# Adaptation to scientific and technical progress of Annex II to Directive 2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS)

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# Content

# 1 Background

Directives 2000/53/EC on end-life-vehicles ("ELV" Directive) and 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment ("RoHS" Directive) both restrict the use of certain hazardous substances in vehicles as well as in electrical and electronic equipment (EEE). Both Directives also include lists of exemptions to these use restrictions which are adapted regularly to scientific and technical progress according to the respective provisions in the Directives. Some of these exemptions are regulated under each of the two Directives since many applications of the regulated substances are used in both vehicles and EEE.

## 1.1 The ELV 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 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.

With regard to this adaptation procedure, Annex II has already been adapted three times (2002, 2005 and 2008)[2].

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.

2 Additionally the Annex has been amended by Commission Decision 2005/63/EC of 24 January 2005 and Commission Decision 2005/438/EC of 10 June 2005 by adding the requirement that spare parts put on the market after 1 July 2003 used for vehicles put on the market before that date are exempted from the use restrictions in Article 4(2)(a).

## 1.2 The RoHS Directive

Article 4(1) of Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment provides "that from 1 July 2006, new electrical and electronic equipment put on the market does not contain lead, mercury, cadmium, hexavalent chromium, PBB or PBDE." The Annex to the Directive lists a limited number of applications of lead, mercury, cadmium and hexavalent chromium, which are exempted from the requirements of Article 4(1).

Article 5(1)(b) of the Directive provides that materials and components can be exempted from the substance restrictions contained in Article 4(1) if their elimination or substitution via design changes or materials and components which do not require any of the materials or substances referred to therein is technically or scientifically impracticable, or where the negative environmental, health and/or consumer safety impacts caused by substitution outweigh the environmental, health and/or consumer safety benefits thereof.

On the basis of this provision the Commission has received (and is still receiving) additional requests for applications to be exempted from the requirements of the Directive from industry. These requests need to be evaluated in order to assess whether they fulfil the above mentioned requirements of Article 5(1)(b). Where the requirements are fulfilled the Commission may propose a draft Decision amending the RoHS Directive and its Annex.

The RoHS Annex has already been amended seven times (2005, 2006 and 2008).

Recently, the Annex as well as 5 new exemption requests have been evaluated by Öko-Institut e.V. and Fraunhofer IZM and will probably lead to a further amendment of the Annex in the course of 2010.

# 2 Scope

Öko-Institut e.V. and Fraunhofer Institute for Reliability and Microintegration IZM have been commissioned by the European Commission with technical assistance for the evaluation of selected exemptions of the ELV and the RoHS Directives as well as for the evaluation of new requests for exemptions with the aim to provide recommendations for a clear and unambiguous wording of the reviewed and new exemptions. The evaluation includes consultations with stakeholders on the possible adaptation of the Annexes and the set up of a website in order to keep stakeholders informed on the progress of work (http://rohs-elv.exemptions.oeko.info/).

In the course of the project, three stakeholder consultations have been conducted. An overview on the covered exemptions and exemption requests is given in Table 1.

On 25 January 2009 a **first stakeholder consultation** round was launched and closed after six weeks on 9 March 2009. In agreement with the Commission, the exemptions covered by this stakeholder consultation were the two ELV exemptions 8a and 8b of the group "Lead and lead compounds in components". All non-confidential stakeholder comments submitted during the first consultation were made available on the EU CIRCA website (http://circa.europa.eu/Public/irc/env/elv_4/library?l=/consultation_1/stakeholder_comments&vm=detailed&sb=Title). The final recommendation of Öko-Institut and Fraunhofer IZM on adaptation of exemption 8 (cf. section 4.7 through to section 4.17) has already been published on the EU CIRCA website in September 2009 (http://circa.europa.eu/Public/irc/env/elv_4/library?l=/reports/099016_finalpdf/_EN 1.0_&a=d). Following these recommendations, the Commission has adopted the fourth revision of Annex II to Directive 2000/53/EC in February 2010 (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32010D0115:EN:NOT).

**A second and a third stakeholder consultation** was launched on Monday 8 June in agreement with the Commission. Both consultations ran for 8 weeks until 3 August 2009. In the second consultation, stakeholders were asked to submit comments on certain entries of Annex II (exemption 1, 2c, 3, 4b, 5, 6, 10, 13, 14a and 14b). Furthermore, stakeholders were asked to comment on what had been posted as new exemption requests (exemption request no. 1 and 2). The stakeholder contributions received with regard to the second stakeholder consultation were made available on the EU CIRCA website (http://circa.europa.eu/Public/irc/env/elv_4/library?l=/consultation_2&vm=detailed&sb=Title). For the third stakeholder consultation on a RoHS exemption request (exemption request no.3), no stakeholder contributions were received.

## 3 Overview

In the course of the project, twelve existing ELV exemptions have been reviewed and three new RoHS and ELV exemption requests have been evaluated. The exemptions and exemption request covered in this project together with the involved stakeholders and the final recommendations and expiry date given are summarized in Table 1. Table 2 and Table 3 summarize the special cases of the review of exemption 8a and of exemption 10. Please refer to the corresponding sections of this report for more details on the evaluation results and for more background on the rationale behind the recommendations.

Table 1 Overview recommendations and expiry date

| No. | Current wording | Stakeholders | Recommendation | Expiry / review date |
|---|---|---|---|---|
| **ELV exemptions** | | | | |
| *Lead as an alloying element* | | | | |
| 1 | Steel for machining purposes and galvanised steel containing up to 0,35% lead by weight | ACEA/JAMA/KAMA/-CLEPA/EUROFER/EGGA | Split into two exemptions with the following wording:<br>1(a): "Steel for machining purposes and batch hot dip galvanised steel components containing up to 0,35% lead by weight"<br>1(b): "Continuously galvanised steel sheet containing up to 0,35% lead by weight for vehicles type approved before 1 January 2016 and spare parts for these vehicles." | (1a): No expiry date<br>(1b): 1 January 2016 |
| 2c | Aluminium with a lead content up to 0,4% by weight | ACEA/JAMA/KAMA/-CLEPA/EAA/OEA et al.; Schrader Electronics Ltd; Schrader S.A.S.; WGM and VDM | Continuation of the exemption with the current wording. | Review 5 years after entry into force. |
| 3 | Copper alloy containing up to 4% lead by weight | ACEA/JAMA/KAMA/CLEPA et al.; Schrader Electronics Ltd; Schrader S.A.S.; WGM and VDM | Continuation of the exemption with the current wording. | Review 5 years after entry into force. |
| 4b | Bearing shells and bushes in engines, transmissions and air conditioning compressors | ACEA/JAMA/KAMA/-CLEPA/et al.; Federal Mogul Deutschland GmbH | No change of wording and expiry date. | 1 July 2011 |
| *Lead and lead compounds in components* | | | | |
| 5 | Batteries | ACEA/JAMA/KAMA/-CLEPA/Eurobat/ILA | Continuation of exemption with the current wording. | Review 5 years after entry into force. |
| 6 | Vibration dampers | ACEA/JAMA/KAMA/CLEPA et al. | Continuation of exemption for all vehicles type approved before 1 January 2016. | 1 January 2016 |
| 8a | Solder in electronic circuit boards and other electrical applications except from glass | ACEA/JAMA/KAMA/CLEPA et al.; EECA / ESIA; EICTA; ON Semiconductor; Society of Motor Manufacturers and Traders (SMMT); Texas Instruments; Umicore; ZVEI | Split into different exemptions, see Table 2 | |
| 8b | Solder in electrical applications on glass | Antaya Technologies; KKAI; Society of Motor Manufacturers and Traders (SMMT); ZVEI | Split into two exemptions with the following wording:<br>(i): Lead in solders in electrical glazing applications on glass except for soldering in laminated glazing in vehicles type approved | (i): 1 January 2013<br>(ii): review in 2014 |

| No. | Current wording | Stakeholders | Recommendation | Expiry / review date |
|---|---|---|---|---|
| | | | before 1 January 2013.<br>(ii) Lead in solders for soldering in laminated glazings; review in 2014. | |
| 10 | Electrical components which contain lead in a glass or ceramic matrix compound except glass in bulbs and glaze of spark plugs | ACEA/JAMA/KAMA/CLEPA et al.; JEITA/CIAJ/JEMA/JBMIA; Sensata Technologies | 2 options due to dissent (cf. section 4.18.8 and Table 3):<br>(i) application-specific full list<br>(ii) application-specific short list | See Table 3 |
| *Hexavalent chromium* | | | | |
| 13 | Absorption refrigerators in motorcaravans | Dometic Group; Thetford B.V. | New wording:<br>“Hexavalent chromium as an anti-corrosion agent of the carbon steel cooling system in absorption refrigerators up to 0,75 weight-% in the cooling solution except where the use of other cooling technologies is practicable (i.e. available on the market for the application in motor caravans) and does not lead to negative environmental, health and/or consumer safety impacts.“ | No expiry date. |
| *Mercury* | | | | |
| 14a | Discharge lamps for headlight application | ACEA/JAMA/KAMA/CLEPA et al. | No change of wording and expiry date. | 1 July 2012 |
| 14b | Fluorescent tubes used in instrument panel displays | ACEA/JAMA/KAMA/CLEPA et al. | | |
| **New RoHS and ELV exemption requests** | | | | |
| **No.** | **Proposed wording (applicant)** | **Stakeholders** | **Recommendation** | **Expiry / review date** |
| 1 | Lead in solders for the connection of very thin (<100 µm) enamelled copper wires and for the connection of enamelled clad aluminium wires (CCAWs) with a copper layer smaller than 20 µm (PSS Belgium NV) | D&M PSS | Not to be granted. | - |
| 2 | Lead in thermoelectric generators (ACEA | ACEA/JAMA/KAMA/CLEPA et al. | “Lead-containing thermoelectric materials in automotive electrical | Review in 2015. |

| No. | Current wording | Stakeholders | Recommendation | Expiry / review date |
|---|---|---|---|---|
| | JAMA KAMA CLEPA) | | applications to reduce $CO_2$ emissions by recuperation of exhaust heat for vehicle types approved before 31 December 2018 and spare parts for these vehicles.” | |
| 3 | Lead and cadmium in glazes and colours used on ceramic lamp bases, lamp carriers and clocks (Faianças Ideal Vale de Ourém Lda.) | Faianças Ideal Vale de Ourém Lda. | “Lead and cadmium in glazes and colours used on ceramic lamp bases, lamp carriers and clocks” | No expiry date. |

Table 2 Overview recommendation for exemption 8(a) “Lead in solder in electronic circuit boards and other electrical applications except on glass”

| | Exemption | Scope and expiry date of the exemption | Recommendation |
|---|---|---|---|
| I | Lead in solders to attach electrical and electronic components to electronic circuit boards and lead in finishes on terminations of components others than electrolyte aluminium capacitors, on component pins and on printed wiring boards | Vehicles type approved before 1 January 2016, and spare parts for these vehicles | Grant |
| | Lead in solder of carry over electric/electronic parts or systems first used in vehicles type approved before 31 December 2010 | | Do not grant |
| II | Lead in solders in other electrical applications than soldering on printed wiring boards or on glass | Vehicles type approved before 1 January 2011, and spare parts for these vehicles | Grant |
| III | Lead in finishes on terminals of electrolyte aluminium capacitors | Vehicles type approved before 1 January 2013, and spare parts for these vehicles | Grant |
| IV | Lead used in soldering on glass in mass airflow sensors | Vehicles type approved before 1 January 2015, and spare parts of such vehicles | Grant |
| V | Lead in high melting temperature type solders (i.e. lead-based alloys containing 85% by weight or more lead) | Review in 2013 | Grant (review together with equivalent exemption 7a in RoHS Directive; align with this expiry date) |
| VI | Lead in compliant pin connector systems | Review in 2014 | Grant |

| | Exemption | Scope and expiry date of the exemption | Recommendation |
|---|---|---|---|
| VII | Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages | Review in 2014 | Grant (review together with equivalent exemption 15 of RoHS Directive) |
| VIII | Lead in solder to attach heat spreaders to the heat sink in power semiconductor assemblies with a chip size of at least 1 cm² of projection area and a nominal current density of at least 1 A/mm2 of silicon chip area | Review in 2014 | Grant. |

Table 3 Overview recommendation for exemption 10

| Option | Recommended wording | Expiry / review date |
|---|---|---|
| 1 „application-specific full list“ | 10(a): Lead in | |
| | (i) ceramic materials of piezoelectric components | |
| | (ii) ceramic materials of PTC components | |
| | (iii) PZT ceramic passivation layers of multilayer ceramic varistors | |
| | (iv) PZT based dielectric ceramic materials of capacitors being part of integrated circuits or discrete semiconductors | |
| | (v) dielectric ceramic materials of capacitors with a rated voltage of 125 V AC or 250 V DC or higher | |
| | (vi) dielectric ceramic materials of capacitors with a rated voltage of less than 125 V AC or 250 V DC in vehicles type approved before 1 January 2016, and in spare parts for these vehicles | 1 January 2016 |
| | (vii) dielectric ceramic materials of capacitors compensating the temperature-related deviations of sensors in ultrasonic sonar systems | Review in 2014 |
| | 10(b): Electrical and electronic components, which contain lead in a glass or a glass matrix compound, in a glass-ceramic material, or in a glass-ceramic matrix compound, forming a functional layer on a substrate, or a sealing, bonding or encapsulation.<br>This exemption does not cover the use of lead in glass of bulbs and in glaze of spark plugs. | |
| | 10(c): Lead in the ceramic materials of components, which are not listed under exemption 10 a), in vehicles type approved before 1 July 2014, and in spare parts for these vehicles | 1 July 2014 |
| | 10(d): Electrical and electronic components, which contain lead in a glass or a glass matrix compound, in a glass-ceramic material, or in a glass-ceramic matrix compound for any other purposes than those listed in 10 b), in vehicles type approved before 1 July 2014, and in spare parts for these vehicles | 1 July 2014 |

| Option | Recommended wording | Expiry / review date |
|---|---|---|
| 2 „application-specific short list“ | 10(a): electrical and electronic components, which contain lead in a glass or ceramic, in a glass or ceramic matrix compound, in a glass-ceramic material, or in a glass-ceramic matrix compound.<br>This exemption does not cover the use of lead in<br>- glass of bulbs and in glaze of spark plugs.<br>- dielectric ceramic materials of components listed under 10 b), 10 c) and 10 d) | |
| | 10(b): lead in PZT based dielectric ceramic materials of capacitors being part of integrated circuits or discrete semiconductors | |
| | 10(c): lead in dielectric ceramic materials of capacitors with a rated voltage of less than 125 V AC or 250 V DC in vehicles type approved before 1 January 2016, and in spare parts for these vehicles | 1 January 2016 |
| | 10(d): lead in the dielectric ceramic materials of capacitors compensating the temperature-related deviations of sensors in ultrasonic sonar systems | Review in 2014 |

# 4 Evaluation results

## 4.1 Exemption no. 1

*“Steel for machining purposes and galvanised steel containing up to 0,35% lead by weight”*

This chapter is the result of an update and review of the former evaluation results. Stakeholders have provided information in the context of the second stakeholder consultation (cf. http://circa.europa.eu/Public/irc/env/elv_4/library?l=/consultation_2/stakeholder_contribution/elv_exemption_1&vm=detailed&sb=Title). This information was evaluated and stakeholders received further questions as a result and provided additional information.

Subsequently, a conference call was held with all involved stakeholders to clarify open questions. As a result, a recommendation was drafted and exchanged with stakeholders in order to ensure technical accuracy of the described application. The contractors then finalised the recommendation.

### 4.1.2 Description of exemption

In its current form, Exemption 1 includes both the addition of lead to steel for machining purposes (i.e. drilling, stamping, etc.) and the use of lead as an additive in the galvanizing of steel.

Stakeholders from the Iron and Steel Industries (represented by the European Confederation of Iron and Steel Industries – Eurofer, the European General Galvanizers Association

(EGGA) and the automotive industry) request an extension of the exemption for machined steel and batch galvanized steel, but voluntarily suggest that a 0,1% lead content limit be set for continuously galvanized steel sheet. Since this is the tolerated maximum concentration as stated in the Annex to the ELV Directive, the proposal is equivalent to restricting a future exemption to batch galvanised steel instead of all types of galvanised steel.

Furthermore, stakeholders have suggested to limit the exemption for continuously galvanised steel sheet to vehicles type approved before the 1 January 2016 and spare parts for these vehicles.

Hence, a possible new wording for Exemption no. 1 could be:

Exemption 1(a): "Steel for machining purposes and batch hot dip galvanised steel components containing up to 0,35% lead by weight" (no expiry date)

Exemption 1(b): "Continuously galvanised steel sheet containing up to 0,35% lead by weight for vehicles type approved before 1 January 2016 and spare parts for these vehicles."

**Steel for machining purposes**

Lead is used in steel to improve machinability. The addition of lead in machined steel allows for the automation of the production process, high cutting speed and federates (low cycle times), improved chip fracturing, longer tool life, better surface finish and more accurate dimension control.

Two different types of leaded steel grades can be distinguished:

a) Low carbon free-cutting steels (aluminium free);

b) Carbon and low alloy steels (which may be aluminium-killed or aluminium free).

Free-cutting steels provide optimum free-machining performance with comparatively low mechanical strength. These steels are used where their strength satisfies the future component's mechanical requirements and requires high machinability.

If greater mechanical strength is required, a carbon or alloy grade may need to be used. If machining is also required on these components, the best method for aiding machining and hence reducing financial and energy costs is to add lead to the steel.

Leaded steel is used in a broad variety of applications in vehicles according to figures provided by the automotive industry. For example, the International Material Data System (IMDS) lists up to 25 000 steel parts containing lead. Leaded steel is used, among others, in bolts, screws, nuts, hollow screws, valve pins, spring guides, valve pistons, valve seats, sleeves, piston rods, magnet/pole cores, solenoids, bushings, housings, distance pieces, bleed screws, axles, shafts, stubs, sockets, locks, brackets, rotors, etc. Most of these parts are used in critical environment or safety systems (e.g. brakes, lighting, fuel systems, restraining systems, and engines).

The amount of lead in machined steel per vehicle is estimated to range from 10 to 25 g (i.e. between 2,9 and 7,1 kg of leaded steel per vehicle, 5 kg on average). The total amount of lead used in these kinds of applications in vehicles produced in Europe is therefore between 180 and 440 t/y considering 17,7 million vehicles, i.e. ignoring the current economic downturn.

**Galvanised steel**

Lead is present in the zinc coating of galvanised steels. Lead has no beneficial (or adverse) effect on the coated product, but has important functions in the galvanizing process:

- Fluidity – optimal drainage reduces excess zinc on the product (i.e. better resource efficiency)
- Ease of drossing – to aid recycling
- Avoidance of “floating dross” during galvanizing of complex geometries which may lead to adverse surface finishes
- Kettle protection against uneven heat distribution (from burners) – preventing dangerous “run-outs” of molten zinc

The importance of each of these factors varies according to the nature of the component to be coated, the technical features of the plant (often related to the age of the plant) and the type of work that is required of the plant (range of work).

Lead can be introduced to the zinc bath in three ways:

- Use of Z5 zinc grades (this application is declining)
- Use of recycled zinc
- Small, controlled, additions of lead ingots to baths of Z1 zinc grades

The maximum content of lead in primary (not recycled) zinc is defined in EN 1179, shown in Table 4.

Table 4 Zinc grades as defined by EN 1179

| EN 1179 Grade | Max lead content |
|---|---|
| Z1 (Special High Grade) | 0,003% |
| Z2 | 0,005% |
| Z3 | 0,03% |
| Z4 | 0,45% |
| Z5 | 1,4% |

The maximum lead content of recycled zinc is defined by EN 13283:2002. The standard cites 3 grades of secondary zinc – ZSA, ZS1 and ZS2 with maximum lead contents of 1,3%, 1,4% and 1,6%, respectively (according to EU Commission 2001). However, it should be noted that, for technical reasons related to other impurities in recycled zinc, recycled zinc is always used in conjunction with primary zinc in the batch galvanizing bath.

*Continuous galvanising*

This method is used for steel sheet that is continuously galvanised.

According to stakeholders, steel sheet "is continuously fed through a bath of molten zinc to apply a coating. Continuous galvanizing is the 'in line' process in which a coil of steel sheet / strip is passed continuously through a bath of molten zinc to apply a thin, formable coating of zinc. This sheet is then coiled and dispatched to a manufacturer who will then form / manufacture after the coating has been applied (e.g. for automotive body panels)."

Continuously galvanized steel used by the automotive industry in the EU amounts to 10 million tonnes.

*Batch galvanising*

General (batch) galvanizing is the immersion of fabricated steel articles into a bath of molten zinc containing a certain amount of lead, to apply a zinc coating that is metallurgically bonded to the steel. The coating is specified according to EN ISO 1461 (1999).

Lead has a low solubility in the zinc-iron alloys that are formed during the galvanizing reaction. Hence, the quantity of lead present in the coating is normally significantly lower than the lead present in the process bath – typically half as much (see Table 5 and Table 6). For a given bath composition, the variations of lead concentrations in the coating mainly depend on the steel type (reactivity with molten zinc). As shown in Table 6, lead is alloyed in the coating at levels between 0,30% and less than 0,80%.

Table 5 Composition of galvanizing bath

| Plant | Pb (%) | Sn (%) | Al (%) |
|---|---|---|---|
| **1** | 1,017 | 0,203 | - |
| **2** | 1,047 | 0,478 | 0,037 |

Table 6 Concentration of lead in coating[a)]

| Steel type | Plant | Dipping time (min) | Pb (%) | Sn (%) | Al (%) |
|---|---|---|---|---|---|
| A | 1 | 5 | 0,456 | 0,076 | - |
| | | 9 | 0,383 | 0,058 | - |
| | 2 | 5 | 0,351 | 0,193 | 0,068 |
| | | 9 | 0,381 | 0,195 | 0,095 |
| B | 1 | 5 | 0,697 | 0,109 | - |
| | | 9 | 0,728 | 0,110 | - |
| | 2 | 5 | 0,477 | 0,275 | 0,084 |
| | | 9 | 0,534 | 0,233 | 0,110 |
| C | 1 | 5 | 0,380 | 0,073 | - |
| | | 9 | 0,315 | 0,059 | - |
| | 2 | 5 | 0,630 | 0,367 | 0,084 |
| | | 9 | 0,521 | 0,283 | 0,086 |

[a)] *Lead concentrations in the entire automobile component galvanized in these baths will be lower*

Generally galvanized automotive components are used in applications such as entire chassis, engine cradles, suspension arms and many others. Advantages of generally galvanized components include:

- highly durable corrosion protection,
- resistance to stone chipping/mechanical damage,
- increased durability allowing lighter steel sections,
- alternative to coatings containing hexavalent chromium,
- recyclable within existing steel recycling circuit.

Batch galvanised steel production volumes for automotive applications that fall within the scope of the ELV Directive are estimated between 10 000 t and 50 000 t per year, representing a range of 0,05 g to 0,71 g of lead use per vehicle in this application[3]. Lead concentrations in finished parts are below 0,024%, however, because the zinc coating may be considered as a homogeneous component, an exemption is still required from a legal point of view.

[3] Considering that the zinc coating represents 3% by weight of the galvanised steel, and that lead concentrations in the zinc coating are between 0,3% and 0,8% by weight, for a total galvanised steel use between 10 000 and 50 000 t..

### 4.1.3 Justification for exemption

**Steel containing lead for machining purposes**

The justification for the continued exemption can be summarised as follows: "All currently identified alternatives to lead as a machinability enhancer in steel have been formally assessed without identifying any addition that effectively replaces lead in all respects. Lead-free alternatives may show acceptable results in single machinability tests, but the overall performance of the lead-free steels is worse than that of leaded steel. If a variety of machining operations is required or if deep drilling of material is required, lead is still considered the best machinability enhancer for industrial production.

Customer demand supports the view that leaded steels are required rather than the alternatives which are currently offered by European steel manufacturers".

Reference is made by the steel industry to different reports investigating the machinability of lead-free steel alloys:

The University of Pittsburgh had developed a non-leaded low carbon free-cutting steel (1215) containing 0,04% to 0,08% tin which they claimed could replace leaded free-cutting steel (12L14). A range of machinability tests was undertaken with tin treated steel in order to investigate these claims (Bateson & Reynolds 1999). The results of these tests indicated that tin treated free-cutting steels showed less favourable results with regard to the different aspects of machinability than leaded steels. It was concluded that tin could not replace lead in free-cutting steels.

The European steelmakers and component manufacturers formed a collaborative research project funded by the European Coal & Steel Research (ECSC) to evaluate potential alternatives to lead for low carbon free-cutting steels and carbon/alloy grades.

The final report of this project summarises the results of machinability tests conducted with different lead-treated and lead-free steel alloys. These machinability tests included measurement of tool life, tool wear, surface finish, chip form, tool force and tool temperature. The steel grades selected for these tests were free-cutting steels (11SMn30), steels for hardening and tempering (C45) and case hardening steels (16MnCr5) with the following machinability enhancing additions: lead, bismuth, increased sulphur (with and without tellurium), tin (with low and high copper), phosphorus and calcium. Bismuth is often considered as a potential alternative to lead due to its proximity in the periodic table (could therefore have similar properties) and its significantly lower health and environmental impacts.

The general conclusion of these tests is that leaded steels showed the best performance in tests at lower cutting speeds, with high speed steel tools and in deep hole drilling. Non-leaded alternative grades generally gave poorer chip form and surface finish. It was shown that of all the alternatives, bismuth is best able to substitute lead under certain conditions, although the cost of the addition may make it uneconomic, particularly for large scale application. Furthermore, the hot workability of bismuth steels is reduced compared to leaded steels. Hot workability is a fundamental requirement for steel production.

This parameter is of significance when the steel is being rolled to the required size for a customer from a piece with a larger (as-cast) cross sectional area. The reduced hot-workability of bismuth steels effectively means that it is significantly harder for a steel roller to produce a bar with the same machining properties and surface integrity if the steel obtains its machining properties from bismuth rather than lead.

Industry emphasized the importance of the 10% reduction in hot workability compared to a low-carbon free-cutting steel. Free-cutting steels are already close to the limit of what can be conventionally rolled, making the rolling of bismuthed steel nearly impossible. This means that the bismuthed steel requires more energy to be rolled in order to increase its ductility. However, this can create ruptures in the steel surface which cannot be rectified and can be difficult to detect, causing problems with material integrity and performance if these ruptures are not detected.

It is therefore expected that the energy cost associated with bismuth would be higher as well as potentially higher error rates.

Although the machining properties of bismuth-treated steels approach those of lead-treated steels for certain machining operations, in the majority of machining operations lead remains the most effective machinability additive through its wide range of machining characteristics.

It was further concluded in the report that calcium can substitute lead in C45 steels for use at higher cutting speeds. However, calcium treated steels require higher cutting forces, have poorer chip form and have their best performance limited to a narrower range of machining speeds in comparison with the leaded product. The more limited benefits of calcium treated grades may not be able to match the benefits of leaded grades in many instances since it is very likely that a large variety of machining operations are required for many automotive components.

Steels containing tin generally did not show good performance in the machinability tests and thus, was not considered as a suitable replacement for lead in steel.

### Galvanised steel

With regard to galvanised steel, two different application areas can be distinguished:

Continuously galvanised steel sheet components, such as body panels that are normally over-painted, account for approximately 99% of the volume of galvanized components used in automotive applications (10 million tonnes of steel). These galvanised steel sheets are mainly produced by steel producers in dedicated facilities. These processes have now been developed so that they can operate with lower levels of lead that allow compliance with the

0,1% lead threshold. In contrast, low volume components of more complex geometry and requiring higher levels of corrosion resistance are processed in general (batch) galvanizing plants. These components include hollow parts and require centrifuge galvanizing (such as those with threads/moving parts, e.g. door hinges for specialised vehicles or crash boxes). For components processed in these plants, the presence of lead is currently not avoidable and could not be reduced to meet the 0,1% lead threshold.

Research is ongoing within the industry to develop new zinc-based alloys for general galvanizing. Principal research goals are: (i) more zinc-efficient coatings (thinner coatings regardless of steel type); and (ii) coatings of more consistent appearance and surface finish. These goals are accompanied with a desire to reduce the presence of hazardous substances, including lead.

Due to the fact that current lead prices are higher than those of zinc, there is no economic advantage to intentionally add lead to a galvanizing bath where it is not technically required[4].

In addition to the technical viability, stakeholders state that there are important consequences to the premature removal of the exemption:

- Requiring lower lead content will result in reduced use of recycled zinc (remelt). The galvanizing industry is the sole outlet for remelt zinc (from roofing applications and remelt of zinc entrained in galvanizers' ashes). Lower prices for remelt zinc will also adversely affect the economic viability of recycling of galvanizers' ashes and dross.
- Reduced drainage can increase zinc use on the component beyond that which is required for its protection.
- Bismuth is discussed as a possible substitute for lead; however bismuth is a co-product of lead production. As there currently is no primary production of bismuth, its adequacy as a replacement for lead in the industrial sector has been questioned due to possible availability issues.
- Any action to discourage the use of galvanized coatings for components can lead to their replacement with alternatives that have higher lifecycle energy and that are not fully recyclable.

**Environmental relevance**

In automotive applications, the coating is mainly employed for its robustness (e.g. stone chipping resistance) and corrosion of the surface is minimal with most of the coating remaining at the end of a vehicle's life. The lead in a galvanized coating behaves the same way as in free-machining steels: there is no preferential release of lead although it is clear

4 Lead was effectively more expensive than Zinc. On 18/11/09, London Metal Exchange Cash Prices were $2404.50 for lead and $2251.00 for zinc, i.e. lead was 6,8% more expensive than zinc.

that very small quantities of lead may be dispersed if the coating is damaged. According to stakeholders, release to the environment during service life is insignificant. Furthermore, the most exposed components are typically those high volume components that already meet the 0,1% limit. The components for which the exemption is required are typically those that are not exposed to higher levels of corrosion (e.g. hinges).

Regarding the environmental relevance of lead in steel during the recycling of end-of-life vehicles, the majority of leaded steel parts end up in the metal scrap fraction which is sent to electric arc furnaces (EAF). There, the lead vaporises into the off-gas, where it condenses onto cooler particles (the solid phase to vapour phase lead ratio is 10 000:1), and is then captured in the EAF fabric filters of the off-gas cleaning system (dust capture efficiency > 99,99%). The captured dust is then transferred together with zinc to recycling facilities where lead is recovered.

It is estimated that the recovery rate of all the zinc used in automobiles exceeds 80%.

### 4.1.4 Critical review of data and information

**Steel containing lead for machining purposes**

As stated by the industry, most lead-free alternatives are significantly less machinable. Some alternatives provide comparable results to lead containing steel in individual machinability tests (calcium or bismuth alloyed steels for example). However, steels used in the automotive industry go through a large variety of machining operations. Thus, the overall performance of steels in the various machinability tests (chip form, tool life and wear, surface finish, tool force, hot workability, deep drilling, etc.) needs to be considered.

Calcium treated steels are capable of replacing leaded steels in various applications, however a general substitution does not seem possible at the moment because calcium treated steels have a narrower optimal range of machining speeds in comparison with leaded grades.

This setback leaves only bismuth approaching lead alloyed steel overall performance. For many characteristics it equals – and sometimes even outperforms – leaded steels but its hot workability is 10% poorer. As mentioned earlier, stakeholders stressed that this is a very significant technical disadvantage in regards to how fundamental and important this characteristic is in steel production. It is stated that this issue alone is enough to rule out the possibility of using bismuthed steels as a replacement of leaded steels.

Another potentially very significant disadvantage of bismuth raised by stakeholders is its limited availability. They explained that today, bismuth is mainly produced as a by-product of other metal mines such as lead or gold mines. There is currently no primary production of bismuth and its ability to meet demand if used as a replacement for lead in industry has been questioned.

In the USGS Minerals Yearbook 2007, Carlin confirms that there is no primary production of bismuth in the world (Carlin 2007). Only one such mine exists in Bolivia and is currently on standby, awaiting a substantial increase in the metal price. Bismuth is currently produced as a lead refining by-product. World refinery production is currently at its stable level of 15 000 t/y. Major producers are China, Mexico and Belgium responsible for 77%, 8% and 5% of total production respectively. World demand has been increasing by 3% to 5% per year. Carlin predicts that a full switch to lead-free solders would be responsible for a 25% increase in bismuth demand and for a 0,8% decrease in lead demand. However, "Chinese supplies are expected to be able to keep the bismuth market stable."

An estimation of the maximum amount of bismuth required to directly replace leaded steels with bismuthed steels will be made in this paragraph. According to Reynolds et al. (2005), steel containing 0,35% lead by weight would, if this alternative were ever to be more technically satisfying, have been replaced by steel containing at most 0,075% bismuth by weight[5]. This would mean saving between 180 and 440 t of lead per year and replacing it with between 39 and 94 t of bismuth per year[6]. This would represent less than a 0,63% increase in demand/world production. Industry argues that process losses would be very significant, possibly increasing demand by a factor of ten or more. Even if the additional increase were of 6,3%, compared to the usual 3% or 5%, it is important to keep in mind that Carlin was not particularly worried by the possible 25% increase in demand caused by a switch to lead-free solders (Carlin 2007). The stakeholder concludes that the availability of bismuth does not seem to be the limiting factor for switching to bismuthed steels.

The higher price of Bismuth is also claimed to be a problem, although stakeholders did not provide any data on this matter. This aspect will be quickly addressed in this paragraph, although economic arguments are not explicitly taken into consideration in the context of this scientific and technical evaluation of exemptions under the ELV Directive.

A quick look at the economics situation however concludes the following. Based on USGS Minerals Yearbook 2007 data (Guberman 2007 and Carlin 2007), bismuth is up to 12 times more expensive than lead[7]. However, considering the assumed maximum replacement ratio of 1:5, this would mean bismuthed steels would be only 2,4 times more expensive than

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5 After testing bismuth steels containing up to 0,075% bismuth by weight, the ECSC study concludes that hot workability issues limit bismuth content to at least 0,05%, meaning that the calculated figures that follow could be overestimated by 50%.

6 Hence substituting 1 g bismuth with about 5 g lead.

7 Lead price 2007: between 1,170 $/lbs. and 1,238 $/lbs.

Bismuth price 2007: 14,07 $/lbs.

leaded steels at most[8], considering the price increase caused solely by the material switch. It is clear however that the disadvantages of bismuth would cause further cost increases. The cost increase would affect between 2,9 and 7,1 kg of leaded steel per vehicle. An estimation of the impact of this switch on the total vehicle price would require further knowledge on the price these steels represent in the whole price of the car. A contribution from an industry stakeholder from Erkert estimated that the sales price of bismuthed steel is expected to be 3% more expensive than leaded steels. No evidence was provided to support this (Gärtner 2009).

Concluding on the above, bismuth is not a technically viable alternative to lead in machined steel. However, other arguments used against its use, such as its limited availability or its significantly higher price, do not seem to be the main limiting factors. A switch from leaded steels, containing 0,35% lead or less, to bismuthed steels is not technically possible, making an exemption necessary.

**Galvanised steel**

Stakeholders suggested that the exemption for continuously galvanised steel sheet expire in 2016. This type of galvanised steel represents more than 99%[9] of galvanised steel used by the auto industry in ELV Directive-concerned applications.

Although continuously galvanised steel sheets no longer require an exemption, batch galvanised parts still do. Low volume, but geometrically complex, parts require additional lead to ensure proper drainage of excess zinc from the product and to ensure better surface finish. Some of this lead will be present in the coating that is deposited.

On this basis, it can be derived that the exemption for lead up to 0,35% by weight as an alloying element in galvanised steel can be limited to batch galvanised steel components as included in the stakeholders' wording proposal (cf. section 4.1.2).

### 4.1.5 Final recommendation

The stakeholders provided consistent evidence on the necessity of lead in steel for machining purposes and in batch galvanized steel. Lead-free steel grades are available, but still show a significantly worse overall performance in machinability compared to leaded steels.

Based on the available information it can be concluded that the use of lead in steel for machining purposes and in batch hot dip galvanized steel is not avoidable.

It is hence recommended to continue the exemption with the following new wording:

8 Only 1,8 times more expensive if steel containing 0,05% bismuth by weight is used.

9 10 million tonnes of continuously galvanised steel sheet vs. the 10 000- 50 000 t of batch galvanised steel.

Exemption 1(a):

*Steel for machining purposes and batch hot dip galvanised steel components containing up to 0,35% lead by weight (no expiry date)*

Exemption 1(b):

*Continuously galvanised steel sheet containing up to 0,35% lead by weight for vehicles type approved before 1 January 2016 and spare parts for these vehicles.*

In view of consistency of environmental legislation, the contractor would like to remark that the RoHS Directive's Annex also includes an exemption for the use of lead up to 0,35% in steel (entry no. 6) which is not consistent with the above proposed wording for ELV Annex II. For future reviews of exemptions under both Directives, possible technical similarities for the use in EEE and automotive applications need to be evaluated in order to check on alignment of the wording if adequate.

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## 4.2 Exemption no. 2(c)

*"Aluminium with a lead content up to 0,4% by weight"*

### 4.2.2 Description of exemption

Currently, the use of lead as an alloying element in aluminium is only allowed up to 0,4%. As a result of the latest consultation, stakeholders request an unchanged extension of the exemption.

Leaded aluminium alloys are widely used for automotive applications. In general, three different types need to be distinguished:

1. aluminium alloys where lead is intentionally added for improved machinability;
2. aluminium alloys where lead is intentionally added for corrosion prevention;
3. aluminium alloys that contain lead unintentionally due to their production from scrap metal.

Aluminium alloys for machining purposes are covered by specific EN standards which define the composition of the different alloys. The widely-used aluminium alloy EN AW 2011 – AlCuBiPb – (AA 2011) with standardized lead range between 0,2% and 0,6% is still in use. This alloy has been specified for many applications, however with a limited lead content of maximum 0,4%. Most of the aluminium used is secondary aluminium (only 3%–5% are primary aluminium).

Typical uses for aluminium alloys from the first category are automotive transmission valves, cylinders and pistons for brake systems or for air conditioning systems, as well as applications in steering systems and in the chassis (e.g. steering knuckles). The following figure shows the applications in a vehicle as a rough example.

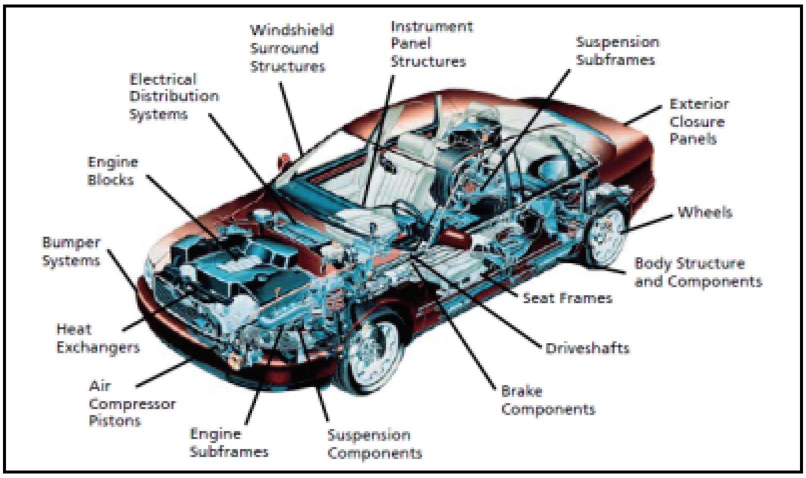


Figure 1 Lead applications in a vehicle

Some body and electrical components e.g. motors, starters, generators and even (machined) casting components are made out of secondary raw material from the scrap streams. Most of the secondary alloys e.g. the most prominent alloy is AlSi9Cu3 (also known as "226 alloy") have lead impurities content of about 0,2%.

Aluminium is increasingly used in automobile production because of its weight reduction potential (which leads to better fuel economy) over steel. Actual lead content is said to vary between 0,1% and 0,35%, with an average 0,18%–0,20% lead concentration. It is estimated that 90% of the aluminium used in this application is secondary, which requires about 90% less production energy than primary lead. When lifecycle energy is taken account, primary lead needs more than 20 times more energy than secondary lead.

The average vehicle is estimated to contain about 70 kg of aluminium, adding up to an average 130–140 g of lead per vehicle from this application. This would represent about 2 500 t of lead use in the EU27, considering a production of 17,7 million vehicles, i.e. 1,3 million tonnes of aluminium.

Unintentionally added lead may have been added to the scrap stream over years through inaccurately separated wheel rims, machined aluminium, lead from batteries and other lead-containing applications. Thus, lead is included in the scrap flow as an impurity which cannot be separated during the scrap process phase. Lead is neither necessary to attain specific properties, nor does the contained lead harm the properties of aluminium alloys as long as its quantity stays within the limits set by European standards[10].

With regard to the environmental relevance of lead in aluminium, (Lohse et al. 2001) concluded that most aluminium will end up in the shredder heavy fraction and will be recycled. A 2006 study by GHK in association with BioIS indicates average recycling rates of 97,8% for non-ferrous metals (GHK 2006). Due to the fact that lead is an unwanted tramp element with negative characteristics in the finished products if exceeding certain levels, the aluminium industry has an interest to keep the lead impurities in the secondary aluminium cycle as low as possible.

### 4.2.3 Justification for exemption

Industry stakeholders from ACEA/KAMA/JAMA/CLEPA/EAA/OEA et al. responded together to the consultation, providing information on leaded aluminium alloys (ACEA et al. 2009a). Stakeholders from the Schrader Group and the German non-ferrous metal association WGM and the German VDM Association also supplied independent answers (Schrader Group

[10] European standard EN 1706 sets standards for a great number of aluminium alloys and specifies different limits for lead.

2009; WGM 2009). Supporting evidence was provided on the energy requirement of secondary aluminium vs. primary aluminium. Furthermore, stakeholders from ACEA/KAMA/JAMA/CLEPA et al. answered to additional questions (ACEA et al. 2009b).

As with all exemptions, the goal is to either reduce lead content or replace lead-containing aluminium alloys altogether. Since the implementation of the ELV Directive, many efforts have gone into lead concentration reductions, from an original maximum 2% lead by weight to the current 0,4% lead by weight.

**Lead reduction**

Much information on this topic was supplied but no supporting evidence was provided. Some references were made to previously supplied data from the last consultation (ACEA et al. 2009a; ACEA et al. 2009b).

Stakeholders claim that 0,4% lead by weight is the minimum value that can be reached by the automotive industry. Lower concentrations are said to lead to reduced machinability through sticking effects, reduced form and flow ability as well as increased tool wear. It is explained that the higher lead concentrations are necessary for complicated machining (small deep hole drilling, small grove milling, etc.). No evidence was provided to support these claims.

Furthermore, stakeholders argue that even if lead concentrations could be reduced from the industry's point of view, concentrations could only be reduced by diluting secondary scrap with primary aluminium. This would in turn create enormous pressures on primary aluminium production. For example, if the average concentration was to be reduced from 0,2% to 0,1%, an additional 1,3 million tonnes/year of primary aluminium would be required to achieve this in the automotive industry alone. Stakeholders argue that this would be a waste of resources and energy, considering that lead in aluminium has no environmental or health impact. Furthermore, such a dilution is said to be impossible given that demand for primary aluminium already surpasses production by 200 000 tonnes according to supply-and-demand models. No supporting evidence was provided to support these claims.

No new information on the possibility of separating lead from scrap aluminium was provided. However, previous consultations provided two studies from the 1990s (Tailoka & Fray 1993; Tailoka et al. 1994) indicating that research in this direction was underway and seemed promising on small scales. It was argued that these technologies are expensive and create too much chlorine waste. Currently, no other methods are known but investigation into other possible technologies is said to be starting soon. In this context, the Organisation of European Aluminium Refiners and Remelters (OEA) is elaborating an overview on current studies and research related to lead removal from scrap aluminium. The results should become available at the end of 2010 (ACEA et al. 2009b).

### Alternative alloys

From what stakeholders have indicated, it would seem that a bismuth-lead aluminium alloy (AlCuBiPb, i.e. AA 2011) is used to substitute aluminium alloys that used to contain 0,7%–1,5% lead (ACEA et al. 2009a). According to its definition, AA 2011 contains 0,2%–0,6%, but only material containing less than 0,4% is used by the automotive industry.

However, the current conclusions from stakeholders stated that some applications of AA 2011 alloy have been replaced by to lead-free alternatives e.g. AlEco62Sn or AA 6023 (AlMgSiSnBi) (ACEA et al. 2009b). They argued also that during the next years it might be possible to introduce some more lead-free materials in automotive application.

No further research in regards to completely lead-free alloys or to alloys containing even less lead are available.

## 4.2.4 Critical review of data and information

Overall, it should be stated that detailed fact and figure based supporting evidence is lacking.

### Lead reduction

Arguments made on scrap dilution are plausible and reliable. The contractor supports the notion that diluting aluminium scrap with primary aluminium to reduce lead concentrations is unreasonable.

One of the main issues with this solution is that it does not reduce the absolute amount of lead in circulation in the sector. It would also require very large amounts of energy as the amount needed to produce primary metal is 20 times higher than the amount needed to produce secondary aluminium. Data provided by stakeholders in previous consultations[11] indicated that recycled aluminium requires 2,9% (for remelted scrap) and 8,2% (for refined scrap) of the energy required to produce primary aluminium.

On the same topic of lead removal from scrap aluminium, the previous contribution had provided 15-year-old publications confirming that in small scale experiments it was possible to energy-efficiently (i.e. less than 0,5 kWh/kg of purified aluminium alloy) remove lead from aluminium by the electrochemical addition of sodium or potassium (Tailoka & Fray 1993; Tailoka et al. 1994). However, up-scaling this method form small scale laboratory experiments to industrial scale applications was considered to be difficult, thus confirming the industry position that the research activities have not yet produced practicable solutions for industry applications. It was claimed by stakeholders that these solutions had proved too expensive and lead to problematic chlorine releases from the lead removal process.

[11] EAA Energy figures primaryrecycled.xls

Regrettably, no newer information was provided on these issues, although explained that the chlorine release and high energy demand could be overcome by electro refining sodium from the sodium-lead and aluminium-sodium alloys (Tailoka & Fray 1993).

No data was provided to support the claim that aluminium demand is 200 000 tonnes higher than production can supply. A short investigation on the contractor's part found no mention of aluminium shortages in global production according to (Bray 2007).

Furthermore, no data was provided to support that machining properties would be too severely affected to allow a reduction of lead concentrations.

**Alternative alloys**

Overall, it is regrettable that so little evidence was provided, as only extensive evidence enables the contractor to definitively and precisely evaluate the necessity of an exemption. Stakeholders indicated that no studies of the type requested were available and could thus not be provided. Furthermore, the industry was unable to indicate what aluminium applications strictly required the use of 0,4% lead. Short reference was made to an alternative alloy already being used, which seems to have allowed the reduction from 0,7-1,5% leaded aluminium to 0,2%–0,4% leaded aluminium. However, no details were given on which applications technically require 0,4% while the majority was stated to use an average 0,18%–0,20% lead concentration. The question on possibilities to reduce the maximum concentration value for a majority of the applications while leaving it at 0,4% for a definite number of applications thus remains unanswered.

Since it was mentioned that the AA 2011 alloy has been changed to lead-free alternatives (e.g. AlEco62Sn or AA 6023 (AlMgSiSnBi)), a future use of lead-free aluminium alloys seems possible. AlEco62Sn is the first lead-free aluminium alloy which for example BOSCH had homologated for their applications. In the next years, researchers will keep developing new lead-free materials with the same quality characteristics as leaded aluminium alloys. A review of the exemption in due time – once more practical experience has been gained – is thus considered useful.

### 4.2.5 Final recommendation

As explained previously, the automotive industry was unable to provide necessary detailed evidence to support their claims that reductions of lead concentrations in aluminium alloys are not feasible. Even though lead-free substitutes are already used in some applications, the automotive industry could not support large efforts for a complete or majoritarian switch to lead-free alternatives.

The contractor cannot support an unconditioned further extension of this exemption without further evidence and duly recommends a review date 5 years after a revised Annex II comes into force. This period of time should allow industry stakeholders to gather the missing evidence and studies supporting their claims.

### 4.2.6 References


| | |
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## 4.3 Exemption no. 3

*"Copper alloy containing up to 4% lead by weight"*

The evaluation of exemption 3 under the current contract was based on results of former evaluations, case studies, reports and further input and comments from industry stakeholders. Initial answers have been received from stakeholders in the context of the second stakeholder consultation. Further questions have been sent to stakeholders who have sent input. Answers have since been received from ACEA et al. (2009a) as well as a separate joint response from Schrader Electronics Limited and Schrader SAS (Schrader SAS 2009) and discussed in two conference calls. Furthermore comments to the draft report from Öko-Institut have been received from ACEA/JAMA/KAMA/CLEPA et al. Attached to these comments were the results of case studies and additional documents (ACEA et al. 2009b2) as well as a new report by the European Copper Institute (ACEA et al. 2009b3).

The outcome of all this information gathering exercise and of the exchange with the above mentioned stakeholders is reflected in the following.

### 4.3.2 Description of exemption

There is a wide range of vehicle components which are made of copper alloys: valve guides, valves for tyres, fuel injectors, jet nozzles, battery terminals, temperature sensor housing, carburettor nozzles, mountings for radios, wiper systems, door locks, electric window lifts, parts of the braking system, pins and fittings.

The typical lead content in these copper alloys is between 0,15% and 4% by weight with an average 2% concentration (ACEA et al. 2009b3). The amount of lead-containing copper alloys in vehicles (other than bearing shells and bushes) can be roughly estimated to be 1–2 kg per car. The average amount of lead used in those applications is therefore between 15 and 40 g per car. The total EU27 lead consumption in this application is thus estimated to be between 265 and 710 t/y[12].

However, the weight distribution among the parts made with copper alloys plays a major role. Less than half of the components contains up to 3% of lead. More than 50% of parts are manufactured with alloys containing 3% to 4% of lead. They are mainly used for small parts in safety relevant areas, such as steering, central control unit, fuel pump unit, level sensors, oil pressure switches, starter, electronic-stability-program, and connector pins. Nevertheless, their weight altogether represents only some 25% of the total weight of the lead containing parts (ACEA et al. 2009b3).

[12] For EU27 incl. EFTA (17,7 million cars – i.e. ignoring the current economic downturn – *source: ACEA 2008*)

Lead is a machinability enhancer. The formation of short chips, which can be removed automatically during machining, is facilitated by its presence (similarly to the use of lead in other metals such as steel and aluminium). This allows products to be processed around the clock on fully-automated, fast-turning lathes. Low strength and high ductility are also a result of the use of lead and allow the cutting force to be reduced leading to reduced power consumption during the machining process and increased tool life. Alloyed lead also contributes to the prevention of the formation of any kind of cracks and finally it increases the copper's corrosion resistance. Therefore lead in copper alloys affects safety properties of the car and its passengers.

Lead, however, does not influence the other characteristics and usage properties of the copper alloy, meaning that the copper's strength and electrical conductivity are not influenced significantly by its presence.

An extension of the exemption is requested by the automotive industry.

### 4.3.3 Justification for exemption

In terms of volume the automotive sector represents a relatively small market for copper and its alloys. Only 6% of the annual global copper demand is consumed by the entire transport sector (ACEA et al. 2009b1).

According to industry, the relative distribution of the weight of the parts according to their lead content (from <1% to 3%–4%) cannot be directly linked to the necessity for an exemption. A much more convincing argument results from the distribution of the number of parts (about 7000 single parts contain leaded brasses (ACEA et al. 2009b2)) made with copper alloys having different lead contents. Less than half of the components contains up to 3% of lead. More than 50% of parts are manufactured with alloys containing up to 3%–4% of lead (ACEA et al. 2009b3). Those are mainly consisting for very small parts or assemblies and used in safety relevant areas, such as steering, central control unit, level sensors, oil pressure switches, connector pins etc.

For the stakeholders it is an utmost concern that the role of lead in copper alloys is multifunctional and not only related the superior machinability aspect. Lead contributes preventing the formation of any cracks, increases the corrosion resistance or reduces friction. Therefore lead in copper affects safety properties. To avoid problems caused by a change of materials like lowering the lead content or finding a lead-free substitute, a full program of test procedures for each one of these applications must be applied. According to stakeholders, even if new alloys and materials would be available in future their validation, availability, testing and qualifying for automotive applications would take a long time (ACEA et al. 2009b1).

### Reduction of lead content

During the previous evaluation, Wieland Werke AG stated that a reduction of the maximum value in the exemption wording from 4% to 3% lead content was possible in principle for free cutting leaded brass. The stakeholder provided different machining test results comparing copper alloys at different lead concentrations, as shown in Figure 2 and Figure 3.

Another graph not presented here showed a parabolic relation between lead content and drilling depth after 100 drill rotations. Above 6%, the added effect of increased lead concentrations became unnoticeable, while the drilling depth obtained with 3% leaded copper was about 80% of that attained with 4% leaded copper.

Based on these results, Wieland Werke AG asserted that it was principally possible to reduce the maximum concentration of lead in free-cutting brass from 4% to 3%.

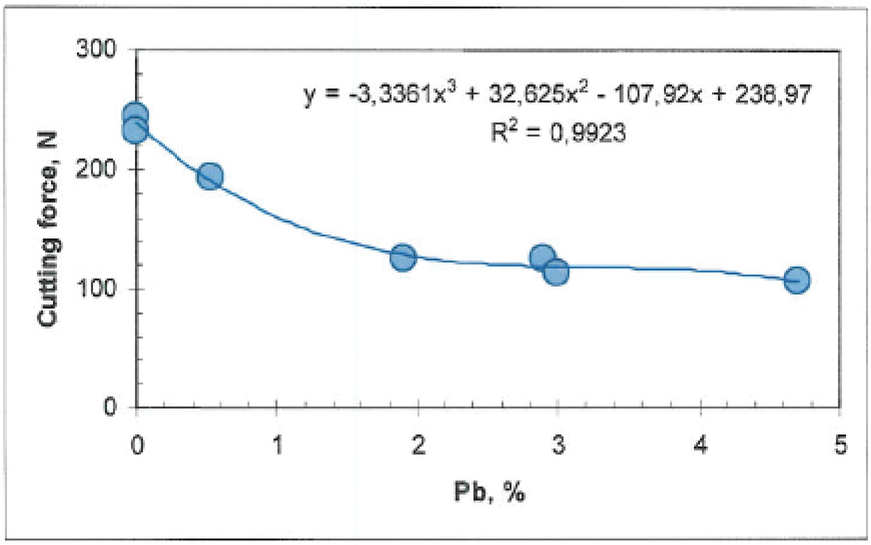


Figure 2 Cutting force for free cutting brass according to lead content (Wieland Werke AG 2007)

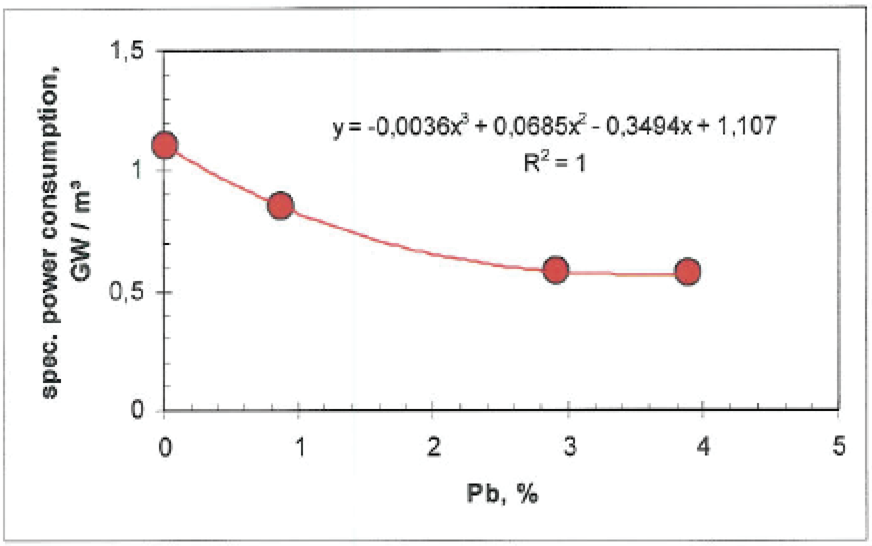


Figure 3 Power consumption per chipped volume for free cutting brass according to lead content (Wieland Werke AG 2007)

When confronted with this during the current revision, stakeholders from automotive industry said that such a reduction depends on the requirements of each individual application and that therefore no general answer on the question of a possible lead content reduction could be given. The automotive industry stressed that optimal lead contents are already in use for each application, making a reduction of the maximum lead concentration not feasible (ACEA et al. 2009b1).

In short, stakeholders explain that simply reducing lead content is not an option; a substitute material with similar characteristics must be developed if the lead content in this application is to be reduced.

### Lead-free and alternative alloys

In order to be able to relate research and development efforts to the results of past assessments, several information has been provided on this topic by stakeholders.

*Input from current consultation*

Stakeholders asserted a certain amount of additional information with evidence (ACEA et al. 2009b2). Data was provided in the form of characteristic comparisons of standard leaded copper alloys (CuZn39Pb2 [1,6%–2,5% lead] or CuZn39Pb3 [2,5%–3,5% lead]) with some of their alternatives, namely Ecobrass (CuZn21Si3 or CuZn31Si1) or the identical standard brass without lead (CuZn37). The silicon alloyed brass Ecobrass is the only suggested replacement material for lead containing brass that might be available in sufficient quantities. But stakeholders state that nevertheless it is a totally different material, which even on initial inspection of the standard performance indicators for leaded brass cannot cover certain areas of material performance at all as explained in the following

Test data provided indicated that:

- The electrical properties of two geometrically identical pieces of copper made from Ecobrass and standard leaded copper alloy were compared. It was observed that the electrical resistance (and therefore the voltage drop) was 2,7 times higher in Ecobrass than the standard leaded alloy.
- The machinability and surface finish of the alternative alloy "M37"[13] was also analysed, and proved to be far less satisfactory than standard leaded copper.
- Another study indicated that Ecobrass was 89% as machinable as the 1,6%–2,5% leaded copper, though only 80% as machinable as the 2,5%–3,5% leaded copper. The main disadvantages of Ecobrass compared to standard leaded copper appeared to be its smaller heat conduction capability and electrical properties, gas-shielded arc weldability and hard solderability. These drawbacks were even more contrasted with the 2,5%–3,5% leaded alloy.
- The lubricating effect of lead in copper alloys is also stressed by tribological tests. In contact with steel CuZn39Pb3 mostly shows a considerable lower friction coefficient than lead free alloys or Ecobrass.
- Negative effect on formability and sealing (e.g. fittings in the fuel feed systems) showed a significant difference between the silicon-alloyed and the lead-alloyed brass. Equally assembled fittings with an approximate torque 25 Nm were tested under pressure and temperature. The residual torque after testing was about 1,3–1,6 times higher for a conventional alloy than for the Ecobrass fittings. Values under 10 Nm (e.g. Ecobrass) can not be accepted for this test.
- In a hot forging trial with lead free material (Ecobrass) on production process with varying electric current condition for electrical resistance heating it was not possible to reach proper forging results. This was allocated to the increased deformation resistance and to the higher hardness of silicon-alloyed compared to lead-alloyed brass.

These tests revealed that the addition of silicon to copper, contrary to the addition of lead, affects the alloy's electrical properties significantly. Stakeholders thus conclude that Ecobrass can therefore not be used where electrical properties are of importance. Furthermore, the machinability of Ecobrass is worse than that of leaded copper alloys.

[13] No reference to this alloy was found in the Copper Institute's database. It was therefore not possible to verify, although it was insinuated by stakeholders, if this alloy is lead-free.

Apart from this, further industry stakeholders asserted a certain amount of additional information, without supporting it with evidence. The following summarizes the provided information.

Schrader SAS and Schrader Electronics Ltd. (SEL), which provide tyre valves, fuel injection valves and air conditioning valves, underline that the surface of the brass must be free of chips or other anomalies in order to ensure proper adhesion of the rubber coating on valve stems. Additionally, in the case of wireless direct Tire Pressure Monitoring Systems (TPMS), the valve is used as the antenna. A change in material would require the retuning of the TPMS circuitry with the valve's new electrical properties (impedance). TPMS has the potential to substantially increase driver safety and vehicle fuel economy (up to 2,5% improvement depending on TPMS accuracy). These devices will become mandatory in new vehicles in 2012 in the EU and are already mandatory in the USA.

Stakeholders state that research on lead-free copper alloys has been carried out for many years without finding technically and economically equivalent alloys. They explain that lead-free copper alloys have different material characteristics and entail much higher costs due to increased copper content. Users of those materials in the testing phase apparently report higher wear of machines and tooling as well as a lack of long term experience in production and use of parts. Higher cycle times for semi-finished parts in lead-free alloys allegedly limit the production capacity which may lead to a bottleneck in supply.

Explanations were also given as to why bismuth-containing alloys were not suitable alternatives. Embrittlement and lower strength and ductility at high temperatures were cited as some of the main issues. The other major disadvantage in bismuth-containing copper alloys is the high internal stress responsible for frequent stress corrosion cracking. This is caused by the expansion of the bismuth during solidification and thus is fundamentally unavoidable. Furthermore, machinability of bismuthed coppers is also between 66% and 85% that of free-cutting, lead-containing brasses. 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.

Stakeholders further stated that alloys containing bismuth were also more difficult to recycle, because recycling must be done separately and so far fully developed recycling only exists for lead-containing copper alloys.

The mixture of chemical composition in very different copper based alloy scraps may end in difficult material recycling and the energy consumption for the recycling of these scrap mixtures will increase enormously. Current copper based scraps derived from end-of-life-vehicles are a valuable resource for secondary copper or brass applications. The discussed silicon or bismuth containing alloys are incompatible to be recycled into alloys which are free of these elements. A mixture may end up in a loss of recyclability.

*Input from last consultation*

During the previous consultation in 2007, stakeholders had already indicated that bismuthed copper was not a reliable alternative, but that CuZnSi and CuZnSiX alloys were the most promising alternatives.

A publication provided during this consultation (Oishi et al. 2007) indicated the following on Ecobrass (a CuZnSi alloy):

- Silicon is a widely abundant and safe material
- Effect of lead contamination on mechanical properties is minor (i.e. high recyclability and separation need of lead-containing and lead-free alloys reduced)
- The lead-free alloy has excellent hot workability and castability
- Thin wall casting is possible and a wide variety of casting methods are selectable
- No lubricant is required for processing, chips are easily handled and thin wall cutting is possible
- Increased strength and equal ductility allow for smaller and lighter products and corrosion resistance is increased.

However, this study seemed to mainly focus on plumbing applications (tested items were plumbing-related).

Another study on low lead alloys was also supplied (Sadayappan et al. 2007). This study, in the context of plumbing applications as well, compared low lead alloys with 4,0%–6,0% leaded copper alloys. The low lead alloy contained less than 0,25% lead and 1,5%–3,5% bismuth as well as 4,0%–7,0% tin. This alloy performed well at room temperatures, having a lower strength than 2,5%–3,5% leaded copper alloys and a typical elongation of 30%, that is to say 75% that of 2,5%–3,5% leaded copper alloys. Despite these promising results, it appeared that the mechanical properties of the low lead alloy quickly deteriorated as temperature was increased above 150°C, more than halving the previously cited characteristics.

Additional information was provided on the outcome of copper alloys in automobile shredder scrap. Copper alloys from automobiles end up in the shredder heavy fraction and will be transferred to metallurgical processes. Recycling of lead-containing copper is possible and widely used in copper recycling plants. Lowering the lead content in copper alloys is possible and takes place in Belgium but would severely increase the costs in the whole material chain in order to keep metal streams separate. Stakeholders argue that it would therefore have a strong negative effect on the very well established and functioning recycling processes, which would need a complete redesign.

### 4.3.4 Critical review of data and information

Provided information will be analysed in order of presentation.

**Reduction of lead content**

Stakeholders seem to have contradicting opinions. As explained earlier, during the previous consultation, Wieland Werke AG claimed that a reduction from 4% lead to 3% lead was principally possible considering the relatively limited impact on machinability for free cutting brass. Other automotive industry stakeholders explained that only a component-by-component test would be able to say whether or not such a reduction is possible. They stressed that leaded copper alloys are already at their optimal concentrations and that any change would require long, costly and demanding development and qualification procedures and testing.

The ELV Directive's interest is not whether or not an alternative is optimal or equivalent to current technology but whether or not the use of selected metals is unavoidable or not. As this is a matter of interpretation, it could be considered that the costs, duration and complexity of procedures necessary for substitution efforts are irrelevant. In that case, such matters would only be relevant for the choice of an exemption's expiry date or the definition of a needed transition period before expiration comes into force.

Stakeholders have implied that the complexity, the amount and distribution of 3%–4% leaded alloyed parts as well as costs of administrative procedures have discouraged them from conducting a study or invest into R&D, and that the environmental benefits of a reduction from 4% to 3% would be minimal. Nevertheless, it is unclear how important from technical point of view a 25% reduction in machinability really is. Stakeholders stress its impact but fail to provide substantial evidence proving that this situation makes the use of 4% leaded copper unavoidable.

No fact-based evidence on the technical feasibility of lead concentration reduction was provided and may not exist.

**Lead free and alternative alloys**

During the last consultation, stakeholders provided an extensive study (Oishi et al. 2007), which concludes that Ecobrass is a good machinable material presenting excellent corrosion resistance, good wear resistance, hot workability and castability and is less brittle than leaded coppers at higher temperatures.

The test data provided revealed that the tested electrical properties of Ecobrass are significantly affected by the presence of silicon in the copper, namely electrical conductivity and resistance. It can therefore be concluded that Ecobrass is unsuitable for applications requiring the conduction of electricity. The data also confirms that the machinability of Ecobrass is between 70% and 82% that of two typical leaded coppers, containing 2,5%–3,5% and 1,6%–2,5% lead respectively. Furthermore, engine tests showed that lead free brasses like Ecobrass or Diehl 474HT[14] were suitable for valve-guide in some cases but failed in some other cases due to friction, wear, and fretting.

Additionally, some of the data provided contradicts previously mentioned test data, namely on the plasticity of Ecobrass. Test data provided during this consultation states a 10%–20% elongation of Ecobrass vs. 10%–45% elongation in traditional leaded copper alloys. Material plasticity is a crucial aspect in material machinability. However, study (Oishi et al. 2007) explains that elongation of Ecobrass reaches 32% and can be further increased through the addition of zirconium and phosphorous to 45%, thus equalling the plasticity of the most machinable leaded copper alloys. Such contradictions should be remedied, considering the importance of this factor in discriminating Ecobrass as an alternative.

Stakeholders affirm that Ecobrass is not suited for use in fittings in vehicles. However, study (Oishi et al. 2007) explains that lead-free fittings for drinking water pipes will be mandatory in the USA[15] started from January 2010. Equally the new Cu-Si-alloy[16] for drinking water applications is completely reusable and has extraordinary mechanical properties. It is however clear that drinking water fittings and automotive fittings do not operate in the same requirements and that results can thus not automatically be transferred to automotive industry as supported by automotive industry (ACEA et al. 2009b2). Nevertheless, it shows that new lead-free materials are principally possible and that it could be worthwhile investigating these further.

Study conducted on low lead alloys can be viewed as a look into possible synergies between lower lead concentrations and possible substitutes, in this case bismuth (Sadayappan et al. 2007). A bismuth-lead synergy as presented in this study does not seem to be beneficial for automotive applications given the possibly high temperatures, which quickly degrade the alloy’s properties.

In short, the copper industry argues that intensive research on lead-free copper alloys has been carried out for many years without finding technically and economically equivalent alloys.

Apart from having received answers from many different stakeholders, they all asserted the same information as explained above. Certain claims are contradicted, at least partly, by

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14 http://www.diehlmetall-messing.de/index.php?id=207

15 It is only mandatory in California and Vermont. The Californian and Vermont legislation define „lead free“ as not more than 0,25% lead weighted in average for the weighted surface in contact with the drinking water.

16 http://www.cuphin.com/index_en.html

provided evidence. In order to give an overview on these claims the following Table 7 lists some important properties for selected copper alloys (Data sheets alloys 2010).

Table 7 Copper alloys properties

| | **Lead free and low leaded** | | **Leaded** | |
|---|---|---|---|---|
| | ECOBRASS CuZn21Si3[17] C87850 | CUZn37 C27200 | CuZn39Pb3[18] CW614N | CuZn39Pb2 CW612N |
| **Chemical Composition** | | | | |
| Cu | ≈ 76% | ≈ 63% | ≈ 58% | ≈ 59% |
| Pb | | | ≈ 3% | ≈ 2% |
| Si | ≈ 3% | | | |
| Zn | ≈ 21% | ≈ 37% | ≈ 39% | ≈ 39% |
| **Fabrication properties** | | | | |
| Machinability Rating | 70-80% | 35% | 100% | 85% |
| Cold Working | + | ++ | - | 0 |
| Hot Working | ++ | + | ++ | + |
| Soldering | ++ | ++ | ++ | ++ |
| Brazing | ++ | ++ | 0 | + |
| Oxyacetylene Welding | + | 0 | + | - |
| Resistance Welding | + | + | 0 | 0 |
| Beam Welding | + | 0 | 0 | - |
| Polishing | + | + | + | ++ |
| Electroplating | + | ++ | ++ | ++ |
| General Properties | | | | |
| Corrosions resistance | + | 0 | + | + |
| Mechanical Properties (*Tensile Strength, Yield Strength, Elongation, Hardness*) | + | 0 | ++ | + |
| Density (g/cm³) | 8,3 | 8,44 | 8,5 | 8,4 |

The comparison in Table 7 with four different copper alloys represents only a few existing copper alloy types. Nonetheless, those four alloys compose a representative sample from lead-free up to the standard copper alloy material for machining. The overview intends to gather the different general properties and to clarify the difference between the single materials. The lead-free copper alloy, namely Ecobrass has in some properties better characteristics than the more often used copper alloy CuZn39Pb2. Ecobrass might also be considered equivalent to the standard leaded copper alloy CuZn39Pb3. For example, a

[17] http://www.greenalloys.com/specs/C87850.pdf

[18] Standard material for machining (machining index 100%)

70%–82% machinability compared to current materials could be considered sufficient for lead used in copper alloys to be avoidable. However, considering that the statements on properties are incomplete, the question arises, whether and how the automotive industry – despite the above mentioned claims – would be willing to put additional effort into research, process technology, investigations and development work.

### 4.3.5 Final recommendation

Considering the fact that the ELV Directive doesn't allow for exemptions until technically equivalent alternatives are available but until the use of selected materials (lead, cadmium, mercury, hexavalent chromium) is no longer unavoidable, it is very unclear what level of technical equivalency must be achieved by alternatives for the original material to no longer be considered unavoidable.

Concluding on the above described technical discussion on feasible lead-reduced or lead-free alternatives. The contractor cannot support an extension of this exemption without any expiry date or a review date. It is therefore recommended to continue the exemption and to set a review date 5 years after the revised Annex II comes into force. This period of time should allow industry stakeholders to carry out the necessary research and development work, to gather more fact and evidence based information as well as to encourage the corresponding implementation of the process technology for lead-free copper alloys.

### 4.3.6 References


| | |
|---|---|
| ACEA et al. 2009a | ACEA/JAMA/KAMA/CLEPA/EAA/OEA et al.; Joint response document "20090804_Global AI_exe 3.pdf" |
| ACEA et al. 2009b | ACEA/JAMA/KAMA/CLEPA et al. to the Draft REPORT FROM Oeko-Insitute document "Frame Document_-Recommendation Exemption 3_FIN_.pdf" |
| ACEA et al. 2009b1 | ACEA/JAMA/KAMA/CLEPA et al. to the Draft REPORT FROM Oeko-Institute document "2_Annex 1 Comments to draft report_FIN.pdf" |
| ACEA et al. 2009b2 | ACEA/JAMA/KAMA/CLEPA et al. to the Draft REPORT FROM Oeko-Insitute document "ANNEX 2 Case studies and additional documents_ fin.pdf" |
| ACEA et al. 2009b3 | ACEA/JAMA/KAMA/CLEPA et al. to the Draft REPORT FROM Oeko-Institute document "ANNEX 3 New Report by the European Copper Institute:_The role of lead as an alloying element in copper alloys_ FIN.pdf" |
| Data sheets alloys 2010 | Data sheets on different alloys (own internet investigation, e.g. with Deutsches Kupferinstitut) |

| | |
|---|---|
| Oishi et al. 2007 | "Development of A Lead Free Copper Alloy 'Ecobrass'"; Proceedings of the Sixth International Copper-Cobre Conference, August 25-30, Toronto, Ontario, Canada, Volume 1, Plenary, Copper and Alloy, Casting and Fabrication, Copper-Economics and Markets, J. Hugens et al., Canadian Institute of Mining, Metallurgy and Petroleum, Quebec, Canada, 2007, p. 325-340. |
| Sadayappan et al. 2007 | "Development of New Low Lead Alloy for Plumbing Applications"; Proceedings of the Sixth International Copper-Cobre Conference, August 25-30, Toronto, Ontario, Canada, Volume 1, Plenary, Copper and Alloy, Casting and Fabrication, Copper-Economics and Markets, J. Hugens et al., Canadian Institute of Mining, Metallurgy and Petroleum, Quebec, Canada, 2007, p. 317-325. |
| Schrader SAS 2009 | Schrader SAS and Schrader Electronics Limited joint response document "20090803_SAS response ELV consultation ex2c and 3.pdf" |


## 4.4 Exemption no. 4b

*"Lead in bearing shells und bushes for engines, transmissions and A/C compressors: 1 July 2011 [Review date: 07/2009]"*

This chapter is the result of an update and review of the former evaluation results. Stakeholders have provided information in the context of the second stakeholder consultation. This information was evaluated and some further exchange took place to clarify open questions. As a result, the final recommendation below was drafted.

