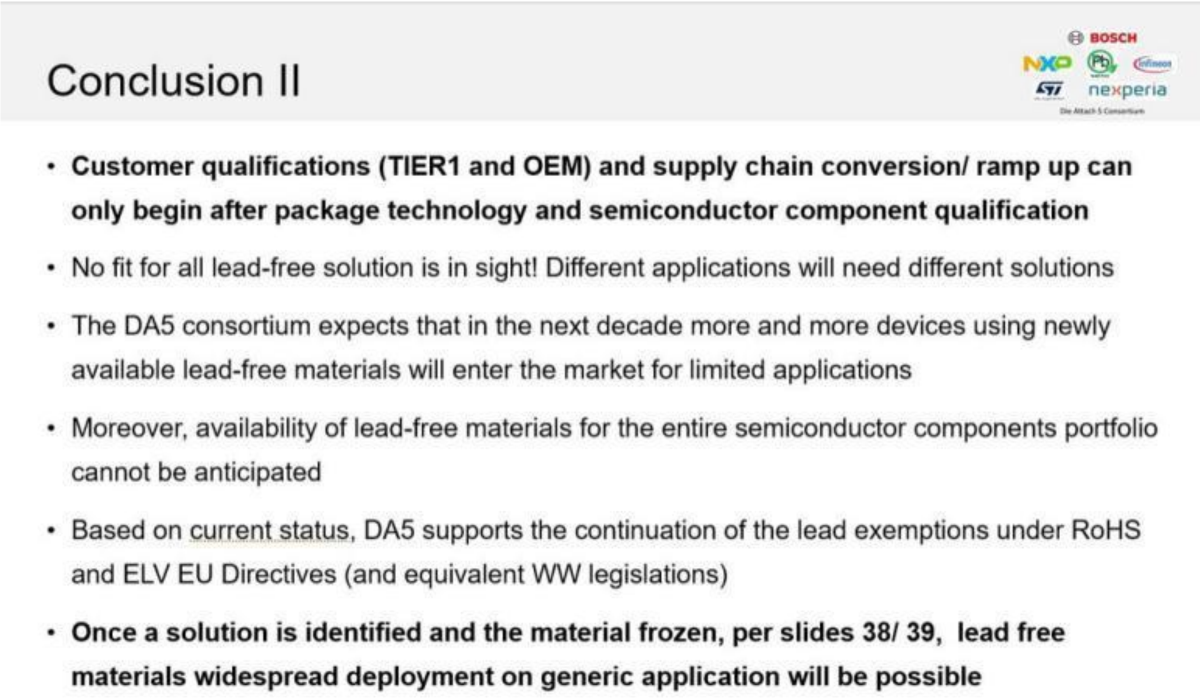
[25] Drop-in substitution approach: Search for a material that can replace LHMPS without any changes in processing or design of the component in which it is applied.

[26] 1:1 substitution approach: In this case, research for one lead-free substance that shall replace LHMPS in all its manifold uses, instead of developing materials that are tailor-made for one or a group of uses of LHMPS.

Figure 6-2: Screenshot of the current DA5 customer presentation



Source: DA5 in ACEA et al. (2024e)

According to ACEA et al. (2024e), the explanation given for that what was meant by “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” is the following: The sentence is only one on the conclusion slide (see above) and is referring to new products. The DA5 never published a roadmap and ACEA et al. can’t publish a roadmap since there is no solution for the conversion of legacy products available.

The consultants have not assumed or interpreted the DA5 statement in the sense that it might apply to old products, i.e. models of components that have been previously produced with LHMPS and would now be produced without in otherwise identical designs. The relevant DA5 statement is still the same in the above recent DA5 presentation like the one presented around six years ago in the previous review of this exemption, which is not necessarily inconsistent, as new devices can become available over more than one decade.

Roadmap and alternative approaches in research towards lead-free solutions

Overall, looking at the provided information, the efforts in the past two decades seem to have been strongly focused on lead-free solders or alternative bonding technologies like e.g. sintering, for the bonding of components whose designs remained unchanged in terms of types of materials used, geometries and possibly other design aspects.

An example of a different development approach with a holistic approach are flip chip packages (FCPs). Two decades ago, FCPs (exemption 8(g)(ii)), could not be manufactured with lead-free solders. Since then, there has been progress so that the respective exemptions (RoHS-exemption 15(a)) in 2016 and later ELV-exemption 8(g)(ii) could be established with a restricted scope compared to the initial exemptions. Meanwhile, there has been further progress so that these exemptions probably no longer reflect the status of lead-free technology. ACEA et al. even state in the information submitted to the stakeholder consultation that exemption 8(g)(ii) may no longer be required for new type-approved vehicles from 2030 on. This progress is assumed to be, among other, the result of adaptations of component designs (different materials, geometries, …) aligned and adapted to accommodate the properties of, in this case, mainly lead-free solders.

The applicants were asked whether there are any efforts of the DA5 and beyond to adapt component/product designs to enable lead-free solutions where LHMPS was used in the past, similar to the approach that resulted in lead-free FCPs. In the DA5 customer presentation referenced by ACEA et al. (2024a), (2024c)[22], there is a strong focus on alternative bonding materials and techniques. More holistic approaches like redesign aspects to accommodate the specific properties of lead-free materials are not mentioned.

ACEA et al. (2024c) confirm the viability and success of this approach in the automotive and military industry stating that two decades ago, the dominating opinion was also that FCPs are not suitable for automotive or military applications. The opinion against the use of lead-free FCP in military applications was yet ending recently with revision of MIL-PRF-38535 in November 2022. Here the development e.g. of new underfill materials and many other little steps in technologies and packaging design in sum after many years resulted in new options.

ACEA et al. (2024c) deem possible that individual companies are taking such approaches, but because this involves the confidentiality of each company, such as product specifications and design know-how, relevant information is not disclosed. Due to compliance rules any detailed commenting on future technologies and market perspectives are excluded.

The above statement reinforces the consultants' impression that the appropriateness of the applications organisational form is of limited use for exemption review processes.

ACEA et al. (2024c) are, however, confident to report further progress in some years. Because a design-based approach at a component level is generally conceivable, manufacturers of electronic components and semiconductor component are likely to be doing something about it. However, they speculate that the reason why no alternative compatible with the current product is proposed is either because it is under development or because there is essentially no technical prospect for its establishment.

ACEA et al. were asked why they have to "speculate" about the recent and foreseeable developments if they could simply ask their suppliers which, according to ACEA et al. (2024c), are part of the automotive industry being represented in their consortium applying for the continuation of the exemption.

ACEA et al. (2024e) note a sensitive reaction to the used word ´speculate´ and ask to understand that not all authors are native speakers. They explain the intended meaning of the word ´speculate´ should be understood as "assume" and refer to question 4(b) of the questionnaire, which however, provides general information on the development process.

The above reply does not clarify why ACEA et al. cannot ask in the automotive supply chain to obtain knowledge about the situation, and it does not answer the core question concerning approaches taken to achieve compliance with the ELV Directive without depending on exemption 8(e). If such requests are not possible due to antitrust and confidentiality reasons, the applicants must organise themselves differently to be in a position to provide essential evidence justifying the continuation of the exemption.

6.3.3 Substitution and elimination of lead: Availability of lead-free components

Use of (conductive) adhesives as LHMPS replacement

ACEA et al. (2024e) point out new products coming to the market with e.g. standard adhesives (Pb-free but with lower electrical/ thermal requirements).

Concerning the use of such (conductive) adhesives, ACEA et al. and the DA5 stated in the previous review of this exemption by Gensch et al. (2019) that *"Low thermal glues have been used for semiconductor die attach over many decades by the entire semiconductor industry, incl. DA5." "[…] electrically conductive adhesive systems have problems and thus cannot substitute lead HMP solders."* The use of (conductive) adhesives is thus not a new development, and the above are not examples of successful LHMPS substitution. The applicants were requested to explain their above statement of LHMPS substitution with adhesives in the light of their statement expressed in the earlier review.

ACEA et al. (2024f) confirm that the consultants' understanding is generally correct in light of the general theory, but ACEA et al. do not think that all cases apply to it. Automotive electronic components are used in various applications. Each application has different operating conditions, environmental requirements (e.g. such as moisture impact) and required durability. In addition, in terms of thermal fatigue design, the properties of the surrounding structural members also affect. The case ACEA et al. (2024f) referred to in the answer to the 3rd Questionnaire is in the research and development stage, and is in the stage before evaluating the feasibility of the application. However, they believe that the application of conductive adhesives as a specific solution is possible when favourable conditions such as application requirements and part design are combined to enable the use of conductive adhesives.

The consultants understood in the past reviews that adhesives have already been used where their properties allow their use but cannot exclude, in the absence of further information, that their application fields could have been extended due to research and resulting scientific and technical progress. The actual status of such novel uses however seems to be in some timely distance to *new products coming to the market with e.g. standard adhesives*. ACEA et al. do not provide further details or examples of glued products whose development is sufficiently advanced for their coming to the market in the near future.

LHMPS-free MOSFETs and Ag-sintered components

ACEA et al. (2024c) received from the supply chain information about new circuit modules developments: MOSFET with DPAK packages using ELV exemption 8(e) have been replaced by MOSFET with LFPAK packages without ELV exemption 8(e). For functional reasons (e.g., transient voltage suppressor (TVS) – function), however, not all *diodes with SMA / SMB / SMC packages using ELV exemption 8(e) can be replaced by packages without ELV Exemption 8(e).*

In the first instance, the question arises why the above information was not provided and discussed as to its usability in automotive applications in the consultation questionnaire already.

A short internet investigation by the consultants showed LFPAK MOSFETs offered by a component manufacturer.[27] The applicants were asked since when these LHMPS-free components have been available on the market already.

ACEA et al. (2024f) regret to inform that they neither have a register of electronic components and their market data, nor information about their availability in different markets. Regarding the manufacturer name, they reassure that their investigation was conducted with consideration given to competition law and that information belonging to a specific company such as the manufacturer name and model is kept confidential.

Another internet investigation by the consultants showed that LFPAK MOSFETs are clip-bond packaged power MOSFETs that have been available on the market for 20 years already.[28] It is unclear whether all LFPAK MOSFETS are produced without LHMPS, and it cannot be followed that ACEA et al. do not know which – and since when - LHMPS-free LPAK MOSFETS are on the market, after highlighting them as a successful example of LHMPS substitution.

ACEA et al. explain that LHMPS-free LFPAK MOSFETS cannot replace all packages using LHMPS. The consultants asked the applicants to specify the applications in which the LHMPS-free packages can replace those relying on exemption 8(e).

ACEA et al. (2024f) confirmed that in the reported application, it was possible to apply a lead-free LFPAK semiconductor, fulfilling the technical requirements. In the development of a new circuit module, when a MOSFET of a new specification is selected, LFPAKs that satisfy the required specification of the circuit module are on the market. This simply means that they are selected as a result. We would like to underline that each one of them is an individual solution and therefore fails be the general solution expected by the consultant. For this reason, they kindly ask to understand that it is impossible to define performance parameters that determine whether lead content is required.

The above information suggests on the one hand that the application field of the LHMPS-free LFPAK MOSFETs cannot be described. On the other hand, ACEA et al. state that (LHMPS-free) LFPAKs are selected if they satisfy the required specification of the circuit module, which means that such specifications exist, which is contradicting the first statement. Possibly, the individual parameters forming the specification may be interdependent, and the combination of applicable parameters may differ depending on the specific application cases, which would, if correct, dissolve the contradiction. The issue could not be discussed further with the applicant due to the limited time available for the review.

[27] Nexperia, https://www.nexperia.com/products/mosfets/family/LFPAK88-MOSFETS/#/p=1,s=0,f=,c=,rpp=,fs=0,sc=,so=,es=

[28] Nexperia: https://www.nexperia.com/promotions/lfpak-20-years

Elimination of LHMPS by silver-sintering

Upon repeated request, ACEA et al. (2024e) also highlight high performance products coming to the market with silver (Ag) sinter solutions (pressure assisted Ag sintering on DCB[29]). But these Ag sinter solutions can't be used for legacy products since they use Cu lead frames and the very harsh connection of the Die to the Cu lead frame will lead to reliability issues due to CTE mismatch of the silicon and the Cu. ACEA et al. (2024e) conclude that there are Pb-free solutions available and used for dedicated (limited) applications, which can't be used for all products. The DA5 continue the common development work with the material supplier to increase the usability of the materials. But there is no guarantee that there will be a common solution in the next years.

The applicants were invited to provide more details about these lead-free high-performance products, i.e. which types of products, since when they have been available, and how/where they have been used.

According to ACEA et al. (2024f), their answer needs to be incomplete due to the given time limit, as answers from supply chain and other experts take more time than granted. There is no obligation to report that parts are produced with sintering technology. The important point here is that the reliability requirements are met.

