

8th Adaptation to scientific and technical progress of exemptions 2(c), 3 and 5 of Annex II to Directive 2000/53/EC (ELV)

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Final Report

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1.0 Background

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

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

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

With regard to this adaptation, Annex II has already been adapted 6 times (2002, 2005, 2008, 2010, 2011 and 2013)².

2.0 Scope

Under Framework Contract no. ENV.C.2/FRA/2011/0020, a consortium led by Eunomia Research & Consulting was requested by DG Environment of the European Commission to provide technical assistance for the evaluation of selected exemptions of the ELV Directive. The evaluation is to provide recommendations for a clear and unambiguous wording of the reviewed exemptions. The work has been undertaken by the Oeko-Institut, and has been peer reviewed by Eunomia Research & Consulting.

The evaluation includes consultation with stakeholders on the possible adaptation of the Annexes and the set-up of a website in order to keep stakeholders informed on the progress of work (<http://elv.exemptions.oeko.info/index.php?id=58>).

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 For further information please see: http://ec.europa.eu/environment/waste/elv_index.htm

In the course of the project, a stakeholder consultation was conducted. The consultation was launched, on 24 September 2014, and ran for twelve weeks, until 17 December 2014. The exemptions covered in this stakeholder consultation, specified in Table 3-1, were reviewed in agreement with the Commission, in light of the review period specified for these exemptions in Annex II of the ELV Directive. All non-confidential stakeholder contributions, submitted during the consultation, were made available on the ELV Exemptions website as well as on the EU CIRCABC website (Communication and Information Resource Centre for Administrations, Businesses and Citizens):

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

Furthermore, a targeted stakeholder meeting took place on 10 April 2015, concerning two of the exemptions, to facilitate a better understanding of the available information. Presentations held at the meeting have also been made available on the EU CIRCABC website as well as on the ELV Exemptions website.

3.0 Overview

In the course of the project, three existing ELV exemptions were reviewed. The exemptions covered in this project, together with the recommended expiration wording formulation and expiry dates, are summarised in Table 3-1. Please refer to the corresponding sections of this report for more details on the evaluation results and for more background on the rationale behind the recommendations.

Table 3-1: Overview Recommendations and Expiry Date

No.	Current wording	Recommended wording / action	Recommended expiration / review date
2(c)	Aluminium with a lead content up to 0.4 % by weight	Aluminium alloys:	
		I. with a lead content up to 0.4 % by weight, provided it is not intentionally introduced	Review in eight years
		II. <i>for machining purposes with a lead content up to 0.4 % by weight</i>	Review in five years
3	Copper alloy containing up to 4 % lead by weight	Copper alloy containing up to 4 % lead by weight	Review in five years
5	Batteries	<i>Lead in batteries:</i>	

No.	Current wording	Recommended wording / action	Recommended expiration / review date
		<i>I. in high voltage systems (systems that have a voltage of >75VDC as defined in the Low Voltage Directive (LVD) 2006/95/EC that are used only for propulsion in M1 and N1 vehicles</i>	Vehicles type approved before 1 January 2019 and spare parts for these vehicles
		<i>II. Battery applications not addressed in paragraph I.</i>	Review to be carried out in 3 to 5 years

4.0 Exemption 2(c) “Aluminium with a lead content up to 0.4 % by weight”

Abbreviations and Definitions

AA 2011	Aluminium alloy containing lead
AlEco62Sn	Lead free alloy alternative used to substitute AA 2011
AA 6023	Lead free alloy alternative used to substitute AA 2011, also known as AlMgSiSnBi
Al	Aluminium
CEN	European Committee for Standardization (from French: Comité Européen de Normalisation')
EAA	European Aluminium Association
EN AW-AlMg1SiPb	Al alloy containing lead also known as EN AW 6262
EN AW-AlCu6BiPb	Al alloy containing lead also known as EN AW-2011
OEA	Organisation of European Aluminium Refiners and Remelters
OEM	Original Equipment Manufacturer
Pb	Lead
R&D	Research & Development

Declaration

The phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text.

4.1 Description of Requested Exemption

The current wording of Exemption 2(c) in Annex II of the ELV Directive is:

Aluminium with a lead content up to 0.4 % by weight.

The exemption is specified in the Annex as due for review in 2015. Industry stakeholders from ACEA, JAMA, KAMA, CLEPA and EAA³ submitted a joint response during the consultation and requested the continuation of Exemption 2(c).

³ ACEA et al. (2014) ACEA, JAMA, KAMA, CLEPA and EAA, Industry contribution of ACEA, JAMA, KAMA, CLEPA and EAA, submitted 10.12.2014,

4.1.1 History of the Exemption

Article 4(2)(b) of the legal text of the ELV Directive published in 2000 required that the Commission evaluate the need for exempting the use of the ELV substances in a number of applications. This included applications, in which lead a constituent of aluminium alloys used in wheel rims, engine parts and window levers. In light of this requirement, an evaluation was carried out, results of which recommended an exemption. A first version of the exemption was published in the first amendment of the Directive, for “Aluminium for machining purposes...” The exemption scope, and respective formulation, changed a few time since publication of this first version (for further details see Appendix A.1.0).

The first revision of Annex II⁴ contained a footnote specifying, “*a maximum concentration value up to 0.4 % by weight of lead in aluminium shall also be tolerated provided it is not intentionally introduced*” This footnote was eventually deleted. In the third revision of Annex II in 2008, the wording of the exemption was changed, based on request of the Organisation of European Aluminium Refiners and Remelters (OEA) and the European Aluminium Association (EAA) who claimed a general exemption of up to 0.4% for the unintentional content of lead in aluminium alloys was needed. Oeko-Institut⁵ recommended the deletion of “for machining purposes” from the wording, resulting in the following formulation: “*Aluminium with a lead content up to 0.4% by weight*”, which thereby inherently allows unintentionally present lead within the scope of the exemption (though not specifically mentioned in the wording formulation).

Exemption 2(c) in its current wording was published in the third revision of Annex II in 2008⁶ and reviewed in 2009/2010. At that time, a review within five years was recommended, seeing as industry did not provide sufficiently detailed evidence, to clarify that a reduction of lead concentrations in aluminium alloys was not feasible, despite the general availability of lead free alternatives that had become apparent.⁷ The requirement to review Exemption 2(c) in 2015 was published in the fifth revision of Annex II in 2011.⁸

http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_2c/20141210_ACE_A_AnnexII_2c_amended.pdf; last accessed 10.03.2015

⁴ Commission Decision 2002/525/EC of 27 June 2002 amending Annex II of Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles

⁵ Oeko-Institut (2008), Dr. Joachim Lohse et al., Oeko-Institut; Otmar Deubzer, Fraunhofer IZM: Adaptation to Scientific and Technical Progress of Annex II Directive 2000/53/EC, Contract N° 07010401/2007/470145/ATA/G4, final report; Freiburg, 16 January 2008; http://elv.exemptions.oeko.info/fileadmin/user_upload/Background/Final_report_ELV_Annex_II_revision.pdf

⁶ Commission Decision 2008/689/EC amending Annex II of Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles

⁷ Op. cit. Oeko-Institut 2010

⁸ Commission Directive 2011/37/EU of 30 March 2011 amending Annex II to Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles

4.1.2 Technical Background

ACEA et al. (2014)⁹ differentiate between aluminium alloys where the lead content is unintentional, due to the use of secondary raw material from aluminium scrap, used for cast alloys, and between aluminium alloys, where lead is intentionally added for machining purposes, which are used for (some types of) wrought alloys.

Aluminium, as castings and wrought alloys (extrusions, forgings and sheets), is used in car bodies, closures, chassis, suspensions and wheels.¹⁰

4.1.2.1 Cast Alloys

ACEA et al.¹¹ state that in cast alloys, the lead content is a result of the use of recycled (secondary) aluminium. Lead is present as an impurity in the Al recycling stream and is not necessary to attain specific properties in cast alloys.

Cast alloys are used for big parts in vehicles. Applications indicated by ACEA et al.¹² are engine-blocks, cylinder-heads, gearbox housings, engine sub frames. ACEA et al.¹³ estimate that 95% of the total lead in aluminium alloys per vehicle is introduced through cast aluminium alloys.

CEN standards allow a lead content up to 0.6% in these alloys.¹⁴ ACEA et al.¹⁵ estimate that casting alloys might contain 0.2 to 0.4% lead, depending on the source of material.

4.1.2.2 Wrought Alloys

According to ACEA et al.¹⁶ leaded Al wrought alloys are needed for a small number of car components to “*ensure appropriate material properties for machining and safety-related corrosion resistance purposes.*”

The wrought alloys require that lead be added intentionally to mediate favourable machining properties, such as a sufficient surface finish, part precision and a long tool life. ACEA et al.¹⁷ explain that the minimal performance for the properties low

⁹ Op. cit. ACEA et al. (2014)

¹⁰ EAA (2013), European Aluminium Association EAA (2013), Aluminium in Cars – Unlocking the light-weighting potential; http://www.alueurope.eu/wp-content/uploads/2013/10/EAA-Aluminium-in-Cars-Unlocking-the-light-weighting-potential_September2013_03.pdf

¹¹ Op. cit. ACEA et al. (2014)

¹² Op. cit. ACEA et al. (2014)

¹³ Op. cit. ACEA et al. (2014)

¹⁴ European standard EN 1706 sets standards for a great number of aluminium alloys and specifies different limits for lead.

¹⁵ Op. cit. ACEA et al. (2014)

¹⁶ Op. cit. ACEA et al. (2014)

¹⁷ Op. cit. ACEA et al. (2014)

friction and corrosion resistance are also achieved in consequence of the addition of lead.

Application examples where the use of lead is unavoidable indicated by ACEA et al.¹⁸ are: valve actuation, valve operation, internal bushing of accelerator sensors, expansion valves, pressure sliding plates, axis pins for pivot levers, pumps, high pressure regulating valves, plungers, pistons, brake power assist units and oil return stop valves.

ACEA et al. state that wrought alloy components are usually small parts and make up 5% of the total lead in Al alloys per vehicle.¹⁹

4.1.3 Amount of Lead Used under the Exemption

ACEA et al.²⁰ estimate that the use of the different Al alloys results in an average lead content of 80 g per vehicle. The lead content due to Al alloys can range from 40 to 200 g of lead in Aluminium material per vehicle depending on the car model; the 200 g lead per vehicle refers to car models with for example, automatic drive and large engines.

Based on the 13.3 million vehicles newly registered in the EU 27 in 2013, ACEA et al.²¹ estimate that the use of Al alloys results in a total amount of lead of 1,064 tonnes per year.

The following table compiles data available from ACEA et al.²² and from earlier reviews to demonstrate how the average lead content in Al alloys per vehicle has changed over the past few years. For 2022, ACEA et al.²³ expect that the unintentional lead content in Al alloys will decrease by an average of approximately 0.1%²⁴ by weight (see Section 4.2.2 for further background), resulting in a lead content per vehicle of 50 g.

¹⁸ Op. cit. ACEA et al. (2014)

¹⁹ Op. cit. ACEA et al. (2014)

²⁰ Op. cit. ACEA et al. (2014)

²¹ Op. cit. ACEA et al. (2014)

²² Op. cit. ACEA et al. (2014)

²³ Op. cit. ACEA et al. (2014)

²⁴ The estimation of ACEA et al. on the development of the lead content in recycled Al is presented in section 4.2.2. In this estimation, ACEA et al. (2014) indicate an overall average decrease of the lead amount in Al alloys: understood to mean that the maximum lead content in recycled Al might drop from 0.4% (see Table 4-2) to an estimated EU wide average of 0.3% by weight.

Table 4-1: Lead Content in Aluminium Alloy per Vehicle (Average and Range)

Year	Average lead content in Al for typical European Car (ACEA et al. 2014)	Range (Source)
2008	(not specified in source)	130 – 140 g (Information provided for earlier review, see Oeko-Institut 2008 for details)
2010	120 g	130 - 140 g (Information provided for earlier review, see Oeko-Institut 2010 for details)
2014	80 g	40 – 200 g (ACEA et al. 2014)
2022	50 g	

ACEA et al.²⁵ indicated that leaded Al wrought alloys make up 5% of the lead content whereas 95% of the amount is a result of using cast alloys. Subsequently, the consultants understand this to mean that the wrought Al alloys (where lead is introduced intentionally) account for an average lead content of 4g per vehicle and the Al cast alloys (where the presence of lead is unintentional) account for an average lead content of 76g per vehicle.

4.2 Stakeholders' Justification for the Exemption

4.2.1 General Justification

Industry stakeholders from ACEA, JAMA, KAMA, CLEPA and EAA²⁶ argue that for cast alloys, the current 0.4% threshold is needed to maintain high recycling rates of Aluminium from ELVs. As for wrought alloys, ACEA et al. argue that for safety relevant components leaded Al alloys are still unavoidable.

4.2.2 Cast Alloys

ACEA et al.²⁷ state that casting alloys contain 0.2 to 0.4% lead depending on the source of material. ACEA et al. see the need to keep the current threshold of 0.4% lead in Al scrap in order to continue recycling automotive Al scrap along with other Al scrap sources in the EU. A lower lead threshold for Al scrap would force some

²⁵ Op. cit. ACEA et al. (2015)

²⁶ Op. cit. ACEA et al. (2014)

²⁷ Op. cit. ACEA et al. (2014)

recyclers to dilute their recycled alloys with more primary material to stay below the exempted levels.

Compared to the last revision, ACEA et al.²⁸ recognize a slight reduction of the average lead amount in recycling Al material because vehicles that were manufactured under the regime of the ELV lead restrictions (adopted in 2000) started to appear in the recycling stream in 2010 (assuming an average lifetime of cars of 10 to 15 years). ACEA et al. further explain that the trend of a lower lead content in Al scrap is more apparent in Northern Europe than in Southern / Eastern Europe because vehicles have a longer lifetime in the latter regions and vehicles produced under the stricter ELV lead restrictions shall enter the recycling loop later. ACEA et al. estimate that the average amount of lead in Al scrap shall only decrease below the 0.4% threshold for lead after the year 2020 (see Table 4-2).