### 4.4.2 Description of exemption

In its current form, Exemption 4b includes lead used in bearing shells and bushes in engines, in transmissions and in air conditioning compressors and is due to expire on 1 July 2011. Exemption 4a exempted the use of leaded bearings in general until 1 July 2008. Spare parts remain exempted for vehicles produced before these expiry dates, respectively.

Several industry associations (ACEA, CCFA, VDA, JAMA, KAMA) submitted an identical contribution to the 2009 stakeholder consultation requesting that exemption 4b not be modified. An independent response was also received from Federal Mogul with the same request.

Originally, exemption 4 governed all leaded bearing applications and was due to expire on 1 July 2008. During the previous Annex II Revision, stakeholders supported that certain engine, transmission and air conditioning compressor applications still required the use of leaded bearing shells and bushes, leading to the exemption in its current form.

Lead-containing bearings were preferred as they allowed for the following characteristics:

- Resists to high surface pressures and peripheral velocities
- Have better lubricating properties allowing dry-running at start-up
- Harmful dirt particles can be embedded
- High mechanical strength and excellent fatigue properties

Stakeholders estimated that 5% of engine and transmission bearings and 3% of air conditioning compressors continue to contain lead. The maximum possible rates are respectively 10% and 5%. The different bearing layers in these applications contain up to 80% lead by weight. Total lead use in this application is thus estimated as being less than 7,9 t every year. Federal Mogul indicated similar figures during a phone conversation.

Stakeholders requested that the timetable no longer be changed to allow reliable planning for all parties.

### 4.4.3 Justification for exemption

Stakeholders asserted that, excluding major setbacks, a full phase out of leaded bearings in the remaining applications will be possible by the current 1 July 2011 expiry date (ACEA et al. 2009). Therefore, no modification of the exemption wording is required. No supporting evidence, additionally to what was supplied in the last revision process, was neither supplied nor deemed necessary.

As the phase out is already underway, no lead content reduction targets are being considered, with only lead-free alternatives being developed and perfected to the needs of manufacturers. Stakeholders underlined that the development process was strict and therefore slow, an error occurring during any testing phase leading to a completely new start in the testing cycle.

### 4.4.4 Critical review of data and information

During the last Annex II Revision, stakeholders had provided information on bearings in engines, some information on the Delphi V5 air conditioning compressing and very little data on transmission bearings (Stakeholder workshop 2007). The only substantial evidence provided to support their claims were regarding bearing shells and bushes in rotary engines, while many roadmaps and tests showed how slow the testing and validation processes can be due to the complex function of bearings (Mazda 2007).

Engine conrod bearings were said to be an essential safety factor, their failure potentially causing road accidents due to sudden engine freezing while driving. Additionally, bearing loads have increased as engine downsizing has been encouraged as a means of reducing $CO_2$ emissions without affecting engine performance. This has led to higher loads on smaller parts as a consequence of maintaining performance despite downsizing.

As of yet, solutions have been found in some cases or are still being developed and it is estimated that the phase out will proceed as planned in July 2011.

Little information and no supporting evidence were supplied for the Delphi V5 air conditioning compressor. Although a phase out of this compressor was originally foreseen in 2006, it also required an extension of the exemption due to increased demand. It is unclear why the Delphi V5 compressor was important enough to require this extension, considering the planned 2006 phase out and the existence of alternatives.

At this time, a lead-free solution has been developed but must be adapted to individual applications which require individual testing. It is estimated that this application will be lead-free by July 2011.

During the previous Revision transmission bearings were practically only mentioned, although they were concerned by the exemption extension.

Current information remains very limited, although it seems that a lead phase out is foreseen by July 2011 as well.

At the time of the previous Annex II Revision, the extension was granted as the slow testing and validation procedure, which is application-specific, and the initially poor test results did not allow for sufficient time to find suitable alternatives before the foreseen expiry date. It was shown that supplier development and testing lasts up to 3 years. At this point, OEM development and testing can begin. If testing by OEM should fail, development activities at the suppliers' level will need to start anew.

Although it would have been more appropriate not to exempt lead in bearing shells and bushes for engines, transmissions and A/C compressors in general but only the specific applications, this was done because it was not possible to comprehensively list relevant applications.

However, Federal Mogul's current statements (Federal Mogul 2009) are in complete contradiction with those made by other industry stakeholders (Stakeholder workshop 2007) during the last Annex II Revision. Federal Mogul explains that most applications were able to switch to lead-free solutions, while lead-free alternatives were available for applications that could not yet complete the switch. Unfortunately this information was not provided during the previous Revision of Annex II.

Although evidence and information supplied during the last Annex II Revision on engine bearings was substantial, this was – and still isn't – the case for transmission and air conditioning compressor bearings.

### 4.4.5 Final recommendation

Despite this, it is clear that many applications have already gone lead-free and that the remainder is expected to become lead-free by 1 July 2011.

Taking the stakeholders' unanimous request into account, it is therefore recommended not to change the wording of exemption 4b and keep the current expiry date.

### 4.4.6 References

| | |
|---|---|
| ACEA et al. 2009 | ACEA/JAMA/KAMA/CLEPA/EAA/OEA et al. joint response document "20090804_Global AI_exe 4b.pdf", 2009 |
| Federal Mogul 2009 | Federal Mogul independent response document, 30 July 2009. |
| Mazda 2007 | Mazda response document, October 2007. |
| Stakeholder workshop 2007 | Stakeholder workshop response document, 10 October 2007. |

## 4.5 Exemption no. 5

*"Lead in Batteries"*

The evaluation of exemption 5 under the current contract was based on results of former evaluations. Initial answers have been received from stakeholders[19] in the context of the second stakeholder consultation. Further questions have been sent to stakeholders who have sent input. Answers have since been received and a conference call has been held.

The outcome of this information gathering exercise and of the exchange with the above mentioned stakeholders is reflected in the following.

[19] Stakeholders include Eurobat/ACEA/JAMA/KAMA/CLEPA/ILA and BDI. Within this chapter "stakeholders" is used as generic term referring to all mentioned organisation if not otherwise specified.

### 4.5.2 Description of exemption

All of the more than 1 billion vehicles worldwide with a combustion engine contain at least one SLI (starting, lighting, and ignition) automotive battery based on the lead / acid / lead-oxide electrochemical system (EUROBAT 2009a).

The common type of an SLI battery consists of the following components:

- A multitude of lead alloy grids, which keep the active mass in place and conduct the current to the terminals;
- the active mass, a mixture of sponge lead (negative plate) and lead oxide (positive plate) with additives;
- an electrolyte of sulphuric acid, in which all plates are immersed;
- separators made of insulating polyethylene material;
- electrical connections including the terminals;
- the case, normally a heavy duty polypropylene box.

According to stakeholders, the average weight of a European SLI battery is 15–16 kg, with a lead content of about 9–9,5 kg. The average lifetime is 5 to 7 years.

17 177 466 vehicles concerned by the ELV Directive were newly registered in the EU in 2007. The annual amount of lead used in lead-acid batteries for new cars in the EU27 thus is around 160 000 t per year[20]. Considering that the average car uses between 2 and 3 batteries throughout its fifteen year lifetime, the annual use of lead in SLI batteries is about 320 000–480 000 t.

Stakeholder input states that a lead containing SLI battery is environmentally safe during its life cycle, since production is regulated by specific EU legislation such as the Directive on Integrated Pollution Prevention and Control (IPPC). Furthermore, lead acid SLI batteries plants need special environmental permits and lead smelters employ Best Available Techniques (BAT) as defined in IPPC and are well controlled by environmental authorities. Therefore the environmental impact of lead emissions from the production of the batteries is considered to be very small. Also, there are no lead emissions into the environment associated with the lead SLI battery during its use (Global Automotive Industry 2009, EUROBAT et al. 2009, ACEA 2010).

Concerning the end-of-life treatment, stakeholders further state that the collection rate of leaded batteries in ELVs is nearly 100%. Stakeholders explained that all of the lead in batteries is recyclable, with an efficiency of 99,5%. During recycling, much more than 99% of lead particulates emissions are captured and reintroduced into the recycling process. Plant emission standards are strict, not exceeding 1,0 mg/m$^3$ of flue gases. Produced slag contains

[20] 2 significant digits.

less than 10% lead in “fairly inert” form, although some processes can reach concentrations of less than 1%.

Stakeholders make clear that secondary lead requires only one third of the energy required to produce primary lead.

Based on the current EC Battery Directive 91/157/EEC and its successor Directive 2006/66/EC, separate collection of spent lead acid batteries is mandatory all over the EU. According to the ELV Directive, the dismantling of lead acid batteries from ELV is also mandatory.

Stakeholders argue that shredding companies operate under strict conditions to ensure that lead and sulphuric acid do not contaminate either the environment or the shredder products. Spent lead acid batteries also have a monetary value, and this acts as an incentive for recycling.

Stakeholders also note that conventional pyrometallurgical recycling is efficient and well-understood and doesn’t have a significant environmental impact. Alternative recycling technologies have been investigated at research level. For example, the CLEANLED project evaluated hydrometallurgical lead recycling as a potentially more environmentally friendly technology. However, as stated by stakeholders, this technology has never been used at larger industrial scale and a full comparison can thus not be made.

Stakeholders request an unlimited extension of exemption 5 with its current wording.

### 4.5.3 Justification for exemption

Stakeholders provided information (Global Automotive Industry 2009) on the need for the current exemption. Information provided during the previous consultation, although no explicit reference was made to it, was still relevant.

As with all lead-related exemptions, the goal is to, if possible, eliminate lead through the use of alternative technologies or reduce the amount used per application. Another possibility is increasing the lifetime of batteries, resulting in reduced fleet battery renewal and thus less lead use.

**Reduction of lead content**

In its contribution, stakeholders explained that efforts had been made to increase the lead use efficiency in lead SLI batteries. 10% reduction of battery weight was achieved through developing more efficient structure material and controlled processes. No detailed data was provided to support this claim or illustrate the success rate.

However, with the increasing amount of electric components in the car and additional functions, battery needs to cover more energy demand (more electrical components, Start&Stop

technology). Hence these effects on efficiency gain have not resulted in a reduced battery weight and has even led to an increase in lead use overall. No statistics were provided to support this.

Apart from ongoing lead-use efficiency research, stakeholders states that no reduction of lead-use can occur without affecting the performance of the battery. Therefore, significant lead reduction is not foreseeable or possible according to the stakeholder.

**Extended battery life**

According to stakeholders, no technology exists to increase the lifespan of batteries. The lifetime of batteries is affected by corrosion of the positive electrode carrier materials, i.e. the grid. Electrodes use a lead-based additive paste used to increase performance. However, every charge cycle affects the adhesion of these pastes which progressively shed. Once shedding of the pastes becomes significant, the battery becomes unusable because its performance is significantly reduced.

Stakeholders claim that only battery design can affect this problem, no chemical additive known can positively influence the shedding process. The stakeholder underlines that the addition of chemicals into batteries is not regulated and can therefore be very harmful to both the battery and the environment.

In short, efforts to increase battery lifespan through better design are ongoing and no chemical additive or other technology is known to positively affect battery life. Nevertheless, it has been observed that lifetime of lead-acid battery has been increased by about 25% over time (based on standardized European test sequences) but no detailed explanation was delivered as regards technical reasons for this effect (EUROBAT et al. 2009). Only, alternator voltage management was mentioned to have further increased the average lifetime of batteries. Moreover, Absorbent Glass Mat (AGM) batteries are lead-based technology used in so-called micro hybrid vehicles which use Start&Stop technology to optimise fuel consumption. AGM were quoted as having twice the cycle lifetime of regular lead-acid batteries (Pers. communication by stakeholders 2009).

**Environmental impact**

Stakeholders state that along battery life cycle, the environmental impact is kept low by regulations and is strictly monitored by national and environmental health authorities. Moreover, the dismantling of lead acid batteries from ELV is also mandatory.

Stakeholders provided key summary (EUROBAT et al. 2009) from a lead industry study on voluntary risk assessment for lead (VRAL) which included an investigation of industrial emissions from the secondary lead industry. The study was completed in 2007. The risk assessment did not reveal evidence of any significant environmental impacts associated with battery recycling by EU secondary lead producers. The VRAL was subjected to formal EU review and submitted to the European Chemicals Agency in 2008 (Global Automotive Industry 2009).

Regarding the collection and recycling issues, stakeholders claim that the recycling of lead-acid batteries in the EU is already close to a closed loop system, that means, best be estimated as close to 100% (Global Automotive Industry 2009).

**Alternative technologies**

Alternative technologies include different lead-free battery chemistries such as Ni-Cd (nickel cadmium), Ni-MH (nickel metal hydride) and Li-Ion (lithium ion) batteries. Ni-Cd batteries have been completely banned by the ELV Directive since the 31 December 2008.

Stakeholders firstly point out that onboard automotive electrical systems are designed for an optimal use with lead-acid batteries. Therefore, any significant change in the battery technology may require the redesigning of many components in order to ensure optimal use of the battery. The stakeholder explained that onboard automotive electronics are designed to be able to sustain up to 15 V. A Li-Ion cell has an initial voltage of 3,6 V and a charge voltage of 4,2 V. Therefore, a switch to Li-Ion batteries will cause either an increase of onboard voltage from 12 V to 14,4 V (4 cells), or a decrease from 12 V to 10,8 V (3 cells). So far, the maximum voltage has not been surpassed. However, charging a 14,4 V Li-Ion battery requires 16,8 V, leading to the burn out of the onboard fuses. The 3 cell alternative was said to provide voltage too small to start the engine. A switch to alternative battery systems was therefore claimed to entail very significant redesign costs of onboard electronics. No evidence was provided to support this last claim.

According to stakeholders, the performance of car batteries is measured by their energy density, their power output and their cold cranking ability. The energy density characterises the battery's ability to store energy, while its power output characterises the battery's ability to supply large amounts of energy quickly. The latter is important in order to start the combustion engine. Finally, the cold cranking ability of a battery is its ability to supply high power at low temperatures, typically at or below –30$^{o}$C. Alternative technologies have higher energy density, higher power output and longer lifespans. However, this is only the case at normal operating temperatures. In cold weather, lead-acid batteries outperform competing technologies. Stakeholders explains that the cold cranking characteristic is the most important from the car maker's perspective since it strongly characterises the reliability of vehicles in cold weather. Because the cold cranking ability of alternative batteries is much smaller than that of lead-acid batteries, the possibility of using alternative battery technologies is ruled out altogether. Data on this was provided during the last consultation as presented in Table 8. Although mention was made of problems with the discharge rate of Ni-MH batteries in the last consultation, this was not repeated during the current consultation.

Table 8    Main characteristics of lead-acid batteries (EUROBAT 2009b)

| Parameter | Lead-acid battery |
|---|---|
| Typical weight | 15-16 kg |
| Power density | 500 W/kg |
| | 1500 W/l |
| Energy density | 30–35 Wh/kg |
| | 100-110 Wh/l |
| Self-discharge rate | Low (~3% per month) |
| Temperature range | -30 to +75°C |
| Cold cranking | yes |
| Operational lifetime | 5-7 years |
| Cost | 50-150€/kWh<br>8-10€/kW |
| Application | Used in combustion engine or hybrid vehicles. |

Additionally, stakeholders explain that lead-acid batteries do not require extra electronics to control cell voltages or other aspects of battery operation, to the contrary of alternatives such as Ni-MH or Li-Ion batteries. According to stakeholders, these control systems greatly increase the cost of alternatives. No data was provided to support this.

Absorbent Glass Mat (AGM) batteries are crucial for the technology which permits a reduction in fuel consumption and $CO_2$ emissions by at least 10% according to stakeholders. Further research in this field may allow even further emission reductions and environmental benefits. The product is still under development and may offer even future chances for improving the environmental compatibility of batteries and vehicles (Global Automotive Industry 2009).

Finally, stakeholders indicate that work is being done on a technology based on lead-acid batteries and materials such as carbon to compete with Ni-MH hybrid vehicle solutions. No further details or data were provided on the topic, especially with respect to the timeline of research & development activities.

Mention is also made of starter systems involving the use of capacitors. The main advantage of this technology is the high power output it provides and its insensibility to cold temperatures. However, the capacitor must be charged before starting the vehicle. Consequently, a capacitor alone cannot be considered as an alternative battery system (EUROBAT 2009b). No data was provided on this technology.

In short, stakeholders believe that no lead-free battery technology is foreseeable at this time. It is currently not known if and when the lead battery can be surely and reliably replaced in vehicles. A roadmap of battery evolution was not possible to provide, but stakeholders said that most efforts were invested in increasing the cycle lifetime of the batteries. Moreover, stakeholders also clarified that a rapid reduction in fuel consumption and in greenhouse gases are key targets of the automotive industry that have priority over lead substitution or reduction in batteries. The lead acid battery industry has developed and invested affordable advanced lead-acid innovations for micro-hybrid vehicles. Such cars are equipped with start/stop systems and recuperation to win back the breaking energy and with intelligently managed alternators (Global Automotive Industry 2009, BDI 2010). Long-term reliable lead battery technology still has a huge development potential (BDI 2010).

**Review date**

Battery industry stakeholders request a prolongation of the exemption without any kind of review or expiry date. They claim that setting such a date would create (investment) uncertainty into battery technology development which could have adverse economic, technological and environmental impacts. The comments received by battery industry are listed below (Pers. communication by stakeholders 2010):

- Fear of political damage to lead acid battery technology since review date is interpreted by industry as the beginning of a full phase-out or complete ban of lead acid batteries. This has already been experienced in the context of the Battery Directive where Nickel-Cadmium batteries have experienced serious drawbacks starting from the set review date.
- Furthermore, battery industry is reluctant about a review date, because US companies – which are important players in the battery market – could be restrictive with future investments leading to possible negative socio-economic drawbacks on battery technology.
- Technological coexistence of all battery technologies is needed since there is so much technological development ongoing in the field of battery systems that there is currently a transition period / paradigm change which needs to be awaited before shifting to new energy storage technologies.

Stakeholders from car industry agreed to setting a review date but request it to be 8 years in order to cover a full vehicle development cycle that would be needed to redesign and type approve a vehicle with a new lead reduced or lead free battery technology (Pers. communication by stakeholders 2010):

- Today industry doesn't know into which direction technological battery development is going and some time is welcomed to get a clearer picture. However, the proposed 5 years are considered not long enough since it is considered that 8 years are requested at least to be able to make a fully clear statement on where development is going with regard to battery technology.

### 4.5.4 Critical review of data and information

Provided information will be analysed in order of presentation.

**Reduction of lead content**

Although no data was provided to support claims made on lead reduction potential, it is well known that significant reductions in lead content will directly affect the performance and the reliability of batteries. Only more efficient lead use can reduce lead content without affecting performance, but the potential of this option seems rather limited. AGM batteries are an example of more efficient lead use although they are mainly used in micro hybrid vehicles. Furthermore, the introduction of TEGs in vehicles to improve fuel consumption actively may also help reduce the battery size (cf. section "req. 2").

**Extended battery life**

Once again, lead-acid technology is several decades old and its inherent problems are well known. Therefore, although large efforts have already been made and the battery's life has been extended a lot, further extending battery life at this stage is difficult.

Confidential information provided during the last consultation also revealed that AGM batteries had a longer cycle life. However, because they are used in micro hybrid vehicles where they are exposed to much more cycling, it is unclear what the overall effect is.

**Environmental impact**

Under the strict legal framework and long-term industry application, the environmental impact associated with life cycle of lead-acid batteries can be considered as very low. A study conducted by Fraunhofer Institut on Chemical Technology (ICT) also revealed that collection and recycling systems of lead-containing products in the EU function well. Germany has 96% recycling rate of lead-acid SLI battery, while the EU has about 95% in 2004 (Hirth et al. 2007). It was also concluded that Improvement in the end-of-life phase of lead-acid battery is not necessary. Nevertheless, there are some recommendations given with regard to the lead battery production, e.g. optimising the corrosion of electrode carrier materials (Hirth et al. 2007).

**Alternative technologies**

To avoid misunderstandings, it must be clarified that the substitution of lead in lead-acid batteries is not possible. The avoidance of lead would result in an alternative battery system.

The stakeholders provided evidence supporting their main technical arguments on the advantages of lead-acid batteries, mainly their reliability in cold weather, over their main alternatives: Ni-MH and Li-Ion batteries. However, when considering potential systems using alternative batteries, stakeholders explained that a 30% battery capacity increase would be necessary to overcome their reduced CCA. This seems to indicate that it is possible to overcome this limiting factor, although other technical issues may prevent a switch and these alternatives are likely to remain less reliable than lead-acid batteries.

A brief mention was made by stakeholders of capacitor use in starting systems. This option was quickly discarded given that it cannot function independently from a battery. However, it seems that this technology has more potential than the stakeholder originally acknowledged.

The stakeholder was actually making reference to supercapacitors, also known as electric double-layer capacitors. These capacitors have far superior power density than electrochemical batteries, even in cold operating conditions. The only apparent disadvantage of such supercapacitors is their high self-discharge rate (20 times higher than a typical battery, i.e. about 5% per day) and low energy density, making them unsuitable to entirely replace a usual battery system, as stated by stakeholders.

Coupled to a lead-free battery or smaller lead-acid battery however, this device could be a suitable alternative to current lead SLI batteries. Such a system is currently increasingly being used by the Denver Regional Transportation District (RTD) in its buses.

According to a quick investigation (Ha 2009 ) conducted by the contractor with the Denver RTD, a supercapacitor is simply connected in parallel to the battery in the starter circuitry. Once it is fully recharged by a regular alternator it is disconnected from the circuit until the next engine start. Previously, batteries were estimated to need about an hour to recharge, while supercapacitors require 30–60 seconds. Simultaneously, RTD has switched from regular lead-acid batteries to maintenance-free batteries.

Initial results from their five-year experience reveal that battery lifespan has doubled, battery use is reported to be two thirds lower and starting-related breakdowns are one fifth as frequent as those in buses not equipped with supercapacitors, making the system very reliable. Furthermore, the system has proven to be very low maintenance, no replacements or repairs of supercapacitors having taken place since the first devices were installed. During starting, the supercapacitor provides two to three times more current than regular batteries. No problems with the discharge rate have been reported, although buses are at most out of service for three consecutive days.

RTD Denver also confirmed that it seemed reasonable to believe that a supercapacitor coupled with a lead-free battery running near 12 V could replace the traditional lead-acid battery used. At the very least, a down-sized battery could be used, although they have not tried this approach yet.

The US National Renewable Energy Laboratory (NREL) also confirms that this type of system can extend battery life and result in the use of a downsized lead-acid battery.

When confronted with this, stakeholders indicated that this solution remained unsuitable due to packaging, safety and volume restrictions. Further investigation on the contractor's behalf into supercapacitors used by RTD Denver from supplier KBi has confirmed packaging constraints, but no safety or volume restrictions. Operational temperatures of KBi products are the cause of the packaging constraints, being between -50°C and 50°C, while storage temperatures are between -60°C and 70°C. The operational upper limit is incompatible with motor block temperatures. According to industry stakeholders, the device would thus have to be installed elsewhere in the vehicle.

As far as safety is concerned, stakeholders claimed that the solvent used posed safety hazards. KBi uses a potassium hydroxide solution that is considered non-flammable and low hazardous (Ha 2009).

RTD Denver uses a 35 kW system running at 24 V, storing up to 120 kJ in the bus. This unit weighs 26 kg and has a volume of 17 L (35x20x25 cm), i.e. about twice the size of a typical car battery, assuming a volume of 9,0 L. A smaller device from KBi offers 8,8 kW at 12 V, storing up to 30 kJ in about 4,8 kg and 2,7 L (27x6,3x16 cm). During a single car start, a typical lead-acid SLI battery will never supply more than 850 A at 12 V (voltage typically drops during engine start, the specified minimum is 7,2 V) for up to 10 seconds (difficult start due to cold weather for example or poor engine condition). It therefore has a maximum power rating of 10 kW and stores up to 300 kJ, allowing for up to three ten-second starts. The previously mentioned small supercapacitor sold by KBi would therefore – at least according to the contractor's theoretical analysis – be able to start an average engine during a typical three-second start (Table 9). Its 2,7 L and 4,8 kg would not impose large weight or volume burdens, although the indicated volume does not include packaging or other possibly necessary devices. A doubling of the volume, a likely worse case scenario, reaching 5,4 L, remains smaller than a car battery.

Table 9 Overview on the maximum power and maximum starting time

| Two battery systems | Maximum power | Maximum starting time |
|---|---|---|
| Lead-acid battery | 10 kW | 10 seconds |
| Supercapacitor (KBi Part Number 700000 as reference) | 8,8 kW | 3,4 seconds |

However, as mentioned before, the energy density of a supercapacitor is very low thus being the main hindrance from the technical point of view. The technical properties together with other possible alternatives are summarised in Table 10. It shows that the supercapacitor alone has very low energy storing capability: it cannot store enough energy to operate the normal electrical bordnet. Nevertheless, a supercapacitor coupled with a battery system could solve this problem. To get a rough feeling about the possible combination, a hypothetical calculation is carried out. In order to reach the same energy density equivalent to a lead-acid battery, option 1 (supercapacitor coupled with 4 kg Li-Ion) and option 2 (supercapacitor coupled with 10 kg Lead-acid) are possible. It should be pointed out that the calculation is theoretical and with the only consideration of energy storing capability.

To avoid misunderstandings, the example here does not declare that a supercapacitor coupled with a battery system can substitute the lead-acid battery used in a passenger car. It is clear that buses and cars do not have equivalent operating conditions and that their battery systems can thus not be compared. Nevertheless, the example shows on a fact-base that at least the supercapacitor technology can function under cold condition and overwhelm the CCA problem which was mentioned as the most important factor from the car maker's perspective. However, until now no evidence showed that this technology either functions or does not function in cars. From reviewers' point of view, it is nonetheless at least a hint on a possibility worth to be investigated.

Table 10 Comparison of alternative battery technologies

| | **Lead-Acid** | **NiMH** | **Li-Ion** | **Supercapacitor (reference KBi Nr 700000)** | **Supercapacitor (reference KBi Nr 700000) + battery** |
|---|---|---|---|---|---|
| Typical weight | 15-16 kg | 8-9,8 kg | 4,9-6,9 kg | 4,8 kg | Option 1: Supercaps+Li-Ion: 4,8 kg+4 kg<br>Option 2: Supercaps+LdA: 4,8 kg+10 kg |
| Power density | 500 W/kg | 1000 W/kg | 1500-2000 W/kg | 1833 W/kg | |
| | 1500 W/l | 2600 W/l | 1500-2000 W/l | 3239 W/l | |
| Energy density | 45-50 Wh/kg | 60 Wh/kg | 100-120 Wh/kg | 1,7 Wh/kg | In order to reach the energy density equivalence of LdA, an extra battery providing 479 Wh is required. It might be 4kg Li-ion or 10kg Lead-acid |
| | 100-110 Wh/l | 170 Wh/l | 120-150 Wh/l | 3,1 Wh/l | |

Stakeholders also made a quick mention of batteries based on lead-acid technology and added carbon to compete with Ni-MH batteries but provided no further details on the subject. A personal investigation (Dickinson 2009) revealed that a new battery produced by Axion Battery Products called the PbC® battery[21], although not exactly what the industry stake-holders implies, is a promising technology. This hybrid lead-acid battery integrates a super-capacitor into the battery used instead of the traditional lead-containing negative electrode. Axion claims the system reduces lead content by 65%, battery weight by 20% as well as recharging time, while increasing power output and the lifespan of the battery. A reduced energy density however is to be noted (the energy density is lowered to about half that of a traditional lead-acid battery). Additionally, these batteries can be easily produced in existing plants and can also be recycled in existing facilities.

[21] A similar product is called UltraBattery™ and developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO)

These batteries are currently aimed at the micro hybrid market where AGM batteries currently used experience increased recharging times when repeatedly charged and discharged in a congested traffic situation. The PbC® battery does not experience this issue. The battery is expected to be marketed very soon but some aspects are still being developed. It can therefore not be considered as an immediate substitute to traditional lead-acid batteries.

Stakeholders' response was that the reduced energy density outweighed the reduced lead content. As of yet, this remains to be proven, as even with half the energy density, a PbC® battery with unchanged energy storage would still contain 30% less lead than a regular battery, although device weight would be 60% higher (i.e. 9,0–9,6 additional kilograms).

PbC® manufacturer Axion Power Limited responded that solutions were with one battery, despite the increased battery load during idling in a microhybrid vehicle. Axion Power was expected to send more information on the subject but did not deliver it in due time before final drafting of this recommendation.

Stakeholders' arguments about costs of possible alternatives and standards are not relevant to the rationale of the ELV Directive. The ELV Directive does not give grounds for a lead-use exemption to be based on economic arguments but on basis of the unavoidability of the use of lead.

In the current state of the revision procedure, it seems that the use of lead-acid batteries containing 9–9,5 kg of lead could be avoidable since supercapacitors, hybrid batteries and alternatives are expected to be developed in several years.

Supercapacitors coupled with a lead-acid or even lead-free battery has not yet been investigated or researched much. It can thus be concluded that a huge improvement potential seems to exist for alternative technologies that remains to be explored. Or at least, stakeholders will in future need to prove on a fact and evidence basis that the use of such an alternative is not possible.

A short screening of the main to be solved technical difficulties or limitation factors is listed in Table 11.

Table 11 Main difficulties remaining from possible alternatives

| Possible alternative | Crucial technical problems | Possible solutions | Limitation |
|---|---|---|---|
| Li-Ion | CCA ability is not reliable | - | |
| PbC | Has sufficient power output, but not sufficient energy content. | In order to reach the sufficient energy output, 100% increase of weight is required. | Some questions with regard to long term stability and lifetime under real vehicle conditions are still not fully clarified. |
| Supercapacitor alone | No CCA problem has sufficient power output, but insufficient energy output. | Supercapacitor coupled with a battery system | Unknown, research and investigation required |

### Review date

To avoid misunderstandings, it should be stressed that the proposed 5 year review date in the below recommendation does not fix a total ban date and is not intended either to be the beginning of a full phase-out. It is too early to draw a conclusion on further technological vehicle battery development- be it lead-free or led reduced. Several battery technologies relevant research projects funded by EU FP7 have been and are carried out (Research Project). The intention of a review date is to obtain sound evidence for re-evaluating the exemption in light of currently ongoing and promising technologies. The assessment procedure will still be done under the provisions of the ELV Directive (2000/53/EC). That means, a termination of an exemption can only be recommended under the condition that the substitution of this substance is scientifically or technically possible without negative environmental, health and/or consumer safety impacts. As long as this is not possible, no total ban or full phase-out will be initiated.

In addition, a 5 year review period is already a quite long compared to the usual expiry, review or phase-out timelines. 5 years are considered a good period to i) gather the missing facts & figures for sound evidence and ii) give better information on the status quo of technological battery development (even if not completed). Research projects will be finalised by then. For R&D 5 years is a quite significant amount of time to make more concrete statements.

An earlier review date would not make much sense since technological development would not be as advanced as necessary for a better assessment of the further need for an exemption.

### Conclusion

In a nutshell, there is no doubt that lead-acid batteries as a long-term marketed technology perform their reliability in the area of safety and control. Nevertheless, there is also no doubt that battery technology has still a huge improved potential from the point of view of a lead reduction through the use of alternative technologies. Further in-depth investigation and research on the use of such alternatives in the automotive industry is needed and should be promoted.

Therefore, carrying out a life cycle assessment being a robust scientific method could contribute to identifying the environmental impacts associated with the possible alternatives compared to the use of lead-acid batteries with a holistic approach.

### 4.5.5 Final recommendation

It is recommended to continue the exemption. The stakeholder presented plausible information showing the current technical superiority of lead-acid batteries. Their short-term substitution by lead-free alternatives would reduce the functionality and reliability of vehicles, the use of lead in this function hence is unavoidable at the time being and in the near future. At least in the industrialized countries, a proper collection and recycling system enabling a high collection and recycling rate of lead from these batteries is in place.

A roadmap or strategy of industry to replace lead-acid batteries in this function was unfortunately not provided and should be requested in the context of future evaluations. Moreover, by means of screening the feasibility of alternative technologies, it appears that there are some promising technologies which should thus be investigated more deeply in the near future.

It is therefore recommended to set a review date of this exemption 5 years after its entry into force aiming at the verification of corresponding research & development efforts into alternative battery technologies for fuel combustion vehicles.

### 4.5.6 References


ACEA 2010 — ACEA position paper and letter to European Commissioner Mr K.F. Falkenberg (provided on 31. 03. 2010 via e-mail)

BDI 2010 — BDI-Position paper “Innovative Antriebstechnologien, Elektromobilität und alternative Kraftstoffe für unsere Mobilität von morgen” – finale Version vom 01.02.2010 (provided by Mr. Eckhard Fahlbusch on 31.03.2010 via e-mail)

Dickinson 2009 — Personal communication with Mr. Enders Dickinson from Axion Power Applications Ltd. on 17.10.2009

EUROBAT 2009a — EUROBAT stakeholder document “Comments_ eurobat_entry_17.pdf”

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|---|---|
| EUROBAT 2009b | EUROBAT stakeholder document "Eurobat ELV SLI position paper – January 2008.pdf", submitted to Otmar Deubzer via e-mail on 11 January 2008 |
| EUROBAT et al. 2009 | Stakeholder documents "Eurobat ACEA ILA et al. Answers to further Questions Exemp Lead No 5 Dec 07 FINAL.doc" (provided on 7.12.2009 via e-mail) |
| Global Automotive Industry 2009 | Stakeholder document "20090804_Global AI_exe 5.pdf" |
| Ha 2009 | Personal communication with Mr. Lou Ha from the Regional Transport District of Denver on 20.09.2009 |
| Hirth et al. 2007 | Nachhaltige rohstoffnahe Produktion, Thomas Hirth, Jörg Woidasky, Peter Eyerer (Hrsg.), Fraunhofer Institut Chemische Technologie (ICT), 2007 (provided by Mr. H.F. Schenk on 30.03.2010 via e-mail) |
| Pers. communication by stakeholders 2009 | Conference call with stakeholders on 16.12.2009 |
| Pers. communication by stakeholders 2010 | Conference call with stakeholders on 31.03.2010 |
| Research Project | Actual EU projects for batteries in FP7 and information from website (provided by Mr. H.F. Schenk on 30.03.2010 via e-mail) |

## 4.6 Exemption no. 6

*"Vibration dampers"*

The evaluation of exemption 6 under the current contract was based on the contributions received during the current consultation and on previous studies (Sander et al. 2000; Lohse et al. 2001; Lohse et al. 2008). Insufficient information was received during the previous Annex II revision in order to assess the situation and provide a well founded recommendation. Initial statements have been received from stakeholders in the context of the second stakeholder consultation (ACEA et al. 2009a). Further questions have been sent and stakeholders from ACEA/JAMA/KAMA/CLEPA provided a common response (ACEA et al. 2009c).

The outcome of this information gathering exercise and of the exchange with the above mentioned stakeholders is reflected in the following.

### 4.6.2 Description of exemption

Vibration dampers made of lead can be used in various applications in vehicles to reduce noise and vibration problems that may occur during vehicle use. They usually consist of a lead weight in order to have the weight on the spot connected to the vibrating part via a spring or screwed that absorbs the vibration energy. They may be used on the axle between the gearbox and the wheels, the steering column, or in other various places on the chassis, or body.

The vibration noise ("buzzing or humming") may arise from more or less any area of the vehicle which is able to create vibrations (e.g. brake drums, lift gates, and body parts). In order to avoid those vibrations, it is necessary to vary the mass of the respective part to change the acoustic properties. However, in these late stages of the development process it may not be possible to change the design of the vibrating component at short notice. In these cases the addition of some mass to the affected component in order to damp the vibration problem is a practicable short-term solution. That means it depends on how much mass is needed to change the acoustic behaviour of the vehicle or the systems.

The quantity of lead used in vibration dampers can be significant. Overall the industry estimates that about 10% of vehicles use lead vibration dampers, with an average mass of 500 g. Typical lead weights range from a few grams (0,1–0,3 kg) up to 4,7 kg, depending on the usage of the vibration dampers, the area of use and the purpose of application. It is unclear what the maximum used dampener weight is and what material it may be manufactured from. The industry explained as well that the earlier reported values up to 20 kg[22] per vibration damper were no longer reached (ACEA et al. 2009a).

On the basis of these figures, the total European lead consumption in this field is estimated to be about 890 tonnes of lead per year[23]. As a general tendency the usage of vibration dampers is more frequent in sports cars and convertibles where the absence of a roof decreases internal stability. Additionally, the mass of vibration dampers increases with efforts in light weight construction.

Principally, manufacturers try to avoid the use of vibration dampers because they increase the weight of the vehicle and thus are in conflict with the targets of weight reduction and fuel saving, and they imply poor design. However, vibration dampers are sometimes deemed necessary to eliminate unexpected vibrations that become apparent at late design or release stages of a new model and even during the production phase, especially in lighter weight vehicles, sports and open-top cars that make use of more plastics.

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22 Heavier lead weights up to 4,7 kg and even 20 kg in new car models have been reported where the increased use of plastics leads to serious noise problems (Lohse et al. 2001).

23 For EU27 incl. EFTA (17,7 million cars – i.e. ignoring the current economic downturn – source: ACEA 2008)

Stakeholders request the extension of exemption 6 for all vehicles type approved before 1 January 2016.

### 4.6.3 Justification for exemption

Stakeholders from ACAE/JAMA/KAMA/CLEPA/et al. provided information on the topic with two common response document (ACEA et al. 2009a and ACEA et al. 2009c). Additionally, an example of labelling by the International Dismantling Information System (IDIS)[24] database was supplied (ACEA et al. 2009b). The IDIS system labels in accordance with Article 4(2)(b)(iv) of the ELV Directive such parts which are marked with an "x" in Annex II. All vehicle manufactures are committed to show the presence and the location of the used leaded vibration dampers and to give further instructions on how to dismantle them. Figure 4 shows an extraction (Alfa Romeo, 156 Sedan 1997–2003) from the IDIS database document (ACEA et al. 2009b). Note that not all objects shown in this extract are vibration dampers such as e.g. the wheel balance weights.

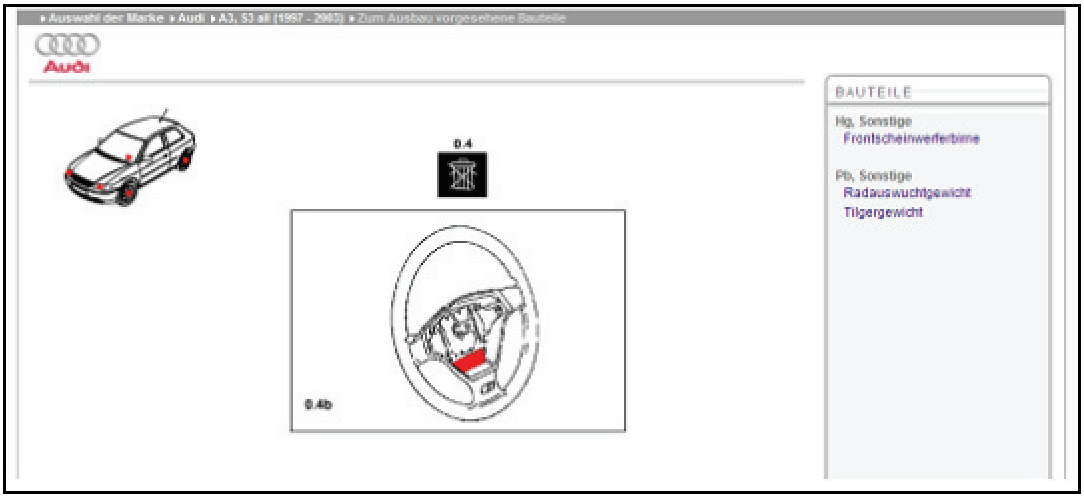


Figure 4 Extraction from the IDIS database

Stakeholders argued that during the development of a new vehicle series unwanted noises and vibrations may appear at late vehicle design or production/testing stages that are not apparent in earlier prototypes. On such short notice, the only way to prevent these vibrations is to vary the mass of the problematic part by using a vibration damper. Manufacturers only use vibration dampeners as a last loophole, a redesign of vibrating components being preferable as dampeners increase the weight of the vehicle and therefore counteract weight reduction and fuel saving efforts.

[24] www.idis2.com

According to stakeholders, the avoidance of vibration dampeners is first priority, but cannot be avoided in some cases under some circumstances. Therefore it cannot be considered during vehicle design and it cannot be designed in to a new vehicle. Which type of dampeners is the suitable one needs to be decided on a case to case basis. This includes also the choice of the material.

Applications where plastics are increasingly used as construction materials or in sports cars and convertibles do not imply that heavier vibration dampeners or vibration dampeners at all need to be applied. This depends on the type of the vibration which needs to be eliminated and which can be required everywhere (3 doors, 5 doors, station wagon etc.).

**Lead content reduction**

With regard to lead content reduction the only way therefore is to reduce the weight of the dampers. As vibration dampers are tuned to the harmonics of the vibrating parts, the minimum mass able to prevent these vibrations is used. In this respect, the additional weight of the vibration dampers is thus minimized as much as possible.

**Lead-free alternatives**

Although alternatives to lead vibration dampers have always existed, lead's high density makes its use inevitable when dampeners are needed in confined, low-clearance regions of the car. .The industry claims to have an incentive to use lead-free vibration dampers where possible through existing heavy metal bans and the initiated substitution and reduction measures. According to industry, lead has already been phased out significantly from this application. Other incentives are better design and construction methods to prevent such cases as well as costs induced through the late addition of vibration dampers to vehicles (ACEA et al. 2009c).

It is possible to use other materials than lead to solve the "noise and vibration problems", e.g. with steel dampers, brass, tin or cast irons. Current vehicle types however do still use lead as vibration dampeners in very rare instances. As in many cases the clearance in that specific area is very limited it is essential to use small parts with a high weight/density as is the case for vibration dampers made of lead. As these types of vibration dampeners in scope will be used for "trouble shooting" solving a problem which occurred unexpected, inconstantly and infrequently, it is difficult to restrict their use to limited applications.

Industry states that substitution is ongoing and the full substitution seems feasible for new vehicle types as of 2016.

### 4.6.4 Critical review of data and information

As mentioned above, stakeholders provided information without substantial supporting evidence. An example of labelled vibration dampers was given, taken from the IDIS database, helping the contractor understand what form labelling actually takes.

**Lead content reduction**

For the coming 5 years it remains unclear whether or not the industry has an incentive to limit the lead content to a necessary minimum. No detailed data is available to allow a differentiation between the lead and non-lead dampers.

**Lead-free alternatives**

Ökopol's 2000 study (Lohse et al. 2001) reports that in several applications lead had been substituted by cast iron or highly filled polyacrylates. In some models, aluminium dampers had replaced lead dampers. It was further concluded that specially adapted solutions could be found, e.g. the use of airbag modules for vibration compensation in the steering column or use of the Integrated Starter Alternator Damper (ISAD) in the drivetrain. In addition, Sander et al. 2000 and Lohse et al. 2001 have discussed substitution for new car models concluding that complete substitution should be possible in 2016 (ACEA et al. 2009c). This was confirmed by automotive industry through the request to continue the existing exemptions for vehicles type approved before 1 January 2016, i.e. phase-out of lead in vibration dampers is possible by then.

### 4.6.5 Final recommendation

As mentioned above, vibration dampers are only in use and needed for a limited number of vehicle types, and will be replaced fully for new vehicle types. Due to the number of various applications in vehicles and the long automotive development and production cycles (5 to 7 years) a transition period for vehicles type approved in the next 6 years needs to be considered before full phase out can be completed.

It is therefore recommended to extend the current exemption for lead in vibration dampers for all vehicles type approved before 1 January 2016.

### 4.6.6 References

ACEA et al. 2009a — ACEA/JAMA/KAMA/CLEPA/ et al.; Request the continued exemption of "20090804_Global AI_exe 6.pdf"

ACEA et al. 2009b — ACEA/JAMA/KAMA/CLEPA/ et al.; Example of labelling by the International Dismantling Information System (IDIS) "20090804_Global AI_exe 6 Mass damper.pdf"

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|---|---|
| ACEA et al. 2009c | ACEA/JAMA/KAMA/CLEPA/ et al.; "Answers to additional questions Exemption 6-draft-final.pdf" |
| Lohse et al. 2001 | Lohse, J. et al. (2001); Heavy Metals in Vehicles II (Final Report); Ökopol – Institut für Ökologie und Politik GmbH, Hamburg, Germany; Report compiled for the Directorate General Environment, Nuclear Safety and Civil Protection of the Commission of the European Communities Contract No B4-3040/2000/300649/MAR/E.3 |
| Lohse et al. 2008 | Lohse, J.; Zangl, S.; Groß, R.; Gensch, C.O.; Deubzer, O. (2008); Adaptation to Scientific and Technical Progress of Annex II Directive 2000/53/EC (Final Report), Öko-Institut e.V. for Applied Ecology and Fraunhofer Insitute fpr Reliability and Microintegration IZM; Contract N°07010401/2007/470145/ATA/G4 |
| Sander et al. 2000 | Sander, J. et al. (2000); Heavy Metals in Vehicles (Final Report); Ökopol – Institut für Ökologie und Politik GmbH, Hamburg, Germany; Report compiled for the Directorate General Environment, Nuclear Safety and Civil Protection of the Commission of the European Communities Contract No B4-3040/2000/300649/MAR/E.3 |


## 4.7 Exemption no. 8a – general remarks

*"Lead in solder in electronic circuit boards and other electrical applications except on glass"*

The recommendations given here have already been published in September 2009 (http://circa.europa.eu/Public/irc/env/elv_4/library?l=/reports/099016_finalpdf/_EN_1.0_&a=d). Following these recommendations on adaptation of exemption 8, the Commission has adopted the fourth revision of Annex II to Directive 2000/53/EC. The amended Annex II has been published in the EU's Official Journal (Commission Decision 2010/115/EU of 23 February 2010;
(http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32010D0115:EN:NOT).

Abbreviations and definitions

| | |
|---|---|
| EES | Electrical and Electronic Systems |
| ECU | Electronic Control Unit, Engine Control Unit |
| RoHS equipment | Equipment under the scope of the RoHS Directive |

### 4.7.2 Background

Exemption 8a was already reviewed by the contract during the previous project on the third adaptation to scientific and technical progress of Annex II ELV Directive (Öko-Institut 2008). The report was published in January 2008. For details on the description of exemption 8a and for further technical background refer to the final report on page 45 ff.

The stakeholders estimate the amount of lead in solders in electronic circuit boards in vehicles to around 500 to 700 t per year (Öko-Institut 2008).

### 4.7.3 Stakeholder proposal for exemptions to replace the current exemption 8a

Figure 5 illustrates the development of exemption 8 and clarifies the complex proposal, which the stakeholders had submitted for the current review round.

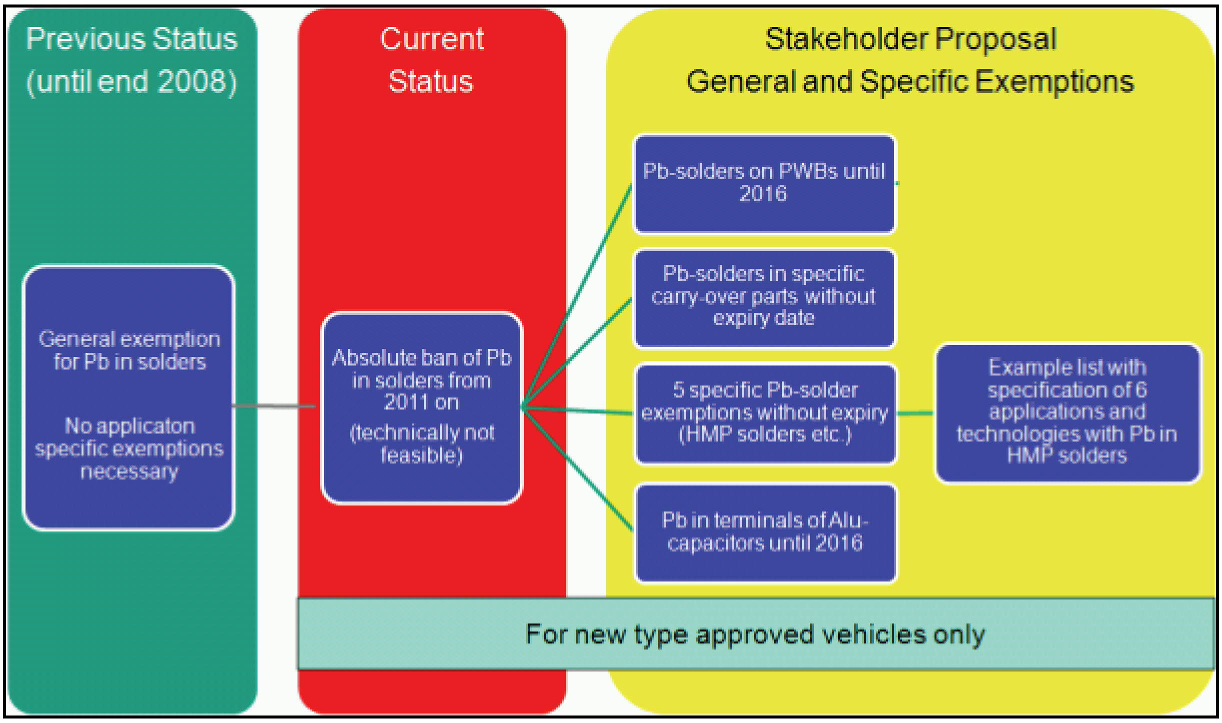



Figure 5 Development of exemption for lead in solders and finishes

Before 2008, the exemption 8 being valid at that time allowed the use of lead in solders and finishes on PWBs without further confinements to specific technologies or applications and without an expiry date (Previous Status). More specific exemptions for the use of lead in solders and finishes therefore were not necessary. After the previous review of Annex II of the ELV Directive in 2007/2008, the Commission did not allow any use of lead in solders and finishes on PWBs for new type approve vehicles from 2011 on. However, a review date was set for 2009 (Current Status).

For the current review round, ACEA et al. (ACEA et al. 2009a; ACEA et al. 2009l) proposed a general exemption for lead as in the previous versions, with an expiry date in end of 2015 for new type approved vehicles. For the time after the expiry of this general exemption, they propose specific exemptions for lead in solders and finishes on PWBs without expiry dates (Stakeholder Proposal).

At the current state of science and technology, lead cannot yet be replaced in all applications and technologies. With the end of the general lead exemption, specific ones will hence be indispensable if the state of science and technology does not change until 2016. The architecture of the exemptions then is equivalent to the structure of the exemptions in the RoHS Directive.

Table 12 shows the stakeholders' proposal in detail.

Table 12 Proposal for new approach and wording for the review of the current exemption 8 a (ACEA et al. 2009a; ACEA et al. 2009l)

| | **Materials and components** | **Scope and expiry date of the exemption** | **Comment** |
|---|---|---|---|
| A | Lead in solders to attach electrical and electronic components to electronic circuit boards and lead in finishes on component terminations, component pins and on printed wiring boards | Vehicles type approved before 31 December 2015 and spare parts for these vehicles | Time for validation, safe implementation and production change required. 90% of solder volume. |
| B | Lead in solder of carry over electric/electronic parts or systems first used in vehicles type approved before 31 December 2010 | | Implementation time, re-development time >= ramp down time |
| C | Solder in other electric/ electronic applications except on glazing | Review after 2015 | |
| i) | • Lead in high melting temperature solder i.e. lead based solder alloys containing above 80% by weight of lead. | | Technically required due to solder hierarchy, ductility and CTE mismatch |
| ii) | • Lead used in compliant pin connector systems | | Technically required to avoid whisker. Growth mechanism not fully understood |
| iii) | • Lead used in soldering on glass for non glazing application | | Technically required due to ductility and CTE mismatch |
| iv) | • Lead in solder for large (>1cm²) power semiconductor assemblies | | Technically required due to solder hierarchy and CTE mismatch |
| v) | • Lead in solders for electrical connection between semiconductor die and carrier within integrated circuit Flip Chip packages. | | Technically required due to solder hierarchy, ductility and CTE mismatch |

| | Materials and components | Scope and expiry date of the exemption | Comment |
|---|---|---|---|
| D | Lead in terminals of Aluminium-Capacitors (Electrolyte Capacitors). | Vehicles type approved before 31 December 2015 and spare parts for these vehicles | Time for validation, safe implementation and production change required |

The principle approach thus is:

A Allow lead in solders to attach electrical and electronic components and lead in finishes of components and printed wiring boards in all cars type approved before 31 December 2015. The exemption further on allows the use of lead solders for the repair of vehicles type approved before December 2015.

B Exempt lead in solders of electrical and electronic carry over parts and systems first used in vehicles type approved before 31 December 2010. Lead in solder for the repair of carry over parts first time used before December 2010 is not intended.

C Allow the use of lead in solders for specific applications and technologies without an expiry date, but adapt to technical and scientific progress after 2015.

D Allow the use of lead in terminals of electrolyte aluminium capacitors.

The different proposals are reviewed step by step in separate chapters using the above numbering.

### 4.7.4 Limitation of exemptions to new type approved vehicles in proposed exemption “A”, “B” and “D”

#### Background and current status

The proposed exemptions “A”, “B” and “D” have expiry dates, which refer to vehicles with type approval after a certain date. In vehicles with type approval before these expiry dates, lead could be used in solders and finishes as long as these types of vehicles are produced. The Commission had adopted the reference to new type approved cars for the current wording of exemption 8a and 8b.

This reference to new type approved vehicles was discussed in the last review of Annex II in 2007/2008, and the stakeholders had explained the background of their request to refer the expiry date to new type approved vehicles. “The stakeholders state that the change of running systems towards lead-free solders and finishes often technically will not be possible and would exceed the personal and technical resources of the automotive industry as well as their suppliers. They say that for products in service for longer time, a significant amount of components are not available any more due to production termination of electronic component suppliers. Therefore, the automotive suppliers take high volumes of components on end of live stock to assure production for the required lifetime (last time buys).

Last time buy issues thus are a major technical reason that, according to the stakeholders, running systems cannot be changed to lead-free. Concerning the personnel constraints, the stakeholders say that a single supplier can have several thousand families of electronic control units (ECU) in his product portfolio. Shifting these ECUs lead-free takes around 1 person-year of labour per ECU family for redesign, testing, and component qualification. This would require several thousand person-years of labour creating an additional demand of several hundred highly qualified engineers, even assuming a transition period of several years. These engineers would have to be readily available so that they could start working right away. The stakeholders say that this situation is impossible to handle for suppliers and car manufacturers and conclude that a transition of running parts and systems to lead-free hence is not possible" (Öko-Institut 2008).

**Definition of car "type" and "type approval"**

According to the stakeholders in approximation a vehicle type can be considered as "model" (ACEA et al. 2009l). For legal purposes and to be correct in the sense of Type Approval, the word "type" should be used, however, not "model".

Type approval in the context of the stakeholders' proposal is defined as any vehicle type approval according to Directive 2007/46/EC (former 70/156/EEC). In this directive e.g. EC type approval is defined: "EC type-approval means the procedure whereby a Member State certifies that a type of vehicle, […] satisfies the relevant administrative provisions and technical requirements of this Directive […]". A later change from a national type approval to an EC type approval is not considered as a new type approval (ACEA et al. 2009l).

ACEA et al. explain that minor modifications (minor face lifts) on a vehicle may not require type approval. If there are significant changes in essential aspects of construction details like chassis or type and kind of power plant (internal combustion / electric / hybrid), a new type approval is necessary (ACEA et al. 2009l).

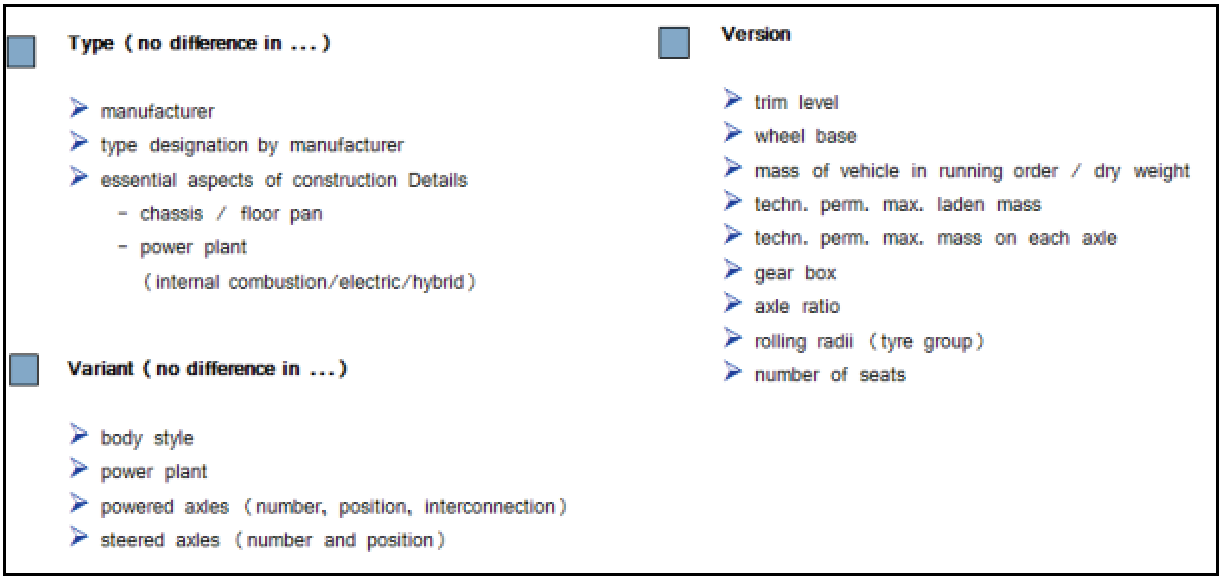



Figure 6 Differentiation of vehicle type, vehicle variant and version (source: GM, H. Schenk)

As long as a vehicle has the same manufacturer, the same type designation from the manufacturer, and does not differ in essential aspects of construction details like the chassis, power plant etc., it is the same type of vehicle. Differences in such features require a new type approval, according to Figure 6. Other differences just discriminate variants or versions of a vehicle type and would hence not result in an obligation to obtain a new type approval.

A wide range of changes thus are possible to a vehicle under the same type, before a type approval becomes indispensable.

**Timescale of lead phase-out with type approval expiry dates**

The stakeholders roughly estimate that in average about 15% to 20% of an OEM vehicle fleet will get a renewal and will therefore be new type approved every year (ACEA et al. 2009m). It takes about five to seven years to undergo a type approval for the whole car fleet of a vehicle manufacturer. This varies between the different OEMs and their product portfolio. A type is marketed for four to five years. There are, however, types that may be marketed for longer than 4 years. Especially vehicles based on or sharing platforms with commercial models have a longer production time period.

ACEA et al. (2009m) assume that the phase out of lead would take 8–10 years with a certain amount of resources.

## 4.8 Exemption no. 8a – stakeholder proposal part A

*"Lead in solders to attach electrical and electronic components to electronic circuit boards and lead in finishes on component terminations, component pins and on printed wiring boards"*

### 4.8.2 Description of exemption

The technical background of this exemption was described in detail in the previous review of Annex II of the ELV Directive in 2007/2008 (Öko-Institut 2008).

### 4.8.3 Justification for exemption

The technical backgrounds for the use of lead in solders and specific problems of lead-free soldering were explained in detail in the final report for the review of Annex II of the ELV Directive (Öko-Institut 2008). The following sections reflect additional facts and arguments the stakeholders put forward during the current review process.

**Specific conditions of testing and use for electrical and electronic devices (EED) in vehicles**

The use of lead-free solders and finishes on printed wiring board level has become standard in all types of electronics under the scope of the RoHS Directive. ACEA et al. (2009h) claim that these experiences in lead free soldering from other industry sectors like consumer electronics cannot be simply transferred to automotive applications due to different demands to the product. The stakeholders claim that the requirements are similar to the demands of aeronautic and defense industry equipment. Specific automotive conditions and requirements are (ACEA et al. 2009h; Öko-Institut 2008):

- high operating temperatures,
- vibrations and other mechanical impacts,
- exposure to temperature changes over a broad temperature range,
- long life time,
- high reliability requirements,
- safety critical functionalities.

| Parameter | Consumer | Industrial | Automotive |
|---|---|---|---|
| temperature | 0°C → 40°C | -10°C → 70°C | -40°C → 85/155°C |
| operation time | 1-3 years | 5-10 years | up to 15 years |
| humidity | low | environment | 0% up to 100% |
| tolerated field failure rates | < 10% | << 1% | target: zero failure |
| supply | none | up to 5 years | up to 30 years |

Figure 7 Comparison of requirements for electrical and electronic devices in different application fields (ACEA et al. 2009h; Öko-Institut 2008)

ACEA et al. (2009h) state that these high demands require extensive validation and a cautious change over to lead free solders. To ensure proper functioning, the test and qualification procedures of electrical and electronics devices (EED) in vehicles are more challenging and stricter than in most other applications. Examples for such tests, some of which are used in combination, are (Öko-Institut 2008):

- temperature cycling -45 to +150°C, 3 000 cycles,
- mechanical vibration tests up to 100 g at elevated temperatures,
- -40°C to +210°C, 100 cycles,
- -40°C to +175°C, 1 000 cycles,
- -40°C to +160°C, 1 000 cycles.

**Specific properties of lead solders**

ACEA et al. (2009h) explain that lead keeps the solder ductile, ensures a reliable bonding, it avoids tin whisker growth which may occur in tin containing layers etc. Lead containing solders are excellent especially in areas with high and intensive thermal stress combined with mechanical vibrations as needed for all automotive applications. The interaction between

- the thermal expansion and heat conductivity of the material at a sufficient level of electric conductivity on the one hand and
- temperature range and mechanical stress due to vibration on the other hand

is the technical reason why lead is used for soldering in automotive applications (ACEA et al. 2009h).

According to the stakeholders lead bearing solder offers significant advantage in high temperature, high vibration, high humidity environments, with less solder fatigue and essentially no risk of tin whiskers compared to lead-free solder designs (ACEA et al. 2009h).

The long term reliability of the soldering is the key. A failure in electronics may endanger life and health of the driver.

ACEA et al. (2009h) reference a document showing whiskers. The report states that short circuits induced by tin whiskers have been reported to have caused catastrophic failures of electronic systems in commercial satellite applications (Kadesch 2001). ACEA et al. state that if the same would happen in automotive electronics, it might lead to a failure of the system, which must be securely precluded.

**Implementation and restrictions of lead-free soldering solutions in automotive applications**

The most common lead free solder are based on tin-silver (copper, bismuth, antimony) alloys. The problems/risks of such alloys are (beside the higher process temperatures) fatigue, brittleness and possible tin whisker growth causing malfunction of the electronic system. This brittleness is mainly caused by the addition of alloying elements (being less compatible and having a lower solubility), which can lead to growth of brittle inter-metallic phases in solder (ACEA et al. 2009h).

The automotive vibration stress leads in consequence to the malfunction like breakage of the solder joint. These issues are still a big challenge for these alloys in automotive applications. ACEA et al. (2009h) highlight that temperature as well as vibration stress apply to all automotive applications. Currently none of the lead-free alloys meets the requirements with respect to a similar melting point such as lead containing solders, in combination with a proven reliability. In addition the production capacities are not sufficient available and need high investments (ACEA et al. 2009h).

According to ACEA et al. (2009h), the changeover to lead free substitutes requires changing and approving the whole system, following the procedure in Figure 8.

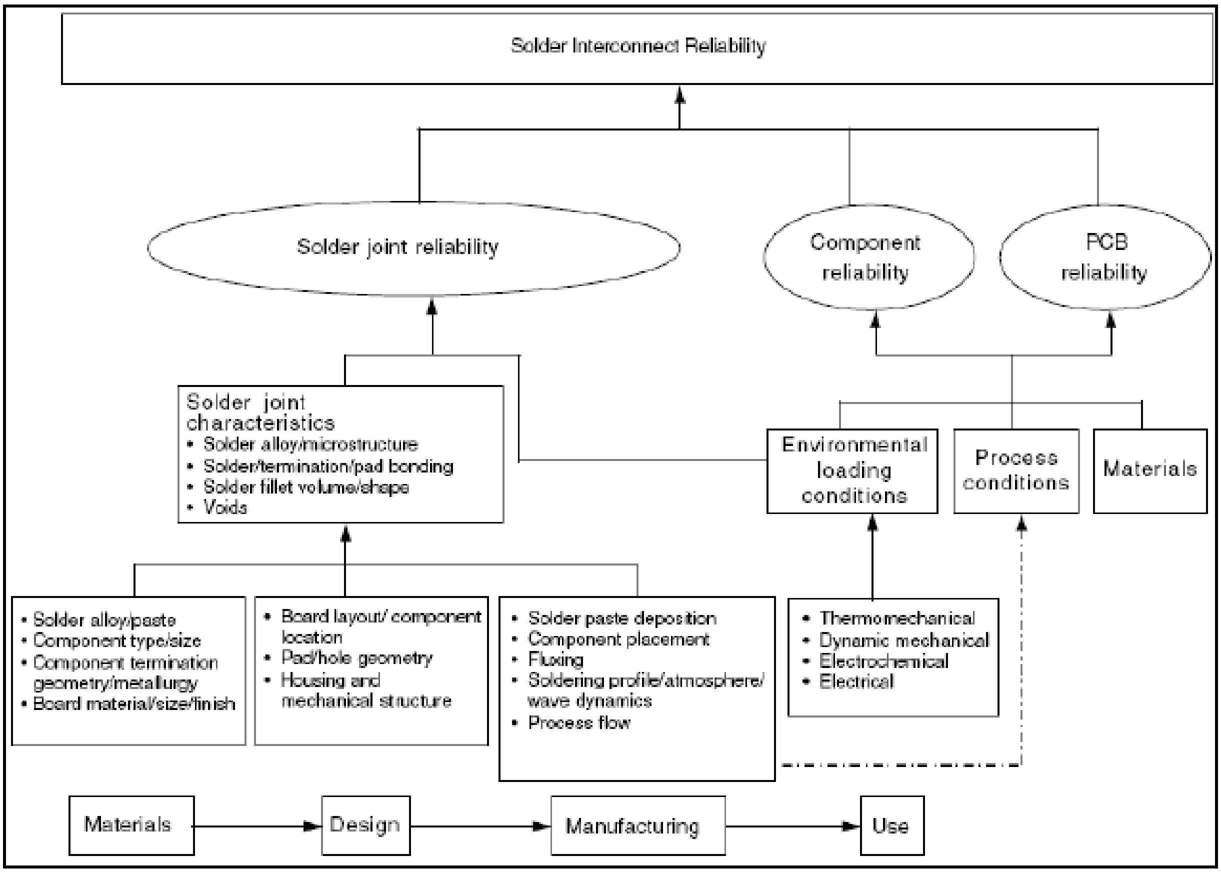



Figure 8 Solder connect reliability (ACEA et al. 2009h)

Other interconnection technologies avoid the use of lead, but cannot replace soldering. Soldering is the most common method known to provide high reliability in electronic devices operating in an automotive environment. Hard wiring or wire wrapping of components together can be done for very low volume prototypes, but the reliability and durability of this type of assembly is far inferior to soldering and would require significantly greater packaging space. The whole system needs to be adjusted and tested if lead in solder is substituted due to complex interactions between material selection, design, manufacturing and use of solder, component and PCB (ACEA et al. 2009h).

According to ACEA et al. (2009h), the development of electronic components like resistors, capacitors and integrated circuits was in the focus during the last years. The main differences for automotive industry components are the noticeable extended requirements regarding reliability, temperature range and mechanical stresses which are reflected throughout all automotive qualification standards. The target was to qualify electronic components able to bear respectively to face the higher temperatures of lead free solder processes, and at the same time can meet the reliability requirements over the necessary lifetime of the electrical and electronic systems (EES). The lead free solder processes need around 25 to

30 Kelvin higher temperatures, which cause thermal stress and a reduced lifetime (ACEA et al. 2009h). ACEA et al. state that for most of the related components, substitutes could be developed. Based on intensive R&D work within the last five years, the entire automotive industry has been successful in implementing some of these substitutes where the more severe and more safety related and reliable automotive requirements have been met (ACEA et al. 2009h).

However, implementation failed so far in some applications by not fulfilling the requirements for a well functioning, reliable and safe vehicle. Life time and reliability demands are in some cases still not on the level of components used for lead containing solder processes (ACEA et al. 2009h). The same application can be affected by different temperature and vibration stress depending for example on the individual vehicle segments. Lead-free solder substitutes still often intend to embrittle or to fatigue earlier which can cause drop outs up to total failure of an assembly. An intensive and specific testing in the target car is required (ACEA et al. 2009h).

**Timing of product cycles**

ACEA et al. (2009m) say that also for timing reasons, it is impossible to comply with the expiry date of 30 December 2010 in the current exemption 8 a. They put forward that the development of new vehicle types with type approval in the next few years already started before the new ELV Annex II came into force in August 2008. According to ACEA et al. (2009m) design and development are already underway for the vehicles of at least 2012 and 2013. Orders are already being placed. Suppliers have not invested in the necessary equipment and there is a long lead time associated to procurement.

### 4.8.4 Critical review of data and information

**Overview on consequences of proposed wordings**

As the consequences of exemption A and B for the use of lead are not easy to overlook, Figure 9 illustrates the use of lead in solders on PWBs in consequence of the proposed and requested exemptions in Table 12 on page 70. Lead-free soldering in this context means the use of lead-free solders and finishes including the use of lead in the further exemptions, which the stakeholders propose as parts C and D of exemption 8.

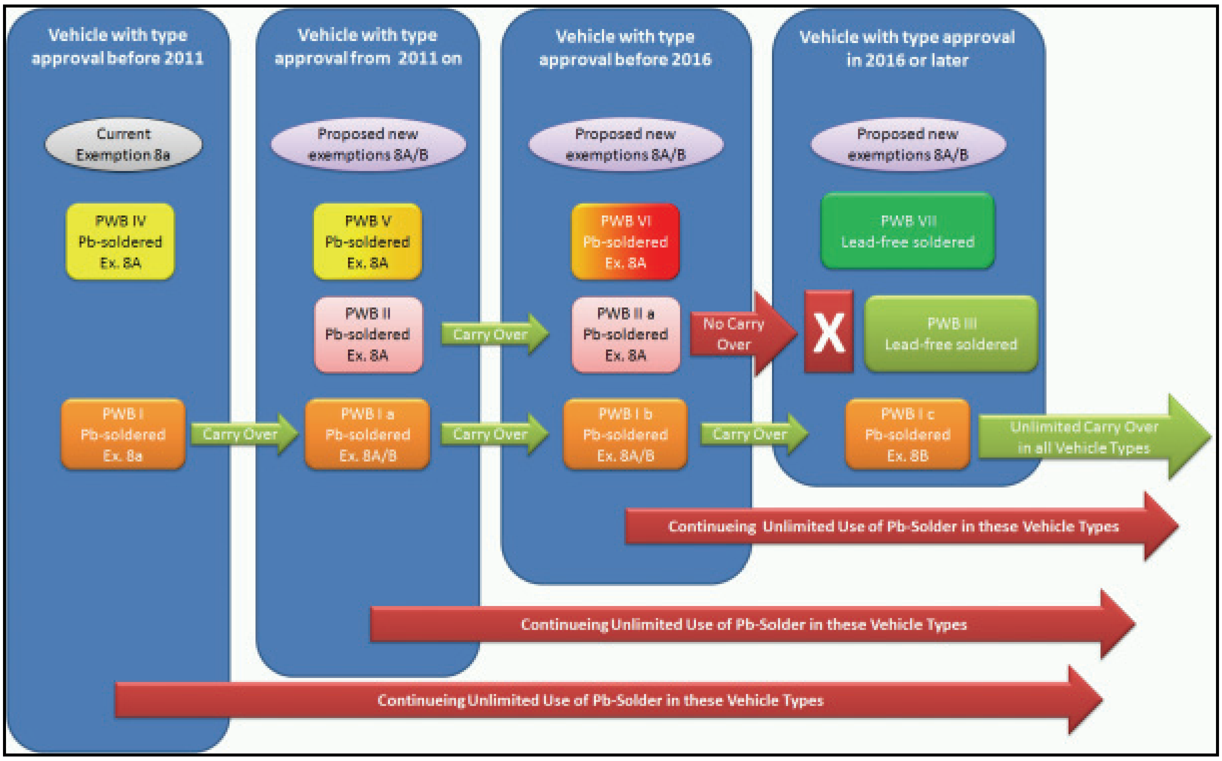



Figure 9 Use of lead in solders on PWBs according to part A and part B of exemption 8

The current exemption 8a allows the use of lead in solders on PWB I in vehicles with type approval before 2011. In case it is decided to use PWB I as a carry over part, exemption 8 B would allow this without limitation in the carry-over-PWBs Ia, Ib, Ic, etc. The only condition is that the first use occurred in a vehicle type approved before 2011. Whether a part is used as carry over, according to the stakeholders is not decided at the design phase of a part, but when the next type of vehicle is designed. Once the specific requirements are clear, it is decided which parts from previous vehicle types can match these requirements and can thus be used as carry over parts in the new type of vehicle.

The proposed exemption 8 A would allow the use of lead in PWB II in vehicles type approved after 2010 and before 2016. PWB II, although first time used in a vehicle with type approval after 2010, could also be used as a carry over part like in PWB IIa. Exemption 8A in the proposed wording generally covers carry over of such parts in vehicles type approved before 2016.

From 2016 on, neither exemption 8A nor exemption 8B would enable the further carry over use of PWB IIa, as its first use was in a vehicle with type approval after 2010. A possible successor PWB III would have to be lead-free soldered.