The time available to answer the question was actually limited. In the consultants' view, however, information describing the status of lead substitution and elimination is an essential part of applicants' preparations for an exemption request. It should therefore be available at the beginning of the review, which has been known for several years to be imminent in 2024, instead of only starting to collect it from the supply chain upon request. Also, the information should have been provided during the consultation period already instead of requesting the continuation of the exemption with its current wording justified with the almost identical information that was provided in the previous reviews.

ACEA et al. (2024f) describe that individual technical solutions with Ag sintered joints had been applied component-specifically in the last years. There are numerous publications in scientific and expert journals. The silver sintering technology however requires further development. ACEA et al. (2024f) reference a webpage of Fraunhofer IZM[30] as evidence that that silver sintering has yet some specific applications, but that the IZM currently takes research and development efforts to enable a use in large-surface, also for cooling bodies, to the reduction of process pressure, to enable sintering of SMD [surface-mount devices, the consultants] *compatible elements and to develop sintering processes suitable for copper surfaces.*

Applicants must provide information in a degree of detail and with supporting evidence which in their view is appropriate to substantiate the continued need for an exemption. It is the consultants' task to critically review this information, not to search and collect this information from various publications or webpages and evaluate their relevance for specific applications in the automotive sector. Further, the consultants did not question the need for further research for Ag-sintering as LHMPS replacement but requested

[29] DCB: Direct copper bonded (substrate)

[30] Cf. Fraunhofer IZM, https://www.izm.fraunhofer.de/en/abteilungen/system_integrationinterconnectiontechnologies/leistungsangebot/prozess-_und_produktentwicklung/silber-sintern.html

information about Ag-sintered components which the applicants announced to be coming to the market or being used already. Such information was not provided.

Qualification status of LHMPS-free components for automotive use

The information discussed in previous sections does neither provide nor allow any conclusions as to when LHMPS-free components or even circuits will actually come to the market for automotive uses, or whether and in which uses those that are in the market already (LFPAK MOSFETS) could replace components with LHMPS. *ACEA et al. (2024c) stated that the long-term reliability of lead-free components under the harsh environmental conditions of use in vehicles need to be assessed and qualified according to automotive specifications (e.g. AEC-Q100).*

To obtain more insights concerning the LHMPS-free components mentioned by ACEA et al., they were asked to specify the relevant automotive qualification standards besides AEC-Q100, and whether any of the above-mentioned or other LHMPS-free components passed these tests and are thus principally qualified for automotive uses.

ACEA et al. (2024f) reply that standards such as AEC-Q100 are quality standards for ensuring the reliability of automotive electronic components. This standard is intended for electronic component manufacturers to meet the requirements for automotive electronic components. It also specifies various test requirements and requirements. Automotive OEMs, on the other hand, have established their own test standards based on vehicle operating conditions and operating environments, in addition to testing based on the above standards. During the previous review in 2018 the following examples were presented:

Answer for question b:

There is still no generic evaluation possible. AEC-Q100 and AEC-Q101 test will not meet OEM environmental test requirements.

OEM test procedure is focused on validation of complete electronic units by powered temperature cycling (for extended requirements > 1000 cycles) and powered high temperature storage test (>> 2000 hrs).
Thermomechanical loads, temperature gradient and heat dissipation is specific for each electronic unit.

Service life specification for e.g. German OEM 1:

Service life	15 years
Driving operation	8000 hrs
Mileage	300,000 km
Charging operation	30,000 hrs
Pre-conditioning	3000 hrs

For the future shall be additionally implemented:

OnGrid parking	67,000 hrs
OffGrid parking	23,400 hrs

Temperature range -40 degC to max. 150 degC

Regarding the certification of components, ACEA et al. (2024f) ask to refer to the other questions of the questionnaire, which describe their view on substitution.

The above answers of ACEA et al. (2024f) do not address and hence do not answer the questions. The referred other questions of the questionnaire do not contain relevant information either for this context. The consultants conclude from this that ACEA et al. are not in the position to provide information as to the relevant standards – unless there are only AEC-Q100 and AEC-Q101 – and which LHMPS-free components or modules are qualified according to these relevant standards. This situation was experienced in a former review already[31] in the context of flip chip packages. At least some of this information is available on the internet[32], and although it might be anecdotal, the qualification status of components for automotive applications seems not to be confidential. It should be feasible for an international consortium of vehicle manufacturers and their suppliers to provide such details, or otherwise provide a sound, technically plausible explanation why such information nevertheless is not available in sufficient completeness.

ACEA et al. (2024f) state that they had less than 8 days to answer the question, and that they may receive further substantial input.

The consultants confirm that the time to reply was limited. Like in other contexts of lacking time raised by the applicants, the consultants raise doubts that this was the root cause in answers are insufficient. Considering that the above standards, according to ACEA et al., are gatekeepers for the principal qualification of LHMPS-free – as well as of all other – components for automotive uses, the consultants wonder how ACEA et al. can apply for the continuation of exemption 8(e) without having investigated and assessed which LHMPS-free components are qualified for automotive use. In the consultants' opinion, this information reflecting the scientific and technical status of lead substitution or elimination would have had to be collected as the base for the continuation request already, not at first upon the consultants' request. It has been known for years that the exemption will be due for review in 2024.

The consultants conclude that essential information is missing to substantiate the applicants' claim concerning the unavoidability of lead use in all applications of LHMPS according to Art. 4(2)(b)(II).

31 Cf. Gensch et al. 2015, page 55 et sq.

32 Cf. Nexperia, https://www.nexperia.com/products/mosfets/family/LFPAK88-MOSFETS/#/p=1,s=0,f=,c=,rpp=,fs=0,sc=,so=,es=; the component is Available in both automotive AEC-Q101 and industrial grades

6.3.4 Scope and wording of exemption 8(e)

Consideration of the recommendation for RoHS-exemption III-7(a) by Baron et al. (2022).

Baron et al. (2022) recommended to define the specific uses of LHMPS for exemption III-7(a) of the RoHS Directive, the technical equivalent to ELV-exemption 8(e). The below table reflects their recommendation.

Table 6-5: Recommended rewording of RoHS-exemption III-7(a)

Exemption formulation 7(a)	Duration
Lead in high melting temperature type solders (i.e., lead-based alloys containing 85 % by weight or more lead) (*excludes those in the scope of exemption 24)*	For all categories except applications covered by point 24 of this Annex, expires on 21 July 2024.
Lead in high melting temperature type solders (i.e., lead-based alloys containing 85 % by weight or more lead) when used for the following applications (excludes those in the scope of exemption 24): *I) for internal interconnections for attaching die, or other components along with a die in semiconductor assembly with steady state or transient/impulse currents of 0.1 A or greater or blocking voltages beyond 10 V, or die edge sizes larger than 0.3 mm x 0.3 mm* *II) for integral (meaning internal and external) connections of die attach in electrical and electronic components, if the thermal conductivity of the cured/sintered die-attach material is >35W/(m*K) AND the electrical conductivity of the cured/sintered die-attach material shall be >4.7MS/m AND solidus melting temperature has to be above 260°C* *III) In first level solder joints (internal or integral connections - meaning internal and external) for manufacturing components so that subsequent mounting of electronic components onto subassemblies (i.e., modules or sub-circuit boards or substrates or point to point soldering) with a secondary solder does not reflow the first level solder. This item excludes die attach applications and hermetic sealings* *IV) In second level solder joints for the attachment of components to printed circuit board or lead frames:*	Applies to all categories except applications covered by point 24 of this Annex, expires on 21 July 2026.

Source: Baron et al. (2022)

The applicants were asked whether they can think of any automotive LHMPS applications that would not be covered by the scope of the above recommendation.

ACEA et al. (2024a) put forward that they do not have the necessary technical information or knowledge to determine whether all the solder applications are listed by subdivision of the exemption wording recommended for RoHS-exemption III-7(a). They leave the technical decision to the EEE industry. ACEA et al. (2024a) are aware that the Umbrella Project (UP) has taken a stand against any subdivision of the exemption wording as described in section 10.6.2 of the consultation report of Baron et al. (2022). UP are highlighting that several applications might exist that are not covered by the subdivided wording of the exemption which the consultants recommended as the LHMPS materials are used in a huge variety of applications. They assume that any split will enact legislation, which will not be implementable and will cause increased administrative burden, only. They also raise some other concerns. ACEA et al. (2024a) confirm that the automotive industry has the same position like the Umbrella Project.

Actually, UP express the above concerns during the review of exemption III-7(a) by Baron et al. (2022). They reconfirm these concerns in a follow-up review of exemption III-7(a) by Deubzer et al. (2024) for EEE of categories 8 (medical devices) and 9 (industrial monitoring and control instruments). Deubzer et al. (2024) concluded that the above recommendation may not cover all uses of LHMPS. They recommend reviewing exemption III-7(a) for all categories of EEE in 2026 as recommended by Baron et al. (2022) to either complement the exemption scope to cover all uses of LHMPS, or to give the EEE industry an opportunity to suggest a better approach for defining the scope.

Rewording of the exemption to exclude non-electronic/electrical uses of LHMPS

ACEA et al. (2024c) mention that in the past for brazing of metal components and for car body repair purposes, LHMPS may have been in use. At their knowledge the automotive related use of LHMPS within the EU is since years limited to electrical and electronical applications.

The current exemption 8(e) would still allow such uses since its scope is open for LHMPS uses outside electrical and electronics applications. As exemption scopes should reflect the scientific and technical capability to avoid the use of lead according to Art. 4(2)(b)(ii), the exemption scope should be adapted to exclude LHMPS use outside electrical and electronic applications. Otherwise, even if currently not practiced, such uses of LHMPS would still be legal.

The consultants therefore proposed the below wording specifying the scope with the “intended uses” of LHMPS in Table 6-4 and potentially excluding LHMPS-free components, and asked ACEA et al. to comment on it.

Table 6-6: Potential amendment of exemption wording with specified scope

No.	Exemption	Scope and dates of applicability
8(e)	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) used in electrical and electronic applications a) for internally combining (i) a functional element with another functional element; (ii) a functional element with non-functional elements like wires, terminals, heatsinks, etc. b) for mounting electronic components onto sub-assembled modules or sub-circuit boards c) as a sealing between a ceramic package or plug and a metal case [This exemption does not cover the use of lead in high melting temperature type solders in MOSFETS …]	This exemption shall be reviewed in [2024 + X]

ACEA et al. (2024f) at first emphasize that at their state of knowledge there is missing evidence for any automotive industry-related cases that violate Exemption 8(e). They disagree with the extended wording proposed by the consultants.

The consultants agree that there is no evidence of abuse of the exemption. Exemptions are, however, updated periodically to reflect the scientific and technical progress, not to react on the status of exemption abuses. Amendments of exemptions therefore do not require evidence for their abuse but shall adapt wordings and scopes to reflect the state-of-the-art unavoidable uses of restricted substances.

ACEA et al. (2024f) elaborate that Table 6-4 *is designed to make the content of the "Intended Use" more clearly understood. It uses concrete expressions as much as possible to refer to parts and manufacturing processes. The table is not an exhaustive list of all cases where exemption 8(e) is actually used. The LHMPS materials are used in a huge variety of applications. Even a thorough examination of the supply may be incomplete.*

ACEA et al. have been using Table 6-4 for more than 10 years already[33] to explain the uses of LHMPS, and ACEA et al. (2024c) confirm that *due to their knowledge, the intended uses listed in the table cover all known applications currently applied.* The three[34] intended uses were reflected in the recent review of the corresponding RoHS exemption III-7(a) by Baron et al. (2022) based on the submissions of the Umbrella Project who ACEA et al. reference as source as well. The consultants cannot follow the

[33] Cf. Gensch et al. 2015, table 4-2 submitted by ACEA et al. in 2013.

[34] Under RoHS, applicants indicate four uses of LHMPS. The fourth one is, however, not relevant for automotive applications.

argumentation that the three defined intended uses should no longer be complete, or, if this statement is correct, why the table has not been updated in the past more than 10 years to integrate LHMPS uses outside the current three ones. It is in the consultants' view reasonable to assume that a consortium of EU, Japanese and Korean vehicle manufacturers and their suppliers would be in the position to collect and have such information available for an exemption review. The consultants are of the opinion that the applicants' arguments against this wording are not substantial and consider the proposed wording a viable option for the case that the continuation of the exemption can be recommended in line with Art. 4(2)(b)(II).

ACEA et al. (2024f) deem beneficial introducing a subentry for MOSFETs, initially to get more detailed information on component level. In a next step then it may be possible to identify the applications where and by when the scope can be narrowed. Such an approach at their opinion requires to be aligned with RoHS in parallel. Under current regulations, the wording of RoHS exemption 7(a) is the same as that of ELV exemption 8(e). If the two wordings are different, supply chain disruptions are to be expected.