For the coming years, ACEA et al.²⁹ explain that lead contents in Al scrap will gradually decrease: In 2010 the ELV Directive lowered the lead threshold in Al alloys down to 0.4%; the majority of the cars produced under this lead restrictions will enter the recycling stream around the year 2024. ACEA et al.³⁰ estimate the maximum lead content in recycled Aluminium from ELVs in 2023 at 0.2% in Western Europe and at 0.24% in South Eastern Europe (see Table 4-2).

ACEA et al.³¹ conclude *“It is therefore too early to reduce the allowed Lead content in Aluminium if it is intended to maintain high recycling rates of Aluminium from ELVs.”* ACEA et al.³² proposes a revision in about eight years: *“By that time an effect of the introduction of the 0.4% limit should be verifiable.”*

²⁸ Op. cit. ACEA et al. (2014)

²⁹ Op. cit. ACEA et al. (2014)

³⁰ Op. cit. ACEA et al. (2015)

³¹ Op. cit. ACEA et al. (2014)

³² Op. cit. ACEA et al. (2014)

Table 4-2: Estimated Maximum Lead Content in Recycled Aluminium from ELVs in Western Europe and South Eastern Europe

Aluminium put in cars [year]	Max allowed lead content* [%]	Western Europe	Estimated maximum lead content in recycled aluminium from ELVs *** [%]
		Average year of recycling [year]	
1995	4%	2010	0,40%
2000	4%	2015	0,40%
2003	2%	2018	0,24%
2008	1,50%	2023	0,20%
2010	0,40%	2025	0,11%
2015	0,40%	2030	0,11%
Aluminium put in cars [year]	Max allowed lead content* [%]	South Eastern Europe	Estimated maximum lead content in recycled aluminium from ELVs *** [%]
		Average year of recycling [year]	
1995	4%	2015	0,40%
2000	4%	2020	0,40%
2003	2%	2023	0,24%
2008	1,50%	2028	0,20%
2010	0,40%	2030	0,11%
2015	0,40%	2035	0,11%

Source: ACEA et al. (2015)

As for possible processes to remove lead from Al scrap, ACEA et al.³³ state that they are in the stage of laboratory/academic research or small scale testing, and that they are economically and ecologically not viable mostly due to the high amount of energy required. To support this conclusion, ACEA et al. refer to a literature study on “Existing technologies for lead removal from Aluminium melts” commissioned by OEA. The study was carried out by MIMI Tech UG and finalized in June 2012. The study reviewed a number of methods to remove lead from aluminium alloys. ACEA et al.³⁴ summarised the study in their contribution. The summary focuses on the feasibility of the methods “phase separation, electrochemical refining and vacuum distillation, concluding that *“All three methods are in the stage of laboratory/academic research and small scale testing, the obstacles to the development of these methods are not only economic in terms of system and equipment cost, but also an environmental issue, mostly due to the high amount of energy required”*”.

4.2.3 Wrought Alloys

ACEA et al.³⁵ state that *“For a very limited number of parts, lead content is still required to ensure:*

- a) necessary material properties (machining / durability / low friction); and*
- b) high safety standard (part precision and corrosion resistance);*

³³ Op. cit. ACEA et al. (2014)

³⁴ Op. cit. ACEA et al. (2014)

³⁵ Op. cit. ACEA et al. (2014)

The industry has changed to lead free alloys as far as possible.”

ACEA et al.³⁶ state that some applications of the AA 2011 alloy have been replaced by applying the lead-free alternatives e.g. AlEco62Sn or AA 6023 (AlMgSiSnBi).

In this regard, where asked where such lead free alternatives are used, ACEA et al.³⁷ specified that *“Lead free Aluminium alloys are applied e.g. in housings, disk plates, closing bodies, hexagonal nuts, sealing plugs, anchors, washers. One has to be aware that part designation is not standardized and can vary from company to company. In general, applications are in focus where high surface precision is not crucial and high mechanical mostly static load needs to be transmitted”*.

However it is explained that there are still various properties relevant for the machining of lead, for which the use of lead [currently³⁸] cannot be avoided. In this respect ACEA et al.³⁹ specify machining as follows: *“The lead content is necessary to reach the performance and accuracy requirements for machining purposes (sufficient surface finish, part precision and tool life, lowering energy requirement to machine parts), low friction properties.”*

ACEA et al.⁴⁰ stress that there are additional properties achieved by the addition of lead, such as corrosion resistance. The corrosion resistance is specified to be important for safety relevant parts: *“Resistances against corrosion – in special pitting corrosion in acid systems e.g. brake systems. This corrosion resistance can only be achieved by lead – alternative alloys are not available. To prevent serious safety risks, it is unavoidable to use Lead as an alloy element for safety relevant parts/components like on chassis and brake-system applications.”*

As an additional property of leaded Al wrought alloys, ACEA et al.⁴¹ also mention emergency lubrication properties. This is not further detailed by ACEA et al.

ACEA et al.⁴² state that *“To our knowledge there are no machining aluminium wrought alloys with lower specified intentional lead content available on the market. There is no information on lead-free substitutes with equivalent machining properties.”*

ACEA et al.⁴³ do not expect a solution to be found in the short or medium term and ask for a continuation of the exemption for eight years.

³⁶ Op. cit. ACEA et al. (2014)

³⁷ Op. cit. ACEA et al. (2015)

³⁸ Added by the consultants.

³⁹ Op. cit. ACEA et al. (2014)

⁴⁰ Op. cit. ACEA et al. (2014)

⁴¹ Op. cit. ACEA et al. (2015)

⁴² Op. cit. ACEA et al. (2015)

⁴³ Op. cit. ACEA et al. (2014)

4.3 Critical Review

ACEA et al.⁴⁴ provided information that clarifies that a large share of aluminium alloys are used for **casting**, where lead is not needed to ensure material properties, though it is unintentionally present due to the use of recycled aluminium. Additionally, ACEA et al.⁴⁵ provided data that shows that due to the lead restriction for the use in aluminium alloys, lead content in the scrap stream will continuously decrease.

As for **wrought** alloys, ACEA et al. provide some new information regarding applications of wrought alloys in which substitutes have been applied to replace alloys containing lead, however still contending that for other applications alternatives are currently not available.

4.3.1 Cast Alloys

As already mentioned above lead in cast alloys is not intentionally added but a result of the use of scrap aluminium. ACEA et al.⁴⁶ claim that due to a growing lead restriction (i.e., a decrease in the allowance for using lead in aluminium alloys) under the ELV regime, the lead content in the Al recycling stream is expected to further decrease. Lead is restricted in automotive applications since 2000.

Besides the information provided by ACEA et al., it is understood that in the recycling of aluminium the accumulation of impurities is a general problem for operators, including Si (Silicon), Mg (Magnesium), Ni (Nickel), Zn (Zinc), Pb (Lead), Cr (Chromium), Fe (Iron), Cu (Copper), V (Vanadium) and Mn (Manganese).⁴⁷ E.g. the review of Gaustad et al. (2012) but also other publications⁴⁸ mention two approaches commonly used today to deal with the negative impact of recycling of aluminium related to the presence of undesired impurities: Dilution with primary aluminium and “Down-cycling” where wrought scrap is used in cast products. Cast alloys have less strict chemical composition limits compared to wrought alloys. The compensation of impurities in aluminium recycling by dilution with purer aluminium fractions or with primary aluminium in order to reach specified product quality is thus also assumed to contribute to the dilution of the lead content in recycled aluminium, aside from the understanding that lead introduced through the ELV waste stream is decreasing (at least on a ‘per vehicle’ basis) as a result of the Directive. According to the European Aluminium Association, ELV-recycled aluminium is currently only partially filling the

⁴⁴ Op. cit. ACEA et al. (2014)

⁴⁵ Op. cit. ACEA et al. (2015)

⁴⁶ Op. cit. ACEA et al. (2014) und (2015)

⁴⁷ Gaustad et al. (2012), Gaustad, G. et al. (2012), Improving aluminum recycling: A survey of sorting and impurity removal technologies; Resources, Conservation and Recycling 58 (2012) 79– 87.

⁴⁸ Paraskevas, D. et al. (2013), Paraskevas, D. et al. (2013), Closed and Open Loop Recycling of Aluminium: A Life Cycle Assessment perspective; 11th Global Conference on Sustainable Manufacturing, 23rd to 25th September Berlin, Germany.

demand for automotive aluminium⁴⁹ (the consultants understand this to mean that the quantity of castings in which recycled alloys are used exceeds the supply of ELV derived scrap alloys). Therefore, the consultants assume that primary aluminium is continuously used to satisfy the remaining demand (as explained in the following paragraph).

Other trends that will affect impurities, in Al scrap in general, are future developments in the Al recycling schemes as well as in the demand for aluminium in general. Regarding recycling schemes, future developments comprise of optimised sorting techniques of different wrought alloys both from cars⁵⁰ and from other sources. Furthermore, it is understood that the overall growing demand for aluminium requires the use of additional primary Al (i.e. there is a lack of supply of recycled material).⁵¹ Aluminium is increasingly used in cars because it is a lightweight material. According to the European Aluminium Association (EAA), the average amount of aluminium used per car produced in Europe almost tripled between 1990 and 2012, increasing from 50 kg to 140 kg.⁵² According to a study⁵³ conducted by Ducker Worldwide in cooperation with the EAA, the amount is predicted to rise further, to 160 kg by 2020, and might reach as much as 180 kg if small and medium cars follow the evolution recorded in the upper segments of the automobile industry. The trend of an increased use of Al in the car production is also related to an increased use of casting alloys. ACEA et al.⁵⁴ indicate that car models with e.g. automatic drive and big engines use larger amounts of Al alloys and therefore today a higher average lead content in aluminium alloy per vehicle (see section 4.1.3).

On the basis of these trends it can be followed that the average lead content per unit of recycled Al shall continue to decrease as the intentional use of lead in ELVs has been in decline since 2000, and this has only recently started having an impact on the lead in the recycled Al stream. Secondly, lead in the Al recycling stream is also decreasing since the recyclers intentionally dilute Al scrap with primary Al to limit general impurity problems. Additionally, the increased demand of Al in vehicles

⁴⁹ Part 1.4.5 ELV recycling – Future trends and use of recovered automotive aluminium in EAA (2012), European Aluminium Association EAA (2012), The Aluminium Automotive Manual, Materials – Resources; <http://www.alueurope.eu/wp-content/uploads/2012/01/AAM-Materials-1-Resources.pdf>

⁵⁰ Op. cit EAA (2012)

EAA/OEA Recycling Division (2006), European Aluminium Association EAA and Organisation of European Aluminium Refiners and Remelters OEA (2006), Aluminium Recycling in Europe, The Road to High Quality Products, 2006; <http://www.alueurope.eu/wp-content/uploads/2011/08/Aluminium-recycling-in-Europe-2007.pdf>. The EAA and OEA anticipate a growing volume of wrought alloy scrap as of 2015/2020 due to an increased use of specialized wrought alloys.

⁵¹ Op. cit EAA (2013)

⁵² Op. cit. EAA (2013)

⁵³ Ducker Worldwide and EAA (2012), Ducker Worldwide in cooperation with the European Aluminium Association (EAA) (2012), EAA Aluminium penetration in cars; Final Report, March 13, 2012; http://www.alueurope.eu/wp-content/uploads/2012/04/EAA-Aluminium-Penetration-in-cars_Final-Report-Public-version.pdf

⁵⁴ Op. cit. ACEA et al. (2014)

requires an increased feed in of primary aluminium, which contributes to the dilution effect.⁵⁵

Finally, it should be noted, that ACEA et al. agree with the reduction of the allowed lead content in recycled aluminium and expect the reduction to be verifiable in eight years. This is supported with the data provided by ACEA regarding the estimated trends in the amount of lead in recycled Al expected to develop in the EU in the various regions (see Table 4-2). It can thus be followed that a review within a shorter period would be less efficient, in so far that ACEA et al. cannot influence these developments in aluminium recycling as the ELVs that are to contribute to the trend are already on the market.

4.3.2 Wrought Alloys

ACEA et al. detail a number of applications for which lead free aluminium alloys can be applied, however claiming that for other applications, alternatives are not yet available. They⁵⁶ contend that:

“For a small number of car components a certain low amount of Lead in Aluminium is needed to ensure appropriate material properties for machining and safety-related corrosion resistance purposes. Substitutes for Lead are not available; no material is known to have the same properties; e.g. research activities / studies show that the required properties cannot be achieved by using Tin/Bismuth as substitute (having properties most similar to Lead in Aluminium alloys).”

ACEA et al.⁵⁷ further argue that the reduction potential for lead in wrought aluminium alloys has already been identified and that substitutes have been applied where possible and that no new alternative or substitute has been identified that is relevant to areas where alloys containing lead are still needed:

“From 2003 to 2008 the reduction potential for lead in wrought aluminium alloys has been investigated and all known potentials have been identified and applied as far as possible. By this, the intentional lead content was reduced from up to 4 % down to 0.4 %. There are no Aluminium wrought materials known being specified for an intentional lead content less than 0.4 % wt... Because no new alloys or materials could have been identified as alternative or substitute the situation for the wrought alloys is unchanged.”

ACEA et al.⁵⁸ did not provide information of any new research or other activities that indicate efforts to substitute the remaining applications of leaded Al wrought alloys.

ACEA et al.⁵⁹ specify that lead containing aluminium wrought alloys EN AW-AlMg1SiPb (EN AW 6262) and EN AW-AlCu6BiPb (EN AW-2011) are still needed for the remaining

⁵⁵ Op. cit. EAA (2012)

⁵⁶ Op. cit. ACEA et al. (2014)

⁵⁷ Op. cit. ACEA et al. (2015)

⁵⁸ Op. cit. ACEA et al. (2014) and (2015)

applications, which have special requirements, i.e., where “lightweight, surface accuracy, emergency lubrication properties and corrosion resistance” are relevant.

For the alloy type EN AW 6262, lead-free alternatives are offered on the market that contain tin and bismuth: As for EN AW-AMg1SiPb (EN AW 6262), manufacturers provide the lead-free EN AW 6262A as a direct alternative to EN AW 6262 used for automotive brake components, hydraulic valve blocks and many other applications.⁶⁰ EN AW 6262A substitutes lead with a mix of tin and bismuth. A patent and marked research on new alloy developments published in 2011⁶¹ also confirms that AlMgSi alloys (6xxx series) and AlCu alloys (2xxx series) contain either lead with a maximum of 0.4% or as substitution elements, a combination of tin and bismuth.