The current exemption 8a allows the use of lead in solders on PWBs like in PWB IV in vehicles with type approval before 2010. Until end of 2016, exemption 8A would at any time allow the use of lead in newly designed PWBs like in PWB V and PWB VI. From 2016 on, such printed wiring boards would have to be lead-free soldered like in PWB VII.

In its proposed wording, exemption 8A would expire end of 2015. For cars with type approval in 2016 or later, lead solder would still be allowed in carry over parts. PWB I, PWB Ia, PWB Ib and PWB Ic could be used further on under the proposed exemption 8B. The numbering of these PWBs as I, Ia, Ib and Ic reflects the fact that carry over does not mean that these PWBs are identical. According to the stakeholders, they have the same function, but can have undergone a number of changes (see Table 13 on page 91). They are still considered as carry over parts going back to PWB I as their ancestor – PWB I – was first time used in a vehicle type approved before 2011.

After 2015, the combination of the proposed parts A and B of exemption 8 thus would allow the continued use of lead in solders and finishes on PWBs

- in all vehicles with type approval before 2016;
- in all vehicles using carry over parts first time used in vehicles type approved before 2011.

**Technical justification for an exemption**

Technically and scientifically, it is impossible to implement the absolute ban of lead as requires the current exemption 8a in Annex II of the ELV Directive. There are several uses of lead in solders where it cannot yet be replaced. The exemptions for lead in solders in the RoHS Directive reflect this fact. Besides the necessity to introduce specific exemptions like in part C and D of the stakeholder proposal, the question is whether technically the general exemption for lead in solders is still required, or whether the use of lead in solders is avoidable besides the proposed specific exemptions. The use of lead in solders would then not be justifiable according to Art. 4 (2) (b) (ii).

The use of lead-free solders and finishes has become the standard interconnection technology for all equipment in the scope of the RoHS Directive. The stakeholders plausibly explain that the requirements in EES (electrical and electronic systems) in vehicles are different to a degree that does not automatically allow transferring to vehicles the status of lead-free soldering in RoHS equipment (equipment in the scope of the RoHS Directive) and the experiences made there.

Summing up, technical problems with lead-free soldering are remaining in automotive applications:

- Higher soldering temperatures for lead-free soldering pre-damage electrical and electronic components during the soldering process, which then may fail in the reliability tests and must be suspected to fail in-field as well. According to the stake-

holders, not yet all components have a sufficient quality level for automotive applications.
The higher soldering temperatures also apply to RoHS equipment. As the testing and operational criteria, however, are not as tough as for electrical and electronic systems (EES) in vehicles, the probability is much lower that possible pre-damages of the components result in failures.

- The material properties of lead and lead-free solders are different. Lead-free solders are stiffer, more brittle. This may result in breakage of solder joints under thermal or vibration stress, or in combination of both stress factors.
- The ageing properties of lead-free solders are different. All solder joints experience microstructural changes over their life time. Ageing may be accelerated in particular under higher temperatures, as they occur in EES in vehicles. It is thus important to understand – and if possible to predict – the microstructural changes in solder joints, and to make sure these changes do not affect the reliability of the solder joints over the targeted life time of the product. With lead solder joints, research and experiences over decades have created the respective knowledge. For lead-free solders and finishes, in particular the experiences for the long-term behavior of solder joints are still missing or scarce.
- Lead-free finishes are more prone to whisker growth than tin-lead finishes. In some applications, whisker growth may be safety critical, the more as the mechanisms of whisker growth are not yet fully understood.

It can be concluded that there are remaining technical issues to be solved for a complete shift to lead-free solders and finishes like for RoHS equipment. The stakeholders arguments are plausible, and they are in line with the arguments they had put forward during the last review of Annex II in 2007/2008 (Öko-Institut 2008). The core question for the review are until when these problems can be assumed to be solved, and whether the general, material specific exemption for lead in solders and finishes can be replaced by more application specific ones.

**General vs. application specific exemption**

Harsh operational and environmental conditions in vehicles and the high safety and reliability requirements are the stakeholders' main argument against a complete shift to lead-free soldering to the degree already implemented in the equipment in the scope of the RoHS Directive (ACEA et al. 2009a; ACEA et al. 2009c; ACEA et al. 2009h). The extreme conditions above all apply to underhood applications, where electronics is, for example, placed close to the engine resulting in vibrations and high operating temperatures the electrical and electronic systems (EES) are exposed to.

In other than underhood applications, e. g. inside the cabin, the environmental conditions are, however, less harsh. This raises the question why lead-free soldering then cannot be introduced in EES that are not exposed to such harsh conditions in vehicles.

In the last review of Annex II of the ELV Directive (Öko-Institut 2008), the stakeholders could not plausibly explain why lead cannot be replaced either in solders for such applications with milder conditions, like e. g. in the cabin, if at the same time lead-free soldering is no longer completely impossible to be implemented in vehicles (ACEA et al. 2009h).

The stakeholders admit that there is a difference between the conditions EES are exposed to in the cabin and in underhood applications resulting in lower loads on the electronics (ACEA et al. 2009c).

They claim, however, that this difference is small, compared with the less demanding conditions of other electronic equipment, e.g. in the scope of RoHS Directive. For example, the operating temperature range of electronic components in cars is much higher than in consumer electronic applications, regardless of its location inside the cabin or underhood. The stakeholders classify the requirements roughly as ABS/ESP > Underhood > Cabin >> Consumer (ABS: Antiblocking system for brakes; ESP: Electronic stability program) (ACEA et al. 2009m).

Figure 10 displays the temperature ranges ECUs (electronic control unit) may be exposed to in vehicles compared to those in personal computers (ACEA et al. 2009c).

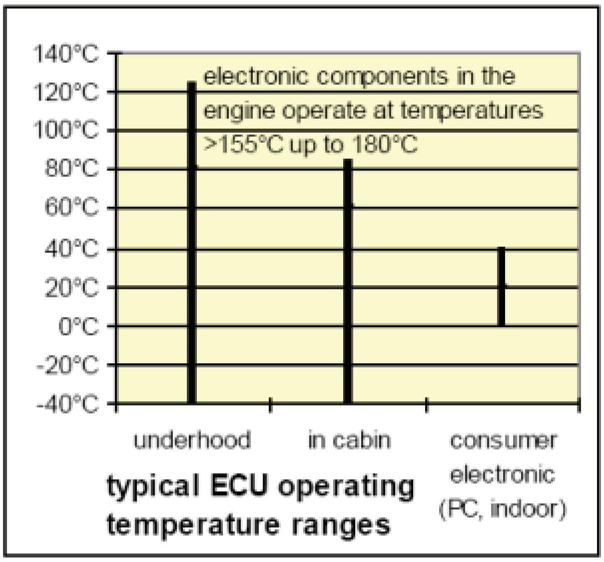



Figure 10 Specific conditions of electrical and electronics devices in vehicles (ACEA et al. 2009c)

ACEA et al. (2009h; 2009m) point out that, although the environmental and operational conditions are milder in the cabin, EES still are heavily impacted by vibration, moisture, etc., requiring highly reliable bonding strengths and yield strength characteristics as delivered by the current lead-containing soldering. ACEA et al. (2009c) add that the demands for car electronics are safety and durability. Steering, brake, and airbags inside the cabin have to be 100% error free over the 15 years lifetime of a car, which is many times the lifetime of a personal computer. A hardware failure e.g. of an IT-server may result in a loss of data; a hardware failure of the airbag control unit may result in a loss of life. These demands are the same in the cabin or underhood. Both aspects show, according to the stakeholders, that in a car there are no areas with significantly less demanding requirements, even if the environmental loads differ. A limitation of the lead exemption to the harshest condition applications like underhood thus is not viable according to the stakeholders (ACEA et al. 2009c, ACEA et al. 2009h).

Further on, the available space and resulting package issues have to be taken into consideration as well. Not always do components fit in the interior area. For package reasons or functional reasons it may be necessary to place an electrical component in the engine or underhood area, even if the same application is used in the interior for a different model (ACEA et al. 2009m). Finally, the stakeholders state that it is impossible to demarcate EES with lower safety and reliability requirements from those with higher ones, as the components interact in a car. The failure of one system thus might result in more failures. ACEA et al. (2009m) consider and strongly believe that all EES mounted on a vehicle are equally (safety) critical, and equally difficult to apply lead-free solder. High (safety) critical and medium (safety) critical applications are linked together by the use of their components, their manufacturing processes and in the vehicle by board net as well as data links like CAN-Bus. The information of the less critical malfunction of e.g. window lifter is transferred on the same channel than the safety critical info concerning brake lights malfunction (ACEA et al. 2009m).

It goes without question that EES in a car must work with the necessary degree of reliability wherever they are applied in the car, and that failures may be safety critical. The objective of the adaptation of Annex II to the scientific and technical progress in this context, however, is to assess whether and how far an exemption can be repealed without endangering the safety and the reliability of products. In this case it means the assessment whether and how far less demanding environmental conditions, e. g. in the cabin, allow the production and use of lead-free soldered EES sufficing the safety and reliability requirements over the life time of a vehicle. Only then can the use of lead be considered as avoidable.

According to the stakeholders, the loads on the EES from the operational and environmental conditions are high in total, but still different. The main justification for the continuation of the lead exemption are the harsh environmental conditions and the high reliability and safety requirements. It is thus not plausible that lead-free soldering is equally difficult or impossible to be introduced in all applications. It is possible to break down the exemption to different application fields with different expiry dates, which allow a transition to lead-free soldering maintaining the required safety and reliability requirements over the product lifetime. The stakeholders themselves promote a step-by-step implementation starting with the least challenging applications, and they declared that some systems even are lead-free already. The stakeholders even justify their carryover-proposal with such a step-by-step approach. The stakeholders as well admit that the requirements are not equally challenging in all applications. If EES in the cabin interact with underhood and highly safety critical EES, it is not understandable why the cabin part should not work reliably with lead-free solders. The stakeholders' claim of equal requirements underhood and in the cabin is not plausible and does not justify continuing the general exemption.

The differentiation would, however, require an in-depth investigation until when and to which degree different components in different locations in a vehicle can be shifted to lead-free soldering maintaining the necessary reliability and safety. The environmental conditions may be different in the cabin or even within the cabin, and in other locations in a vehicle besides the cabin and underhood. The complexity of EES is different as well, and more complex systems may be more difficult to transfer to lead-free soldering. It would hence also need an exact definition of the location and a precise technological description of each of the EES concerned, related to different expiry dates. The resulting exemptions would very probably not be manageable and produce insecurities and confusion. A split of the exemption according to different locations and applications in vehicles thus may not be practicable.

The recommendation therefore is to maintain the general exemption for lead in solders and finishes, but to give it an appropriate expiry date balancing the technical situation and complexity on one hand and the requirements of Art. 4 (2) (b) (ii) on the other hand.

**Justification of expiry dates**

The core issues to be clarified in the context with the expiry dates are:

- whether the deadline of 2011 in the current exemption 8a can be met;
- whether the deadline end of 2015 proposed by the stakeholders is adequate to suffice the requirements of Art. 4 (2) (b) (ii).

*Collision of the current 2011 deadline with product development cycles*

The stakeholders put forward that they cannot comply with the 2011 timeline as the development of the new vehicle types for 2012 and 2013 has already started before the official amendment of Annex II in August 2008 (ACEA et al. 2009m). Orders are already being placed. Suppliers have not invested in the necessary equipment and there is a long lead time associated to procurement.

This argument is only plausible as far as the implementation of lead-free soldering is technically not practicable and the use of lead thus unavoidable. It is the vehicle manufacturers' responsibility to adapt their printed wiring boards to the respective state of science and technology of lead-free soldering. The stakeholders' timing argument cannot serve as a general argument against a legal limitation of lead use in solders in 2011 or in the near future.

The core question thus is whether the scientific and technical state of the art justifies a shift of the deadline beyond 2011 to 2015, as the stakeholders propose.

*Justification of expiry dates*

ACEA et al. state that due to the harsh operation conditions of vehicle electronics in combination with the high reliability and safety demands, an earlier phase-out of lead in solders is technically impossible, as summed up on page 80.

The stakeholders say that next to the remaining technical problems it is a question of transition and implementation time as well as capacity for development of products, components, their validation and change of production equipment (ACEA et al. 2009m). As a further restriction, the stakeholders claim that this applies the more as the capacity in the automotive industry will rather decrease than increase with the economic crisis. The stakeholders point out that it is impossible to do all the work simultaneously for all electronic products and vehicles (ACEA et al. 2009m). Currently, a significant amount of capacity is used to develop completely new technologies for hybrid and electrical vehicles as well as electrical and electronic systems for higher fuel efficiency to cover the CO2 reduction demands of the near future. The teams designing, testing and implementing for example new motor ECUs (electronic control units) for hybrid vehicles cannot redesign, test and implement a window lifter controller at the same time (ACEA et al. 2009m).

On further inquiry, ACEA et al. (2009m) admit that in principle lead-free soldering on PCBs is possible, although not all technical problems have been solved. The fact that according to the proposed part B of exemption 8, the stakeholders want to start implementing lead-free soldering on carry over parts step by step from 2011 on underlines this statement.

It is plausible that the tough operational conditions in combination with the high reliability and safety requirements in the automotive industry require specific caution in a general transition to lead-free soldering to the degree like in RoHS equipment. The available information proposes that a complete shift to lead-free soldering before 2011 as required in the current exemption 8a, even with the further specific exemptions in place (parts B and D of stakeholder proposal) thus is not possible under maintenance of the necessary level of reliability and safety until 2011. The stakeholders should be given time until 2016 to achieve the transition to lead-free solders and finishes, as they propose. There is no clear evidence from other stakeholders indicating that an earlier general and complete transition would be possible.

The stakeholders' other arguments are not of technical, but of logistical and economic nature, which do not allow an exemption according to Art. 4 (2) (b) (ii).

Based on the available technical information, and in the absence of contrary stakeholder views, the reviewers recommend adopting the stakeholders' proposed expiry date. For clarity and easier communication it is further on recommended to shift it for one day, so that the ban of lead in solders and finishes would apply to vehicles with type approval before 1 January 2016. The expiry date would then be 31 December, not 30 December as in the current stakeholder proposal.

**Lead in finishes**

The stakeholder stated that soldering lead-free finish components with lead-containing solders is feasible without problems. Electronics in vehicles, according to the stakeholders makes only around 8% share of the total electronic market. Most of electronic components and printed wiring boards is used in equipment, which is under the scope of the RoHS Directive and hence has lead-free finishes. It is increasingly difficult to find lead-finished components and printed wiring boards on the market.

On the other hand, the stakeholders claim that certain components used in lead-soldered electronic control units can only be transferred to lead-free finishes when the entire unit is transferred to lead-free soldering. Components like BGAs (ball grid arrays) use leaded finishes as long as the solder balls contain lead (for a BGA see Figure 19 on page 104), and the solder balls need to contain lead until the whole unit is transferred to lead-free soldering.

It was not possible during the review to obtain a clear idea of

- which components are available lead-free and can be used in lead soldered assemblies without limitations,
- which components could be produced with lead-free finishes, but need to contain lead-finishes as they can only be shifted to lead-free with the whole electronic assembly they are used in,
- which components still cannot be produced and/or used with lead-free finishes for other reasons.

Given the complexity of the component market, it is well possible that a clear picture on the above would be difficult to obtain. Additionally, probably the same component could be used with lead-free finishes in one application, while the same lead-free finish component is not useable in another one. The same applies to the use of lead finishes on printed wiring boards.

On the other hand, it cannot be excluded that with more time it would have been possible to clearly define components where the use of lead finishes is avoidable. Within the given time and capacity, however, such a result could not be achieved.

To arrive at a clear wording, it is therefore recommended to adopt the exemption in the wording as proposed by the stakeholders. At least those components, which are no longer available with lead-free finishes, will avoid lead anyway.

One component, however, the electrolyte aluminium capacitors, is available with lead-free finishes (proposed exemption “D”) until end of 2012. These capacitors need to be excluded in the wording.

#### 4.8.5 Final recommendation exemption 8 A

It is recommended to grant the proposed part A of exemption 8 and for the finishes, but to exclude the finishes on electrolyte aluminium capacitors. Lead can be avoided in this application. For the other applications, the available information justifies the exemption in line with Art. 4 (2) (b) (ii), or, for the finishes, makes it impossible to exclude finishes on other specified components from the exemption.

The proposed wording of the new exemption thus is:

> *Lead in solders to attach electrical and electronic components to electronic circuit boards and lead in finishes on terminations of components others than electrolyte aluminium capacitors, on component pins and on printed wiring boards in vehicles type approved before 1 January 2016, and in spare parts for these vehicles.*

For clearer understanding and easier communication, the expiry date in the stakeholder proposal was postponed for one day so that the exemption expires on 31 December 2015, not on 30 December 2015. The ban thus applies from 1 January 2016 on for new type approved vehicles and their spare parts.

### 4.9 Exemption no. 8a – stakeholder proposal part B

*“Lead in solder of carry over electric/electronic parts or systems first used in vehicles type approved before 31 December 2010”*

#### 4.9.2 Description of exemption

ACEA et al. (2009a) propose the following exemption:
*Lead in solder of carry over electric/electronic parts or systems first used in vehicles type approved before 31 December 2010.*

ACEA et al. (2009i) explain that a Carry-over (C/O) part (COP) is an electrical or electronic system (EES) used in a new type approved vehicle, which was or still is used in a previous vehicle type with earlier type approval without any functional change. The technical function is identical to that of the EES used in previous vehicle types. C/O is a usual strategy for the “decoupled” development processes. Not all EES are completely newly developed for new vehicle types. Engine, transmissions or brake systems, e.g., are used in various vehicle types (cross carline) and in vehicles with new as well as older type approval. The development cycles of such systems are not identical with those of the new vehicle types – hence “decoupled”. The strategy is not to implement e.g. new engines into new vehicle types. The carry over rate from one vehicle type to the next one is around 30% to 40% of EE depending on the type of EE application or system and vehicle type (ACEA et al. 2009i).

The amount of lead in EES, according to the stakeholders has decreased. COPs developed in e.g. 2007 contain less lead compared to those of e.g. 2003. COP will phase out over time with the next generation of the system. The stakeholders do not indicate what amounts of lead would be used under this exemption (ACEA et al. 2009i).

### 4.9.3 Justification for exemption

**Necessity of carry over**

ACEA et al. (2009i) state that e.g. new engines are implemented during the production cycle of a vehicle type. A development of new vehicle types without COP is impossible with today’s engineering and test capacities, according to the stakeholders. The stakeholders prefer using their resources on the development of new EES (ACEA et al. 2009i).

ACEA et al. (2009i) state that not all known alternatives to the lead in solder of electric/ electronic parts or systems can be applied for automotive purposes. From the technical point of view, the stakeholders say that the justification for the use of lead in solders on electronic circuit boards applies.

**Limited development and testing capacities**

The stakeholders explain that changing over to lead-free soldered COPs would require individual re-design, development as well as testing and qualification due to the differing properties of lead-free alloys (ACEA et al. 2009i).

ACEA et al. (2009i) point out that carry over parts reduce the expense for development and testing from one car type to the next one, and across car types (cross carline). If all carry over parts have to be switched to lead free solders, it possibly causes a lack of testing facilities, engineers and operators at vehicle manufacturers and car makers. The necessary development and evaluation for vehicle durability and reliability could no longer be conducted completely (ACEA et al. 2009i).

The stakeholder put forward that re-developing every single component of a new car would increase product prices, which the customers would refuse to pay. The price for the validation of a single component is around 50 000 € and the price for the validation of a board exceeds this figure by far (ACEA et al. 2009i). The modified board then needs to be tested in combination with other boards to check if these components interact without any trouble. The changes in electronic systems thus cause exorbitant prices which are affordable only if the costs can be spread over the investment period and multiple models (ACEA et al. 2009i).

Carry over is particularly used in powertrain (engines/transmissions) systems. According to the stakeholders, the development of a new powertrain system requires at least five years up to 10 years. A change of the powertrain in one car would mean to change it the same manner in all other cars. The changes have to be approved in all models and not only in the new vehicle which is in the scope. This is an inappropriate and not affordable demand (ACEA et al. 2009i).

Figure 11 shows that the amount of lead containing carry over parts is continuously decreasing in the same curve as the new developed lead free parts are developed. ACEA et al. (2009m) state that nobody is interested to implement "carry over electronics" for an unlimited period of time.

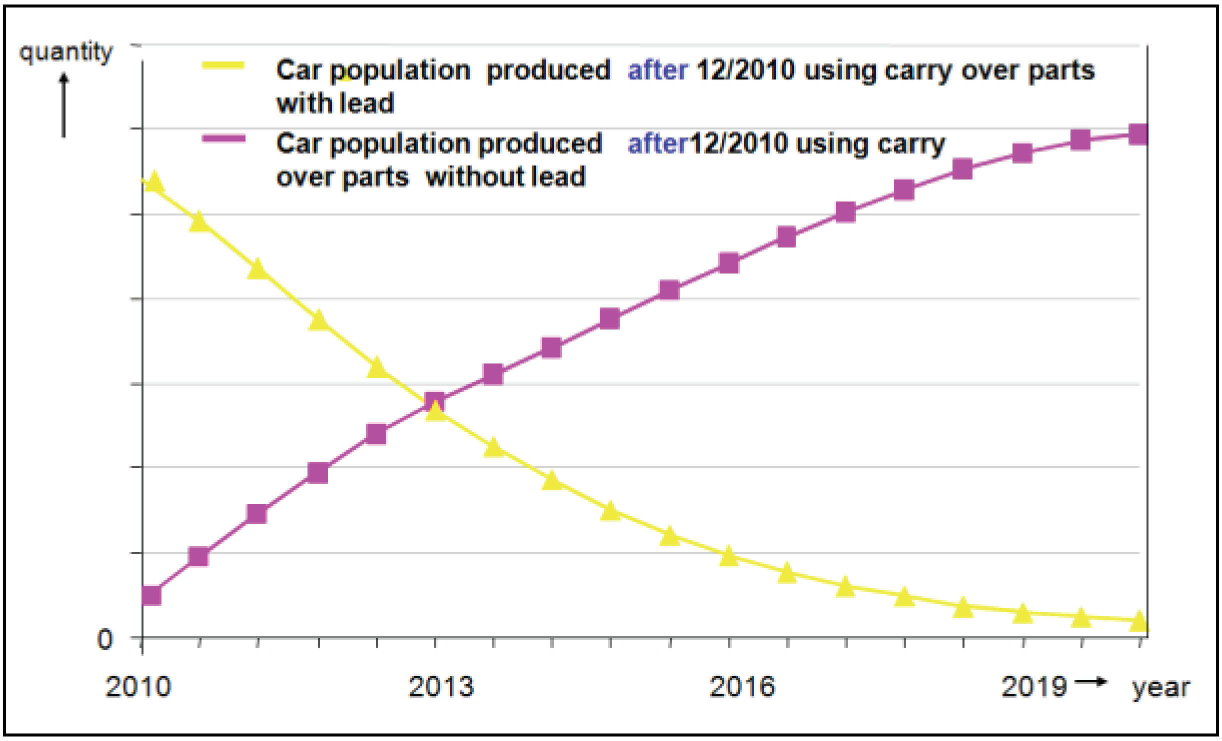



Figure 11 Development of cars put on the market with lead-soldered carry-over parts (ACEA et al. 2009m)

To make a definite phase out schedule, the stakeholders say that they need to count the remaining carry over parts around 2015. The rate of replacement is a matter of resources and capacity (ACEA et al. 2009m).

#### 4.9.4 Critical review of data and information

The stakeholders explain the practice and the necessity of carry over in the automotive industry. The main reasons for carry over are:

- Reduce expenses for development, testing and qualification of completely new EES.
- Economize on development and qualification cost for electrical and electronic systems (EES) including the numbers of staff required.

Part A of exemption 8 allows the use of lead-soldered carry over parts (COP) until end of 2015, irrespective of when they were used for the first time (see Figure 9 on page 79). After 2015, the proposed Part B of exemption 8 would allow the further and unlimited use of lead soldered COPs if they were first time used in vehicles type approved before 2011. There are plausible reasons for carry over. The core question for this review is why carry over of lead-soldered PWBs should be allowed after 2015, as the stakeholders propose in Part B of exemption 8 (see Table 12 on page 70).

**Type approval "grandfathering" as justification for carry over**

ACEA et al. (2009m) demand that in the current wording of exemption 8 a, the current vehicle types can „grandfather" over the current phase out date. The grandfathering of current EES should therefore be granted as well (ACEA et al. 2009m). What the stakeholders mean is the following:

Exemption 8a bans the use of lead in solders from 2011 on for new type approved vehicles only, not for all vehicles. Vehicles with earlier type approval can continue using lead in solders without legal limitation in the ELV Directive. From this fact, the stakeholders deduce that lead-free soldered EES used or first time used before 2011 should also be allowed to be used without expiry date in all vehicles. The stakeholders put forward limited development capacities and high cost as further necessities requiring a carry over after 2015.

During the 2007/2008 review of Annex II of the ELV Directive, the stakeholders had asked to confine the ban of lead in solders and finishes to new type approved vehicles (Öko-Institut 2008). The arguments at that time were the same as the ones the stakeholders bring forward now to justify the carry over of EES beyond 2015. In this 2007/2008 review, they argued that the available development capacities are not sufficient to transfer all the EES to lead-free, even those already used in currently marketed vehicles. The stakeholders had plausible examples to underpin their statements. The reviewers therefore recommended to limit the ban of lead to new type approved vehicles after the expiry of the exemption. The Commission accepted this proposal in exemption 8a in the current Annex II of the ELV Directive. (Öko-Institut 2008)

The stakeholders' arguments for the justification of carry over beyond 2015 thus are already taken into account with a restriction of the ban of lead in solders to new type approved vehicles, as recommended for the new exemption 8 A. The already adopted reference to new type approved vehicles is no justification for the carry over of lead-soldered PWBs after 2015. The carry-over stipulation shall tackle the same concerns, which were already taken into account in the restriction of the lead ban to new type approved vehicles.

Further on, "grandfathering" would not mean to carry over technically identical electrical and electronic systems (EES). Carry over as the stakeholders propose would allow the continued and legally unlimited use of EES, which have the same technical function. Table 13 shows that "carry over" allows a wide range of changes to an EES.

Table 13 Differences between carry over and newly developed EES (ACEA et al. 2009o; ACEA et al. 2009p)

| **Carry Over EES** | **New EES** |
|---|---|
| Type name remains unchanged except some index | Product is assigned a new type name |
| Change of the index in the part name, or change of the part number e.g. due to software adaption | The new part definitively gets assigned a new part number |
| Same customer | Same or different customer |
| No or only minor changes to the specification | New, at least significantly changed specification not only describing the principle function but the functional as well as environmental parameters quite in detail. E.g. all the connector pins are assigned and described here. |
| Same assignment of almost all connector pins, or changes of less than 10 connector assignments | Same, similar or different assignment of connector pins |
| Housing changes only to fixation holes, not in general geometry | Changes of general geometry possible |
| Same size of PCB | Size of PCB may be different |
| Usually no complete design / development cycle from QA0 to QA4 (QA = quality assessment) | New design and development process including quality assessments, initial series respective APQP (Advanced product qualification plan) for US customers acc. QS9000 |
| Only partial testing (functional) | New qualification / testing cycle for all customers. For US customers called DV and PV (design validation and production validation) acc. QS9000 |
| Minor changes to I/O behaviour e.g. timing, in-/output voltages resp. currents. | Major changes possible to I/O behaviours, e. g. timing, in-/output voltages resp. currents, etc. |
| Minor changes in components (usually passive components) to adapt for small i/o changes | Minor and major changes in components |
| Minor layout adaption according to those changes | Minor to major layout changes, or completely new layout |

The table underpins that carry over parts are identical in function, but not necessarily in the actual hardware enabling the function. The only clearly defined difference between a new EES and a COP is the new type number of a new COP.

Beyond this, however, there is a wide, not exactly definable range of changes possible on an electrical and electronic system (EES). Despite of such changes, it can still be considered a COP, not a new EES requiring a new type name, and requiring a changeover to lead-free soldering.

A carry over exemption as requested by ACEA et al. thus would not result in a transparent and clear scope and timing for the use – and the phase out – of lead in solders in new type approved vehicles. Exemptions must be clear in their wording and timing so that they can reflect the state of science and technology. Either solutions are available. The exemption must then expire. Or solutions are at hand or foreseeable. Exemptions in this case must expire as well within a reasonable time frame. For the same reason the stakeholders' claim that "nobody is interested to implement carry over electronics for an unlimited period of time" (ACEA et al. 2009m) is not viable. Exemptions would then assume the character of a voluntary self-commitment, whereas the material bans are a legal requirement the vehicle manufacturers have to comply with.

The carry over of lead-soldered PWBs beyond 2015 thus should not be granted. If the Commission follows the reviewers' recommendation, there are more than six years left before the expiry of exemption 8A. In case there are unsolved technical problems before the expiry of the exemption end of 2015, the stakeholders may apply for specific exemptions, which then reflect the state of science and technology and allow the use of lead in line with Art. 4 (2) (b) (ii). The carry over of lead-soldered PWBs after 2015 as requested by the stakeholders would not be in line with the requirements of Art. 4 (2) (b) (ii).

**Consequences for use of lead solders in other applications than on printed wiring boards**

In the discussion of part B of exemption 8a, the stakeholders said that they had, among others, intended to use the carry over exemption for lead in solders, which are not used on printed wiring boards, but in other electrical applications. As this exemption is recommended not to be granted, the stakeholders say that they cannot yet replace lead in some of these applications, e. g. in relays, starters, motors, switches, generators (Schenk 2009). The list, according to the stakeholders is not comprehensive. In such applications, the lead solders are used, e. g., to solder cables in an engine to connectors, which are not fixed to a printed circuit board.

The stakeholders say that lead-free developments are underway, but that they need until end of 2010 to shift such applications to lead-free solders or alternative designs avoiding the use of solders. This time is required to allow proper testing, validation and implementation/ integration into the new type vehicles (Schenk 2009).

It is thus recommended to add an exemption for lead in solders in other applications than on printed wiring boards until end of 2010.

### 4.9.5 Final recommendation exemption 8 B

It is recommended not to grant this exemption. This exemption would result in an unclear scope and timing of the lead phase-out, the more as the other exemptions, in particular 8A, already confine the ban of lead to new type approved vehicles. A carry over exemption as proposed by the stakeholders thus would not reflect the current state of science and technology.

The stakeholders' justification that the limited capacities for development and testing require carry over after 2015 are already taken into consideration with the recommended restriction of the ban of lead to new type approved vehicles. If specific technical issues will not yet have a solution, the stakeholders can apply for specific exemptions within the next six years before exemption 8 part A expires.

Granting exemption 8B thus would not be in line with the requirements of Art. 4 (2) (b) (ii) to restrict the use of lead to those applications where its use is unavoidable according to the state of science and technology.

To cover the use of lead in solders in other applications than on printed wiring boards or glass, it is recommended to grant an exemption until end of 2010. Lead-free developments are under way and will be implemented until then.

The wording of this exemption is proposed as

> *Lead in solders in other applications than soldering on printed wiring boards and on glass in vehicles type approved before 1 January 2011.*

## 4.10 Exemption no. 8a – stakeholder proposal part C (i)

*“Lead in high melting temperature solders, i.e. lead based solder alloys containing above 80% by weight of lead”*

### 4.10.2 Description of exemption

ACEA et al. (2009a) propose the following exemption without an expiry date:

*Lead in high melting temperature solder i.e. lead based solder alloys containing above 80% by weight of lead.*

The stakeholders say that an expiry date cannot be defined as a technical solution currently is not foreseeable. The exemption shall be reviewed after 2015 (ACEA et al. 2009a).

High melting point solders with lead are used in several applications and technologies. The following list gives examples and solder compositions (in % of weight) (ACEA et al. 2009e):

- internal connections: ≥ 85%;
- die attach: ≥ 90%;
- sealing: ≥ 85%;
- over-moulding: ≥ 90%;
- ceramic BGAs: ≥ 90%.

The details of the different applications will be explained in the subsequent sections of this chapter.

ACEA et al. (2009e) list automotive applications using such electrical applications, like, for instance, starters, alternators, converters, electrical assisted steering, engines & gearboxes computer-control devices, electrical brakes, ABS & ESP systems, etc.

ACEA et al. (2009e) state that nearly all automotive electronics products contain components utilizing high melting point (HMP) lead solder. The majority of high powered components are found in steering, braking and powertrain electronic control units (ECU). Assuming the amount of lead used in solder in the above applications is ~0,003 g per component, then typical automotive ECU’s would contain (ACEA et al. 2009e):

- for Braking ECU approximately 30 affected parts;
- for Steering ECU approximately 20 parts;
- for Powertrain ECU approximately 40 affected parts;
- for Power Management (Generator Diodes) approximately 9 affected parts;
- & other ECU’s within the vehicle about 20 parts.

This equates to (ACEA et al. 2009e):

- for Braking ECU 0,09g/vehicle;
- for Steering ECU 0,06g/vehicle;
- for Powertrain ECU 0,12g/vehicle;
- for Power Management (Generator Diodes) 0,14g/vehicle;
- & other ECU's (e.g. body control modules, climate control, seat memory, roof modules, etc.) 0,06g/vehicle.

The stakeholders calculate the total amounts of lead as follows (ACEA et al. 2009e):

Assuming 16 million vehicles registered per year (ref: ACEA 2007, EU27 + EFTA), the total amount of lead is 16 million x 0,47g = 7,5 t of HMP solder per year. With a lead content of at least 85%, the amount of lead in these solders is at least 6,4 t per year in the EU27 + EFTA.

The following sections will provide details on the several applications of lead-containing HMP solders as submitted by the stakeholders.

### 4.10.3 Justification for exemption

**Justification for the use of lead in high melting point solders**

ACEA et al. (2009e) put forward that thermal fluctuations during normal operations cause strain due to differences in the thermal coefficient of expansion within the assembly (thermal mismatch). Thermal fluctuations can be produced by heat being dissipated or by environmental temperature changes. Repetition will produce cyclic strain which will cause the solder joint to fail through fatigue.

The reliability of the solder joint will depend upon the alloys resistance to fatigue, and the magnitude of the strain generated. The fatigue life of a solder joint can be approximated by the Coffin – Manson equation (ACEA et al. 2009e):

$$N_f = C \, \Delta\varepsilon_p^{-n}$$

$N_f$ is the number of thermal cycles to fatigue failure, C and n are material constants and $\Delta\varepsilon_p$ is the strain generated. The smaller the strain, the greater the fatigue life.

The strain generated due to CTE mismatch can be calculated approximately (ACEA et al. 2009e):

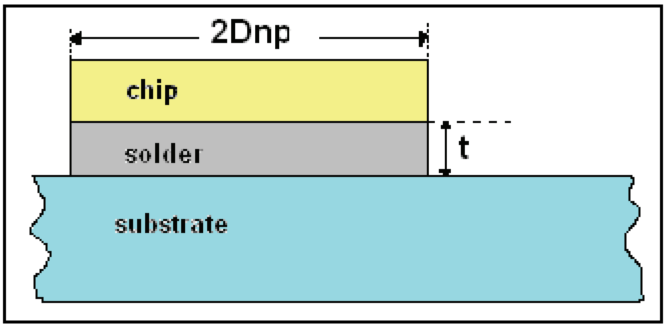



Figure 12 Cross section of solder joint

- ΔT is the temperature excursion, dependent upon the power dissipation and the change from minimum–maximum operating temperature,
- Δα is the difference between CTE of the substrate and the component chip,
- Dnp is the distance from neutral point – the larger the die or packaged component, the greater the strain generated.
- t is the solder joint height. The larger the solder joint height, the less strain is generated.

ACEA et al. (2009e) say that automotive electronics differs from consumer applications in that the desired number of cycles $N_f$ is much larger, and the environment is much harsher.

Table 14 Differences between consumer and automotive electronics (ACEA et al. 2009e)

| | **Consumer** | **Automotive** |
|---|---|---|
| Life | 3–5 years | up to 15 years |
| Environment | 0–40°C | -40° to 125/155°C |

There are basically two types of solder:

- 'soft solders' based on Sn-Pb, lead, tin, indium alloys;
- 'hard solders' based on gold eutectics such as Au-Sn, Au-Ge.

Die attach and applications which require some ductility within the joint have to use soft solders, which can compensate the strain in the solder joint and thus transmit very little stress to the die and/or to a ceramic body. These solders, however, will degrade due to thermal fatigue during temperature or power cycling.

ACEA et al. state that Figure 14 and Table 15 on page 98 show that there are no soft solder alternatives which have appropriate melting points.

Hard solders based on Au-Sn do not usually degrade by fatigue due to the high mechanical strength. Ceramics and silicon dies are brittle materials and will crack if they are subjected to any tensile or torsional stress, resulting in lower product reliability. High temperature solder is used for die attachment (silicon to copper alloy) or as a lid seal (e.g. Analogue Sensor packaged in a CLCC (ceramic body, steel lid). The CTE mismatch will exert considerable stress on the die, ceramic body and may fracture in some cases, if the solder is too brittle (ACEA et al. 2009e).

ACEA et al. (2009e) describe the example of new generation stop-start systems under development. They require the use of high melting point lead containing solder because of higher constraints, such as electric current circulation up to 50ms@1000A + 600ms@600A + permanent 150A in combination with an increase of thermal environment up to 170 deg C. Tests performed with six types of lead free solders show a drastic decrease of number of cycles to failure, and so an unaccepted level of reliability, as the next table shows.

| | | | Number of power cycles to failure (Welbull B50)<br>Test @ 50 A DC / 40 mm² die<br>Failure is Short-Circuit | | | |
|---|---|---|---|---|---|---|
| $TC_{min}$ | $TC_{max}$ | $\Delta Tj$ | High lead solder | | Lead free solder | |
| | | | Vacuum reflow | Laser reflow | Vacuum reflow | Laser reflow |
| 75°C | 165°C | 110°C | 11 000 to 15 000 | 13 700 to 14 200 | 4 500 to 5 100 | 4 800 to 5 050 |

Figure 13 Power cycling test results comparing HMP lead solder and lead-free solders (ACEA et al. 2009e)

ACEA et al. (2009e) state that for long life reliability no other material than high melting point (HMP) lead containing solder has been found. HMP solders have a unique combination of melting point, mechanical, thermal, electrical and chemical properties.

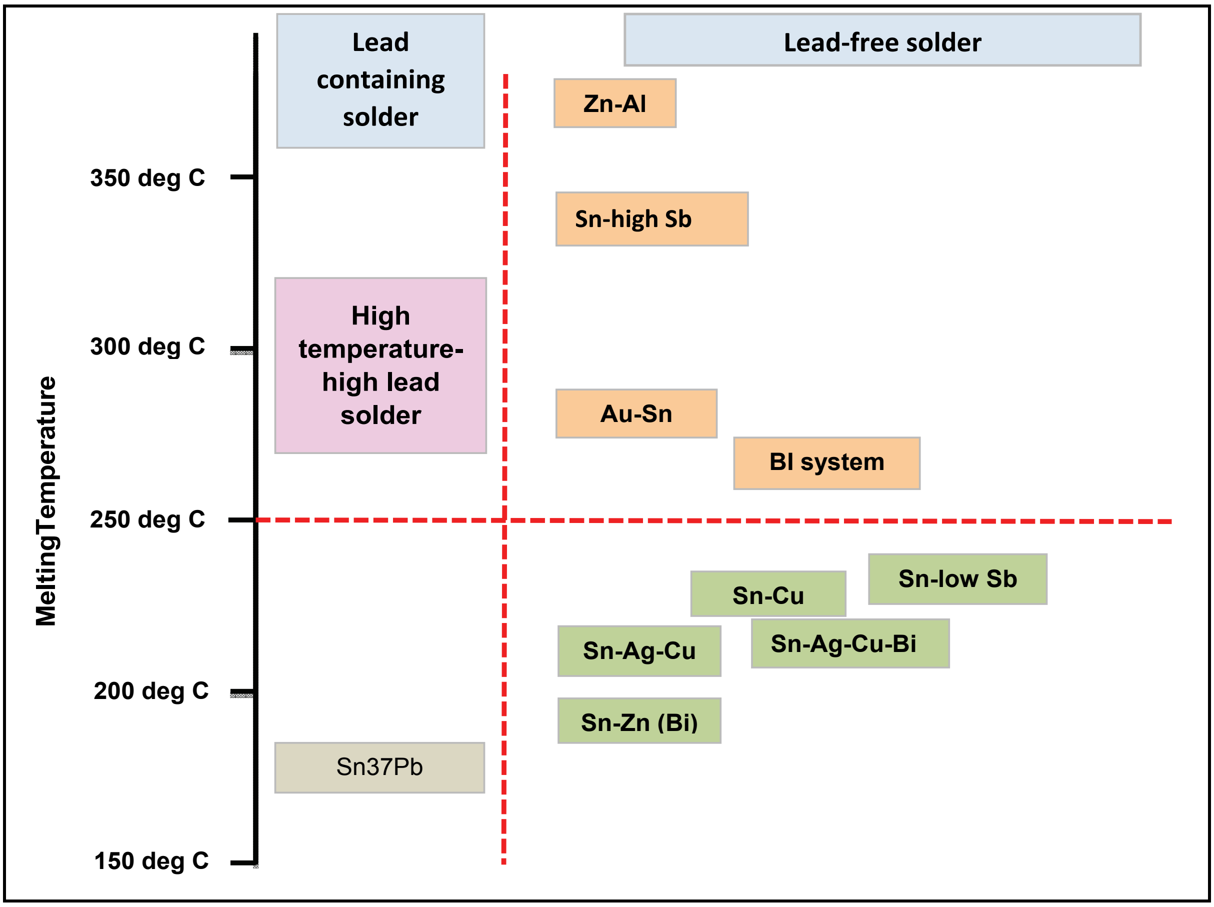



Figure 14 Melting points of different lead-free solders (HMP solders with 80% and more of lead: „high temperature – high lead solder“ (ACEA et al. 2009e)

Table 15 Alternatives for HMP solders with lead (ACEA et al. 2009e)

| Solder Type | Alloy | Melting Point °C | Comments on Unsuitability |
|---|---|---|---|
| Sn-Zn (Bi) | Sn 8Zn 3Bi | 190–197 | Melting point too low |
| Sn-Ag-Cu-Bi | Sn 2,5Ag 1Bi 0,5Cu | 213–218 | |
| Sn-Ag-Cu | Sn 3Ag 0,5Cu | 217–220 | |
| Sn-Cu | Sn 0,7Cu | 227 | |
| Sn-low Sb | Sn 5Sb | 235–240 | |
| Bi systems | Bi 2,5Ag | 263 | Melting temperature only slightly higher than SAC<br>Low Ductility, Low Strength |
| Au-Sn | Au 20Sn | 280 | Low Ductility,<br>Negative environmental impact due to being Au based |
| Sn-high Sb | Sn >43Sb | 325–>420 | Melting point too high |
| Zn-Al | Zn (4-6)Al (Ga,Ge<Mg) | 350–380 | |

ACEA et al. (2009e) describe in more detail main alloys of each group.

*Tin, Silver, Copper – (SAC) Alloys*

These lead-free solder alloys are based on Tin, Silver and Copper and are the solders most commonly used in lead-free board assembly. If SAC alloys were used for die attach, internal connections, and sealings, they would lose strength and become 'pasty' during the board assembly process resulting in movement inside the components and reduced reliability (ACEA et al. 2009e).

*Tin Gold System (SnAu80)*

The melting point is 280 deg C which would be acceptable in terms of processing, but SnAu forms a brittle intermetallic compound which would result in poor thermal fatigue and mechanical shock performance resulting in a reliability hazard.

Other solder systems exist with a higher melting point but could result in component issues.

*Electrically Conductive Adhesives*

These will be acceptable for addressing process thermal excursions, however they have a poor thermal conductivity compared with solder which would make them unacceptable for die attach and internal connectivity including BGAs. They would also not form a hermetic seal which would be unacceptable for sealing applications (ACEA et al. 2009e).

Solder alloys with high lead content stay solid up to (ACEA et al. 2009e)

- 235 deg C for a 85% lead content alloy;
- 270 deg C for a 90% lead content alloy;
- 385 deg C for a 95% lead content alloy.

When above those temperature levels, the alloy becomes pasty and so looses its mechanical properties (ACEA et al. 2009e).

ACEA et al. (2009e) state that no reliable substitutes are available to replace lead in HMP solders. Other stakeholders support this position (Umicore 2009; ON Semiconductor 2009).

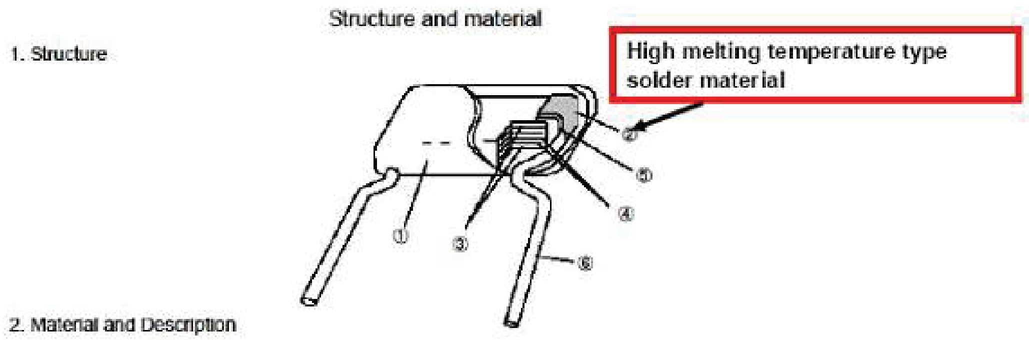
**Examples for uses of lead HMP solders**

The stakeholders provide examples on specific applications and technologies where the HMP lead solders are applied (ACEA et al. 2009e). The below listings are not exclusive. There may be uses of HMP lead solders, which are not included in the below descriptions. In agreement with the stakeholders involved in this review of exemption 8a, it is therefore not recommended to enact these example exemptions and to restrict the use of lead HMP solders to these exemptions. A specification of the HMP solder exemption away from a material specific towards an application and technology specific exemption would require another stakeholder consultation in order to make sure all stakeholders worldwide have chance to have their applications of lead HMP solders reviewed. The same proceeding was proposed for the lead HMP solder exemption in the RoHS Directive.

As the below HMP lead solder exemptions are not thought to be transferred into the Annex II of the ELV Directive, the reviewers did not review and assess them. They are just listed with the information provided by the stakeholders, without further critical review.

*Internal electrical interconnections in components*

High melting point lead containing solders are used to form high reliability internal connections in electronic components, as shown in Figure 15.




| No. | Material | Description |
|---|---|---|
| ① | Enclosure | Epoxy resin |
| ② | Inner solder | Sn-Pb type solder *1 |
| ③ | Dielectric | Ceramic |
| ④ | Inner electrode | Ni or Pd or Ag/Pd |
| ⑤ | Outer electrode | 1)Ag/Pd or 2) Ag or Ag/Pd or Cu + Ni plating + Sn plating |
| ⑥ | Lead wire | Solder(Sn-2.5Cu) coated copper wire or Solder(Sn-2.5Cu) coated CP wire |

*1 Lead in high melting temperature type solders (Pb;85% or more) are exempted from the requirements of RoHS.

Figure 15 Capacitor with HMP solder inner interconnects (no. 2) (ACEA et al. 2009e)

The stakeholders explain that for high reliability internal connections in electronic components, the melting point of the solder must be higher than the reflow temperature for lead-free assembly. The higher melting point is particularly important considering higher lead-free processing temperatures. When components are soldered onto printed wiring boards in reflow or wave soldering processes, soldering temperatures up to 260°C or even higher are applied. If the melting point of the solder used for interconnects inside the components does not have a considerably higher melting point, the inner solder joints remelt during the soldering process, which may damage the component, or reduce its reliability (ACEA et al. 2009e).

Substitution or elimination of HMP lead solders, according to ACEA et al. (2009e) is not possible because automotive electronics are used in harsh environments often in an enclosed environment at elevated temperatures, where convection cooling is not an option. They are used in safety applications and are expected to have 10–15 year lifetime. Automotive electronics also have to be commercially viable. Expensive thermal management techniques are not commercially viable (ACEA et al. 2009e).

During the life of the product, the electrical interface connections are subject to wide range of temperature, vibration and humidity. To replace the high temperature solder would require a dramatic reduction in the internal solder joint stress. This can only be achieved by the use of new component packaging materials, which would require extensive characterization and validation to ensure long term reliability (ACEA et al. 2009e).

*Die Attach*

High melting point lead containing solders are used to attach dies for power devices and discrete semiconductors providing both an interface with high thermal conductivity and electrical reliability (ACEA et al. 2009e).

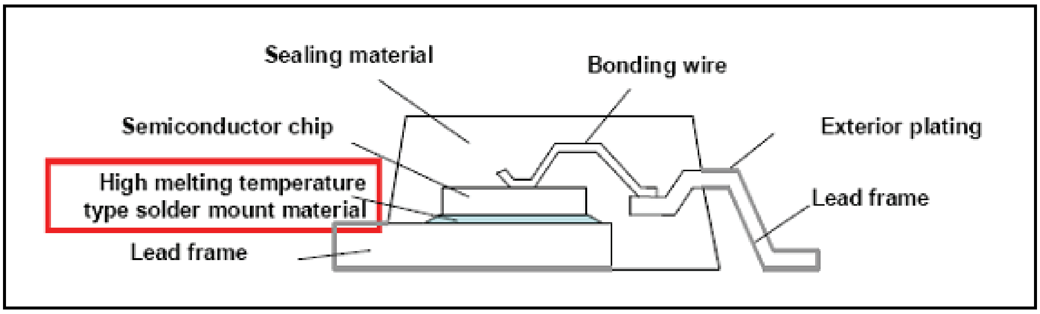



Figure 16 Example for use of HMP solders with lead for die-attach (semiconductor chip) in a power semiconductor (ACEA et al. 2009e)

ACEA et al. (2009e) explain that HMP lead solders have some unique properties that are necessary in this application. In die attach processes, high stress is generated due to the increase in junction temperature, die size and mismatch of the Coefficient of Thermal Expansion (CTE) between component materials. The solder must have low modulus of elasticity (high elasticity) to withstand a high number of thermal fatigue cycles required in automotive applications. The die attach is also required to possess high thermal conductivity since power and semiconductor devices generate significant levels of heat which must be dissipated (ACEA et al. 2009e).

According to ACEA et al. (2009e), in an automotive environment the ambient temperature can be in excess of 125°C. In order to maintain product reliability over 10–15 years, the junction temperature of the silicon die must not exceed 150°C (175°C for some specific power components). During operation the die temperature rises due to the power dissipation. In order to minimise the temperature increase, a material with high thermal conductivity is required.

Stress is also generated due to the CTE mismatch between the silicon die and copper heat slug/leadframe. If excessive stress is generated, de-lamination will occur resulting in a decrease in thermal performance, die fracture, and possible movement of the die causing wire bond failure (ACEA et al. 2009e).

Automotive electronics are used in harsh environments often in an enclosed environment where convection cooling is not an option. They are used in safety applications and are expected to have 10–15 year lifetime. Automotive electronics also have to be commercially viable. Expensive thermal management techniques are not commercially viable.

During the life of the product, the electrical interface connection and die attach are subject to wide range of temperature, vibration and humidity. To replace the high temperature solder would require a dramatic reduction in the internal solder joint stress. This can only be achieved by the use of new component packaging materials which would require extensive characterization and validation to ensure long term reliability (ACEA et al. 2009e).

*Hermetic Sealing*

High melting point lead containing solders are used as a substance for hermetic sealing (ACEA et al. 2009e).

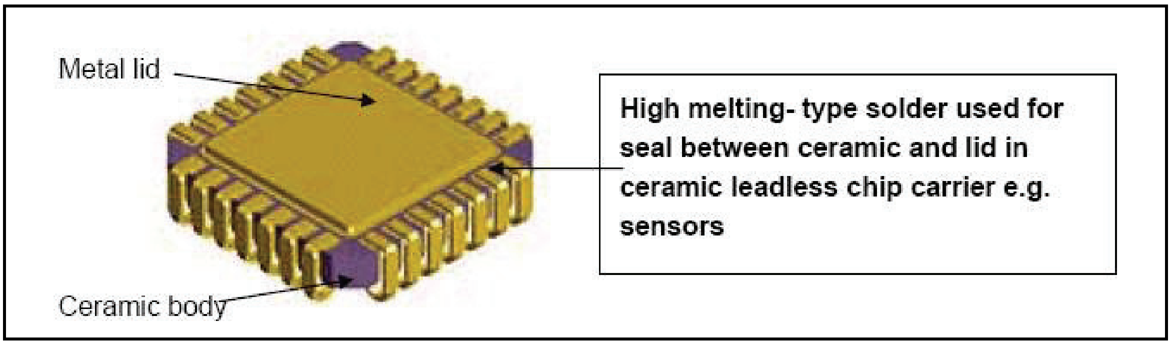



Figure 17 Example for use of HMP solders with lead in ceramic leadless chip carrier (ACEA et al. 2009e). Remark: “Leadless” chip carrier does not refer to the substance lead (Pb), but describes a component without leads, which form a carrying part in other, not leadless components (ACEA et al. 2009e).

According to ACEA et al. (2009e), hermetic sealing on the one hand requires a material that can be applied at sufficiently low temperature so as not to overstress the internal device. On the other hand, the solder used as a sealing substance between ceramic and metal must withstand processing temperatures of 260 deg C in soldering. It must accommodate the CTE mismatch between the lid and base. Therefore, they must form an intermetallic compound with the base and lid resulting in a solder joint which is not brittle and has sufficient ductility to accommodate the CTE between base and lid. Further on, the solder must provide hermetic sealing so as not to impair the performance of the device, e.g. crystal oscillators and sensors.

ACEA et al. (2009e) point out that any substitute has to be commercially viable which rules out alternative hermetic sealing methods.

*Availability of substitutes for RoHS equipment*

A stakeholder had applied for an exemption in the RoHS Directive for the use of lead in a similar application (SMMT 2009). The exemption request was assessed and recommended not to be granted, as another stakeholder at that time offered lead-free solutions (Swatch 2009). Although the application specific conditions in automotive electronics are different from those in RoHS equipment, an assessment of this exemption in a later phase should take into account the result of this previous review.

*Plastic overmoulding*

High temperature plastic overmoulding (>220°C) uses high lead containing solder for component attachment, which is required to withstand the higher temperatures of the moulding process (ACEA et al. 2009e).

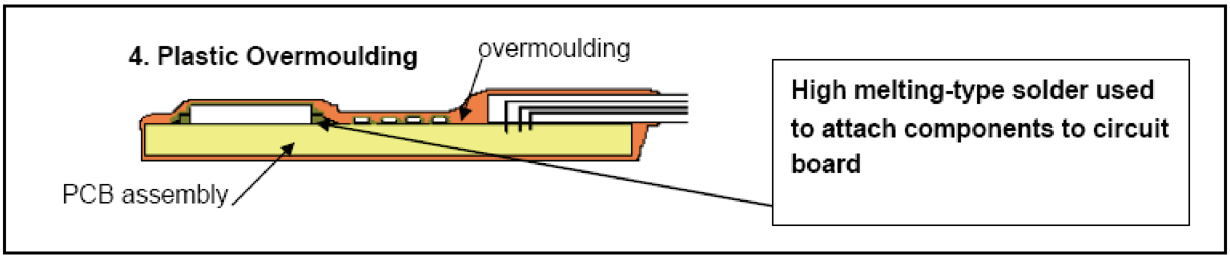



Figure 18 Example for use of HMP lead solder for component attach in plastic overmolded components (ACEA et al. 2009e)

ACEA et el. (2009e) explain that the components are attached to the printed circuit board (PCB) and then over-moulded. The solder joints must have sufficient strength above 220°C to withstand the temperature and force generated during the moulding process. The assembly must then be reliable in a harsh automotive environment over the life of the product.

ACEA et al. (2009e) say that lead-free HMP solders do exist that would give sufficient strength during the overmoulding process. They would however not meet the reliability requirements (see Figure 14 on page 98 and the stakeholders' explanations there).

*Ceramic BGA*

Ceramic BGAs require high melting point lead containing solder balls for electrical connections.

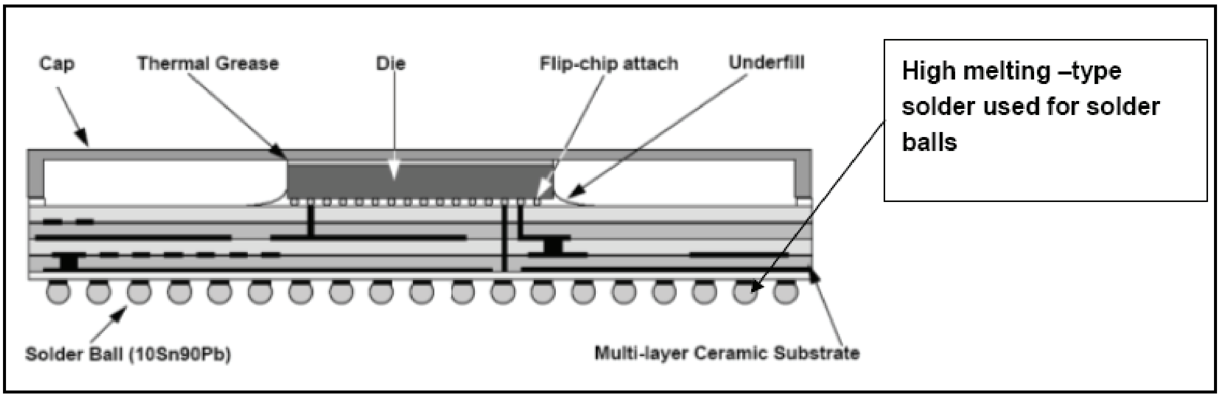



Figure 19 Example for use of HMP lead solder in ceramic ball grid arrays (BGA) (ACEA et al. 2009e)

ACEA et al. explain that ceramic BGAs have a large CTE mismatch between the board and BGA. In order to fulfil automotive requirements, the strain has to be minimised. HMP lead solder does not collapse like a SAC lead-free solder during processing. Therefore, the solder joint stand-off height – distance between the BGA substrate and the printed circuit board to which the BGA is attached – is maintained (ACEA et al. 2009e).

This improves the thermal fatigue robustness. The strain generated within the solder joint is inversely proportional to the solder joint height. Increasing the solder joint height decreases the strain and increases the fatigue life (ACEA et al. 2009e).

*High Power Applications*

High power applications require high melting point lead-containing solder to maintain internal electrical integrity due to internal power dissipation (ACEA et al. 2009e).

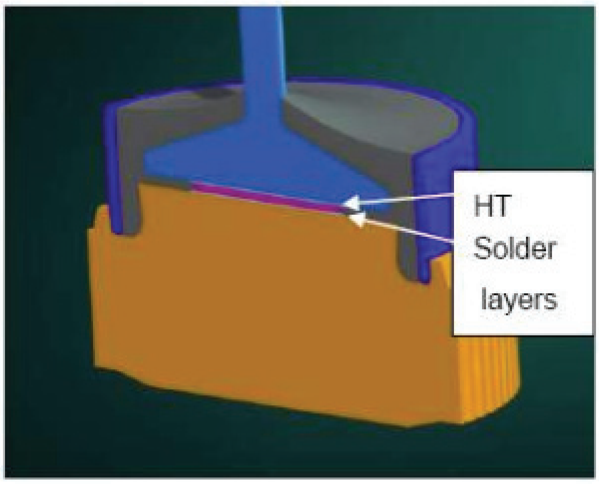



Figure 20 Example for use of HMP lead solder in a generator diode (ACEA et al. 2009e)

High power applications generate heat during use and require high melting point lead-containing solder to prevent the internal interconnections melting during operation. Generator/alternator diodes, e. g., to rectify the current for board net must survive temperatures of 280°C (ACEA et al. 2009e).

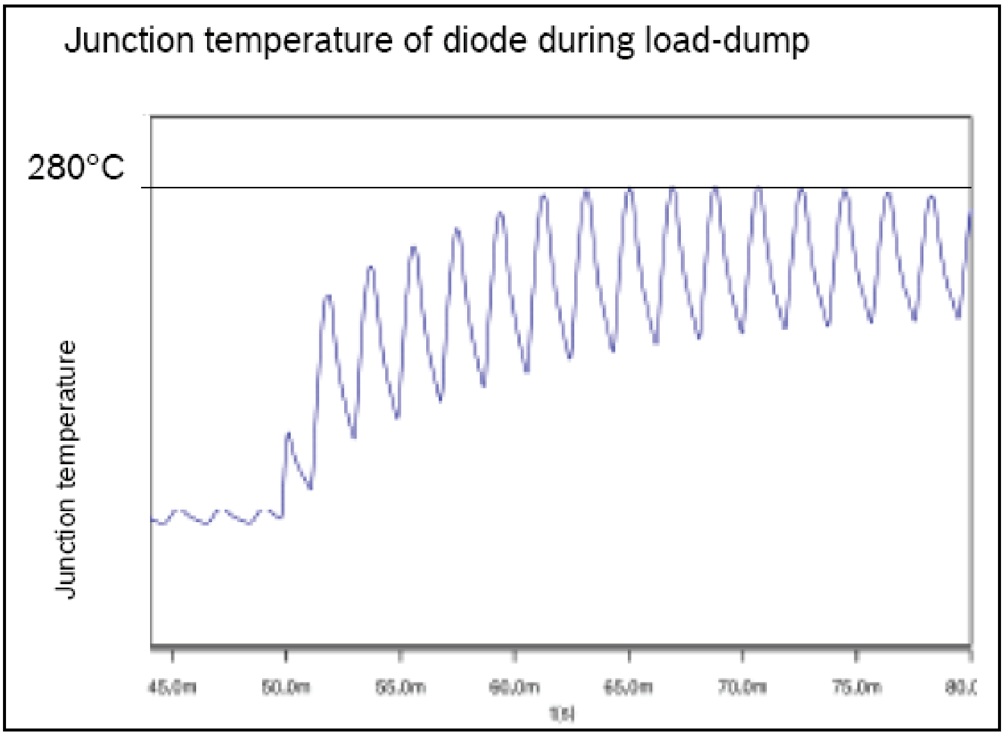



Figure 21 Junction temperature of a diode during load dump

The melting point of the applied solders must be higher than 280°C. The diode will be short-circuited if the melting point of the solder is exceeded (ACEA et al. 2009e).

As a lead-free alternative for generator diodes, low temperature silver sintering is under laboratory scale investigation. First results show problems due to the brittleness of the silver interface. Also the simultaneous connection on both sides of the diode showed to be very difficult. Laboratory solutions are not expected in the near future (ACEA et al. 2009e).

ACEA et al. (2009e) claim that substitution or elimination would require a design change, which is not possible within the given timeframes of ELV Annex II.

### 4.10.4 Critical review of data and information

The above examples for HMP lead solder uses are just listed, they were not reviewed as the stakeholders did not request them as exemption, but just gave examples of HMP lead solder uses.

**Necessity of an exemption for leaded HMP solders**

The stakeholders plausibly explain that in several technologies and specific applications, leaded HMP solders cannot yet be substituted. For the same reason, the RoHS Directive exempts the use of lead in high melting point solders (exemption 7a), as long as the lead content is at least 85% (weight). It is hence not contentious that an exemption for leaded HMP solders is required.

**Deviation of solder limit from the exemption for leaded HMP solders in the RoHS Directive**

Differently from the RoHS Directive, ACEA et al. (2009e) want leaded HMP solders to be exempted starting from 80% of lead content by weight. ACEA et al. (2009e) put forward that, although the lead contents of the different solders used are above 85%, the soldering process will result in some blending of the original solder (HMP solder) alloy with the solder alloy used for component attach (with a lead content of well below 85%). This blending effect may result in regions within the alloy that could fall below 85% lead content.

If this effect actually was to be observed, systematic non-compliance of equipment with the stipulations of the RoHS Directive would be the consequence.

On further request, the ACEA et al. (2009n) explain that the proposed wording of the proposed exemption C(i) for HMP solders is a merger of two exemptions in the current version of the RoHS Directive, namely 7a and 14:

- Current wording of Exemption 14:
  "Lead in solders consisting of more than two elements for the connection between the

pins and the package of microprocessors with a lead content of more than 80% and less than 85% by weight."

- Current wording of exemption 7a:
  "Lead in high melting temperature type solders (i.e. lead-based alloys containing 85% by weight or more lead)"

ACEA et al. (2009n) explain that they had intended minimizing the number of application based exemptions.

As exemption 14 of the RoHS Directive is recommended to expire in 2010, the stakeholders agree to align the wording of the requested exemption C (i) with the wording of exemption 7a of the RoHS Directive if the Commission decides to follow the reviewers' recommendation for exemption 14 of the RoHS Directive (Gensch et al. 2009).

The reviewers recommend not to follow the stakeholders' proposal with the 80% lead limit, even in case the Commission would decide to maintain exemption 14 of the RoHS Directive. Exemption 14 is a highly specific exemption limiting the use of 80% lead solders to specific pin grid arrays. Lowering the lead limit down to 80% like in the stakeholders' proposed exemption wording would allow a general use of such solders. The wording of exemption C (i) targets a material specific exemption for such leaded solders, not an application or technology specific one.

**Alignment with exemption 7a of the RoHS Directive**

Most of the examples of HMP solder uses, which ACEA et al. (2009e) had indicated apply to specific uses of HMP solders in the RoHS Directive as well. The RoHS stakeholders had presented such examples in the last review of the Annex of the RoHS Directive (Gensch et al. 2009). ACEA et al. (2009e) did not provide evidence justifying the requested 80% limit. Granting a different lead limit in the ELV Directive thus technically would not be justified and, as it affects the same industries, might create confusion.

Exemption 7a in the RoHS Directive, in alignment with the Commission's policy and to prevent abuse of the exemption, was recommended to be transferred from a material specific to an application and technology specific exemption. There were cases of abuse of leaded HMP solder materials (Gensch et al. 2009).

It is recommended to follow the same principle for the requested leaded HMP solder exemption in the ELV Directive. Exemptions allow the use of a banned substance if its use is unavoidable according to Art. 4 (2) (b) (ii). Exemptions therefore should be as specific as possible to avoid misuse of banned substances. Exemption 7a of the RoHS Directive is recommended to expire on 30 June 2013 (Gensch et al. 2009). Until then, before the expiry, application and technology specific exemptions for leaded HMP solders must be in place, which industry can apply for once the Annex of the RoHS Directive is amended officially. For the requested HMP solder exemption in the RoHS Directive, the stakeholders ask not to set an expiry date, but a review date instead. Due to the long development cycles, an expiry date would cause troubles in the supply chain. Vehicle manufacturers want to make sure their legal compliance in case the lead HMP solder exemption expires before more specific exemptions are in place. They may thus try to oblige their suppliers to sign certificates stating that they can supply without using lead in HMP solders. The stakeholders report such experiences since Annex II of the ELV Directive was published with an absolute ban of lead from 2011 on.

It is therefore recommended to grant an exemption for HMP solders with 85% of lead by weight or more for now, but to transfer it to an application and technology specific exemption at the same time and in alignment with exemption 7 a of the RoHS Directive, as far as such an alignment is technically justified. Lead containing HMP solders are used in equipment under the RoHS Directive as well as in vehicles for the same technical reasons, in similar applications, and at least in parts the same industries are affected by the HMP solder exemptions. An alignment thus improves the understanding and handling of the exemption.

Like in the RoHS Directive, the ELV stakeholders are not sure whether the listed HMP solder applications actually are complete and cover all applications (ACEA et al. 2009n). A transfer of the material specific to an application and technology specific exemption hence would require a separate stakeholder process.

### 4.10.5 Final recommendation exemption 8 C (i)

The use of lead in HMP solders is not unavoidable, and Art. 4 (2) (b) (ii) thus would justify an exemption. It is recommended to grant the exemption, but to transfer it later from a material specific exemption to an application and technology specific one, following the example of exemption 7a in the Annex of the RoHS Directive. An alignment with the RoHS Directive makes sense, as the technical background is similar, and as the exemption at least in parts affects the same industries e. g. the component industry.

The proposed wording for exemption C (i) hence is:

> *Lead in high melting temperature type solders (i.e. lead-based alloys containing 85% by weight or more lead), review in 2013.*

The review date should enable the review of exemption C (i) together with exemption 7a in the Annex of the RoHS Directive. The 2013 timing for the review is based on the reviewers' recommendation for exemption 7a of the RoHS Directive (Gensch et al. 2009). In case the Commission decides a different expiry or review date for exemption 7a RoHS Directive, the review date for this exemption should be adapted accordingly.

## 4.11 Exemption no. 8a – stakeholder proposal part C (ii)

*"Lead used in compliant pin connector systems"*

### 4.11.2 Description of exemption

ACEA et al. (2009f) ask for an exemption for lead use in compliant pin connector systems (pressfit technology). According to ACEA et al. (2009f), no expiry date can be defined, as a technical solution is not available, and they propose a review after 2015.

The requested exemption still exists in the current version of the RoHS Directive as exemption no. 11 (status May 2009).

Compliant pin connector or press-fit connectors systems provide a method of attachment and electrical contact between a connector and printed circuit board (PCB) which does not require a soldering operation. The pin contacts are inserted into plated through holes (PTH) in the PCB and the mechanical design of the pin provides reliable electrical contact. The compliant pins must be sufficiently flexible to deform as they are inserted into the holes without an excessively high force that might damage the plating in the holes (Gensch et al. 2009). The pressfit technology thus saves solder, but its applicability is limited. Its use is, e. g., impossible for high power electronics (ACEA et al. 2009f).

The tin-lead plating on the pins contains about 10% lead and is only about 1,5 microns thick. It is required to

- provide lubrication while the pins are inserted in order to reduce the insertion force;
- have an oxide on the surface that can be displaced during insertion;
- ensure good electrical contact once the pin has been inserted;
- prevent whisker growth.

Technologically, pin compliant connectors avoid the difficulties encountered in soldering a large number of closely spaced pins. The total thermal mass would be so large that it was difficult to achieve the correct temperature throughout the connector for the solder to flow and wet the surfaces. The situation would be even more difficult with lead-free solders due to their slower wetting and higher assembly temperature. As solder is not used, smaller pads can be used around each pin, so that they can be placed closer together (Gensch et al. 2009).

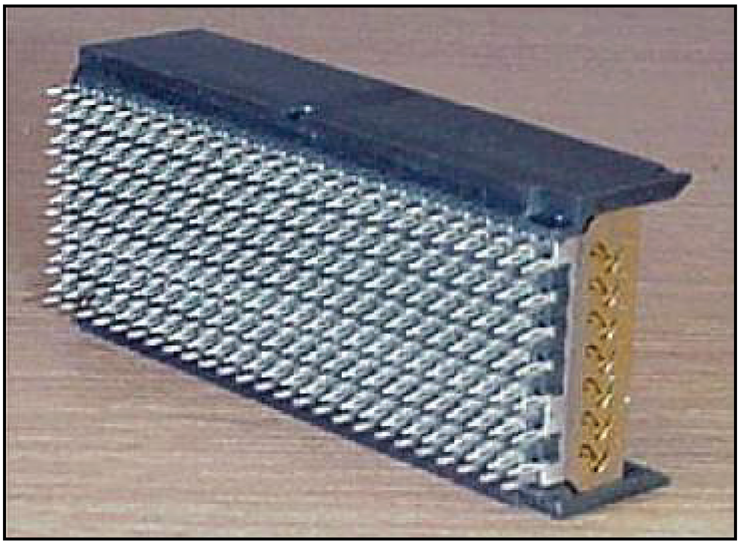
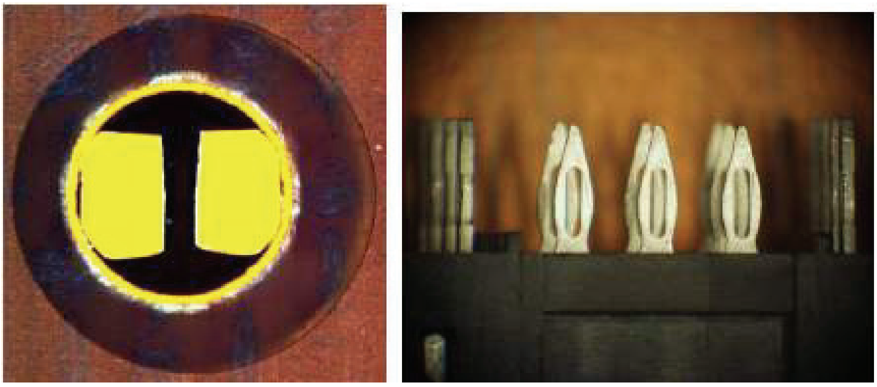


Figure 22 Example of a compliant pin connector system (Gensch et al. 2009)

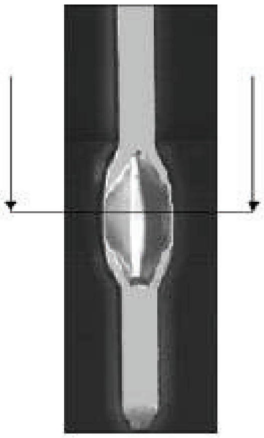
There are different types of compliant pin connector systems in use.

a) *eye of needle*



b) *C-press*

*c) Bowtie*



*d) Action pin*

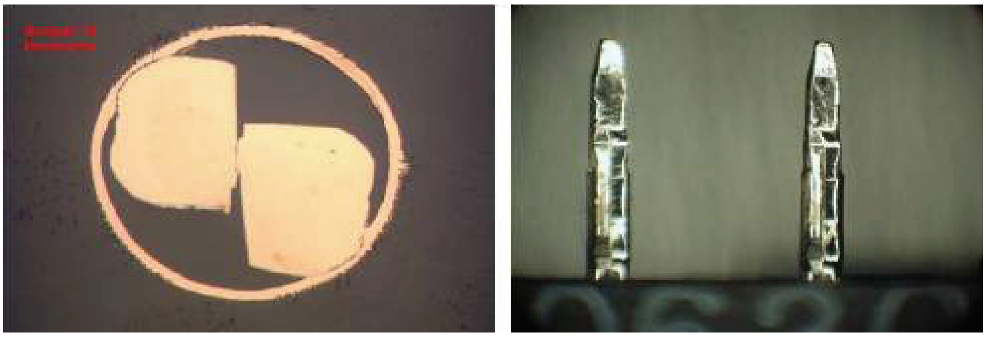


Figure 23 Types of compliant pin connector systems (Gensch et al. 2009)

Tin-lead plating covers only the termination portion of the contact, which includes the compliant section. The lead provides lubrication while the pin is inserted and withdrawn. The lead oxides on its surface are displaced during insertion enabling good electrical contact once the pin is inserted. Such connectors are used on printed circuit board assemblies contained in many types of computer and telecommunication equipment (Kadesch 2001).