ACEA et al. (2024f) also reference the review of RoHS exemption III-7(a) for EEE of category 9 and 11 where Deubzer et al. (2024) recommended the renewal of the exemption for categories 9 and 11 with the current wording, including expiry dates aligned with recommendations of Baron et al. (2022) for exemption III-7(a) for all categories of EEE, without the suggested sophisticated subentries (cf. Table 6-5*).*

Therefore, ACEA et al. (2024f) propose maintaining consistency. They are also aware of the approach to address the concerns of KEMI and present the below proposal on how this issue could be solved.

Table 6-7: Wording of the exemption 8-series proposed by ACEA et al.

	Materials and components	Scope and expiry date of the exemption	To be labelled or made identifiable in accordance with Article 4(2)(b)(iv)
8.	Lead in solders or in coatings of electrical and electronic applications as specified in the following subentries		
8(a).	Lead in solders to attach electrical and electronic components to electronic circuit boards and lead in finishes on terminations of components other than electrolyte aluminium capacitors, on component pins and on electronic circuit boards	Vehicles type approved before 1 January 2016 and spare parts for these vehicles	X
…			
…			
8 (e)	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)	(2019) (1) This exemption shall be reviewed in 2024.	X
…			

Source: ACEA et al. (2024f)

The consultants welcome the initiative of ACEA et al. to create a mechanism to obtain more information on lead use on component level for MOSFETs, or also for other components like silver-sintered or glued ones. This objective cannot be achieved with the exemption architecture proposed in Table 6-6, which also fails to address the concerns of KEMI (2024) who *support a new wording of the exemption which specifies in what applications the exemption can be used.*

On the positive side, the proposed approach excludes the use of LHMPS in uses outside electrical and electronic components, modules or devices. The proposal is also in line with the consultant's approach followed in the past years to parallelise or at least approximate wordings of technically equivalent exemptions of ELV Annex II and RoHS Annex III. The applicants refer to the last review of RoHS-exemption III-7(a) for cat. 9 industrial monitoring and control instruments and for category 11, in this case specifically (parts for) combustion engines used in devices that are considered electrical and electronic equipment in the scope of the RoHS Directive, i.e. in equipment which is in parts close to automotive applications. In this review, Deubzer et al. (2024) recommend to renew exemption 7(a) until 2026 in the current wording for cat. 9 and cat. 11 but with the focus to thereafter specify the exemption scope for all categories of EEE as proposed by Baron et al. (2022) (cf. section 1.3.4 on page 82), or following an alternative approach proposed by stakeholders. The consultants saw the opportunity that all relevant stakeholder groups along the supply chain and their expertise can be involved to either further elaborate the recommendation of Baron et al. (2022), or to present a different approach. The consultants also recommended to add the requirement proposed by KEMI during that review that the use of LHMPS needs to be specified and justified in the technical documentation.

As an option, this approach could be followed for exemption 8(e) as well, which would imply a review in parallel or at least in timely proximity of exemptions 8(e) and III-7(a). ACEA et al. mention in several contexts that they do not have the expertise or access to knowledge to answer certain detailed technical questions but refer to the supply chain and the EEE industry. This proceeding could hence open a window of opportunity to involve all stakeholders and their expertise also in the review of exemption 8(e) given the situation that there is a large overlap of the supply chains in particular on the electronic component and module level, where most of the LHMPS is used. As it can be assumed that exemption III-7(a) will be modified in this next review, this approach would also avoid that exemption 8(e) and III-7(a) develop in different ways, or at least limit the time where their wordings and scopes are different.

For the case that the exemption can be recommended to be continued in line with Art. 4(2)(b)(II), the consultants suggest prioritising parallel wordings of exemptions 8(e) and III-7(a) for easier communication in the supply chain, and to address the concerns of ACEA et al. as to supply chain interruptions in case of diverging wordings. The wording proposed by ACEA et al. in Table 6-7 should be adopted, and the next review of exemption 8(e) should be scheduled in alignment with the expiry date of the renewed RoHS-exemption III-7(a), foreseeably[35] in 2026.

6.3.5 Environmental, health, safety and socio-economic impacts

ACEA et al. (2024a) point out that the solder in most cases is encapsulated in the components and that during component use in vehicle a release of lead can be excluded. In ELV utilization procedures, they expect that most of the lead will enter metal recovery routes.

[35] The COM's decision as to the renewal of exemption III-7(a) is still pending (status July 2024).

It must be highlighted that Art. 4(2)(b)(ii) requires the substitution/elimination of restricted substances unless their use is unavoidable. This applies in first instance regardless whether the substance is encapsulated and/or recycled (see also the last paragraph in this context). Adding to this, a considerable share of ELVs is exported from the EEA to developing countries where their end-of-life treatment will not necessarily result in the recycling of lead or other restricted substances. Even if ELVs are treated within the EEA, the situation can be assumed to be similar to electrical and electronic equipment where, if 100 % of the electronic parts containing LHMPS will be treated, only part of the lead would be recycled.[36]

ACEA et al. (2024a) further claim that any substitute and the processing chemicals, needed for their application, should have clear evidence for reducing environmental loads. In this sense the Lead-free criterion should align with further targets of the European chemical policy and best available technology approach.

The applicants are invited to present substantiated, transparent and publicly available evidence whether the continued use of lead in LHMPS may outweigh the environmental, health and/or safety benefits of its substitution. As to alignment with other EU policies, considerations and decisions in this context, including the revised ELV-Directive/ELV regulation etc., are at the COM's discretion and beyond the consultants' mandate for this exemption review.

6.3.6 Socioeconomic impacts

ACEA et al. (2024a) state that, if a new applicable substitute for LHMPS will be found, the economic implications of changing designs and validation will be very high and time consuming.

The consultants assume that legislators, when deciding the substance restrictions for vehicles in the scope of the ELV Directive, were aware that legal compliance implies economic impacts for the automotive industry. Economic impacts of substitution/elimination in the consultants' understanding and interpretation of Art. 4(2)(b)(ii) in the past years, would not justify recommending the COM to grant an exemption. Once substitution/elimination of LHMPS is scientifically and technically practicable, ACEA et al. are welcome to explain the economic impacts of these LHMPS-free solutions. The consultants would, in this case, ensure that this information is provided to the COM along with the technical assessment resulting in the recommendation to enable well-informed decision making.

6.3.7 Summary and conclusions

ACEA et al. request the continuation of exemption 8(e) without specifying a review date. Based on the largely same technical information and justifications like in the two previous reviews of the exemption in 2014/2015 and in 2018/2019, they explain that the use of

[36] Cf. Deubzer 2007.

lead in LHMPS is still unavoidable in three "intended uses" for which elimination and substitution are not yet feasible despite committed research.

As to their research and compliance efforts, ACEA et al. point out the activities of the DA5 consortium but otherwise claim that all other substitution and elimination activities are confidential, or cannot be disclosed and discussed in the applicant consortium for antitrust regulations.

Upon repeated request whether any of the progress announced in previous reviews or other substitution/elimination successes have been achieved, ACEA et al. provide examples of components for which they claim that LHMPS has been substituted or eliminated. The applicant consortium cannot provide further detail or information, highlighting antitrust/confidentiality reasons and that the time was too short to collect more details. The provided information lacks substance and detail and does not allow insights into the status of lead substitution or elimination, or to restrict the exemption scope. While the time for answering the questions was actually limited, the consultants consider collecting and presenting information concerning the scientific and technical status of lead substitution/elimination as essential preparation for an exemption request. While the consultants understand that confidentiality and antitrust aspects can be an obstacle to provide certain information, the review process requires applicants to be in the position to substantiate requests for continuation of exemptions with adequate information.

For time reasons, the applicants also claim that they cannot provide information either as to whether any of the above-mentioned or other LHMPS-free components are qualified for automotive uses according to applicable reliability standards. This knowledge is in the consultants' opinion essential as well to understand the status of lead substitution and elimination as the applicants highlight that only such qualified components can be used in automotive applications. Like in the above case, it should have been collected and prepared for the consultation already.

In the absence of tangible substitution/elimination successes despite around 20 years of research, the consultants proposed more holistic research approaches with less focus on the LHMPS as interconnecting material and more effort on optimising the entire component design to accommodate the properties of lead-free solutions. The applicants considered this approach as conceivable but can only speculate about the approaches taken in research.

The general approach in past reviews and the current one has been to highlight the DA5 activities if consultants requested information about compliance efforts in the past years. The consultants wonder why there is only the DA5 consortium working on substitution/elimination of LHMPS in die attach, which is one of many other uses of LHMPS within the three "intended uses". The consultants expressed doubts in past reviews already that a lead-free solution for die attach would be applicable to all other uses of LHMPS. The automotive industry should consider establishing other working groups for applications of LHMPS with similar material requirement profiles, e.g. a working group "Vacuum Sealing". These groups could promote application-specific research and could report about their activities like the DA5.

It is also recommended that applicants organise themselves in a way that supports the collection and provision of essential information so that sound evidence can be provided on the status and future development of lead.

6.4 Recommendation

The provided information suggests that exemption 8(e) is still required but the consultants see severe deficits on the applicants' side to provide and substantiate information as to the actual scientific and technical status of lead-free solutions, and to further principle approaches followed in the coming years to achieve and implement further lead-free solutions. Applicants are obliged to substantiate their exemption request to enable consultants to assess whether and where the use of lead is still unavoidable in the sense of Art. 4(2)(b)(II). In the absence of such information, the consultants cannot give a recommendation as to the continuation of the exemption.

If the COM decides to continue the exemption, the below wording with an addition (underlined) proposed by ACEA et al. could be adopted to exclude the use of LHMPS outside electrical and electronic applications.

No.	Materials and components	Scope and expiry date of the exemption
8	<u>Lead in solders or coatings of electrical and electronic applications specified in the following subentries:</u>	
…	…	…
8(e)	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)	This exemption shall be reviewed in [YEAR]* ** Remark (not part of the final exemption text): Since the COM has not yet decided the renewal of exemption III-7(a), the date should be adapted to the actual expiry date of this exemption, or with the earliest possible date in timely proximity to the review date of RoHS-exemption III-7(a). In this context, the COM might also consider setting the expiry of the exemption at a date that enables the next review of this exemption to be conducted under the revised ELV Regulation after its entry into force.*[37]
…	…	…

As to the review date, it is considered useful to align the next review of this exemption with the review[38] of the corresponding RoHS-exemption III-7(a) which targets the transformation of the current purely material-specific exemption into a more application-specific one. A parallel review, or, if this is not feasible, a review in timely proximity after the renewal of the corresponding RoHS exemption would offer an opportunity to improved access to essential technical information as to the status and prospects of lead substitution and elimination, and avoid that the wordings of these exemptions develop differently with potentially negative impacts on the supply chain.

[37] Cf. the Commission proposal: https://eur-lex.europa.eu/resource.html?uri=cellar:8e016dde-215c-11ee-94cb-01aa75ed71a1.0001.02/DOC_1&format=PDF

[38] (Baron et al. 2022) recommend the expiry of RoHS-exemption III-6(c) on 21 July 2026; the COM's decision is pending.

6.5 References

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7 Exemption 8(g)(ii): Lead in solder of flip chip packages

The below Table 7-1 shows the wording, scope and dates of applicability of the exemption.

Table 7-1: Current wording of exemption 8(g)(ii)

No.	Current exemption wording	Current scope and dates of applicability
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 that electrical connection consists of any of the following: (1) a semiconductor technology node of 90 nm or larger; (2) a single die of 300 mm^2 or larger in any semiconductor technology node; (3) stacked die packages with dies of 300 mm^2 or larger, or silicon interposers of 300 mm^2 or larger.	Vehicles type-approved from 1 October 2022 and spare parts for these vehicles. This exemption shall be reviewed in 2024.

Declaration

In the sections preceding the “Critical review”, the phrasings and wordings applicants’ and stakeholders’ explanations and arguments have been adopted from the documents they provided as far as required and reasonable in the context of the evaluation at hand. In all sections, this information as well as information from other sources is described in italics. Formulations were altered or completed in cases where it was necessary to maintain the readability and comprehensibility of the text.