It is apparent from the paragraph above that there are alternatives on the market for certain lead based alloys. However, it is not clear in what cases, or on what basis they cannot be used as substitutes for alloys with lead, which are understood, from the information provided by ACEA et al., to still be in use. To clarify if they are not used at all or just not for the full range of application of those alloys, further information is needed. i.e., it is necessary to indicate the “small number of components”, in which *“a certain low amount of lead in Aluminium is needed to ensure appropriate material properties for machining and safety-related corrosion resistance purposes”*. Specific technical requirements and performance indicators relevant for these components should be defined in parallel.

ACEA et al.⁶² generally question the substitution of lead with alternatives including tin or bismuth saying that:

“Substitution of Lead by tin or bismuth in alloys will

1. Increase cutting forces / energy consumption and shorten tool-life

2. Cannot provide the needed surface-finish & low friction properties

3. Increase environmental impact of Aluminium production

- Bismuth is a by-product of Lead production

- to produce 1 Ton of Bismuth production of 30-200 tons of Lead are necessary ⁽²⁾

4. Lower the eutectic point

5. Exclude use of significant amounts of end-of-life scrap as material source.

(2) ‘Recommendation on the non-use of bismuth for Lead substitution’, 2007, European Copper Institute.”⁶³

⁵⁹ Op. cit. ACEA et al. (2015)

⁶⁰ Datasheet Aluminium Alloy AA6262A/en aw 6262^a by Impol;
http://www.impol.si/files/default/Tehnoloski-listi/AC62-AA6262A_JS.pdf

⁶¹ Op. cit. Koch et al. (2011)

⁶² Op. cit. ACEA et al. (2014)

This general questioning of bismuth in alloys that can be used as substitute for lead alloys does not coincide with other statements of ACEA et al.⁶⁴, which among others indicate that the alternatives AlEco62Sn and AA 6023, which contain bismuth, are used for some applications of the EN AW-2011 alloy.

Based on various data sheets, the alloy AlEco62Sn contains bismuth in a range of 0.4 to 0.9% per weight⁶⁵ and the alloy AA 6023 contains bismuth in a range of 0.3 to 0.8 % per weight⁶⁶. ACEA et al.⁶⁷ specified the following applications as applications where these lead free alternatives are used; *“ housings, disk plates, closing bodies, hexagonal nuts, sealing plugs, anchors, washers.”*⁶⁸ Part designation is explained not to be standardized, possibly varying from company to company.” It thus remains unclear, whether these lead-free bismuth containing alloys have been applied in all car models or only by some car manufacturers. It is also not clear if these are the only applications where these substitutes can be used, or rather the only applications where substitution has been realised throughout the full automotive range.

ACEA et al. explain some of the limitations of bismuth in alloys used to substitute lead based alloys. *“As substitute for lead as machining (co-)enabler bismuth is in use and Bi and Pb are used in the same alloy. Compared to the system lead liquid /aluminium solid with 327 °C, the system bismuth liquid /aluminium solid has a characteristic temperature of 271 °C⁶⁹. As a consequence temperature resistance is lower. Furthermore the electrochemical potentials of Pb and Bi are different (lead -126 mV, bismuth +280 mV copper +340 mV, aluminium -1660 mV). In addition, where most of all materials are shrinking from liquid to solid phase bismuth expands for around 4 %. This can cause mechanical stress in the material. The different physical properties of Bismuth are considered as a reason that e.g. for hydraulic applications – as of pistons or cylinders of brake systems – lead free respectively Bi containing alloys are*

⁶³ European Copper Institute (2007), Recommendation on the non-use of bismuth for lead substitution Paper on behalf of European Copper Institute, September 2007;
<http://copperalliance.eu/docs/default-source/reach-documents/bismuthnonsuitability.pdf?sfvrsn=2>

⁶⁴ Op. cit. ACEA et al. (2014)

⁶⁵ AlEco62Sn contains Bismuth in a range of 0.4 to 0.9% per weight, see e.g. datasheet at
http://www.haeuselmann.ch/webautor-data/40/Alecod01_05.pdf

⁶⁶ According to different datasheets, AA 6023 contains Bismuth in a range of 0.3 to 0.8 % per weight; see e.g the following datasheets available at the web: http://www.impol.si/files/default/Tehnoloski-listi/AC61-%20AA6023%20Conforming%20to%20RoHS_JS.pdf;
http://www.alu-menziken.com/fileadmin/user_upload/alu-menziken/dokumente/Extrusion/Promotion/100427_Menzikal003_e.pdf;
<http://www.matweb.com/search/DataSheet.aspx?MatGUID=96be7b8b0c2b47b7b5573902cf294d85>

⁶⁷ Op. cit. ACEA et al. (2015)

⁶⁸ Op. cit. ACEA et al. (2015)

⁶⁹ Referenced in ACEA et al. (2015) as „Aluminium Taschenbuch Band1 Bilder 3.15d und 3.16 a Aluminium Verlag Düsseldorf 2002“

not applied.” ACEA et al. conclude that “*in order to provide the needed reliability to safety relevant parts, Pb cannot be substituted by alternatives*”.⁷⁰

Though it can be followed from the information above, that bismuth would not allow substituting lead in Al alloys for certain applications, it appears to be in use as a substitute for others. It is however not clear if the lists provided by ACEA et al. are exhaustive, nor if other alloys are in use as substitutes in some applications. The consultants can follow that a comprehensive list may be long and impractical for refining the scope of the exemption in Annex II. However, the scope of the current exemption is viewed as very wide, and thus possibly open to misuse. As ACEA et al. claim that substitutes have been applied where this was possible, the consultants would expect that the scope could be narrowed based on application groups or based on critical properties and required performance.

Though particular properties which require the use of lead in Al alloys have been detailed by ACEA et al., it is assumed that these could further be specified through referring to quantitative thresholds, above (or below) which the use of lead in Al alloys is currently unavoidable. Assuming that an exhaustive list of properties could be formulated (including aspects mentioned in this review such as machining, durability, low friction and corrosion resistance), it should be possible to specify the required performance level and the relevant performance indicators that are relevant for such properties, to allow adjusting the scope of the exemption while also clarifying on what basis possible substitutes could be evaluated.

If, as ACEA et al. claim, lead has been substituted in all applications where this was possible, through the use of available substitutes, the automotive industry should be able to clarify how the scope could be adjusted to reflect the state of scientific and technical progress. Though time may be needed in order to screen all relevant automotive applications to arrive at a comprehensive list (of applications or of properties) this effort is presumed to be feasible as well as important for communicating to suppliers where additional effort is needed in the development of substitutes in the future.

Furthermore, the possible increase in use of specialized wrought alloys as described by EAA and OEA⁷¹ should also be observed in the future to clarify that it does not lead to an unjustified increase in the use of leaded Al wrought alloys. This aspect supports the adjustment of the scope of Ex. 2(c), which would assist in limiting future trends to areas where substitution remains not possible within the limits of contemporary scientific and technical progress.

⁷⁰ Op. cit. ACEA et al. (2015)

⁷¹ EAA/OEA Recycling Division (2006)

4.3.3 Conclusions

Overall, it seems important to differentiate in the future between applications of aluminium alloys where lead is unintentionally present and between applications where lead provides necessary properties and is intentionally added. The entry pathways of lead into automotive applications are different. Whereas in wrought alloys lead is needed for specific properties, lead in Al scrap is an unintentional impurity.⁷² Though currently the lead allowances for both application areas are identical, the presence of lead in these two cases is related to completely different technical aspects, which should be reflected in the wording formulation of the exemption.

As for the unintentional lead in Al scrap, ACEA et al.⁷³ expect the threshold to decrease over the years due to the lead restrictions under ELV. The threshold under the ELV Directive has decreased over the years from 2% in Al alloys for machining purposes to 0.4% since 2010. It can be followed that this trend shall continue over the next few years as the lead restricted Al alloys from these more recent ELVs reach end-of-life (i.e., are sent to recycling and thus start to have a larger impact on the recycled stream). For the cast alloys produced from Al scrap, the substitution of lead is consequently not an issue, though retaining the lead allowance shall ensure that the trend continues in the form of a decreasing lead content in recycled Al.

In wrought alloys, it is understood that for a small number of applications, lead free alloys have been applied in some cases. As it was not completely clear how far such substitution had been applied throughout the automotive sector, ACEA et al. were consulted.

ACEA⁷⁴ et al. explained that the components proposed are taken from examples for the application of a specific lead-free aluminium alloy. However, this is not a generic approach and the process to apply these alloys depends on the function of the component and its surrounding/ambient conditions. This means in several cases a use might be possible but impossible in other applications. Furthermore, ACEA et al. emphasize that the designation of parts is not standardized and can therefore not be used for a legally binding and technically sufficient description of specific applications.

The consultants can thus understand that the use of lead in the various components mentioned may still not be avoidable in all cases. Nonetheless, it is clear from the various information that lead based alloys are needed in various cases. This is a result of properties that the addition of lead ensures in some cases and/or of the environmental conditions of use of Al alloys. ACEA were thus asked to clarify what properties and operative conditions are relevant and what interrelations exist between such aspects, i.e., in which cases a substitute must provide the relevant

⁷² Op. cit. Gaustad et al. (2012), Lohse et al. (2001)

⁷³ Op. cit ACEA et al. (2014)

⁷⁴ ACEA et al. (2015b), ACEA, JAMA, KAMA, CLEPA and EAA , Statement for draft proposals on entry 2c Annex II, submitted to the EU COM 3.7.2015 and forwarded to the consultant.

performance for multiple requirements. The information was submitted in table form (see Appendix A.2.0)⁷⁵ and clarifies that applying substitutes in different cases may be complex. ACEA was also asked to provide performance indicators for each requirement as this would be a basis for comparing the applicability of substitutes where these become available. However, it was explained that completing this last task would require more time, in light of the need to clarify such aspects with the supply chain, members of which prepare and apply the alloys that are later present in automotive components. As the consultants can agree that collecting and compiling such information could require more time, it can be followed that, at present, the reference to wrought alloys in the exemption could not further specify between components or properties for which the use of lead has become avoidable.

It can be followed that changing the scope of the exemption in this respect would require a comprehensive review of the various applications of leaded wrought Al alloys to allow clarifying an exhaustive list of components where Pb is still needed in Al alloys to ensure specific properties. Should such a study be carried out, technical requirements and relevant performance criteria could be derived in order to discuss possible substitutes and respectively the possibilities of specifying the exemption for a narrower scope of applications than that relevant for the current exemption or for an exemption for Al alloys used for machining purposes.

Based on these aspects, it is currently suggested to split the exemption, in order to differentiate between lead in casting alloys and in wrought alloys.

- For casting alloys, the trends of Pb presence in recycled aluminium streams suggest that quantities shall continue to decrease. The current threshold is understood to remain relevant over the next few years, and should be reconsidered in future reviews in light of the expectation for Pb contents to further decrease. As the motivators for this trend are in some cases external (dilution) and in some cases shall have a slower impact over time (entry of ELVs into the waste stream), the consultants agree with ACEA et al. that the next review could be held at a later period.
- In contrast, for wrought alloys, the available information does not suffice for a further adjustment of the scope, which would require more detail as to applications where substitution is not possible (or property thresholds relevant for such applications). As the consultants can follow that the collection of such data would require more time in light of the need to involve various levels of the supply chain, a revised formulation of the exemption could be granted for a short period. After this period, industry would be expected to provide information to allow a further limitation of the exemption scope to areas where the use of lead is unavoidable. In this regard it should be noted, that even if this effort would not immediately lead to a change in the amounts to be used, at least it would allow communicating to the R&D sector in what areas they should focus research on the development of new substitutes.

⁷⁵ ACEA et al. (2015c), ACEA, JAMA, KAMA, CLEPA and EAA, Ex. 2C List of Relevant Properties and Performance Indicators, submitted per email 22.8.2015

4.4 Recommendation

As explained above, it is recommended to split the exemption to allow addressing the various applications separately in future reviews, while also clarifying where it is more urgent to search for substitutes.

It is understood that the unintentional content of lead in Al scrap will decrease gradually within the coming years with a reduction in the lead share expected to become apparent in 2023 throughout the EU. A review is thus recommended in eight years as requested by ACEA et al.

The second part of the exemption is proposed to be reformulated by re-introducing the limitation “for machining purposes”. This should provide a first limitation of the exemption to wrought alloy applications. Further specification, however is still presumed to be relevant and should be discussed within a few years, to allow the automotive industry to collect and compile data from the supply chain to allow further specification. A review period of five years is proposed to allow a thorough supply chain survey. As industry has communicated that potential substitutes for lead have been applied where currently possible, the consultants assume that collecting and compiling such information should be achievable, despite the time that this could require. Though environmental benefits may not be immediately related with such an effort, specifying the actual areas where the use of lead is considered unavoidable will comprise an essential exercise for clarifying further potentials for future substitution, which could be the focus of further scientific and technical research.