ACEA et al. (2009f) calculate the amount of lead used in pressfits for automotive applications:

- The SnPb coating contains 5%–10% of lead.
- This results in around 0,0001 g of Pb per press-fit zone; around 100 pins per press-fit on average /vehicle.
- Around 16 000 000 cars are assumed to be built per year (ACEA 2007, EU27+ EFTA), equipped with 5 ECUs with an effected press-fit

Based on the above assumptions, the amount of lead used under this exemption would be around 0,8 t lead per year in Europe and the EFTA states (ACEA et al. 2009f).

### 4.11.3 Justification for exemption

ACEA et al. (2009f) say that lead is necessary to avoid whisker growth. Whisker problems appear if lead-free chemical tin finish on the PCB and galvanized tin surfaces on the press-fit pins are combined together (2 x pure tin layer). The probability of whisker growth increases by (ACEA et al. 2009f)

- large deformation in the entrance area of the press-fit zone;
- tin abrasion from the pin surface, adhering at the PCB-bushing surface.

The growth of whiskers thus is related to the insertion process, as the deformation as well as abrasions are caused during insertion. Whiskers can grow very fast, up to the range of millimetres per week. Whiskers are observed only in the entrance area of the press-fit zone (see REM pictures in Figure 26 below). Press-fit whiskers appear independent on PCB supplier and supplier of the chem. tin bath (ACEA et al. 2009f).

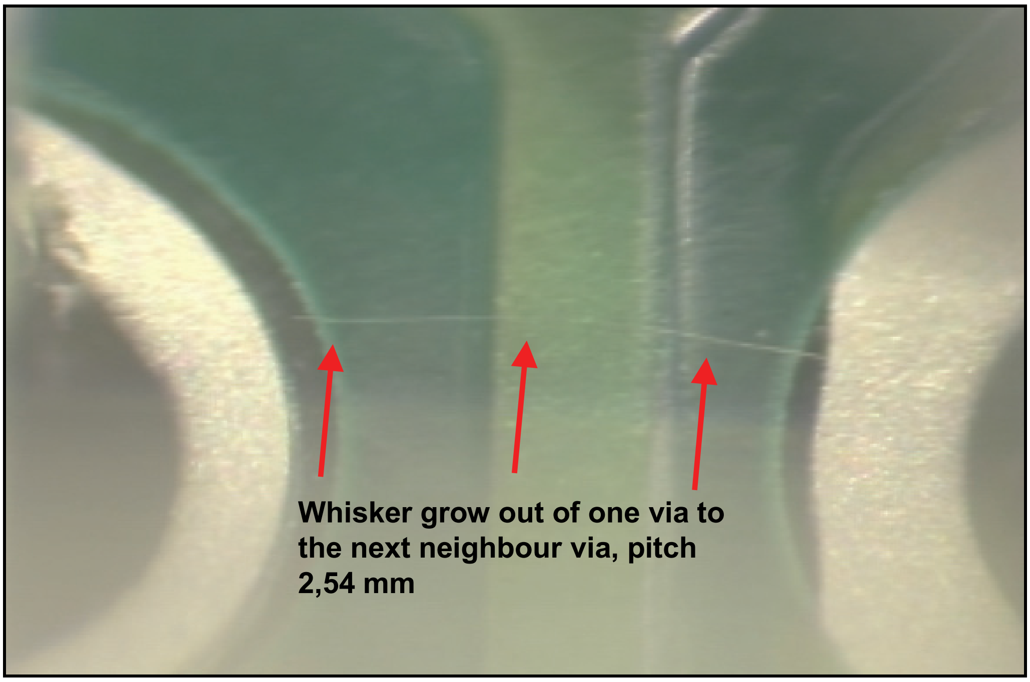



Figure 24 Whisker formation on pressfits I

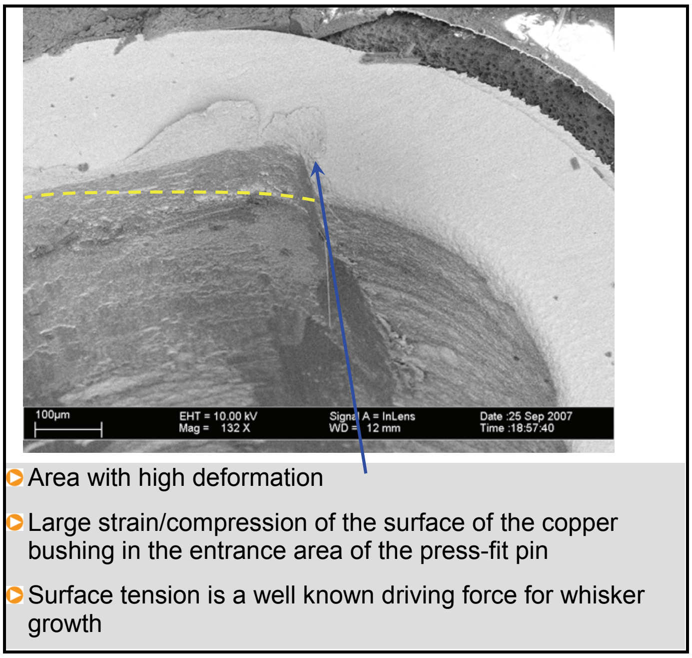



Figure 25 Whisker formation on pressfits II

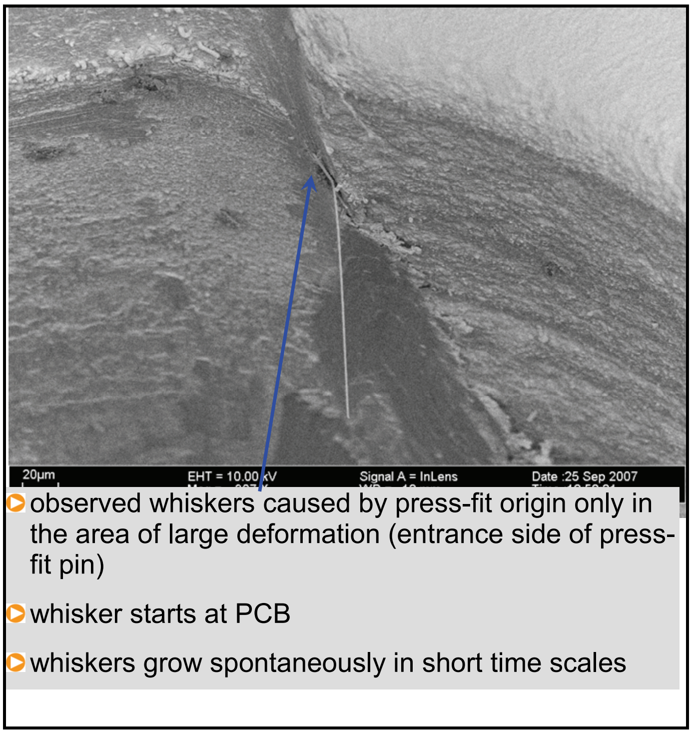



Figure 26 Whisker formation on pressfits III

ACEA et al. (2009f) state that the mechanism of whisker building is not fully understood today. They claim that there is no known alternative to the lead use in compliant pin connector systems to avoid whisker growth. Some pre-studies were conducted for SnAg and SnCu platings, but no reliability study with satisfying results is available. Suitable lead-free alternatives for new types are under further development and qualification. A substitution of lead in compliant pin connector systems hence is not possible (ACEA et al. 2009f).

The stakeholders explain that soldering is not an alternative interconnection technology that would allow eliminating the use of lead. Compliant pin connector systems have the following advantages compared to soldering (ACEA et al. 2009f):

- "simple" mechanical process;
- no additional thermal stress to PCB and components;
- no risk of solder bridges or open solder joints;
- higher FPY (first pass yield, number of PWBs without failures after processing);
- lower dpm rate (defects per million, field returns/band returns);
- less solder needed per contact;
- less energy consumption of process.

ACEA et al. (2009f) point out that a failure in electronics may endanger life and health of the driver. A short cut due to whiskers might lead to serious malfunction of the device, e.g. by wrong sensor signals or even a failure of the whole device.

ACEA et al. (2009f) conclude that only lead avoids rapid whisker growth resulting from the press-fit process. Pure tin surfaces therefore cannot substitute the tin-lead surfaces. Design and technology alternatives like soldering cannot replace compliant pin connector systems. The use of lead in compliant pin connector systems must therefore be exempted.

ACEA et al. (2009f) add that the latest Commission proposal on new RoHS (COM(2008) 809/4) exempts press-fits in Annex V: “11. Lead used in compliant pin connector systems”. They claim that this would be a further proof that feasible substitutes do not exist.

### 4.11.4 Critical review of data and information

#### Compliant pin connector systems under the RoHS Directive

ACEA et al. (2009f) put forward that the Commission proposal on the recast of the RoHS Directive exempts the use of lead in compliant pin connector systems (exemption 11), and that this would prove that feasible substitutes are not available. This is not correct. The exemptions listed in this proposed recast just reflect the current status of the RoHS Annex (status May 2009).

As a matter of fact, the Annex of the RoHS Directive was reviewed until end of 2008. Exemption 11 of the RoHS Directive allowing the use of “Lead in compliant pin connector systems" was recommended to be adapted to the scientific and technical progress as follows (Kadesch 2001):

*11 a) Lead used in C-press compliant pin connector systems until 30 June 2010, and for the repair, or to the reuse, of electrical and electronic equipment put on the market before 1 July 2010.*

*11 b) Lead used in other than C-press compliant pin connector systems until 31 December 2012, and for the repair, or to the reuse, of electrical and electronic equipment put on the market before 1 January 2013.*

The reviewers' recommendation to restrict the use of lead in compliant pin connectors reflects the fact that viable lead-free solutions are available or foreseeable in the near future for the equipment under the scope of the RoHS Directive (for details see review of exemption 11 in the final review report; Gensch et al. 2009).

The question is whether and how far the scientific and technical assessment resulting in the proposed rewording of exemption 11 of the RoHS Directive is transferable to compliant pin connector systems used in vehicles under the scope of the ELV Directive.

**Correlation of exemptions in the RoHS and the ELV Directive**

It needs to be clarified whether and how far an exemption for lead in pressfit connectors is justified under the ELV Directive, while solutions are available or foreseeable for equipment under the RoHS Directive.

*The different role of the cold welding effect*

Compliant pin connectors in most "RoHS" equipment, in particular on complex PWBs like in high end servers, are used among other reasons because pin connections can be repaired and replaced. For repair, rework and upgrade e. g. of servers, the compliant pin connectors must be removable and reinsertable without causing damages to the pins or the plated through holes, and still work reliably (Gensch et al. 2009). Any bonding of the pins to the plated through hole (PTH) due to cold welding effects must be avoided in such uses under the scope of the RoHS Directive (Gensch et al. 2009).

This is a crucial difference between automotive and non-automotive pressfit applications. While cold welding must be avoided in RoHS equipment, it is the aspired effect in automotive pressfit applications. Cold welding of the pins to the pin walls is necessary that the pin connector systems can reliably withstand the mechanical forces enacted onto them due to vibration and temperature changes, and the combination thereof. Pin movement in the holes would result in unreliable functionality.

To achieve the cold welding effect, a higher pressure of the pin to the pin wall is required. This higher pressure entails a higher force to insert the pins into the holes. ACEA et al. (2009o) claim that for pin connectors in telecom equipment typical insertion forces are 20 to

50 N/pin, while automotive pin connectors are inserted with 120 to 150 N/pin. The stronger force, which the pin applies to the wall to induce cold welding, also explains why automotive pressfits generally and in particular with tin surfaces are more prone to whisker growth compared to pressfits in RoHS equipment. Whiskers are a consequence of internal or external compressive stress onto the surface tin layer. The higher compressive stress onto the pin and the wall surfaces in automotive applications increases the risk of whisker growth.

Next to increased forces, only specific combinations of metallizations are appropriate to achieve cold welding. In case of lead-free surfaces, the stakeholders claim chemical tin surfaces on the printed wiring board in combination with galvanized tin on the pin to be the metallization combination warranting efficient cold welding with superior processability. As, according to the stakeholders, this combination results in whisker growth under the described automotive conditions, leaded metallizations are without alternative for the time being and for the near future in automotive applications of compliant pin connectors. Lead-containing metallizations combine moderate insertion forces due to the lubrication effect of lead with efficient cold welding properties and higher whisker resistance compared to lead-free surface metallizations. The lubrification effect of lead improves the ratio of insertion force to the force the pin enacts onto the pin walls. The insertion force at identical force between the wall and the pin is lower compared to lead-free surfaces.

Gold surfaces, which are more resistant to whisker growth, would increase the insertion forces even more. Given the already higher insertion forces in automotive applications, gold surfaces may even more easily result in damages during the insertion process. The higher insertion forces of gold surfaces are a problem already in RoHS equipment at lower, but still increased insertion forces compared to lead-containing pin connectors (Gensch et al. 2009).

What remains to be clarified is why the automotive industry rejects gold surfaces due to their insufficient cold welding properties (ACEA et al. 2009n), while the stakeholders in the RoHS Annex review reject gold surfaces with the argument that they would result in bonding of the pin to the PTH of the PWB (Gensch et al. 2009). Possibly, the RoHS stakeholders were talking about gold surfaces without nickel underlayer between the gold and the copper, while the ELV stakeholders refer to nickel gold surfaces. The nickel underlayer between the copper and the gold surface reduces diffusion between the gold and the copper. During the review of the RoHS Annex in 2008/2009, the gold surfaces were not further investigated, as the RoHS stakeholders had announced lead-free substitutes until end of 2012, and as gold surfaces had been rejected due to the higher insertion forces compared to tin-lead or pure tin surfaces.

*Geometrical changes to reduce insertion forces*

The insertion and retention forces could in principle also be aligned changing the geometrical dimensions of the pins and the pin hole. The pins could be made smaller, and the holes be made bigger. Lead-free materials with a higher friction (no lubrication from lead) could thus be inserted at lower forces. The higher friction would result in higher static friction increasing the retention forces, which could then promote the cold welding effect. It is, however, not clear if cold welding would still occur under these conditions.

The stakeholders explain that there are narrow limits to geometrical adaptations (Warburg 2009b). The pin hole diameters as well as the pressfit diameters are well aligned to each other in order to balance insertion forces and the pressure required to achieve the cold welding effect. The printed wiring board manufacturers can only change the hole diameters in steps of 0,05 mm. For example, the pin hole diameter may be 1,00 to 1,09 mm, the pin diagonal 1,16 to 1,24 mm. An increase in the pin hole diameter for 0,05 mm would result in an overlap of only 0;02 mm. Such a pin connect would not be reliable (Warburg 2009b).

It could not be clarified whether and how far further adaptations of the pin diameter might allow a better alignment. It is, however, clear that the automotive industry in this case depends on the supplies and on the technical possibilities and limits of their suppliers. The state of technology and the specific requirements of pressfit applications in the vehicle industry put limits to geometrical changes.

*Environmental impacts of gold*

The stakeholders explain that, besides the adverse properties described above, is not a viable option from the environmental point of view (Warburg 2009a). Gold is – due to its physical properties and excellent conductivity – the material of choice in some applications within electronics. Anyway, the replacement of other materials by gold should be assessed carefully before realization. The production of gold causes significant emissions and requires huge amounts of energy. This might overcompensate environmental benefits due to reduced lead content. The production of 1 kg gold consumes approx. 400 000 MJ of primary energy, compared to e.g. 20 MJ for lead (Warburg 2009a).

Within the MEEuP Project, carried out for the European Commission in connection with the EuP legislation, experts stated reduction of gold as clear goal for environmental friendly design of electronics (Warburg 2009a).

From the review point of view, the above would only justify an exemption if the environmental impact from substituting lead by gold would outweigh the environmental benefits of the substitution. As gold is not considered as a technically viable substitute, such environmental aspects were not further investigated and clarified in this review process.

### 4.11.5 Final recommendation exemption 8 C (ii)

It is recommended to grant the exemption. The specific operational conditions – vibration and thermomechanical stress – in automotive applications of compliant pin connector systems require cold welding between the pins and the hole surfaces. Cold welding, in contrary, must be avoided in pin connector systems used in RoHS equipment. This application specific difference justifies a continued exemption for the use of lead in line with Art. 4 (2) (b) (ii), although the equivalent exemption no. 11 in the RoHS Directive is recommended to expire in 2012 latest.

The reviewers recommended the following wording for the exemption:

> *Lead in compliant pin connector systems; review in 2014.*

The review in 2014 is recommended as the stakeholders state that lead-free alternatives are under development.

## 4.12 Exemption no. 8 a – stakeholder proposal part C (iii)

*“Lead used in soldering on glass for non glazing application”*

### 4.12.2 Description of exemption

ACEA et al. (2009d) apply for an exemption for “Lead used in soldering on glass for non glazing applications”. “Non-glazing applications” demarcates the requested exemption from exemption 8b, currently still exempting the use of lead for soldering on glass in vehicles. The stakeholders propose the review of the exemption after 2015 (ACEA et al. 2009d).

The exemption is applied in Mass Airflow Sensors (MAF) used to measure the mass of air entering an internal combustion engine, mainly in diesel engines. The engine management system needs the airflow information to optimize the engine with regard to fuel efficiency and emissions.

The typical method of mass-airflow sensing is hot-film or hot-wire anemometry: A flow sensing element consisting of an electrically heated hot film or hot-wire is heated to a defined offset temperature relative to the ambient temperature, which is determined by a separate temperature sensor. As the airflow cools the hot film or hot wire, the power needed to keep the sensing element at the offset temperature is a measure of the mass air flow passing the sensor (ACEA et al. 2009d).

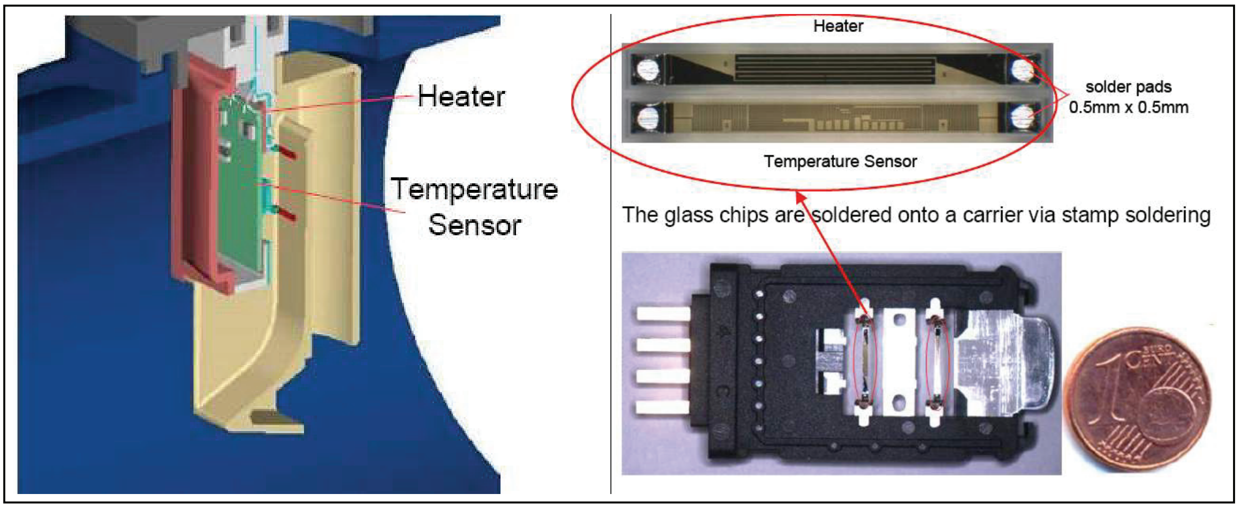



Figure 27 Cross-section of a mass airflow sensor in a tube (left) and interior details of an air massflow sensor (ACEA et al. 2009d)

The stakeholders put forward that the base material of the flow and temperature sensing elements must fulfill certain requirements (ACEA et al. 2009d). Among other requirements, a low thermal conductivity and the capability of thin film application is of critical importance for thin-film elements. Glass is the ideal material to meet these requirements. Due to the mechanical sensitivity of glass, the mechanical connection of the sensing element to a carrier must be chosen carefully, so that the glass is not damaged during processing and in use. Lead solder is used for these interconnects. With the soldering process both the mechanical fixation of the element and the electrical connection to the thin-film can be achieved, according to the stakeholders (ACEA et al. 2009d).

The lead solder reservoir is applied to the glass chips via solder-paste screen-printing and subsequent reflow soldering (ACEA et al. 2009d).

The stakeholders calculate the amount of lead under this exemption as follows (ACEA et al. 2009d):

The solder used is tin lead solder with 36% of lead content. The 4 solder joints of a Mass Airflow Sensor contain approx. 480 µg or 0,5 mg lead in total (worst case assumption). Assuming 16 million cars built per year (ACEA 2007, EU 27 + EFTA), equipped with one mass airflow sensor this sums up to 7,7 kg (0,0077 t) of lead per year.

The total use of lead under this exemption thus would be around 8 kg per year.

### 4.12.3 Justification for exemption

**Constraints of lead-free soldering solutions in manufacturing and operation**

The stakeholders explain that the intake air temperature can reach up to 130°C (e.g. hot idle conditions) (ACEA et al. 2009d). The heat conduction from the flow sensing element to the solder joint causes additional temperature increase at the solder joint. For this reason, connections that can not withstand temperatures up to 160°C may not be implemented. Lead-free solder has a melting point of ~220°C, 40°C more than lead-containing solder (ACEA et al. 2009d). This increase in melting temperature compared to lead-containing solder results in a 30% strength reduction of the glass element, due to increased thermo-mechanical stresses during the soldering process. That is a significant quality risk, since an element fracture would cause the emission relevant Mass Airflow Sensor (MAF) to fail in vehicle use. In addition, the scrap rate will go up. Another quality issue with lead-free solder for this application is the poor resistance to environmental influences such as sulphur in the atmosphere, which are present in automotive environments (ACEA et al. 2009d).

The stakeholders explain the risks in case of MAF malfunctions (ACEA et al. 2009d):

- engine runs in emergency "limp-home" mode,
- reduced fuel efficiency,
- increased emissions.

**Lead-free solutions**

ACEA et al. (2009d) explain that zirconium-dioxide ($ZrO_2$) may be an alternative substrate material avoiding the loss of sensor element strength during the lead-free soldering process. It offers only slightly worse material properties compared to glass. To achieve the same resistance of lead-free solder against environmental influences, an additional protective coating of the solder joint is required. Another alternative is the development of a new flow sensing concept, based on a micromechanical silicon sensor element (ACEA et al. 2009d).

*Zirconium-dioxide based solutions*

ACEA et al. (2009d) explain that despite of slightly worse material properties, $ZrO_2$ can be used as a substrate material for Mass Airflow Sensors (MAF) using thin film processes. The remaining strength of the sensor element after soldering with a lead-free solder is still higher than the strength of glass. ZrO2 becomes conductive at higher temperatures, so a new protective layer between the substrate and the TDR (temperature dependant resistor) material had to be developed. The required protective coating is under preliminary investigation. The substitution of glass by $ZrO_2$ is mainly restricted by the availability of thin film capable $ZrO_2$ in production volumes (ACEA et al. 2009d).

ACEA et al. (2009d) inform that first samples of a Mass Airflow Sensor (MAF) based on a $ZrO_2$ sensor element are available. A rough estimation for the time needed to ramp up the production could be 3 years. This includes the qualification of a ZrO2 supplier, being capable of the production volumes, and the development of the different (productive) layer compositions needed for the ZrO2 substrate. Although the development of a $ZrO_2$ sensor element can run parallel to a production ramp up, at least another 2 years are needed for a qualification of series parts under series conditions. The thermal conductivity of ZrO2 is increased by factor 3, which changes the sensor dynamics dramatically. This may require a modification and adaptation of the sensor mechanical design and the electronic control unit. This can partly run parallel to the development of the new sensor element, but at least another year is needed to run the generic qualification. Once the development and generic qualification is complete, customer-specific validation must be conducted with production-level parts and must be completed roughly 1 year before the start of production of the vehicle it shall be used in.

Altogether, the stakeholders calculate a lead-time of five years before a qualified lead free Mass Airflow Sensor based on hot film technology is available (ACEA et al. 2009d). The stakeholders assume that the earliest lead-free sensors could be produced in 2014.

*Micromechanical Mass Airflow Sensors*

Micromechanical Mass Airflow Sensors are another alternative. The development of a new sensor concept was started in 2005. Currently first samples are available (ACEA et al. 2009d). An alternative Mass Airflow Sensor technology based on silicon MEMS sensing element is under development since 2005 and is now entering a B-sample phase. A possible SOP (start of production) could be in 2012/2013. The lead-free mass flow sensors need to be qualified at the customer, so that customers could earliest use the lead-free mass flow sensors in production of electronic systems for vehicles in 2014 (ACEA et al. 2009l).

### 4.12.4 Critical review of data and information

**Availability of alternative solutions**

Zirconium-dioxide based mass airflow sensors (MAF) micromechanical MAF are possible solutions not depending on the use of lead solders.

The stakeholders were asked whether indium-based lead-free solders might be another alternative allowing the replacement of lead in the solders. ACEA et al. (2009l) explain that the temperatures of indium-based lead-free solders are too low. The maximum specified operating temperature is 130°C in hot idle mode. Because of the measurement principle (hot film anemometry) and the associated heating of the sensor element, the temperature of the solder joint reaches up to 160°C. Indium-tin alloys have a eutectic temperature of about

125°C, which is too low. The risk of re-crystallizations and a weak solder joint after high temperature endurance storage (e.g. 130°C for 1667 hours with operation) is very high. Further on, indium based alloys exhibit poor corrosion resistance in combination with mass flow and high humidity atmospheres, which is a common environmental operation condition for MAFs in automotive applications (ACEA et al. 2009l).

Currently, lead-free versions of mass airflow sensors are not available. Art. 4 (2) (b) (ii) would thus allow an exemption for this application of lead in solders.

**Confinement and expiry of the exemption**

The only applications the stakeholders explain for the non-glazing lead soldering are mass flow sensors. The stakeholders agreed to restrict the exemption to mass flow sensors (ACEA et al. 2009l).

The stakeholders present two concepts of mass airflow sensors where the use of lead is avoidable. According to the stakeholders, the lead-free MAFs are available for use in vehicles in 2014 earliest. It is therefore recommended to set an expiry date for the exemption end of 2014 and to restrict it to cars type approved before 1 January 2015.

### 4.12.5 Final recommendation exemption 8 C (iii)

It is recommended to grant the exemption. The stakeholders plausibly explain the technical problems currently still requiring the use of lead solders. As compliant solutions are foreseeable for 2014 earliest, an expiry date should be set, which the reviewers recommend for 31 December June 2014.

The reviewers propose the following wording for the exemption:

> *Lead used in soldering on glass in mass airflow sensors in vehicles type approved before 1 January 2015, and in spare parts of such vehicles.*

The reference to new type approved vehicles reflects the fact that MAFs need to be qualified for vehicle types and should not be used as a drop-in replacement for existing mass airflow sensors.

## 4.13 Exemption no. 8 a – stakeholder proposal part C (iv)

*"Lead in solder for large power semiconductor assemblies"*

### 4.13.2 Description of exemption

ACEA at el. (2009g) apply for an exemption for "Lead in solder for large (> 1cm$^2$) power semiconductor assemblies". According to the stakeholders, no technical solution is at hand. ACEA et al. (2009g) hence do not propose an expiry date, but just a review of the exemption after 2015.

The lead-containing solder is used for the soldering of Silicon chips (Si chips) of 1 cm$^2$ and more of surface area to lead frames, as shown in Figure 28.

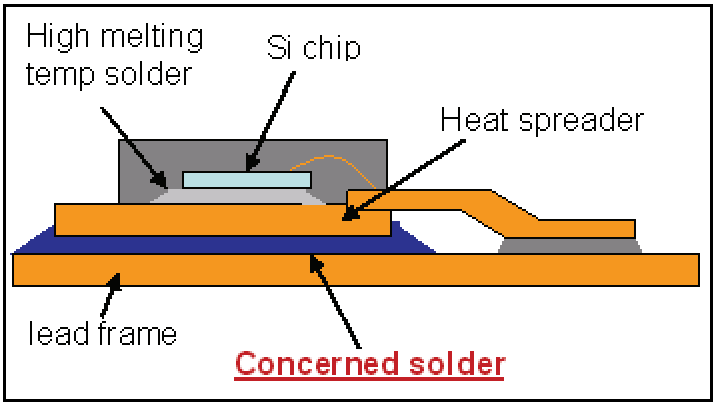



Figure 28 Example describing the requested exemption (ACEA et al. 2009g)

The design can involve an intermediate heat spreader, as illustrated in Figure 28.

The solder joints have to suffice the following requirements (ACEA et al. 2009g):

- The thermal conductivity of all components must be as high as possible and uniform over the complete chip surface, to ensure the fast flow of thermal energy from the chip to the lead frame.
- No appearance of cracks within the soldering phase
- The bond must be stable against cyclic loads

The stakeholders request that the exemption should apply to any soldering of large size power semiconductor assemblies as used in inverters (= power control units to convert AC / DC and DC / AC) (ACEA et al. 2009n). An example of such components are Insulated Gate Bipolar Transistors (IGBT). ACEA et al. (2009g) say that IGBT are silicone (Si) semiconductor chips; they are the main active component in power modules for Hybrid Electric

Vehicles (HEV) and Electric Vehicles (EV). The semiconductor chips are converters that control the electric voltage and current between battery and the electric drive motor / alternator of a vehicle.

ACEA et al. (2009n) say that inverters are used in many stationary applications, and in trains. The here described power modules are automotive–specific development with the exclusive use in HEV and EV. The stakeholders do not know any other uses of these specific units inside or outside the automotive industry.

The power modules are a new development including the specific transistor chip (e.g. IGBT) and including the way of assembly. The development focuses on operational energy efficiency, which implies to concentrate the controlled current as dense as possible in as little volume as possible (ACEA et al. 2009n).

The amounts of SnPb solder used under the requested exemption can be calculated using the example of a of current HEV power module (ACEA et al. 2009g):

- The SnPb solder contains around 50% of lead (w/w, SnPb50),
- each silicon chip requires about 0,64 g of solder, equalling to 23,2 g of SnPb solder per power module (36 chips per module, one module per car),
- each HEV or EV car thus contains around 11,6 g of pure lead,
- assuming sales of 10,000 HEV and EV cars would result in around 120 kg of lead per year.

### 4.13.3 Justification for exemption

ACEA et al. (2009g) claim that no lead-free substitutes are available that are technically sufficiently reliable. The stakeholders following sections describe the stakeholders' justification.

**Soldering process and performance of the solder joint (ACEA et al. 2009g)**

The solder between the heat spreader and the lead frame must melt at a temperature lower than the melting temperature of the solder used for the Si chip soldering (around 300°C).

Cracks and voids have a detrimental influence on the bond reliability and the heat dissipation of the soldered transistor chips. These chips, Insulated Gate Bipolar Transistor (IGBT) type components, are subjected to high currents during the operation, which result in high thermal loads. As the application, high-density power modules for HEV and EV, are newly developed, there is yet no practical experience available on the amount and magnitude of real-life load cycles, and no experience on the fatigue behaviour of the solder and the soldered components. To allow an assessment of the long-term solder stability, and conduction capacity, specific temperature cycle and power cycle tests have been designed, to determine a minimum needed resistance against high cyclic loads.

ACEA et al. (2009g) claim that the currently available lead free soldering materials, SnAgCu solder, and SnPb solder, have different physical characteristics, which are displayed in Table 16. Cracks and voids will more likely occur in the soldering phase of lead-free solders. The risk of a detriment of the in-vehicle reliability is increased. Therefore the substitution is technically yet impracticable, according to the stakeholders (2009g).

Table 16 Comparison of material parameters of eutectic SnPb and SnAg3Cu0.5 solder (ACEA et al. 2009g)

| | SnPb | SnAgCu | |
|---|---|---|---|
| Young's modulus (E) | 22 | 31 | GPa |
| Elongation | 38 | 23 | % |
| Hardness | 13 | 15 | HV |
| Melting Point | 183 | 218 | deg. |
| Solder spread (240°C) | 87 | 75 | % |

ACEA et al. (2009q) explain that the higher elongation and the lower E-modulus indicate the higher ductility of SnPb solder. It has better surface wetting properties due to the higher solder spread value. The operational conditions are characterized by sharp heat gradients, and high currents. The material properties of the SnPb solder make it more appropriate for the use in very demanding applications, where the good connection of both soldered surfaces must remain under the conditions of use (ACEA et al. 2009q). The higher ductility can better compensate the differences in thermal expansion between the bonded materials, which occur under operation conditions with sharp heat gradients.

### Crack expansion investigation

According to the stakeholders the research for lead-free alternatives has just started. The most important criterion for failure / non-failure is the tendency of a solder to withstand crack propagation under thermal stresses. Thermal stresses, with steep variations of the amplitude, result from the power cycles occurring during the normal in-duty use of the modules (ACEA et al. 2009g).

The stakeholders explain that, if cracks occur, the shape of cracks is usually sharp and straight (ACEA et al. 2009g). Greatest matter of concern is the progression of the crack under cyclic load. Figure 29 shows a solder joint being cracked due to the cyclic thermal loads. Solder material is SnAgCu solder.

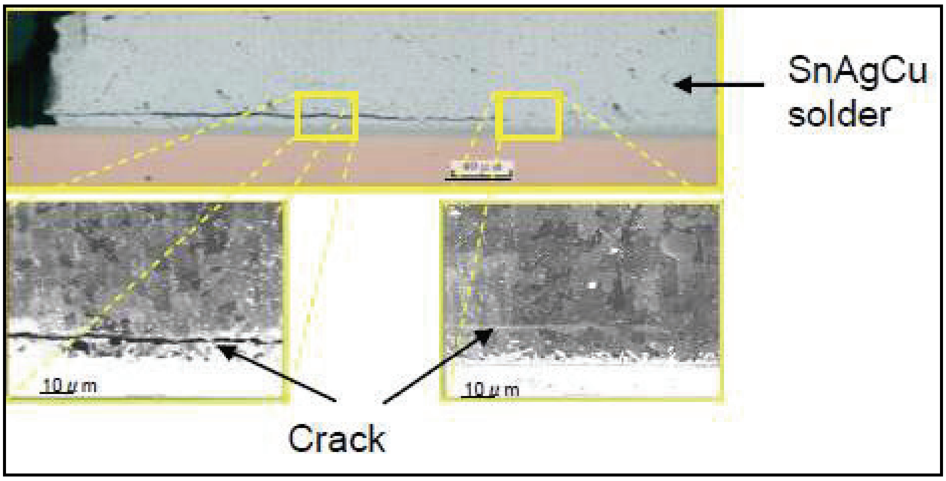



Figure 29 Crack in SnAgCu solder (ACEA et al. 2009g)

The straight crack is progressing from the outer side towards the inside. ACEA et al. (2009g) explain that the SnAgCu solder's phase structure does not prevent the expansion of the crack.

Figure 30 shows the structure an SnPb solder joint consisting two phases, Pb and Sn, and the structure of a SnAgCu solder joint (with crack).

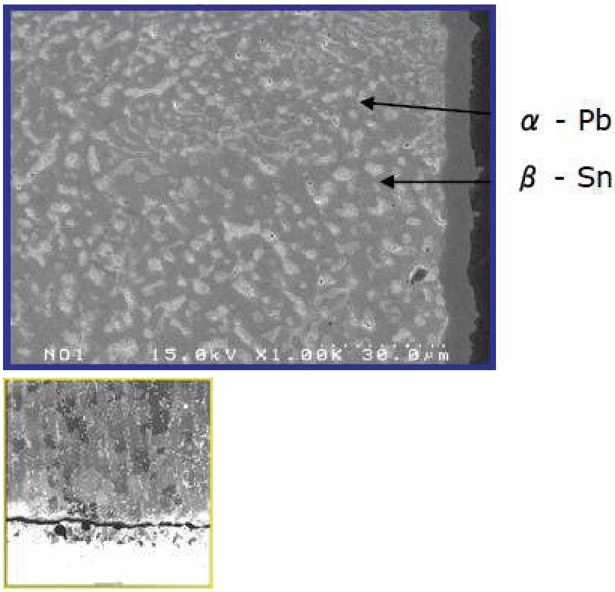



Figure 30 Phase appearance in SnPb solder (above) (ACEA et al. 2009g) and in SnAgCu solder (with crack) (ACEA et al. 2009n)

According to ACEA et al. (2009g) the SnPb solder phase structure shows more ductile properties than the one of the SnAgCu, especially considering creep fatigue. The Sn and the Pb phase coexist. The shapes of the phase boundary lines are round, like balls or globulites.

This appearance indicates a ductile behavior. The borders do not end abruptly, as in the case of SnAgCu solder Figure 29 on page 126 (ACEA et al. 2009n).

A numerical simulation of the temperature cycling test confirms the above findings. The simulations were carried out using a CAD model as shown in Figure 31. (ACEA et al. 2009g).

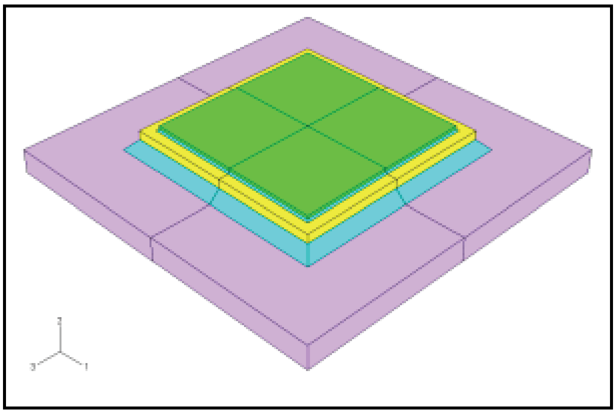


Figure 31 Model for simulation of loads in thermal cycling (ACEA et al. 2009g)

The load is assumed to be thermally induced stresses following the conditions shown in Figure 32. The cyclic load simulates the condition of high stress fatigue with long holding times (ACEA et al. 2009g).

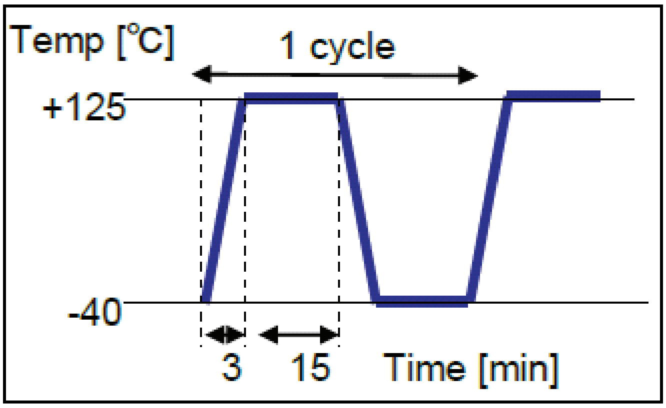



Figure 32 Temperature profile used in thermal cycling simulation (ACEA et al. 2009g). Amplitude of temperature: -40 to +125; Holding time: 15 min; Cycle time: 36 min

Failure criterion is the (simulated) crack length, the failure condition the amount of thermal cycles (ACEA et al. 2009g). Figure 33 shows the result of the numerical simulation.

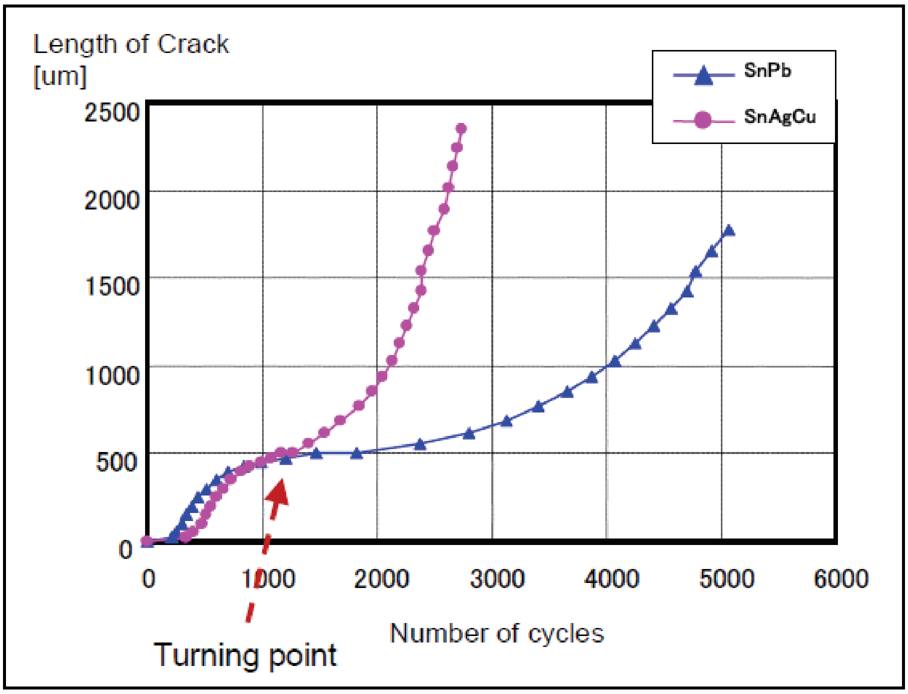



Figure 33 Result of the simulated thermal cycling test (ACEA et al. 2009g)

The result confirms the findings that the crack propagation is faster in lead-free solders.

**Voiding**

ACEA et al. (2009g) explain that the vaporization of contained materials, such as the flux, cause formation of voids. The gases cause void inclusions, if they can not evaporate from the liquid solder. The higher the liquidity of the solder material during the process, the easier the gases can be released out of the solder. The liquidity of SnPb solder at a given temperature is better than those one of the lead free SnAgCu solder. Figure 34 shows solder samples processed in a reflow oven under similar conditions (ACEA et al. 2009g).

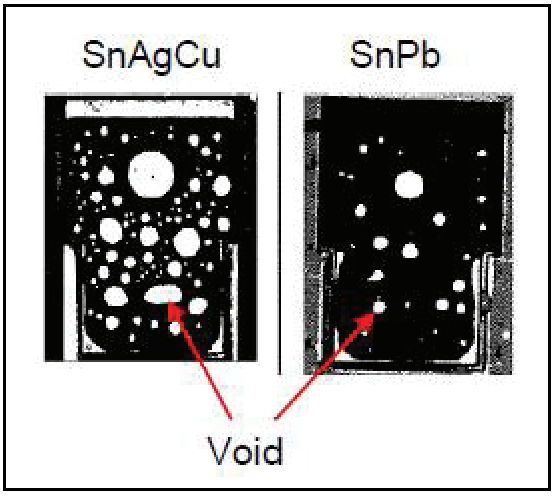



Figure 34 Forming of voids in lead-free and non-lead-free solder joints (ACEA et al. 2009g)

The picture shows more voids in the lead-free soldered solder joint.

**Voiding and failure mechanisms**

A soldered connection was exposed to a thermocycling test (TCT) of over 4 000 cycles, after which following photos were taken by Scanning Acoustic Tomography. Voids on the crack surface of lead free and lead containing solder is documented (ACEA et al. 2009g).

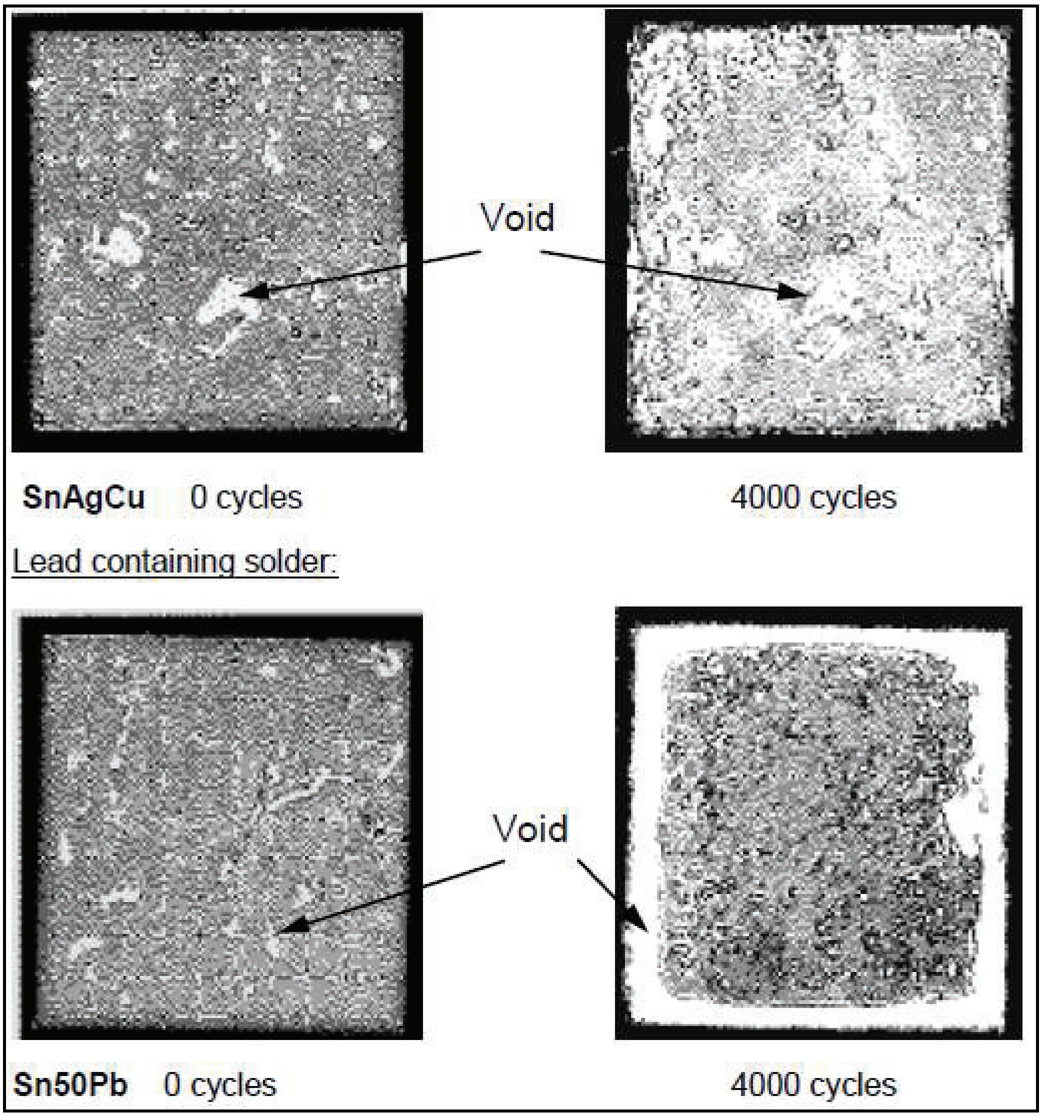



Figure 35 Voids on crack surface (ACEA et al. 2009g)

According to the ACEA et al. (2009g), the pictures show that the occurrence of cracks in SnAgCu solder and in SnPb solder is following different rules. Crack expansion in SnPb is initiated from outside the chip, which is the expected mode under thermal induced bending, where the points of highest stress are at the boundaries of the soldered areas. In the SnAgCu solder, the formation of cracks starts at the place of existing voids, which is not according to the expectations (ACEA et al. 2009n).

The stakeholders draw the conclusion that in the case of lead free solder the forming of cracks happens in an unexpected and unpredicted way. The failure mechanism is not known (ACEA et al. 2009n). Any material, solder or other, should only be introduced in mass production when the failure mode is known; with the underlying goal to calculate and avoid any damage that would cause a failure (ACEA et al. 2009n).

**Design changes facilitating the use of lead-free solders**

The stakeholders explain that the described design of power modules containing die bonded Si chips (IBGT) are a major innovative component in hybrid electric vehicles (HEV) and in electric vehicles (EV) (ACEA et al. 2009g). In those vehicles, a fast and energy-efficient control of voltage and current must be assured, with fast and abrupt changes of the current direction (to / from the battery). These vehicles must function in similar environment and with similar robustness as any other vehicle that is on the market.

ACEA et al. (2009g) say that a design change could possibly reduce or make obsolete the need for using SnPb solder. However, the described design is now just about to show its functionality in practice. Any design change should be linked to the development of a second generation of the power modules. Therefore, the change of the design is at that moment impracticable (ACEA et al. 2009g).

**Environmental arguments**

ACEA et al. (2009g) claim that HEV have the potential to realize saving of fuel compared to similar vehicles with a combustion engine only. EVs are widely recognised as the most environment friendly and future relevant means of personal road transport, as any local emission of exhaust gases becomes obsolete (ACEA et al. 2009g).

**Stakeholders' conclusions**

ACEA et al. (2009g) sum up that the solder must offer a good balance of hardness and elongation, to withstand cyclic thermal stresses. Not enough experience is yet available regarding the estimation of the life time of lead free soldered joints. The development of a suitable new solder, and the development of process condition for the production and production facilities is ongoing. The evaluations are being continued, but results are not yet promising enough to initiate a change towards lead-free solders and appropriate designs (ACEA et al. 2009g).

### 4.13.4 Critical review of data and information

**Efforts to achieve legal compliance**

ACEA et al. (2009g) state that a design change could possibly allow the replacement of lead in this application. The stakeholders were asked to provide a roadmap when these design change will be implemented. ACEA et al. (2009q) regret to not be able to provide a well developed roadmap. The stakeholders target 2015 for these design changes, but confine that upcoming difficulties during development would postpone this date (ACEA et al. 2009q).

ACEA et al. explain that that these power devices are newly developed. The stakeholders hence were asked to justify why these power modules were developed for the use of lead-containing solders and not for lead-free soldering knowing that lead has been banned in the ELV Directive.

The stakeholders explain that the power modules with semiconductors of large size (> 1cm$^2$) have been developed since 1999, with prototypes being built since 2003 (ACEA et al. 2009l).

The specialty in this design is the large size of the transistor chips, and the high density of currents. The controlled electric current is about 100 A per chip, corresponding to almost 1 A per mm$^2$ or higher. The high energy density increases the efficiency of the unit, and decreases its size and weight (ACEA et al. 2009l). The stakeholders further on put forward that SnPb solders of special composition (SnPb50) were used in the designs because of the challenges the energy density poses to the solder quality and the soldering process (ACEA et al. 2009l). The use of lead solders reduces the number of novelties in the design at the early phase. The risk of failure is therefore less than in the case of development of a new soldering process at the same time. As a result, the units will be available earlier on the market, where they will lead to positive effects on fuel consumption, according to the stakeholders (ACEA et al. 2009l). Moreover, the stakeholders explain that earlier developed modules are soldered with high melting temperature solders containing above 80% of lead. The current designs hence are already an improvement. The first attempts for lead free soldering, according to the stakeholders, were done in 2007, and are ongoing since then (ACEA et al. 2009l).

The stakeholders' approach to restrict the number of unknown factors at the beginning of the development using well-known lead solders is understandable. In the context with the fact that the development already started in 1999, it is also acceptable that lead-free solders at that time were not taken into account as highest initial development priority, the more as the lead content was reduced in later development stages from around 80% of lead down to around 50% according to the stakeholders.

In the later phase, although the ban of lead is in place since 2003, the attempts for lead-free soldering started in 2007 only. The stakeholders argue that the ELV Directive and its Annex II always have provided an unlimited exemption for solder in electronic circuit boards and other electric applications from the ban of lead (ACEA et al. 2009q). It was only from 01. August 2008, the Commission Decision 2008/689/EC introduced an expiry date (ACEA et al. 2009q). In addition, the stakeholders mention that the power semiconductor market is not necessarily depending from the automotive industry, but vice versa the activities for E-driven systems and hybrid vehicles largely depend on the availability of suitable power semiconductors and systems (ACEA et al. 2009q). If the automotive industry cannot rely on the availability of components with proven components and processes, the very successful and efficient introduced, $CO_2$ reducing, efficiency measures which were developed under the required and unlimited exemption for lead in electronics are endangered.

Exemptions are always temporary, as they are reviewed periodically. It is the manufacturers' obligation to aspire legal compliance, and to move their suppliers towards development and supply of compliant products wherever technically possible even though an exemption might still be in place. As can be seen in the review of exemption 8b (lead in solders for soldering on glass), exemptions can easily be at disposition, once a stakeholder claims to have a solution. Once a solution is available, the use of lead is no longer unavoidable and the exemption would have to be repealed to suffice the requirements for exemptions in Art. 4 (2) (b) (ii). The previously unlimited exemption for lead in solders thus is no justification for a start of lead-free developments as late as in 2007.

Although the new developments may result in environmental improvements as higher fuel efficiency, this cannot serve as a justification not to aspire compliance with the material bans in the ELV Directive. The manufacturers' legal obligation is to undertake efforts to develop and produce compliant equipment. Only if the use of the banned substances is demonstrably unavoidable, exemptions can be justified.

The stakeholders further on justify the 2007 starting date for lead-free soldering development that they concentrated their lead-free attempts on the components with the highest lead content (ACEA et al. 2009q). Automotive power electronic of the size in question is relatively new and got increased importance in the last years in relation with new fuel saving concepts (e.g. "hybridization", and other novel systems, etc.). Before that, there were single niche applications for power electronics in some vehicles only (ACEA et al. 2009q).

Unless the legislators lift the ban of lead in general or for specific exemptions permanently, the stakeholders will have to prove in the next review round that they have undertaken steps to achieve compliance with the material bans in the ELV Directive.

**Melting point of the solder and voiding**

The stakeholders justify their exemption request that the solder melting point must be lower than the melting temperature of the solder used for the Si chip soldering (around 300 °C). This, however, can be achieved with lead-free solders as well, as the stakeholder themselves indicate in Table 16 on page 125. The melting point of most lead-free solders is between around 210 and 230°C.

The stakeholders agree that the melting point is not a justification for the exemption, but explain that their exemption request is based on the other described material properties of lead-free solders (ACEA et al. 2009n).

Higher occurrence of voiding in lead-free soldering is a well-known phenomenon which can be tackled with adapted solder profiles like peak temperatures, time at peak, cooling rates, optimization of the flux, etc. The stakeholders, however, put forward in their example in

Figure 34 on page 129, that the soldering conditions were similar. What would be necessary for a viable comparison are soldering conditions optimized for the soldered product and the applied solders. The effect might then at least be reduced.

ACEA et al. (2009n) agree to this, but put forward that under any, and even as optimal as possible conditions, there are always more voids been formed with lead free solder than in eutectic SnPb solder. This comes mainly from the higher viscosity of the former in comparison to the very low viscosity of the latter. The optimal solder stays at low viscosity and high liquidity over a long time during the cooling, so that the gases can escape the solder before being entrapped (ACEA et al. 2009n).

Given the additional constraint that cracks have been observed to form at the voids in the large power semiconductor chips, the stakeholders' explanation is a plausible reason to assume that the voiding in lead-free solders is an additional reliability problem.

**Confinement of the exemption**

From the information available, and in the absence of contrary information, it is recommended to grant this exemption. The exemption needs further clarification in its scope and wording, however.

The stakeholders propose the following exemption wording:

*Lead in solder for large (> 1cm$^2$) power semiconductor assemblies.*

The stakeholders explain that the main reasons for selecting lead-containing solders for this new development was the were the steep profile temperature changes as consequence of the high current densities to be processed, in combination with the large area of the heat spreader to be soldered. The exemption in the currently proposed wording could, however, be used for applications as well, where the high current density criteria does not apply. Further on, the proposed wording scopes power semiconductors, without giving an exact definition of the "power" that makes the semiconductor a power semiconductor in the sense of the exemption. To avoid abuse and uncertainties, the exemption is therefore limited to nominal current densities of 1 A/mm$^2$. The stakeholders agreed to this confinement (ACEA et al. 2009n).

From the explanation the stakeholders provided for the construction of the power semiconductors, the lead solder is used for soldering the heat spreader carrying the power semiconductor to the lead frame:

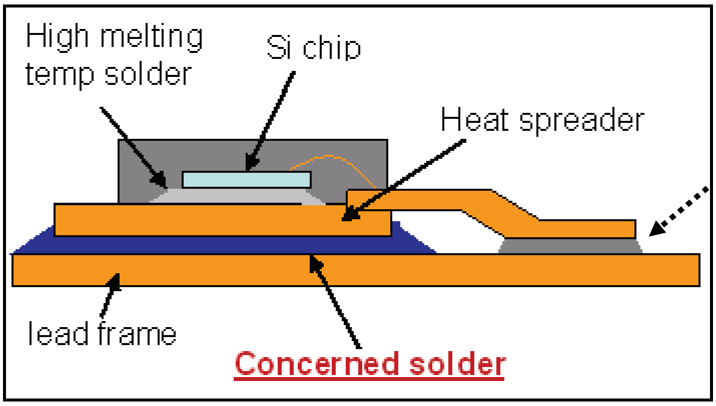



Figure 36 Use of lead solder in requested exemption (ACEA et al. 2009g)

The stakeholders' wording proposal "Lead in solder for large (>1cm²) power semiconductor assemblies" does not take this into account and would, e. g., also allow the use of lead solder in other locations, e. g. the one indicated with the dashed line arrow in Figure 36, or where the high melting point solders with 85% and more of lead content are used in the above figure.

*"Lead frame" reference*

The "lead frame" in Figure 36 was discussed with the stakeholders, too. "Lead frame" is too specific, as heat spreaders may also be soldered to printed wiring boards, which would be different from soldering to a "lead frame". It was decided that "heat sink" is the better term, as this comprises soldering the heat spreader to a lead frame as well as to a printed wiring board or other substrate materials.

*Clarification of size reference*

It is further on not clear what the 1 cm$^2$ in the wording is referring to. According to the stakeholders' submitted exemption request, it should refer to the size of the semiconductor chip (Si chip in Figure 36) (ACEA et al. 2009g). According to other information , the 1 cm$^2$ area should refer to the solder area size (ACEA et al. 2009n). The solder area, however, is not a clear reference, as this might be the area covered by the solder joint on the lead frame in the above figure or the area on the bottom of the heat spreader. These areas are different, as due to the gravity, the solder joint covers a larger area on the heat spreader than on the semiconductor. *The projection area of the chip is therefore recommended as an unequivocal reference for the size of at least 1 cm².*

*Limitation to HEV and EV*

The stakeholders had explained that these power semiconductor assemblies were specifically developed for use in hybrid electrical vehicles and in electrical vehicles. It was therefore discussed with the stakeholders whether the exemption could be limited to hybrid electrical and electrical vehicles. The stakeholders say that power semiconductors are essential components also in other vehicles, such as in start-stop systems or power electric peripheral equipment (ACEA et al. 2009q). A restriction of the exemption to specific vehicles thus is not adequate.

*Wording of the confined exemption*

Other exemptions, like the proposed exemption C (v), describe a similarly complex construction (see section 4.14 on page 137). This exemption is taken over from the RoHS Directive, where other, similarly or even more complex exemptions (e. g. exemption 15 of the RoHS Directive) give detailed guidance on where the exempted lead solder may be used.

Following these examples, the reviewers recommend the following wording:

*Lead in solder to attach heat spreaders to the heat sink in power semiconductor assemblies with a chip size of at least 1 cm² of projection area and a nominal current density of at least 1 A/mm² of silicon chip area.*

### 4.13.5 Final recommendation exemption 8 C (iv)

It is recommended to grant the exemption. According to the information submitted, there are currently no sufficiently reliable lead-free alternatives available. Art. 4 (2) (b) (ii) thus would justify an exemption. As the stakeholders indicate that lead-free solutions may be available in 2015, it is recommended to review the exemption in 2014 and to adapt it to the scientific and technical progress.

The proposed wording is:

> *Lead in solder to attach heat spreaders to the heat sink in power semiconductor assemblies with a chip size of at least 1 cm² of projection area and a nominal current density of at least 1 A/mm² of silicon chip area; review in 2014.*

## 4.14 Exemption no. 8a – stakeholder proposal part C (v)

*“Lead in solders for electrical connection between semiconductor die and carrier within integrated circuit Flip Chip packages”*

This exemption is currently listed as exemption no. 15 in the Annex of the RoHS Directive. It has been reviewed during the 2008/2009 review of the RoHS Annex. It was recommended to be continued until 2014 with the following wording (Gensch et al. 2009):

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

Flip chip packages under this exemption are used in EES in vehicles as well. Texas Instruments provides some examples (Texas Instruments 2009):

- electronic stability control systems;
- advanced emergency braking systems;
- distance control;
- lane departure warning systems;
- frontal projection systems;
- pedestrian protection
  tire pressure monitoring systems to reduce rolling resistance and noise emissions;
- hydrogen and hybrid cars;
- car radio;
- vision systems;
- car-infotainment;
- traffic sign recognition;
- navigation;
- telematics;
- head-up displays.

The exemption was thoroughly assessed and reviewed during the RoHS Annex review in 2008 and 2009. For details see page 175 ff in the Final Review Report (Gensch et al. 2009). The stakeholders submitted the same information for this review of exemption 8a in the ELV Directive like for the previous review of the RoHS Annex (ESIA 2009).

There is no new evidence that the use of lead in this technology could be avoidable. As flip chip packages are used in EES in vehicles as well, the exemption is recommended to be transferred to Annex II of the ELV Directive. There is no reason to assume that, contrary to applications in RoHS equipment, lead could be avoided in automotive EES in this flip chip technology. Art. 4 (2) (b) (ii) therefore would justify an exemption.

It is recommended to grant the requested exemption with the same wording as in the Annex of the RoHS Directive:

> *Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages; review in 2014.*

The review date in 2014 is recommended to enable a parallel assessment of the exemption in the ELV and the RoHS Directive in order to maintain the congruence of the exemption as far as possible.

## 4.15 Exemption no. 8a – stakeholder proposal part D

*"Lead in terminals of Aluminium-Capacitors (Electrolyte Capacitors)"*

The stakeholders had proposed part D of exemption 8 for "Lead in terminals of aluminium capacitors (electrolyte capacitors)" with expiry in 2016 for new type approved vehicles (ACEA et al. 2009b).

### 4.15.2 Description of exemption

The standard use of Aluminium Capacitors is buffering and stabilising of the supply voltage from the vehicles board net. Also they are required to filter the electromagnetic "noise" on the ECU input terminals. Their high capacity and reliability is also needed in high power applications to reduce the outgoing power peaks from the ECU to avoid negative impact on other automotive electronic systems (ACEA et al. 2009b).

In airbag ECU and sensors, aluminium-capacitors (electrolyte capacitors) are used as energy buffer to assure functionality (Airbag deployment) even during an accident when battery and generator are already destroyed. Energy buffering is also needed to provide the short high power pulses for electromagnetic valves as required in fuel saving gasoline and diesel common rail systems (ACEA et al. 2009b).

All Al-capacitors need to be soldered to electronic circuit boards. Therefore the terminals of the component must have a solderable surface. As the inner structure of the Aluminium capacitor is required to be solely of aluminium, an interface between the solderable terminal and the aluminium (paddle-tab) is required. As industry standard this joint is done by welding (ACEA et al. 2009b).

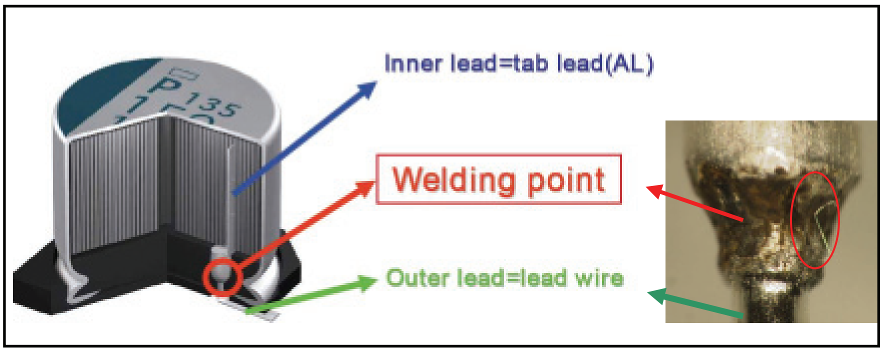



Figure 37 Position of welding joint on SMD AL-Capacitor (ACEA et al. 2009b)

Please note that "lead" in the above figure does not refer to the chemical element Pb, but describes the wire as outer terminal to the component.

In consumer electronics, the solderable terminals (outer lead wire) have a pure Sn surface as standard. At the described inner interface (welding point), terminals with pure Sn surface show increased numbers (Factor 10) and size (up to 800 µm observed) of tin whiskers compared to surface finishes containing lead. It was proven that under vehicle-typical vibration those whiskers can brake off. Free whiskers can lead to shortages at unpredictable positions in the circuit (ACEA et al. 2009b).

Table 17 Calculation of total amount of lead used under the requested exemption (ACEA et al. 2009b)

| Estimation of lead content in Al Capacitors | | |
|---|---|---|
| | typical values | |
| Thickness of SnPb layer | 7 | µm |
| Wire diameter | 0,8 | mm |
| Wire length | 10 | mm |
| Average Pb concentration in terminal finish | 20% | |
| specific weight | 1134 | kg/m³ |
| Mass/Capacitor (2wires) | 80 | µg / Elko |
| Capacitor/ECU | 6 | Elkos |
| ECU w Capacitor/Vehicle | 20 | ECU |
| Vehicles in EU | 16 | Mill vehicles |
| Al Caps | 1,9 | bn |
| **Lead from Al Caps / y** | **0,15** | **t/y** |

The total use of lead in the requested exemption would be around 150 kg per year, according to the stakeholders' estimates (ACEA et al. 2009b).

### 4.15.3 Justification for exemption

**Whisker growth on lead free tin surfaces**

According to the stakeholder, there is currently no workable and reliable alternative to the lead in terminals of Aluminium-Capacitors known for automotive applications. It is therefore necessary to apply for a timely limited exemption for Lead in terminals of Aluminium-Capacitors (ACEA et al. 2009b).

**Pure Sn surface finishes** of terminals (paddle tabs) lead to high whisker growth on the Al/Sn welding point with high risk of shortages due to migrating whiskers in the electronic system, as can be seen in Figure 38 and Figure 39.

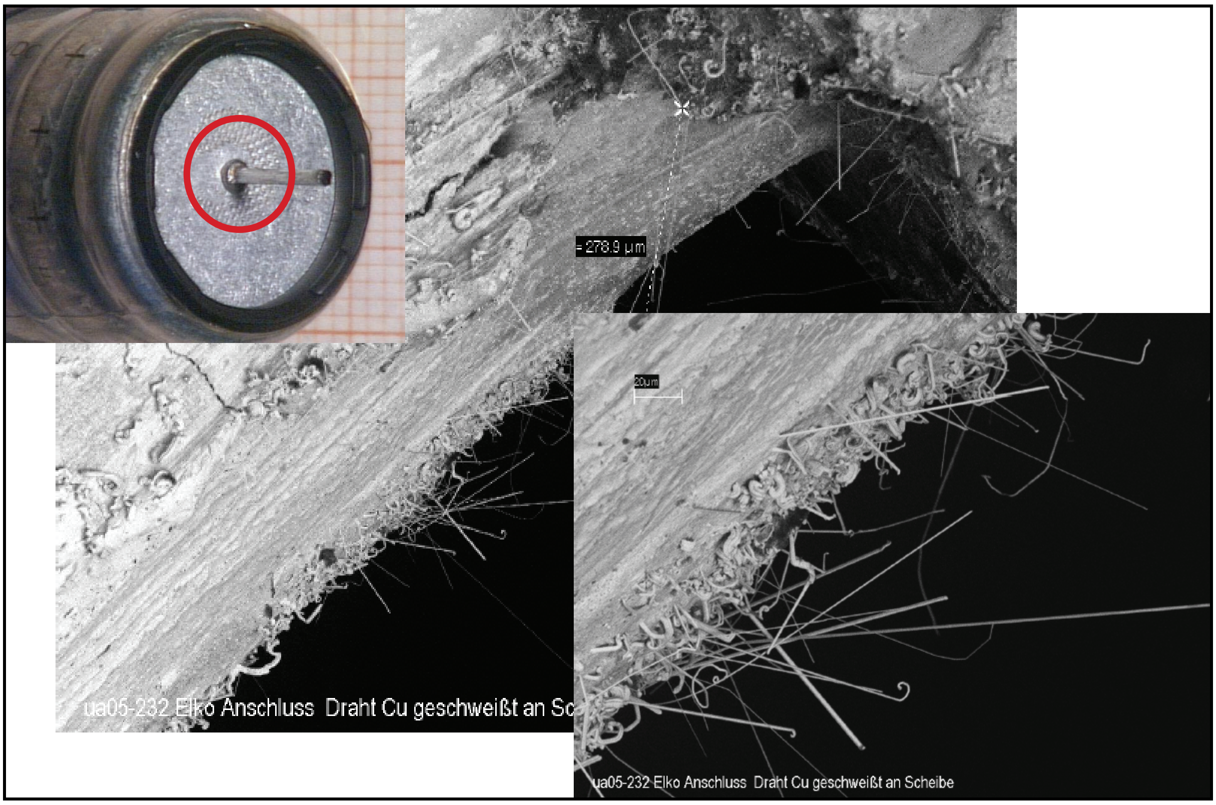
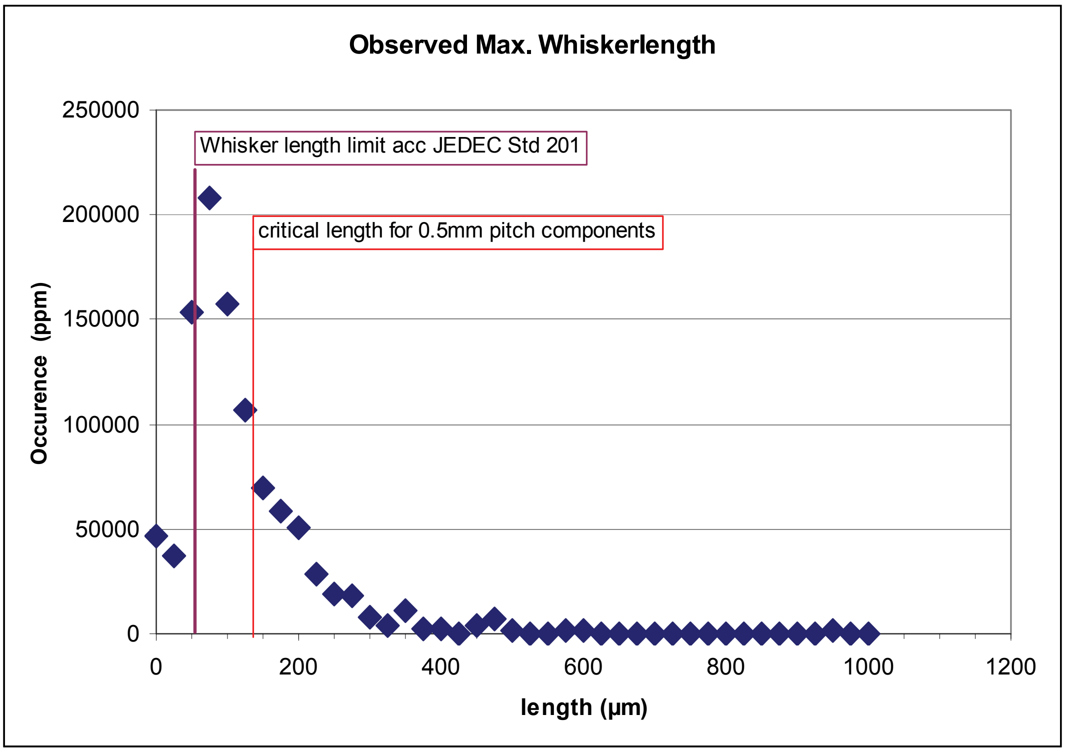



Figure 38 Whiskers on welding joint of pure Tin coated Al-Capacitor terminal (ACEA et al. 2009b)



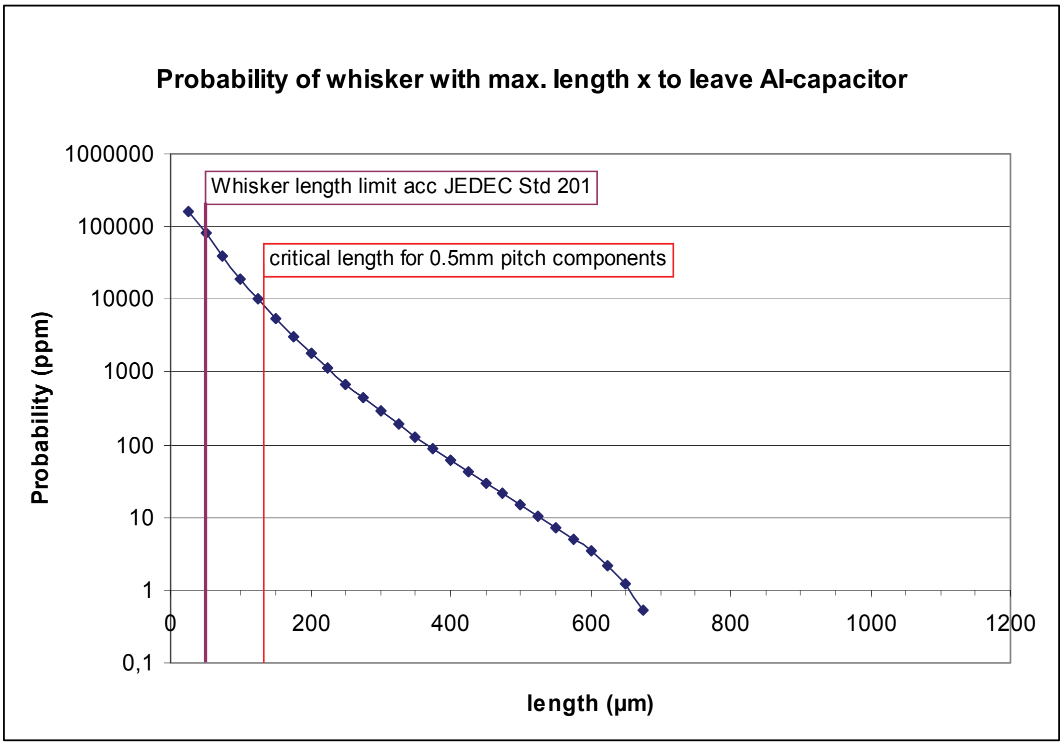




Figure 39 Observed whisker length distribution and level of whisker diffusion out of unprotected Al-Caps with pure tin finishes is unacceptable with regard to automotive quality demands.