Acronyms and Definitions

ACEA	Association des Constructeurs Européens d'Automobiles, European Automobile Manufacturers Association
BGA	Ball grid array
CLEPA	European Association of Automotive Suppliers
COM	European Commission
ECB	Electronic circuit board
EEA	European Economic Area

EEE	Electrical and electronic equipment
EFTA	European Free Trade Association (Iceland, Liechtenstein, Norway and Switzerland)
ELV	End-of-Life Vehicle Directive 2000/53/EC
EU (27)	27 Member States of the EU (year 2022)
FCP	Flip chip package
FTEOS	Fluorinated tetraethyl orthosilicate
IC	Integrated circuit
JAMA	Japan Automobile Manufacturers Association, Inc.
KAMA	Korea Automobile Manufacturers Association
Lead-free	Not containing lead in the applications in scope of the exemption to be reviewed
OEM	Original equipment manufacturer
Pb	Lead [chem.]
RoHS	Directive 2011/65/EU, current RoHS Directive
UK	United Kingdom
WLSCP	Wafer-level chip-scale package

7.1 Background and technical information

On 2 May 2024, ACEA, CLEPA, JAMA, JAPIA and KAMA (from here on referenced as ACEA et al. 2024a) requested the continuation of the exemption in its current wording and a validity period as shown in the table below.

Table 7-2: Requested wording and review date

No.	*Requested exemption*	*Requested scope and dates of applicability*
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 that electrical connection consists of any of the following:* *(1) a semiconductor technology node of 90 nm or larger;* *(2) a single die of 300 mm² or larger in any semiconductor technology node;* *(3) stacked die packages with dies of 300 mm² or larger, or silicon interposers of 300 mm² or larger.*	*Vehicles type-approved before 1 January 2030 and spare parts for these vehicles.*

(ACEA et al. 2024b) submitted additional documentation containing general information along with the specific information addressing exemption 8(g)(ii).

7.1.1 History of the exemption

History of exemption 8(g)(ii) of the ELV Directive

(ACEA et al. 2024a) provided the following information on the development of exemption 8(g)(ii) under the ELV Directive:

The Commission decided with Commission Decision 2010/115/EU of 23 February 2010, to split the exemptions 8(a) 'Solder in electronic circuit boards and other electrical applications except on glass' and 8(b) 'Solder in electrical applications on glass', prior defined in Commission decision 2008/689/EC of 1 August 2008. The split was extended to 10 new defined entries. For the new introduced subentry 8(g) ´Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages´ the Directive 2010/115/EU determined a first review in 2014. With the Commission Directive (EU) 2016/774 of 18 May 2016, the Commission decided to continue exemption 8(g) and a review for the year 2019, as the applications covered by exemption 8(g) remains unavoidable as substitutes have not become available yet. In May 2018, the Oeko Institute launched a stakeholder consultation for the review of several exemptions of Annex II including the review of exemption 8(g). In their report, the consultants Oeko Institute and Fraunhofer IZM from October 2019 recommend splitting the exemption 8(g) into the two subentries 8g(i) and 8(g)(ii). 8(g)(i) shall cover the scope of the previous entry 8(g), but are only applicable for ´Vehicles type approved before 1 October 2022 and spare parts for these vehicles.' Exemption 8(g)(ii) shall continue the previous entry 8(g), but with narrowed scope and with a suggested review date in the year 2024 [c.f. the currently valid wording reproduced in Table 7-1, the consultants].

With Commission delegated Directive (EU) 2020/363 from 17. December 2019, the Commission followed the consultant recommendation and amended Annex II entry 8(g) accordingly, as there are currently no suitable alternatives to the use of lead for the materials and components covered by this exemption. The date for a new review of the new exemption 8(g)(ii) was determined for the year 2024.

History of exemption 15-series of the RoHS Directive

(ACEA et al. 2024a) further provided the following information on the development of exemption 15-series under the RoHS Directive (2011/65/EU):

The above addressed exemption 8(g) is also listed in Annex III of Directive 2011/65/EU (RoHS Directive) as exemption no. 15. For products in scope of WEEE and RoHS other use profiles may apply than for vehicles. E.g. demands to consumer electronics or smart phones are different from requirements to an engine controller in a vehicle. Exemption 15 of RoHS was reviewed during the 2008/2009 review of RoHS Annex and a continuation of the exemption was granted by COM with review date 2016. In 2015, exemption 15 of Annex III of RoHS Directive (2011) was reviewed, 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.

According to the specific rules of the RoHS legislation, the stakeholders applied to continue this exemption 15(a) with submissions of 16.01.2020 and to continue exemption 15 with submissions of 16.01.2020 for RoHS categories 8 and 9. As long as there is no COM decision to the submission, the exemption remains valid. Until today there is no valid COM decision.

The consultants add the following information:

- Exemption 15(a) was last reviewed by (Deubzer et al. 2022). *At the time, the consultants concluded that the applicants did not provide substantiated evidence that would allow the consultants to recommend the exemption renewal in line with the conditions for exemptions laid out in RoHS Art. 5(1)(a), i.e. it could not be clarified whether and how far substitution or elimination of lead were still scientifically and technically impracticable. The consultants therefore did not recommend a renewal of exemption 15(a) but recommended a transition period of 12 months before its expiration.* To date, the European Commission has not yet published a decision on the adoption of this recommendation.

7.1.2 Summary of the stakeholder contributions

The consultants summarize ACEA et al.'s response to the stakeholder consultation questionnaire as follows:

Flip chip is a synonym for a technology for interconnecting dies such as semiconductor devices, IC chips, integrated passive devices and microelectromechanical systems (MEMS), to external circuitry with (solder) bumps that have been deposited onto the chip pads. FCP technology has in many cases substituted the wire bonding technology for electrical connections on semiconductors / IC´s. The advantages of Flip chips technologies include enabling high density packing of complex integrated circuits, high speed of signal processing, and input and output lines can be connected to all parts of the chip. The main disadvantage is the sensitivity to thermomechanical stress. FCPs and their connections are sensitive to thermomechanical stress, as caused by CTE mismatch in all three dimensions (x/y/z) of different materials applied. By using Pb internal solder joint, fatigue resistance to thermal cycling is higher and resists cracking where Pb-free solutions currently fail.

The automotive industry sector has the necessity to continue the exemption 8(g)(ii) for the purpose of an implementation and transition phase as there are more complex objects in the industrialisation and validation phase along the automotive industry sector *supply chain. After the gradual introduction along the supply chain with its finalization through a vehicle type approval, a subsequent expire date for exemption 8(g)(ii) is considered possible in the automotive industry sector.*

The expiry will be possible at the earliest 60 month after publication of the amending of Annex II to Directive 2000/53/EC in the Official Journal of the European Union due to its exemption 8(g)(ii) at the earliest ´Scope and expiry date of the exemption: Vehicles type-approved before 1 January 2030 and spare parts for these vehicles´.

7.1.3 Technical description of the exemption and use of the restricted substance

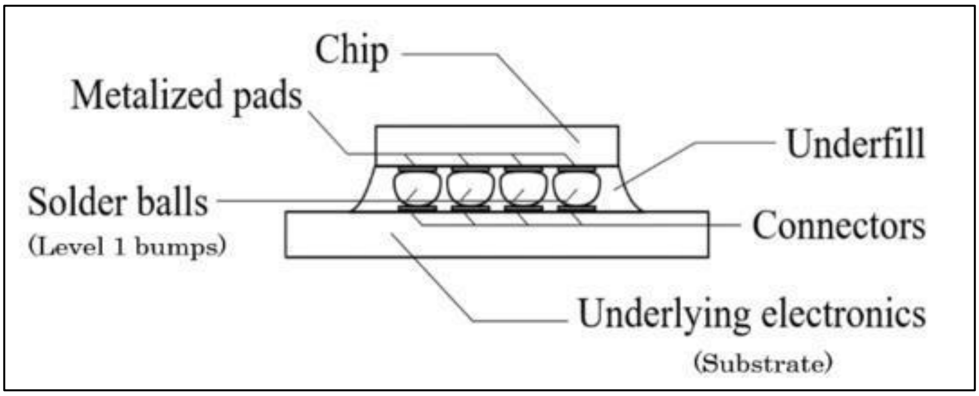
The technical background of the exemption is described in the review reports of (Gensch et al. 2015) as well as in the report of (Gensch et al. 2016).

(ACEA et al. 2024a) provided the following technical information on the exemption.

FCP technology basics

Flip chip is a synonym for a technology for interconnecting dies such as semiconductor devices, IC chips, integrated passive devices and microelectromechanical systems (MEMS), to external circuitry with (solder) bumps that have been deposited onto the chip pads. FCP technology has in many cases substituted the wire bonding technology for electrical connections on semiconductors / IC´s.

Figure 7-1: Schematic diagram of Flip chip



Source: (ACEA et al. 2024a) [39]

According to (ACEA et al. 2024a), the advantages of Flip chips technologies are:

- *Enabling high density packing of complex integrated circuits*
- *High speed of signal processing*
- *Input and output lines can be connected to all parts of the chip*

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[39] *Given source: web Creative Commons CC0 License, Author Twisp (description in brackets added)*

The disadvantages are:

- *Sensitivity to thermomechanical stress*

(ACEA et al. 2024a) further describe that FCPs and their connections are sensitive to thermomechanical stress, as caused by CTE mismatch in all three dimensions (x/y/z) of different materials applied. By using Pb internal solder joint, fatigue resistance to thermal cycling is higher and resists cracking where Pb-free solutions currently fail. Underfills are used to reduce the thermomechanical stress between silicon die, solder and substrate. Additional mechanical stress by warping of the substrate stimulates failure of the connections to the silicon die.

In vehicles the temperature windows for electronics are specified for around up to 200 degrees Kelvin and additional harsh mechanical shocks can impact the long-term reliability of electronics. The requirements are more similar to military applications than to consumer electronics.

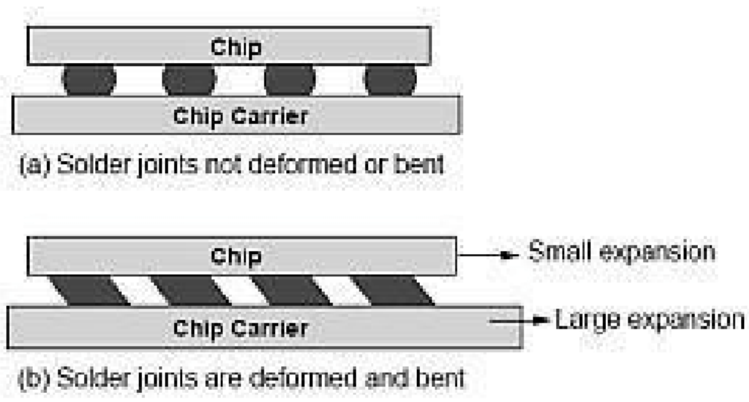
The solders used on ´level 1 bumps´ in the flip chip connections must be:

- *Resistant to electro-migration failure at the extremely high current densities required;*
- *Able to create a solder hierarchy that allows staged assembly and rework of components in the manufacture process; and*
- *Have high ductility to reduce thermo-mechanical stress in under bump metallurgy structures in particular in larger dies.*

Based on the previous review reports on this exemption and the equivalent exemption 15 / 15a under RoHS, the consultants summarize the following points which need to be known in order to follow the technical arguments discussed in the context of this review.

According to Deubzer et al. (2022), *"Differences in the coefficients of thermal expansion (CTEs) between the chip carrier and the chip exert mechanical stress on the level 1 solder bumps resulting in their deformation. Lead-free solders are more brittle than the ductile lead-containing solders so that compensate less thermomechanical stress increasing the strain on the chip and chip carriers. Larger thermomechanical stress may thus result in debonding of the joints or cracks in the bonded materials."* This is illustrated in Figure 7-2.

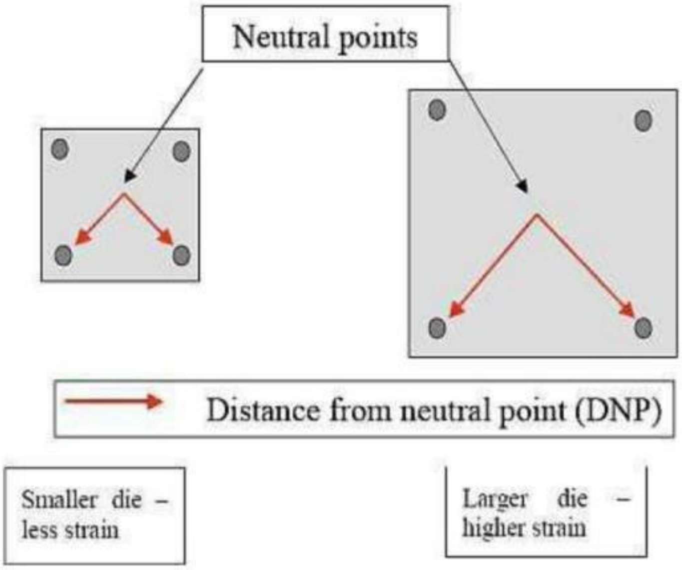
Figure 7-2: Thermomechanical deformation of level 1 solder bumps in FCPs



Source: (Goodman 2004)

(Deubzer et al. 2022) added that larger dies (chips) exert larger thermomechanical stress in particular on those bumps with longer distance from the "neutral points" near the centre, as displayed in Figure 7-3.