Based on the above considerations, the consultants recommend splitting the exemption in two with the following wording and review periods:

Materials and components	Scope and expiry date of the exemption
<i>Aluminium alloys:</i>	
<i>i) with a lead content up to 0.4 % by weight, provided it is not intentionally introduced</i>	<i>Review in eight years</i>
<i>ii) for machining purposes with a lead content up to 0.4 % by weight</i>	<i>Review in five years</i>

4.5 References Exemption 2(c)

ACEA et al. (2014) ACEA, JAMA, KAMA, CLEPA and EAA (2014a), Industry contribution of ACEA, JAMA, KAMA, CLEPA and EAA, submitted during the online stakeholder consultation, retrieved from http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_2c/20141210_ACEA_AnnexII_2c_amended.pdf ; last accessed 10.03.2015

- ACEA et al. (2015) ACEA, JAMA, KAMA, CLEPA and EAA (2015), Answers to Clarification Questionnaire, provided 27 February 2015.
- ACEA et al. (2015b) ACEA, JAMA, KAMA, CLEPA and EAA (2015b), Statement for draft proposals on entry 2c Annex II, submitted to the EU COM 3.7.2015 and forwarded to the consultant.
- ACEA et al. (2015c) ACEA, JAMA, KAMA, CLEPA and EAA (2015c), Ex. 2C List of Relevant Properties and Performance Indicators, submitted per email 22.8.2015
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Ducker Worldwide in cooperation with the European Aluminium Association (EAA) (2012), EAA Aluminium penetration in cars; Final Report, March 13, 2012; http://www.alueurope.eu/wp-content/uploads/2012/04/EAA-Aluminium-Penetration-in-cars_Final-Report-Public-version.pdf
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- Oeko-Institut (2010) Stéphanie Zangl et al., Oeko-Institut; Otmar Deubzer, Fraunhofer IZM (2010), Adaptation to scientific and technical progress of Annex II to Directive 2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS), final report; Freiburg, 28 July 2010; http://elv.exemptions.oeko.info/fileadmin/user_upload/Final_Report/Corr_Final_report_ELV_RoHS_28_07_2010.pdf
- Paraskevas et al. (2013) Paraskevas, D. et al. (2013), Closed and Open Loop Recycling of Aluminium: A Life Cycle Assessment perspective; 11th Global Conference on Sustainable Manufacturing, 23rd to 25th September Berlin, Germany.

5.0 Exemption 3 “Copper alloy containing up to 4 % lead by weight”

Abbreviations and Definitions

C36000	CuZn39Pb3, brass alloy with 3.3% Pb
Cu	Copper
CuZn42	Lead-free copper alloy with a higher zinc content
CuZn38As	Lead-free copper alloy with a higher zinc content (As – Arsenic)
CuZn39Pb3	Brass alloy with 3.3% Pb
CuZn38Pb2	Brass alloy with 2% Pb
CuZn21Si3	Silicon alloyed copper
OEM	Original Equipment Manufacturer
Pb	Lead
Si	Silicon
Zn	Zinc

Declaration

The phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as was required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text.

5.1 Description of Requested Exemption

The current wording of Exemption 3 in Annex II of the ELV Directive is

Copper alloy containing up to 4 % lead by weight.

The exemption has become due for review in 2015. The automotive industry associations ACEA, CLEPA, JAMA, KAMA et al. have submitted a contribution during the stakeholder consultation in support of the renewal of the above mentioned exemption and claim an unlimited prolongation of the exemption and propose a review time of eight years.⁷⁶

⁷⁶ ACEA et al. (2014) Industry contribution of ACEA, JAMA, JAPIA, KAMA and CLEPA, Industry contribution of ACEA, JAMA, JAPIA, KAMA and CLEPA, submitted 10.12.2014, http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3/20141210_ACEA_AnnexII_3.pdf; last accessed 10.03.2015

During the stakeholder consultation Mitsubishi Shindoh Co., Ltd submitted a contribution objecting the renewal of the above mentioned exemption and proposes Ecobrass as a lead free copper alloy alternative.⁷⁷

A stakeholder meeting was held on 10 April 2015 as part of the evaluation that was attended by representatives from ACEA et al. and Mitsubishi Shindoh Co., Ltd.

5.1.1 History of the Exemption

Since the publication of the ELV Directive, Exemption 3 has been listed in Annex II with the above mentioned wording. Exemption 3 was reviewed in 2009/2010. A review in five years was recommended by Oeko-Institut in 2010⁷⁸ because:

- Lead free copper alloys were available at the time, but stakeholders claimed that they were not technically equivalent for all applications;
- There were contradicting opinions on the technical feasibility of lead reduction in copper alloys.

The review of Exemption 3 in 2010 was published in the fifth revision of Annex II in 2011.⁷⁹

5.1.2 Technical Background

ACEA et al.⁸⁰ identified three main application groups for the wide variety of small components consisting of leaded copper alloy: sliding elements, mechanical connecting elements and electric applications. Provided by ACEA et al., Table 5-1 summarizes typical applications their technical requirements.

ACEA et al. state⁸¹ that *“500 mainly tiny components are the detected maximum quantity in a fully equipped vehicle”*. ACEA et al. further detail that the total number of automotive components might even be larger as the applications and requirements are different within each vehicle.

⁷⁷ Mitsubishi Shindoh Co., Ltd. (2014), Contribution of Mitsubishi Shindoh Co., Ltd., submitted during the online stakeholder consultation, retrieved from http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3/2014-12-10_Mitsubishi_elv-exception-main-en.pdf

⁷⁸ Oeko-Institut (2010), Stéphanie Zangl et al., Oeko-Institut; Otmar Deubzer, Fraunhofer IZM (2010), Adaptation to scientific and technical progress of Annex II to Directive 2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS), final report; Freiburg, 28 July 2010; http://elv.exemptions.oeko.info/fileadmin/user_upload/Final_Report/Corr_Final_report_ELV_RoHS_28_07_2010.pdf

⁷⁹ Commission Directive 2011/37/EU of 30 March 2011 amending Annex II to Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles

⁸⁰ Op. cit. ACEA et al. (2014)

⁸¹ ACEA et al. (2015c), Industry contribution of ACEA, CLEPA JAMA, KAMA et al.; Answers to the additional questions after stakeholder meeting, April 10 – Exemption No. 3; submitted by Email at 27 April 2015.

ACEA et al.⁸² state that the wide variety of applications of leaded copper alloy found during a dismantling study; usually the parts are very small and integrated in a larger automotive component, which are typically developed at sub-supplier level.

Table 5-1: Main Application Groups, Typical Applications and Requirements of Leaded Copper Alloys in Vehicles

Application Group		Typical Applications	Typical Requirements	Additional Remarks (Functionality, Surrounding)
Sliding Elements	+ small applications of each group	Valve guides, bearing shells, clutch, door locks, ...	Surface quality, friction/abrasion, cleanliness, dry running performance, ...	microfinishing, pressed on parts, coatings, structurized surface, grease, ...
Mechanical Connecting Elements		Fittings for fuel feed injection system, bearings, ...	Formability cold/hot, leak tightness, relaxation behavior, machinability, etc.	high deformation degree, permanent tension or pressure, corrosive media, hydraulic fluids, ...
Electric Applications		Battery clamp, cable, connector pins, ...	conductivity, corrosion, machinability, elastic formability, etc.	smooth surfaces, small tolerances, small deep bores permanent tension or pressure, ...

Source: ACEA et al. (2014)

The average lead content in the main application groups vary according to ACEA et al.⁸³:

- 0.3 – 3.7 % Pb within “sliding elements”
- 2.0 – 3.7 % Pb within “electric elements”
- 0.2 – 3.7 % Pb within “mechanical connecting elements”

ACEA et al.⁸⁴ cannot indicate a single typical average, but do offer an average lead content for two vehicle types: The average lead occurring within the copper alloys content was indicated to be 1.4% for standard vehicle models and 2.1% for “fully equipped” vehicle models. ACEA et al. do not define the term “fully equipped”. However, a fully equipped vehicle model is understood to contain more electronic control units, sensors and actuators in comparison to a standard vehicle model, according to Welter (2014).

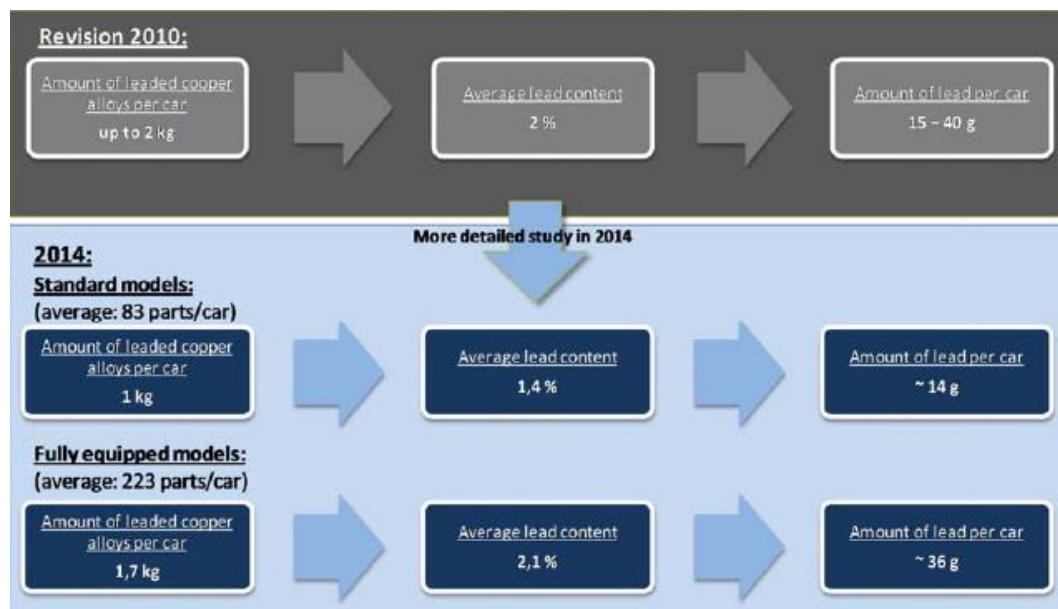
⁸² Op. cit. ACEA et al. (2014)

⁸³ ACEA et al. (2015b), Industry contribution of ACEA, CLEPA JAMA, KAMA et al.; Answers to the additional questions for stakeholder meeting, April 10 – Exemption No. 3; submitted by Email at 27 April 2015.

⁸⁴ Opt. cit. ACEA et al. (2015b)

The differentiation in different vehicle models results in a different lead content and consequently in different amounts of lead based on the use of leaded copper alloys (see Figure 5-1 below). It is assumed that this data is provided to explain, at least in part, the differing amounts of leaded copper alloys in standard vehicles and fully equipped vehicles. However, the provided data does not reveal anything about the lead content of individual applications as previously identified in Table 5-1.

Figure 5-1: Leaded Copper Alloys per Vehicle, Differentiated in Standard and Fully Equipped Car Models for 2014



Source: ACEA et al. (2014)

Welter (2014)⁸⁵ explains that there are some 100 different lead containing copper alloys: The most popular brass alloy is CuZn39Pb3 (3.3% Pb) used to make around 50 % of the brass components; the second most popular is CuZn38Pb2 (2% Pb), with the third most popular group consisting of a series of brasses with varying zinc concentrations from 36 to 40 % and varying in lead concentration from 0 to 2%.

5.1.3 Amount of Lead Used under the Exemption

ACEA et al.⁸⁶ estimates the amount of lead contained in copper alloys at a range of 15 to 40 g per vehicle. The range depends on the different vehicle models: ACEA et

⁸⁵ Welter (2014), Jean-Marie Welter 2014: Leaded copper alloys for automotive applications: a scrutiny; European Copper Institute, November 20, 2014; submitted as Annex 2 with the contribution of ACEA et al. (2014); http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3/E3_02_Welter_2014_leaded_copper_alloys_for_automotive_applications-a_scrutiny.pdf

⁸⁶ Op. cit. ACEA et al. (2014)

al.⁸⁷ explain that a standard car model contains about 14 g of lead in copper alloys due to an average of 83 parts (about one kg) of leaded copper alloys. A fully equipped model contains about 36 g of lead in copper alloys due to an average of 223 parts with a total weight of 1.7 kg of leaded copper alloys (see Figure 5-1 above).

ACEA et al.⁸⁸ further detail that more than 75% of the parts have a weight of less than 10 grams. It is also indicated that more than the half of the parts contain 3 to 4% lead but these only account for 25% of the total weight of leaded copper alloys, for many of these parts are less than 10 grams per part and according to Welter (2014)⁸⁹ usually even less than 1 g per part.

ACEA et al. estimates a total lead consumption for leaded copper alloys of 245 tonnes per year in the EU. This estimation is based on the number of newly registered vehicles in EU 27 in 2013, which was 13.3. million, and is further based on 80% standard vehicle models and 20% “fully equipped” vehicle models.⁹⁰

The following table compiles data available from ACEA et al. and from earlier reviews. Compared to the range of 265 to 710 tonnes lead per year indicated by the automotive industry for the last revision⁹¹ the annual lead consumption for leaded copper alloys appears to have decreased.

The consultants note the appearance of a few aspects that may explain this decrease. First of all the average content in each case is based on a different number of vehicles newly registered in EU27 per annum (13.3 million in 2013 compared to 17.7 million at the time of the prior revision). Furthermore, the differentiation between the average amount of lead contributed by standard and fully equipped vehicles has only been introduced in this current review, where only 20% of fully equipped car models were taken into account with the upper range of 40 g lead content per vehicle (leaded copper alloy related). It is not clear if additional factors in the survey method were different, and thus not possible to conclude as to the trend of decrease.

⁸⁷ Op. cit. ACEA et al. (2014)

⁸⁸ Op. cit. ACEA et al. (2014)

⁸⁹ Op. cit. Welter (2014)

⁹⁰ Op. cit. ACEA et al. (2014)

⁹¹ Op. cit. Oeko-Institut (2010)

Table 5-2: Lead Content in Copper Alloys per Vehicle and Total Amount of Lead Used in Lead Copper Alloy Applications

Year	Average lead content per vehicle due to lead copper alloys	Total lead amount in EU27 used for lead copper alloys	Source
2008	40 – 80 g	n.i.	Detailed in Oeko-Institut 2008
2010	15 – 40 g	265 – 710 t/y	Detailed in Oeko-Institut 2010
2014	15 – 40 g	245 t/y	ACEA et al. 2014

Source: Compilation of information as detailed for the various values.

Welter⁹² states that technical requirements to make driving safer and more comfortable prevent OEMs from reducing lead at the high end of the concentration range of the exemption. There is a growing demand and imposition for more electronic control units, sensors and actuators where high lead copper alloys are mainly used. As these are small parts in a great number (75 % of all the parts made from lead copper alloys), their contribution to the total amount of lead is estimated to be small.

5.2 Stakeholder Contributions

ACEA et al.⁹³ requests an unlimited prolongation of Exemption 3: *“The maximum lead content must remain at 4%. Due to the lack of new materials in research, and typical model cycles within the automotive industry, the joint associations propose a review time of 8 years.”*

Mitsubishi Shindoh Co., Ltd. questions the renewal of the exemption for lead copper alloys and proposes Ecobrase as a lead free copper alloy alternative.