The stakeholders explain that the level of whisker diffusion out of unprotected Al-Caps with pure tin finishes is unacceptable for automotive quality demands (ACEA et al. 2009b).

**Alternatives to avoid whiskers**

Other metals or metal systems in surface finish or terminal wire like bismuth replacing lead or nickel a nickel diffusion barrier were tested, but did not eliminate the whiskers, according to the stakeholders, according to the stakeholders (ACEA et al. 2009b). Other capacitor types can not replace all Al-Caps as they are limited in capacity (up to 15000µF required) and electrical parameters like low ohmic switch pulses. Accumulators are no alternative due to the high number of required charge/discharge cycles over the vehicles 15years lifetime. Additionally their electrical parameters are not suitable for Al-Capacitors applications (ACEA et al. 2009b).

The stakeholders further on point out that there are some welding alternatives that could reduce the content of tin and increase the content of copper at the welding area in order to reduce or avoid the growth of whiskers (ACEA et al. 2009b). There were preliminary some good results, but the process control is very complex and the stability of the process need to be deeply investigated (ACEA et al. 2009b).

The stakeholders say that the inclusion of the whisker by glue, additional parts or housing changes is promising, according to the stakeholders (ACEA et al. 2009b). Several solutions of this kind are under investigation. Stress by vibration or temperature on joints may lead to electrical / mechanical failure of connections or leakages of electrolyte with following electrochemical corrosion of the printed wiring board. Extensive testing is running (ACEA et al. 2009b).

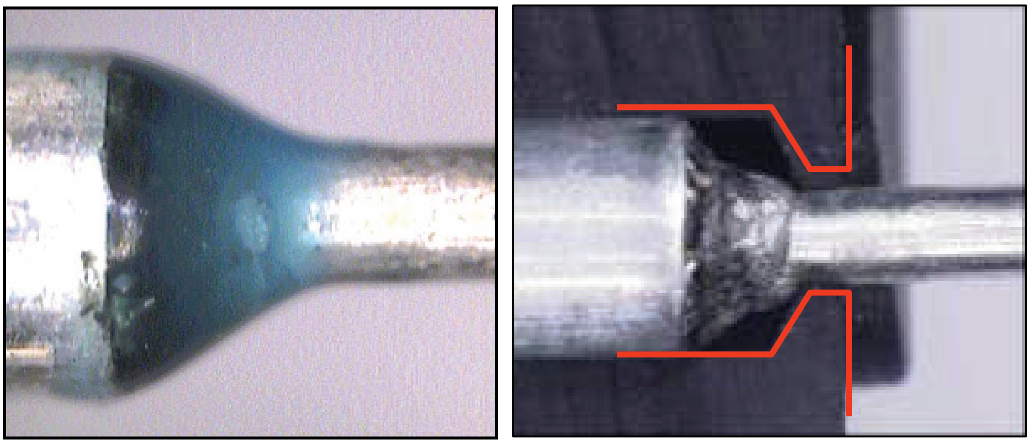


Figure 40 Coating with epoxy resin (left) or enclosing of the welding joint (ACEA et al. 2009b)

Epoxy and UV resins works well regarding the whisker mitigation, but increase the height at the welding nugget, which leads to technical problems. Also with UV and epoxy resins, cracks might occur in thermal cycling, which could theoretical create a passage for whiskers. There are other types of resins that would not create cracks, but increase dramatically the cure time, thus leading to higher process cost (ACEA et al. 2009b).

Any resin solution might lead to a redesign of an electronic board. To avoid a damage of the resin it is necessary to bend the wire at reasonable distance from the resin margin, which influences the position of the connecting points at an equipped board.

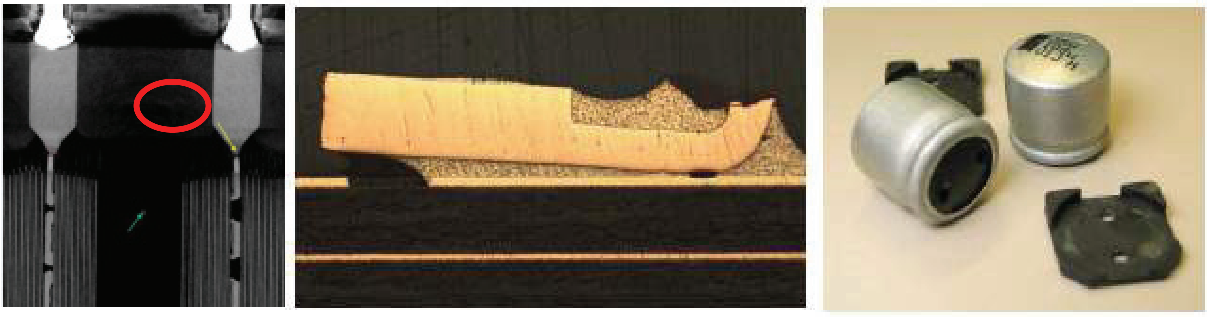


Figure 41 Examples of mechanically failed Al-Capacitor terminals (ACEA et al. 2009b)

A plastic element covering the welding works well in principle, but is not a reliable solution, as the necessary accuracy of the positioning of plastic elements is difficult to achieve (ACEA et al. 2009b).

Producers of automobiles are responsible to ensure that the use of their products is safe and comfortable for citizens worldwide. A failure in electronics may endanger life and health of the driver. In this case, the risk is a short cut due to whiskers which might lead to serious malfunction of the device, e.g. by wrong sensor signals due to the short cut or even a failure of the whole device (ACEA et al. 2009b). The stakeholders describe some possible consequences of such shortages from migrating whiskers in Electronic Control Units (ACEA et al. 2009b).

*Airbag*

Shortage may lead controlled shutdown of ECU with warning (control-light) to the driver. As in this case, the airbag will not deploy and in the case of an accident, life and health risk of passengers is increased severely (ACEA et al. 2009b).

*Motronic, TCU*

Shortages may lead to a controlled shutdown of the ECU with warning (control-light) to the driver. The vehicle will go into fail-safe mode (limb-home with reduced speed and functionality) (ACEA et al. 2009b).

*ABS, ESP, Gear Rate Sensors*

A shortage may lead controlled shutdown of ECU with warning (control-light) to the driver. The vehicle will go into fail-safe mode (fall back to standard brake functionality). Hard braking can lead to uncontrolled skidding of car as known for cars without ABS System (ACEA et al. 2009b).

*Body Controller*

Shortage may lead to controlled shutdown of ECU with warning (control-light) to driver. Stopping wipers during rain could be safety risk, at least hinder driver to continue driving. Failure to open or close windows / sunroofs would reduce comfort drastically (ACEA et al. 2009b).

*Lighting*

Shortage may lead controlled shutdown of ECU with warning (control-light) to driver. Unexpected shut off of lights (front-, rear-, indicator- or breaking-lights) could be a safety risk, at least hinder driver to continue driving (ACEA et al. 2009b).

*Electric Steering*

Shortage may lead controlled shutdown of ECU with warning (control-light) to driver. Vehicle will go into fail-safe mode (limb-home with reduced speed and functionality) and mechanical steering. Steering forces will increase (ACEA et al. 2009b).

The stakeholders say that solutions technically will be available until 2010 on component level. It is very unlikely that a suitable component portfolio will be available before (ACEA et al. 2009b). Different housing types (SMD, radial, axial) need to be validated. Besides development and testing, also the production equipment needs to be changed respective added.

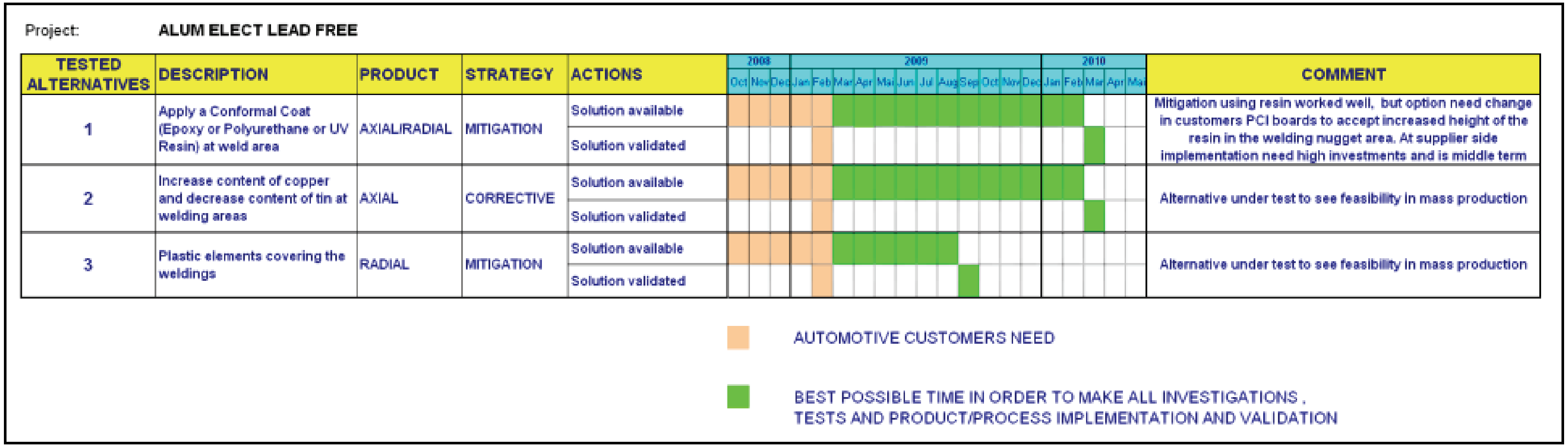



Figure 42 Development timeline for lead-free electrolytic aluminium capacitors (ACEA et al. 2009b)

The validation on system and vehicle level will need additional time according to standard testing procedures of automotive electronics and vehicles.

### 4.15.4 Critical review of data and information

The stakeholders plausibly explain the whisker phenomenon in aluminium electrolytic capacitors. Lead-free alternatives are under development and will be available until end of 2010. The components will have to be qualified in the subsequent supply chain levels for the use in vehicles. After a discussion to clarify the further qualification steps, the stakeholders agreed to set an earlier expiry date for this exemption at end of 2012 instead of 2015.

### 4.15.5 Final recommendation exemption 8 D

It is recommended to grant the exemption. Currently, reliable lead-free alternatives are not available, and Art. 4 (2) (b) (ii) would thus justify an exemption. As lead-free aluminium capacitors will be produced and qualified until end of 2012, it is recommended to set the expiry date for end of 2012.

The reviewers' recommend the following wording for the exemption:

*Lead in terminals of electrolyte aluminium capacitors in vehicles type approved before 1 January 2013, and in spare parts for these vehicles.*

## 4.16 Summary exemption no. 8 a

The table below gives the synopsis of the exemptions as proposed by the stakeholders and the reviewers' recommendations.

Table 18 Exemptions as proposed by the stakeholders and reviewers' recommendations

| | **Stakeholder Proposal** | **Scope/expiry date as proposed by stakeholders** | **Reviewers' recommendations** |
|---|---|---|---|
| A | Lead in solders to attach electrical and electronic components to electronic circuit boards and lead in finishes on component terminations, on component pins and on printed wiring boards | Vehicles type approved before 31 December 2015 and spare parts for these vehicles | Grant |
| B | Lead in solder of carry over electric/electronic parts or systems first used in vehicles type approved before 31 December 2010 | | Do not grant |
| B new | *Lead in solders in other applications than soldering on printed wiring boards and on glass* | *Vehicles type approved before 1 January 2011* | Grant; transition time needed to lead-free soldering, originally intended to be covered by proposed part B (carry over) of exemption 8a |

| | Stakeholder Proposal | Scope/expiry date as proposed by stakeholders | Reviewers' recommendations |
|---|---|---|---|
| C | Solder in other electric/ electronic applications except on glazing | Review after 2015 | |
| i) | • Lead in high melting temperature solder i.e. lead based solder alloys containing above 80% by weight of lead. | | Grant; review together with exemption 7a in current Annex of RoHS Directive (2013) |
| ii) | • Lead used in compliant pin connector systems | | Grant; review in 2014 |
| iii) | • Lead used in soldering on glass for non glazing application | | Grant, but restrict to air mass flow sensors; expiry end of 2014 for new type approved vehicles |
| iv) | • Lead in solder for large (>1cm²) power semiconductor assemblies | | Grant, but with new wording; review in 2014 |
| v) | • Lead in solders for electrical connection between semiconductor die and carrier within integrated circuit Flip Chip packages. | | Grant; review 2014 together with equivalent exemption 15 in Annex of RoHS Directive |
| D | Lead in terminals of Aluminium-Capacitors (Electrolyte Capacitors). | Vehicles type approved before 31 December 2015 and spare parts for these vehicles | Grant; expiry end of 2012 for new type approved vehicles |

### 4.16.1 Recommendation

Table 19 shows the reviewers' recommendations resulting from the synopsis of the above review results of the single exemptions.

Table 19 Overview on recommended successor exemptions for current exemption 8a

| | Exemption | Scope and expiry date of the exemption | Reviewers' comments |
|---|---|---|---|
| *I* | *Lead in solders to attach electrical and electronic components to electronic circuit boards and lead in finishes on terminations of components others than electrolyte aluminium capacitors, on component pins and on printed wiring boards* | *Vehicles type approved before 1 January 2016, and spare parts for these vehicles* | |
| II | *Lead in solders in other electrical applications than soldering on printed wiring boards or on glass* | *Vehicles type approved before 1 January 2011* | Transition time to lead-free soldering, originally intended to be covered by proposed part B (carry over) of exemption 8a |
| *III* | *Lead in finishes on terminals of electrolyte aluminium capacitors in vehicles type approved before 1 January 2013* | | |

| | Exemption | Scope and expiry date of the exemption | Reviewers' comments |
|---|---|---|---|
| *IV* | *Lead used in soldering on glass in mass airflow sensors* | *Vehicles type approved before 1 January 2015, and spare parts of such vehicles* | |
| *V* | *Lead in high melting temperature type solders (i.e. lead-based alloys containing 85% by weight or more lead)* | *Review in 2013* | *Review together with equivalent exemption 7a in RoHS Directive (see final report (Gensch et al. 2009); align with this expiry date* |
| *VI* | *Lead in compliant pin connector systems* | *Review in 2014* | |
| *VII* | *Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages* | *Review in 2014* | *Review together with equivalent exemption 15 of RoHS Directive* |
| *VIII* | *Lead in solder to attach heat spreaders to the heat sink in power semiconductor assemblies with a chip size of at least 1 cm² of projection area and a nominal current density of at least 1 A/mm$^2$ of silicon chip area* | *Review in 2014* | |

### 4.16.2 References Exemption 8 a


ACEA et al. 2009a — ACEA, JAMA, KAMA, CLEPA et al.; stakeholder document "Wording Proposal Overview_Annex_II_Lead_in_solder-final.pdf", submitted during online stakeholder consultation

ACEA et al. 2009b — ACEA, JAMA, KAMA, CLEPA et al.; stakeholder document "ELV Al_Elkos-final.pdf", submitted during online stakeholder consultation

ACEA et al. 2009c — ACEA, JAMA, KAMA, CLEPA et al.; stakeholder document "Specific_questionnaire_8a_Automotive_Industry.pdf", submitted during online stakeholder consultation

ACEA et al. 2009d — ACEA, JAMA, KAMA, CLEPA et al.; stakeholder document "Solder_on_Glass_non-glazing.pdf", submitted during online stakeholder consultation

ACEA et al. 2009e — ACEA, JAMA, KAMA, CLEPA et al.; stakeholder document "Lead in HMT Solder.pdf", submitted during online stakeholder consultation

ACEA et al. 2009f — ACEA, JAMA, KAMA, CLEPA et al.; stakeholder document "ELV Press-Fits final.pdf", submitted during online stakeholder consultation

ACEA et al. 2009g — ACEA, JAMA, KAMA, CLEPA et al.; stakeholder document "ELV large_power semicons-final.pdf", submitted during online stakeholder consultation

ACEA et al. 2009h ACEA, JAMA, KAMA, CLEPA et al.; stakeholder document "ELV Electronic circuit board_final.pdf", submitted during online stakeholder consultation

ACEA et al. 2009i ACEA, JAMA, KAMA, CLEPA et al.; stakeholder document "ELV Carry over electronics- final.pdf", submitted during online stakeholder consultation

ACEA et al. 2009j ACEA, JAMA, KAMA, CLEPA et al.; "automotive_industry_introduction_letter.pdf", submitted during online stakeholder consultation

ACEA et al. 2009k ACEA, JAMA, KAMA, CLEPA et al.; stakeholder document "2009-03-30-Answers_Exemption_8a.doc", submitted 30 March 2009

ACEA et al. 2009l ACEA et al.; Stakeholder document "2009-03-30-Answers_Exemption _8a.doc" submitted by ACEA et al.; additional questions to stakeholders sent out 17 March 2009, answer received via e-mail on 30 March 2009

ACEA et al. 2009m ACEA et al.; Stakeholder document "2009-04-08-Answers_Exemption _8a.doc" submitted by ACEA et al.; additional questions to stakeholders sent out 1 April 2009, answer received via e-mail on 8 April 2009

ACEA et al. 2009n ACEA et al.; Stakeholder document "2009-05-20-Answers_Exemption _8a.doc", additional questions to stakeholders sent out May 13, answer received via E-Mail from Mr. Harald Schenk on 20 May 2009

ACEA et al. 2009o ACEA et al.; E-mail sent to Otmar Deubzer on 27 May 2009 by Mr. Uwe Lipphard, as answer to questions sent to ACEA et al. on 22 May 2009

ACEA et al. 2009p ACEA et al.; Stakeholder document „Questions_4_Carry_Over _090605_final.doc", additional questions to stakeholders sent out 29 May 2009, answer received via E-Mail from Mr. Uwe Lipphard, Bosch, on 5 June 2009

ACEA et al. 2009q ACEA et al.; Stakeholder document „Questions_4_large_power_IC_090605_final.doc", additional questions to stakeholders sent out 2 June 2009, answer received via E-Mail from Mr. Uwe Lipphard, Bosch, on 5 June 2009

ESIA 2009 ESIA; Stakeholder document "ESIA_Flip-Chip.pdf", submitted during the online stakeholder consultation

Gensch et al. 2009 Gensch et al., Öko-Institut Freiburg; Deubzer, O., Fraunhofer IZM; Adaptation to scientific and technical progress under Directive 2002/95/EC, Final Report, February 2009

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|---|---|
| Kadesch 2001 | Kadesch, J., Orbital Sciences Corporation/NASA, et al.; The Continuing Dangers of Tin Whiskers and Attempts to Control Them with Conformal Coating, download from http://nepp.nasa.gov/whisker/reference/tech_papers/kadesch2001-articledangers-of-tin-whiskers-and-conformal-coat-study.pdf |
| Öko-Institut 2006 | Öko-Institut Freiburg, Fraunhofer IZM: Adaptation to the Scientific and Technical Progress of Directive 2002/95/EC (RoHS Directive); final report July 2006, download from http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf |
| Öko-Institut 2008 | Adaptation to Scientific and Technical Progress of Annex II Directive 2000/53/EC, final report from January 2008, Öko-Institut e.V., Fraunhofer IZM; download from http://circa.europa.eu/Public/irc/env/elv/library?l=/stakeholder_consultation/evaluation_procedure/reports/final_report/report_revision/_EN_1.0_&a=d |
| ON Semiconductor 2009 | ON Semiconductor: "ON-Semiconductor.pdf", submitted during the online stakeholder consultation |
| Schenk 2009 | Schenk, Harald, ACEA: information sent by e-mail to Otmar Deubzer, Fraunhofer IZM, on 15 June 2009 |
| SMMT 2009 | SMMT: Stakeholder document "Motor-Industry.pdf", submitted during the online stakeholder consultation |
| Swatch 2009 | Swatch exemption request, download from http://circa.europa.eu/Public/irc/env/dir_2002_95/library?l=/requests_exempions/resonator_electronics&vm=detailed&sb=Title |
| Texas Instruments 2009 | Texas Instruments: Stakeholder document "Letter Texas Instruments Pichl.pdf", submitted during the online stakeholder consultation |
| Umicore 2009 | Umicore: Stakeholder document "Umicore_exemption_8a.pdf", submitted during the online stakeholder consultation |
| Warburg 2009a | Warburg, N., Continental, on behalf of ACEA et al.; stakeholder document "Gold as substitute.doc", submitted via e-mail to Otmar Deubzer, Fraunhofer IZM, on 10 June 2009 |
| Warburg 2009b | Warburg, N., Continental.; information sent by e-mail to Otmar Deubzer, Fraunhofer IZM, on 9 June 2009 |

## 4.17 Exemption no. 8b

*“Lead in solder in electrical applications on glass”*

The recommendations given here have already been published in September 2009 (http://circa.europa.eu/Public/irc/env/elv_4/library?l=/reports/099016_finalpdf/_EN_1.0_&a=d). Following these recommendations on adaptation of exemption 8, the Commission has adopted the fourth revision of Annex II to Directive 2000/53/EC. The amended Annex II has been published in the EU's Official Journal (Commission Decision 2010/115/EU of 23 February 2010; (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32010D0115:EN:NOT).

The wording of the current wording of exemption 8 b is:

*Solder in electrical applications on glass in vehicles type approved before 31 December 2010 and spare parts for these vehicles.*

The exemption is due for review in 2009 and hence must be adapted to the scientific and technical progress.

### 4.17.2 Background

Exemption 8 b was evaluated during the last revision of Annex II of the ELV Directive in 2007/2008 (Öko-Institut 2008). A stakeholder, Antaya, in 2007 had applied for repealing the exemption as they claimed to have a viable solution to substitute the lead-containing solders for soldering on glass. Glass makers and vehicle manufacturers opposed Antaya’s arguments and views.

During the review process, the available stakeholder comments did not give a base for a clear recommendation. The reviewers hence recommended continuing the exemption, but to review it in 2009. The Commission set an expiry date in December 2011 for new type approved vehicles with a review in 2009 (Joint stakeholder working group 2009).

During the last review, the stakeholders – Antaya, glass makers, vehicle manufacturers – wanted to agree on a test program to find out whether Antaya’s indium-based lead-free solders can be a substitute to the degree to makes the use of lead in soldering on glass avoidable.

The stakeholders set up a joint working group in April 2008 for this purpose. The group was open to all vehicle manufacturers and glass makers. The glass makers, the vehicle manufacturers, and Antaya, designated Otmar Deubzer to moderate and to coordinate the discussions and the activities of the group. Otmar Deubzer on the one hand already knew the technical background and the stakeholders’ arguments and positions, and on the other hand as employee of a scientific institute was seen to be in a neutral position.

After several meetings, phone conferences and discussions, the stakeholders agreed upon a test program and started conducting tests in March 2009. The results have become available in April and May 2009.

### 4.17.3 Description of exemption

The exemption was described in detail during the last adaptation of Annex II of the ELV Directive to the scientific and technical progress in 2007/2008 (Öko-Institut 2008). For details on the technical background refer to this report.

### 4.17.4 Justification for exemption

**Justification for the postponement of the expiry date in the current exemption 8 b by ACEA et al.**

ACEA et al. (2009) put forward that most lead free solders are known to be unsuitable for soldering electrical connectors to printed automotive glass products. The main reason for this is that lead is very good at equalising the thermal expansion differences between the metallic connectors used for these products and the base glass used for the product. These physical differences between the two components are very difficult to overcome. Use of lead free solders that do not have the desired properties results in glass cracks as shown in the example photograph below (ACEA et al. 2009).

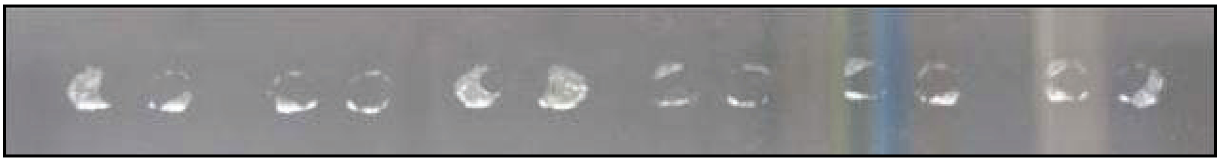

Figure 43 Cracks in glass caused by soldered connectors as visible from the outside face of the product (ACEA et al. 2009)

ACEA et al. (2009) explain that indium is the only known element that could be considered as a possible replacement for lead in solders for this application. However, solders that contain Indium have much lower melting points than other solders. This can cause significant difficulties when operating temperatures are elevated and in meeting OEM specifications. Figure 44 shows the phase diagram for indium-tin (InSn) solder compositions.

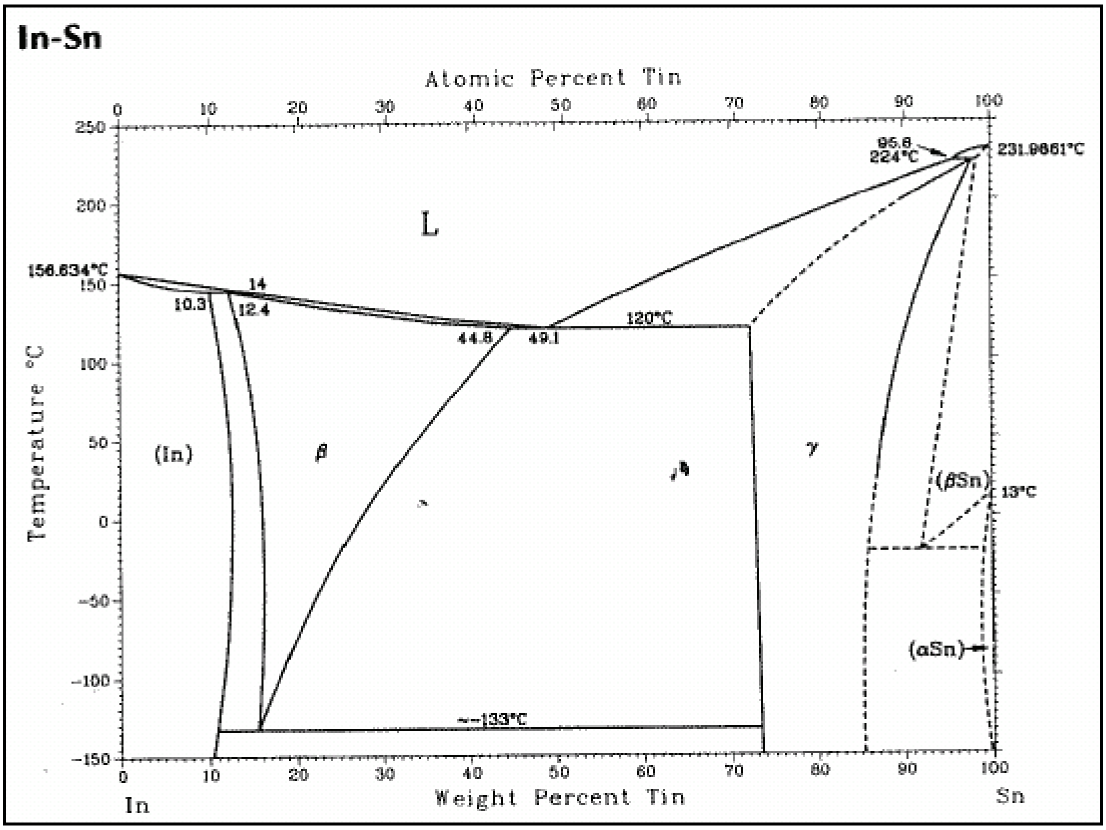


Figure 44 Indium-tin solder phase diagram (ACEA et al. 2009)

According to ACEA et al. (2009), the phase diagram shows that many solders with combinations of these two elements have a melting point of 120°C. With Vehicle Manufacturers having a requirement that the glass products should be capable of surviving elevated temperature (for example 110°C for one OEM and 120°C for another OEM) without any deterioration in performance, this low melting point is of great concern. ACEA et al. (2009) say that InSn solder compositions are not suitable for use on automotive glass products and it is necessary to add other elements to the solders to make them suitable. The addition of other elements to such solders affects the melting point further. As the composition and the melting point (solidus temperature and liquidus temperature) for the proposed solution from Antaya has not yet been confirmed, it is not possible to determine if that proposed solution will be capable of passing the high temperature requirements (product and process requirements) and will therefore be of concern for stability of the glazing product in service.

ACEA et al. (2009) say that some tests have been conducted on other indium containing solders and they maintain that it has been found that these do not pass the requirements of thermal cycle testing and humidity exposure tests with elevated temperatures and can therefore not be considered as replacements for lead containing solders (ACEA et al. 2009).

Further on, ACEA et al. (2009) say that lead free solders that are being used in other industries (e. g. electronics) are not suitable for soldering electrical connectors to glass products because of the aforementioned thermal expansion problems. These solders are generally high tin content and cause glass breakage if they are used on automotive glass products (ACEA et al. 2009).

Taking into consideration the lack of results from the Joint Stakeholder Working Group, the available data from testing of other Indium containing solders, the unknown suitability of the Antaya proposal and the timeline required by the Vehicle Manufacturers to implement any validated lead free solder, ACEA et al. (2009) conclude that the present timing in exemption 8b (31 December 2010) is not achievable .

ACEA et al. (2009) therefore propose to postpone the phase out date to 31 December 2014 with a review of technical progress starting in March 2011, after the first OEM field tests have been completed and results assessed.

**Justification for the maintenance of the current expiry date in exemption 8 b by Antaya**

Antaya claims that the current exemption 8b is not necessary as scientific evidence proves that the use of lead in this application is no longer unavoidable (Antaya 2009a). Antaya (2009a) hence wants exemption 8b to expire in 2011 following the current version of exemption 8b.

Antaya (2009a) explains that no evidence has been produced since the last review in January 2008 that would give reason to change the current exemption 8b in its wording and its expiry date. Antaya claims that in the previous year, the lead-free solder has been scrutinized, tested and evaluated by car companies, glass companies, independent testing laboratories and the widely recognized and independent worldwide authority on lead free solder, Dr. Jenny Hwang (Antaya 2009a). According to Antaya (2009a), the lead-free 65-indium alloy has passed every test to which it has been subjected. Furthermore, Antaya states to have worked with glass plants in the US, Mexico and Europe to validate the suitability of the lead free parts as replacements for the existing leaded parts. Antaya (2009a) claims that the lead-free material has been in use on over 700,000 vehicles dating back as far as 10 years with no reported failures.

Antaya (2009a) says to have developed a 65% indium based solder (65 alloy) in 1996 that proved to be more ductile and forgiving than its leaded equivalent, but more expensive. The solder was approved for use by Ford, Chrysler and the tier I supplier PPG Industries. According to Antaya (2009a), the alloy was originally developed for the Chrysler programs Dodge Caravan, Plymouth Voyager and Chrysler Town and Country. The lead free alloy was first adopted for use on the Ford Thunderbird. With the outstanding success of the “T-Bird” PPG recommended it be used on the GM U-Vans: Chevrolet Venture, Pontiac Montana and Oldsmobile Silhouette. According to Antaya (2009a), in more than 10 years, there has never been a warranty claim or complaint regarding the lead free alloy.

Antaya states that subsequently, Ford and General Motors had asked Antaya Technologies to develop a lead free solder alloy which would perform identically to the widely used leaded version on all automotive glass from fully annealed to fully tempered (Antaya 2009a).

In recent years, as a result of the ELV Directive banning heavy metals including lead, there has been renewed interest in the lead free material. Antaya has developed a series of much lower cost alloys which do not have the range of performance of the 65 alloy, but which pass many of the automotive industry tests (Antaya 2009a). Antaya says to have allowed Sekurit Saint Gobain (SSG) access to a 25% indium alloy which although less costly is only suitable to a limited range of conditions in accordance with certain specifications. SSG conducted tests, which Antaya maintains were wholly inappropriate for this less expensive material and extrapolated from this limited test that the material had failed (Antaya 2009a).

*Standards*

Antaya says that the Automotive industry uses a collection of testing standards to validate materials and parts for general use (Antaya 2009a). The widely recognized standards were submitted to the EC by leading glass manufacturers in January 2008 as part of the Third Adaptation of Annex II (Antaya 2009b). Antaya Technologies took these standards and commissioned an extensive test procedure to be conducted in accordance with these Standards. An independent laboratory used extensively by the global car companies was selected to conduct the tests and a well respected engineering firm was commissioned to oversee the work and to audit the results. According to Antaya (2009a), the material passed all the tests. Antaya says that the results can be reviewed in summary form in Section 2e) and 2 f-g (Antaya 2009g).

Antaya (2009a) further on states that on April 18th 2008, at VDA in Frankfurt, the following test scenario, which differs somewhat from the test protocol above, was jointly proposed by CLEPA, St Gobain, Guardian, AGC and Pilkington (Section 2b) (Antaya 2009i):

- **Temperature cycling tests** at defined humidity similar to ISO 16750-4:2003 G (-40°C to +90°C, 20 cycles)
- **Constant climatic humidity tests** (50°C/100% rel. humidity, duration 336h) according to ECE R43 and ANSI Z26.1 1996 or UNECE Global Technical Regulation
- **Climatic temperature with humidity tests** (40°C) according to DIN EN ISO 6270-2
- **High temperature storage** (100°C) according to UNECE Global Technical Regulation
- (Salt spray test according to DIN EN ISO 9227)

The salt spray test was discarded by the group for a variety of reasons (Antaya 2009a).

Antaya Technologies commissioned another study conforming to the test protocol above, once again passing all the tests under the scrutiny of an independent laboratory with third party oversight (Antaya 2009a). These results can be seen in Section 2f-g according to Antaya (Antaya 2009g).

According to Antaya , in July of 2008, Jerry Exner, Validation Engineer of General Motors raised a question about the study of Kirkendall voids in the lead free solder (Antaya 2009a). At General Motors' request, Antaya commissioned a special test procedure that included 500 hour 100°C aging procedure followed by a vibration test intended to simulate the effects of 10 years of potholes and closure shocks. Upon completion of analysis by General Motors, Mr. Exner wrote "It certainly allows us to conclude that there is no higher fatigue risk with the Indium solder than the leaded solder" (Antaya 2009a). The detailed results and commentary can be seen in Section 2f (Antaya 2009a and 2009g).

**Results of the joint test program**

The joint testing group had worked out a test program in order to assess the feasibility of Antaya's lead-free solder (Joint Testing Group 2009). The ageing procedures were conducted as laid down in the Joint Test Program in the section 2 "Laboratory Test Program". After the ageing, the soldered glass samples were tested (IR inspection, microcrack inspection, pull test) as described in section 4 "Acceptance criteria for laboratory tests" in the Joint Testing Program (Joint Testing Group 2009).

*Ageing and testing*

The ageing and testing was conducted following the Joint Testing Program (Joint Testing Group 2009).

Ageing procedures 1 and 4 and the subsequent testing were prepared and conducted in Wolfsburg at Volkswagen, ageing procedures 2 and 3 at BMW in Munich. The results were presented and discussed in detail among the stakeholders in a meeting open to all stakeholders in Frankfurt/Main, Germany, on 11 May 2009.

Table 20 shows the alloys and their melting points used in the joint test program, according to Antaya (Booth 2009b).

Table 20 Composition and melting points of solder alloys in the joint test program according to Antaya (Booth 2009b)

| Alloy | Liquidus Temperature in °C | Solidus Temperature in °C |
|---|---|---|
| 25Sn 62 Ag 10Bi 3 Ag | 224 | 160 |
| 30Sn 65In 0.5Cu 4.5 Ag | 127 | 109 |

Volkswagen had the composition of the lead-alloy analyzed used in the joint test program. The result in Figure 45 shows deviations from the nominal composition of the lead solder in Table 20.

| Element | Massen% | Atom% |
|---|---|---|
| Pb | 52.45 +/- 0.85 | 41.93 |
| Sn | 34.80 +/- 0.63 | 48.57 |
| Bi | 7.70 +/- 0.90 | 6.11 |
| Ag | 2.21 +/- 0.38 | 3.40 |
| Insgesamt | 97.17 | 100.00 |

| Spalte1 | Pb solder | Pb-free solder |
|---|---|---|
| Pb | 61% | - |
| Bi | 7.7% | - |
| Sn | 29% | 30% |
| Ag | 2% | 5% |
| In | - | 65% |

Figure 45 Analyses of solders used in the joint test program at Volkswagen (Rakus 2009) (left) and BMW (right) (Pinsker 2009c)

The lead content in the Volkswagen analysis is around 10% below the nominal composition, while the tin content is increased for around 10% compared to the nominal analysis.

The Volkswagen analysis of the lead alloy was presented to the stakeholders (Antaya, vehicle manufacturers, glass makers) at an open meeting in Frankfurt/Main on 14 May 2009. The stakeholders had agreed that the analyzed alloy was a usual lead alloy used for soldering on vehicle glass. The deviation from the nominal alloy composition was therefore not further discussed.

| Element | 1 (Wt %) | 2 (Wt %) | 3 (Wt %) |
|---|---|---|---|
| Sn | 24.76 | 24.38 | 25.01 |
| Pb | 62.12 | 62.25 | 61.65 |
| Cu | 0.30 | 0.22 | 0.18 |
| Bi | 9.95 | 9.54 | 10.16 |
| In | 0.001 | 0.002 | 0.001 |
| Ag | 2.77 | 3.48 | 2.90 |
| Sb | 0.08 | 0.11 | 0.08 |

| ELEMENT/ELEMENTO | % |
|---|---|
| (Al) ALUMINIUM/ALUMINUM/ALLUMINIO | < 0.001 |
| (Sn) ETAIN/TIN/STANO | 24.9 |
| (Pb) PLOMB/LEAD/PLOMO | BALANCE |
| (Sb) ANTIMOINE/ANTIMONY/ANTIMONIO | 0.02 |
| (Cu) CUIVRE/COPPER/COBRE | 0.03 |
| (Ag) ARGENT/SILVER/PLATA | 2.9 |
| (As) ARSENIC/ARSENIC/ARSENICO | < 0.01 |
| (Bi) BISMUTH/BISMUTH/BISMUTO | 10.2 |
| (Fe) FER/IRON/HIERRO | < 0.01 |
| (Zn) ZINC/ZINC/ZINC | < 0.001 |

Figure 46 Analysis of lead solders as used in the joint test program by two different external labs contracted by Antaya (Booth 2009c; Booth 2009d)

The analyses results from documents (Booth 2009c) and (Booth 2009d) indicate good congruence with the nominal composition of the lead solder indicated by Antaya.

Volkswagen also had the lead-free alloy analyzed on possible lead content. No lead could be detected in the lead-free alloy (Rakus 2009).

### Pull test results

After the ageing procedures, pull testing of the connectors soldered to the glass samples was conducted according to the Joint Testing Program (Joint Testing Group 2009).

Figure 47 shows a summary of the pull test results from the joint test program.

| | | | Connector types: | T-bridge | | | | | | | | Crimp | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tested glass samples | | | | Ageings 1 - 4 LF no. of connectors/no. failed/no. of glass | | | | Ageings 1 - 4 Pb no. of connectors/no. failed/no. of glass | | | | Ageings 1 - 4 LF no. of connectors/no. failed/no. of glass | | | | Ageings 1 - 4 Pb no. of connectors/no. failed/no. of glass | | | |
| Supplier | OEM | Type | glass tpye | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| AGC | Audi | Q5 | tempered | 6 / 0 / 1 | 6 / 0 / 1 | | 6 / 0 / 1 | 6 / 0 / 1 | 6 / 0 / 1 | | 6 / 0 / 1 | | | | | | | | |
| | Lancia | Musa | tempered | 6 / 0 / 1 | 6 / 0 / 1 | | 6 / 0 / 1 | 6 / 0 / 1 | 6 / 0 / 1 | | 6 / 0 / 1 | | | | | | | | |
| | Toyota | Aygo | tempered | 8 / 3 / 1 | 8 / 0 / 1 | | 8 / 5 / 1 | 8 / 0 / 1 | 8 / 0 / 1 | | 8 / 0 / 1 | | | | | | | | |
| | Citroën | C4 | tempered | | | 2 / 0 / 1 | | | | 2 / 0 / 1 | | | | | | | | | |
| | Citroën | Prototype | tempered | | | 2 / 0 / 1 | | | | 2 / 0 / 1 | | | | | | | | | |
| | Volkswagen | Passat | tempered | | | 4 / 0 / 2 | | | | 4 / 0 / 2 | | | | | | | | | |
| Guardian | Audi | A6 Avant | tempered | 8 / 0 / 1 | 8 / 0 / 1 | | 32 / 1 / 3 | 8 / 0 / 1 | 8 / 0 / 1 | | 33 / 0 / 3 | 3 / 1 / 1 | | | 3 / 1 / 1 | 3 / 3 / 1 | | | 3 / 2 / 1 |
| | Audi | A8 | laminated | 36 / 0 / 3 | 12 / 0 / 1 | | | 36 / 1 / 3 | 12 / 0 / 1 | | | | | | | | | | |
| | Porsche | Panamera | laminated | 24 / 8 / 2 | | | | 24 / 1 / 2 | | | | | | | | | | | |
| | Daimler | S-Class | privacy | | | | | | | | | | | | 1 / 1 / 1 | | | | 1 / 0 / 1 |
| | BMW | X6 | tempered | | | 4 / 0 / 2 | | | | 4 / 0 / 2 | | | | | | | | | |
| | BMW | X5 | tempered | | | 4 / 0 / 2 | | | | 4 / 0 / 2 | | | | | | | | | |
| PPG | Daimler | S-Class | tempered | | | 4 / 0 / 2 | | | | 4 / 0 / 2 | | | | | | | | | |
| | Daimler | S-Class | laminated | 24 / 0 / 2 | | | 12 / 5 / 1 | 24 / 15 / 2 | | | 12 / 8 / 1 | | | | | | | | |
| Pilkington | BMW | 1-series | tempered | 20 / 0 / 5 | 6 / 0 / 1 | 4 / 0 / 2 | | 16 / 0 / 4 | 6 / 0 / 1 | 4 / 0 / 2 | | 5 / 4 / 5 | | | | 4 / 4 / 4 | | | |
| | BMW | XXX | | | | | 18 / 0 / 4 | | | | 18 / 0 / 4 | 4 / 0 / 4 | | | | 4 / 4 / 4 | | | |
| Saint-Gobain | BMW | 5-series | tempered | 63 / 0 / 5 | 28 / 0 / 2 | | 42 / 0 / 3 | 63 / 0 / 5 | 28 / 0 / 2 | | 42 / 0 / 3 | | | | | | | | |
| | Volkswagen | Golf | tempered | 30 / 0 / 5 | | | 17 / 0 / 3 | 30 / 0 / 5 | | | 18 / 0 / 3 | 5 / 5 / 5 | | | 1 / 1 / 1 | 5 / 3 / 5 | | | 1 / 1 / 1 |
| | Opel | Corsa | tempered | 6 / 0 / 1 | | | 6 / 1 / 1 | 6 / 0 / 1 | | | 6 / 0 / 1 | | | | | | | | |
| | Renault | Megane | tempered | 8 / 0 / 1 | | | 7 / 0 / 1 | 8 / 0 / 1 | | | 8 / 0 / 1 | | | | | | | | |

Figure 47 Summary of results from joint test program (Pinsker 2009a)

*LF: Lead-free solder*

*Pb: Lead solder*

Figure 47 shows that in tests 2 and 3 no failures occurred in pull testing, neither for the lead-free nor for the lead-containing solders. In tests 1 and 4, the result shows failures both with lead-free and lead-containing solders.

Table 21 shows the summary of the pull test results after ageing procedures 1 and 4 conducted at Volkswagen.

Table 21 Overall result of pull-off tests after ageing procedures 1 and 4 (Rakus 2009)

| | LF | Pb |
|---|---|---|
| Total | 381 | 380 |
| Pass | 358 | 362 |
| Failed | 23 | 18 |

Figure 48 shows the results of the pull-of test broken down to the ageing procedures 1 and 4.

| Ageing Proc. | Ageing Procedure 1 | | Ageing Procedure 4 | |
|---|---|---|---|---|
| Solder | Pb-free solder | Pb-solder | Pb-free solder | Pb-solder |
| No. of joints | 227 | 223 | 154 | 157 |
| Passed | 216 | 213 | 142 | 149 |
| Failed | 11 | 10 | 12 | 8 |
| % of failures | 5% | 4% | 8% | 5% |

Figure 48 Result of pull-off test for tests 1 and 4 (summary of slides 5 and 6 from (Rakus 2009) by Otmar Deubzer)

Figure 49 shows the results of the pull-of test for ageing procedures 1 and 4 broken broken down to the performance on laminated and tempered glass.

| Glass Type | Laminated glass | | Tempered glass | |
|---|---|---|---|---|
| Solder | Pb-free solder | Pb-solder | Pb-free solder | Pb-solder |
| No. of joints | 84 | 84 | 297 | 296 |
| Passed | 71 | 66 | 287 | 296 |
| Failed | 13 | 18 | 10 | 0 |
| % of failures | 15% | 21% | 3% | 0% |

Figure 49 Result of pull-off test for tests 1 and 4 by type of glass (summary slides 7 and 8 from (Rakus 2009) by Otmar Deubzer)

The pull testing results do not show significant performance differences between the lead-free and the lead solder joints (Pinsker 2009b; Rakus 2009). In the IR hot spot detection test as well as in the inspection for micro cracks, the lead-free solder joints did not show performances inferior to that of the lead solder joints (Pinsker 2009b; Rakus 2009).

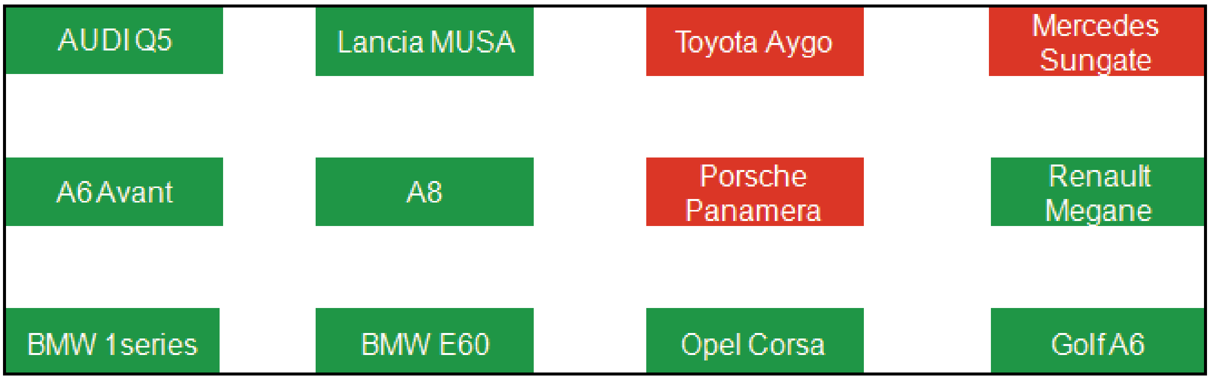


Figure 50 Failure accumulation of lead-free and lead soldered joints on specific samples (Rakus 2009)

On some glass samples, the observed failures after pull testing both of lead-free as well as of leaded solder joints was higher than on other glass. The reasons for the accumulated failure rates on the above glass could not be identified.

In the meeting in Frankfurt Main, it was discussed with the stakeholders whether this result might indicate that the tested lead-free solder alloy clearly would have failed on specific types of glass, which could technically be described and confined independently from glass maker and vehicle type. It was agreed that this was not possible.

**Microcracks**

The glass samples soldered at Volkswagen in Wolfsburg were inspected for microcracks before pull testing according to the Joint Testing Program (Joint Testing Group 2009). Figure 51 shows the summary of microcrack countings detected in the glass samples after soldering and before pull testing (Antaya 2009c).

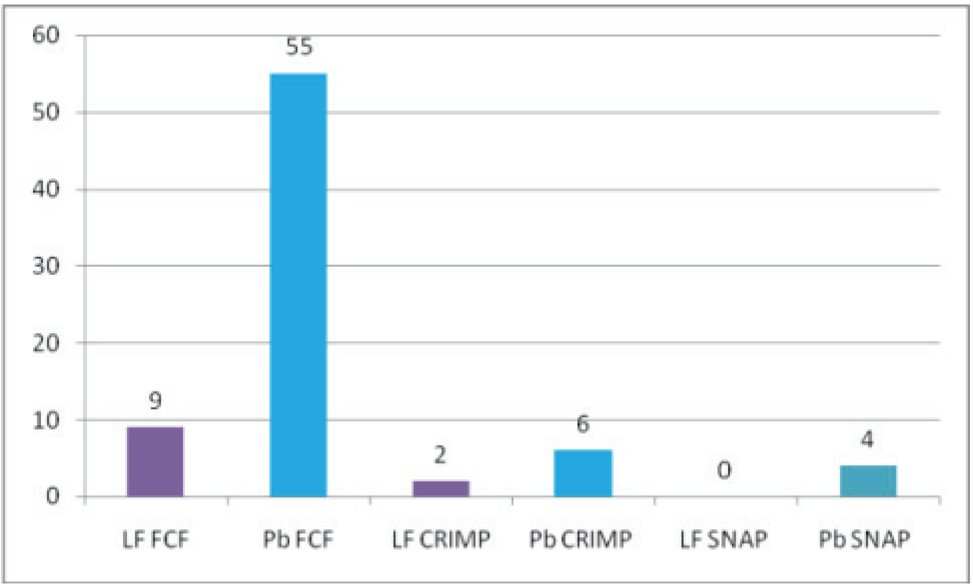


Figure 51 Microcracks in glass samples (Antaya 2009c); LF: lead-free soldered connections, Pb: lead soldered connections, FCF: classical T-bridge connectors

Figure 51 shows clearly higher counts of microcracks under the solder joints soldered with the lead-containing solder. A European glass maker (Marchant 2009) pointed out that the 32 of the 55 microcracks on Pb FCF had occurred on a single glass sample only. Such a high figure, according to this stakeholder, may indicate that something went completely wrong in the soldering of leaded connectors on this part. It would therefore not be adequate to fully include this glass with 32 failures into the statistical evaluation of the test (Marchant 2009).

The stakeholders agree on the fact that under the applied test conditions, the lead-free solders caused less microcracking than the lead solders. A further investigation of the backgrounds and possible reasons for the microcracks was therefore not conducted. Such an evaluation would have to include the lead-free solder micro cracks as well to maintain the balance in the evaluation of the results.

**Infrared inspection**

All soldered joints were inspected by IR-camera during operation as laid down in the Joint Testing Program (Joint Testing Group 2009). If a hot spot was detected indicating a defect, the test was counted as “not passed” for the respective solder joint.

On the test samples at BMW, no hot spots were detected. On the test samples at Volkswagen, there was no unacceptable temperature distribution, and no difference in performance between lead and lead-free solder joints.

**Resistance test**

A resistance measurement as demanded by the Joint Test Program (2009) was not conducted. The infrared hotspot inspection did not indicate any impairment of the solder joints. The temperatures measured at the connector in the IR inspection as well as the measured current were in the expected range. In case of a resistivity increase, the temperature would have been increased, and the current would have been lower. The absence of such phenomena were interpreted in that way that the resistance of the solder joints was in the normal range.

**Summary of results from joint testing program**

To sum up, the lead-free indium-based alloy did not show performances inferior to the lead alloy, neither in pull testing after the ageing tests, nor in the IR inspection (Pinsker 2009b) (Rakus 2009). The lead-free solder joints caused less microcracks in the glass samples compared to the lead solders. Within the range of tested glass samples and connectors, there are no technically definable glass and connectors, where the lead-free solder joints would have failed to a degree that would prove that they are not appropriate for this kind of glass or connectors. In the joint test program, the lead-free solders could not be found to be not viable on any of the glass and connector technologies tested.

Antaya (2009f) had additional tests conducted at external laboratories. The tests were the same or identical tests like in the joint test program. The results underpin the findings from this joint testing program.

**Conclusions from the test results**

There were no significant performance differences of the lead-free and the lead solder in the joint test program (Pinsker 2009b; Rakus 2009). The glass makers and vehicle manufacturers stated that the results are promising, Antaya considers the results a full success for its lead-free solders.

This difference in the views on the test results become obvious in the stakeholders' stand points on the timing of the lead replacement, and in remaining concerns of the vehicle manufacturers and glass makers, in particular concerning the low melting point of the lead-free solders.

Antaya considers its lead-free alloy a drop-in solution, which can replace the lead-containing solders within short time (Booth 2009a). Antaya hence requests remaining with the current exemption 8a in its current wording and timing. The exemption for lead in solders on glass would then expire end of 2010 for new type approved vehicles.

The vehicle manufacturers and the glass makers plea for at least 4,5 years of total transition time from start of development on (Pinsker 2009b). This would result in an expiry of the exemption end of 2013.

The stakeholders positions are discussed in the following sections.

**Position of vehicle manufacturers and glass makers (Pinsker 2009b)**

The vehicle and glass manufacturers provided a roadmap for the further timeline towards the lead replacement in solders for soldering on glass.

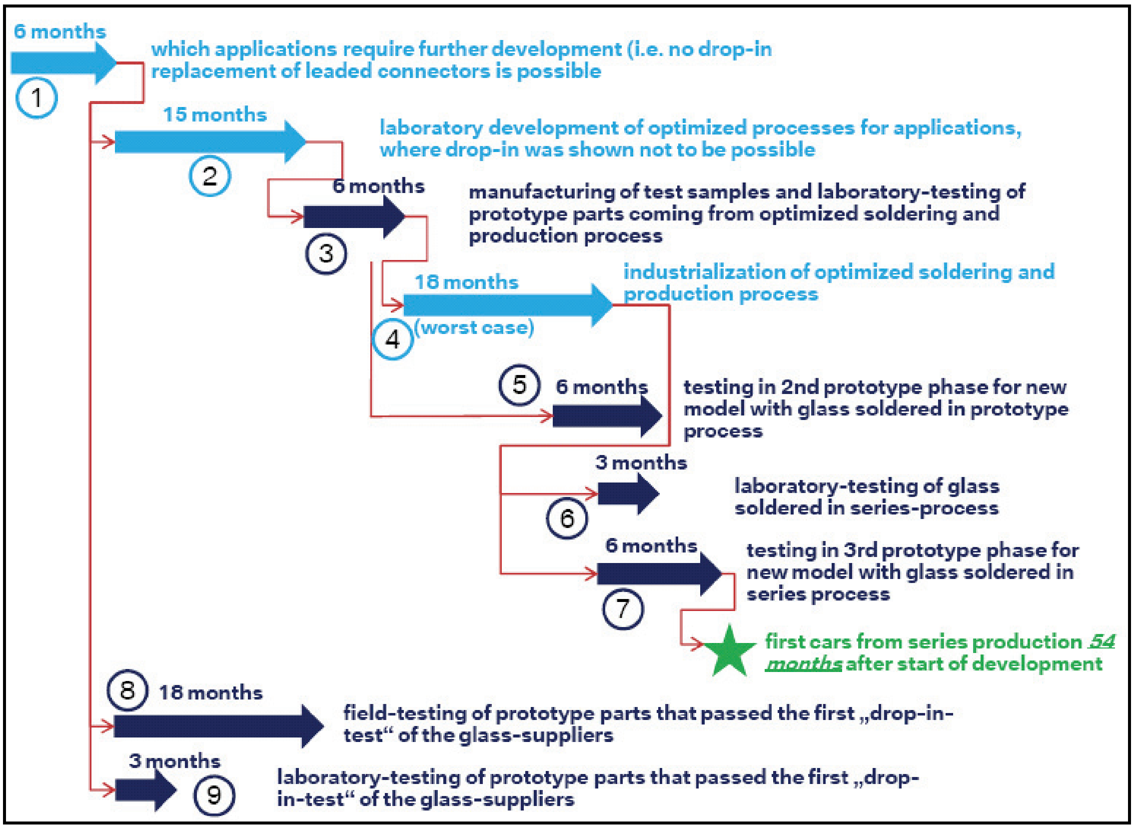


Figure 52 Proposed schedule for lead replacement in soldering on glass (Pinsker 2009b)

ACEA et al. describe the above roadmap in more detail (Pinsker 2009b):

1. Determination of applications requiring further development (Pinsker 2009b)
   a) Preparation of samples for all applications ⇨ 3 months [Samples must originate from "normal" production.
   b) Soldering ⇨ 1 month [roughly: 20 applications x 200 connectors = 4000 connectors].
   c) Since no adapted tooling for the series designs is available, all connectors must be processed by hand on a manual series production line.
   d) Tests and evaluation ⇨ 2 months.

   Total: 6 months.

2. A lab-development has to be started for all applications where no drop-in is feasible (Pinsker 2009b).

   a) Optimistically, the stakeholders assume for all such applications (only) two development cycles á lab-analysis of the failure-reasons, definition of process or product actions ⇨ 1–2 months.

   b) Execution of optimization ⇨ 2 months [if new tooling is required (e.g. new printing screens), time of delivery has to be taken into account].

   c) Preparation of samples incl. soldering ⇨ 1/2 month.

   d) Tests and evaluation ⇨ 2 months.

   Total: 6 months per cycle, ergo a good 12 months of development [Parallelization of the developments for different applications are limited by man-power. Hence, if the number of applications is big (>3), delays are unavoidable].

3. Presentation of prototypes for all applications at all OEMs, as all OEMs will want to apply their validation program (Pinsker 2009b)

   a) Preparation of prototypes on series or pilot lines ⇨ 3–6 months, depending on OEM demands.

   b) Validation program OEMs ⇨ 3 months.

   c) Field tests with prototypes ⇨ 15 months, but can be done in parallel to industrialization.

   d) After this validation introduction of the new technology into running development projects can start.

   Minimum lead-time until SOP (start of production) is 1 year, if no big engineering of production lines is required. Otherwise (e.g. new printing room), 1,5–2 years are realistic.

4. Industrialization (here the case of a required invest is discussed) (Pinsker 2009b)

   a) Invest preparation (dossier) and decision ⇨ 3 months.

   b) Engineering (compilation of list of requirements until PO) ⇨ 3–6 months.

   c) Time of delivery: 3–6 months.

   d) Waiting for shut-down ⇨ 0–6 months [larger modifications of the shop floor, e.g. an additional printing room or a modification of an automated soldering line, are only possible during summer or Christmas shut-down]

   e) Start-up and ramp-up ⇨ 3 months.

   Total: 1 to 1,5 years [The extent of the required actions is crucial, e.g. if no space on the shop floor is available to install a new printing machine + curing station (which unfortunately is quite often the case), it is necessary to change the complete line design. Then 1,5 year is quite challenging. If "only" a flux application apparatus has to be added to a line with amply shop floor space (and amply cycle time!!!), the engineering can be done in 6 months].

5. Testing in 2nd prototype phase of OEM (Pinsker 2009b)
   a) In the 2nd prototype phase cars are produced with toolings that are either series or close to series.
   b) The cars are used for thorough testing of the complete system. As for example chemicals used in the interior may interfere with the solder contacts, it is required that also the material used for the solder contacts is the same that will be used for series, thus the glass for these prototypes must have been produced under conditions close to series.
      - car buildup (prototypes!) ⇨ 1 month
      - laboratory testing (climate, shaker, ...) ⇨ 2 months.
      - summer- and winter testing ⇨ 2 months each, not including the time for waiting for correct weather conditions in the relevant countries.

   Total: around 9 months.

6. Laboratory-testing of glass soldered in series-process (Pinsker 2009b)
   a) As for the 2nd prototype phase no parts from series-process may be available, additional laboratory testing is necessary with series parts.

   Duration: 3 months including production of test specimen.

7. Testing in 3rd prototype phase for new model with glass produced and soldered in series process (Pinsker 2009b).
   a) As for the 2nd prototype phase no parts from series-process may be available, there is only the 3rd.
   b) prototype phase to test the parts coming from series tooling and series process.
      - car buildup (prototypes!) ⇨ 1 month.
      - laboratory testing (climate, shaker, ...) ⇨ 2 months
      - summer- and winter testing ⇨ 2 months each, not including the time for waiting for correct weather conditions in the relevant countries.

   Total: around 9 months.

8. Field-/laboratory testing of prototype parts that passed the first „drop-in-test“ of the glass-suppliers (Pinsker 2009b)
   a) In order to get first results and hints on what to focus on in the further development, first prototypes of glass with lead-free solder connectors are tested in

laboratory as well as in current series-cars under heavy driving conditions and special climates.

b) Main purpose of this test and the corresponding laboratory-test is to get a comparison between laboratory and real-life conditions: does the laboratory test really reflect real-life conditions?

These tests do not influence the total time needed for the development, they are done in parallel.

The stakeholders confine that in all cases of mentioned periods it was assumed that all work can be perfectly parallelized for all applications, products, plants, lines, customers, etc. (Pinsker 2009b). Since this technology concerns all customers and all plants and service centers, the limiting resource is man-power. The required know-how according to the stakeholders is very specific and cannot be studied at universities. All engineers are trained by the glass industry and there are only about 15–20 experts in all companies in total all over the world. Such experts hence are difficult to find, according to the stakeholders (Pinsker 2009b).

**Antaya position (Booth 2009a)**

*Lead-free solders as drop-in replacement*

Antaya defines "drop in" as meaning that the lead free part can be used as a substitute for the leaded part so long as the manufacturing process and its components may only be subjected to either usual and customary, or reasonable and inexpensive adjustments (Booth 2009a). For the purpose of clarification, a change to the glass itself such as making it thicker or changing its shape would not pass the "drop in" test. If a simple change to the part or process is made, then it would be considered within this definition of "drop in" (Booth 2009a).

Antaya explains that, when a new vehicle program comes online, the glass and its attachments (connectors) are designed to meet the requirements of the vehicle manufacturer. As part of the customary optimization of the glass and the leaded connectors, the following, almost certainly incomplete, list of adjustments can be made (Booth 2009a).

- Adjustments to glass (Booth 2009a):
  - % silver in the paste – (higher % means better adhesion);
  - thickness of the silver paste (double buss bar) – (thicker usually means better adhesion);
  - construction of screen which affects the profile of the silver paste, which in turn affects adhesion;
  - ceramic type – different ceramics have different performance characteristics;

 – ceramic thickness;
 – firing temperature.
- Adjustments to the part (connectors) (Booth 2009a):
 – flux type;
 – amount of flux;
 – application of flux (inside the solder or on the solder);
 – amount of solder on the part (connectors already contain solder deposit);
 – dimensions of solder pad (shape / size) – (bigger pad means better adhesion);
 – profile of solder.
- Soldering process (Booth 2009a):
 – silver abrasion method prior to soldering;
 – soldering temperature;
 – soldering time;
 – cool down time.
- Assembly plant (Booth 2009a):
 – installation method;
 – packaging in vehicle.

Antaya emphasizes that the above list of adjustments are not lead free adjustments. They are the customary variables that can be easily adjusted to improve performance (Booth 2009a). Antaya claims that it is inconceivable that the lead free part could require any adjustments beyond those detailed above in order to meet the standards as provided by the vehicle manufacturers. Antaya believes that 99% of adjustments will be part adjustments (i.e. adjustments that have to be done anyway). Antaya further maintains that since any possible adjustment is both customary and inexpensive, adjustments such as these should not be considered as grounds for further delays in the implementation of the ban on lead (Booth 2009a).

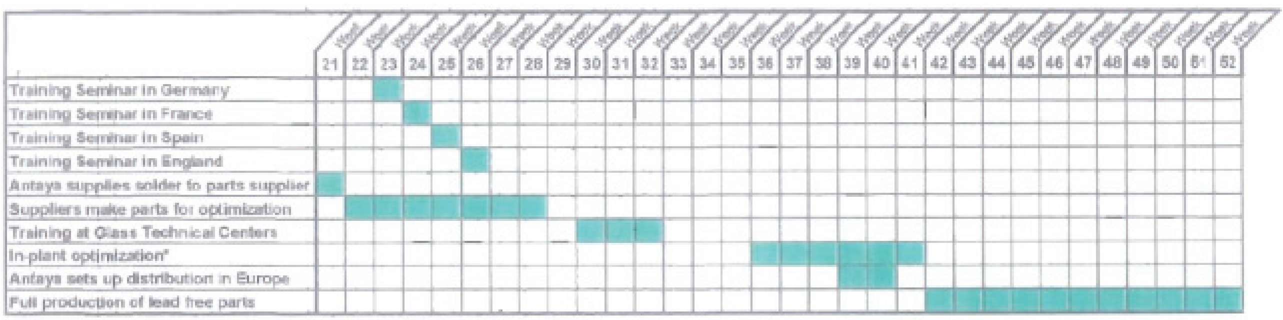


Figure 53 Antaya's schedule for transition to lead-free soldering on glass in vehicles (Antaya 2009e)

Antaya asks to consider what was learned from the joint test program (Booth 2009a). According to Antaya a representative range of glass types was tested, with 1,026 connectors across 5 global glass manufacturers, 9 OEMs and 14 vehicle programs. All of these programs were designed for a leaded part and Antaya had no previous experience with any of the glass. And yet, the lead free parts incurred fewer failures from pull tests and less than 1/6$^{th}$ the failures from cracking than the leaded parts (Booth 2009a). In short, Antaya states that it came to Volkswagen and BMW with a box of lead free parts and outperformed the leaded parts with absolutely no optimization or adjustments other than five minutes on the soldering device. None of the parts were designed for the glass on which they were tested and Antaya used demo soldering equipment which the Antaya representatives brought with them to Volkswagen and BMW (Booth 2009a).

*Research and development*

Two examples of research and development were mentioned at the meeting in Frankfurt on 11 May 2009:

- the possible use of online fluxing, and
- the potential need for double buss bars (at AGC).

Antaya believes that the term "research and development implies some kind of prolonged and extraordinary activity that has an unknown outcome and cost (Booth 2009a). Antaya states that double buss bars are widely used in many plants across Europe and around the world today. Double buss bars, according to Antaya, were in evidence on 25% of the vehicle manufacturers' glass tested in the joint test program. Antaya concludes that therefore double buss bars cannot be considered "research and development" (Booth 2009a).

Antaya continues that secondly, online fluxing, which is the use of flux core solder wire or ribbons at the part supplier (Antaya and its competitors), is not a requirement of the vehicle manufacturers (Booth 2009a). It is a convenience used by some glass plants in Europe. The alternative, post applied flux, is widely used by parts suppliers all over the world, including Europe, Asia, and the United States. Antaya currently supplies the alloy only in ingot, post-applied or pre-applied form. But firstly, Antaya claims to have been advised by a large multi national supplier of solder wire that they will supply Antaya's alloy in flux core solder wire worldwide and secondly, even if they are unable to do as they say, this nuance does not come close to the implied requirement that an exemption to Annex II should be sustained by a reasonably substantial issue (Booth 2009a).

*Field Tests*

Antaya challenges the vehicle manufacturers' position who had asked for field tests in addition to the "Joint Test Program" (Booth 2009a). Antaya cites the coordinator of the Joint

Test Program, Otmar Deubzer, as having said that it “was not up to [him] to tell the OEMs what field tests they might need”. Antaya argues that the accelerated aging protocol that was completed over the past two months was specifically designed to simulate the life cycle of the lead free alloy in its working environment. For the purpose of clarity, Antaya wishes to draw the attention to the document sent out on March 18 to the participants in the Joint Testing Group (Booth 2009a):

*Test 2.1 Temperature cycle test ISO 16750-4:2003*

This test ensures that the stress relaxation mechanism of the solder alloy is sufficient. About 20–30 cycles are required to simulate the ageing (e.g. work-hardening) of the alloy.

*Test 2.2 High temperature storage test according to UNECE Global*

This ageing procedure simulates the microstructural changes in the solder joint over the life-time of the car on an accelerated time scale to enable the testing of an aged sample.

*Test 2.3 Climatic temperature with humidity tests according to DIN EN ISO 6270-2 under load*

Condensation is a typical phenomenon in the cabin of a car. This procedure ensures that the product functionalities persist under condensation during the life-time of the car.

*Test 2.4 Constant climatic humidity tests ECE-TRANS-WP.29-GRSG-2007-28e*

Some alloys are vulnerable to this type of exposure. The alloy may become brittle or the adhesion at the interfaces might fail. The result is a cohesive or adhesive failure of the joint. This procedure ensures that the product functionalities persist during the life-time of the car.

Antaya claims that there are around 700 000 vehicles (and growing) on the road all over the world today using lead free on-glass connectors (Booth 2009a). Many of these vehicles have been on the road for more than 10 years. Antaya says that Tom Hagen, Senior Executive at General Motors responsible for Glass and Moldings personally went through all the warranty data on many of these vehicles looking for lead free issues, prior to approving the Antaya material for use on GM vehicles. There were no incidents reported on lead free connectors (Booth 2009a).

*Summary of the Antaya position (Booth 2009a)*

Antaya sums up that it has considerable experience with the lead free alloy and has never failed to “drop in” a replacement (Booth 2009a). According to Antaya, the alloy has been in use for ten years. The Joint Testing Group has been working collaboratively on this for 13 months and individually for several more years. Antaya claims that there is not one piece of evidence suggesting that the parts are not “drop in”. With only 5 minutes of optimization, the lead free parts in the group test outperformed the leaded parts, moderately in pull tests and significantly in cracking. Antaya states that there is no evidence that its solution is not a “drop in” (Booth 2009a).

### 4.17.5 Critical review of data and information

**Concerns on the melting point of the lead-free alloy**

The lead-free alloy, compared to the lead alloy, has a considerably lower melting point (Booth 2009b):

- liquidus temperature 127°C, compared to 224°C of the lead solder;
- solidus temperature 109°C, compared to 160°C of the lead solder.

*Liquidus temperature*

Maximum temperature at which crystals (unmolten metal or alloy) can co-exist with the melt. Above the liquidus temperature, the material is homogeneous, consisting of melt only.

*Solidus temperature*

Temperature at which an alloy begins to melt. Below the solidus temperature, the substance is completely solid, without molten phase.

Between the solidus and liquidus temperature (between 109°C and 127°C), solid phases (crystals) and the melt coexist.

ACEA et al. express concerns on possible adverse impacts of the low melting point of the lead-free alloy. High temperatures can be reached when a car is parked in direct sunlight (Pinsker 2009b).

*Antaya high temperature tests*

Antaya presented two tests to prove that the melting point is of no concern. The tests were conducted in external labs. The tests and their results are displayed in the Annex as test I and II.

In test I, test samples were stored at 105°C for 500 h. During the 500 h, weights of 500 g were hung from each of the connectors soldered to the carrier with the lead-free solder used in the joint testing program. According to the test report, no failures occurred, the connectors held the weights.

In test II (see Annex), test samples soldered with the lead-free alloy used in the joint testing program were stored at 100°C for 500 h and then subjected to mechanical shock and vibration tests. The samples passed the tests, according to the test results presented by Antaya.

The vehicle manufacturers and the glass makers were asked whether these test results might accommodate their concerns.

*Persisting concerns about adverse effects from the low melting point*

ACEA et al. explain that the maximum temperatures reached vary with installation location, the highest temperatures relevant for glazing applications are typically measured at the roof (Pinsker 2009b). The stakeholders put forward that on the surface of the IP-pad or on the inner surface of the rooflite, temperatures measured under real life conditions (ambient temperature 45°C, incident solar energy 1100 W/m² at mid-day sun, car parked for approx. 2 hours) are as high as 115 to 120°C (Pinsker 2009b). These temperatures may vary depending on parameters like

- incident solar energy (depends mainly on the climatic region where the car resides);
- color of the absorbing surface;
- installation angle;
- additional sources of energy like electrical power of the heater grids, which may create temperature differences as compared to the surface temperature at the connector of up to 50°C (see Figure 54 on page 172).

At these locations, measured temperatures exceed by far the value of 110°C where Antaya's solder alloy is known to fail, according to ACEA et al. (Pinsker 2009b). In very humid climate the maximum temperature reached on inner surfaces is usually lower (around 70 to 80°C), but the humid air often leads to fog on the inner surfaces of the car. Defogging of the rear window, which is crucial for the clear outside view of the driver and is thus a safety-relevant function, is usually done using the heater grid. Activation of the heater grid also heats up the connectors to up to 50°C above the surface temperature of the glazing, which may reach 70 °C to 80 °C under real-life conditions (Pinsker 2009b).

Hence, when the heater is activated in a humid environment for de-fogging of the rear window, the temperatures reached will be even higher than when exposed to direct sunlight without operation of the heater. Failure of the soldered joint in these high temperatures in the field will create a safety concern.