Figure 7-3: Increased thermomechanical stress in larger die FCPs



]

Source: Intel et al. in (Zangl et al. 2010)

(Deubzer et al. 2022) added that a thorough redesign of FCPs (materials, geometries, sizes, technologies) allows the use of lead-free solders nevertheless within the limits. Such redesigns are linked to the technical progress since the materials and technologies used needed to be developed as well. According to the applicants at the time, the above physical effects, mostly based on thermal mismatches due to differences in the applied materials' coefficient of thermal expansion, still required the use of lead in the context of electrical and electronic equipment (EEE) in the scope of the RoHS Directive.

FCP automotive market

According to (ACEA et al. 2024a), the market for FCPs, validated for automotive applications, is a sub-segment of the FCP market and due to the elevated requirements e.g. like long-term availability, there are limitations in offered products. FCPs are used in circuit modules, which are sub-assemblies for electronic schematics of electronic circuits (respectively electronic circuit board assemblies). In the context of vehicular systems, complex electronic components such as FCPs play a crucial role. These components are integral parts of control units or sensor systems that interact within a vehicle's board network, in conjunction with validated software. A validated board network design, once established, can be utilized across different car models, thereby enhancing the efficiency of the design process and ensuring consistency in performance across various car models.

Vehicle applications, as described in previous contributions, are

- *4G / 5G communication*
- *Electronic stability control systems*

- *Advanced emergency braking systems*
- *Distance control, assisted driving*
- *Lane departure warning systems*
- *Frontal projection systems*
- *Pedestrian protection*
- *Tire pressure monitoring systems to reduce rolling resistance and noise emissions*
- *Hydrogen and hybrid cars*
- *Vision systems*
- *Audio/multimedia/car radio/car infotainment*
- *Traffic sign recognition*
- *Navigation*
- *Telematic systems, emergency call (e-call)*
- *Head-up displays*
- *Last but not least, a use of FCPs is linked to the board network design and the related control units and software installed in a vehicle.*

(ACEA et al. 2024a) state that the automotive industry sector is a downstream user of electronics and relies on components provided by suppliers who are the value chain partner responsible for ELV Directive compliance and for making their products available to many industries using existing and established production processes and equipment.

The components subject to exemption 8(g)(ii) of ELV Annex II are being used less and less in the automotive industry sector. Simpler FCPs in particular have been phased out in recent years, and typically only a few complex FCP types are still in use, with long lived older IC technologies for which lead-free designs could not be reliably produced. The automotive industry sector is not aware of new developments of FCPs in scope of exemption 8(g)(ii), newer variants due to minor adaptions are possible.

7.1.4 Amount(s) of restricted substance(s) used under the exemption

(ACEA et al. 2024a) provided information on used quantities from previous reviews of this exemption in addition to the most recent data, as follows:

ACEA et al 2013

The flip chip products are used in selected few sockets within automotive applications. There are no metrics to identify the number of lead flip chip components within an average vehicle. Assuming one to three flip chip components per vehicle, based upon the latest estimated 13.4 million registered units in the EU + EFTA, the total lead placed on the EU market is estimated at about 0.2 to 0.6 metric tons per year.

ACEA et al 2018

With 15.7 million vehicles new registered in 2017 in the European Economic Area (EU28 +EFTA) the total lead placed on the EU market making use of Exemption 8(g) is estimated with about 31 kg to 548 kg per year (2017). With an average value of 17 mg/car and 15,7 Mio. vehicles put on EC market in 2017 we estimate a total Lead quantity of around 0.25 t/a for entry 8g applications.

Figure 10: Exemption 8(g) Lead in Vehicles Approximation

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. 2024a)

Table provided by JAPIA for 2 flip chip use cases

Use example of exemption 8(g) in JAPIA (2018.06.13)				
Application	Component	Number of component per application	Mass of lead in component [mg]	Lead content in material [wt%]
Navigation	IC	1	2.48	37
Digital TV tuner	IC	1	5.34	36

Source: (ACEA et al. 2024a)

ACEA/JAMA/JAPIA/CLEPA/KAMA 2024

Assuming, depending on the car model and its equipment, approx. 1 to 5 electronic systems (like Navigation or Digital TV tuner) of average 130 control devices per vehicle are equipped with FCPs.

With a mean value of around 12 mg (mass of lead per vehicle; based on mean value of around 4 mg (based on 3 FPCs per vehicle and on the mean value mass of lead per FPC) and 12,910,891 vehicles new placed (registered) on the EU market in the year 2022 (detail see frame document), we estimate a total Lead quantity of around 0,16 t/a in the scope of exemption 8(g)(ii).

Calculation of vehicles new registered in EU

According to (ACEA et al. 2024b), Europe accounts for around 19 % of global vehicle sales in 2022. Cars and vans new EU registered in 2022 in the European Union, UK, EFTA, and Malta were 12.92 million units.

For all the submissions the following data for vehicles new placed (registered) on the EU market in the year 2022, including EU(27), EFTA, UK and Malta, were used as basis for quantity calculations:

Table 7-3: Car registration figures for the year 2022

Registrations 2022	Passenger cars	Light commercial vehicles up to 3,5 t (´vans´)	Total
EU 27 (without Malta)	9.255.926	1.278.509	
EFTA	416.949	56.121	
UK	1.614.063	282.139	
EU + EFTA + UK	**11.286.935**	**1.616.769**	12.903.704
+ Malta	6.429	847	7.187
All:			**12.910.891**

Table 1: *Registration figures for year 2022; new registrations figures for Malta were not yet available in ACEA pocket guide 2023/24; data source for Malta is Malta NSO National Statistics Office (see footnote)*

Source: (ACEA et al. 2024b)

As ACEA et al. do not have access to technical data of vehicles in some specific markets, worldwide figures on applications would be incomplete and therefore they concentrate on figures of EU market only.

(ACEA et al. 2024a) added that the amount of Lead in FCPs placed on the EU market and worldwide has been reduced due to the phasing out in recent years and will decrease further.

7.2 Justification of the requested exemption

7.2.1 Substitution and Elimination of the restricted substance

(ACEA et al. 2024a) describe the following challenges with the substitution of lead.

(ACEA et al. 2024a) described that the components subject to exemption 8(g)(ii) of ELV Annex II are being used less and less in the automotive industry sector. Simpler FCPs in particular have been phased out in recent years, and typically only a few complex FCP types are still in use, with long lived older IC technologies for which lead-free designs could not be reliably produced. When it comes to changes in hardware and software, stringent and comprehensive procedures are implemented. These procedures are designed to ensure the reliability and safety of the vehicle, even if they may interfere with vehicle type approval demands. Furthermore, changes in hardware and software can have significant implications due to the various vehicle type approvals and for maintenance and repair procedures. They can increase the complexity of service requirements, necessitating advanced technical skills and knowledge for effective vehicle servicing. Therefore, any changes made must be carefully considered, keeping in mind their potential impact on the overall lifecycle of the vehicle and the corresponding

availability of components along the whole supply chain. Some of the products with these electronic circuit board assemblies are themselves relevant for type approvals and/or are relevant for or influence the vehicle type approval. The subsystem modules like for displays or radar signal processing are also made available to many car models by various automobile manufacturers. The complexity of these variants impacts vehicle type approvals and the phase-out period.

To the knowledge of (ACEA et al. 2024a), FCPs in scope of exemption 8(g)(ii) have not been used for new circuit modules developments for years. If at all, they assume, circuit modules with these FCPs were only reused for variant products (of more complex objects). In case the coefficient of thermal expansion (CTE) did not fit and the use of lead-free solder caused unsolvable problems, a return to leaded solder version was required to meet the production start date. Since the long-term availability of the electronic elements contained in new circuit modules is already taken into account during their development, they see a high probability given that FCPs within the scope of exemption 8(g)(ii) have hardly been considered in new developments (of e.g., circuit modules and electronic schematics of electronic circuits (respectively electronic circuit board assemblies)) in the automotive industry sector for years.

Regarding the (ACEA et al. 2024a) describe the challenges with substitution as follows.

(ACEA et al. 2024b) emphasize that vehicles and their components have to face harsh ambient conditions in Europe. Ambient temperatures from - 40 up to 50°C outside and interior temperatures to above 100°C have to be tolerated and operating temperatures e.g. of some engine components may exceed 800°C. Components like electronic control units have to be robust against vibrations and acceleration figures up to 100 g. With more and more electronic assisting driving functions and sensor or camera signals triggered actions of software, also IT related endurance is an important task.

The operating hours of vehicle electronics are up to around 25 000 h and even more in specific cases. During vehicle use, all components and their functions undergo long termed high levels of mechanical and thermo- mechanical stress and dynamic load conditions. This is valid not only for a short period, but over for a use period of ten to fifteen years and sometimes longer. That is one of the reasons, why development and validation of new components require such long development periods. This ensures that safety and reliability demands are fulfilled.

Furthermore, the continued improvement of the overall environmental performance of vehicles and their production processes requires that we also assess the environmental performance of substitute materials in order to allow long lasting decisions for optimized materials in each application. The entire industry, however, needs a reliable planning basis for these substitute materials for at least one development cycle of a vehicle. This needs to be considered in any future phase out recommendation and plans and EU Commission decisions.

7.2.2 Environmental, health, safety and socioeconomic impacts

(ACEA et al. 2024b) stated that the lead uses covered by these exemptions are either alloys in which the lead is physically bound within the metal matrix and does not significantly release through corrosion, friction, or wear, or other lead-based solder alloys used within electronic components' interiors. In these cases, the solders are

encapsulated within the components and do not release during product use. Recycling is also feasible without challenges and has been successfully realized in practice.

7.2.3 Roadmap towards substitution or elimination of the restricted substance

(ACEA et al. 2024b) stated that, as communicated in previous stakeholder contributions, the development period for implementation of lab-validated solutions into production is still 3 to 6 years if no failures occur. The average model cycle is typically around 8 years.

According to (ACEA et al. 2024a), after a potential automotive suitable, lead-free component is identified, usually a minimum of 6 years will be required to qualify (e.g. AEC-Q 100) it through the whole supply chain until release in volume scale car production. Based upon the current status of these special products, it is not possible to specify and hardly possible to estimate a real transition date. Product delivery for replacement and repair will need to continue for the life of type approved vehicles

However, (ACEA et al. 2024b) stated that for entry 8(g)(ii) they see the possibility to end his exemption for vehicles with a new whole vehicle type approval after 1.1.2030. More specifically, (ACEA et al. 2024a) stated "The expire will be possible at the earliest 60 month after publication of the amending of Annex II to Directive 2000/53/EC in the Official Journal of the European Union due to its exemption 8(g)(ii) at the earliest ´Scope and expiry date of the exemption: Vehicles type-approved before 1 January 2030 and spare parts for these vehicles´."

(ACEA et al. 2024a) added that the automotive industry sector has the necessity to continue exemption 8(g)(ii) for the purpose of an implementation and transition phase as there are more complex objects in the industrialisation and validation phase along the automotive industry sector supply chain. After the gradual introduction along the supply chain with its finalization through a vehicle type approval, a subsequent expire date for exemption 8(g)(ii) is considered possible in the automotive industry sector. The expire will be possible at the earliest 60 month after publication of the amending of Annex II to Directive 2000/53/EC in the Official Journal of the European Union due to its exemption 8(g)(ii) at the earliest ´Scope and expiry date of the exemption: Vehicles type-approved before 1 January 2030 and spare parts for these vehicles´.

7.3 Critical review

7.3.1 Substitution and elimination of the restricted substance

ACEA et al. expressed that exemption 8(g)(ii) can expire for vehicles type approved from 1 January 2030 onwards. The critical review therefore focused on establishing evidence to support the timeline until the exemption is no longer needed, in addition to establishing the current status of substitution and elimination of lead in the three sub-clauses of this exemption. The structure of this section reflects these aspects.

The critical review references insights from previous reviews of exemption 8(g)(ii) in addition to information from previous reviews of the equivalent exemption 15(a) under the RoHS Directive. The wording of exemption 15(a) under RoHS is identical to exemption 8(g)(ii), with the notable difference between both being that 15(a) applies to electrical and electronic equipment and 8(g)(ii) to automotive applications.

The consultants highlight that the last review of the equivalent exemption 15(a) under RoHS, conducted by (Deubzer et al. 2022/2024), did not result in a recommendation for its renewal. The main reason given is that the applicants at the time did not answer technical questions, resulting in the absence of clear evidence to which degree the substitution of lead in flip chip packages is in fact still scientifically and technically impracticable. (Deubzer et al. 2022) summarized the questions that remained unanswered by the applicants at the time. The consultants of this present review of exemption 8(g)(ii) therefore requested the technical evidence needed from ACEA et al. specific to each of the three sub-clauses of exemption 8(g)(ii), as is reproduced in the respective sub-sections on each exemption sub-clause below.