5.2.1 Stakeholders Justification for Exemption Renewal

ACEA et al.⁹⁴ justify the need for lead copper alloys based on lead being a multifunctional ingredient required for optimizing properties such as machinability as well as corrosion protection, tribology and formability. ACEA et al.⁹⁵ claim that *“copper alloys are neither cheap nor light materials, so will only be used when needed.”*

⁹² Op. cit. Welter (2014)

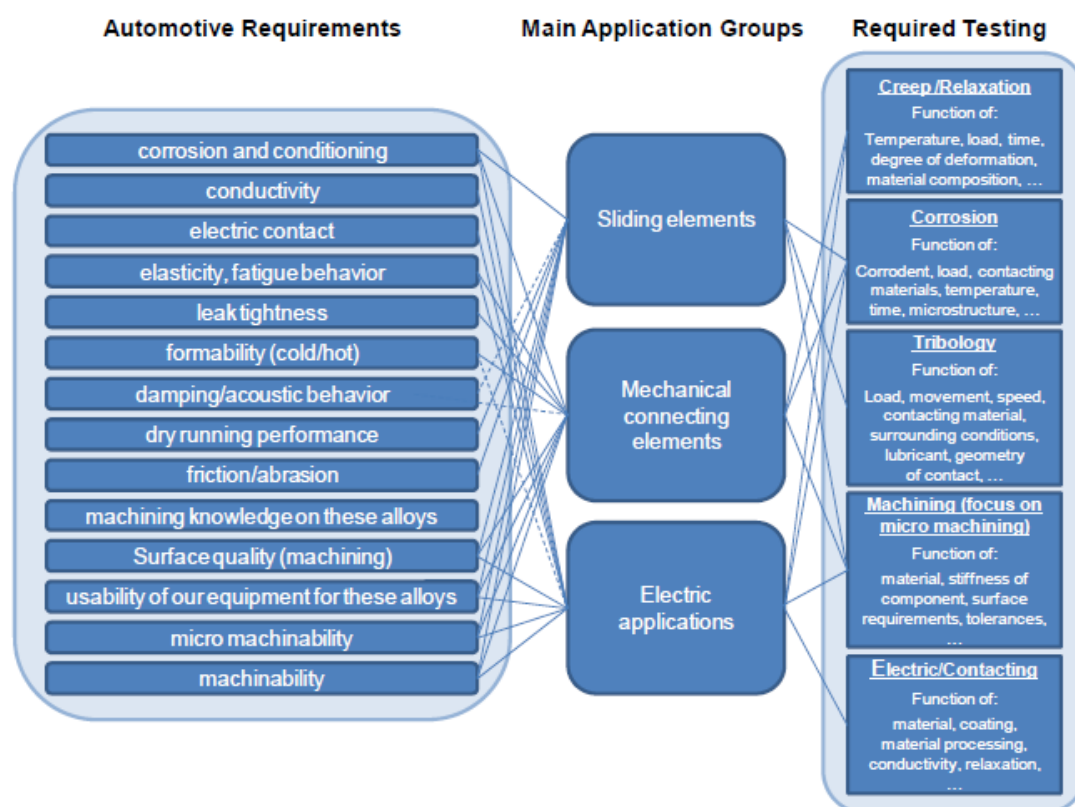
⁹³ Op. cit. ACEA et al. (2014)

⁹⁴ ACEA et al. (2015d), ACEA, CLEPA JAMA, KAMA et al.; presentation for stakeholder meeting on Review of ELV Exemption 3, held 10 April 2015.

⁹⁵ Op. cit. ACEA et al. (2014)

ACEA et al.⁹⁶ explain that the “zero lead approach” - substitution by lead-free copper alloys - failed in several tests conducted for the last revision of the exemption in 2008 because the lead-free copper alloys did not fulfil the technical requirements. Therefore ACEA et al. initiated a copper inventory after the last revision in order to define the parts of leaded copper alloys and the amount of lead therein and secondly to define the function of lead in these parts. Based on the functions identified during the copper inventory, ACEA et al. defined the three main application groups of leaded copper alloys. The main application groups and their technical requirements are summarised in Figure 5-2.

Figure 5-2: Automotive Requirements of the Main Application Groups for Leaded Copper Alloys



Source: ACEA et al. (2014)

ACEA et al.⁹⁷ explain: “Looking into the supply chain we also noticed that specific and for these groups generally valid test standards could not be identified and we were in contact on this topic with several material producers. Due to this shortfall we (finally) had to develop specific test programs on our own and then we mandated tests.”

⁹⁶ Op. cit. ACEA et al. (2015c)

⁹⁷ Op. cit. ACEA et al. (2015c)

ACEA et al.⁹⁸ submitted 16 test reports as Annexes to their contribution.⁹⁹ They are summarised in Table 6-3 in Appendix A.2.0 and are referred to in the following discussion by codes to identify the test, such as E3_[01] etc.. The alternative materials that were investigated comprise brass with higher zinc content than leaded brass (mostly CuZn42), silicon-alloyed coppers (sometimes specified as Ecobrass) and also lead-reduced alloys (Pb content 0.2%; in one case 0.2 to 0.8%; in another case (E3_[29]), the lead reduced alloy contained 2.2% Pb). The tests did not use the same alternative alloys and not all tests included Ecobrass as a substitute. ACEA et al. did not specify the causes for selecting different substitutes.

The test reports can be clustered into tests regarding physical properties, regarding types of components and regarding machinability:

- Five test reports explored physical properties of the lead-free copper alloys (E3_[09]: wear resistance; E3_[10]: galvanic corrosion; E3_[11]: stress corrosion cracking; E3_[30]: corrosion in aggressive conditions).
- Five tests compared the conventionally fabricated components with components made from lead-free copper alloys. In four cases, the lead-free copper alloy components were assessed to have failed (pinions, shift forks, valve stems, crimp contact material). In the case of fittings to fuel feeding systems (E3_[18]), it is understood that the silicon-based alloys achieved the best results.
- Six tests addressed the machinability of alternative copper alloys. Five machinability tests were performed in the way that the existing equipment was operated and the process with lead reduced / lead free alternatives mostly malfunctioned. One test approach applied was to adapt the tools (E3_[07]). The results of the tests of E3_[07] with different tool material are not presented as they were still ongoing at the time the results were submitted. The research project on micro-drilling explores an adaption of the drilling strategy (E3_[12]).

ACEA et al.¹⁰⁰ conclude from these tests: *“The test results illustrated, that none of the tested lead-free machining alloys was able to fulfil the diverse set of minimum requirements for one application group. Therefore, this approach to find alloys being able to replace leaded material for at least one main application group was not successful. This is the most recent research status.”*

⁹⁸ Op. cit. ACEA et al. (2014)

⁹⁹ ACEA et al. (2014) submitted 19 Annexes to its contribution; they can be found at <http://elv.exemptions.oeko.info/index.php?id=60>. The majority of these annexes were test reports. Literature studies were included as two annexes, these labelled as “E3_[01]_[WE-03]_Literature_Study_completed_2013-09-03.pdf” and “E3_[02]_Welter_2014_leaded copper alloys for automotive applications-a scrutiny.pdf”. One further Annex is a compilation of information from material data sheets, labelled as “E3_[08]_Compilation_Material property data sheets lead and lead free alloys.pdf”. These three Annexes are not included in the summary of the test reports in Table 6-3 in Appendix A.2.0.

¹⁰⁰ Op. cit. ACEA et al. (2015c)

5.2.2 Possible Substance Alternatives

5.2.2.1 Input of ACEA et al.

According to ACEA et al.¹⁰¹, mainly three families of machinable lead-free copper alloys are available on the market:

- Brass with higher zinc content than leaded brass as well as some other minor additions (CuZn38-42 alloys);
- Silicon-alloyed copper, e.g. CuZn21Si3; Ecobrass® is the brand name of one of these alloys;
- Bismuth-alloyed copper; bismuth containing alloys were not included in the test programs according to Welter.¹⁰² Bismuthed copper was not considered to be a reliable alternative since the revision in 2007 according to Oeko-Institut (2010) because of cold and hot cracking.

ACEA et al.¹⁰³ claim to have checked the general suitability of alternative alloys using a set of tests that are defined in the test reports submitted as Annexes (see Table 6-3).

ACEA et al.¹⁰⁴ present an evaluation of the general suitability for each main application group against different material and testing requirements (see Table 5-1). The alternative alloys are silicon-alloyed copper in the left hand column and two lead-free copper alloys with a higher zinc content (CuZn42 and CuZn38As) in the right hand columns compared to CuZn39Pb3. ACEA et al.¹⁰⁵ state that a 20% worse test result compared to the most widely used leaded copper alloy CuZn39Pb3 should be considered unacceptable performance. As already mentioned, ACEA et al. conclude that no lead-free machining alloys were able to fulfil the diverse set of minimum requirements relevant for the various application groups.

¹⁰¹ Op. cit. ACEA et al. (2014)

¹⁰² Op. cit. Welter (2014)

¹⁰³ Op. cit. ACEA et al. (2015d)

¹⁰⁴ Op. cit. ACEA et al. (2014)

¹⁰⁵ Op. cit. ACEA et al. (2015c)

Table 5-3: Automotive Requirement Test Results for Lead-Free Copper Alloys

sliding elements	(compared to CuZn39Pb3)		
material requirements	CuZn21Si3	CuZn42	CuZn38As
wear of copper disc	300% better	300% better	not tested
adhesion	similar	300% worse	not tested
friction coefficient	30% worse	10% worse	not tested
machinability (outside)	35% worse	45% worse	50% worse
surface quality (outside)	30% worse	45% worse	50% worse
corrosion galvanic	45% worse	35% worse	40% worse
Technical drawback:			
	friction coefficient	adhesion	machinability
	machinability	machinability	machinability
	surface quality	surface quality	surface quality
		galv. corrosion	
+ additional drawback for small parts (micro machining)			
drilling time	600% worse	600% worse	600% worse
tool life	> 10000% worse	> 10000% worse	not tested
tool force	200% worse	300% worse	300% worse
mechanical connecting elements	(compared to CuZn39Pb3)		
material requirements	CuZn21Si3	CuZn42	CuZn38As
tensile strenght at 150°C	30% better	10% better	10 % worse
relaxation fittings (at 130°C)	180%	175% worse	330% worse
machinability (outside)	35% worse	45% worse	50% worse
surface quality (outside)	30% worse	45% worse	50% worse
corrosion galvanic	45% worse	35% worse	40% worse
Stress Corrosion Cracking	330%	24% worse	340%
Technical drawback:			
	relaxation	relaxation	relaxation
	machinability	machinability	machinability
	surface quality	surface quality	surface quality
	galv. corrosion	galv. corrosion	
		stress corrosion cracking	
+ additional drawback for small parts (micro machining)			
drilling time	600% worse	600% worse	600% worse
tool life	> 10000% worse	> 10000% worse	not tested
tool force	200% worse	300% worse	300% worse
electric applications	(compared to CuZn39Pb3)		
material requirements	CuZn21Si3	CuZn42	CuZn38As
relaxation in electric contacts	not tested	145 % worse	not tested
machinability (outside)	35% worse	45% worse	50% worse
surface quality (outside)	30% worse	45% worse	50% worse
conductivity	320% worse	similar	similar
corrosion galvanic	45% worse	35% worse	40% worse
stress corrosion cracking	330%	24% worse	340%
Technical drawback:			
	relaxation	relaxation	relaxation
	machinability	machinability	machinability
	surface quality	surface quality	surface quality
	conductivity	galv. corrosion	galv. corrosion
		stress corrosion cracking	
+ additional drawback for small parts (micro machining)			
drilling time	600% worse	600% worse	600% worse
tool life	> 10000% worse	> 10000% worse	not tested
tool force	200% worse	300% worse	300% worse

Source: ACEA et al. (2014)

5.2.2.2 Input of Mitsubishi Shindo Co., Ltd.

Mitsubishi Shindo Co., Ltd.¹⁰⁶ state that Ecobrass is available and suitable as a Pb-free brass alternative in the automotive sector. According to Mitsubishi Shindo Co., Ltd.¹⁰⁷, Ecobrass is already applied in at least five motor vehicle applications, which are control valves for a variety of displacement air-conditioner compressors, check valves for a variety of displacement air-conditioner compressors, relief valves, pressure sensors and brake parts.

As for the availability on the market, Mitsubishi Shindo Co., Ltd.¹⁰⁸ state that Ecobrass is available from various suppliers, e.g. in Europe, there are agreements with five rod manufacturers and four casting manufacturers including sub-licensees.

Mitsubishi Shindo Co., Ltd.¹⁰⁹ summarizes the properties of Ecobrass as follows (see Table 5-4) and point out the properties electrical conductivity, tool life and friction coefficient as the major challenges for applying Ecobrass.

Table 5-4: Comparison of Properties between Ecobrass and C36000/CuZnPb3

Properties	Method	ECO BRASS /C36000	Evaluation of ECO BRASS
Electrical Conductivity	JIS H 0505	0.3	Electrical Conductivity Deteriorates
Tensile Strength	JIS Z 2241	1.4	High Strength, Weight Saving
Elongation	JIS Z 2241	1.5	Elongation Either Equaling or Surpassing
Fatigue Limit	JIS Z 2273	1.6	High Fatigue Limit, Weight Saving
Creep Strength (150°C)	JIS Z 2271	2.5	Can be Used in High Temperature Environment
Tool Life	JIS B 4011, ASTM E 618	0.7	Tool Life Deteriorates
Surface Roughness	JIS B 0601	0.4	Good Surface Roughness
Friction Coefficient		1.3	Friction Increased
Wear Loss		0.05	Lower Wear Loss by Friction
Cavitation Erosion Loss	ASTM G32	1.7	Lower Cavitation Erosion Loss
Dezincification	ISO 6509	0.01	Reduced Corrosion
Stress Corrosion Cracking	ASTM B858	0.01	Reduced Corrosion Cracking Sensitivity

Source: Mitsubishi Shindo Co., Ltd. (2015c)

As for machinability of Ecobrass, Mitsubishi Shindo Co., Ltd. provide further information on cutting conditions and chip formation¹¹⁰ and drilling:¹¹¹

¹⁰⁶ Op. cit. Mitsubishi Shindo Co., Ltd. (2014)

¹⁰⁷ Mitsubishi Shindoh Co., Ltd. (2015a), Mitsubishi Shindoh Co., Ltd., Answers to the additional questions for clarification – Exemption No. 3; submitted by Email 04 February 2015.