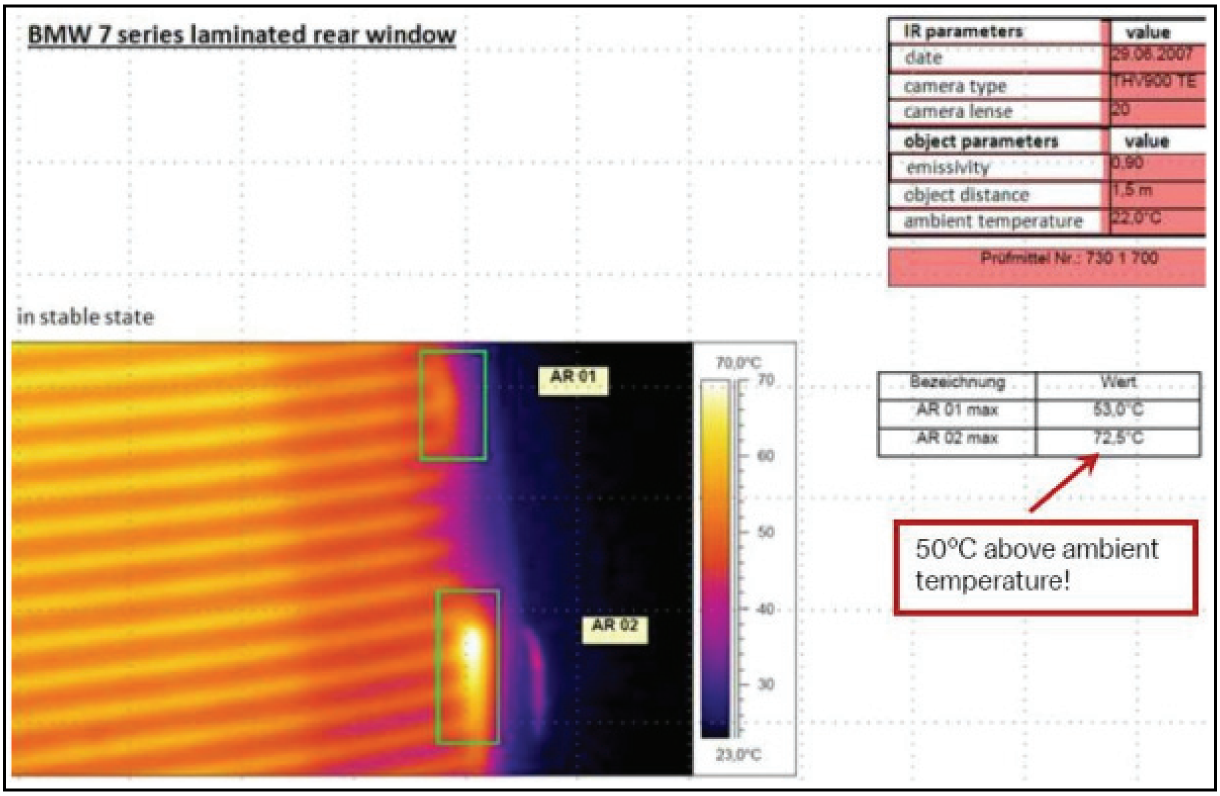


Figure 54 Elevation of temperature in heating grid connector of a rear window during defogging (Pinsker 2009b)

Another measurement was conducted at Volkswagen showing the temperature curve at a rear window defroster (Rakus 2009).

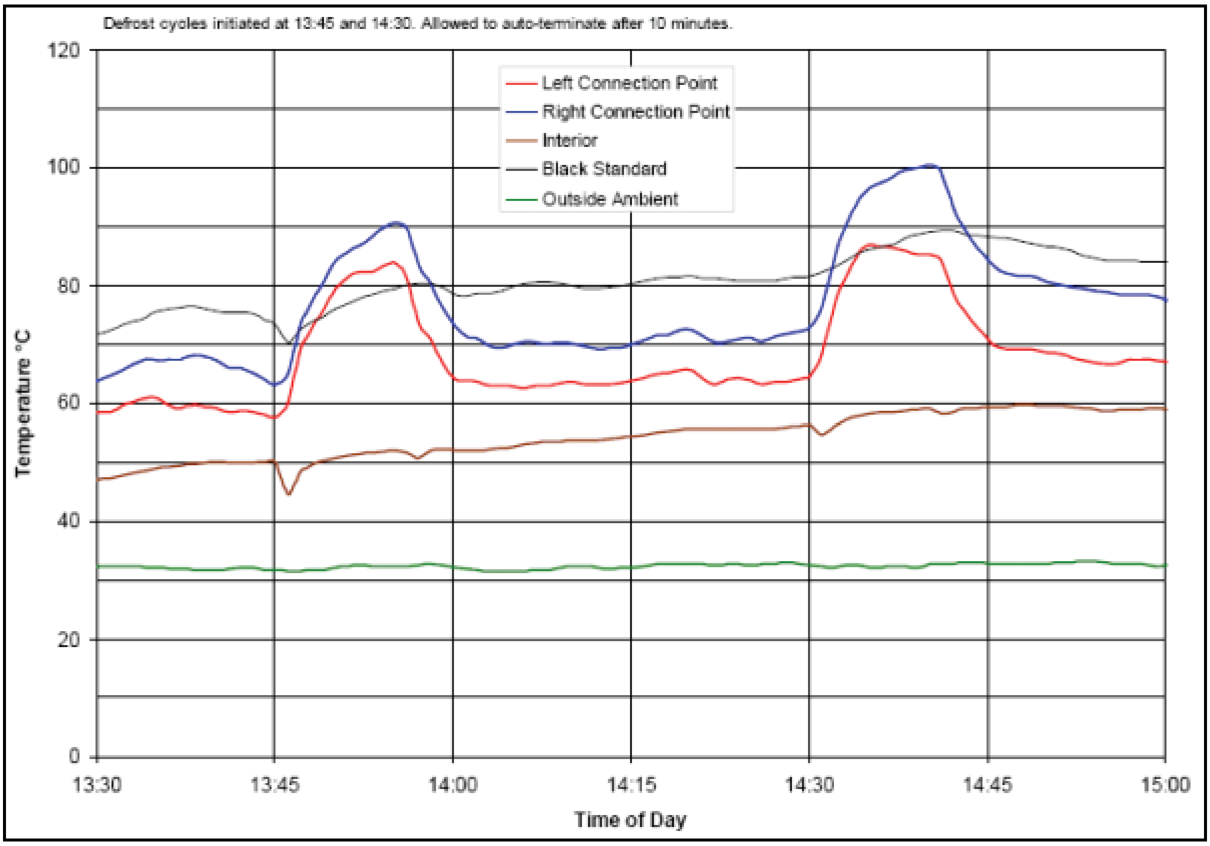


Figure 55 Temperatures measured at a rear window defroster (Rakus 2009)

At an ambient temperature between 30 to 40°C, the maximum temperature measured was around 100°C.

The Antaya high temperature tests do not scatter the vehicle and glass manufacturers worries (Pinsker 2009b). They say that Antaya presents high-temperature tests at 105°C. Tests performed at slightly higher temperatures (110°C) failed due to the low solidus point of the solder, according to the stakeholders (Pinsker 2009b). ACEA et al., however, did not submit any evidence for this.

The car and glass manufacturers state that currently they do not know the tolerances of the melting point of the solder alloy. To ensure proper operation of safety-features like front and rear window heaters under all environmental conditions that may occur in the life-cycle of a car, the car manufacturers typically require testing at a minimum of 10°C above the maximum temperatures measured under real-life conditions at the installation locations.

The stakeholders further on state that in the production process, high temperatures mainly occur during the drying phase of paint refurbishing / respray (Pinsker 2009b). Running at lower temperatures is generally possible, but will lead to longer drying periods and thus higher cost. Currently, maximum temperatures reached during certain paint refurbishing processes exceed 110°C (Pinsker 2009b). If these processes cannot be used due to the low melting point of the solder alloy, new processes need to be developed and investments will be necessary, which will require a longer leadtime than currently planned (Pinsker 2009b).

Also to be considered the refurbishing/respray process at the repair garages for vehicles in use: some use an infrared lamp, which locally heats up areas to be cured, and as it is high power infrared radiation, it could lead into high temperatures on soldering, if used on an area close to a connector (Pinsker 2009b).

The stakeholders say that, if the European Industry is forced by legislation to put on the EC market products, which are not suitable for countries where high temperatures occur and to manufacture different products for those countries, this will be highly detrimental to the competitiveness of the European manufacturers against their competitors whose main market is not the EC. It also will be in contradiction with the conclusions of the CARS 21 High Level Group which were supported by the EC Commission, the European Parliament and the Council (Pinsker 2009b).

**Priorities in the review process**

In the face of the multitude of information and facts presented, and given the contrary statements and opinions of the involved stakeholders, the reviewers would like to point out the corner stones of the review process.

*Piority of vehicle manufacturers' testing and qualification criteria*

The vehicle manufacturers' testing and qualification procedures are taken as the base for testing and evaluation. The vehicle manufacturers are responsible for the reliability and safety of their vehicles. Based on experiences and scientific knowledge, they have developed testing and qualification criteria in order to make sure their vehicles suffice the reliability and safety requirements. Failures at least damage the brand image, but might also endanger life. The vehicle manufacturers should hence not be forced to adopt a material outside their testing and qualification criteria.

*Individual versus joint testing and qualification*

Normally, each car manufacturer or glass manufacturer performs his own tests to qualify materials. This is not possible in this review process due to time and other constraints. A joint testing program is hence required.

This implies several problems. The first one is the setup of a testing and qualification procedure. The vehicle manufacturers' testing and qualification procedures are at least partially different. This problem was experienced during the setup of the Joint Testing Program (Joint Testing Group 2009). Although there are standard tests, there is no standard test program defined, which all vehicle manufacturers apply identically. And there is nothing like an official European Union or European Commission test program, or a test program supported or required by the Commission, as Antaya claims.

While all or almost all vehicle manufacturers apply the four ageing procedures in the Joint Test Program, the parameters of these procedures are individual to each vehicle manufacturer, as well as, at least in parts, the testing and acceptance criteria (Joint Testing Group 2009). Further on, there is a range of ageing procedures and tests, which are individual to single vehicle manufacturers.

As Antaya points out in several of its stakeholder comments, the standard way of approving a material therefore is to work individually with a vehicle manufacturer and/or its supply chain following the vehicle manufacturers testing and qualification procedure. The material will then be qualified for specific applications, e. g. on a specific glass of one or several car models.

This review process, however, forced a deviation from this procedure. It must be decided whether lead in solders for soldering on glass actually can be banned after 2010 in all applications on all glass of all vehicles with new type approval of all vehicle manufacturers. The decision would be easy if the material had been qualified by each vehicle manufacturer for all its applications. As this is not the case, a Joint Test Program had to be set up to which the vehicle manufacturers agreed, which took time and numerous discussions, and required compromises from many of the vehicle manufacturers involved.

The vehicle manufacturers' procedural priority has its limits where the requirements are not plausible in their contents or timings. Art. 4 (2) (b) (ii) requires the replacement of lead where its use is avoidable. The vehicle manufacturers have to aspire legal compliance, which implies their due cooperation in the review and evaluation process.

*Priority of Joint Testing Program over other test results*

The priority of the vehicle manufacturers testing and qualification procedures consequently results in giving priority to the Joint Testing program over other test results submitted in case of conflicting results. The Joint Testing Program was set up with involvement and agreement of the vehicle manufacturers and other stakeholders. This does, however, not mean that other test results are not taken into account during the review. They are used as supporting evidence, or as complementary information.

**Reviewers' conclusions**

The core task of the review process is to find out whether the state of science and technology enables avoiding the use of lead for soldering on glass in vehicles. Art. 4 (2) (b) (ii) only allows an exemption if the use of lead is unavoidable.

The situation can be described as follows from the review point of view:

- The lead-free solders performed well in the joint testing program.
- There are remaining concerns on the low melting points of the lead-free alloy.
- There are different views on the timing of implementing lead-free soldering in glazings.

In the Joint Test Program, the lead-free solders did not exhibit specific weaknesses in the ageing procedures and tests performed. The lead solders preformed well. Compared to the lead solders, their performance was at least not inferior in the pull testing and the infrared inspection after ageing tests 1 to 4, and the lead-free solders caused less microcracks in the glass than the lead solders.

*Necessity of field testing and available field data*

The priority given to the vehicle manufacturers testing and qualification procedures has direct consequences for Antaya's claim that in-field testing of the lead-free solders is not required. All vehicle manufacturers involved had agreed that the lead-free solders had to pass the Joint Test Program, and then would have to undergo an in-field test (Joint stakeholder working group 2009). The vehicle manufacturers had set out around one year of field testing in the very beginning of the Joint Testing Program.

Antaya claims that the indium based lead-free solder alloy is in use in numerous cars already and that therefore field experience is available. The only clearly documented cases of "on the road" use are two different car types or models of two different manufacturers. Further information Antaya has submitted shows that Antaya is involved in development and qualification activities with its lead-free alloy at several OEMs and glass makers or other suppliers (Antaya 2009f).

PPG, a glass maker, confirms that a solder of the composition 30Sn65In0.5Cu4.5Ag was applied in

- the GM "U" Van (Chevrolet Venture, Pontiac Montana and Oldsmobile Silhouette)
  It was used in an integrated circuit replacing the antenna in the windshield. The design was in use from around 1999 to 2001 or 2002 (Antaya 2009d).
- the Ford "T" Bird
  The alloy was used in a heated wiper circuit along the bottom edge of the windshield. Around 70,000 units of this vehicle were built from 2002 to 2005 (Antaya 2009d).

PPG applied the indium-based lead-free solder because of its low melting point to avoid breakage of the glass or of the silver, as PPG had to solder to silver screened annealed glass. PPG was not notified of any damages or failures of its product in the vehicles (Antaya 2009d). The fact that the design using lead-free solders was only used for around 3 years thus does not go back to failures, but has other reasons, which are not known to the reviewers. The same applies to the short production time of the Ford T Bird.

PPG adds that this is no way an endorsement of Antaya's indium based solder as it is up to each manufacturer to test and evaluate materials they use (Antaya 2009d). Different silvers, paint compositions and processing parameters can all affect the reliability of the final product. PPG further on explains that they ¨have never used or validated any lead free solder for tempered automotive glass use. The significance of this is that none of the laminated parts carried any current greater than 5 amps (Beckim 2007). Heated backlight circuits, the majority of applications, require 20 to 30 amps of power."

The above field experience thus justifies claiming that Antaya's lead-free solders have proven to be a viable and reliable substitute in field for lead in the above application, beyond the laboratory test level. This confirms the positive result of the Joint Test Program in the laboratory. PPG states that there are numerous applications with different connectors on different prints and under different operating conditions, which may be individual for each car model (Antaya 2009d). According to PPG's statement, the lead-free alloy was operated with a maximum of 5 Ampere, not with 20 to 30 Ampere as in heated backlights.

Antaya is involved in qualification programs at several glass makers and vehicle manufacturers (Antaya 2009g), and reports some other vehicles that were put on the road just recently using the 49141-32-13-65 alloy, which is the lead-free alloy used in the Joint Test Program (Antaya 2009j).

*Melting points of the lead-free alloy*

Concerns are remaining on the low melting point of the lead-free alloy. Antaya had provided tests conducted at 100 °C and at 105 °C, which according to Antaya should prove that the lower melting point of the alloy is not of concern. According to the submitted tests (see Test I and Test II in the Annex), the tested samples have passed the tests.

ACEA et al. claim that temperatures in a car at certain solder joints may rise up to 130 °C. The vehicle manufacturers therefore do not accept the Antaya high temperature test results as a proof that the low melting point is of no concern. They maintain that the Antaya lead-free solders failed in tests at 110 °C already. ACEA et al. did, however, not provide evidence neither on the 130 °C temperature maximum nor on their claim that the Antaya alloy fails at 110 °C, and under which conditions this was tested. Available data from Volkswagen measured at the defogging/defrosting of a rear window suggest that temperatures of slightly above 100 °C may actually occur.

The Joint Test Program suggests that, besides the four tests adopted, additional tests may be required depending on the material properties of the lead-free alloy (Joint Testing Group 2009). This clause was inserted as Antaya (2009h) refused revealing the composition and material properties of its lead-free solder alloy. It was only on 22 May that Antaya finally provided official information on the lead-free alloy composition and on its solidus and liquidus temperature.

Ageing procedures and tests at high temperatures well over 100°C were not part of the testing program worked out with the vehicle manufacturers in the Joint Testing Program. With the solidus temperature of the lead solder being at 160°C, (Table 20 on page 156), the lead solders did not give reasons for concerns about possible effects from the alloy melting point. Even if the temperature at solder joint reaches 130°C, there are still 30°C safety margin to the solidus temperature of the alloy.

The Joint Testing Program states that such tests might be additionally required if material properties of the lead-free alloy would differ considerably from the material properties of the lead solder. The lower melting points are a considerable difference in material properties. As Antaya was not willing to provide the required data, the vehicle manufacturers were not able to have their concerns reflected in appropriate tests in the Joint Test Program.

Finally, the vehicle manufacturers express concerns on the high temperature capabilities of Antaya's lead-free alloy. According to the high temperature tests provided by Antaya (Test I and Test II in the Annex), the lead-free solder is capable to withstand certain mechanical burdens at higher temperatures of up to 105°C. Clear evidence is available that the heat grid connectors may heat up to more than 100°C under ambient temperatures of around 30 to 35°C. In some hotter climates with high humidity, defogging of backlights may be necessary despite of high ambient temperatures, which may result in possibly higher temperatures at the solder joint exceeding the 105 C. On the other hand, the vehicle manufacturers did not provide evidence that temperatures higher than 105 °C, up to 130 °C, as they had claimed, actually occur. As Antaya's high temperature tests show that the lead-free alloy has mechanical stability at 105°C, while the other stakeholders could not provide evidence for their opposing statements, the expiry date of the exemption should include heating grid applications.

Given the around 60 C lower melting point of the lead-free alloy, it is at least clear that the safety margin for higher temperatures in terms of temperature distance to the melting point is small and may cause problems. As Antaya had refused until May 2009 to reveal the composition and the melting point of the alloy, and alloy samples were not available, there was no opportunity for glass makers and the vehicle manufacturers to check the viability of the lead-free alloy under extreme temperature conditions so that non-confidential information would be available for the review process.

As the material exhibited good performance in the prevention of microcracking, increases of the melting point might be possible at still satisfying ductility to prevent microcracks. This would require adaptation and development work.

The overall situation thus does not justify lifting the expiry date for specific applications, in which high temperatures may occur.

*Discontinuation of the exemption*

The overall picture shows that lead is no longer unavoidable in solders for soldering on glass in vehicles. Art. 4 (2) (b) (ii) thus in principle requires revoking the exemption. As the implementation may need time, and as it is not ultimately clear whether the lead-free alloy actually can replace lead in all applications, an appropriate transition time will be necessary allowing a safe and reliable shift to the use of lead-free alloys wherever possible. The remaining question to be clarified thus is whether the current expiry of exemption 8b at end of 2010 for new type approved vehicles is appropriate in this respect.

**Appropriate expiry date**

The stakeholders' comments on an appropriate transition period until the expiry of exemption 8b are widely different. Antaya claims that the current expiry date at end of 2010 is appropriate, which corresponds to around 19 months of transition time. The vehicle and glass manufacturers claim 54 months of transition time as appropriate, which translates into an expiry date in end of November 2013 (see page 166 ff).

Antaya states that there is no evidence that the lead-free alloy is not a drop-in solution. It can be implemented with just minor changes within a short time in each application, and without requiring more than standard technologies already available in most of the glass plants.

It is correct, that an evidence is not available that the lead-free solder is not a drop-in solution. The results of the joint test program at least show that in most cases the lead-free alloy passed the tests without prior optimization of connectors, glass and soldering, as Antaya had stated.

Vice versa, however, there is no evidence that the lead-free alloy is a drop-in solution in each and every case, as the testing program as well as other available evidence cannot cover each and every application. It is thus, contrary to Antaya's statement, not inconceivable that in some cases further development works might be required. PPG, the glass maker confirming the use of Antaya's lead-free solders in GM and Ford cars (Antaya 2009d), stated that "the automotive application of this new technology will require validation and performance testing before indium based lead free solder could be certified for use in production. The lead time for this type of effort typically requires a 2 year minimum to complete exposure testing and an additional 1 year lead time to establish supply" (Beckim 2007).

The glass and vehicle manufacturers have set up a worst case scenario. The field testing time has been extended from one year to 18 months, which does, however, not affect the total timing due to the parallelization of this step with other stages of the transition. The steps where these stakeholders indicate additional time needed are those cases where the lead-free alloy cannot be considered a drop-in (Figure 52 on page 163) and requires additional development works, changes of process equipment in glass plants, etc. However, it may not be necessary that the lead-free alloy actually is a drop-in in every case. Exemption 8b in its current version bans the use of lead in new type approved vehicles only in order to avoid retrofitting into existing or already developed vehicles. The new type developments and qualifications may require development works and even changes to the processing equipment anyway.

There is no clear evidence that either the one or the other position on the expiry of exemption 8b is completely correct. The alloy may actually work as a drop-in solution for many applications. Lifting this exemption would ban the lead in each and all applications for soldering on glass. For some applications, more development and adaptation might hence be required with more time. PPG, as a stakeholder not directly involved in this or the previous review process, points out three years of transition time in the glass plant (Beckim 2007). Additionally, some time may be needed at the vehicle manufacturers.

Taking into account all the information and aspects raised, the reviewers recommend shifting the expiry date to end of 2012. The expiry of the exemption on the one hand should accommodate the requirements of Art. 4 (2) (b) (ii) to substitute lead where its use is no longer unavoidable, and the transition period of around 40 months on the other hand should leave sufficient time to adequately develop and implement the shift to lead-free soldering in the supply chain and with the vehicle manufacturers:

- The introduction of the lead-free alloy can be prepared and implemented in the vehicles, which are under development for type approval after 2012 following the established development and qualification procedures.
- This transition period of 40 months, although well below the requested 54 months, should be long enough to prepare and implement the use of the lead-free alloy in the supply chain for the vehicles with new type approval after 2012.
- This transition period should be long enough on one hand to find out possible problems with the low melting point alloy in high temperature applications, and to improve and adapt the lead-free alloy if possible. It should as well be long enough to allow applying for specific exemptions in case lead-free solutions prove to be not appropriate for some applications.
- The transition period should be short enough to accommodate the requirements of Art. 4 (2) (b) (ii) to substitute lead in all applications where it’s use is no longer unavoidable. As the expiry date is not lifted off, vehicle and glass manufacturers will have to continue with the implementation of lead-free soldering solutions.

**Exclusion of soldering in laminated glazings**

Soldering in laminated glazings was excluded from the Joint Test Program. Antaya had not tested its solders for this application (Joint stakeholder working group 2009; Antaya 2009h). At a meeting of the Joint Testing Group, Antaya suggested integrating soldering in laminated glass into the testing program, but would need the glass makers' support for the supply of the laminated glass. The glass makers opposed this plan stating that soldering in laminated glass would be product and technology development and that the Joint Testing Program focuses on testing solutions, which Antaya had claimed to have, not those that have to be developed (Joint stakeholder working group 2009).

Antaya (2009h) admits that none of its test results submitted to the review process proves that the lead free solution works in the "in lamination" application. Antaya (2009h) explains that the chemical and physical relationship between the buss bars, the wires and the connectors are exactly the same as those "on-glass" as opposed to "in-glass". Antaya has for many years supplied leaded solder parts for use "in-glass and on-glass" with identical results. Antaya has successfully converted leaded on-glass applications over to lead free.

Antaya points out that soldering in laminated glass, however, needs an autoclave machine and all the customary expertise of an automotive glass plant (Antaya 2009h). Antaya complains that the glass companies refused cooperation in the Joint Testing Group for testing of the lead free solder in the in-glass application. For Antaya , it is apparent therefore that since the glass companies have refused to test the lead free solution, and Antaya cannot test the lead free solder parts without the cooperation of at least one glass company, there is something of a stalemate (Antaya 2009h). It is Antaya's contention that the exemption should be removed since the in-glass technology is substantially identical to the proven on-glass technology. Furthermore, if the glass companies are allowed to "stonewall" the Commission by refusing to cooperate in tests designed to remove the exemption, the requirement of the ELV Directive can never be met. The coordinated obstruction of the glass manufacturers is entirely inconsistent with the will of the Commission and the Commission should take this opportunity to send the appropriate message (Antaya 2009h). Antaya therefore believes that this issue may fall beyond the boundaries of the technical and scientific assessment and be more political in nature.

The reviewers' task is the technical assessment of the progress of science and technology in order to adapt exemption 8b. As a matter of fact, no evidence is available that Antaya's lead-free solders work for soldering in laminated glass. The reviewers' can only give recommendations based on publicly available technical and scientific information. The assessment of political issues is beyond the reviewers' mandate, as Art. 4(2)(b)(ii) does not allow such arguments as justification of exemptions or their repeal.

It is therefore recommended to exclude soldering in laminated glass from the ban of lead until there is evidence that a solution is available. To promote the technical and scientific progress towards a lead-free solution, it is recommended to review this exemption in 2014. The stakeholders will then have to show that they have undertaken steps to achieve compliance with the material bans in the ELV Directive.

### 4.17.6 Final recommendation

It is recommended to maintain the expiry date in exemption 8b, but to shift it to the end of 2012. It is further on recommended to introduce a specific exemption for soldering inside laminated glazings and to set an expiry date in 2014. While the proposed lead-free solution could sufficiently prove that it can be a substitute for lead in solders in glazing applications, there is no evidence that the solution works for soldering inside laminated glass. Art. 4 (2) (b) (ii) thus would allow the continuation of the exemption.

The recommended wording is:

> *Lead in solders in electrical glazing applications on glass except for soldering in laminated glazing in vehicles type approved before 1 January 2013.*

and

> *Lead in solders for soldering in laminated glazings; review in 2014.*

### 4.17.7 References exemption 8b


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Antaya 2009a — Antaya; Stakeholder document “1a-Antaya_Specific-Questionnaire .pdf”, submitted during online stakeholder consultation

Antaya 2009b — Antaya; stakeholder document “2.a Test Protocol Submitted to EC by European Glass Manufacturers January 2008”, submitted to online stakeholder consultation

Antaya 2009c — Antaya; stakeholder document “VW MICRO CRACK DATA 3-6-09.xls”; numbers of microcracks in glass samples; assessed by Antaya, AGC, Guardian, Pilkington

Antaya 2009d — Antaya; stakeholder document “4.h Documents from Pittsburgh Glass Works.pdf”, submitted during the online stakeholder consultation

Antaya 2009e — Antaya; stakeholder document “5 Timeline for Substitution of Hazardous Material”, submitted during the online stakeholder consultation

Antaya 2009f — Antaya stakeholder documents in folder "Antaya Applications and Developments", submitted during the online stakeholder consultation

Antaya 2009g — Antaya stakeholder documents in folder "Antaya Test Results", submitted during the online stakeholder consultation

Antaya 2009h — Antaya; stakeholder document "Letter_to_Otmar_Deubzer-oct-08-2008", sent to Otmar Deubzer, Fraunhofer IZM, via e-mail on 8 Oct. 2008

Antaya 2009h — Antaya; stakeholder document "OD Response 5-27-09.doc", sent to Otmar Deubzer, Fraunhofer IZM, via e-mail in May 2009

Antaya 2009i — Antaya; stakeholder document "2.b Test Protocol Submitted by CLEPA April 2008.pdf", submitted during the online stakeholder consultation

Antaya 2009j — Antaya; stakeholder documents in folder "Antaya_on_the_Road", sent via e-mail to Otmar Deubzer, Fraunhofer IZM, on 9 June 2009

Beckim 2007 — Ken Beckim, PPG; E-mail sent to Otmar Deubzer, Fraunhofer IZM, on 5 December 2007 during the 2007/2008 review of Annex II of the ELV Directive

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Joint stakeholder working group 2009 — Document "Minutes-08-04-18-final.doc", minutes from the joint stakeholder working group, confirmed by all participants (OEMs, ACEA et al., glass makers, Antaya)

Joint Testing Group 2009 — Document "Joint Test Program Final.doc"; set up by the open Joint Testing Group in January 2009

Marchant 2009 — Marchant, Philippe, AGC Automotive Europe; information sent via e-mail to Otmar Deubzer, Fraunhofer IZM, on 08 June 2009

| | |
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| Pinsker 2009a | Martin Pinsker, BMW; Document "Summary of products tested.xls", sent to Otmar Deubzer via e-mail on 2 June 2009 |
| Pinsker 2009b | Pinsker, Martin on behalf of ACEA, CLEPA et al.; Stakeholder document "BMW-results and statements.pdf", sent to Otmar Deubzer, Fraunhofer IZM, via e-mail on 5 June 2009 |
| Pinsker 2009c | Pinsker, Martin; Information on composition of Antaya solders, sent to Otmar Deubzer on 9 June 2009 via e-mail |
| Rakus 2009 | Rakus, Hagen, Volkswagen; Document "Präsentation Indium Soldering-VW.pdf"; sent to Otmar Deubzer via e-mail on 26 May 2009 as Microsoft Powerpoint document; converted to Adobe PDF-document by Otmar Deubzer, Fraunhofer IZM |

## 4.18 Exemption no. 10

*"Electrical components which contain lead in a glass or ceramic matrix compound except glass in bulbs and glaze of spark plugs"*

### 4.18.2 Terms and definitions

| | |
|---|---|
| Curie temperature | temperature at which ferromagnetic materials become paramagnetic |

### 4.18.3 Background

This exemption was reviewed in 2007/8 during the review of Annex II of the ELV Directive (Gensch et al. 2008). The corresponding exemption in the Annex of the RoHS Directive was reviewed in 2008/09 (see final report of the previous review of RoHS Annex (exemption 7c) (Gensch et al. 2009).

During the review of exemption 7c of the RoHS Directive, it was found that lead can be replaced in the dielectric ceramic materials of low voltage capacitors. To adapt the exemptions for lead in ceramics to scientific and technical progress, and in line with the Commission's approach to make exemptions as application-specific as possible, the consultants had recommended to limit the use of lead in dielectric ceramics to high voltage applications of capacitors (Gensch et al. 2009). Yet, there were remaining questions about whether the proposed recommendation would sufficiently specify all relevant applications, or whether other applications of lead in glass and ceramics of components could have been identified.

In the current review of Annex II of the ELV Directive, it must be checked whether and how far the findings during the review of the Annex in the RoHS Directive also apply for the respective exemption 10 of the ELV Directive. The technical background for the exemptions for lead in glass and ceramics of components is identical in both Directives. Technical and scientific alignment of these exemptions and their wording between the two Directives is thus desirable, as far as specific conditions for the use of such components in vehicles compared to non-automotive applications do not justify differences.

#### 4.18.4 Description of exemption

The exemption and its technical background were described in detail in the final report of the previous review of Annex II of the ELV Directive on page 65 ff (Gensch et al. 2008), as well as in the final report of the review of the RoHS Annex (exemption 7c) (Gensch et al. 2009).

Glass, ceramics, and mixes of glass and ceramics with or without lead are used in multifold applications in electrical and electronic components:

- Electrical and electronic components may contain different types of ceramics with different properties. In some of these ceramics, the use of lead still is unavoidable. Figure 56 shows a classification of ceramic materials and their main uses.

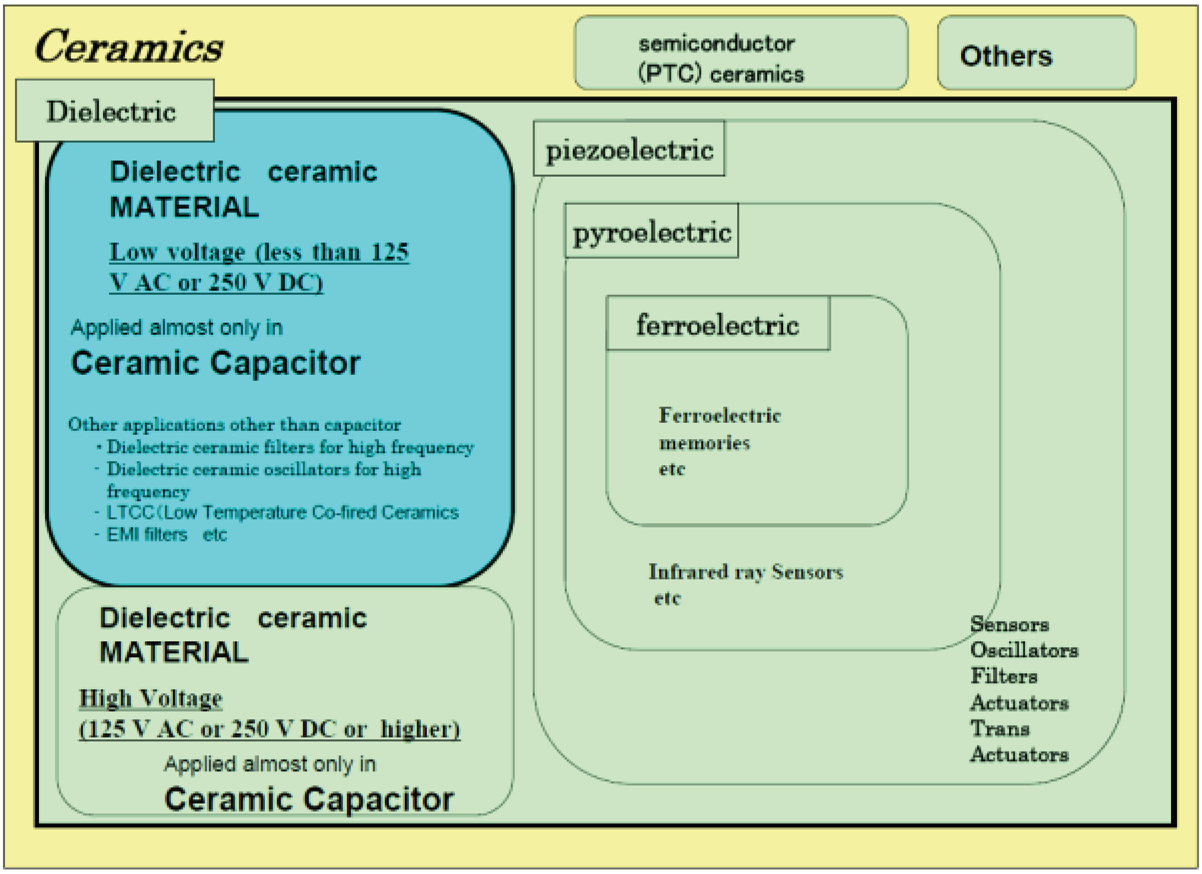


Figure 56 Classification of ceramic materials and their main uses (JEITA et al. 2009)

Figure 76 on page 258 in the annex gives a more detailed overview on these different applications.

- Glass and glass-ceramic materials, as well as glass and glass-ceramic matrix compounds are used in components for specific electrical and mechanical functions. Why in the applications in Figure 56 ceramics can be clearly identified as ceramics, in many other applications, this is not always clearly possible. There are overlaps, so that the exemption covers the use of glass and glass-ceramic materials and matrix compounds. In some applications, the use of lead is still unavoidable. Figure 76 on page 258 and Figure 78 in the Annex give a detailed overview on the uses of such materials in components.

The stakeholders indicate the amounts of lead used in ceramics and in glass in vehicles covered by the ELV-Directive as shown in Table 22.

Table 22 Estimated amounts of lead in glass and ceramics of electrical and electronic components in vehicles (CLEPA et al. 2009b)

| Area of lead use | Amount |
|---|---|
| Pb in glass | 27 t |
| Pb in ceramic (piezo) | 250 t |
| Pb in other ceramics | 100 t |
| Total | ~ 380 t |

The above numbers do not comprise 100% of lead used in these applications, but just a good estimate of the main applications, according to the stakeholders (CLEPA et al. 2009b). The detailed uses of lead in different applications is listed in Figure 77 in the annex. Summing up the amounts of lead uses indicated in this table results in a total amount of around 550 t of lead used under exemption 10 in vehicles. It is not clear how much other than the main uses of these materials actual contribute to the total amount of lead used.

### 4.18.5 Justification for exemption

**Basic information on ceramic capacitors**

*Dielectric ceramics*

If electrodes are set on both sides of a substance which does not conduct electricity (insulator), and if they are connected to positive/negative power sources respectively, "electric polarization" is generated within the insulator. Ceramics generating such electric polarizations are "dielectric ceramics". The major characteristics of dielectric materials are to store electricity, not to conduct electrical currents (JEITA et al. 2009a).

Dielectric ceramics are mainly made of titanium dioxide (rutile), calcium titanate, strontium titanate, magnesium titanate and barium titanate. To obtain the intended electrical properties, these materials are used individually or in multiple combinations, sometimes with additional dopants like for example lead.

*Crucial performance requirements of capacitors*

The main characteristics of capacitors are (JEITA et al. 2009a):

- high capacity to accumulate electricity (high dielectric constant, high relative permittivity) for both low and high voltage uses;
- small dielectric losses when electricity is accumulated, important in particular for high voltage uses;
- high breakdown voltage (capacity to withstand high voltage), important in particular for high voltage;
- high frequency characteristics (capacity to be used with high frequencies), important for both low and high voltage.

High and low voltage uses of ceramic capacitors are a crucial distinction criteria with respect to lead use and substitution.

*Shapes and manufacturing technologies of capacitors*

Ceramic capacitors can be found as disk-type and as multilayer ceramic capacitors (MLCC).

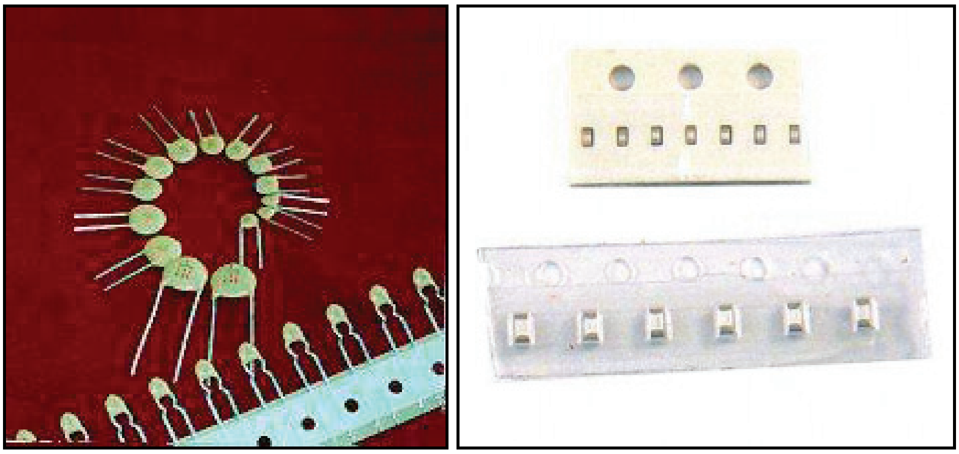

Figure 57 Disk (left) and MLCC type capacitors (source: www.allproducts.com)

A crosscut view of an MLCC capacitor is shown in Figure 60 on page 191.

Besides their shape, ceramic capacitors can be differentiated by their electrodes into noble metal electrode (NME) capacitors and base metal electrode (BME) capacitors (ACEA et al. 2009). The use of noble metal electrodes characterizes a manufacturing technology of ceramic capacitors. The inner electrodes are formed by noble metals (silver and palladium), which are sintered together with the dielectric ceramic, which contains lead. The NME technology was used from the very beginning to produce ceramic capacitors. The first ceramics needed high sintering temperatures of more than 1 000°C, and the noble metals forming the electrode are needed to withstand these high temperatures without being oxidized (Murata 2009).

The demand for ceramic capacitors grew rapidly in the past. The base metal electrode (BME) technology was therefore developed in the 1980s. A main driver were the high material prices of the noble metals in the NME capacitors, especially of palladium. In this BME technology, “base metals” like nickel or copper form the inner electrodes. Nickel and copper electrodes, however, cannot withstand high temperatures and therefore need ceramics with lower sintering temperatures. They must be sintered in ovens with nitrogen atmosphere. In consequence, the BME technology needs special low temperature ceramic systems and high investments for the manufacturing technology. These ceramics can be lead-free for capacitors in low voltage applications, as explained in the subsequent sections of this report (Murata 2009).

Due to the high investments, BME technology capacitors can be used only in high volume productions, whereas capacitors with special characteristics and/or in lower quantities may have to be produced in NME technology also in the future. BME capacitors cannot be used in small scale productions (Murata 2009).

Currently, high voltage capacitors in applications with high quantities and lower performances are produced with BME technology, whereas capacitors for higher performance and lower quantities have to be produced in NME technology also in future (Murata 2009).

**Use of lead in dielectric ceramic materials of low voltage capacitors**

*Lead as dopant in the dielectric ceramic of capacitors*

The high sintering temperature ceramics used in NME technology as explained in the previous chapter still are used in applications, which need high performance and stable electrical features. In the low voltage area, these types of ceramics need lead as dopant. Dopants are added to a base material ceramic to achieve the specific electrical and/or mechanical properties needed in the capacitor (Murata 2009). For low voltage NME capacitors, barium-titanate ceramics are doped with lead, so that the lead content is around ~1% in the ceramic lattice (ACEA et al. 2009).

*Possibilities and limits of lead-free ceramic capacitor use*

Generally, capacitors with a rated voltage of less than 125 V AC or 250 V DC do not use lead-containing dielectric ceramics. In remaining low voltage applications, (BME) capacitors with lead-free dielectric ceramics in principle can replace the (NME) capacitors with leaded ceramics in most cases. The substitution requires, however, a redesign of the whole electrical module or unit. BME-types are suitable and even better performing substitutes in nearly all cases except where good mechanical stability and/or high ESD (electrostatic discharge) robustness are required (ACEA et al. 2009, Murata 2009).

The stakeholders say (ACEA et al. 2009) that there were ongoing efforts to replace NME type by lead-free BME type capacitors. BME capacitors, according to the stakeholders (Murata 2009), cannot fully replace the NME capacitors due to the performance differences of the ceramic materials. For those applications new exemption requests will have to be issued (Murata 2009).

The majority of automotive applications operate at voltages below 125 V AC or 250 V DC. Most ceramic capacitors used in automotive electronics thus can be lead-free. Lead-containing NME type capacitors are, however, used in vehicles to prevent damages in case of high voltage impulses from the electrical system or from electrostatic discharges (ESD).

The breaking strength of BME type capacitors is lower (~100 MPa as the order of magnitude) The stakeholders (ACEA et al. 2009) list typical applications in automotive areas that rely on good mechanical stability and/or high ESD robustness, like (ACEA et al. 2009):

- battery line applications;
- engine control units;
- airbag control units;
- air conditioning;
- antiblocking system (ABS) control units.

ACEA et al. (ACEA et al. 2009) explain that for the same ESD robustness, a 10 nF (nano-Farad, unit for the capacity) lead-containing NME type multilayer ceramic capacitor (MLCC) has to be replaced by a BME type capacitor with a higher capacity. The submitted results of an ESD stress test shall support this statement (ACEA et al. 2009).

| Case | Cap. | Char. | Voltage rating (V) | designation |
|---|---|---|---|---|
| 0603 **NME w. Pb** | 10 nF | X7R/NME | 50 | „10nF ESD“ |
| 0603 **BME w/o Pb** | 10 nF | X7R/BME | 50 | „10nF std“ |

Figure 58 NME and BME capacitor used in ESD testing (ACEA et al. 2009)

The above capacitors of equal capacity were used in an ESD test. Figure 59 shows the test result.

| | AEC-Q200 | contact discharge | | air discharge | |
|---|---|---|---|---|---|
| **10 nF NME w. Pb** | 18kV | 18kV | 8kV | 18kV | 8kV |
| **10 nF BME w/o Pb** | 8kV | 6kV | 4kV | 6kV | 4kV |

Figure 59 Result of ESD testing (green: passed; red: failed) (ACEA et al. 2009)

The lead-free BME capacitor has a clearly higher failure rate.

Figure 60 shows an ESD damage in a BME MLCC capacitor.

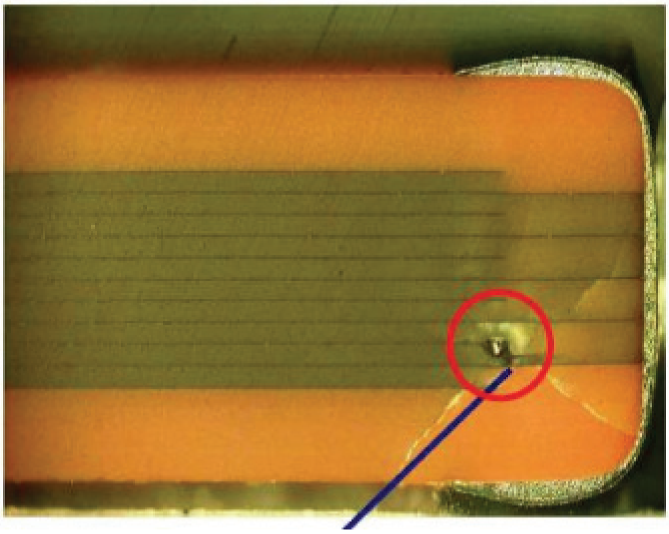

Figure 60 Failure produced with 25kV air discharge in a BME-type capacitor (ACEA et al. 2009)

ACEA et al. (2009) explain that for the same ESD robustness, a lead-containing NME MLCC of 10 nF capacity has to be replaced by a 47 nF BME capacitor, which deteriorates the system function. Other solutions are being developed, but are currently not validated at system level. The conflicts apparently are not resolved yet on system level (ACEA et al. 2009).

BME capacitors thus can replace NME capacitors in the low voltage area, which, however, requires a redesign and requalification of the electronic circuit and the printed wiring board. Lead containing NME type capacitors currently are still needed for reliability and safety reasons (ACEA et al. 2009).

**Lead in dielectric ceramic materials of high voltage capacitors**

The stakeholders point out (CLEPA et al. 2009a) that higher voltages above 125 V AC or 250 V DC may occur in specific automotive applications such as

- in electric and in hybrid electric vehicles (HEV);
- mechatronics;
- head lights;
- VFD/LCD displays.

*Function of lead in ceramics of high voltage capacitors*

JEITA et al. (2009a) explain that high operational voltages and high capacities require dielectric ceramics with small dielectric losses.

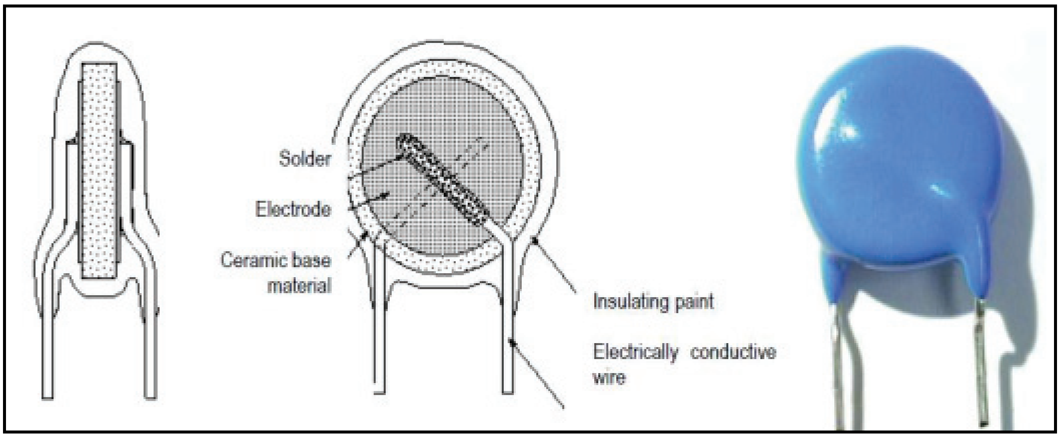


Figure 61 High-voltage disk type ceramic capacitor (JEITA et al. 2009a)

Strontium titanate ceramics are used for high voltage capacitors. Without lead, however, strontium titanate has a very low relative permittivity (capacity) at room temperature. It is less than 10% of the leaded strontium-titanate ceramic materials. In order to obtain the same capacity, a very large shape would be necessary, which in most uses technically is not acceptable (JEITA et al. 2009a).

Lead-oxide is therefore added to increase the relative permittivity (capacity). Different to lead containing ceramics in the low voltage area, lead here is not used as a dopant, but the ceramic system itself is based on lead and other heavy metals (Murata 2009). Leaded strontium-titanate ceramics are the current standard material for high voltage capacitors. (JEITA et al. 2009a, Murata 2009) These lead based ceramics in the high voltage area are used both with NME and BME technology (Murata 2009).

In the voltage range above 125 V DC and 250 V AC, lead containing ceramics hence are needed to achieve sufficient performance. Key parameter is the dielectric loss at high electrical field strength. (Murata 2009) During polarization and de-polarization of a dielectric material, its molecules and atoms are aligned according to the electrical field. This alignment results in dielectrical losses, which heat up the dielectric ceramic.

Lead-free barium titanate (BaTi) ceramics have a high relative permittivity, as can be seen in Figure 62. This lead-free ceramic thus can be used in low voltage applications. However, under high voltage, the dielectric loss is around one magnitude higher compared to lead containing capacitors.

| | Relative permittivity | Dielectric loss (%) | DC breakdown voltage (kV/mm) | AC breakdown voltage (kV/mm) | Impulse breakdown voltage (kV/mm) |
|---|---|---|---|---|---|
| Current lead-based materials | 2700 | 0.04 | 15.3 | 8.0 | 8.0 |
| Barium titanate-based materials | 3000 | 0.80 | 11.8 | 6.7 | 6.0 |
| Strontium titanate | 200 | | | | |
| Notes | Bigger is better | Smaller is better | Bigger is better | Bigger is better | Bigger is better |

Figure 62 Comparison of materials for high-voltage capacitors (JEITA et al. 2009a)

Due to the high dielectrical loss, the lead-free BaTi capacitor heats up much more than the lead-strontium-titanate one (current lead-based material), as shown in Figure 63 (JEITA et al. 2009a).

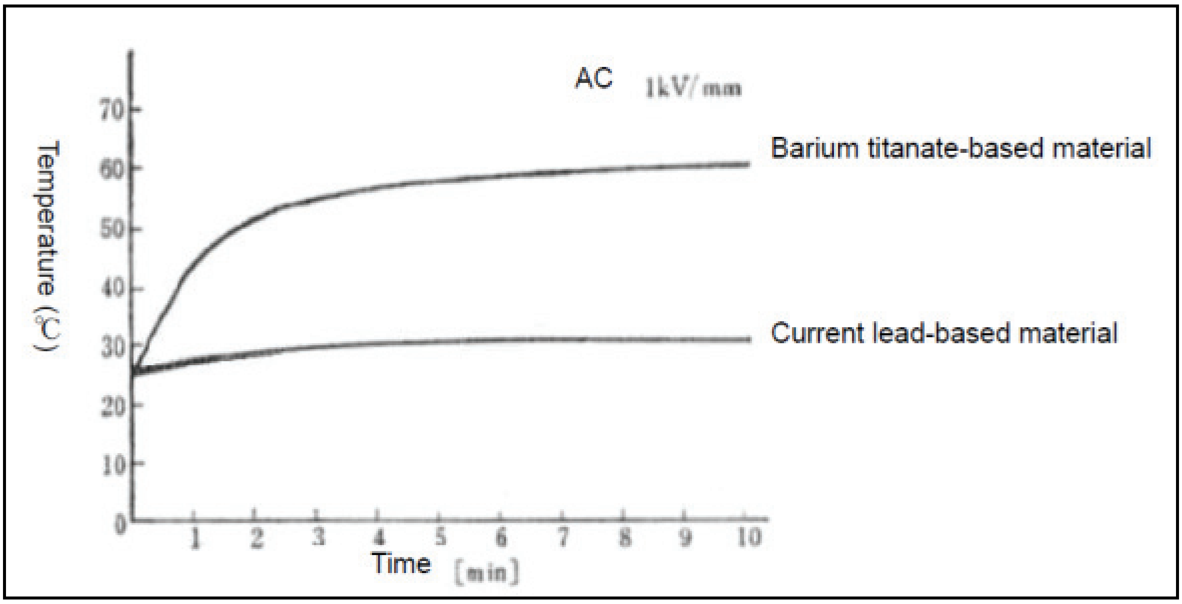


Figure 63 Temperature increase of capacitors under high voltage load (JEITA et al. 2009a)

The hot BaTi capacitor may become unstable. Additionally, barium titanate easily warps when high electric voltage is applied, which may reduce the mechanical stability even further (JEITA et al. 2009a).

Presently, according to the stakeholders (JEITA et al. 2009a), lead-strontium-titanate ceramics are the only possibility offering high relative permittivity and low dielectrical losses and at the same time sufficing all other requirements of high voltage capacitors (cf. Figure 76). NME and BME metal capacitors in high voltage uses.

*Alternatives to ceramic capacitors*

Capacitors using dielectric materials other than ceramics have problems concerning frequency characteristics and breakdown voltages. JEITA et al. (2009a) claim that there is no perspective for substitution since the high voltage capacitor characteristics cannot be obtained.

*Conclusion*

The stakeholders conclude (JEITA et al. 2009a) that non lead-based materials are not practical for capacitors used with high voltage voltages. Other than ceramic capacitors cannot replace ceramic capacitors in such applications. The use of lead thus is unavoidable.

**Lead in the ceramic of piezoelectric components**

In 2008, the use of lead in the ceramics of piezoelectric and PTC components was explained in detail in the review of the Annex of the RoHS Directive (exemption 7c) (Gensch et al. 2009), as well as in the last review of Annex II of the ELV Directive (Gensch et al. 2008). The stakeholders had shown that viable substitutes at an industrial level are not yet available and are not foreseeable in the near future. There is neither evidence nor hints that this situation has changed since these last reviews.

**PZT based dielectric ceramic materials of capacitors in integrated circuits (ICs)**

*Specific material properties and uses*

The stakeholders (NXP 2009) explain that besides the piezoelectric properties, lead-zirconium-titanate (PZT) shows also ferroelectric properties: They are polarized, and the polarization can be reversed by an external electromagnetic field. PZT ceramic thus has the ability to switch polarisation in the electrical field. It has the highest known dielectric constant (k = 1000 – 1200) (ESIA 2006), and a high electrical breakdown voltage of 100 V and more. PZT ceramics therefore are the most effective technical ceramic material to ensure best filter and electrostatic discharge (ESD) performance as required in automotive applications. The PZT based materials in combination with NME (noble metal electrode) only (MIM) meet the ESD performance required in integrated circuits (ICs) or discrete semiconductors. There are no alternative technologies/materials, which can provide the same performance (NXP 2009, ESIA 2006).

The lead content of the PZT based material is typically between 58% and 68% by weight, depending on the proportion of Zr and Ti, with the PZT layers being very thin (ACEA et al. 2009).

Lead is required to achieve the high dielectric constant of the PZT based applications in semiconductors. The PZT layer is encapsulated by layers of silicon nitrides and oxides, electrode metals and polymer layers. Therefore, the PZT is not exposed to the environment (NXP 2009).

Ferroelectric thin films based on PZT are currently used on silicon chips for (NXP 2009):

- FRAM (ferroelectric random access memories, non-volatile memories;
- low voltage high-density (MIM) capacitors ("high-k") with a breakdown voltage of more than 100 V;
- research activities worldwide also consider PZT for use in microactuators ("piezo-MEMS" (micro-electromechanical systems).

Capacitors store electrical energy in dielectric materials. Two electrodes are used to conduct the energy to and from the capacitor. Figure 64 illustrates the two common capacitor types for integrated capacitors. The silicon substrate can be used as electrode (MIS or MOS). In this case, all capacitors share the substrate as ground electrode. MIM capacitors can be used in any configuration (NXP 2009).

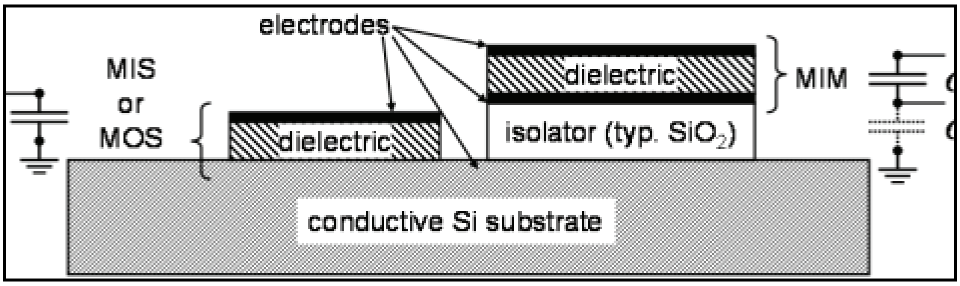


Figure 64 Typical thin-film capacitor configurations: MIM and MIS or MOS (NXP 2009)

*MIM* *metal insulator metal*

*MIS* *metal insulator semiconductor*

*MOS* *metal oxide silicon*

Only thin film ceramics based on PZT offer the combination of high breakdown voltages, high permittivity and temperature stability to realize silicon integrated capacitors and the ferroelectric advantageous properties of FRAMs. These devices are highly reliable and are easy to manufacture (Ramtron 2009).

The stakeholders say (Ramtron 2009) that for automotive FRAM applications, in particular the long term memory retention cannot be achieved with potential substitute materials. Such FRAMs are used in anti-lock brake systems and airbag controllers. They are thus safety-relevant and at the current state of science and technology cannot be replaced (Ramtron 2009).

According to the stakeholders (NXP 2009), PZT based ferroelectric memories have unique properties for mainstream flash and EEPROM chips (NXP 2009):

- low voltage
- low power consumption
- fast write
- high endurance over a broad temperature range

The FRAMS and integrated capacitors based on PZT outperform existing technologies. For both the PZT based integrated capacitors as well as for the FRAMS, market introduction is fairly new. Mass production only started around 2000 (NXP 2009).

*Physical background*

The capacitance density is a measure for how much capacitance “C” can be achieved at a given plate area “A” of a capacitor. With the progressing miniaturization in microelectronics, the available space becomes smaller. It is therefore crucial to achieve high capacitances on small available spaces (areas), which requires high capacitance densities.

The stakeholders explain (NXP 2009) that the capacitance density (capacitance C per area A) of a plate capacitor depends on the relative permittivity k and the thickness d of the dielectric layer. The vacuum permittivity ε0 is constant, while k depends on the dielectric material:

$$\frac{C}{A} = \frac{\varepsilon_0 k}{d}$$

Equation 1: Density of capacitance (NXP 2009)

The thickness of the capacitor depends on the desired breakdown voltage $V_b$ and the breakdown field $E_b$.

$$d = \frac{V_b}{E_b}$$

Equation 2: Thickness of capacitors (NXP 2009, modified)

Replacing “d” in Equation 1 by Equation 2 results in the following equation for the density of the capacitance:

$$\frac{C}{A} = \frac{\varepsilon_0 k E_b}{V_b}$$

Equation 3: Thickness of capacitors (NXP 2009)

The capacitance density increases for a desired breakdown voltage $V_b$ with the relative permittivity k of the dielectric material used in a capacitor and the breakdown field. These two parameters, however, are not independent from each other. Empirical investigations show for low and medium permittivity k that the breakdown field decreases with increased permittivity (NXP 2009) (see Figure 65 on page 198):

$$E_b \propto 1/\sqrt{k}$$

Equation 4: Proportionality of breakdown field and permittivity

For the capacitance density this means that a higher permittivity k leads to an increased capacitance density for a given breakdown voltage specification:

$$\frac{C}{A} \propto \sqrt{k}$$

Equation 5: Proportionality of capacitance density and relative permittivity

According to the stakeholder (NXP 2009) recent results for PZT exceed the empirical trend so that the capacitance density is even higher than expected from the extrapolation from low permittivities. Thus, the PZT-based ceramics offer the unique combination of high relative permittivity k at a high breakdown field and high breakdown voltage.

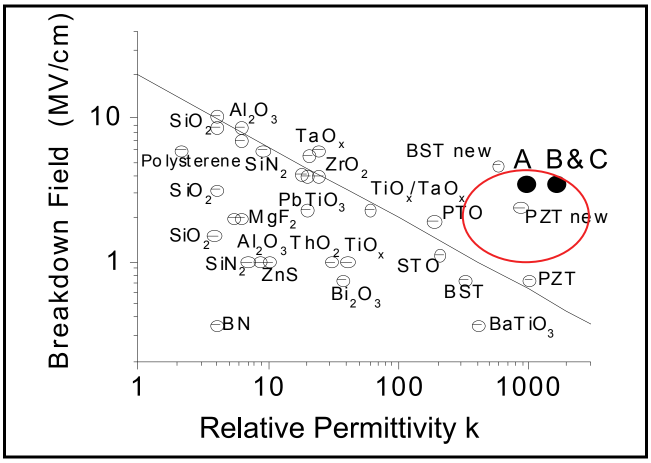


Figure 65 Breakdown field as function of the dielectric permittivity k for various thin film dielectrics (NXP 2009)

According to the stakeholder (NXP 2009), no alternative to PZT is currently known for thin films that achieve the same high permittivity, the same high breakdown field and at the same time meet stability specifications of 20% for temperatures between -25 to +85°C.

*Substitute materials*

ESIA states (ESIA 2006) that its member companies are committed to finding alternatives to the use of lead in semiconductor devices, e. g. through participation in EU funded projects, such as MAXCAPS or FOXPAD, searching for alternative materials (NXP 2009). So far, non of the examined alternative materials like SBT, BST, ZnO, and others works as well as PZT.

BST (Barium strontium titanate) has proven sufficient permittivity and temperature behavior. The permittivity of BST is only half the permittivity of PZT (NXP 2009, ESIA 2006). This would result in much larger devices, which won't meet the size dimensions of current and future applications in semiconductors. Barium titanates have also the disadvantage of a worse matching of the thermal expansion coefficient to the silicon substrate. They thus increase the thermal mismatch, which over time may result in failures. Performance characteristics with alternatives are severely degraded (ESIA 2006).

NXP and ESIA claim (NXP 2009; ESIA 2006; Ramtron 2009) that only thin films ceramics based on PZT offer breakdown voltages, permittivity and temperature stability to realize silicon integrated capacitors.

*Substitute technologies*

Trench (MOS) capacitors could be a potential alternative to high-density silicon integrated capacitors.

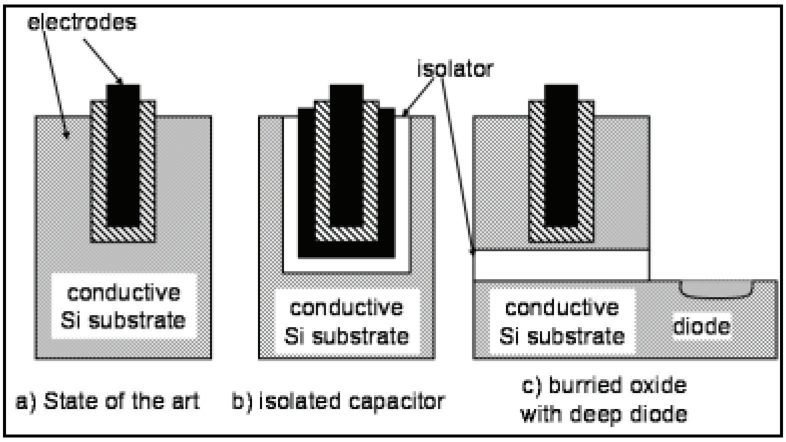


Figure 66 MOS trench capacitors (NXP 2009)

According to the stakeholders (NXP 2009, ESIA 2006), however, trench capacitors have

- much lower capacitance density and
- significantly lower breakdown voltage only (30 V, compared to 100 V for PZT-based materials (ESIA 2006)

compared to PZT based capacitors.

The disadvantage of a the lower capacitance density can partially be compensated by using the 3rd dimension making the capacitors larger. However, the stakeholder claims (NXP 2009) that the breakdown voltage of PZT based capacitors cannot be reached and that the MOS trench capacitors thus are not a viable substitute for the PZT based capacitors containing lead. MIM-type high k capacitors cannot be verified without PZT ceramics.

*Conclusion*

The stakeholder concludes (NXP 2009) that technically there are no alternatives for integrated MIM like PZT capacitors. PZT is the only material to integrate highest capacitance density with high breakdown voltages on silicon to ensure best filter- and ESD-performance at low leakage current levels. Trench- and BST-capacitors cannot fulfil the requirements.

**Lead in PZT ceramic passivation layers of multilayer ceramic varistors**

Multilayer ceramic varistors (MLVs) are used in electronic circuits to protect the circuitry from overly high voltage (e. g. from ESD, electrostatic discharge) or from electromagnetic interferences (EMI). The ceramic material used in MLVs is hexagonal zinc oxide (ZnO), doped with Bismuth, Cobalt, Manganese and Antimony oxides. Lead is contained in a ~20 µm thick passivation layer in the form of a lead-zirconate-titanate (PZT) ceramic. The lead content within these materials is up to 0,5% by weight (ACEA et al. 2009).

The PZT layer together with bismuth serves as sintering aid for liquid phase sintering. Without lead, the phase equilibrium between palladium (Pd, the inner electrode is Ag/Pd 75%/25%), and bismuth is distorted so that reliability and function parameters decline (ACEA et al. 2009).

The stakeholders claim (ACEA et al. 2009) that at the current state of science and technology, there is no reliable alternative to the use of the lead-containing PZT passivation layers. The use of glass coatings instead of a ceramic PZT coating resulted in high failure rates in most automotive applications compared to the lead-containing coating. As safety functions are involved (e. g. airbag, ABS, gear control) the research has to be continued until all failure rates have been dropped to required levels (ACEA et al. 2009).

**Lead in the ceramic of PTC components**

*Function and ceramic materials used*

Positive temperature coefficient ceramics (PTC ceramics) increase their electrical resistance with increasing temperature. Examples of material compositions are barium-strontium-lead-titanate, barium-titanate and lead-zirconate-titanate with dopants. The basic PTC material barium-strontium-lead-titanate undergoes a phase transition (from ferro- to paraelectric) at a certain temperature (Curie temperature, material dependent). If properly processed and slightly donor doped (< 1 mol %), such materials are “PTCR active”, meaning that they become semiconductive at low temperatures and quite highly resistive at temperatures above the Curie temperature (ACEA et al. 2009).

*PTC components and their use*

PTC ceramics are used in components called thermistors as overheating detector (temperature sensor) and for over-current protection in all engine section parts and all car electronic circuits. PTC materials as self regulated heaters are in use also for cabin heating, fuel and fuel filter preheating, and nozzle heating (e.g. washer and crankcase ventilation) (ACEA et al. 2009, JEITA et al. 2009a).

*Function of lead*

The lead content of these materials is up to 50% by weight. Lead is used in the solid solution of barium titanate and lead titanate. Substituting the barium atoms of barium titanate by lead atoms increases the Curie temperature and creates a PTC ceramic for high-temperature operation.

In automotive applications with its high operating temperatures, only material with a Curie temperature of at least 120°C is suitable for automotive applications. Lead is also indispensable for these ceramics to achieve the required resistance-voltage characteristics and distribution of the resistance value. Typical Curie temperatures for PTC cabin heaters, for example, are in the range of 140–190°C (ACEA et al. 2009). PTC ceramics with lower temperatures cannot achieve the necessary heating power (ACEA et al. 2009).

To achieve Curie-temperatures of 120°C and more, lead in the PTC ceramic cannot be replaced. Adding lead to the Barium titanate matrix of the PTC ceramic is the only possibility to raise the Curie temperature of the basic Barium titanate to the required levels (ACEA et al. 2009).

*Substitution of lead*

The alternative material for lead in PTCR's, bismuth (Bi), can be used in very rare cases only. Its solubility in barium titanate is low compared to lead. There are reports that Bi can raise the Curie temperature by approx. 18 K, which is insufficient. At the same time, it is known that Bi can improve the volume resistivity of PTC resistors. $Bi_2Sn_3O_9$ in small amounts improves the resistivity above the Curie point. Higher amounts of Bi will form bismuth-titanate phases, which are not ferroelectric and thus do not contribute to the PCTR performance. Bi thus cannot be considered a replacement for lead. In fact, there is no other material than lead containing material available to shift the Curie temperature as necessary for PTC applications (ACEA et al. 2009).

Besides the Curie temperature effect, lead in PTC ceramics is crucial for switching applications and over current protection, where it enables high switching reliability and high voltage strength. Lead free alternatives are only available for operation temperatures far below 120°C, which is too low for most automotive applications. Lead-free PTCs are less reliable and have less voltage strength. Furthermore, higher Curie-temperatures are often needed to obtain equal permissible currents with miniaturized parts (ACEA et al. 2009).

For PTC components, which are used for temperatures below 120°C, lead-free alternatives might become available in the next three years (JEITA et al. 2009e). According to the stakeholders, automotive applications require components that can withstand at least 120°C.

**Lead in the ceramic of compensation capacitors in ultrasonic sonars**

*Functional principle of ultrasonic sonars*

Ultrasonic sensors in vehicles are used as sonars to detect obstacles e. g. when driving backwards and for parking assistance systems. They measure the distance between the car and an obstacle and warn the driver to avoid accidents and damages.

The ultrasonic ceramic is a piezoceramic and works as sender and receiver. It is therefore called sensor. An alternating current electrical impulse (drive signal) into the piezoelectric ceramic makes the piezoceramic vibrate and generates an ultrasonic signal, which is transmitted, as illustrated in Figure 67.

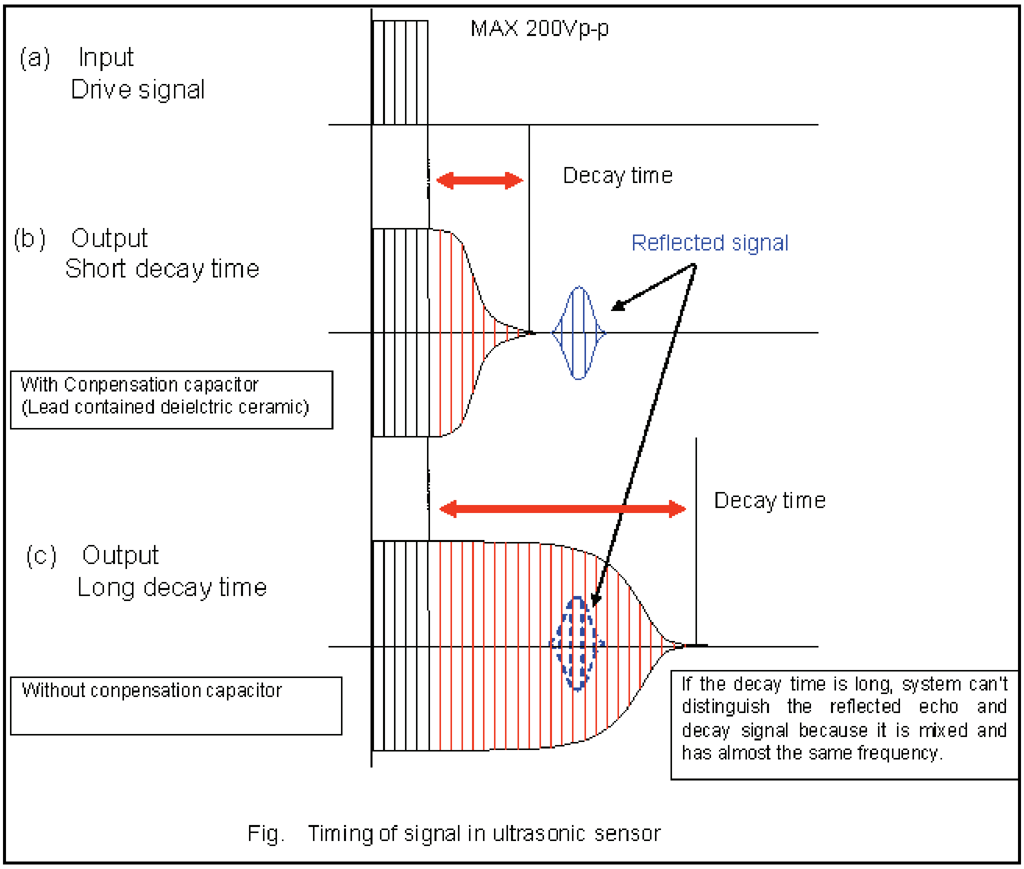


Figure 67 Functional principle of an ultrasonic sonar (JEITA et al. 2009c)

An obstacle would reflect the ultrasonic sound wave (echo). The reflected signal hits the piezoelectric ceramic and makes it vibrate, which generates an electronic signal. The signal processor calculates the distance of the vehicle to the obstacle via the time difference between the transmission and reception (JEITA et al. 2009c).

*Use of lead-containing compensating capacitors*

The stakeholders explain (JEITA et al. 2009c) that the ultrasonic sensor is based on lead-containing ceramics. The sensor's precision of distance measurement depends on the capacitance of the sensor ceramic, which, however, changes with the outside temperature to which the car – and the sensor – is exposed to. The capacitance increases for more than 0,5% per degree Celsius of temperature increase. Exact distance measurements over a wider outside temperature range thus are impossible.

To compensate the temperature-related shift of capacitance in the ultrasonic ceramic, a compensating ceramic capacitor is used. The capacitance of this capacitor also changes with the temperature, but inverse to the capacitance of the ultrasonic sensor. The capacitance of this compensating capacitor decreases for more than 0,4% per degree of temperature increase. The capacitance changes in the ultrasonic sensor ceramic and in the ceramic compensating capacitor thus are working in opposite directions and thus almost compensate each other. Figure 68 illustrates these effects.