ACEA et al.'s statement on the relevancy of technical discussions with a view to phasing out exemption 8(g)(ii)

(ACEA et al. 2024b) stated that they see the possibility to end this exemption for vehicles with a new whole vehicle type approval after 1 January 2030. When engaged in discussions on the reasons that FCPs in scope of this exemption are currently not manufactured using lead-free level 1 solder bumps, (ACEA et al. 2024c) provided the following statement, to which they referred back to repeatedly when responding to other technical questions. Therefore, the statement is discussed here first and referred back to in the sub-chapters that follow.

(ACEA et al. 2024c) stated that for automotive semiconductors it is not common to specify the transistor gate lengths like 90 nm. Requirements are mainly oriented to function and demand compliance with existing material restrictions. A discussion on production technologies is interesting, but only takes effect if it leads to a market offer of components that are available in automotive grade and have long-term availability. For several years now, electronic components without lead are already being used in the automotive industry sector for new developments of circuit modules and it is assumed, that it will be possible to phase out the exemption 8(g)(ii) in the automotive industry sector. Therefore, the details for the information are no longer relevant for the automotive industry sector, as the phase-out of all components with these three exemptions has already been planned and implemented for some time. To create legal certainty, only the legally regulated transition period is required in a sufficient length of time that is appropriate for the automotive industry sector.

The consultants note that the objective of this exemption review and the consultants' mandate is to adapt the scope and validity period of exemption 8(g)(ii) to the scientific and technical progress to ensure that the use of lead is restricted to those cases where its use is unavoidable and only for as long as is necessary. While ACEA et al. proposed a date after which newly type-approved vehicles are expected to no longer require the exemption, 1 January 2030 is almost six years into the future from the time of this review. The consultants therefore need to ensure that the exemption is still required in vehicles type approved before January 2030, thereby justifying the continuation of the exemption. The consultants further note that although ACEA et al. expect that the exemption will no longer be needed for vehicles type approved from January 2030 onwards, this may not be considered a binding statement. Therefore, the technical discussion on the current status of the use of lead in this exemption is still relevant.

General discussion on the status of the use of lead in automotive FCPs

(ACEA et al. 2024a) did not provide comprehensive technical descriptions and justification to support the continuation of this exemption. When asked whether the last review of the equivalent exemption under the RoHS Directive, exemption 15(a) of Annex III, conducted by (Deubzer et al. 2022), could be referenced for the technical background and justification, or whether ACEA et al. would like to contribute new information, *(ACEA et al. 2024c) stated that in their opinion, they had clearly addressed the key issues in their last submission and previous submissions. In their answer to the stakeholder questionnaire, they stated "we noted the claims addressed (by stakeholder) in the application renewal for exemption 15(a) of RoHS Annex III and consider them justified." (ACEA et al. 2024c) further stated to refrain from comments to reviews of legislation of other industry sectors, which may have different usage profiles with which they are not familiar. The RoHS Pack 23 evaluation originates from December 2022, and ACEA et al. are not aware of any ground-breaking new developments in the 16 months since. (ACEA et al. 2024c) further stated that the starting point for automotive electronic applications are suitable electronic components. As the production and the research know-how for semiconductors is concentrated at their partners in the electronic industry, ACEA et al. have full confidence that they know which exemptions are necessary. ACEA et al. understand that the hard and extensive requirements for automotive-grade electronics and the long-time delivery request as well as the expectable margins reduce the attractiveness to serve this minor FCP market.*

When asked to explain the efforts undertaken to find and implement the use of lead-free alternatives for automotive uses, (ACEA et al. 2024a) explained that for over two decades, the automotive industry is engaged in developing reliable lead-free electronic solutions under consideration of steadily increasing performance and environmental requirements. The transition from lead-based soldering of electronic circuit board (ECB) assemblies to lead-free soldering, which meets the automotive industry's high-quality standards, took approximately 15 years. To illustrate an example (ACEA et al. 2024a), highlight that the use of lead-based soldering for electrical / electronical components on ECB´s has become obsolete.

Attempting to gather evidence that the exemption is still needed, ACEA et al. were requested to provide a list of relevant automotive electronics modules, their functionality, the functionality provided by the FCPs, and reasoning as to why lead-containing FCPs are still needed for each application, differentiated by the three sub-clauses of exemption 8(g)(ii). *(ACEA et al. 2024a) stated in response that FCPs in scope of exemption 8(g)(ii) are currently still used in various electronic systems of generations already in series production, referring to the examples reproduced in section 7.1.3 of this report (cf. page 96). ACEA et al. also highlighted that the main reason for using FCPs is the computing power and the processing speed of signals and large amounts of data, which are required in the applications mentioned and for which FCPs are then and now without alternative. Consequently, the use of lead-based solder in FCPs may still be necessary for the applications mentioned.*

The consultants note that the requested information was not provided in this response. To follow-up, ACEA et al. were asked to provide a list and descriptions of specific FCPs that still require this exemption, including relevant data sheets. *In response, (ACEA et al. 2024c) stated that "detailed information on specific components and their data sheets is usually proprietary and not publicly available. As this as competitive sensitive information affects disclosure of future planned technologies, used components and its sub-suppliers,* *this information is not provided."* Therefore, the consultants did not receive verifiable evidence that the exemption is still currently needed, as examples of specific FCPs in use in production vehicles were not provided.

ACEA et al. were further requested to name the companies that manufacture the semiconductors that are used in FCPs making use of this exemption. The intention of this question was to enable the consultants to engage with those companies directly to collect complementing information on the status of substitution and elimination or to request ACEA et al. to request technical information from those companies. *(ACEA et al. 2024a) replied that FCPs in automotive grade are sourced based on their functions and technical parameters, not production technology. ACEA et al. state that due to insufficient information on the production technologies used, it is currently unfeasible to allocate these components and their producers along the supply chain to the sub-clauses […]. Due to legal obligations and contractual agreements, the disclosure of information about subcontractors is strictly prohibited. In addition, such data is considered to be competitive sensitive, and sharing it violates their compliance policy. In the absence of information on the specific suppliers of relevant FCPs, the consultants considered inquiring with known semiconductor suppliers. However, given that the semiconductor industry was involved in the previous evaluation of the equivalent exemption 15(a) under RoHS, and the requested technical information was not made available, as was highlighted by Deubzer et al. (2022), substantial informational gain through the involvement of these additional stakeholders was considered unlikely.*

Discussing the continued need for FCPs, ACEA et al. were asked for which reasons the industry requires FCPs and cannot use integrated circuit packages using alternative interconnection technologies that do not require lead. (ACEA et al. 2024a) responded that in the automotive industry sector, designs and technologies that are already established on the market in other sectors are used for complex chips in particular. And the automotive industry sector custom designed / adapted / optimized chip variants were then used in series production for 15, 20 years, or more, because these components have their own development lifecycle and period of use. For some time now, new generations of more complex objects without FCPs in scope of exemption 8(g)(ii) have been developed and industrialized in the automotive industry sector. This is why many FCPs in scope of exemption 8(g)(ii) have already been phased out in recent years and the remaining ones will phased out too. Upon request, (ACEA et al. 2024d) specified the term 'complex object' in this context to mean flip chips and products that use them, as opposed to simple products such as paper clips or printer paper. FCPs and such products take on an extraordinary complexity by linking and multiplying functionality along the supply chain and getting, due to their safety relevance, a particular difficulty and special awareness.

The consultants acknowledge that the automotive industry has managed to displace lead-containing components and FCPs from vehicles over the past years, however, the question meant to address the reasons for which relevant FCPs that are currently still used in production vehicles and may still be used in newly type approved vehicles before January 2030 still require the exemption and cannot be substituted via alternative, lead-free technologies. One obvious alternative interconnection technology, w*ire bonding, had already been discussed with ACEA et al. in a previous review of this exemption. At the time, (Gensch et al. 2015) concluded that for a number of technical advantages of FCPs,* it was plausible that ICs using wire bonding are not appropriate to eliminate the use of lead – not least as wire bonded ball grid array (BGA) packages also depend on the use of lead, as had been stated by ACEA et al. at the time. This discussion was not repeated in this review.

However, the consultants addressed wafer-level chip-scale packages (WLCSP) as a potential alternative technology to FCP. WLCSP have been described to feature larger solder balls of a few hundred micrometres, in contrast to solder bumps used in FCPs that are only a couple of dozen micrometres in diameter. Thereby, WLCSP solder balls can handle the stress from the difference in the coefficient of thermal expansion between the substrate and the chip, while FCP solder bumps cannot (SK Hynix 2023). When asked to explain under which conditions lead-free WLCSP can or cannot be used to eliminate FCPs that require this exemption, including providing evidence from testing where available, (ACEA et al. 2024c) did not provide any technical information, but referred to their statement provided prior indicating that first, semiconductor devices are not specified using such technical parameters and second, such technical discussions are no longer relevant to the automotive industry, given that a phase out for vehicles type approved from January 2030 on is foreseen (cf. ACEA et al.'s statement on the relevancy of technical discussions with a view to phasing out exemption 8(g)(ii) reproduced on page 103 of this report).

The consultants further addressed copper pillar bumps as a potential lead-free alternative to the solder bumps used in FCPs in the scope of exemption 8(g)(ii). In a review of manufacturing processes for the fabrication of flip-chip bumps for chip-package interconnection, (Datta 2020) concluded that *"electrochemically fabricated copper pillar bumps offer fine pitch capabilities with excellent electromigration performance. Due to these virtues, the copper pillar bumping technology is emerging as a lead-free bumping technology option for high-performance electronic packaging". "[…] copper pillar structure with or without SnAg cap is now one of the key solutions for lead-free interconnect."* When asked whether there are any barriers for copper pillars as a lead-free alternative to lead-containing solder bumps for FCPs that require this exemption, (ACEA et al. 2024c) did not engage in a technical discussion, but referred to the above discussed statement on the relevancy of technical parameters and technical discussions (cf. page 103).

Clause (1): Semiconductor technology node of 90 nm or larger

Reviewing the equivalent exemption 15 under RoHS, (Gensch et al. 2016) already concluded in 2015/2016 that FCPs with smaller technology nodes can substitute larger technology nodes, recommending renewing the exemption until 2019 to allow the industry to adapt to using FCPs with smaller nodes. Following the most recent review, (Deubzer et al. 2022, 2024) did not recommend renewing the exemption again, citing the lack of conclusive evidence. (Deubzer et al. 2022) indicated the following open question related to clause (1): *"It remained unclear why larger node (≥ 90 nm) flip chip packages still are used and intended to be used another five or seven years in new EEE placed on the EU market while smaller node lead-free alternatives have been available since 2007."*

(Gensch et al. 2016), reviewing the equivalent exemption 15 under RoHS, detailed the technical background for which semiconductor devices fabricated in a larger technology node were not compatible with lead-free level 1 solder bumps. *According to the applicants at the time, Intel et al., devices on the 250 nm to 90 nm technology nodes used a common low dielectric constant film (low-k) fluorinated tetraethyl orthosilicate (FTEOS), which made copper interconnects possible and offered improved electrical* *performance, however, at the expense of film mechanical strength, making it susceptible to dielectric fracturing beneath the underbump metallization on the silicon chip with lead-free wafer bumps. The applicants at the time, Intel et al., explained that lead-free wafer bumps are significantly less ductile than those containing lead, and the observed failure mode mechanism is driven by mismatch in the coefficients of thermal expansion between the lead-free bump and the FTEOS dielectric. Intel et al. further explained that more advanced silicon technology nodes, with transistor gate lengths of 65 nm and smaller, completely replaced FTEOS. These replacement technologies were designed to address the stress levels associated with lead-free die solders so that lead solders were no longer required for those FCP unless they use large dies or large interposers of 300 mm² size or larger.*

A screening of publicly available information on the status of larger technology nodes in the automotive industry revealed that semiconductors fabricated in 90 nm or larger technology node (= transistor gate length) have been reported to be increasingly important for the automotive industry. For instance, the German Association of the Automotive Industry (VDA) cite a commissioned study that found that "*Chips larger than 90 nm are of enormous importance for the automotive industry. According to the study, by 2030, around 60 % of the automotive industry's chip requirements will be of this node size*", and further state that "*Chinese semiconductor companies in particular are investing in the node size of 90 nm or larger to promote domestic automobile companies*" (VDA 2023). The same trend was reported in a study from McKinsey & Company, in which it is stated that *"Continuing the pattern seen today, most future automotive-wafer demand will involve nodes of 90 nanometres (nm) and above because many vehicle controllers and electric powertrains, including electric drive inverters and actuators, rely on these mature chips. Such nodes will account for about 67 percent of automotive demand in 2030", adding that "OEMs that rely on 90 nm chips for many applications have little incentive to migrate to smaller nodes, because the shift would require additional development and qualification costs, as well as more R&D staff. Those disadvantages often outweigh the technological benefits" (McKinsey 2022). In contrast, another article reported that "automotive chips are on track for manufacturing process upgrades, with 40 nm technology likely to replace 90 nm as the mainstream process node in five years, according to industry sources." (DIGITIMES Asia 2022)*

The consultants note that the above-cited sources report on semiconductor fabrication technology nodes and do not differentiate packaging or interconnection technologies, such as FCPs. It can therefore not be concluded that the number FCPs fabricated in 90 nm and larger technology nodes used in automotive applications will increase, even if the number and/or share of 90 nm or larger semiconductor devices in automotive applications increases. The cited articles also do not discuss interconnection technologies and potential implications for compliance with the ELV Directive.