¹⁰⁸ Op. cit. Mitsubishi Shindo Co., Ltd. (2014)

¹⁰⁹ Mitsubishi Shindoh Co., Ltd. (2015c), Mitsubishi Shindoh Co., Ltd., presentation for stakeholder meeting on Review of ELV Exemption 3, held 10 April 2015.

¹¹⁰ Op. cit. Mitsubishi Shindo Co., Ltd. (2015c)

- Ecob brass differs from the leaded copper alloy CuZn39Pb3 in the chip breaking mechanism: The dispersed soft Pb particles melt due to machining heat and result in chip breakage. *“In the case of ECO BRASS, stress is concentrated on the hard phases of κ and γ and chips are divided.”*¹¹² Mitsubishi Shindo Co., Ltd.¹¹³ claims that by reducing the cutting speed and increasing the feed, good chip breaking performance is achieved and should be the basis for setting cutting conditions.
- Mitsubishi Shindo Co., Ltd.¹¹⁴ provided a drilling report based on the drilling strategy published in the test report of the German Copper Institute and RWTH Aachen University¹¹⁵ and applying adaptations such as e.g. a different drill material.

Mitsubishi Shindo Co., Ltd.¹¹⁶ conclude that Ecob brass is *“suitable for forging, machining, and casting. Examples of all these processing methods have been provided to demonstrate that industry can adapt to Pb-free materials, can realize production gains, and can utilize advanced material properties to cut costs and make better products.”* However, at the stakeholder meeting Mitsubishi Shindo Co., Ltd. stated that they assess the pros and cons from a material suppliers’ point of view. They admitted that they cannot comment on the performance criteria at the level of automobile components.

5.2.2.3 Comparison of Inputs

There is agreement between both groups of stakeholders as to the physical properties of Ecob brass (for more details see Table 6-4 in Appendix A.2.0):

- Stakeholders agree that Ecob brass has properties that are favourable to CuZn39Pb3 / C36000 in tensile strength, wear of copper disc and stress corrosion cracking.
- Stakeholders agree that for friction coefficient and electrical conductivity, Ecob brass has less favourable properties than CuZn39Pb3 / C36000.

There are conflicting views among the stakeholders regarding the micro machining properties of Ecob brass, which are summarized in the following Table 5-5. The quantitative statements are expressed in relation to different reference values. As the consistency of the testing conditions could not be assessed by the consultants, the

¹¹¹ Mitsubishi Shindoh Co., Ltd. (2015b), Mitsubishi Shindoh Co., Ltd., Micro-Drilling test report; submitted by Email 13 March 2015.

¹¹² Op. cit. Mitsubishi Shindo Co., Ltd. (2015a)

¹¹³ Op. cit. Mitsubishi Shindo Co., Ltd. (2015a)

¹¹⁴ Op. cit. Mitsubishi Shindo Co., Ltd. (2015b)

¹¹⁵ E3_[12]_[LU-02]_Micro drilling final.pdf;
http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3/12_-source-microdrilling-FINAL_amended.pdf

¹¹⁶ Op. cit. Mitsubishi Shindo Co., Ltd. (2014)

quantitative statements as reported by the stakeholders are detailed in the table. The disagreement mostly refers to the implications e.g. of the different chip breakage mechanism. Micromachining is related to the established cost effective automated series production.

Table 5-5: Micro machining properties of Ecobrass compared to CuZn39Pb3 / C36000

Properties	ACEA	Mitsubishi
Drilling time	600% worse	Drilling time 4.9 sec, no productivity issues, continuous processing of 3200 holes is possible, no need for special equipment
Tool life	> 10.000% worse	Tool Life(Frank Wear-Turning): pieces Ecobrass 4400, C36000 6300; ratio: 0.7 Tool Life(Frank Wear-Drilling) pieces Ecobrass 4200; C36000 5900; ratio 0.71
Tool force	200% worse	The cutting force of ECO BRASS is almost 1.4 times of that of C36000 because the cross sectional shape of chips is almost the same and the strength of ECO BRASS is almost 1.4 times of that of C36000.
Surface	Surface quality 30% worse	Surface Roughness Ra (JIS B 0601) μm Ecobrass 0.4, C36000 1.1; ratio: 0.36 Surface Roughness Rz (JIS B 0601) μm Ecobrass 4.4, C36000 9.4; ratio: 0.47
Appearance of chips / chipping quality	Short chip sizes for CuZn39Pb3. Chip size obtained for Ecobrass is much larger. Such large chip size gives lower process stability, tool life, surface quality and other issues	ECO BRASS differs from C36000 in the chip breaking mechanism, therefore it is necessary to adjust the cutting conditions by lowering the cutting force. Reducing the cutting speed and increasing the feed results in good chip breaking and should be the basis for setting cutting conditions.
Cutting conditions / cutting force	Cutting forces will rise by some 40% when Ecobrass is used.	The cutting force of ECO BRASS is almost 1.4 times of that of C36000 because the cross sectional shape of chips is almost the same and the strength of ECO BRASS is almost 1.4 times of that of C36000.

Source: Op. cit. ACEA et al. (2014 and 2015a); Mitsubishi Shindo Co., Ltd. (2015a)

For electrical connecting elements, Mitsubishi Shindo Co., Ltd.¹¹⁷ agrees that Ecobrass does not provide the necessary properties but instead proposes another lead-free copper alloy C18625¹¹⁸ with good electrical conductivity that was so far not included in tests by ACEA et al.

As for recycling, the two stakeholders have opposing views but did not provide technical evidences to explain their views. Mitsubishi Shindo Co., Ltd.¹¹⁹ state that at the end of product life, Ecobrass can easily be recycled through the regular scrap stream into standard brass; segregating Ecobrass scrap allows for cost savings when recycling back into Ecobrass as already established in the sanitary supply industry. ACEA et al.¹²⁰ point out that a mixed use of leaded and silicon-based alloy types would damage existing recycling cycles as Si has low limits as an impurity in leaded copper alloy specifications and in scrap streams a separation of leaded and silicon containing copper is not possible.

5.2.3 Road Map for Substitution

ACEA et al.¹²¹ intend to further reduce lead content in certain applications or application groups. Based on experiences from the last years, ACEA et al. explain that further lead reduction is possible for parts, which already have a low lead content.¹²² Thereby ACEA et al. intend to focus on most relevant applications or application groups in terms of weight:¹²³

“Priority is on bigger parts currently containing lead alloyed copper. So based on a Pareto-approach we will consider most relevant cases in terms of weight resp. lead. For these components agreements on the necessary test program have to be defined jointly with supply chain partners and material producers including Mitsubishi Shindoh.”

To implement substitution, ACEA et al.¹²⁴ state that they need to identify “new high performing materials” and “economical processing technologies.” For the current lead-free copper alloys, ACEA et al.¹²⁵ see a need for “considerable additional development in production equipment and technology”.

¹¹⁷ Op. cit. Mitsubishi Shindo Co., Ltd. (2015c)

¹¹⁸ High Copper Alloy (99.40% Cu) according to Copper Development Association Inc. at <http://alloys.copper.org/alloy/C18625?referrer=facetedsearch>

¹¹⁹ Op. cit. Mitsubishi Shindo Co., Ltd. (2015c)

¹²⁰ Op. cit. ACEA et al. (2015b)

¹²¹ ACEA et al. (2015d), ACEA, CLEPA JAMA, KAMA et al.; presentation for stakeholder meeting on Review of ELV Exemption 3, held 10 April 2015. and op. cit. Welter (2014)

¹²² Lead reduction does not mean reducing the lead content, but a substitute material with similar characteristics.

¹²³ Op. cit. ACEA et al. (2015c)

¹²⁴ Op. cit. ACEA et al. (2015c)

¹²⁵ Op. cit. ACEA et al. (2014)

As for the time frame, ACEA et al.¹²⁶ estimate that implementation of reduction and or substitution will require over 10 years for material testing and component testing in vehicles. ACEA et al.¹²⁷ estimate that the component-oriented approach (copper alloy lead reduction test programmes for individual components, defined jointly between supply chain partners and material producers) will take 3 to 5 years. The components then need to pass through test programs within complete vehicles, which will also require 3 to 5 years.

5.3 Critical Review

ACEA et al. state that in more than 500 different components the use of leaded copper alloys is still unavoidable. Based on a detailed inventory, ACEA et al. deduced three main application groups and defined the technical requirements. Some of the testing requirements are published in the Annexes submitted with the contribution during the stakeholder consultation (see Table 6-3).

From the Annexes submitted by ACEA et al., it is not obvious for which applications a lead reduction or use of lead free alternatives is envisaged. ACEA et al.¹²⁸ estimate that a further lead reduction is most likely to be successful in parts with an already low lead content. This is not reflected by the test reports submitted for the manufacturing of unions (E3_[29]) containing normally leaded copper alloys at the high end of the lead allowance of the exemption (Pb 3.7%); a lead-reduced material with 2.2% Pb content was tested.

The tests on components being directly substituted with lead-free copper alloys ended with the conclusion that lead-free alloys failed and did not explore further solutions, e.g. using other types of lead-free copper alloys. In addition, the majority of the tests on machinability did not explore further solutions: Four machinability tests only applied the existing equipment to lead reduced / lead free alternatives; the tests ended concluding that the lead reduced / lead free alternatives have failed. To conclude, it is not obvious whether the substitution strategy consistently explored all possibilities.

ACEA et al. (2014) summarizes a series of test results conducted for the main application groups (see Table 5-3:). The summary evaluates three lead-free alternatives compared to the most applied leaded copper alloys. The results of the alternative materials also depend on processing technology, especially relating to metal-cutting manufacturing. It is unclear if attempts were made to adjust the processing to accommodate the various alternatives tested. This makes it difficult to assess the overall conclusion of ACEA et al. stating that none of the tested lead-free machining alloys was able to fulfil the diverse set of minimum requirements for one application group. It may also be noted that one of the identified lead free alloys

¹²⁶ Op. cit. ACEA et al. (2015c)

¹²⁷ Op. cit. ACEA et al. (2015c)

¹²⁸ Op. cit. ACEA et al. (2014)

C18625, a high copper alloy, that may be suitable for electrical applications, is not included in the tests of ACEA et al..

In order to draw a clearer roadmap to identify, which applications could be substituted earlier, a matrix for single applications mapping the key requirements would help to monitor the further efforts for substitution. As ACEA et al. are able to identify the average number of components for different vehicle models (standard and fully equipped) and the respective average lead content (see Table 5-1), the consultants assume that such a matrix is feasible. As from the information provided by ACEA et al. and Mitsubishi Shindo Co., Ltd., it is understood that an earlier substitution is possible in applications with an already low lead content and possibly in cases where machining can be adapted:

- It is understood that a reduction of the threshold for lead is not possible as small parts in electrical applications with a lead content at the high end of the exemption are increasingly applied. ACEA et al. agreed that applications with an already low lead content are most promising for achieving substitution. Within the 'sliding elements' and 'mechanical connecting elements' application groups there are applications with an already low lead content (close to 0.3% Pb within sliding elements and 0.2% Pb within mechanical connecting elements). As such, the consultants expect that ACEA et al. will be able to identify specific components in the future that can be evaluated for the applicability of substitution.
- The consultants can follow that substitutes may still suffer technical drawbacks that still delay their implementation, e.g. in the case of Ecobrass, for micromachining in automated series production. Mitsubishi Shindo Co., Ltd. suggests how machining processes could be adapted to process Ecobrass: E.g. Mitsubishi Shindo Co., Ltd.¹²⁹ submitted a drilling report that used a different drilling bit (carbide compared to high speed steel applied by ACEA et al.¹³⁰). These adaptations are important in cases where machining knowledge on these alloys or usability of required equipment for these alloys consist the key requirements (see Figure 5-2) for successful application.

Thus, it is understood that some restrictions on putting lead-free copper alloys into successful application especially for Ecobrass might be overcome in the coming years. ACEA et al.¹³¹ refer to further tests on machinability and cooperation with material suppliers including Mitsubishi as future challenges. ACEA et al.¹³² argue that machining and processing of alternative alloys is in a very basic research stage today, because public funded research on fundamental parameters is still on-going in the

¹²⁹ Op. cit. Mitsubishi Shindo Co., Ltd. (2015c)

¹³⁰ ACEA et al. (2014) in Annex E3_[12]_[LU-02]_Micro drilling final.pdf; http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3/12-source-microdrilling-FINAL_amended.pdf

¹³¹ Op. cit. ACEA et al. (2015c)

¹³² Op. cit. ACEA et al. (2014)

field of machining. Welter¹³³ state that there is little know-how among the subcontractors specialized in micromachining and their tool suppliers and machining companies.

The matrix suggested above would further help to clarify whether or more importantly how, the scope of the exemption could be narrowed in the future. A possibility to narrow the scope of the exemption could be e.g. to limit the scope of the exemption to very small parts, adding a size/weight threshold e.g. such as *“Copper alloy containing up to 4% lead by weight in parts with a weight below XXX gr or in parts with a volume below XXX mm³”*. So far, ACEA et al.¹³⁴ see no possibility to derive a common definition for the parts because even larger parts seem to be dependent on lead containing alloys and need micro-machining.