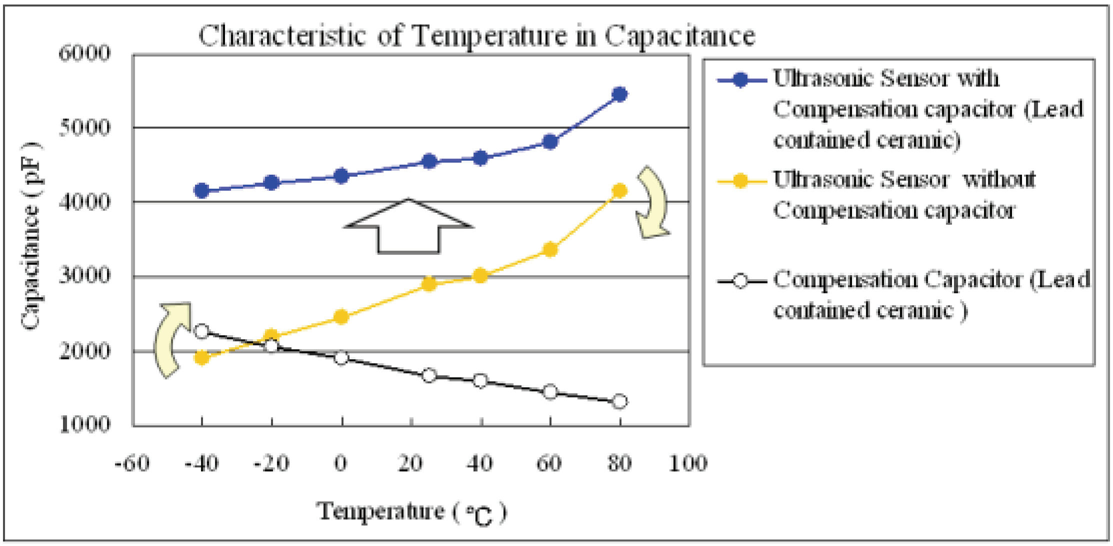


Figure 68 Temperature characteristics of capacitance in sensor and temperature compensating capacitor (JEITA et al. 2009c)

Lead-free dielectric ceramic capacitors have a temperature coefficient of only around 0,3% per degree Celsius (JEITA et al. 2009c). The overall compensation thus is not sufficient, according to the stakeholders (JEITA et al. 2009c), to achieve a sufficiently exact distance measurement over a broad temperature range. Without the lead-containing compensation capacitor, the measured distance can deviate up to 50% from the actual deviation, in particular in the low distance range below one meter. As the sensor also is part of the parking assistance system, these deviations are unacceptable and may lead to accidents and damages.

The dielectric ceramic of the compensating capacitor contains less than 1 mg of lead. The stakeholders claim (JEITA et al. 2009c) that the use of these lead-containing capacitors is unavoidable.

As such capacitors in ultrasonic sensors are operated below 125 V DC, the use of such capacitors requires a specific exemption. The proposed exemption “Use of lead in dielectric ceramic materials of capacitors with a rated voltage of less than 125 V DC/250 V AC” does not cover this application.

#### Lead in glass and glass-ceramic materials

Glass, glass-ceramic and glass or glass-ceramic matrix compounds with lead are used in manifold applications. From the material scientific point of view, a clear differentiation between glass and glass-ceramic materials and matrix compounds is not always possible. It thus does not make sense at the current state of science and technology to further differentiate these materials in their applications and in the exemption wording.

Glass and glass-ceramic materials and matrix compounds with lead are used in (ACEA et al. 2009):

- low melting type glass frit in thick film paste for electronic components, such as hybrid integrated circuits, resistors, capacitors, VFD Displays, etc.;
- low melting type glass frits in glass paste for protection (such as hermetic seals) and bonding applications (such as sensor components);
- glass encapsulations based on low melting type glass tubes such as glass diodes, VFD Displays and thermistors.

The main functional aspects of lead glass and glass-ceramic materials and matrix compounds are (ACEA et al. 2009):

- pre-coating for thick film resistors;
- surface protection coating;
- vacuum (adhesion) assurance;
- resistor binder (adhesion assurance for ceramic base materials);
- electrode binder (adhesion assurance for ceramic base materials);
- hermetic sealing.

Several components contain such glass materials (ACEA et al. 2009):

- varistors;
- chip resistors;
- pressure and strain sensors;
- bridge rectifying devices;
- power transistors;
- power thyristors;
- quartz oscillators;
- diodes;
- thermistors;
- vfd displays.

Figure 78 in the annex gives a detailed overview on the different uses of these materials. This annex also explains the details of the lead uses and the problems with substitution (JEITA et al. 2009b).

The contents of lead in these materials depend on the exact application:

- glass / Surface protection coatings with 45% to 5% (weight) lead concentration;
- glass in electrodes with 1% to 57% (weight) lead concentration;
- glass in resistor binders (adhesion assurance for ceramic base materials) with 3% to 30% (weight) lead concentration;
- glass for bonding pastes with 5% to 80% (weight) of lead concentration;
- frit glass used in VFDs with up to 60% (weight) of lead concentration;
- ruthenium lead oxide for resistors with around 55% to 60% (weight) of lead concentration;
- glass in the thick film layers of components.

Figure 78 in the annex lists the amounts of lead used in more details. The total amount of lead used in glass, glass-ceramic and glass- and glass-ceramic matrix compounds is around 30 t per year (CLEPA et al. 2009b).

The stakeholders explain the functions of the lead in glass, glass-ceramic and matrix compounds (ACEA et al. 2009):

- lowering the softening points and the viscosity during processing;
- better alignment of thermal expansion;
- improved electrical insulative properties;
- higher affinity to other materials for binding and bonding materials;
- higher weather resistance.

According to the stakeholders (ACEA et al. 2009), the above specific properties of leaded glass are of importance (ACEA et al. 2009):

*Viscosity (ACEA et al. 2009)*

Leaded glass is used for bonding of materials. It has a low viscosity needed to flow well during such bonding process. Bad flow potentially causes pin holes and other (surface) imperfections. The glass thus may become sensitive to cracks and other mechanical damage when subjected to mechanical stresses, which will occur during normal operation. Cracks, occurring e. g. in sensors, cause unacceptable sensor drift and potential sensor failure. Lead-free materials' viscosities are lower in the order of 100.

*Softening temperature range (ACEA et al. 2009)*

Leaded glass has a low softening temperature. The glass is used to bond silicon strain gages with aluminium bond pads on stainless steel diaphragms as well as for ceramic-on-ceramic bonds. The firing temperature – i. e. the temperature at which the silicon is bonded to the stainless steel, normally around 850°C range – must not exceed the (eutectic) melting temperature of the aluminium. Other bonding materials than leaded glass have higher softening temperatures potentially causing junction spiking and other reliability issues in the aluminium on silicon.

*Differences in the coefficient of thermal expansion (CTE) (ACEA et al. 2009)*

The CTE of the glass should be within a specific window and compatible with the materials, to which it is bonded, such as stainless steel and aluminium. Under temperature changes, low values compared to the bonding partner can cause tensile stress, too high values can generate high compressive stress in the glass. Both may result in glass cracks and, consequently, component failure.

*Electrical Properties (ACEA et al. 2009)*

The insulation properties of leaded glass are acceptable, while alternative glass materials show higher ionic conductivity. The electrical insulation thus may break down affecting reliability and performance of the components.

In principle, lead-free alternatives are (ACEA et al. 2009):

- organic based alternatives have issues with stability, inability to withstand the processing temperatures, and no protection (ability to create a good vacuum seal).
- other metal oxides than lead oxides

Figure 77 in the annex shows the discussed substitutes and the main obstacles for their use at the current state of science and technology. Currently available lead-free materials cannot satisfy all necessary conditions (JEITA et al. 2009b). When substituting leaded materials by lead-free ones, typically the requirements for one set of attributes leads to unacceptable performance in another attributes, according to the stakeholders (ACEA et al. 2009).

Figure 69 shows examples of properties of some of the alternative glass compositions evaluated. This is not an exhaustive list, but highlights the tradeoffs found in substitute materials (ACEA et al. 2009).

| Characteristics | Pb glass | Zn glass | P-Sn glass | Na-Al-P-B |
|---|---|---|---|---|
| Affinity | Good | Not good | Not good | Good |
| Low softening point | Yes | No | Yes | Yes |
| Coefficient to thermal expansion | Good | Good | Good | Not good |
| Weather resistance | Good | Good | Not Good | Not Good |
| Electrical Properties | Good | Good | Good | Not Good |

Figure 69 Properties of lead and other type glass materials (ACEA et al. 2009)

The stakeholders put forward (ACEA et al. 2009) that, although alternative compositions have been employed partly in consumer electronics products, the much wider temperature ranges, vibration, the combination thereof, and reliability concerns have made substitution within automotive applications unfeasible for most components. Several types of compositions, e.g., have been developed and tested for lead free glass frits. They are, however, inferior in their weather resistance characteristics. For hermetical sealing, bonding & glass encapsulations, lead free glass materials are available in general, but their process temperatures are too high, and the interactions between glass and ceramic during bonding are unpredictable.

The stakeholders maintain (ACEA et al. 2009) that, lead-free glass types are not expected to be applicable in vehicles before 2018 to 2019. They propose to continue the exemption without expiry.

### 4.18.6 Stakeholders' request to leave exemption 10 unchanged

The stakeholders cooperated in the recast of exemption 10. Nevertheless, they express their preference to leave exemption 10 unchanged (CLEPA et al. 2010) for the reasons explained in the subsequent sections.

#### Status of lead reduction

The stakeholders put forward that the lead content per vehicle has already been reduced from approx. 2 kg in 2003, when the ELV directive came into force, to approx. 300 g today. The battery is not taken into account in these values, because it has a special position given the possibility of return and recycling (CLEPA et al. 2010).

The stakeholders call for a strategy for further substitution or reduction that takes the following criteria into account (CLEPA et al. 2010):

- cost/benefit analysis;
- social and economic criteria;

- permitted “residual content.

**Feasibility**

The industry stakeholders claim (CLEPA et al. 2010) that their representatives and the EU Commission consultants had worked closely together to come up with a recast of exemption 8 (a–j) that is acceptable for all parties. However, in practice, comprehensive procedural guidelines are required to describe the complex interrelations that enable a “compliance” decision at project level. Automotive industry claims that such guidelines make enforcement of an exemption unnecessary burdensome compared to the environmental benefit of the relatively small reduction of lead content.

The stakeholders raise the question how the relevant authority could check the compliance of such a complex application-specific exemption, because

- valid or non-valid applications first have to be identified, which is practically impossible in the above-mentioned case for laymen – and sometimes even for material laboratories.
- In most cases, the parts are very small and are therefore practically impossible to identify as an element of the component.

The stakeholders fear that a comparable situation will result if exemption 10 is broken down to detailed applications (CLEPA et al. 2010).

**Hampering innovation**

The stakeholders claim (CLEPA et al. 2010) that an application-specific exemption list means in essence a limited list and no longer an informative description of what is meant. Furthermore, such a listing is based on today’s knowledge, i.e. would block innovation since future technological developments are not yet known. For example, in case of completely new applications giving technical solutions to future (societal) questions (safety, aging population, environment), it would be necessary to apply for an exemption to be added to the list. The stakeholders are not certain that such an exemption request would be granted based on today’s evaluation criteria (CLEPA et al. 2010).

Particularly in the case of exemption 10, where the amount of lead is in the (milli)gram range (excluding PZT application injectors, which use more lead (see Table 22 on page 187), the stakeholders believe that it would be justified for reviews to take a broader scope rather than just examining the possibility of avoiding use (i.e. use criteria going beyond Article 5(1)(b)) (CLEPA et al. 2010).

**Alternative proposal**

On the basis of the above arguments, CLEPA et al. (2010) take the following stance to the consultants' proposal for providing a greater level of detail for exemption 10:

- A list of the applications known today as containing lead in glass or ceramics was drawn up in the documents provided by CLEPA et al. during the stakeholder consultation. Details and explanations have been added during the evaluation.
- Industry represented by members of the relevant EU and U.S. automotive industry (AI) supplier associations and JEITA from Japan provided input, thus ensuring a representtative and international cross-section of views.
- Only one application was identified for which an expiry date could be defined, which is NME capacitors. Estimated overall amount of lead caused by the use of such capacitors is not more than 25 milligrams.
- There is no suitable substitute for any other applications known today, which is why no expiry date can be defined for them.
- Altogether, the applications that come under this exemption involve approx. 2–5 grams of lead per vehicle, without PZT injectors, which contain higher amounts of lead (see Table 22 on page 187).

The stakeholders put forward (CLEPA et al. 2010) that a further regulative reduction can only be obtained once an expiry date for a corresponding application has been defined, which does not rule out the basic option of voluntary substitution as soon as alternatives are known and available.

The automotive industry believes (CLEPA et al. 2010) that it is neither beneficial nor expedient to further detail exemption 10 with regard to covered applications on the basis of the existing information. Even defining a fallback option (cf. proposed wording for b) above) makes no sense from the automotive industry's perspective, because:

- there is currently no application known that would require the fallback option;
- and, if an application were to be identified, there would not be sufficient time to search for and implement alternatives before the expiry of the exemption in 2014.

Therefore, the automotive industry proposes the following approach:

1. Retain the generic material-specific exemption for the time being;
2. start discussions with decision makers on how to improve revision of Annex 2 in general;
3. and then decide about future handling of this exemption.

The stakeholders claim that in any case, the current collection and evaluation of information would be a sound basis for future evaluations (CLEPA et al. 2010).

### 4.18.7 Critical review of data and information

**Use of lead in dielectric ceramic materials of low voltage capacitors**

The stakeholders plausibly explain why lead is used in such capacitors (see page 189). The use of lead in ceramics is linked to noble metal electrode (NME) capacitors in the low voltage area. These NME capacitors, however, can be replaced by base metal electrode (BME) capacitors, which can be produced and used with lead-free dielectric ceramics. The use of lead thus is avoidable, and Art. 4 (2) (b) (ii) of the ELV Directive does no longer justify an exemption.

The stakeholders point out that there may be cases where specific mechanical stability and electrical requirements make the use of lead-containing NME capacitors indispensable due to reliability reasons. They can, however, not put forward either clear cases or clear evidence. The use of ceramics in electrical and electronic components, however, is a complex field, which is difficult to overlook in all its application cases and component variations. Additionally, the replacement of such lead-containing capacitors requires a redesign of entire electrical systems, which may take time given the long redesign cycles in the automotive industry.

It was hence agreed with the stakeholders to recommend an expiry date as late as in 2016 to accommodate the situation.

As was shown in the previous review of Annex II of the ELV Directive (Gensch et al. 2008), the redesign of existing electrical and electronic modules is not possible. It is hence recommended to repeal the exemption for vehicles type approved after 31 December 2015.

The reviewers recommended the following wording for this exemption:

*Lead in dielectric ceramic materials of capacitors with a rated voltage of less than 125 V AC or 250 V DC in vehicles type approved before 1 January 2016, and in spare parts for these vehicles*

**Use of lead in the ceramic of piezoelectric components**

During the previous review of Annex II (Gensch et al. 2008) and the review of the annex of the RoHS Directive (Gensch et al. 2009), the stakeholders plausibly explained that lead currently cannot be substituted in the ceramic of piezoelectric devices. There are not hints that this situation has changed since the last reviews. A viable technical solution currently is not foreseeable.

The use of lead in this application hence is unavoidable and Art. 4 (2) (b) (ii) of the ELV Directive would justify an exemption without setting an expiry date. The recommended wording for this exemption is:

*Lead in the ceramic material of piezoelectric components*

**Critical review of other uses of lead in ceramics**

The following other uses of lead were identified and discussed with the stakeholders:

- lead in dielectric ceramic materials of high voltage capacitors (page 191)
- lead in PZT based dielectric ceramic materials of capacitors being part of integrated circuits (ICs) or discrete semiconductors (page 194)
- lead in the PZT ceramic passivation layers of multilayer ceramic varistors (page 199)
- lead in the ceramic materials of PTC components (page 200)

In several meetings, phone conferences and information exchanges via e-mail, the above uses of lead in ceramics were identified and casted into a clear and unambiguous exemption wording. Within the available time and budget and the information submitted by the stakeholders, no evidence was found that lead could be substituted in the above ceramic materials, or that viable substitutes will be available in the near future.

Given this background, the use of lead in these applications must be considered as unavoidable, and Art. 4 (2) (b) (ii) of the ELV Directive would justify granting exemptions without setting an expiry date.

The following wordings are recommended for these exemptions:

- *Lead in dielectric ceramic materials of capacitors with a rated voltage of 125 V AC or 250 V DC or higher.*
- *Lead in PZT based dielectric ceramic materials for capacitors being part of integrated circuits (ICs) or discrete semiconductors.*
- *Lead in the PZT ceramic passivation layers of multilayer ceramic varistors.*
- *Lead in the ceramic materials of PTC components.*

The current state of knowledge suggests that the above exemption covers all uses of lead in ceramics, where it is indispensable. Nevertheless, the following temporary exemption is recommended additionally as a fall-back option in case any use or application is not listed:

*Lead in the ceramic material of electrical and electronic components, which are not listed under the above exemption, in vehicles type approved before 1 July 2014, and in spare parts for these vehicles.*

This temporary fallback option shall offer enough time for the stakeholders to find lead-free solutions or to apply for additional exemptions in case the use of lead in the ceramic materials of other components is unavoidable.

**Lead in the ceramics of compensation capacitors of ultrasonic systems**

The stakeholders' request to exempt lead in compensation capacitors of ultrasonic systems (see page 201) was discussed in order to check, whethr alternatives might be available.

*Alternative ultrasonic systems*

JEITA et al. (2009d) explain the advantages and disadvantages of different ultrasonic systems.

Technology A: Ultrasonic system with lead-containing compensation capacitor

This ultrasonic sonar system demonstrates high sensitivity over a wide temperature range. Additionally, it detects obstacles reliably in the distance of 0,1 to 7 m, which is crucial for parking assistance systems.

This system hence is most appropriate to be used in parking assistance systems.

Technology B: Ultrasonic system without compensation capacitor

JEITA et al. state that in an alternative system, the lead-containing compensation capacitor can be foregone, if the detector signal is amplified with a higher factor. The reflected signal can then easier be detected and differentiated from the transmitted signal. The background noise of the system, however, is amplified as well. The system can be used over a wide temperature range, and it is appropriate to detect nearby objects. The reflected echo from such objects is large and strong, so that the strong amplification can resolve it. The weak echo from a more distant obstacle, however, cannot be detected reliably. The strong amplification increases the background noise together with the weak signal from the distant object. The signal cannot be reliably differentiated from this background noise. For parking assistance systems, technology B thus is not appropriate, as it shows weaknesses in the distance measurement for obstacles in the range of 1 to 7 m behind the car (JEITA et al. 2009d).

Technology C: Ultrasonic systems with lead-free compensation capacitors

According to JEITA et al. (2009d), ultrasonic systems with lead-free compensation capacitors are under development. They have a high sensitivity, but over a small temperature range only. Such systems therefore are not yet commercially available.

*Alternative compensation mechanisms in ultrasonic systems*

It was discussed with the stakeholders why the vehicles' signal processor or board computer cannot compensate the ultrasonic sensor's temperature shift. Modern vehicles have thermometers measuring the outside temperature. The board computer could thus correct the sensor signal for the temperature shift and thus calculate the correct distance (calculated correction).

The stakeholders say (JEITA et al. 2009c) that this is impossible as the ultrasonic ceramic sensor at the same time is sender and receiver. After having generated and sent the ultrasonic signal, the sensor must stop vibrating as soon as possible (short decay time, see b) in Figure 67). Otherwise, the sensor is still vibrating when the signal comes back (long decay time, see c) in Figure 67) and the signal cannot be differentiated from the sensor's reverberation vibration. A distance measurement in particular on short distances is impossible. The sensor does not work.

As the decay time (see Figure 67 on page 202) increases with the capacitance, an insufficient compensation of the temperature-related capacitance shift makes the measurement impossible on shorter distances. A subsequent temperature-correction of the sensor signal in the signal processor cannot solve this problem.

*Separation of transmitter and receiver*

The calculated correction does not work because the transmitter at the same time is the receiver. Thus, separating the sending ultrasonic ceramic from the receiving one, could be a solution enabling a calculated correction of the signal.

This separation, however, does not solve the problem either. The stakeholders (JEITA et al. 2009c) say that the receiving sensor would not be able to differentiate the transmitted signal coming directly from the sender from the signal reflected by an obstacle. The transmitted signal already would cause vibration in the sender, thus making the distance measurement impossible.

*Alternative sensor materials*

Possibly, other than the lead-containing piezoelectric sensors could be used, which are less temperature dependent or can be compensated with lead-free capacitors.

The stakeholders explain (JEITA et al. 2009d) that the piezoelectric device is the best material to generate high sound pressures with minimum power. Alternatives like audio speakers and microphones use the magnet/coil technique to make sounds. This system, according to the stakeholders (JEITA et al. 2009d), consumes high current power, and is not sufficiently reliable for the harsh conditions in a vehicle. Lead-free alternatives to the currently used lead-containing piezoelectric ceramics have been studied, but are not available at industrial level yet. The stakeholders say they do not know another system to generate high sound levels with the same quality like the piezoelectric device used in the current ultrasonic sonars (JEITA et al. 2009d).

*Alternative sensor systems*

Possibly, other than ultrasonic systems can serve the same function without using compensation capacitors. Table 23 shows different systems and their basic properties.

Table 23 Comparison of systems (JEITA et al. 2009d)

| **Technology** | **Feature** |
|---|---|
| Ultrasonic | Detectable range is 0,3 to 2,5 m<br>Stable against rain drops and mud<br>Most popular in the world at this moment |
| Microwave (radar) | Detectable range is 10 to 100 m<br>Cannot detect near distance and thus cannot be used for parking assistance |
| CCD camera | Detectable range is wide and 0 to 5 m (Driver have to check monitor or distance)<br>Does not work in the dark or when lens is dirty |
| Capacitance | Detectable range is 0 to 0,5 m (not clear at this moment)<br>Unstable against rain drops and mud |

Thus, alternative systems currently cannot be used The ultrasonic sonar is the most appropriate and reliable system (JEITA et al. 2009d).

The stakeholders claim (Bosch 2010) that ultrasonic sonars are simple, light-weight and cheap compared to other systems like e. g. the radar systems. Besides the technical features, the higher complexity of alternative systems burdens the environment, and it may well compensate the possible environmental impacts of lead used in the ultrasonic sonar systems, as explained in Table 24.

Table 24 Comparison of ultrasonic sonar and radar systems (Bosch 2010)

| | **Ultrasonic system** | **Radar system** |
|---|---|---|
| Weight | 15 to20 g | ~460 g |
| Number of electronic components | Around 20 on 1 PWB, mostly standard components | Around 300 on 2 printed wiring boards (PWB), partially specific components |
| Lead content | Ceramics of components incl. compensating capacitor: 0,5–3 mg<br>High melting point solder in components: none<br>Piezo-ceramic (sensor): 40 mg<br>Aluminium (less than 0,05% of lead as alloying element): less than 1,5 mg<br>Cu-based punch scrap: less than 0,1 mg<br>Total lead in electrical/electronic components: ~40 mg<br>Overall total: ~45 mg | Ceramics of components: 25–60 mg<br>High melting point solder in components: <10 mg<br>Aluminium (less than 0,05% of lead as alloying element): max. 100 mg<br>Cu-based punch scrap: 0,5–1 mg<br>Total lead in electrical/electronic components: ~30 to 70 mg<br>Overall total: 130 to 170 mg |

| | Ultrasonic system | Radar system |
|---|---|---|
| Cost | | Around 10 times more expensive compared to ultrasonic sonar systems |

The stakeholders explain (Bosch 2010) that the above data for lead contents are taken from the IMDS (International Material Data System), a database used in the automotive industry to declare material data. These are generic data based on averages.

The above figures show that alternative, more complex systems like radars may use at least equal amounts of lead in the electronics components compared to ultrasonic sonars with compensating capacitors. Additionally, higher weights increase the energy consumption of vehicles.

*Conclusions*

The above technical information shows that ultrasonic sonar systems are the best and most reliable option. Some alternative systems can cover part of the functionalities, but not the whole range of functions in the quality and reliability necessary in this automotive application. Environmental data illustrate that alternative, more complex systems like radars may use the same or even higher amounts of lead. Higher weights of such systems additionally increase the energy consumption of vehicles and the burden the natural resources.

The stakeholders show that the use of piezoelectric systems is required in ultrasonic sonars. Such systems depend on the use of lead-containing compensating capacitors.

The use of lead at the current state of science and technology is unavoidable in this application, and Art. 4 (2) (b) (ii) would justify an exemption.

The recommended wording for this exemption is proposed as:

*Lead in the ceramics of capacitors compensating the temperature-related deviations of sensors in ultrasonic sonar systems*

As alternative systems using lead-free compensation capacitors are under development, it is suggested to review the exemption in 2014.

**Lead in glass and glass-ceramic materials or matrix compounds**

Lead in glass and glass ceramic materials or in matrix compounds has important functions, as the stakeholders explained (page 201). Within the available time, and based on the available information, no evidence could be found that lead-free alternatives are commercially available or foreseeable for the near future.

The use of lead in these applications currently must be considered as unavoidable, and Art. 4 (2) (b) (ii) of the ELV Directive would justify granting exemptions without setting an expiry date.

Given the multitude of glass and glass-ceramic applications, a component-related wording of the exemption was not possible at the time being. The recommended wording of the exemption therefore must be related to the functions of the glass and glass-ceramic materials. The following wording is recommended for this exemption:

*Electrical and electronic components, which contain lead in a glass, in a glass matrix compound, in a glass-ceramic material, or in a glass-ceramic matrix compound, forming a functional layer on a substrate, or a sealing, bonding or encapsulation. This exemption does not cover the use of lead in glass of bulbs and in glaze of spark plugs.*

The current state of knowledge suggests that the above exemption covers all functions of materials, in which the use of lead is indispensable. Nevertheless, the following temporary exemption is recommended additionally as a fall-back option in case any function would have been forgotten:

*Electrical and electronic components, which contain lead in a glass, in a glass matrix compound, in a glass-ceramic material, or in a glass-ceramic matrix compound for any other purposes than those listed above in vehicles type approved before 1 July 2014, and in spare parts for these vehicles.*

This fallback option shall offer enough time for the stakeholders to find lead-free solutions or to apply for an additional exemption in case the use of lead in glass and glass-ceramic materials is unavoidable in any other function.

**Stakeholders' request to leave exemption 10 unchanged**

<u>Basic settings and approach for exemption reviews</u>

The basic requirement of this review is to adapt exemptions under the ELV Directive to scientific and technical progress. Banned substances shall only be allowed, "[…] if the use of these substances is unavoidable", as stipulated in Art. 4(2)(b)(ii) ELV Directive. The past reviews, following the requirements of Art. 4(2)(b)(ii) and the Commission's specifications, were conducted based on the following basic principles:

- The ELV-Directive stipulates a minimum allowable concentration of the banned materials, which is at 0,1%, with the exemption of cadmium, for which the threshold limit is 0,01% of weight in the homogeneous material.
  Any use of a banned substance in a concentration higher than the above maximum concentrations is only allowed if the use of this substance is unavoidable according to Art. 4(2)(b)(ii).

- The interpretation of “unavoidable” uses was aligned to the provisions of Art.5(1)(b) of the RoHS Directive. The use of a banned substance thus is unavoidable,
  - if its elimination or substitution via design changes or materials and components which do not require the banned substance is technically or scientifically impracticable,

    or
  - where the negative environmental, health and/or consumer safety impacts caused by substitution are likely to outweigh the environmental, health and/or consumer safety benefits thereof .
- Exemptions hence need to be as application-specific as possible to clearly delimitate avoidable from unavoidable uses of banned substances in order to prevent uses of banned materials in applications where their use is avoidable.
- Generic, material-specific exemptions hence should be transferred to application-specific ones, as long as the specific applications can be defined clearly and unambiguously.

The reviewers have evaluated the stakeholders’ arguments and the proposal to leave exemption 10 unchanged in the light of these basic settings in the following sections.

*Plausibility of figures on lead usage*

The stakeholders claim that repealing the exemption of lead use in low voltage capacitors only would avoid 25 mg of lead.

CLEPA et al. do not specify the reference of this figure. For plausibility reasons, the 25 mg must be the amount of lead per vehicle. Assuming that such capacitors are used in every vehicle, the cancellation of this exemption would avoid 425 kg of lead worldwide (~ 17 mio new cars per year according to ACEA), and around 25 kg in Europe (around 1 mio new vehicles per year, according to ACEA).

It can be discussed whether these amounts of lead are worth the expense of substitution, however, not on the exemption review level. The ELV Directive requires avoiding lead wherever possible. Neither does it specify a minimum amount of lead nor a maximum of cost that would allow foregoing substitution if the use of lead technically and scientifically is avoidable.

The same applies for the stakeholders’ statement that exemption 10 only would deal with milligrams of lead. This is correct for the single applications, but in total, the amount of lead used sums up to more than 300 t per year worldwide, or more than 20 t in Europe.

*Status of lead reduction*

The stakeholders' argue that they have reduced the amount of lead in vehicles from around 2 kg down to 300 g and that a further reduction would generate an effort that is not proportionate to the environmental benefit generated. The ELV-Directive allows maximum threshold levels of banned substances, as explained above. A permitted "residual content", as the stakeholders demand, thus is in place already. The contractors cannot decide about an increase of such threshold levels. This would require an amendment of the ELV Directive, or of the maximum threshold levels in Annex II of the ELV Directive. The contractors do not have the mandate to evaluate such threshold levels.

*Socioeconomic arguments, efficiency and cost-benefit analysis*

The ELV Directive only allows the use of banned materials, where their use is unavoidable. Cost-benefit analysis (cost versus environmental benefit), or socio-economic criteria, as the stakeholders request, thus cannot be base for a positive recommendation for an exemption.

The stakeholders' demand cannot be taken into consideration on the exemption review level, but needs an amendment of the ELV Directive itself. The current ELV Directive would not cover such evaluation criteria. It is clearly beyond the reviewers' mandate and competence to introduce new evaluation criteria.

It may nevertheless be useful if the policy makers and legislators reconsider the material bans and their implementation under efficiency criteria to avoid that valuable research and financial resources are channeled towards tasks where they possibly only yield minor environmental successes.

*Hampering innovation*

The stakeholders put forward that more detailed exemptions might hamper innovation (see section They doubt that the current review criteria would allow an exemption for the use of banned substances in new applications contributing to improvements of societal problems.

The contractors do not put forward evidence for this, but express their fears. In the reviewers opinion, if a new technology provides clear benefits, an exemption for such an application of a banned material could be recommended in line with Art. 4 (2) (b) (ii). Material bans, and specific exemptions, on the other hand can spur innovation by promoting the competition towards components and technologies that do not depend on the use of heavy metals.

An assessment of whether and how far the current regulation and exemption review practices actually could hamper innovations is beyond the reviewers' mandate. It must be stated, however, that the material bans as such may then hamper innovation to the same degree as application specific and focused exemptions. This would require an evaluation of the material bans of the ELV Directive itself, which is clearly beyond the reviewers' mandate.

As technical and technological innovations, however, can be part of a solution for environmental, resource and societal problems, it is recommended to review the existing regulations and exemption review guidelines to make sure the evaluation procedures are adequate not to hamper innovation. Possibly, there could be a timely mismatch between the time from development to marketing on the one hand, and the time from application for an exemption until this exemption is granted. Introducing an initial grace period for new applications, e. g. for four years, could mitigate the problem.

If desired, the reviewers are ready to contribute with their experiences and knowledge from several years of exemption assessments to improve the situation.

*Feasibility*

The feasibility of exemptions and of their monitoring is an aspect, which at least in parts is relevant for the contractor's exemption assessments. It is part of the reviewer's mandate to recommend exemptions, which

1. are clear in their scope and wording.
2. can be implemented in the supply chain.

At least partially, the reviewers must also take care that

3. compliance with exemptions can be monitored.

*Expense for implementation*

The stakeholders express their concerns that in practice it may be difficult to implement application-specific exemptions in some cases. The decision-making generates large efforts since it is sometimes not clear how to achieve compliance (see section "Feasibility" on page 208).

Within their mandate, the reviewers are obliged to minimize such effects by clear scopes and wordings of exemptions. The contractor is not entitled to decide about how much effort actually is reasonable to achieve compliance, as long as the necessary expense does not make compliance impossible. Taking into account the expense for the implementation of an exemption would introduce economical arguments as an additional criterion, which does not have ground in Art. 4 (2) (b) (ii) and in the Commission's basic settings for the review.

As the proposed recast of exemption 10 was discussed and agreed upon with the stakeholders, it must be assumed that, despite of some problems possibly arising, the recast exemption 10 can be implemented in the supply chain. It must be pointed out additionally, that the RoHS Directive as well contains application-specific exemptions for electrical and electronics appliances, which the respective industries have implemented successfully.

*Monitoring*

The stakeholders additionally claim problems with monitoring. They say that application specific exemptions like 8 a) or as recommended for the recast of exemption 10 cannot be identified and monitored by laymen, and that even for experts, it might be difficult sometimes.

It is very likely that laymen are overburdened with such a complex task. The reviewers must assume, however, that personnel responsible for the identification and monitoring of exemptions is sufficiently qualified for this task. The producers are responsible to contribute to the good implementation in the supply chain by e.g. delivering proper documentation regarding the use of exemptions so that they can be identified and monitored.

Nevertheless, the monitoring of exemptions beyond doubt may create practical problems. This phenomenon is well known from the RoHS Directive. In particular, there are problems with the definition of homogeneous materials in the context of sampling and analyzing the contents of banned materials, as well as with the necessary minimum amounts of sampling material necessary for the analysis. This applies especially in cases where small components with thin layers of homogeneous materials or with low volumes are involved. The European Parliament in its draft report on the Commission's proposal for the recast of the RoHS Directive (European Parliament) proposes introducing minimum volumes or areas for homogeneous materials. This could indicate a possible solution for the stakeholders' concerns. The reviewers cannot solve such principal problems related to the implementation and monitoring of substance bans on the review level.

The reviewers therefore propose to tackle this problem in the recast of the RoHS Directive and to transfer such solutions to the ELV Directive, or otherwise to give the reviewers clear guidance so that they can take into account this problem. The review process then would remain transparent and comprehensible, whereas otherwise, in the absence of clear criteria, recommendations might become arbitrary.

Nevertheless, if the stakeholders can clearly prove that sampling and analyzing and thus monitoring are impossible not only for some cases covered by an exemption, but generally, they should submit this evidence and the reviewers will certainly try to take it into account within the possibilities of their mandate.

*Alternative proposal of the stakeholders*

The stakeholders propose to retain exemption 10 in its current generic status, without further specification to applications. Their main argument is that for none of the specified applications besides for the low voltage capacitors, an expiry date could be defined, because there are no suitable substitutes. (Remark of reviewers: The exemption request for lead in compensation capacitors, for which lead-free alternatives are under development, had not yet been reviewed by the time the stakeholders submitted their request to leave exemption 10 unchanged).

The stakeholders affirm that the proposed list of applications under exemption 10 will not result in any further lead reduction. No substitutes or alternative technologies are available, and therefore none of the listed applications besides the low voltage capacitors have an expiry date. As the application specific wording of exemption 10 does not result in foreseeable lead reductions, the stakeholders argue to leave the exemption 10 unchanged. It just increases their expenses for compliance without any environmental benefit. The stakeholders say that a material specific, generic exemption wording does not rule out the basic option of voluntary substitution as soon as alternatives are known and available.

It must be highlighted that the substitution of banned substances is not voluntary, as the stakeholders put forward, but obligatory as soon as alternatives are available. To affirm and to promote this, applications are made specific, not just generic. The specification of exemptions increases the incentives to search for alternatives and to apply them as soon as they are available.

There may be reasons as well, why some exemptions in Annex II were made generic, not application specific, at the time when the ELV Directive was enacted. If these reasons still persist and are still valid after almost a decade of scientific and technical progress, the stakeholders should have put them forward in the exemption review processes, or discuss with the Commission, whether they are still sufficient to leave exemption 10 unchanged.

Finally, the stakeholders argue that the fallback option (recommended exemption 10 b, see page 223) does not make sense because there is currently no application known that would require the fallback option. They further argue that, if an application were to be identified, there would not be sufficient time to search for and implement alternatives before the deadline of 2014.

It must be stated that the fallback option 10 b) on page 223 was introduced on demand of and in agreement with the stakeholders to prevent problems in case a specific application would have been forgotten in 10 a). During the review, it became clear that the knowledge about the use of leaded ceramics was distributed in the supply chain, and not centrally available. As it is impossible to reach and to involve each and every user of leaded ceramics worldwide, it was plausible to introduce exemption 10 b) as a fallback option.

The time frame for expiry of exemption 10 c) (see page 223) was set in order to allow applying for a further exemption, in case this is needed and justifiable in line with Art. 4 (2) (b) (ii). It was never thought only to give enough time to search for and to come up with alternatives by then.

*Conclusions*

The stakeholders request to leave exemption 10 unchanged. Arguments brought forward by stakeholders are to be addressed to decision makers since they go beyond the mandate of this review.

The contractor reviewed the stakeholders' proposal in the previous chapter in the light of the basic settings and approaches that have been applied so far in the past reviews of exemptions based on Art. 4 (2) (b) (ii). Accepting the stakeholders' proposal in the reviewers' opinion would require introducing new and additional review criteria.

In case the Commission draws different conclusions from Art. 4 (2) (b) (ii) with respect to the recast of exemption 10 and from the stakeholders' reasoning, the following wording is recommended for exemption 10:

*10 a) Electrical and electronic components, which contain lead in a glass or ceramic, in a glass or ceramic matrix compound, in a glass-ceramic material, or in a glass-ceramic matrix compound.*
*This exemption does not cover the use of lead in*
*- glass of bulbs and in glaze of spark plugs.*
*- dielectric ceramic materials of components listed under 10 b), 10 c)and 10 d)*

*10 b) Lead in PZT based dielectric ceramic materials of capacitors being part of integrated circuits or discrete semiconductors*

*10 c) Lead in dielectric ceramic materials of capacitors with a rated voltage of less than 125 V AC or 250 V DC in vehicles type approved before 1 January 2016, and in spare parts for these vehicles*

*10 d) Lead in the dielectric ceramic materials of capacitors compensating the temperature-related deviations of sensors in ultrasonic sonar systems; review in 2014*

This wording would take out the low voltage capacitors and the compensating capacitors from the generic exemptions, where a sunset date can be defined, or where substitutes are foreseeable. In the face of the minor amounts of lead involved in exemption 10, this part of the exemption could be cancelled as well, if the Commission wishes to follow the stakeholders' efficiency and cost-benefit approaches.

Exemption 10 b) has been added upon request of the stakeholder ESIA (European Semiconductor Industry Association) to the above wording proposal, since the capacitors addressed in this exemption operate at low voltages and hence may be affected by the restriction of lead use in low voltage capacitors (covered by 10 c which expires end of 2015), depending on the interpretation of "dielectric" ceramics, which, in the absence of a clear and internationally accepted terminology, is not quite clear (ESIA 2010). In case substitutes would not be available by 2016, this application would thus no longer be exempted. In the long version recommended below, ESIA's proposal is already included and mentioned separately (10 a) iv). In both the long and the shorter version, the exemption is in line with the requirements of Art. 4 (2) (b) (ii), as substitutes currently and in the foreseeable future are not at hand and the use of lead is therefore unavoidable. An expiry date can not yet be set. .

### 4.18.8 Final recommendation

The contractor recommends transferring exemption 10 from a generic to an application-specific exemption following the example of other exemptions in Annex II of the ELV Directive. This recommendation is in line with the review criteria derived from Art. 4(2)(b)(ii), the Commission's settings for the review process, and the approaches applied in the past review processes (see page 216 for details). Several applications were identified in cooperation with the stakeholders, where the use of lead is currently unavoidable. Art.4(2)(b)(ii) would hence justify an exemption.

The reviewers recommend the following recast and rewording of exemption 10:

*10 a) Lead in*

- *i. ceramic materials of piezoelectric components;*
- *ii. ceramic materials of PTC components;*
- *iii. PZT ceramic passivation layers of multilayer ceramic varistors;*
- *iv. PZT based dielectric ceramic materials of capacitors being part of integrated circuits or discrete semiconductors;*
- *v. dielectric ceramic materials of capacitors with a rated voltage of 125 V AC or 250 V DC or higher;*
- *vi. dielectric ceramic materials of capacitors with a rated voltage of less than 125 V AC or 250 V DC in vehicles type approved before 1 January 2016, and in spare parts for these vehicles;*
- *vii. dielectric ceramic materials of capacitors compensating the temperature-related deviations of sensors in ultrasonic sonar systems; review in 2014.*

*10 b) Electrical and electronic components, which contain lead in a glass or a glass matrix compound, in a glass-ceramic material, or in a glass-ceramic matrix compound, forming a functional layer on a substrate, or a sealing, bonding or encapsulation.*
*This exemption does not cover the use of lead in glass of bulbs and in glaze of spark plugs.*

*10 c) Lead in the ceramic materials of components, which are not listed under exemption 10 a), in vehicles type approved before 1 July 2014, and in spare parts for these vehicles*

*10 d) Electrical and electronic components, which contain lead in a glass or a glass matrix compound, in a glass-ceramic material, or in a glass-ceramic matrix compound for any other purposes than those listed in 10 b), in vehicles type approved before 1 July 2014, and in spare parts for these vehicles*

Exemptions 10 a) and 10 b) are supposed to cover all relevant cases, where the use of lead is indispensable. Due to the complexity of the field, exemptions 10 c) and 10 d) are recommended as temporary fallback options, in case exemptions 10 a) and 10 b) should not cover any component or function, in which the use of lead is unavoidable. Stakeholders thus have a chance to either find lead-free alternatives in time or to apply for further specific exemptions to be added to 10 a) and 10 b), before exemptions 10 c) and 10 d) expire.

The stakeholders (CLEPA et al. 2010) submitted a request to leave exemption 10 unchanged. The stakeholders' arguments can be found in section 4.18.6 on page 207. The contractor reviewed these arguments based on the review criteria and practices applied so far to identify unavoidable uses of lead (see page 216).

In case the Commission decides to follow the stakeholders' arguments, the reviewers recommend the following wording:

*10 a) Electrical and electronic components, which contain lead in a glass or ceramic, in a glass or ceramic matrix compound, in a glass-ceramic material, or in a glass-ceramic matrix compound.*
*This exemption does not cover the use of lead in*
*- glass of bulbs and in glaze of spark plugs.*
*- dielectric ceramic materials of components listed under 10 b), 10 c) and 10 d)*

*10 b) Lead in PZT based dielectric ceramic materials of capacitors being part of integrated circuits or discrete semiconductors*

*10 c) Lead in dielectric ceramic materials of capacitors with a rated voltage of less than 125 V AC or 250 V DC in vehicles type approved before 1 January 2016, and in spare parts for these vehicles*

*10 d) Lead in the dielectric ceramic materials of capacitors compensating the temperature-related deviations of sensors in ultrasonic sonar systems; review in 2014*

### 4.18.9 References


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## 4.19 Exemption no. 13

*"Absorption refrigerators in motor caravans"*

The evaluation of exemption 13 under the current contract was based on results of former evaluations. Initial answers have been received from stakeholders in the context of the second stakeholder consultation (cf. http://circa.europa.eu/Public/irc/env/elv_4/library?l=/consultation_2/stakeholder_contribution/elv_exemption_13&vm=detailed&sb=Title). Further questions have been sent to stakeholders (Dometic and Thetford). Answers have since been received and conference calls with both stakeholders have been held.

The outcome of this information gathering exercise and of the exchange with the above mentioned stakeholders is reflected in the following.

### 4.19.2 Description of exemption

Absorption refrigerators are covered by the ELV Directive because they are inter alia used in motor caravans. Absorption refrigerators function solely from a single heat source, no compressor is necessary. This is permitted by the use of ammonia, water and hydrogen gas. Sodium chromate is mixed to the ammonia solution to protect the steel tubing from the mildly corrosive ammonia. Due to the complex geometry of the system, it is very sensitive to corrosion.

As sodium chromate is slowly consumed during normal operation, the lifespan of the device is limited, albeit over 15 years, exceeding that of the vehicle in which the refrigerator is built-in (i.e. motor caravans).

Liquid ammonia is sent to the top of the hydrogen-containing part of the system. Here, due to the presence of pure hydrogen gas, the partial pressure of the ammonia is zero. Ammonia, until its partial pressure has equalised with its vapour pressure, is forced to evaporate into the hydrogen gas.

This evaporation creates the cooling used by the refrigerator/freezer. The remainder of the cycle involves separating the ammonia gas from the hydrogen gas by mixing it with water[25], then separating the ammonia from the water[26] by boiling it thanks to a heat source[27], then condensing the ammonia before the cycle can repeat itself.

This has the main advantage of eliminating noise from the device as well as independence from electricity. This makes the use of absorption refrigerators ideal for hotel room minibars and motor caravans where reduced space makes noise reduction important and in the case of motor caravans, mobility means that electricity is not always (sufficiently) available.

Dometic – formerly Electrolux – is one of the main producers of absorption refrigerators in Europe. Its absorption cooling units are made of carbon steel because of the material's strength and good welding properties.

Dometic explains that "hexavalent chromium works very well thanks to a thin chromium oxide ($Cr_2O_3$) layer that is formed on the surface of the steel tubes. This layer is very thin and tight which protects the steel from further corrosion." However, the layer is fragile and therefore needs to be repaired by readily-available CrVI.

The stakeholders explained that the damage mechanism of the protective layer is misunderstood. However, tests have revealed that temperature cycling of the tubing, which occurs when the boiler turns on and off during normal use, causing the tubing to expand and contract is not the main parameter responsible. It is thought that the coating is slowly worn out by the constant flow of the fluids.

The current exemption was granted due to the fact that industry members claimed not to have found an alternative to chromate so far. The use of CrVI for corrosion protection is not only exempted from substance restrictions under the ELV Directive but is also included in the Annex to the RoHS Directive and thus exempted from its substance requirements as well (item no. 9).

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25 Ammonia gas is more soluble in water than hydrogen gas is.

26 Ammonia will evaporate sooner than water.

27 This heat source can be a gas burner, waste heat from an industrial process or an electric resistor.

According to Dometic, the annual production of absorption fridges in Europe amounts to about 600 000 units. In 2009, Dometic explained that about 85 000 units were sold for use in motorcaravans, containing an average amount of 3 g CrVI per fridge. The annual amount used in ELV relevant applications therefore adds up to about 260 kg of CrVI[28].

Apart from Dometic, a stakeholder contribution was received by its main competitor Thetford. Thetford says to also produce refrigerators for campers and caravans, with significant numbers of those being used for caravans, and also supports a continuation of the exemption.

Stakeholders agree on the proposed new wording: "Hexavalent chromium as an anti-corrosion agent of the carbon steel cooling system in absorption refrigerators up to 0,75 weight-% in the cooling solution except where the use of other cooling technologies is practicable (i.e. available on the market for the application in motor caravans) and does not lead to negative environmental, health and/or consumer safety impacts."

Additional information was provided by the European Caravaning Federation (European Caravaning Federation 2009).

### 4.19.3 Justification for exemption

Dometic has provided solid supporting evidence for an extension of the exemption, with its new wording (Dometic 2009b).

With regard to substitution efforts, the goal is to reduce hexavalent chromium content as much as possible or to eliminate it completely from products.

Dometic explained that extensive research has been carried out: "Since the 1930's Electrolux/Dometic has been conducting research into finding possible alternatives for the corrosion protection of absorption refrigerators. Not only has a significant in-house commitment been made but also Electrolux/Dometic has worked with a number of external research institutes and universities on this issue. Several long-term projects have been run with theoretical and practical studies on the corrosion process. Work has also been carried out with companies who are expert in corrosion protection where commercial inhibitors have been tested. The research has looked at alternative refrigerants, inhibitors, structural materials, surface treatment and combinations thereof." Extensive and comprehensive documentation on these research activities has been provided as evidence.

Thetford explained that research with independent experts and testing of marketed alternatives has also taken place (Thetford 2009b).

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[28] Two significant digits.

**Chromate concentration reduction**

Stakeholders explained that current amounts of chromate use have been the standard practice since the 1930s. Field experience has confirmed that these concentrations are necessary to ensure a 15 year lifespan. Any reduction in chromate use would result in a direct reduction of product lifespan which is counterproductive from an environmental point of view.

**Alternative inhibitors**

Dometic and Thetford both stated having conducted extensive research on the subject of alternative, chromium-free inhibitors. As of yet, only Dometic provided detailed supporting evidence of these studies. Both stakeholders indicate that research is slow and cannot be accelerated as the performance of an inhibitor is mainly measured by its effect on the lifespan of products. Test cycles can therefore last up to ten years or more.

Until now, no suitable alternative inhibitor could be found although different options have been considered in order to eliminate hexavalent chromium.

Test results by Dometic can be summarized as follows:

Potential alternatives so far have systematically entailed a reduced product lifespan. Absorption refrigerators with alternative inhibitors combined with other solutions reach lifespans of 3–5 years, compared to the original lifespan with CrVI exceeding 15 years. A refrigerator without any inhibitor at all runs continuously for less than one year.

The use of alternatives, through the reduction of the lifespan, reduces the safety of users. A reduced lifespan means that refrigerant flow is stopped earlier. This leads to the overheating of the boiler, where corrosion is thus further accelerated. This entails a higher risk of pipe wall corrosion sufficient to cause leakage of refrigerant. Alternative systems so far have therefore increased the risk of refrigerant leakage during product use.

In order to compensate for the reduced corrosion protection, one possible solution is to reduce the operating temperature of the boiler, thus reducing the corrosion rate. However, this causes a reduction of cooling performance, making it difficult to have a functional freezer compartment as the minimum temperature of the coolant increases by 3–4$^{o}$C. Customer demands are said to require a freezer compartment.

Energy efficiency is also reduced as a higher energy use is required to compensate as much as possible the temperature increase of the coolant. The increase in energy consumption is said to be of approximately 10%–15%.

No time frame for substitution is expected to be available before at least ten years due to the slow testing process.

Thetford delivers arguments that go in the same direction, supporting their claims with a timeline of their investigation into an alternative corrosion inhibitor (Thetford 2009b).

Thetford has provided documentation indicating that they began investigating alternatives in 1993. The research has partly taken place with external consultants and with a research university. Currently, testing continues, but conclusive results as to possible alternatives are not expected for at least five years.

Thetford claims that as of yet, no other substance has been able to produce the same effect while keeping sufficient inhibitor in solution to insure long life of the refrigerator (Thetford 2009a).

### 4.19.4 Critical review of data and information

The contractor would first like to thank stakeholders for their complete and detailed answers and supporting evidence. Such levels of information and detail are fundamental to be able to accurately judge the need for an exemption as defined by the ELV Directive.

Both stakeholders provided consistent information, supported by extensive evidence on the behalf of Dometic.

**Chromate concentration reduction**

No data was provided on this option. It would seem that any further reduction in chromate concentrations would lead to a shorter product lifespan.

Stakeholders claim that any reduction of product lifespan is unacceptable based on their knowledge of consumer usage. Input provided by the European Caravaning Federation indicated that situations where the motor caravan was used in off-grid situations was frequent in the EU27, with users often “free camping” in designated caravan pitches and near tourist attractions (European Caravaning Federation 2009).

Most research efforts have gone in the direction of completely replacing chromium VI as an inhibitor.

**Alternative inhibitors**

Evidently, research in this field is taken very seriously and has been long running. Provided evidence was very extensive and detailed.

As of yet, no alternative absorption refrigeration systems are able to reach a lifespan of 10 years or more. This is true no matter what combination of alternative inhibitor, structural material or surface treatment is used. Ongoing research is taking place but results are slow coming. Promising alternative solutions are however slowly making headway.

Stakeholders agreed that a reduction in boiler temperature would reduce corrosion due in part to the simple reduction in temperature and in part to the reduction of the temperature cycle amplitude (i.e. difference between highest temperature and lowest temperature). However, such a move would come at the sacrifice of the freezer compartment.

Dometic claimed that increased insulation would not allow the freezer compartment to be maintained. A significant reduction in boiler temperature would limit corrosion at the cost of performance and smaller useable space due to the increased insulation.

Although this outcome is viewed as unacceptable by manufacturers, the necessity of a freezer can be questioned. The presence of a refrigerator in a motor caravan isolated from the electricity grid could be considered as “avoidable” in the sense that a motor caravan also fulfils its function without a built-in low-noise and electricity-independent refrigerator. Use information provided by the European Caravaning Federation indicates that use in out-of-grid situations is frequent (European Caravaning Federation 2009).

In any case, it is not yet proven that a reduction of the boiler temperature is sufficient to switch to a hexavalent chromium-free alternative while reaching a minimum ten year lifespan.

Additionally, the contractor would like to point out that the environmental impact of this application is unknown. Collection rates of used units, as indicated by the European Caravaning Federation, are unknown due to lack of data as it appears that no significant amount of vehicles has yet been recycled, with slightly more than 20% of registered vehicles being over 20 years old (European Caravaning Federation 2009). Furthermore, possible CrVI emissions which may occur during the life of these products is unknown as of yet. It can be safely assumed that CrVI emissions may be most significant during the production process or the recycling/disposal process. However, stakeholders point out that chromium (VI) content of used units is very low if not inexistent at the end of the products lifespan.

### 4.19.5 Final recommendation

Provided information and evidence strongly supports that the industry is actively pursuing an alternative to chromium VI inhibitors. Research as of yet has not provided an answer to this query and may not do so for the next few years due to the unavoidably slow testing procedures.

It is thus recommended to continue the exemption with the proposed new wording:

> *“Hexavalent chromium as an anti-corrosion agent of the carbon steel cooling system in absorption refrigerators up to 0,75 weight-% in the cooling solution except where the use of other cooling technologies is practicable (i.e. available on the market for the application in motor caravans) and does not lead to negative environmental, health and/or consumer safety impacts.“*

The contractor underlines that having a high performance refrigerator with a freezer compartment while being in a secluded area can be viewed as expendable and thus avoidable in the sense of the ELV Directive. No use statistics indicating the frequency of out-of-grid use of refrigerators was provided, making it impossible to tell how often this highly valued characteristic is actually used.

Furthermore, an in depth study should take place to assess the consequences on fossil fuel consumption likely to be caused by the performance reduction resulting from the lowering of the boiler temperature. The benefit of a reduction of chromium use, and linked emissions, should be carefully weighed against the likely increase in fossil fuels.

### 4.19.6 References

Dometic 2009a — Dometic response document "2009_08_03_Dometic Öko-institute ELV.pdf"

Dometic 2009b — Dometic confidential evidence sent by e-mail with the response document.

European Caravaning Federation 2009 — European Caravaning Federation; e-mail communication with Mr. Onggowinarso on 24.11.2009

Thetford 2009a — Thetford response document "2009_07_31_Thetford_Exe13_mh.pdf"

Thetford 2009b — Thetford research timeline sent by e-mail on 23.11.2009

## 4.20 Exemption no. 14a

*"Mercury in discharge lamps for headlight applications"*

### 4.20.2 Description of exemption

Mercury is used in certain automotive headlights, in so called HID (High Intensity Discharge) lamps. Compared to standard halogen light bulbs, discharge lamps have a higher efficiency and a higher light output.

The exemption to use mercury in automotive lighting systems has been in place since the ELV Directive first came into force in 2000. In the course of Annex II amendments the exemption has successively been changed and adapted. The last amendment in 2008 led to an expiry date on the 1 July 2012, after which the exemption will only be valid for spare parts.

The aim of the current review is thus to verify whether the foreseen expiry date is still feasible and whether it correctly reflects practicability of substitution. Substitution has already begun to take place: the first approved vehicle type using mercury-free HID headlamps have been on the EU market since 2007. In the long run, LED-based headlight systems may also be used as a substitute.

HIDs contain an average of 0,5 mg / lamp (Automotive Industry 2009). Considering that approximately 10%–20% of the EU automotive market (~17 Mio cars / y) uses HID-based systems, the total amount of mercury used in this application was about 2,6 kg / y and is now steadily decreasing due to ongoing substitution efforts (Automotive Industry 2009a). According to the automotive industry, the actual annual volume of discharge headlamps in Europe is of about 2,5 Mio units (= 1,25 kg mercury) (Automotive industry 2009).

#### Technological comparison

The most common headlights used in the automotive industry are low efficiency halogen light bulbs (cf. Table 25). Mercury-containing HID-lamps were developed because they offer higher energy efficiency, whiter light and a longer life span. Furthermore, studies have shown that HID lamps are safer since fewer accidents occur when using HIDs than with halogen lights (Automotive Industry 2009).

Stakeholders state that the efficiency gain from HIDs compared to conventional halogen headlights is not outweighed by the high energy need of the ballast (Automotive Industry 2009).

LED-based headlamps are also mercury-free but are not yet technologically mature enough to be broadly applied in automotive applications. Currently, the efficiency is still too low and is expected to only significantly improve by 2015. Audi has started a pilot application in its R8 type. Advantages of LEDs in headlights are a very white light as well as expected lower energy consumption than with HIDs (cf. Table 25) (Automotive Industry 2009a).

The difference of technical parameters for all existing headlight technologies is shown in the following table provided by the automotive industry:

Table 25: Technical parameters for different headlight systems (Automotive Industry 2009)

| Power (Watt) | Halogene System (12V) | Halogene System (13,5V) | HID-System with Hg | HID-System without Hg | LED today* | LED 2015** forecast |
|---|---|---|---|---|---|---|
| Lamp | 55 | 65–70 | 35 | 35 | 50 | 35 |
| ECU | | | 7 | 9 | 9 | 7 |
| Additional equipment like cooler | | | | | 2 | |
| Total | 55 | 65–70 | 42 | 44 | 61 | 42 |

**Environmental aspects**

According to the automotive industry, mercury-free HIDs have a higher electrical energy consumption leading to an additional 4 W needed per car (this in turn may lead to a slightly higher but negligible increase in fuel consumption) (Automotive Industry 20099. However, there is a 1 mg mercury reduction per vehicle. Also, mercury-containing HIDs are dismantled from end-of-life vehicles and recycled. Hazards associated with substances used in mercury-free headlamps are currently not assessed and no dismantling / recycling is in place (Automotive Industry 2009a).

The conclusion of stakeholders is thus that mercury-free systems might have environmental disadvantages which can however not be quantified at the moment. Manufacturers of headlight systems are currently carrying out LCA analyses for the different technologies (halogen, HID with and without mercury, LED) in order to be able to have a better idea of the overall environmental impact of each solution. Results are expected to be ready by late 2010 (Automotive Industry 2009a).

### 4.20.3 Justification for exemption

During the last stakeholder consultation, the automotive industry confirmed that the foreseen phase out date of 1 July 2012 could be kept. The choice of this date has been justified as follows (Automotive Industry 2009):

- A 1:1 replacement is not possible since mercury-containing and mercury-free HID burners have completely different technical parameters and therefore a different validation according to UN ECE regulation R99 is necessary:
  - Need different ECUs (Electronic Control Unit).

– Operating voltage is lower (45 V vs. 85 V), thus operating current higher (0,8 A vs. 0,4 A)
– Higher run-up power needed to fulfil R99.
– Run-up behaviour is slower
– Lower arc diffusion leads to 10%–20% lower light output

▪ Because of all the necessary technical changes, Hg-free technology is only possible in new vehicle development.
▪ Implementation of a new mercury-free headlight technology needs several years:
  – The first stage is the design and development of the mercury-free HID lamp itself (this was the case in 2003/2004 for mercury-free HIDs)
  – Once the lamp technology is ready, pilot applications are put in place and field-tested (this was the case in 2007 with introduction in the Audi A5)
  – At last, broad application for all types of vehicles takes place.
  – Since vehicle types are not put on the market every year, since a vehicle type is produced for about 6 years and since the development of a vehicle type (including type approval) needs about four years, a full phase-out is only feasible by 2012.

This argumentation line is shown in the following roadmap provided by automotive industry.

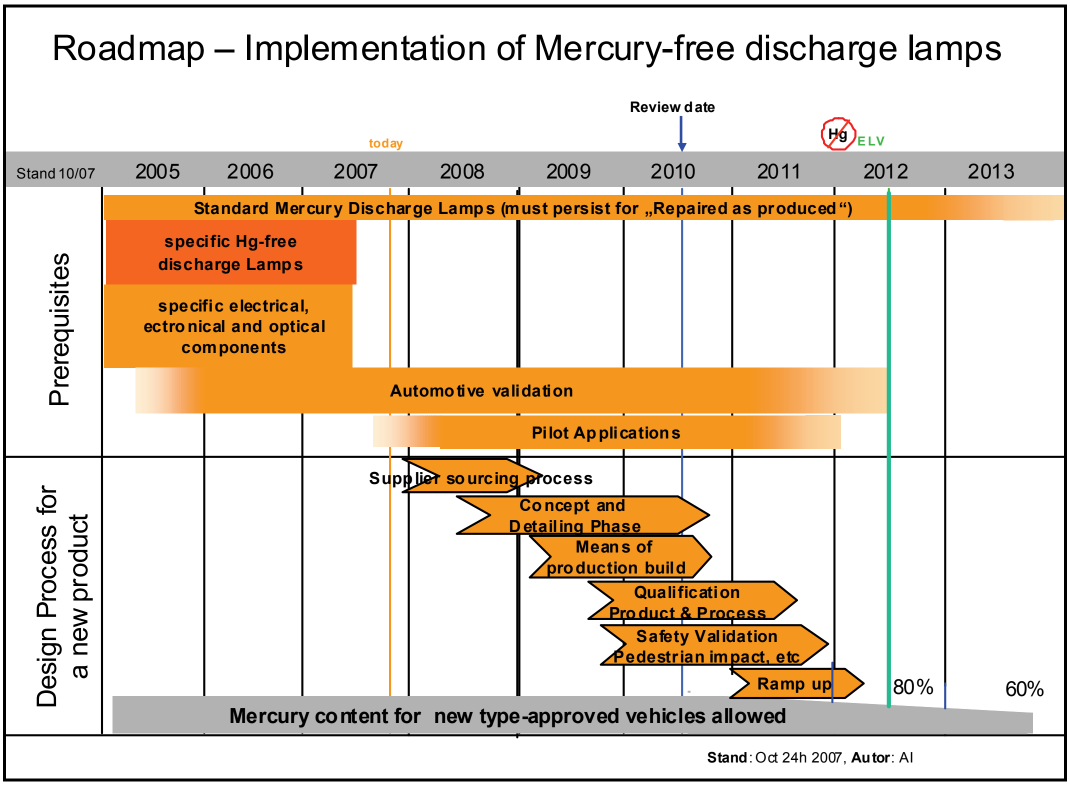



Figure 70 Mercury phase-out roadmap for headlight applications (Automotive Industry 2007)

### 4.20.4 Critical review of data and information

- Currently HID headlight systems seem to be the most efficient and safe technology on the market compared to conventional halogen and still under development LEDs.
  - Halogen have higher power demand (less energy efficient) and a reduced object recognition and therefore a higher accident risk than HIDs.
  - LED-based headlight systems are currently still more power demanding (hence less energy efficient); sufficiently efficient systems are expected in vehicles put on the market by 2015.
- Hg-free HID headlight systems currently on the market meet R99 requirements.
- Substitution and type approval on a broad scale only started around 2007; an earlier phase-out date is thus not possible.
- Mercury substitution would lead to annual savings of ~1,5 kg mercury. However, a small additional amount of energy is needed to operate mercury-free systems (+ 4 W per car). Whether this additional energy need outweighs the benefits of reduced mercury use or not cannot be assessed in the context of the present evaluation. Thus, the overall environmental benefit of substitution might not be positive. LCA data is however not available to fully confirm this (energy needed for production and recycling / disposal of the two systems would also need to be considered in order to give a sound appreciation of the overall environmental benefits).

### 4.20.5 Final recommendation

In light of the above, it is recommended to continue the phase-out of the exemption on the 1st of July 2012. The current wording can thus be kept as it is.

However, the contractor would like to remark that there is currently no assessment that allows a conclusion on the overall environmental benefit of phasing out the use of mercury in automotive headlights. The above recommendation only follows the requirements as set in Article 4 (2) (b) of the ELV Directive.

### 4.20.6 References


| | |
|---|---|
| Automotive Industry 2009 | ACEA, JAMA, KAMA, CLEPA et al. joint contribution to the online stakeholder consultation; “Mercury in discharge lamps for headlight applications”; provided on 3 August 2009 |
| Automotive Industry 2007 | “Mercury phase-out roadmap for headlights”; provided by automotive industry during the last evaluation in October 2007 |
| Automotive Industry 2009a | Conference call held on 2 October 2009 by Öko-Institut with ACEA and Automotive Lighting |

## 4.21 Exemption no. 14b

*"Mercury in fluorescent tubes used in instrument panel displays"*

### 4.21.2 Description of exemption

Mercury is used for display backlighting in certain automotive applications (e.g. instrument panels and navigation systems). The display backlights use discharge lamps of the so-called CCFL (cold cathode fluorescent lamp) type. CCFLs are commonly used in other display backlighting applications (e.g. TVs, notebooks).

The exemption to use mercury in instrument panel displays has been in place since the ELV Directive first came into force in 2000. In the course of Annex II amendments, the exemption has successively been changed and adapted. The last amendment in 2008 led to an expiry date on 1 July 2012 after which the exemption will only be valid for spare parts.

The aim of the current review is thus to verify whether the foreseen expiry date is still feasible and whether it correctly reflects practicability of substitution. Substitution has already started to take place with the use of LED-based backlights.

CCFLs contain 3–5 mg mercury on average with some applications having up to 10 mg (inter alia depending on the screen size). Assuming that 25% of vehicles put on the EU market annually (~17 Mio cars / y) contain CCFL-lit backlights (Automotive Industry 2009), the total amount of mercury used in this application was about 20 kg / y (with 4 mg mercury / vehicle) and is now steadily decreasing due to ongoing substitution efforts.

Stakeholders request the current wording of the exemption be kept as it is (Automotive Industry 2009):

- Repaired as produced;
- Phase-out of mercury in new type approved vehicles after 1 July 2012 (effectively until 2019 since vehicles are produced for about seven years).

**LEDs as a substitute**

As stated by the automotive industry in its contribution to the stakeholder consultation (Automotive Industry 2009), it is beginning to use LED backlights for instrument panel displays in new approved vehicle types. The roadmap provided shows that automotive validation and pilot applications have started in order to meet the set phase-out target of 1 July 2012 (cf. Figure 71).

LED-based instrument panel backlights have technological differences compared to CCFL-based ones:

- different power supply (DC not AC), illumination pattern and thus geometry;

- different ambient surrounding of the component (due to difference in heat loss behaviour);
- different electronic control systems (due to different power supply);
- completely different packaging and PCB layout.

**Environmental aspects**

According to stakeholders, no direct comparison of LEDs and CCFLs is possible in regards to their environmental impact due to differences in design and architecture. No cradle-to-grave LCA is available which can confirm that LEDs are overall an environmentally advantageous substitute for mercury (i.e. no mercury reduction scientifically proven over lifetime). However, both technologies have comparable energy efficiencies.

With regard to end of life treatment, instrument panel displays have to be dismantled and are then processed in specific recycling schemes thus limiting the environmental impact as much as possible.

### 4.21.3 Justification for exemption

Stakeholders from the automotive industry justify their request that no changes be made to the exemption as follows (Automotive Industry 2009):

- Mercury content of CCFLs used in automotive instrument panel backlights cannot be compared to the mercury content of other CCFLs used as display backlights in other applications.
  - Mercury content depends inter alia on ambient temperature which is different in automotive applications.
  - Limiting the mercury content in the current exemption in view of harmonisation with the RoHS Directive is thus not considered practicable. Furthermore, the new proposed wording for the use of mercury in CCFLs under RoHS is not yet in force. Also, the phase out of mercury in this application under ELV is ongoing and should not be disturbed by restricting the amount of mercury in instrument panel displays backlights.
- The purpose of the review is to check whether the automotive industry is on schedule with regard to phase-out. It can now be confirmed that the schedule proposed during the last review can be met (cf. Figure 71). Stakeholders would welcome legal certainty during change-over and thus would like to keep the wording and expiry date as it is.
- Because of technological differences, LED is not a retrofit solution, and hence cannot be built in current production vehicles (new type approval necessary).

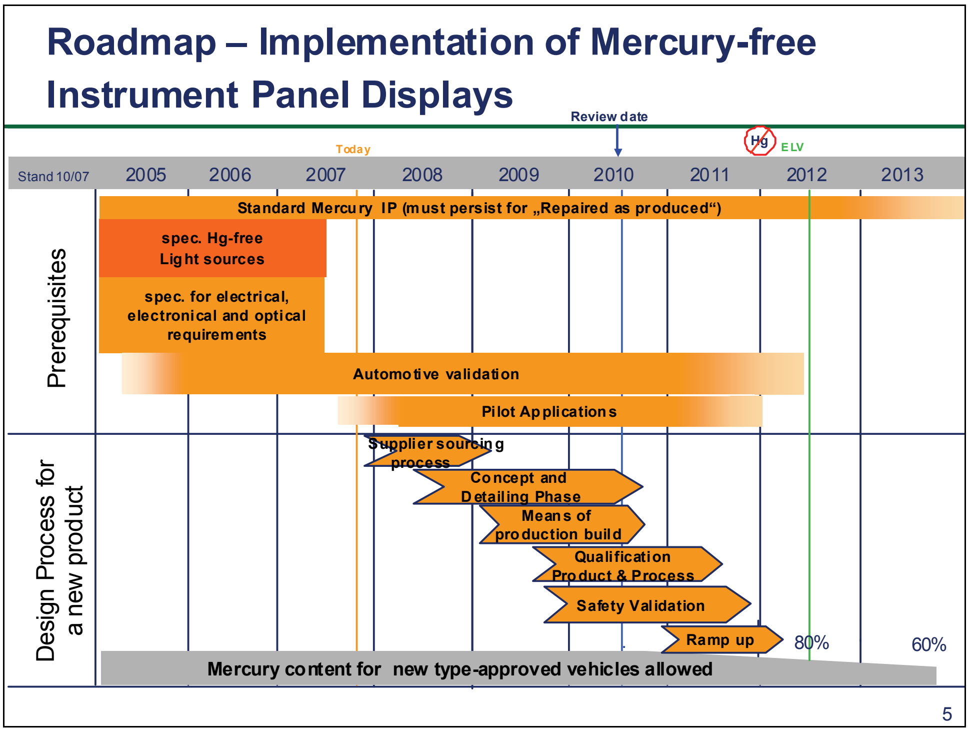



Figure 71 Road map for phase out of mercury in instrument panel displays (Automotive Industry 2007)

### 4.21.4 Critical review of data and information

- The argumentation used by stakeholders is plausible and justified.
- The current phase-out is underway within the foreseen timeline and cannot be accelerated even if LED technology for backlight displays is already available, since a 1:1 retrofit replacement is not possible.
- New vehicle development and type approval needs about 4 years. The phase out date of 1 July 2012 allows automotive industry to change over to LED-based backlights appropriately, for all vehicles newly put on the market since the beginning of the substitution process was mid 2007.
- LED is a mercury-free substitute and has as such environmental advantages in waste treatment but no scientific proof exists on its overall environmental benefit.

### 4.21.5 Final recommendation

In light of the above, the contractor recommends continuing the phase-out of the exemption until 1 July 2012. The current wording can thus be kept as it is.

However, the consultants would like to remark that there is currently no assessment that allows drawing a conclusion on the overall environmental benefit of phasing out the use of mercury in display backlights. The above recommendation though complies with the requirements as set in article 4 (2) (b) of ELV Directive.

#### 4.21.6 References


| | |
|---|---|
| Automotive Industry 2009 | ACEA, JAMA, KAMA, CLEPA et al. joint contribution to the online stakeholder consultation; "Mercury in fluorescent tubes in instrument panel displays"; provided on 3 August 2009 |
| Automotive Industry 2007 | "Mercury phase-out roadmap for instrument panels"; provided by automotive industry during the last evaluation in October 2007 |
| Automotive Industry 2009a | Conference call held on 28 September 2009 by Öko-Institut with ACEA et al. |


### 4.22 Exemption request no. 1

*"Lead in solders for the connection of very thin (<100 µm) enamelled copper wires and for the connection of enamelled copper clad aluminum wires (CCAWs) with a copper layer smaller than 20 µm for tweeters in vehicles"*

The applicant D&M Premium Sound Solutions requests a new exemption from the material bans in the ELV Directive.

#### 4.22.2 Description of exemption

**Copper clad aluminium wires**

The applicant uses thin enamelled copper wires (ECW) and copper clad aluminium wires (CCAW) in the production of light coils. Such light voice coils are applied in high tone tweeters, where the high frequencies cause fast movements. The thin wires of the voice coil are soldered to the tweeter frame using leaded solders (D&M Sound Solutions 2009a).

According to the applicant, the total amount of lead in one device is calculated to fall between 12 and 60 mg for a 50 g tweeter (D&M Sound Solutions 2009a). Thus the total amount of lead in a vehicle that would be covered by this application falls below 240 mg. The applicant sells a total amount of speakers in the order of magnitude of 10 million annually worldwide that would in principle fall under this exemption since the larger part is designated towards the automotive industry (D&M Sound Solutions 2009a).

The amount of lead, which the applicant uses to solder copper clad aluminium wires in tweeters thus is in the range of around 2,000 kg per year. The applicant did not provide data on the total amount of lead that would be used under this exemption in the EU or worldwide.

In the proposed exemption wording, the applicant does not indicate applications for the use of the very thin wires. The wording does neither mention the voice coils nor the high tone tweeters as specific applications, where this exemption would be used. D&M states that scientifically and technically, the soldering of such thin wires is critical. To avoid a number of parallel exemption initiatives that are all related to the same technological challenges, the applicant based his exemption request on the technical and scientific aspects, that shall justify the exemption and not on the final market application (D&M Sound Solutions 2009a). The applicant refers to the current exemption 33 of the RoHS Directive “Lead in solders for the soldering of thin copper wires of 100 µm diameter and less in power transformers” as proof that other companies are struggling with the same problems and an application specific exemption thus would just increase the number of exemptions (D&M Sound Solutions 2009a).

### 4.22.3 Justification for exemption

**Copper clad aluminium wires (CCAW)**

According to the applicant, compared to the thin enameled copper wires, the more severe problems occur in the lead-free soldering of CCAWs (D&M Sound Solutions 2009c).