Given the above-described background, including the projected increased use of 90 nm semiconductors in the automotive sector, ACEA et al. were requested to describe the technical reasons that the FCPs making use of clause (1) are not manufactured using lead-free level 1 bumps. In response, (ACEA et al. 2024c) provided the statement on the relevancy of technical parameters when choosing semiconductor products in the automotive industry, as well as the relevancy of discussing production technologies, which is reproduced in this report on page 104. However, in the consultants' view, the fact that the automotive industry does not specify the transistor gate length (like 90 nm), does not mean that the information which FCPs still require the exemption and are used in current production cars is not available to the automotive industry. Such information on individual semiconductor devices, including ELV compliance, can be assumed to be available through data sheets and compliance statements.

Referencing the information reported by (DIGITIMES Asia 2022) cited above, ACEA et al. were requested to comment on the projected timeline that 40 nm fabrication technologies would likely become the standard for automotive semiconductors within five years (until 2027), and whether this may mean that sub-clause (1) could expire by then, *(ACEA et al. 2024c) responded that the statement is not from the automotive industry and that it is related mainly to production methods and not to FCP production specifically. ACEA et al. added that 2027 is too early as qualification and development require a longer transition period. An expiry of sub-clause (1) in 2027 would mean that ongoing developments using this exemption would already have to be completed and would already get a vehicle type approval in 2026. And it would affect the contracts and time schedules already concluded between the OEMs and suppliers in 2023 or earlier.*

The consultants acknowledge that the cited information discusses semiconductor fabrication technologies in general without specific reference to FCPs.

(Deubzer et al. 2022) reported that the applicants during the previous review of the equivalent exemption III-15(a) under RoHS, Texas Instruments et al., agreed that *„lead-free smaller node FCPs can provide all electrical/electronic functionalities of larger node FCPs.“* When asked why the electronic modules that contain the FCPs that still require this exemption have not been redesigned to accommodate smaller node (= lead-free) FCPs that provide the same functionality, (ACEA et al. 2024c) once more referred to their statement reproduced on page 103 above. The consultants note that this statement does not contain the requested technical information.

Following up on this aspect, the consultants requested ACEA et al. to discuss alternative technologies, including application-specific integrated circuits (ASICs) and field-programmable gate arrays (FPGAs), that may use more advanced technology nodes (transistor gate length below 90 nm) while providing the individually required functionality, form factor, and pin out. *In response, (ACEA et al. 2024d) stated that in their view, this question should be addressed to semiconductor producers. Their customers only specify the functions of the component to be delivered, but not the production technology and process. Requested to explain why such technologies have not been useful in substituting the remaining FCPs that still require the exemption, (ACEA et al. 2024d) stated that there is currently no legal requirement, that the remaining FCPs using ELV Exemption 8(g)(ii) must be substituted and therefore, the changeover would only cause effort and tie up resources needed elsewhere, thus only leading to disadvantages and no advantage for each individual player in the supply chain. (ACEA et al. 2024d) added that despite not being legally required, the automotive industry has voluntarily contributed to the fact that FCPs within the scope of ELV exemption 8(g)(ii) have not been considered and side-lined in new developments in the automotive industry sector for years, although the immense effort and additional resources required.*

The consultants cannot follow the above arguments. Firstly, the consultants consider it may well be a possibility for customers of semiconductor manufacturers to discuss opportunities to produce a specific functionality using technologies that may avoid the use of lead. Secondly, Article 4(2)(a) of the ELV Directive mandates that materials and components of vehicles put on the market after 1 July 2003 do not contain the specified hazardous substances including lead. The listed exemptions on Annex II should, in the consultants' view, not be understood to imply that substitution and elimination are not mandated and, if implemented, are implemented on a voluntary basis.

Overall, the consultants note that the responses provided by ACEA et al. did not help to clarify the key technical question that had been identified during the last review of the equivalent exemption 15(a) under RoHS by (Deubzer et al. 2022, 2024) in context of sub-clause (1) of this exemption. More broadly, the reason given by ACEA et al. for the continued use of FCPs that rely on sub-clause (1) is the known safety and reliability of FCPs that have been used in automotive products for a long time, while the testing and verification of new semiconductor devices requires lengthy test and qualification processes.

Clause (2): Single die of 300 mm2 or larger

According to (Deubzer et al. 2022), the applicants of the requested renewal of exemption 15(a) under RoHS at the time of the last review did not clarify whether and how far the technological state of the art would allow restricting the scopes of these exemption clauses, i.e. whether, how far and under which conditions dies larger than 300 mm² could be produced without the use of lead solders. As was stated by the applicants at the time, *"new products introduced into the market in the last several years are assembled with Pb-free bumps even though the die size is greater than 300 mm^2"* (Deubzer et al. 2022). This may be interpreted to mean that clause (2) and potentially clause (3) are no longer technically needed. When asked to comment, (ACEA et al. 2024a) referenced their statement on production technologies and the planned phase out of exemption 8(g)(ii) reproduced on page 103, without engaging in a technical discussion.

(Deubzer et al. 2022) had highlighted that larger die size FCPs with smaller technology nodes were produced with lead-free solders which may allow restricting the exemption scope. When asked to provide conclusive information regarding which die size / technology node combinations that can or cannot be produced using lead-free level 1 solder bumps, *(ACEA et al. 2024c) responded that this question was impossible to be answered in detail in the granted answering period.* In response, the consultants communicated to ACEA et al. that more information could be provided on this question throughout the duration of the review process. However, more information on this aspect was not provided.

ACEA et al. were further asked whether there is an overlap and causal relation between the first and second clause of this exemption. With this question, the consultants attempted to establish whether FCPs with a die size ≥ 300 mm^2 may, at least in part, be this large because they are fabricated in 90 nm or larger technology node, and whether smaller dies (< 300 mm^2) could be produced that provide the same functionality when < 90 nm fabrication technologies were used instead. *In response, (ACEA et al. 2024c) stated that they are not the owner of semiconductor production strategies and are not deeply enough involved in these component-specific details to comment on them.*

Reviewing information from previous reviews of exemption 8(g)(ii) and the equivalent exemption 15(a) under RoHS on this aspect, the consultants note that (Gensch et al. 2016) stated, citing Intel et al., the applicants at the time, that even more advanced technology nodes, such as 65 nm and smaller cannot accommodate the stress levels associated with lead-free die solders when the die size is 300 mm² or larger. *According to (Gensch et al. 2016), Intel et al. concluded that the additional strain from large die increased the failure rate for the solder mask, which adds another variable to the* *equation in developing a solution to use lead-free solders or any substitute interconnection technology for large dies. Consequently, lead-free die solder bumps were concluded to not to be compatible with large die sizes even in the most advanced silicon technologies.*

The consultants understand the role and obligation of applicants that request the continuation of an exemption to include providing the technical insights needed to allow the consultants to form a complete picture of the technical and scientific status that is relevant to the substitution and elimination of lead. In the consultants' view, it can reasonably be expected that the applicants bring themselves into a position to be able to respond to the technical questions.

Overall, the consultants note that the responses provided by ACEA et al. did not help to clarify the key technical question that had been identified during the last review of the equivalent exemption 15(a) under RoHS by (Deubzer et al. 2022) in context of sub-clause (2) of this exemption.

Clause (3): Stacked dies or silicon interposers of 300 mm2 or larger

The review of the equivalent exemption 15 under RoHS conducted by (Gensch et al. 2016) showed that using plastic / organic interposers instead of silicon interposers enables lead-free soldering of stacked die FCPs with interposers of 300 mm² and more. In the last review of exemption 15(a) by Deubzer et al. (2022), applicants stated that the usability of plastics instead of silicon interposers has its limits and, among others, depends on the number of connections between adjacent dies in the FCP. According to (Deubzer et al. 2022), the applicants failed, however, to explain the conditions and limitations for the use of organic interposers, or why these conditions are not adequate to restrict the exemption scope. The actual scientific and technical practicability of lead-free soldering in FCPs with large (≥ 300 mm²) interposers remained unclear.

ACEA et al. were asked to explain the conditions – or sets of conditions – that require the use of silicon interposers for interposer sizes ≥ 300 mm² instead of organic interposers, including commenting on whether and how far chiplet technology and/or the use of silicon bridges instead of silicon interposers enable the use of lead-free solders in such FCPs. In their response, (ACEA et al. 2024c) referred to their statement on production technologies and the planned phasing out of exemption 8(g)(ii) (cf. page 103 of this report), which, however, does not include any technical information on this matter.

The consultants note that the responses provided by ACEA et al. did not help to clarify the key technical question that had been identified during the last review of the equivalent exemption 15(a) under RoHS by (Deubzer et al. 2022) in context of sub-clause (3) of this exemption.

Roadmap to phasing out exemption 8(g)(ii)

When asked for a more specific roadmap that details the process until the exemption will no longer be needed for vehicles newly type approved January 2030 onward, including technical issues that still need to be solved and expected milestones towards that goal on a timeline, *(ACEA et al. 2024c) reiterated that as outlined in their initial submission package, usually around 6 years will be required to qualify a new microchip completely through the whole supply chain until release in volume scale car production. The* *procedures resp. timeline are similar to those which they have communicated in previous consultations for lead substitution. Safety and long-term reliability have highest importance for automotive products, especially with electronics, where speed of data processing can save lives. The assessment of the long-term reliability of automotive components is very time consuming. Generally, between 5 to 7 years of development time are needed for a control device.*

(ACEA et al. 2024c) further described the following steps necessary for substitution:

- *As a first step the constructor creates a technical specification sheet for the control unit. This takes roundabout a year. During this time, the technical specifications will be described in the most accurate way. Once this is done the sheet is ready for contracting.*
- *Usually, it takes approximately a year until the control unit is assigned to a tier-1 supplier.*
- *After the assignment to a tier-1 supplier, the actual development time is starting. This phase takes up to three years. During this time, the single components are secured, including design validation of hardware and software, validation of functionality and reliability and several correction loops. Lifespan testing alone takes between 6 months and 1 year.*
- *Once the components are secured, the product, in our case the control unit, needs to be validated as well. During this time span, usually another 6 months and up to 1 year, it must be proven by means of several vehicle tests, that the product has the necessary maturity in terms of functionality and reliability. An important initial step in this stage is that the electronic components have to pass successfully the AEQ requirements like AEC Q100. As this causes efforts of several months and significant costs, FCP´s on the market have not AEQ qualification as standard feature; this limits the market offer.*
- *The next step is the integration of the component into electronic circuit board design. There are maybe several design variants to scrutinize and to validate to identify the most reliable design. Also, this is a procedure of at least several months.*
- *Then the testing of boards being produced under volume production similar conditions is following. These samples (ECU) than have to pass all component tests.*
- *After successful ECU laboratory validation, the samples go into tests in prototype cars for winter and summer test under different conditions.*
- *The software is developed in parallel and its testing and revision/adaptation must be released and harmonized with the various component and vehicle tests on the different degrees of maturity.*
- *Since many control units support the driver assistance systems required by law based on GSR II ((EU) 2019/2144), vehicle testing is one of the most important instruments of the development period.*
- *Following this phase, the homologation phase begins. Series vehicles are subject to various tests during this phase, be it emissions or tests for active and passive*

safety. This phase takes up to 1.5 years from the provision of vehicles for system approval tests to the receipt of the whole vehicle type approval (WVTA).