ACEA et al. state that *“a mixed use of leaded and silicon-based alloy types would damage existing recycling cycles as Si has low limits as an impurity in leaded copper alloy specifications and as in scrap streams a separation of leaded and silicon containing copper is not possible”*. It is understood that Mitsubishi assume that such a segregation is possible, stating that *“segregating Pb-free material from leaded brass will have the benefit of saving cost and energy of lead (Pb) removal... Silicon, the chip-breaker in ECO BRASS, can easily be removed in secondary recycling.”* On the basis of available documents concerning copper recycling^{135,136,137}, there is a distinction between the technological processes used on parts that can be disassembled and parts that are left in the vehicle after disassembling efforts (thus being included in the shredded fraction):

- Where parts can be easily disassembled, they can be redirected to separate recycling (re-melting which is more efficient from an energy consumption perspective).
- Where parts are less accessible in terms of disassembling, or where there size would not make the disassembling effort worthwhile, they remain in the ELV

¹³³ Op. cit. Welter (2014)

¹³⁴ Op. cit. ACEA et al. (2015c)

¹³⁵ Deutsches Kupferinstitut (n.d.), Deutsches Kupferinstitut (n.d.), Recycling von Kupferwerkstoffen; <http://admin.copperalliance.eu/docs/librariesprovider3/recycling-von-kupferwerkstoffen---final-pdf.pdf?sfvrsn=0&sfvrsn=0>

¹³⁶ Kawohl (2011), Kawohl, C. (2011), Multi-Metal Recycling bei der Aurubis AG, Praxisdialog „Ressourcen- und materialeffiziente Produktgestaltung“ 2. November 2011, Berlin; http://www.deutsche-rohstoffagentur.de/DERA/DE/Downloads/Praxisdialog_02112011_Kawohl.pdf?__blob=publicationFile&v=5

¹³⁷ CAR (2006), Manufacturing, Engineering & Technology Group Center for Automotive Research (November 2006), Copper in End-of-Life Vehicle Recycling, prepared for the Copper Development Association (CDA), available under: http://www.google.de/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&cad=rja&uact=8&ved=OCCEQFjAA&url=http%3A%2F%2Fwww.cargroup.org%2F%3Fmodule%3DPublications%26event%3DDownload%26pubID%3D35%26fileID%3D41&ei=H9eCVY-AMqW17gaN-YTOBw&usq=AFOjCNGgmRI_kH_OCNK0SXwbCkto2bfGug

which is decontaminated (of battery and liquids etc.) and shredded prior to further processing.

From the information provided by ACEA it can be understood that the applications of leaded copper alloys are for the most part in small components. Copper recyclers explain that the relevant parts in e.g. ELV scrap are becoming smaller, increasing the need for sorting and refining in comparison to the past.¹³⁸ Alloy specific re-melting is becoming difficult especially in light of this trend towards smaller parts.¹³⁹ It is thus assumed that most of the small parts would end up in the shredded fraction.

As for the shredded fraction, the separation stages that are performed are understood to suffice to separate between copper and other metal impurities including lead. It is understood that this is done through the use of reduction and oxidation during the smelting and refining stages.¹⁴⁰ Silicon acts as a reducing agent during these process steps and is brought out as a part of iron silicate, a major by-product of copper refining.¹⁴¹

On this basis, the consultant cannot follow the statement of ACEA et al.¹⁴² that “a mixed use of leaded and silicon-based alloy types would damage existing recycling cycles.” Although the smelting and refining stages for shredded ELVs is identified to be less preferable (more complex and with a higher energy use than disassembly and re-melt), the approach appears capable of extracting and separating the relevant impurities, and thus effective recycling cycles can be maintained.

Against the background of scope of the exemption being general (wide) and with the trend towards smaller and smaller parts in a growing number of applications (especially electrical) with a lead content at the high end of the exemption, the consultant recommends a shorter review period for the exemption than proposed by ACEA et al. There is potential for significant quantities of lead to enter the market in light of this exemption, and hence progress needs to be made soon to seek to reduce lead use via this route.

A further review within a shorter period than proposed by the applicant should still be beneficial, and may lead to additional reductions in hazardous substances in a shorter time period. Even if in the next review, leaded copper alloys can still not be substituted in a number of applications, the above described matrix would help to clarify the substitution strategy for the applications with different lead contents as well as the different time needed for the implementation of the substitution. Also, the matrix would assist to evaluate the possibility of a narrower scope of the exemption.

¹³⁸ Op cit. Deutsches Kupferinstitut (n.d.)

¹³⁹ Op. cit. Kawohl (2011)

¹⁴⁰ See also <https://www.aurubis.com/en/en/corp/products/recycling/technology>

¹⁴¹ Aurubis AG (2015), Aurubis AG Recyclingzentrum Lünen, Dr. Hendrik Roth, Director Environmental Protection Lünen.

¹⁴² Op. cit. ACEA et al. (2015b)

5.4 Recommendation

The consultants acknowledge that ACEA et al. put efforts into making an inventory of the uses of leaded copper alloys. They can follow that use of copper alloys containing lead up to 4% by weight is still unavoidable in a number of components. However, it is understood that starting points for substitution exist, e.g. opportunities for substitution exist especially for components with an already low lead content.

The overall picture where substitution efforts are promising is not clear enough at present. The aim of a future review should therefore be a compilation of information on applications of leaded copper alloys together with their technical requirements in order to check the applicability of a more narrow scope for the exemption. Thus, the consultants recommend the continuation of Exemption 3 with the current scope and wording. The consultants recommend reviewing the exemption in five years to allow monitoring developments in the potential for substitution and to clarify that the increased use of electrical applications within vehicles does not lead to an unjustified increase in the use of leaded copper alloys. Thus, a review is recommended for 2020 with a view to, at least, identify lists of components or categories of applications for lead reduction or substitution.

Materials and components	Scope and expiry date of the exemption
<i>Copper alloy containing up to 4 % lead by weight</i>	<i>Review in five years.</i>

5.5 References Exemption 3

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6.0 Exemption 5 “Lead and lead compounds in batteries”

Abbreviations and Definitions

AGM	Absorbent-glass matt [lead based batteries]
BMS	Battery management system
CCA	Cold cranking amperage
EFB	Enhanced flooded [lead based] batteries
EN-50342	British Standard European Norm 50342-1, 2006
EV	Electric vehicles
HEV	Full-hybrid electric vehicles
ICE	Internal combustion engine
LAB	Lead acid batteries
Li-Ion	Lithium-ion
LFP	Lithium-iron-phosphate
LTO	Lithium titanate (lithium titanium oxide)
NiMH	Nickel-metal hydride
NMC	Lithium manganese cobalt oxide
Pb	Lead
PHEV	Plug-in hybrid electric vehicles
SLI	Main battery functions in conventional vehicles: S tarting the internal combustion engine, L ighting and I gnition
SOC	State of charge
VDA-LV124	Standards MBN LV124-1 & -2, Electric and Electronic Components in Motor Vehicles up to 3,5t – General Requirements, Test Conditions and Tests

Declaration

The phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as possible. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text.

6.1 Description of Exemption

The current wording of Exemption 5 in Annex II of the ELV Directive is

Lead and lead compounds in batteries.

The exemption has become due for review in 2015.

In a joint contribution, ACEA, JAMA, KAMA, CLEPA, ILA and EUROBAT¹⁴³ request the continuation of Exemption 5. ACEA et al. explain that lead acid batteries (LAB) are essential for various types of vehicles:

- Conventional internal combustion engine (ICE) vehicles;
- All hybrid vehicles; and
- Full electric vehicles (EV).

According to ACEA et al.¹⁴⁴ Pb-based batteries are the only mass market battery system available for conventional vehicles (including vehicles with start-stop functionality and micro-hybrid systems). These batteries are required to start the engine and supply the complete 12V electrical system (i.e. the starter-lighting-ignition or “SLI”). *“Its excellent cold-cranking capability, with decades of proven reliability, low combined cost and compatibility with these vehicles’ 12 V electrical system set the Pb battery apart from other battery technologies in conventional vehicles”*. ACEA et al also explain Pb-based batteries to be essential for hybrid vehicles which include electric power trains (advanced micro-hybrid, mild-hybrid and full-hybrid vehicles), plug-in hybrid vehicles and full electric vehicles. In these vehicles, a 12 V lead-based battery is employed for controls, comfort features, redundancy and safety features. It is explained that a 12V lead-based battery powers the following functionality: (non-exhaustive):

- Starter, lighting, ignition;
- Emergency flashers;
- Electronic locks;
- Airbag control units;
- ABS (anti-lock braking system) control units;
- ESP (Electronic Stability Control) control units;
- Defrost systems;
- Displays for car information;
- Power steering;

¹⁴³ ACEA et al. (2014) ACEA, JAMA, KAMA, CLEPA, ILA and EUROBAT (2014a), Industry contribution of ACEA, JAMA, KAMA, CLEPA, ILA and EUROBAT, submitted 10.12.2014, http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_5/20141210_ACEA_AnnexII_5.pdf; last accessed 10.03.2015

¹⁴⁴ Op. cit. ACEA et al. (2014)

- Electric windows levers;
- Audio/stereo systems;
- DVD systems; and
- Heated seats.

In addition to the above functions, 12v batteries are important in hybrid and electric vehicles for providing the battery management system and to power range extenders.

6.1.1 History of the Exemption

The legal text of the ELV Directive published in 2000 required in Article 4(2)(b), that the Commission shall evaluate the need for exempting the use of the ELV substances in a number of applications. This included evaluations for a number of specific applications including the use of lead in batteries. In light of this requirement, an evaluation was carried out, results of which recommended an exemption, subsequently added to Annex II. Exemption 5 has been available for such applications as early as the first amendment of Annex II to the Directive. It was last reviewed in 2009/2010, at which time it was recommended to extend the exemption, scheduling a review within five years. Based on evidence available at the time, the main rationale behind the recommendation was that substitution with the available lead-free alternatives would reduce the functionality and reliability of vehicles. The requirement to review Exemptions 5 in 2015 was published in the fifth revision of Annex II in 2011 and has led to the current evaluation.¹⁴⁵

6.1.2 Technical Background

EUROBAT et al.¹⁴⁶ explain that batteries of several technologies are employed in different automotive applications. A range of different vehicle types are currently available on the European market, featuring increasing degrees of hybridisation and electrification:

- **“Conventional (ICE) vehicles** – No electrification. The battery is used only for *Starting the internal combustion engine, Lighting and Ignition (commonly referred to as SLI functions).*
- **Start-stop vehicles** – Low degree of electrification. The internal combustion engine is automatically shut down under braking and rest.

¹⁴⁵ Commission Directive 2011/37/EU of 30 March 2011 amending Annex II to Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles

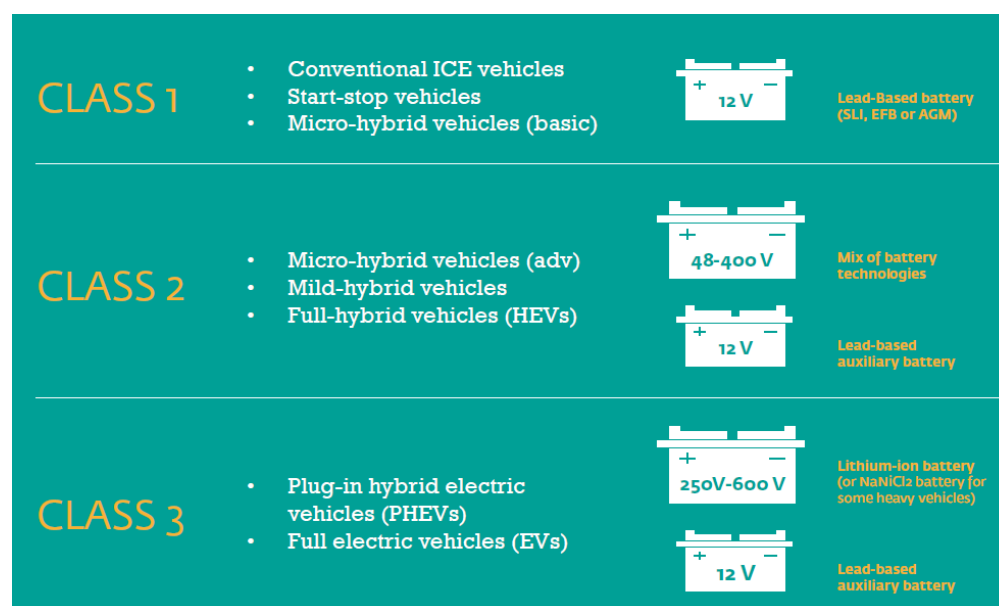
¹⁴⁶ EUROBAT et al. (2014), EUROBAT, ILA, ACEA, JAMA and KAMA (2014), A Review of Battery Technologies for Automotive Applications - A joint industry analysis of the technological suitability of different battery technologies for use across various automotive applications in the foreseeable future, available under: http://ewfa.org/sites/default/files/rev_of_battery_executive_web_1.pdf, last accessed 10.03.2015

- **Micro-hybrid and mild-hybrid vehicles** – Low to medium degree of electrification. Start-stop systems combined with regenerative braking, where stored energy is then used to boost the vehicle's acceleration.
- **Full-hybrid electric vehicles (HEVs)** – Medium degree of electrification. Equivalent characteristics to mild-hybrid vehicles, but the stored energy within the battery is also used for a certain range of electric driving.
- **Plug-in hybrid electric vehicles (PHEVs)** – High degree of electrification. The battery is used as the main energy source for daily trips (i.e. 20-50km), but if necessary PHEVs can also run in hybrid mode using a combustion engine. Batteries may be charged with off-board electric energy.
- **Electric vehicles (EVs)** – Full electrification. The battery is used as the vehicle's only energy source, with no internal combustion engine. Batteries are charged with off-board electric energy."

EUROBAT et al. state that each of these vehicle types place different requirements on the installed batteries, in terms of performance, lifetime, safety and cost. Lead based batteries are commonly used in the automotive sector, both in conventional vehicles (mainly for SLI functions), and in the various types of hybrid and electric vehicles. Though the various types of hybrid and electric vehicles use other battery types for most functions (i.e., nickel-metal hydride, lithium-ion, etc.), they also utilise a second lead based battery for certain electric features, for redundancy and more importantly for safety features. The commonly applied battery systems for various vehicle types are detailed in 6Figure 6-1, which makes a distinction between 3 vehicle classes in this regard.¹⁴⁷

¹⁴⁷ Op. cit. EUROBAT et al. (2014)

6Figure 6-1: Overview of the three vehicle classes identified and their corresponding battery technologies



Source: EUROBAT et al. (2014)

EUROBAT et al.¹⁴⁸ state that for **Class 1 conventional vehicles**, the excellent cold-cranking ability, low combined cost and compatibility of the lead acid battery with the vehicle's 12V electrical system set it apart from other battery technologies.