Figure 72 schematically depicts an enamelled copper clad aluminium wire (CCAW).

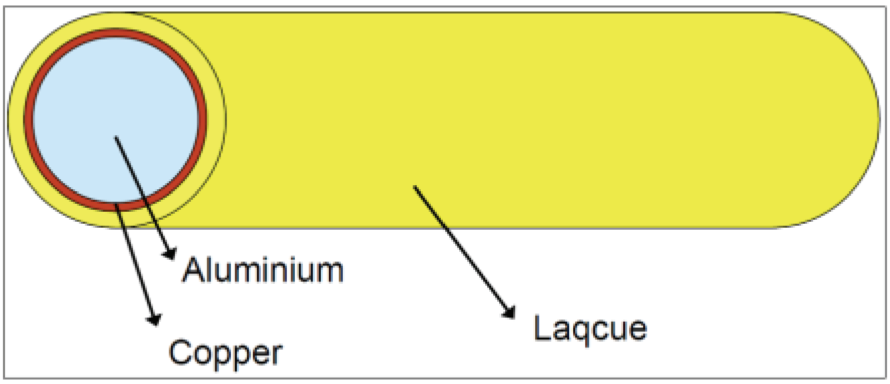



Figure 72 Enamelled copper clad aluminium wire (CCAW) (D&M Sound Solutions 2009a)

Enamelled CCAWs are used to make light coils, which are used where fast movements are required, like in high tone tweeters. Aluminium is used as a core material because of its combination of good electrical conductivity and light weight. The copper cladding ensures a good and reliable contact between the wire and the soldering contact. Without this thin copper layer, the aluminium is hydrolysed because of the electrical potential between tin and aluminium in combination with humidity (Volta element). This would make the aluminium wire brittle and vulnerable to microcracks, resulting in the breaking of wires and failure of the product. In practice, the copper layer is 3–10 µm thick.

The lacquer is the electrical insulation layer isolating the wire in the coil and against the coil frame. As a large amount of heat is generated in the electrical conductive wire during operation, the lacquer has to withstand high temperatures.

**Processing of CCAWs**

A solder with 60% lead is the most viable option to make a good electrical contact between the enamelled CCAW and the electrical power source.

- The solder has to remove the enamel by thermal decomposition at a temperature above 450°C.
- The solder has to give an electrically conductive, mechanically strong and reliable connection.

The applicant explains that the enamelled CCAW is soldered in a two step process. The two-step process minimizes the use of lead solder.

1. In a first step, the thin enamelled CCAW is pre-tinned using a lead containing solder (60(Pb) / 38(Sn) / 2(Cu)). During this processing step, the lacquer is removed by thermal degradation, and a thin (<10 µm) layer of solder is deposited on the CCAW. The estimated weight of solder (60% Pb) necessary to pre-tin a single voice coil is calculated to be below 0,1 g (20 to 100 mg). An example of the resulting intermediate article is presented in Figure 73.

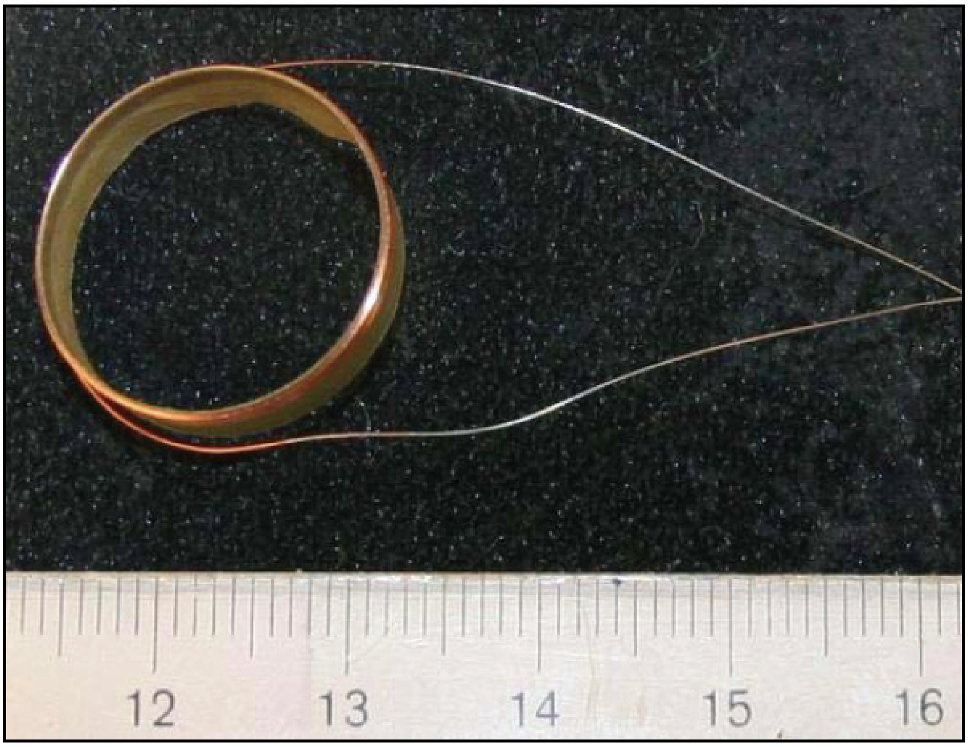



Figure 73 Voice-coil with a pre-tinned enamelled CCAW

2. In a second step, the pre-tinned enamelled wire is soldered to the loudspeaker frame with lead free solder. During this second solder step, part of the lead present on the pre-tinned wire dissolves in the secondly used solder. This results in a solder connection point with variable concentration of lead ranging from below 0,1% to 2% depending on measuring area.

**Replacement of lead solder**

The applicant explains that copper dissolves too fast in RoHS and ELV compliant solders to make a reliable connection to CCAWs (D&M Sound Solutions 2009a). Figure 74 illustrates how fast a copper wire dissolves in the current state-of-the art lead free solder, specially developed to reduce the dissolution of substrate metal.

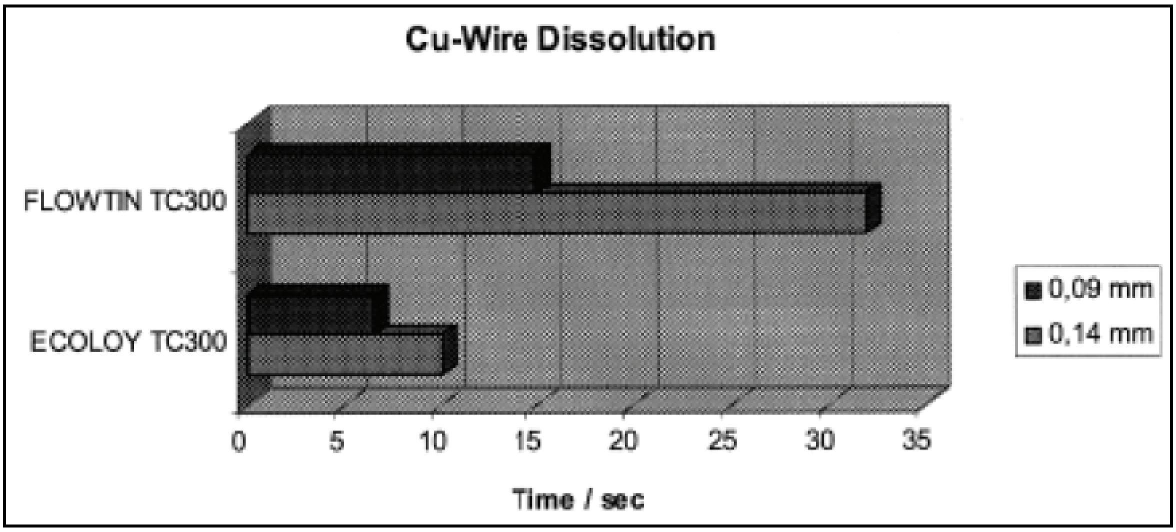



Figure 74 Time for the complete dissolution of copper wires in lead-free solders (Ecoloy TC300) compared to lead solder (source: Stannol) (D&M Sound Solutions 2009a)

- During the contact time in the pre-tinning process, an important fraction of the copper wire/cladding is dissolved, leading to a less reliable connection. The above results are obtained at 350°C; the dissolution will be significantly higher at 450°C, according to the stakeholder. The use of lead-free solders thus is impossible.
- Other substitutes cannot withstand the high temperatures (450°C) needed for stripping the enamels. These solders are oxidising too fast at these temperatures. Mechanical stripping of the insulation is impossible because the small wire cannot withstand forces higher than 0,35 N.
- Chemical stripping was tested as an alternative but proved to be impossible due to incomplete removal of the lacquer. Also the chemical stripping would have a serious negative environmental impact.
- Removing the lacquer in a single separate step with hot air stripping proved to be impossible due to the small possible operating temperature window. Either there is no reaction at all and the lacquer is not removed, or the total wire is destroyed.
- Removal of the lacquer with heated molten salts proved also to be incomplete and very critical. In addition, incomplete removal of the residual salt created an extra problem.

As described in the Öko-Institut report "Adaptation to Scientific and Technical progress under Directive 2002/95/EC, Final Report 22 October 2007", 5.1.4, "there is no clear evidence that it is feasible to solder thin wires of 100 micrometer diameter and less with RoHS compliant solders".

## Design Changes

The applicant explains the following alternatives and why they are not viable (D&M Sound Solutions 2009a):

- The soldering problem could be partially overcome by replacing the CCAWs with copper wires. For applications that need a very thin (< 100 µm) copper wire, this is still not a technically reliable option. The reason to make the changeover from copper wires to CCAWs was primarily to improve the environmental impact. First of all, there is the difference in weight of the winding wire itself, which leads to weight increase of 240% of the coil wire. As the voice-coil is a fast moving part in the envisaged application, higher electrical power will be consumed. In the envisaged application of tweeters, replacement of the CCAWs with copper can easily double the weight of the moving part of the speaker. According to the formula below, this decreases the output of the speaker for 6 dB. To compensate this loss in acoustical power, the electrical power needs to be multiplied by a factor 4.

  -20 log (Mmd with copper/Mmd with CCAW ) = 20 log (2) = -6 dB
- In practice, the loss in acoustical power will be partially compensated by using a stronger magnet system, which leads to a higher yield in the transfer of electrical to acoustical power. To fully compensate the extra weight of the copper wire, 12% of extra material and thus extra weight needs to be added to the magnet system.
- Another viable option would be looking for alternatives for CCAWs that have an intermediate density between CCAWs and copper. A solution would be an Al/Cu/Ni/Cu wire, as introduced by Totoku under the name KCCAW. Upon drawing the wires to obtain very small diameters, small defects in one of the very thin layers can easily cause failure to the desired functionality of this layer. At his time KCCAWs are not available on the market with diameter smaller than 150 µm. Due to the complicated production process, KCCAWs currently are only technical practicable for larger diameters.
- Changeover to HMP solder as alternative does not make sense because of the even higher Pb content (>85%) (D&M Sound Solutions 2009c).
- CCAW wires with an extra intermediate barrier layer to prevent the solder erosion of the thin copper layer: The production of wires with a core diameter 80–400 micrometer, with 3 different sheet layers of metal of several micrometers is not that straightforward. Selection of base materials for every layer needs to be optimal, heat treatment of this combination of materials needs to be optimized and iteration between the selection of materials is necessary. Also during the drawing process, it is important that the drawing does not result in micro cracks, which is very difficult to establish in this multi layer structure. Research as a substitute is ongoing, but this substitute is not available yet (D&M Sound Solutions 2009c).

### 4.22.4 Critical review of data and information

**Availability of lead-free soldered high tone tweeters**

"Harman Becker Automotive Systems GmbH" provided information on its lead-free products with thin wires (Becker 2009):

| **Kunden Teilenummer** *(Customer Part Number)* | **HBAS Teilenummer** *(Part Number)* | **Kunde** *(Customer)* | **Beschreibung** *(Description)* | **relevantes Merkmal** *(relevant feature)* |
|---|---|---|---|---|
| 6513 6 964 012 | 49134 30944 | BMW AG | Hochtoener Hifi 25mm *(Tweeter)* | Cu Draht, 0.09mm *(Draht: wire)* |
| AH4218808AC | 9907013401A | Landrover | Hochtoener premium 25mm *(Tweeter)* | CCA Draht 0.12mm mit <20µm Cu |

Figure 75 Lead-free soldered high tone tweeters (Becker 2009)

The above table proves that lead-free soldered high tone tweeters with thin wires are available and in use. Harman Becker said that constructive changes facilitated avoiding lead and to achieve a reliable operation of such high tone tweeters.

The applicant was given the opportunity to comment on the above findings (D&M Sound Solutions 2009b). For the lead-free soldered CCAW high tone tweeters, the applicant claims that his experience (fall out production, failures in accelerated life-time testing, customer warranties, scientific data, etc.) resulted in a design rule not to use CCAW wire (<150 micrometer) in new designs with lead free solder. The applicant says that from the information he has from the Landrover tweeter he cannot judge whether all technical issues are solved, or if Harman Becker simply takes the risk. The applicant is convinced that the process window in which reliable products can be delivered is too small to deliver premium products towards the automotive customer. It is not impossible to make such products. The applicant states that he had such products in the market, too, but he estimates the quality risk as being simply too high and references the scientific and technical data submitted (see previous chapter) (D&M Sound Solutions 2009b).

D&M also uses lead-free solders with enamelled copper wires of less than 100 micrometer diameter. The stakeholder claims to have several products in the market that deliver up to the high quality standards of the consumer and automotive industry. He stated that the inclusion of these wires into the exemption request was merely for harmonization of exemptions in RoHS and ELV. The applicant does not plan to switch to leaded solders for the soldering of small copper wires (D&M Sound Solutions 2009b).

**Conclusions**

*Availability of compliant high tone tweeters*

The information available clearly indicates that the current state of science and technology allows producing high tone tweeters with lead-free thin wires. The applicant suspects that the reliability of such products might not be sufficient. There is, however, no evidence for this statement.

The applicant states that "…for automotive applications, more stringent requirements on resistance to corrosion are in place. […] automotive requirements are very often a combination of cyclic humidity, salt spray testing, often during operation, implying electrical current and voltage applied on the components" (D&M Sound Solutions 2009c). The lead-free soldered high tone tweeters must have passed all necessary tests, as they are used in vehicles. The producer of the ELV-compliant high tone tweeters confirms this (Becker 2009 ).

For the thin enamelled thin copper wires, the applicant himself admits that they can be soldered without using lead solders. The applicant justifies his request to exempt lead for soldering thin enamelled copper wires with reference to exemption 33 of the RoHS Directive: "Lead in solders for the soldering of thin copper wires of 100 µm diameter and less in power transformers". He claims that this would be a proof for the principal technical problem of soldering thin enamelled copper wires. To avoid multiple exemptions for the same principal technical constraint, this exemption request was submitted.

The fact is well known that lead-free solders with high tin contents are more aggressive and thus dissolve copper faster than lead solders do. The availability of lead-free soldered products, however, proves that the effect can be mastered for high tone tweeters. For the high voltage power transformers, additional requirements, in particular concerning the shape of the solder joints, justified the exemption. The pure scientific and technical effect thus may have different impacts depending on the specific application. A general exemption for the soldering of thin wires thus would not be in line with the requirements of Art. 4 (2) (b) (ii). Despite of the principal technical constraints, lead still is avoidable depending on the applications, as constructive means can help to overcome the problem.

*Restriction to new type approved vehicles*

The use of lead in high tone tweeters so far has been covered by exemption 8 a in Annex II of the current ELV Directive: *Solder in electronic circuit boards and other electrical applications except on glass*. The exemption expires end of 2010. After the review of this exemption in the current review process of Annex II this use of lead would be covered by the proposed exemption *"Lead in solders in other electrical applications than soldering on printed* *wiring boards or on glass"*, which is proposed to expire end of 2010 as well. After 2010, this use of lead would no longer be ELV-compliant in case the Commission follows the reviewers' recommendation.

The global automotive industry demands that "If a phase out seems to be feasible, it needs to be linked to vehicles type approved" (Automotive Industry 2009). This request to restrict the ban to vehicles with no type approval yet – allowing its continued use in vehicles, which are already type approved – is not plausible. The automotive industry did not submit any evidence to substantiate this request. The ban should therefore apply to high tone tweeters in all vehicles.

### 4.22.5 Final recommendation

It is recommended not to grant this exemption. Lead-free soldered products are available on the market showing the use of lead is avoidable in this application. An exemption would thus not be in line with the criteria, which Art. 4 (2) (b) (ii) stipulates for an exemption.

The use of lead in this application so far has been covered by exemption 8a of Annex II, which expires end of 2010. The stakeholders' request to further on allow the use of lead in high tone tweeters for vehicles with type approval before the expiry date of exemption 8a or later is not substantiated and should therefore not be granted either.

### 4.22.6 References


| | |
|---|---|
| Automotive Industry 2009 | Automotive Industry, stakeholder document "automotive_industry_general.pdf" |
| Becker 2009 | Harman Becker Automotive Systems GmbH, documents "Harman-Becker-Thin-Wires-deutsch.pdf" and "Harman-Becker-Thin-Wires.pdf"; information sent via e-mail to Dr. Otmar Deubzer, Fraunhofer IZM |
| D&M Sound Solutions 2009a | D&M Sound Solutions, stakeholder document „exemption_ELV_PSS_letter.pdf“ |
| D&M Sound Solutions 2009b | D&M Sound Solutions, stakeholder document "Thin Wires Schaerlaekens.pdf" |
| D&M Sound Solutions 2009c | D&M Sound Solutions, stakeholder document "dmpss__EN_1.pdf" |

## 4.23 Exemption request no. 2

*"Lead-containing thermoelectric materials in automotive electrical applications to reduce $CO_2$ emissions by recuperation of exhaust heat"*

The evaluation of exemption request 2 under the current contract was based on information and supporting evidence supplied during this consultation. Initial answers have been received from stakeholders in the context of the second stakeholder consultation. Further questions have been sent to stakeholders who have sent input. Additionally the applicant provided further explanation to the technology as well as to the data in a face-to-face meeting.

### 4.23.2 Description of exemption

In passenger cars, an Internal Combustion Engine (ICE) never reaches efficiencies higher than 33% in practical conditions, typically no more than 20%–25%. This means that no more than 33% of the heat produced by fuel combustion is transformed into mechanical energy, the remainder being released as heat through the exhaust fumes and excess heat emitted by the radiator or motor block. One rather newly identified method to improve fuel efficiency of ICE vehicles is to use a Thermal Electric Generator (TEG) to extract some of the energy content of wasted heat.

A TEG is made of a thermoelectric material and uses the Seebeck effect to generate an electric current from a temperature difference between the so-called hot side and cold side of the TEG module[29]. TEGs have been used in aerospace applications for decades, where a TEG coupled with a radioactive heat source provide the most reliable energy source. The most widespread material used in cooling applications is Bismuth Telluride (BiTe), used in Peltier refrigerators for example.

The performance of a thermoelectric material at converting a temperature difference into electricity or vice versa is measured by the dimensionless figure of merit Z.T, where T is the operating temperature expressed in Kelvin and Z is defined as follows, where S is the material's Seebeck coefficient, σ its electrical conductivity, and κ its thermal conductivity:

$$Z = S^2 \sigma / \kappa$$

As can be seen in the expression of the figure of merit Z.T, a thermoelectric material's performance depends on the temperature(s) of operation.

[29] The opposite phenomenon is known as the Peltier effect where the application of electricity to the module creates a temperature difference.

The automotive industry requests this exemption in order to use a Lead Telluride (PbTe) TEG to recover some of the energy content of exhaust heat to supply power to onboard electrical applications. This electrical power source helps relieve load on the alternator, in turn reducing engine load and thus fuel consumption. Fuel economy improvements of up to 5% are cited. The industry is expecting to implement the widespread use of this technology by 2018, but will begin implementation on select models in 2012.

The TEG module would contain 300 g of PbTe, with a lead content of 61,5% by weight, i.e. 110/190 g of lead.

The applicant requests a new exemption with the following wording, scope and expiry date, and labelling requirements:

“Lead-containing thermoelectric materials in automotive electrical applications to reduce $CO_2$ emissions by recuperation of exhaust heat.”

To be labelled or made identifiable in accordance with Article 4(2)(b)(iv) for dismantling.

For vehicle types approved before the 31$^{st}$ of December 2018 and spare parts for these vehicles.

#### 4.23.3 Justification for exemption

ACEA/KAMA/JAMA/CLEPA/et al. provided information (ACEA et al. 2009a and ACEA et al. 2009b) and strong independent supporting evidence conducted by the German Aerospace Center (DLR) (see DLR 2009) for the use of lead-containing thermoelectric material.

As previously stated, implementation of this technology is intended to start in 2012. Stakeholders therefore performed a detailed material screening on the following criteria:

- sufficient performance in the 200–500°C temperature range (typical in exhaust environment);
- sufficiently high acceptable maximum temperature (must be able to resist temperatures of up to 600°C for short periods of time without degrading);
- 3000 h of operation without degrading under normal operating conditions (thermo-mechanical cycling, vibrations, oxidising, etc.);
- environmental compatibility and health risks;
- industrial availability of material or thermoelectric modules (2012 is critical);
- material resources;
- existing examples of reliable technical or commercial applications;
- physical data availability (thermal conductivity, thermal expansion, melting point, fire hazards, etc.);
- possible reactions with other materials.

According to the information quoted above, lead-free alternatives exist or are being developed. However, none of them currently fit the conditions necessary for proper application. Essentially, only two materials are mature enough for industrial applications, namely BiTe and PbTe, with BiTe being the best known and most efficient material of the two. The latest BiTe modules reach energy conversion efficiencies of 7%. However, the optimal operating temperature of BiTe TEGs is 50–150°C and the material cannot be used at temperatures above 300 °C.

The only remaining candidate available for use as soon as 2012 is therefore PbTe, which has good performance between 350–600°C and fulfils the other practical requirements.

In addition to the information covering the possibilities to substitute PbTe the applicant provided a LCA-Study which has been reviewed independently by the organisation DEKRA (BMW 2009). According to the results of this study the application of the TEG was beneficial for the environment in all environmental impact categories being considered (i.e. Global Warming Potential, Acidification Potential, Photochemical Ozone Creation Potential, Cumulative Energy Demand). This is due to the fact that the reduction of the fuel consumption during the use phase is the dominating factor for the environmental friendliness of the TEG vehicle. In contrast production and recycling of the TEG component have no notable influence on the result. Comparing two different types of TEG the results of the study also demonstrate that the bigger TEG with the higher amount of thermo electrical material (PbTe) produces more benefits for the environment than the smaller TEG.

**Alternative technologies**

As previously mentioned, alternatives are not yet ready for small-scale 2012 industrial applications. However, the applicant considers that they should be mature within the next ten years, at which point they hope to switch entirely to lead-free alternatives.

Industry underlines that this switch to lead-free is in their interest as telluride is not a very abundant or readily available material. No primary production of telluride exists as of yet and it is currently produced as a by-product of other mining activities including that of copper. Therefore, in order to go through with a widespread implementation of this technology, the automotive industry intends to switch to alternatives that do not use telluride (and subsequently lead) as soon as possible.

### 4.23.4 Critical review of data and information

Provided information and supporting evidence was detailed and comprehensive:

- Lead reduction: Provided evidence clearly explained that material composition was optimised in order to increase the TEG's performance. No lead reduction is therefore foreseeable. According to the physical principles which are relevant for the TEG the thermoelectric properties react very sensitively to the smallest change of composition.

A reduction of the lead content in the PbTe compound would significantly reduce the thermoelectric performance of the TEG module in general.

- Alternative technologies: Supporting evidence was detailed and clearly explained why alternatives were not yet mature enough or did not respect the necessary criteria.

Furthermore, it is clear that the automotive industry has more incentives to switch to lead-free alternatives as soon as possible for economic reasons than to continue to use PbTe for widespread production due to the problems raised by the availability of Telluride.

Additionally the results of the LCA-Study provided by the applicant are comprehensive and conclusive.

### 4.23.5 Final recommendation

In light of provided information and supporting evidence, the contractor recommends granting a new exemption with the following wording, scope and expiry date, and labelling requirements:

"Lead-containing thermoelectric materials in automotive electrical applications to reduce $CO_2$ emissions by recuperation of exhaust heat for vehicle types approved before 31 December 2018 and spare parts for these vehicles." To be labelled or made identifiable for dismantling in accordance with Article 4(2)(b)(iv).

This recommendation is based upon the evidence that currently no viable substitute or alternative technologies are available. Additionally the TEG makes the reduction of the fuel consumption possible, which results under a life cycle perspective to environmental benefits in four impact categories (see above). According to the general procedure and based on the provisions of the ELV Directive this request for exemption should be granted even in the case that no environmental benefits would result, as the main justification for this exemption is based on the non-availability of substitutes.

Following the applicants argumentation the consultant recommend to conduct a first review in 2015. This is due to the situation that lead free materials are being expected to be available in 2018 at latest due to the promising ongoing material development, especially in the field of skutterudites and silicides. A review in 2015 could therefore focus on the scientific state of the art of these new thermoelectric material groups.

### 4.23.6 References

ACEA et al. 2009a — ACEA/KAMA/JAMA/CLEPA/et al. exemption request document

ACEA et al. 2009b — ACEA/KAMA/JAMA/CLEPA/et al. answers to further questions

| | |
|---|---|
| BMW 2009 | The Thermo Electrical Generator (TEG); Life Cycle Assessment. BMW Group, Department for Environmental Management and Recycling. Munich, 27.11.2009 |
| DLR 2009 | German Aerospace Center (DLR), Thermoelectric materials, Maturity for technological applications, Short Survey, July 2009 |


## 4.24 Exemption request no. 3

*"Pb, Cd and CrVI glazed coating on ceramic body" (RoHS)*

The draft recommendation on the RoHS exemption request related to "Pb, Cd and CrVI glazed coating on ceramic body" was finalised and brought forward to the Commission in progress report 6. The applicant, Faianças Ideal Vale de Ourém Lda., a Portuguese company in the ceramic business, was involved in a further exchange with Öko-Institut.

The Commission has meanwhile also commented on the recommendation. A slightly revised version is thus included in this progress report 10.

### 4.24.2 Description of exemption

Exemption request 3 is very similar to a previous request submitted by Ceram Unie during the last evaluation (cf. http://rohs.exemptions.oeko.info/index.php?id=47 for the corresponding consultation and http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf for the report containing the recommendation under section 4.37).

The current request refers to glazed coatings on ceramic bodies made from – among others – metallic and/or semi-metallic oxides. The ceramic glazes are used as a waterproof and decorative coating for lamp bases.

Lead compounds (oxides, carbonates, silicates) are used in frits and ceramic pigments. Cadmium and hexavalent chromium (CrVI) are used in ceramic pigments (oxides and silicates). Suppliers of the applicant – the Portuguese company Faianças Ideal Vale de Ourém Lda. – stated that the amount of these substances in the glazing depends on the colours (grading) and the thickness of the glaze. They can be estimated at:

- 0%–30% lead compounds leading to ~2,50 t/y;
- 0%–1,4% cadmium compounds leading to ~0,45 t/y;
- 0%–0,9% CrVI compounds leading to ~0,50 t/y.

The function of the substances is:

- Lead compounds
  - act as flux on the development of glazed colour surfaces, thus promoting special design effects;
  - lower melting point of glazed surface and pigments;
  - are used to create metallic-like glazed surfaces (silver and gold).
- Cadmium compounds
  - are used in the development of bright reddish and orange colours.
- CrVI compounds
  - are used in the development of dark, black colours.

The applicant requests an exemption for the use of lead and cadmium in glazes and colours used on ceramic lamp bases and lamp carriers. No wording proposal was initially proposed by the applicant but Faianças Ideal Vale de Ourém Lda. agreed to the proposed wording of the contractor taken from the recommendation for the similar former exemption request:

"Lead and cadmium in glazes and colours used on ceramic lamp bases, lamp carriers and clocks".

### 4.24.3 Justification for exemption

The applicant justifies the need for an exemption as follows:

- Although many efforts are being made across the world, in academic centres, and company labs, a proper substitute to these materials in these applications, with the same or similar chemical and physical properties, has not yet been found.
- These properties consist mainly of:
  - lowering the glaze melting points, along with colouring pigments;
  - as a silicate glaze, obtaining smooth, glossy, bright colours and special effects.
- Design changes on the product do not lead to a possible substitution.
- The applicant thus concludes that it is currently technically and scientifically impracticable to substitute the use of these substances. This has been confirmed by declaration letters from three suppliers.
- Furthermore, the applicant states that it does not understand why an exemption is granted for the use of lead in crystal glass and why it would not thus be justified for the use in ceramic glazes since in both cases the main function of the substances is to fulfil a decorative purpose. The following aspects are mentioned:

- Glaze coatings, made from compounds that include Pb, CrVI and Cd, are allowed to come into contact with food, as long as they meet the requirements of Directive 84/500/EEC[30] regulating the use of lead and cadmium in ceramic articles:
  - For articles that can be filled: 4,0 mg/l for lead and 0,3 mg/l for Cd (migration levels for these metals in acetic acids).
  - These values cannot be compared to the maximum concentration values under RoHS in weight-%, but the applicant states that they far exceed them.
- The same substances are used for non-tableware products, such as jars, ashtrays, candleholders, among other objects.
- These substances are used in the manufacturing of crystal glass, often in larger quantities and concentrations (24% to 33% lead in its composition). However, crystal glass is exempted from RoHS substance use restrictions.
- In the applicant's production line, all types of products – whether they are covered by RoHS or not – follow the same process.

▪ The applicant has stated that it has tried to sell compliant ceramic products covered by RoHS, i.e. products without e.g. colour glazing but customers have not bought these. Hence, demand is decreasing and the company – a SME – is encountering economic difficulties. Due to the fact that market surveillance under RoHS is not functioning well, Asian imports with coloured ceramic glazes – declared as RoHS compliant – are demanded by customers.
  - To support his statement, the applicant has provided sales data showing that sales were reduced by 33,5% between 2007 and 2008.
  - As a direct link to RoHS provisions cannot be given and as this decrease was – according to the applicant – also partly influenced by the overall economic situation, the applicant also provided data on purchase volume of products that are used for the manufacture of colours and glazes showing a decrease by 69,43% between 2007 and 2008.
  - The applicant argues that the latter decrease is much larger than the overall sales decrease which gives a hint on the effects of the RoHS Directive on the company's production.

30 Council Directive of 15 October 1984 on the approximation of the laws of the Member States relating to ceramic articles intended to come in contact with foodstuffs.

### 4.24.4 Critical review of data and information

- The applicant has provided sound and well-justified information to support his exemption request.
- The former evaluation of the similar request by Cérame Unie came to the following conclusion:
  - Technically, the exemption is not required. Other materials than ceramic materials can provide the functionality of ceramic parts for lamp bases, lamp carriers and clocks. If ceramic parts are used in these applications, they could be used either without colours, or with lead-free glazes and colours. The substitution or elimination of lead and cadmium in this application thus is technically practicable.
  - Aesthetically, the result of the elimination and substitution is not equivalent, as not all glazes and colours are producible in the same quality as with lead and cadmium. In case these aesthetical aspects are considered as a crucial practicability aspect, Art. 5 (1) (b) could justify an exemption. The substitution or the elimination of lead and cadmium would then be technically impracticable with respect to the outcome.
- Implementation and thus interpretation of Article 5 (1) (b) is the responsibility of Member States. A decision on whether aesthetic aspects are covered by Article 5 (1) (b) is currently pending.
- Hence, two possibilities exist concerning a recommendation in line with Article 5 (1) (b):
  1. Technical practicability of substitution is given if the aesthetic function of the application is not covered by Article 5 (1) (b).
  2. Technical practicability of substitution is not given if the aesthetic function of the application is covered by Article 5 (1) (b).
- Going beyond the provisions of Article 5 (1) (b) the contractor would like to draw the attention to the following two points considered relevant here:
  - It has already been stated before, that SMEs have a particularly difficult position with regard to the RoHS Directive and its exemption process and that they may face hard economic consequences when an exemption is not granted.
  - Coated lamp bases are covered by the RoHS Directive. Other ceramic products which may have a more direct impact on human health (e.g. tableware) are not covered by the RoHS Directive. From a technical point of view, both are produced in the same production lines and both currently meet the respective requirements of Directive 84/500/EEC. There is thus no human health justification not to grant an exemption under RoHS.

### 4.24.5 Final recommendation

In light of the above and assuming that Article 5 (1) (b) is interpreted as including aesthetic functions of applications, it is recommended to grant the requested exemption. The proposed wording is

> *Lead and cadmium in glazes and colours used on ceramic lamp bases, lamp carriers and clocks.*

# 5 Annex

## 5.1 Annex for exemption no. 10

**Uses and amounts of lead in ceramics and in glass**

Figure 76 provides a table with the main applications of lead in ceramic and glass in vehicles. The table also gives an overview on the main obstacles and effects of lead substitutions in these applications.

| | Current applications | | Effects of using the current applications | Negative impacts by substitution |
|---|---|---|---|---|
| Ceramic resonators | Engine Section Parts | Engine Control (knocking) Oxygen Sensor | Piezo ceramics application Lead piezoelectric ceramics can contribute to the realization of high grade electronic control for improving energy saving, safety and comfort in vehicles due to its excellent frequency stability and oscillation characteristics | Because the frequency stability of lead-free piezoelectric ceramics with Bi layer-structured compounds or tungstenbronze structures suggested as alternative candidates is worse than that of piezoelectric ceramics containing lead, and oscillation characteristics are also inferior, it is difficult to achieve high grade electronic control for vehicles. |
| | Speedometer | Controller (Clock) | | |
| | ABS | " | | |
| | Driving Operations | Sonar Controller | | |
| | Air Bag | Controller (Clock) | | |
| | Car Radio/Audio | CD/MD Controller (Clock) | | |
| | Car Navigation | CD/DVD/HDD Controller (Clock) Remote Control (Clock) | | |
| | Anti-Theft Alarm System | Controller (Clock) | | |
| | Keyless Entry | Receiving (Controller) | | |
| | General Purpose | PC Clock | | |
| Ceramic filters | Car Radio/Audio | AM Filter FM Filter | Piezo ceramics application As lead piezoelectric ceramics has superior frequency accuracy and thermal stability, high reliability information communication between electronic equipment in the vehicle can be achieved and it can contribute to improve energy saving, safety and comfort through the advancement of car electronics. | Lead-free piezoelectric ceramics with Bi layerstructured compounds or tungsten-bronze structures suggested as alternative candidates have poorer frequency accuracy and thermal stability than lead piezoelectric ceramics not being able to improve the reliability of information and communication between electronic equipment in the vehicle. Therefore, it is not possible to contribute with energy conservation, safety and comfort through the advancement of car electronics. |
| | Car Navigation | TV Filter | | |
| | Keyless Entry | AM Filter | | |
| Piezoelectric buzzers | Speedometer | For alarms, sirens | Piezo ceramics application Lead piezoelectric ceramics can produce high sound pressure under low voltage, and the mechanical operation part has a simple structure set to a minimum due to its small number of components. Therefore it can contribute with reduction of the number of set components, secure longterm reliability and low power consumption. | As lead-free piezoelectric ceramics has worse piezoelectric properties when compared to those containing lead, this will lead to the increase of power consumption. |
| | Driving Operations | " | | |
| | General Purpose | Buzzer | | |
| Ceramic sensors | Engine Section Parts | Knock Sensor Load Sensor | Piezo ceramics application As lead piezoelectric ceramics has excellent piezoelectric characteristics, small size, high-functionality sensors can be achieved. As a result, it becomes possible to contribute to the realization of high grade electronic control for improving energy saving, safety and comfort of the vehicle. | There are concerns of product size enlargement and insufficiency of reliability due to poor piezoelectric characteristics in nonlead piezoelectric ceramics. As a result, it becomes difficult to achieve a high grade electronic control of the vehicle. |
| | ABS | Acceleration Sensor/Shock Sensor | | |
| | Driving Operations | Rear Side Sonar Corner Sensor | | |
| | Air Bag | Acceleration Sensor/Shock Sensor | | |
| | Car Navigation | Angular Rate Sensor Shock Sensor for HDD | | |
| | Anti-Theft Alarm System | Acceleration Sensor Microphone | | |
| Thickfilm and glas applications | ABS / ESP | Angular Rate Sensor, Acceleration sensor | Leaded glass materials used for thick film pastes, hermetic seals, bonding, and glass encapsulation have excellent characteristics with respect to needed size and performance properties. As a result, it becomes possible to contribute to the realization of high grade electronic control for improving energy saving, safety and comfort of the vehicle. | Concerns of reliability based on processing incompatabilities, inadequate adhesion, electrical properties, and thermal expansion coefficient mismatch. |
| | Air Bag | Acceleration Sensor | | |
| | Car Navigation | Angular Rate Sensor | | |
| | General purpose | Resistor, Diodes | | |
| | Other Control units and relevant sensors such as for engine management, suspension systems, airconditioning, brake systems, common rail diesel, | Pressure sensor, circuit carrier temperature sensors | | |
| | Vacuum fluorescent displays (VFD's) | General panel meter | | |
| | | displays for climate control | | |
| | | displays for radio application (ETR) | | |
| | | Head Up displays (HUD) | | |
| PZT | Engine Section Parts | For Fuel Injection | Piezo ceramics application | There are concerns of product size enlargement and insufficiency of reliability due to poor piezoelectric characteristics in nonlead piezoelectric ceramics. As a result, it becomes difficult to achieve a high grade electronic control of the vehicle. |
| | General Purpose | Mechanical Operations | | |
| PTC ceramics (Thermistors) | Engine Section Parts | Overheating Detector | PTC ceramics application As lead PTC ceramics possesses self thermal control functions, it presents high reliability and safety. | Lead-free PTC materials possess poorer reliability and safety than lead PTC ceramics, and this leads up to the increase in power consumption. |
| | Air bag | Current Overflow Protection | | |
| | Car Radio/Car Audio | Overheating Detector Current Overflow Protection | | |
| | Keyless Entry | " | | |
| | General Purpose | " | | |
| | Heater | Heater with Control Function | | |
| Ceramic capacitor (MLCC) | General Purpose | energy storage decoupling bypassing | | Reliability |
| Varistor (MLV) | DC motors | RFI suppression | | Reliability |

Figure 76 Main applications of Pb-containing glass and ceramics in vehicles

The stakeholders indicate the amounts of lead used in PZT ceramics, thickfilm and in glass applications (CLEPA et al. 2009b).

| A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|
| Application | Name of Component | General Despriction / Details | Number per vehicle | mass of ceramics / glass per piece[4] | Mass of Pb[1] | mass of Pb per vehicle[7] (D*F) | average ratio[5] | average mass of Pb per vehicle (G*H) | average mass of Pb per vehicles on the market (2008)6 |
| | | | (pieces) | (mg) | (mg) | (mg) | (mg) | (mg) | (kg) |
| Around Motor | Oxygen Sensor | Resonator | 1 | 52 | 31 | 31 | 30% | 9 | 164,6 |
| | Knocking Sensor | Non-resonant type | 1 | 5.000 | 2.500 | 2.500 | 90% | 2.250 | 39.825,0 |
| | Knocking Sensor | Resonant type | 1 | 600 | 350 | 350 | 10% | 35 | 619,5 |
| | Load Sensor | | 2 | 9.000 | 6.150 | 12.300 | 5% | 615 | 10.885,5 |
| | Actuator | Fuel Injection - GAS min | 4 | 10.000 | 6.000 | 24.000 | 20% | 4.800 | 84.960,0 |
| | | Fuel Injection - GAS max | 4 | 12.000 | 7.500 | 30.000 | 20% | 6.000 | 106.200,0 |
| | Actuator | Fuel Injection - Diesel min | 4 | 10.000 | 6.500 | 26.000 | 20% | 5.200 | 92.040,0 |
| | | Fuel Injection - Diesel max | 4 | 16.000 | 10.000 | 40.000 | 20% | 8.000 | 141.600,0 |
| | PTC Thermistors | Over heat sensing | 1 | 3,9 | 0,1 | 0,1 | 10% | 0 | 0,2 |
| | PTC Thermistors | Over heat sensing | 1 | 8,8 | 0,4 | 0,4 | 10% | 0 | 0,6 |
| Speed-o-meter | Resonator | | 1 | 52 | 31 | 31 | 80% | 25 | 439,0 |
| | Piezo Sounder | Warning・ Information | 1 | 81 | 53 | 53 | 50% | 27 | 469,1 |
| | VFD Display | min | 1 - 2 | 25.000 | 3.000 | 1.500 | 3% | 45 | 796,5 |
| | | max | 1 - 2 | 200.000 | 13.000 | 6.500 | 3% | 195 | 3.451,5 |
| ABS/ESP | G Sensor | | 1 | 10 | 0,035 | 0 | 70% | 0 | 0,4 |
| | yawrate sensor | | 1 | 740 | 15 | 15 | 40% | 6 | 106,2 |
| | MEMS gyro | ESP, min | 1 | 40 | 0,15 | 0,2 | 15% | 0,02 | 0,4 |
| | MEMS gyro | ESP, roll-over, max | 4 | 40 | 0,15 | 0,6 | 5% | 0,03 | 0,5 |
| | Cicuit carrier | | 1 | 3 | 20 | 20 | 50% | 10 | 177,0 |
| | Resonator | | 1 | 52 | 31 | 31 | 70% | 22 | 384,1 |
| | Resonator | | 1 | 5,0 | 3,3 | 3,3 | 70% | 2,3 | 40,9 |
| | F-RAM Memory | Adaptive controls | 1 | 0,004 | 0,002 | 0,0 | 5% | 0,0 | 0,002 |
| Warning | Back Soner | US Microphone | 2 | 110 | 70 | 140 | 10% | 14 | 247,8 |
| | Corner Soner | US Microphone | 3 | 110 | 70 | 210 | 10% | 21 | 371,7 |
| | Piezo Sounder | Back Buzzer | 1 | 610 | 430 | 430 | 90% | 387 | 6.849,9 |
| | Resonator | | 4 | 52 | 31 | 124 | 90% | 112 | 1.975,3 |
| | Resonator | | 4 | 5,0 | 3,3 | 13 | 50% | 6,6 | 116,8 |
| Safety Air Bag | G Sensor Shock Sensor | Failsafe | 4 | 158 | 72 | 288 | 70% | 202 | 3.568,3 |
| | MEMS accelerometer | min | 1 | 10 | 0,035 | 0,04 | 90% | 0,03 | 0,6 |

Figure 77 Mass of lead in main PZT ceramics, thickfilm and glass applications (CLEPA et al. 2009b)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MEMS accelerometer | max | 6 | 10 | 0,035 | 0,21 | 10% | 0,02 | 0,4 |
| | Resonator | | 4 | 5 | 3,3 | 13 | 50% | 6,6 | 116,8 |
| | Resonator | | 2 | 52 | 31 | 62 | 70% | 43 | 768,2 |
| | PTC Thermistors | Circuit Protection | 1 | 249 | 18 | 18 | 5% | 0,9 | 15,9 |
| | F-RAM Memory | data recorder | 1 | 0,004 | 0,002 | 0,0 | 35% | 0,0 | 0,01 |
| Car Radio / Car Stereo | Filter | AM Radder F i l t e r | 1 | 540 | 320 | 320 | 90% | 288 | 5.097,6 |
| | Filter | FM Filter | 2 | 40 | 26 | 52 | 90% | 47 | 828,4 |
| | Resonator | CD/MD | 1 | 52 | 31 | 31 | 50% | 16 | 274,4 |
| | Resonator | CD/MD | 1 | 5 | 3,3 | 3,3 | 50% | 1,7 | 29 |
| | PTC Thermistors | Over heat sensing | 1 | 12,64 | 0,23 | 0,2 | 20% | 0 | 1 |
| | PTC Thermistors | Circuit Protection | 1 | 145,91 | 10,84 | 11 | 20% | 2,2 | 38 |
| | VFD Display | min | 1 | 20.000 | 2.500 | 2.500 | 7% | 175,0 | 3.098 |
| | | max | 1 | 70.000 | 4.500 | 4.500 | 7% | 315,0 | 5.576 |
| Car Navigation | Filter | | | | | | | | |
| | MEMS gyroscope | Angular Rate | 2 | 40 | 0,15 | 0,3 | 10% | 0,03 | 0,5 |
| | Resonator | CD/DVD/HDD | 3 | 52 | 31 | 93 | 10% | 9,3 | 165 |
| | Resonator | System Clock | 2 | 30 | 20 | 40 | 30% | 12 | 212 |
| | Resonator | CD/DVD/HDD | 1 | 5 | 3,3 | 3,3 | 10% | 0,3 | 6 |
| | TV Filter | TV functions | 1 | 33 | 20 | 20 | 10% | 2,0 | 35 |
| | G Sensor | HDD | 1 | | Footnote [3] | | 10% | | |
| | VFD Display | Turn by turn navigation | 1 | 60.000 | 3.900 | 3.900 | 0% | | |
| | | HUD application | 1 | 100.000 | 6.500 | 6.500 | 0% | | |
| | | compass | 1 | 20.000 | 2.500 | 2.500 | 0% | Footnote [3] | |
| | F-RAM Memory | Settings | 1 | 0,004 | 0,002 | 0,0 | 25% | 0,0 | 0,01 |
| Burglar Alarm | G Sensor | Vibration Sensing | | | | Footnote [3] | | | |
| | US Mirophone | | 2 | 150 | 100 | 200 | 20% | 40 | 708 |
| | Piezo Sounder | Alarm | 1 | 610 | 430 | 430 | 20% | 86 | 1.522 |
| | Resonator | | 1 | 52 | 31 | 31 | 20% | 6,2 | 110 |
| Keyless Entry[2] | Filter | AM Radder filter | 1 | 540 | 320 | 320 | 30% | 96 | 1.699 |
| | Filter | FM Filter | 1 | 33 | 20 | 20 | 60% | 12 | 212 |
| | Discriminator | | 1 | 150 | 105 | 105 | 30% | 32 | 558 |
| | Resonator | | 1 | 30 | 20 | 20 | 30% | 6,0 | 106 |
| | PTC Thermistors | Circuit Protection | 1 | 139,68 | 6 | 6,0 | 5% | 0,3 | 5 |
| Climate control | VFD Display | | 1 - 4 | 20.000 | 2.500 | 6.250 | 15% | 937,5 | 16.594 |
| General Purpose | Resonator | Clock of MPU | | 30 | 20 | | | | |
| | Filter | AM filter | | 200 | 140 | | | | |
| | | AM Radder filter | | 540 | 320 | | | | |
| | | FM Filter | | 33 | 20 | | | | |
| | | TV/VTR | | 33 | 20 | | | | |
| | Piezo Sounder | Buzzer/Speaker | Footnote [3] | 600 | 420 | 0,0 | | Footnote [3] | |
| | Piezo Transformer | LCD | 1 | 6.000 | 4.000 | 4.000,0 | 10% | 400,0 | 7.080 |
| | PTC Thermistors | Circuit Protection (Door mirror) | 4 | 38 | 2,9 | 11,6 | 20% | 2,3 | 41 |
| | PTC Thermistors | For Heater | 10 | 7.780 | 1.700 | 17.000,0 | 5% | 850,0 | 15.045 |
| | Leaded RFI supp./ SHCVs | RFI suppression of DC motors | 2 | 600 | 3 | 6,0 | 100% | 6,0 | 106 |
| | Actuator | Mechanical movement | | 350 | 200 | | | | |
| | Actuator | Mechanical movement | Footnote [3] | 20 | 12 | | | Footnote [3] | |
| | Shock sensor | Rolling detection (Tire Pressure monitor) | 4 | 120 | 0,15 | 0,6 | 10% | 0,1 | 1 |
| | MEMS pressure sensor | | 1 | 120 | 0,15 | 0,15 | 10% | 0,02 | 0,3 |
| | MEMS pressure sensor | | 5 | 120 | 0,75 | 3,8 | 5% | 0,19 | 3,3 |
| Control Unit - general | Circuit Carrier | Ceramic based carriers | 3 | 10.000 | 50 | 150,0 | 40% | 60,0 | 1.062 |
| | Resistor | Control unit | 200 | 5 | 0,02 | 4,0 | 100% | 4,0 | 71 |
| | Resonator | Engine Control | 1 | 52 | 31 | 31 | 80% | 24,8 | 439 |
| | Resonator | Engine Control | 3 | 5 | 3,3 | 9,9 | 30% | 3,0 | 53 |
| | Diode | | 3 | 14 | 8 | 24 | 80% | 19,2 | 340 |
| | Capacitor (MLCC/NME)) | energy storage | 150 | 10 | 0,1 | 15 | 100% | 15,0 | 266 |
| | Temp. sensors | | 1 | 14 | 8 | 8 | 80% | 6,4 | 113 |
| | Pressure sensor | | 1 to 5 | < 120 | 0,15 - 7 | 10,725 | 100% | 10,7 | 189 |

<u>Following figures are based on the above listed main applications thus not showing 100 % but a good estimation</u>

| | | | | |
|---|---|---|---|---|
| **Sum Pb in ceramic (total)** | 64 g | 36 g | 20 g | 350 to |
| **Sum Pb in ceramic (actuator)** | 28 g | 18 g | 14 g | 248 to |
| **Sum Pb in glass** | 481 g | 33 g | 1,5 g | 27,4 to |

[1] pure Pb (metal) content
[2] key(controller) of keyless entry is not counted.
[3] value differs depending on the specification.
[4] this is the mass of ceramic / glass containing Pb
[5] the number of vehicles that use this type of component
[6] 17.7 mio, according to ACEA
[7] vehicles of category M1 and N1 acc. To ELV are considered
[8] only pilot projects for the moment

Continuation Figure 77 Mass of lead in main PZT ceramics, thickfilm and glass applications

| Target parts | Part/usage | Component | Usage | Effects and tasks when excluding lead | Data attached with task: Attached data | Applications | Substitution material for assessment |
|---|---|---|---|---|---|---|---|
| Zinc oxide varistor (low varistor voltage product) Hybrid IC Piezoelectric product Moisture sensor etc | Electrode | silver | Ensuring conductivity | ○ (no effect) | | general electric installation control circuit | |
| | | lead borosilicate glass | Ensuring adhesiveness to ceramic base material | Deterioration of surge current withstand | Data a | | Bi-Co-based borosilicate glass |
| | | | | Deterioration of load life characteristics at high temperature | Data b | | Bi-Co-based borosilicate glass |
| Chip resistor | Electrode | silver / palladium | Ensuring conductivity | ○ (non lead-based) | | It is basically used in electronic circuit | |
| | | lead borosilicate glass | Ensuring adhesiveness to ceramic base material | Reduction of resistance to plating liquid<br>Reduced adhesiveness | Data c | | P-Sn-based glass 、Na-Al-P-B-based glass |
| | Resistor | ruthenium oxide (Rutile type) | Main component of low resistance (10kΩ or below) | ○ (non lead-based) | | | |
| | | ruthenium oxide (Plumbopyrochlore type) | Main component for high resistance (10kΩ or above) | Deterioration of load characteristics<br>Increased temperature coefficient of resistance (TCR) | Data d | | ruthenium oxide (Rutile type) |
| | | lead borosilicate glass | Ensuring adhesiveness to ceramic base material<br>Distribution of main component<br>Adjustment of resistance values | Occurrence of phase separation of glass<br>Reduction of water resistance<br>Reduced wettability with resistive element<br>Reduced stability of resistance values<br>Occurrence of crack in adjusting resistance values | | | B-Si-Ca-Al-Oglass , B-Si-Bi-Al-Oglass |
| | Protective coat | (Preglass ) lead borosilicate glass | Shock absorption in adjusment of resistance values | Reduction of strength of film | Data e | | Bi-glass, P-glass |
| | | (Protective glass ) lead borosilicate glass | Protection of resistor | Substitution possible | | | epoxy-based resin |
| Thick film distortion sensor | Sensor element (resistor ) | •ruthenium oxide<br>•lead borosilicate glass | •Resistance taper with high-sensitivity and linearity for extensive distortion | •Significant deterioration of detection accuracy as the sensitivity reduces to less than half | | Sheet weight sensor | |
| | | | ·Long-term stability of resistance valu | •When distortion is continuously added, the fluctuation of the original point is more than two times and the detection accuracy deteriorates significantly. | | | |
| Bridge rectification element Power transistor Power thyristor Power transistor etc | Protective coat | lead oxide-based glass | Ensuring chemical resistance | Reduction of electric stability | Data f | | borosilicate glass |
| | | | | Impossible to ensure thermal expandability coefficient similar to silicon | | | silica glass |
| | | | | Calcination temperature exceeds 1000 ℃ | | | silica glass<br>borosilicate glass |
| | | | | Deterioration of chemical resistance | | | zinc glass |
| Crystal oscillator Diode Thermistor etc | Sealant of ceramic base and lid | lead oxide-based glass | Ensuring vacuum (adhesiveness) | Data g | | | $P_2O_5$-based<br>Bi2O3-based<br>V2O5-based |
| Crystalline silicon photovoltaic cell | Electrode on the cell | Silver | Conductivity | ○ | Generally, low melting point lead-free glasses can be used as a substitute for lead oxide glass for electrode. But when these glasses is used for photovoltaic cell, the contact resistance between the cell and electrode grow big and cannot realize a desire | | |
| | | Lead oxide glass | Adhere to silicon cell substrate | Deterioration in adhesion | | | |
| | Electrode on the cell | Aluminum | Conductivity | ○ | Generally, low melting point lead-free glasses can be used as a substitute for lead oxide glass for electrode. But when these glasses is used for photovoltaic cell, the contact resistance between the cell and electrode grow big and cannot realize a desire | | |
| | | Lead oxide glass | Adhere to silicon cell substrate | Deterioration in adhesion | | | |

Figure 78 Uses and substitution of lead in glass of electrical and electronic components (JEITA et al. 2009b); data a, b, c, … can be found in subsequent sections

Data a

**Comparison Data of the Withstanding Surge Current Test**

Each n＝5

| Product number | Current product A（glass frit for lead-based electrode ） | Comparative product（glass frit for non lead-based electrode） |
|---|---|---|
| Test values（rated value） | 1000A × 1time | |
| V1mA rate of change | positive direction 0.20%<br>negative direction -1.20% | positive direction 0.80%<br>negative direction -8.50% |
| Withstanding surge current | 1500A | 1000A |

In case of using an electrode with non lead-based glass frit, there is no balance threshold value relative to the rated value as the withstanding surge current deteriorates.

Data b

Test 1 each n=5

| Product number | Current product B (glass frit for lead-based electrode ) | | Comparative product (glass frit for non lead-based electrode) | |
|---|---|---|---|---|
| Test conditions | 85℃, Current application rate DC90%, 1200 hours | | | |
| V1mA rate of change | positive direction | 2.40% | positive direction | 1.30% |
| | negative direction | 0.60% | negative direction | 0.00% |
| Withstanding surge current | 1500A | | 1000A | |

A significant difference was not found in the 85℃ high temperature load test.

Test 2 each n=5

| Product number | Current product B (glass frit for lead-based electrode) | | Comparative product (glass frit for non lead-based electrode) | |
|---|---|---|---|---|
| Test conditions | 125℃, Current application rate DC10%, 1150 hours | | | |
| V1mA rate of change | positive direction | 4.80% | positive direction | 3.60% |
| | negative direction | -1.50% | negative direction | -9.20% |
| Withstanding surge current | 1500A | | 1000A | |

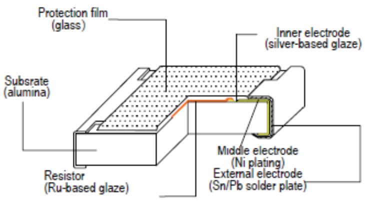
The non lead-based product shows a fluctuation range close to ±10% of the decision criterion of V1mA rate of change when the period of high-temperature load test exceeds 1000 hours.

Data c

| Type of substance | Usage | Reduction difficulty level |
|---|---|---|
| Glass frit contained in a thick film material forming electronic device | Resistors, capacitors, chip coils,<br>chip inductors,<br>resistance networks, capacitor networks,<br>hybrid ICs | **Substitution by 2008 is not assured** |

**Reason for usage**

| Portion of usage (Sketch) | Reason for usage |
|---|---|
| Ex) Chip resistance | Material and characteristics of glass frits for thick film technology |




| | Pb glass | Zn glass | P-Sn glass | Na-Al-P-B |
|---|---|---|---|---|
| Compatibility of component | ○ | △ | △ | ○ |
| Low softening temperature | ○ | △ | ○ | ○ |
| Thermal expandability coefficient | ○ | ○ | ○ | △ |
| Climatic conditions | ○ | ○ | △ | △ |

The lead-based glass is composed to have the flexibility to satisfy the characteristics required for thick film materials and it is inexpensive. Therefore, it is used for many glass frit compositions.

**Substitution difficulty**

Though we have examined many alternative glass frit compositions in the past, they do not satisfy the requirement for glass frit mentioned above. For example, $P_2O_5$-SnO-based glass and $Na_2O$-$Al_2O_3$-$P_2O_5$-$B_2O_3$-based glass have been developed, though they are not practical in application as they are inferior to lead-based glass in Climatic conditions.

There are many glass frit compositions containing lead in the world. A long period of time will be required to develop lead-free glass frit to replace them.

**Explanation of Technical terms**

| Technical terms | Explanation |
|---|---|
| ・Thick film technology | ・Form the pattern out of functional material such as conductors, resistors, and dielectric bodies on substrates using screen printing technology. The material is processed in paste form and calcinated at around 800℃. |
| ・Glass frit | ・Glass finely ground into powder form |

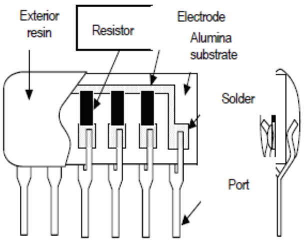
continuation Data c

| Type of Substance | Related Usage | Reduction difficulty level |
|---|---|---|
| Lead in thick film resistors as the resistance component of various resistance parts | RC networks , potentiometers, hybrid ICs, chip resistance , chip resistance networks, chip RC networks , chip capacitor networks , chip resistance arrays, trimmer potentiometers, etc. | **A** (Substitution by 2008 is impossible) |

## Reason for usage

**Portion of usage (Sketch)**

(Example)
Resistance network




**Reason for usage**

Thick film resistors are used by printing a resistive paste of thick film on the alumina substrate and calcinating it. Thick film resistors cannot be produced without lead.

Table1 shows the ingredient example of typical resistive paste.

| Name of material | | e (wt%) |
|---|---|---|
| Conductive materia | **Pb**2Ru2O7 | 15～20 |
| Glass frit | **Pb**-Si-B-O | 20～45 |
| Vehicle | resin, solvent | 30～45 |
| Metal oxide | MnO,CuO etc | 0.1～5 |

**Table 1**

Lead (Pb) is found in lead ruthenium oxide ($Pb_2Ru_2O_7$) of conductive materials and glass frit.

The range of resistance value of lead (Pb) is as wide as $10^{-3}$ Ω·cm～$10^{4}$Ω·cm.

It is the key material for resistors with TCR characteristics of -55□～150□ and ±100ppm～±250ppm.

Lead ruthenium oxide has a wide range of resistance value and the fine grain and coarse grain are well balanced, which enhances the current withstand and contains the contact resistance. See Figure 1.

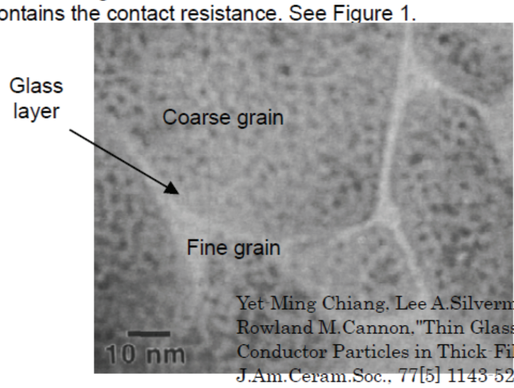



**Figure 1**

Yet-Ming Chiang, Lee A.Silverman, Roger H.French and Rowland M.Cannon,"Thin Glass Film between Ultrafine Conductor Particles in Thick FilmResistors", J.Am.Ceram.Soc., 77[5] 1143-52 (1994)

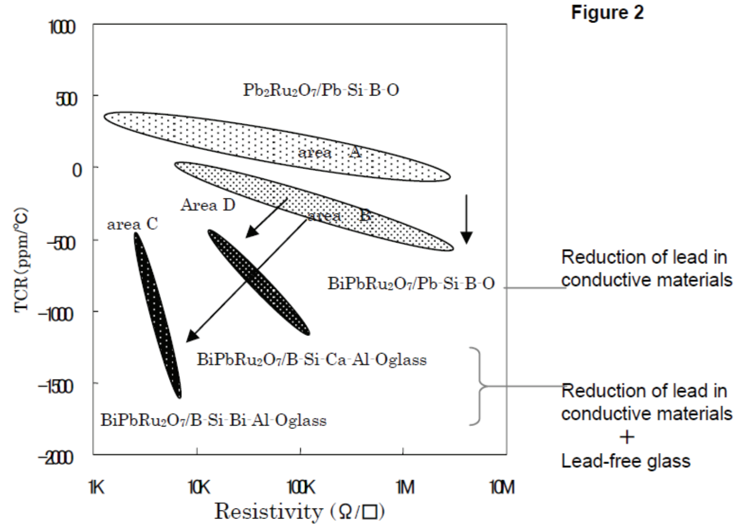
Lead-containing glass has a wide range of softening point and wettability with conductive particles, forming a thin glass layer between the particles easily, which is deeply connected with the good TCR properties.

## Substitution Difficulties

When we substitute a part of lead of lead ruthenium oxide with Bi, the area A changes into Area B as shown in Figure 2 and the range of resistance values shrinks, deteriorating TCR properties. Moreover, when we substitute the material of this glass with Ca-Al or Bi-Al, it changes into Area C or Area D and the resistance values and TCR properties deviate from the range of use.

Continuation Data c

Figure 2




Metal oxide UMnO or CuO) is used as an additive to adjust TCR to be closer to a particular required area.
As shown in Figure 3, the non lead-based conductive material and glass material violates such properties of metal oxide(MnO or CuO).

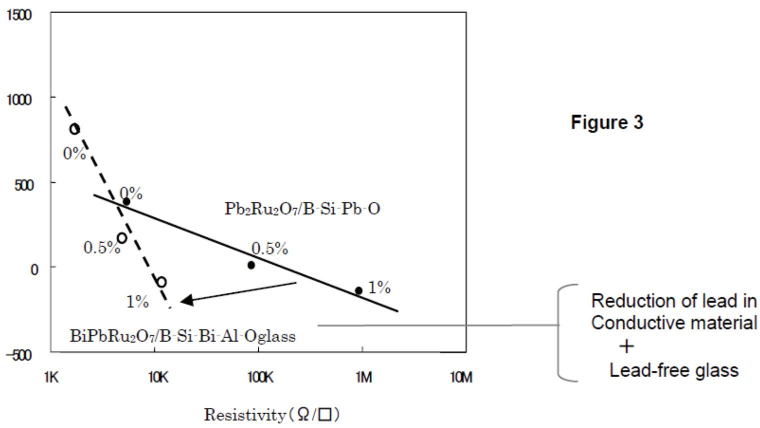



Figure 3

Alternative non lead-based substances used in the above evaluation are the most feasible option.

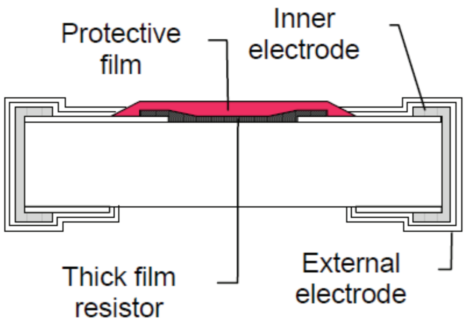
## Explanation of technical terms

| Technical terms | Explanation |
|---|---|
| Paste | Liquid in which large amount of fine solid particle is scattered. |
| TCR | Coefficient to indicate the fluctuation of resistance values when the ambient air temperature rises by 1℃. Resistance temperature coefficient。 |
| Contact resistance | Electrical resistance present between the contact surfaces of two substances |
| Softening point | Temperature at which the substance softens |
| Wettability | Penetration and blending of glass into the gap of conductive particles |

Data e

| Item | Object | Reduction difficulty level |
|---|---|---|
| Lead contained in glass which is a thick film insulator | Fixed metal glaze flat chip resistors,<br>Chip-shaped R networks , multiple chip-fixed resistors<br>Chip-shaped RC networks , chip–shaped C networks etc | Substitution by 2008 is not assured |

**Reason for usage**

| Parts of usage | Reason for usage |
|---|---|
| Fig. 1 shows the structure of a square chip resistor used in glass as thick film insulator. The protective film contains a lead compound as material and the protective film is made of two layers of pre-coated glass and protection-coated glass.<br><br><br>**Fig.1 Structure of a square chip resistor** | **Pre-coated glass**<br>1. Low fusing point<br>When correcting resistance values of thick film resistors by trimming, the pre-coated glass must be able to be cut with the heat of laser trimming. Therefore, the pre-coated glass formed on the thick film resistor needs to be sintered at a relatively low temperature (600°C).<br>2. Moisture & Acidity resistance<br>Pre-coated glass is required to control the fluctuation of resistance values due to moisture and acid etc. Due to these reasons, lead-based glass is used.<br><br>**Protection coating**<br>Use of non lead-based alternative product is possible. |

**Reason of difficulty of substitution**

**Pre-coated glass**

Due to the absence of materials superior to lead-based substances in moisture resistance and acidity resistance.

Characteristics of substitute glass ○:Excellent △:Slightly poor ×:Poor

| Material | Trimming properties | Acid resistance | Moisture resistance | Heat resistance |
|---|---|---|---|---|
| Lead glass | ○ | ○ | ○ | ○ |
| Bi Glass | ○ | × | △ | ○ |
| P glass | ○ | × | △ | ○ |

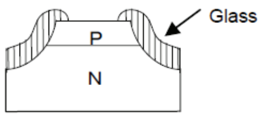
**Explanation of technical terms**

| Technical terms | Explanation |
|---|---|
| Pre-coated glass | Material used to control the fluctuation of resistance values in post-processes etc. |
| Coated glass | Material used to protect resistors |
| Laser trimming | Method to correct the resistance values to obtain the given resistance values |

Data f

| Type of substance | Related products | Reduction difficulty level |
|---|---|---|
| Lead-based glass (Pb glass) :Used for the protection of surfaces of semiconductor chips | Bridge rectifying devices, power diodes , power thyristors, power transistors etc | A Impossible to substitute |

**Reason for usage**

| Portion of usage (Sketch) | Reason for usage |
|---|---|
|   Cross section of a power diode | Widely used as the passivation film on the surface of P･N junction of power semiconductor devices.<br>The glass material to be used for this purpose needs to satisfy all the following conditions.<br>①High electrical stability<br>②Thermal expandability similar to that of silicon<br>③Calcination temperature is at 1000℃ or below<br>④High chemical resistance<br>Pb glass is equipped with all the properties from ① to ④ above. |

**Difficulty for substitution**

The main ingredient of Pb glass is PbO and Pb glass also includes $Al_2O_3$ and $SiO_2$ etc as well.
This glass does not contain the material to reduce the chemical resistance and it is extremely stable towards various chemicals used in semiconductor processing.
Moreover, the thermal expandability coefficient relatively similar to silicon can be obtained as the thermal expandability coefficient can be adjusted with the composition of Pb O and $SiO_2$.
The calcination temperature for this is low at 1000℃ or below and does not affect the property of P-N junction.
In terms of reliability, since it can be made into a thick film, it is highly resistant to moisture and its characteristics are stable under high voltage in the range from several hundred V upto 1000 V.

On the other hand non lead-based glass materials include Zn glass, quartz glass and borosilicate glass, etc.
Table 1 shows the comparison of characteristics of these glasses and Pb glass.

1

| Type of glass | Electric stability | Thermal expansion coefficient | Calcination temperature | Chemical resistance |
|---|---|---|---|---|
| Pb glass | ○ | ○ | ○ | ○ |
| Zn glass | ○ | ○ | ○ | × |
| Quartz glass | ○ | × | × | ○ |
| Silicate glass | × | ○ | × | ○ |

Table 1

Continuation Data f

Zn, which is the main ingredient of Zn glass has low resistance for etching and the chemical resistance is very low. Figure 1 shows the result of acid treatment of Pb glass and Zn glass. Zn glass is extensively damaged by this treatment though Pb glass is not. Therefore, Zn glass cannot be used.

The thermal expandability coefficient of quartz glass is too small and the calcination temperature is too high to use.

The borosilicate glass cannot be used because the calcination temperature is too high and the alkali ingredient in glass deteriorates the electric characteristic too much.

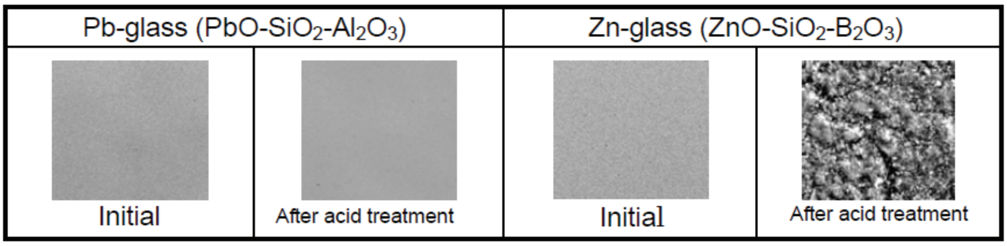



Fig.1 Photo of scanning electron microscope x150
Conditions for acid treatment: Nitric acid ($HNO_3$) Boiling 3 min.

Due to these reasons, it is impossible to use Pb-free glass as substitution for Pb glass.

**Explanation of Technical terms**

| Technical terms | Explanation |
|---|---|
| Passivation | Stabilization layer on the surface of semiconductors |
| Bridge rectifying device<br>Power diode<br>Power thyristor<br>Power transistor | Type of electric semiconductor element |
| P-N junction | Basic structure of semiconductor elements |
| Calcination temperature | Temperature to form glass film |
| Zn glass | Glass mainly composed of ZnO |
| Quartz glass | Glass mainly composed of $SiO_2$ |
| Borosilicate glass | Glass mainly composed of $SiO_2$, $B_2O_3$ and $Na_2O$ |

## Data g

| Type of Substance Related Usage | Target parts | Part | Usage | Reduction difficulty level |
|---|---|---|---|---|
| lead oxide-based glass | Crystal oscillator<br>Diode<br>Thermistor etc | Sealant of ceramic base and lid | Ensuring vacuum (adhesiveness) | A<br>Impossible to substitute |

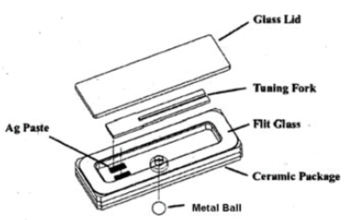
Reason of difficulty of substitution

| Material | Effects and tasks when excluding lead | Details |
|---|---|---|
| phosphoric acid-based glas | The fusing point is similar to lead oxide-based products (320℃), however, waterproofness deteriorates | Use of P2O5-based material as the substitute of lead oxide-based material is possible, however P2O5-based material is "highly absorbent", reacting with water and generating heat and meta phosphoric acid (HPO3), thus having the problem of low waterproofn |
| bismuth-based glass | The fusing point is high (450℃) and decomposition of conductive adhesiveness occurs within the parts. | Use of Bi2O3-based material as the substitution for lead oxide-based material is possible, however, the use of Bi2O3-based material raises the fusing point (450℃) and decomposes the silicon-based conductive adhesive used inside of oscillator (between 200℃ |
| Vanadium-based glass | The fusing point is high (400℃) and decomposition of conductive adhesiveness occurs within the parts. | Use of V2O5-based material as the substitution for lead oxide-based material is possible, however, the use of V2O5-based material raises the fusing point (400℃) and decomposes the silicon-based conductive adhesive used inside of oscillator (between 200℃ to |

As a prerequisite, the structure and support method of crystal oscillator is described here.
The feature of SMD package adopted here is the bond of the package constituted of multilayer-type ceramic insulating substrate and the lid constituted by transparent glass board with the low fusing point glass.
The tuning fork type vibrating piece inside is mounted with conductive adhesive.
Moreover, a through-hole is equipped at the bottom of the the ceramic package, which realizes the highly vacuum air sealing after preserving the high vacuum in the inside area where the tuning fork type vibrating piece is incorporated by melting the metalic ball set in the through-hole.
" The low fusing point glass mentioned here is lead oxide-based and contains lead (fusing point at 320℃).【Fig1】

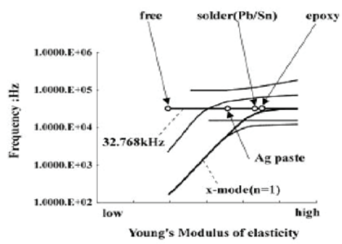
Also, Soldering support and support with epoxy-based conductive adhesiveness represented by cylinder form, for which Young's modulus is high, are considered to be vulnerable to the effect of bonding because x-mode (asymmetric mode in x-axis direction which is the crystal axis of the crystal) is close to the flexural mode (32.768kHz). As a result of this analysis of specific values, silicon-based conductive adhesive in the area of low elasticity side (Young's modulus is 0.01 Gpa or below) is selected instead of soldering support or support with epoxy-based conductive adhesive.【Fig2】

【Fig1】




【Fig2】

Ag paste is a silicon-based conductive adhesive . Solder and epoxy-type conductive adhesive are shown for comparison.




1)Silicon-based conductive adhesive is decomposed by the lead-free low melting point glass which has a higher melting point than itself.

2)If other conductive adhesive (non silicon-based) is used it will suffer the influence of other x-mode.