- *Soft- and hardware may fall in addition under Regulation (EU) 2018/1832 and later modifications need to be agreed by type approval authorities. By this the final hardware/software combination is element of the type approval.*

(ACEA et al. 2024c) add that it is in the key interest of the automotive industry to have long-term availability of electronic components. As the technologies in the semiconductor industry are changing and older fabs or older production methods are closed or terminated, there is the essential need to look at new developed components in new production technologies, with default requirement to be lead-free, as the probability for their future availability is higher than for semiconductors produced in older production technologies or fabs. The industry does not stick to lead-containing FCPs if there are lead-free substitutes available that fulfil the requirements. ACEA et al. ask to understand that changing of electronics in automotive is a very time-consuming procedure. The staff capacities along the supply chain and OEM for electronic and software development are limited. Electrical components with FPCs in particular are selected strategically and for the long term due to their complex functionality and interactions with software. Therefore, the number of variants used is minimized.

The consultants acknowledge the time-consuming process of changing electronic components within the automotive sector. Nevertheless, the above descriptions of the timeline are not sufficient to substantiate the need to continue this exemption for vehicles type approved before January 2030. Further, details are missing on how, technologically, the remaining FCPs that currently rely on this exemption will be phased out. Thereby, the above statements are not sufficiently specific to be considered a verifiable timeline. The consultants consider that the steps described above would already need to be completed in order to implement the phasing out that, according to ACEA et al., is and has been already carried out for some time.

According to ACEA et al., the exemption needs to remain valid for vehicles type approved before January 2030 as a transitional period. *Providing more insight on the need for a transition period,* (ACEA et al. 2024d) *stated that the requirements for long-term reliable automotive electronics are similar to military and aviation (or other means of transport equipment applications) and less to consumer electronics. The market offers for the best technical long-term reliable solutions is much more limited than for consumer products. Security, including cyber security, safety, including functional safety and long-term reliability, are very important for automotive electronic applications. For this reason, in general, instead of standard electronic components, specific selected components with stringent long-term reliability properties are used. The product life cycle of electronic components for automotive applications is many times higher as for e.g. microprocessors used in mobile phones, where new versions may come to market nearly every year. It takes several years to design and test new electronic systems until they can be released for use in series production of the automotive industry. Changing a known capacitor or resistor on an electronic circuit board (ECB) from supplier A to supplier B can be realized as minor product change and implemented as drop-in solution with limited testing efforts. However, changing large semiconductors with different properties in existing applications generally requires the complete validation including software testing and tests on vehicle level. A prerequisite for this is that the reliability of substitutes is ensured and validated. Further,* (ACEA et al. 2024d) *highlight that the limited manpower of design* *engineers for electronic assemblies and limited test capacities are concentrated on future systems instead of the redesign of applications with limited remaining product life cycle.*

(ACEA et al. 2024d) further stated that the exemption for vehicles that will be type approved before January 2030 is still necessary because the activities for the type approval and for series production of such vehicles have already been started in the past.

The consultants understand that the planning horizon for the change in components in the automotive sector is much longer compared to e.g. consumer electronics, as safety and reliability considerations play a more significant role, thereby limiting the number of components to those that have already been qualified, and making the process of introducing new electronic devices, such as flip chip semiconductor devices, time-consuming.

7.3.2 Environmental, health, safety and socioeconomic impacts

ACEA et al. were asked to provide insights on the impacts in case this exemption was not continued as requested. In response, (ACEA et al. 2024d) provided descriptions of assumed impacts, which are reproduced below. *ACEA et al. also highlighted that the circumstances and the tight time frame set for answering these questions do not allow to conduct a comparing life cycle impact analysis to assess the overall impact of different FCP variants.*

On assumed environmental, health and safety impacts, (ACEA et al. 2024d) states that the estimated total lead quantity of around 0.16 tonnes per year in the scope of ELV exemption 8(g)(ii) on vehicles new placed on the EU market in the year 2022 has a volume equivalent to 2.5x footballs or corresponds to the amount of lead in three starter batteries of heavy-duty trucks. In contrast to other products that contain lead, like fishing weights, shotgun cartridges and diving weights, this significantly smaller amount of used under ELV exemption 8(g)(ii) is encapsulated by a chemically stable polymer (underfill). The FCPs are normally part of an ECB which is also encapsulated in a housing. The contained Lead amount on average per vehicle is estimated with around 12 mg. The FCPs used will not be recycled separately, but as part of the ECB, on which they are mounted on, enter in the common ELV recycling procedures. A release of Lead and an impact on the environment after the component production / during the use phase of an article can almost be excluded. Further explaining that the environmental risks during automotive recycling are minimal due to small volumes of lead, high recycling rates, and legally regulated and monitored recycling processes, (ACEA et al. 2024d) conclude that in their opinion, the contribution to vehicle safety enabled by the use of such FCPs outweighs the disadvantages of using ELV exemption 8(g)(ii).

On the socio-economic impacts, (ACEA et al. 2024d) explained that such a significant change as the expiry of the ELV exemption 8(g)(ii) in these complex vehicle applications during the ongoing development of Tier 2 and Tier 1 and OEM for already planned requires a typical lead time of 6 years. Only software in vehicles is estimated to cause expenses in the amount of billions of euros per year and OEM, plus the efforts for the software at the suppliers for the same applications. In this case, necessary changes in current developments due to changes in legislation at short notice (short-term from the perspective of the automotive industry) only cause unconsidered additional expenses and negative monetary effects due to reduced amortization periods for all players in the supply chain with uncertain end. The additional efforts for these changes in the bridging *period between the early expiry and 2030 are disproportionate and can no longer be economically compensated by the remaining sales figures. In addition, these unplanned changes tie up resources for necessary new developments to improve competitiveness. (ACEA et al. 2024d) further assume that such a significant change as the expiry of exemption 8(g)(ii) in these complex vehicle applications before 2030 will cause, that the affected vehicle applications will not be changed, but the projects will be cancelled for the EU market, which could lead to a distortion of competition, particularly in the area of Small Car & Compact Car - class vehicles and their (sometimes safety-enhancing) equipment. A stop of exemption 8(g)(ii) will make it impossible to equip vehicles in the EU market with advanced vehicle safety systems, where such FCPs may be required to be in use. In cases where this is linked with meeting of requirements defined in the EU General Safety Regulation 2019/2144 EC such vehicles (e.g., new Whole Vehicle Type Approval after July 5th, 2022) will lose their type approval as providing such advanced vehicle safety systems is obligatory. As a consequence, an interruption of the market offer is caused.*

In the opinion of ACEA et al., the premature expiry of ELV exemptions harms both European consumers and European businesses. They are therefore not in the interest of the European Union. Furthermore, the decision-makers on the European side must fulfil their responsibility and create fair competitive conditions for all economic players that serve the European goals, to which the automotive industry has also committed itself as part of the Green Deal. From a socio-economic point of view, if product changes due to premature ELV exemptions expiry are possible at all in the short term, every Euro spent on additional product changes will interact with the requirements for the immense investments needed for the necessary transformation in Europe. This will limit the availability of affordable electric vehicles for customers and make the already faltering ramp-up of electromobility even more difficult.

The consultants acknowledge that it may not be possible to produce substantiated information on the potential impacts for the scenario that this exemption was not continued within a short time frame.

Regarding the described impacts, the consultants consider that on the one hand, it appears plausible to the consultants that in general, an abrupt expiry of the exemption will interfere with the OEMs' ability to put on the market vehicles already type approved and vehicles for which production schedules have been planned for the coming years. This may imply a potentially significant cost for OEMs and their supply chains. On the other hand, given that from the information provided by ACEA et al., the consultants cannot draw conclusions on whether and to which degree FCPs relying on this exemption are still used in production cars now and until January 2030, uncertainty remains whether such impacts would actually materialize in practice. The relevancy of the described impacts therefore remains unclear.

7.3.3 Summary and conclusions

ACEA et al. expect that exemption 8(g)(ii) can expire for vehicles type approved from 1 January 2030 onwards. For this reason, ACEA et al. have expressed their view that technical discussions on the current status of substitution and elimination are no longer relevant for the automotive sector. However, the objective of the exemption review and the consultants' mandate is to adapt the scope and validity period of exemption 8(g)(ii) to the scientific and technical progress to ensure that the use of lead is restricted to those cases where its use is unavoidable only for as long as is necessary. Further, the roadmap for the phasing out of the relevant FCPs provided by ACEA et al. does not include sufficient technical detail to clearly demonstrate how this phase out will be achieved. The consultants therefore aimed to focus this review on the question whether a continuation of exemption 8(g)(ii) for vehicles type approved before 1 January 2030 is still needed.

The automotive industry seems to rely on the electronics industry to know whether exemption 8(g)(ii) is still needed in practice. However, the last review of the equivalent exemption 15(a) on Annex III of RoHS did not lead the consultants to recommend a renewal, as the applicants at the time, represented by Texas Instruments, did not provide the evidence needed to substantiate the renewal request. During the present review of exemption 8(g)(ii), the automotive industry, represented by ACEA et al., also did not provide the requested technical information needed to justify the continuation of the exemption. ACEA et al. acknowledged not to possess the technical knowledge to respond to all questions. Despite this, ACEA et al. did evidently also not include expertise that can be assumed to be available when including relevant member companies and supply chain actors, including the semiconductor industry, to be able to provide the requested technical information. From this viewpoint, the lack of information on the technical specifics does not allow the consultants to form an opinion that differs from the conclusions of (Deubzer et al. 2022).

To summarize, ACEA et al.

- did not provide any examples of specific FCPs that require the exemption, including their functionality, data sheets, manufacturers, and reasons for why transitioning to lead-free solders or lead-free FCP variants was not feasible in these cases;
- did not provide technical insights to explain why lead-free FCPs fabricated in a technology node of 90 nm and above have not yet been substituted with lead-free FCPs fabricated in a technology node below 90 nm in all cases, although such fabrication technologies have been available since 2007 (clause (1));
- did not provide technical information that details under which conditions FCPs with semiconductor dies with an area equal or above 300 mm^2 can or cannot be produced using lead-free interconnection technologies (clause (2));
- did not provide technical information that details under which conditions FCPs that contain several dies can be produced using plastic interposers instead of silicon interposers (clause (3));
- did not provide details substantiating how the automotive industry wants to achieve that newly type approved vehicles will no longer be dependent on exemption 8(g)(ii) from 1 January 2030 on for new type-approved vehicles.

ACEA et al. did emphasize the need for a transition period before the exemption can expire and provided details on the timeframe of the planning horizon within the automotive industry. Electronic components need to be tested and qualified extensively before they can be considered for the integration into designs of mass-production vehicles. The timespan between design, start of production, and the end of production of type approved vehicles is expansive. This reasoning appears plausible and may justify a transition period, as opposed to an abrupt expiry of the exemption. Therefore, the consultants cannot exclude that at least some of the impacts described by ACEA et al., which are assumed to occur in case this exemption expired abruptly, may materialize in practice. However, the lack of evidence to which degree FCPs that rely on this exemption are currently actually used in production vehicles introduces uncertainty into these considerations.

In conclusion, ACEA et al. consider that this exemption will no longer be needed for vehicles type approved from 1 January 2030 on and request the validity of exemption 8(g)(ii) until that date as a transition period. ACEA et al. did generally not provide the technical information requested by the consultants needed to evaluate the current status of the possibility to substitute or eliminate lead-containing solders used in level 1 bumps of flip chip packages. Therefore, technically, the consultants do not have the evidence needed to recommend continuing the exemption. Further, in the consultants' view, the lack of technical information provided on the status and the developments in the phasing out of FCPs that require this exemption leads to uncertainty regarding the proposed timeline until a phasing out of the exemption for newly type approved vehicles from January 2030 onwards.

7.4 Recommendation

The information provided by ACEA et al. is insufficient and does not allow a proper assessment of the current and developing status of lead-free FCP in automotive uses. Since the applicants did not provide sufficient information justifying that the use of lead can be considered as unavoidable in line with Art. 4(2)(b)(ii), the consultants cannot give a recommendation as to the continuation of exemption 8(g)(ii).

However, given that ACEA et al. indicated to no longer require the exemption starting January 2030, the COM may also decide to grant this exemption as a transitional period towards the phaseout of this exemption. In this case, the COM may consider adopting the proposal of ACEA et al. for the continuation of the exemption as is displayed in Table 7-4.

Table 7-4: Recommendation of the exemption wording

No.	Exemption	Scope and dates of applicability
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 that electrical connection consists of any of the following: (1) a semiconductor technology node of 90 nm or larger; (2) a single die of 300 mm^2 or larger in any semiconductor technology node; (3) stacked die packages with dies of 300 mm^2 or larger, or silicon interposers of 300 mm^2 or larger.	Vehicles type-approved before 1 January 2030 and spare parts for these vehicles.

The consultants highlight that ACEA et al. stated that FCPs that currently rely on the three sub-clauses of exemption 8(g)(ii) are already in the process of being phased out and the exemption is expected to no longer be needed for vehicles type approved from 1 January 2030 on. The consultants therefore consider that a continuation of this exemption for vehicles type approved from January 2030 on should not be needed.

7.5 References

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