In the **Class 2 hybrid vehicles**, the battery is explained to play a more active role, with energy stored from braking used to boost the vehicle's acceleration. In full-hybrid vehicles, the battery system is additionally employed for a certain range of electric driving. It is understood that dual battery systems are employed, with several battery technologies being able to provide these functions in different combinations. Nickel-metal hydride (NiMH) and lithium-ion (Li-Ion) batteries are said to be preferred at higher voltages due to their fast recharge capability, good discharge performance and lifetime endurance. NiMH batteries have been the predominant battery technology for full-hybrid vehicles, however the decreasing costs of Li-Ion systems continue to improve their competitiveness. These vehicles utilise a second electrical system on a 12V level for comfort features, redundancy and safety features. This electrical system is supplied by a 12V lead-based battery.¹⁴⁹

In **Class 3 plug-in hybrid vehicles and full electric vehicles**, high voltage systems with a battery storage capability of at least 15kWh are installed to provide significant levels of vehicle propulsion, either for daily trips (20-50km) in plug-in hybrid vehicles, or as the only energy source in full electric vehicles (100km+). In plug-in hybrid

¹⁴⁸ Op. cit. EUROBAT et al. (2014)

¹⁴⁹ Op. cit. EUROBAT et al. (2014)

vehicles, the battery must also perform hybrid functions (i.e. regenerative braking) when its capability for electric drive is depleted. Plug-in hybrid and electric passenger cars are propelled by Li-Ion battery systems. Due to their high energy density, fast recharge capability and high discharge power, Li-Ion batteries are the only available technology capable of meeting OEM requirements for vehicle driving range and charging time. For commercial applications, harsh environments and heavy-duty vehicles, sodium-nickel chloride batteries are a competitive option. NiMH batteries and Pb-based batteries cannot meet these requirements at a competitive weight. Similar to hybrid vehicles, an auxiliary 12V lead-based battery is installed in all plug-in hybrid and electric vehicles to supply their electrical components, including the safety relevant features.¹⁵⁰

Of relevance to the auxiliary batteries described above, ACEA et al. explain that the on-board electronics of vehicles operate at 12V. This is relevant for understanding limitations for the auxiliary batteries mentioned in Class 2 and Class 3 vehicles, but is also a general aspect that is relevant for developing battery technologies on the vehicle level. On board electronics include the lighting for the car as well as control electronics, entertainment, navigation and safety devices like airbags or door lock systems. The vehicle electrical system has developed over decades in parallel and together with the 12V lead acid starter battery. Operating voltage of electrical and electronic components has been globally standardized at this level, and installed batteries must be compatible with these 12V systems. The vehicle electrical system is globally standardised for all vehicles – from ICE up to EV – to be compatible with 12V lead-based batteries. This compatibility is true also for designs targeting vehicles with start-stop systems, like enhanced flooded (EFB) and AGM batteries.¹⁵¹

Currently, all automotive components have been developed for 12V power supply. Changing the voltage of the system would require a total redesign of the electrical system and components of all cars, which would impose a significant cost onto OEMs and suppliers of automotive parts. On-board electric systems of vehicles currently in production are designed for an optimal use of a 12V battery, in practice a lead-based battery. Changing the battery output voltage would imply a full redesign of many of the vehicle's electrical components (e.g. its starter, generator, various electric powered appliances, engine controllers, security features and switches, entertainment, comfort and guidance devices). These components would have to be redesigned to make optimal use of the battery system, as is the case for currently employed lead-based battery systems.¹⁵²

6.1.2.1 Details as to lead based batteries - summary

EUROBAT et al.¹⁵³ state that lead-based batteries are currently the only available mass-market technology for SLI applications in conventional vehicles, including those

¹⁵⁰ Op. cit. EUROBAT et al. (2014)

¹⁵¹ Op. cit. ACEA et al. (2014)

¹⁵² Op. cit. ACEA et al. (2014)

¹⁵³ Op. cit. EUROBAT et al. (2014)

with start-stop and basic micro-hybrid systems, due to their excellent cold cranking performance, reliability and low cost. Starter batteries of 12V are standardised globally. All lead-based batteries use the same basic chemistry. It is explained that in vehicles, three lead-based sub-technologies are currently available:

- Flooded SLI batteries;
- Enhanced Flooded Batteries (EFB); and
- Absorbent Glass Mat (AGM) batteries.

Lead-based batteries all use the same basic chemistry. The active material of the positive plate mainly consists of lead dioxide, and the active material of the negative plate is finely dispersed metallic lead. These active materials react with the sulphuric acid electrolyte to form lead sulphate on discharge and the reactions are reversed on recharge. Batteries are constructed with lead grids to support the active materials. Individual cells are connected in series within a single plastic case. The nominal voltage of a cell is 2.0V. Components of lead-based batteries include: ¹⁵⁴

- Lead and lead dioxide: average 60% of the total weight
- Electrolyte: diluted sulphuric acid: average 30% of the total weight
- Others, like alloying components and polymers (separators PE, battery case PP): average 10% of the total weight

Because of their lower cost, flooded lead-based batteries are used in the vast majority of conventional ICE vehicles to provide SLI functions. Flooded lead-based batteries are characterised by a vented design and an excess of free-flowing electrolyte between and above the electrode stack. ¹⁵⁵

ACEA et. al.¹⁵⁶ explain that advanced lead-based batteries (AGM and EFB technologies) are installed to meet extra requirements in start-stop and basic micro-hybrid vehicles, due to their increased charge recoverability and higher deep-cycle resistance. In addition to start-stop functionality, these batteries provide braking recuperation and passive boosting (resulting in 5-10% fuel efficiency improvements).

Successful efforts have been made to increase the efficiency of the lead-based battery by reducing the amount of lead needed to achieve the required performance. However, the increasing number of electrical components in cars and the additional functions that the battery is required to cover (e.g. start-stop functionality for improving fuel efficiency) has imposed extra requirements on the automotive battery (i.e. deeper and more frequent discharge), meaning there has not been a corresponding reduction in battery weight for EFB and AGM technologies.

The average total weight of a lead-based battery (flooded and EFB/AGM) for a compact passenger car is 18-20kg. The lifetime of an SLI battery heavily depends on

¹⁵⁴ Op. cit. EUROBAT et al. (2014)

¹⁵⁵ Op. cit. EUROBAT et al. (2014)

¹⁵⁶ Op. cit. ACEA et al. (2014)

usage patterns and the climate in the area of use. A lifetime estimate of 5 to 7 years is provided by EUROBAT.¹⁵⁷ An equivalent operational life is also demonstrated by advanced AGM/EFB batteries in start-stop and basic micro-hybrid applications, after years of operation in partial states of charge (PSoC).¹⁵⁸

EUROBAT et al.¹⁵⁹ explain that in comparison with other battery technologies, lead-based traction batteries are not competitive for use in full hybrid electric vehicles or electric vehicles because of their lower specific energy and higher weight. However, for all electrified powertrains (from micro-hybrid to full electric vehicles), the 12V board-net and electronic component supply are currently provided by auxiliary 12V lead-based batteries (in addition to the larger traction battery). The 12V lead-based battery is also used to maintain the safety management of the larger traction battery. This is expected to continue for the foreseeable future.

6.1.2.2 Amount of Lead Used under the Exemption

A report prepared by IHS et al.¹⁶⁰ concerning the availability of Pb based automotive batteries for recycling, estimated the Pb component of a lead based automotive battery to make up for approximately 60% of the weight of the battery. The report states that automotive batteries have an average life expectancy of more than six years¹⁶¹. The estimation of the total amount of batteries available for collection is based on a method developed in the study. The authors used two existing recognised data sources:

- “Used automotive batteries recovered within the vehicle lifetime: Using IHS¹⁶² proprietary parc data by vehicle age, and then applying a formula for the battery’s expected lifetime within the vehicle.
- Used automotive batteries recovered from end-of-life vehicles: Using EUROSTAT data on End-of-Life vehicles (ELV), by Member State where the battery is recovered during vehicle scrappage.”

Based on these data sources, the authors estimate “*the quantity of used automotive lead-based batteries “available for collection and recycling” in the current year (units)*

¹⁵⁷ Op. cit. EUROBAT et al. (2014)

¹⁵⁸ Op. cit. ACEA et al. (2014)

¹⁵⁹ Op. cit. EUROBAT et al. (2014)

¹⁶⁰ IHS et. al. (2014) IHS, EUROBAT, ILA, ACEA, JAMA and KAMA (2014), The Availability of Automotive Lead-Based Batteries for Recycling in the EU - A joint industry analysis of EU collection and recycling rates 2010-2012, prepared by information company IHS, Pg. 20, available under: http://www.eurobat.org/sites/default/files/ihs_eurobat_report_lead_lores_final.pdf

¹⁶¹ According to IHS et. al. (2014) the average replacement cycle for light vehicles is said to be between 3 to 10 years, and 6 years on average. The average replacement cycle for heavy vehicles is said to be between 1 to 3 years and 2 years on average.

¹⁶² Explained in the report: IHS/Polk Car Parc gives a segmentation of the European vehicle parc in each EU member state for 15 years (the reference years in the study were 2010, 2011 and 2012) split by age and by vehicle type.

by quantifying used batteries recovered within the vehicle's lifetime (i.e. batteries that come to the end of their life and are replaced in the vehicle) and used automotive batteries recovered from end-of-life vehicles (ELVs). Over the three years between 2010 and 2012, it was estimated that:

- Approximately 54.1 million lead based automotive batteries were available for collection in the EU market from use in light vehicles¹⁶³ (estimated to weigh approximately 945 thousand tonnes);
- Approximately 3.7 million lead based automotive batteries were available for collection in the EU market from use in heavy vehicles¹⁶³ (estimated to weigh approximately 165.6 thousand tonnes);
- In total close to 58 million lead based automotive batteries were available for collection in the EU market for recycling, with a total weight of approximately 1,110 thousand tonnes;

The consultants would like to point out that the information provided in this respect is relevant only for batteries available for recycling, understood to be collected batteries. The amount of batteries available for collection over three years does not allow calculating the exact amount of batteries placed on the EU market per annum as is further explained in Section 6.2.2 below. However, this data provides insight as to the magnitude of lead based batteries put on the EU market per annum. Along with the estimation of the lead components weight from the total battery weight, this provides some indication as to how much Pb is placed on the EU market per annum, through the application relevant to ELV Exemption 5.

6.1.2.3 End-of-Life of Lead-acid Batteries

According to an analysis prepared by IHS et al. ¹⁶⁴, the recycling rate of automotive lead batteries is estimated to be close to 99% (as explained above, understood to be 99% of collected batteries). As some of the material components are recycled and reused in the manufacture of new automotive batteries, the report considers automotive lead battery manufacture to operate in a closed loop as suggests the following information:

“In the EU, used automotive lead-based batteries are typically returned to the point of sale, for example, vehicle workshops, vehicle dealerships, accessory shops, and DIY stores; or they are returned to recycling businesses or metal dealerships. In all cases they are then sent on to collection points... specialised companies... transport and deliver the batteries to secondary smelting plants operating under strict environmental regulations... the battery is broken down into component parts, the majority of which can be recycled. The lead-acid

¹⁶³ According to IHS et. al. (2014), “‘Light Vehicles’ are defined as vehicles of less than 3.5 tonnes.; ‘Heavy Vehicles’ are vehicles of more than 3.5 tonnes.” The weight of batteries used in this estimation was between 15-22.5 Kg for batteries used in light vehicles and 45 kg for batteries used in heavy vehicles. Heavy vehicles usually use more than one lead based battery for SLI requirements.

¹⁶⁴ Op. cit. IHS et. al. (2014)

battery is an excellent example of a product allowing an almost complete end-of-life recycling, with more than 93% of a lead-based battery available for recycling. The only component of the battery that cannot be recycled is the separators (these represent just 2% to 7% of the battery). The components that can be recycled and re-used are as follows:

- *The lead components (approximately 60% of the weight) are smelted and refined to be used to make new batteries.*
- *The battery casing, which is made of plastic (approximately 7% of the weight), is usually separated before the lead is recycled, depending on the method used, and is then reprocessed and re-used for batteries or for other products in the automobile industry, for example in bumpers, wheel arches and other parts.*
- *The spent electrolyte (diluted sulphuric acid, approximately 30% of the weight) is treated in a variety of ways. In some processes the spent electrolyte is separated and filtered to make it suitable for regenerating fresh acid for a variety of applications. Other processes convert the spent electrolyte into calcium sulphate (gypsum) or sodium sulphate (soda), which can be used for various applications such as building products or detergents. Some processes neutralise the spent electrolyte and then dispose of it.*

It is useful to note that even without the pressure from resource conservation and environmental protection, there is a significant incentive to collect and recycle used automotive lead-based batteries. Recycling lead is relatively simple and cost effective and in most of the applications where lead is used, especially lead-based batteries, it is possible to recover it for use over and over again without any loss in quality. The lead-battery recycling process can be repeated indefinitely, meaning that new lead batteries are made with materials that have been recycled many times over. Furthermore, as all lead-based batteries have the same basic chemistry, this means that all types of lead battery can be processed easily by lead smelters. This is not the case with all automotive battery technologies...”¹⁶⁵

6.1.3 Alternative Battery Chemistries

Various technologies have been developed with the aim of finding alternatives for automotive systems. Information provided by stakeholders covers several technologies described below, with a summary provided in Table 6-1.

ACEA et. al.¹⁶⁶ refer to a comparison of lead-based batteries and alternative technologies which is covered in the study “A review of battery technologies for

¹⁶⁵ Op. cit. IHS et. al. (2014)

¹⁶⁶ Op. cit. ACEA et al. (2014)

*automotive applications*¹⁶⁷. ACEA summarise relevant information for the various technologies as follows:

- Despite on-going research, nickel and sodium based batteries are not considered as an alternative for use in SLI, start-stop and micro hybrid applications.
- Super-capacitors coupled with a lead-acid battery would not substantially reduce the size, or lead demand, of the main battery.
- Hybrid lead-acid batteries [such as the PbC® battery or the UltraBattery™] are still in the developmental phase, but cannot meet the stable voltage requirement of automotive power supply systems. However, the electrochemical elements are based on the same lead chemistry and the components are similar to those found in standard 12 V lead-based batteries. Furthermore, the amount of lead in these technologies is not expected to be significantly different from those in a standard lead-based battery.
- Research into Li-Ion batteries as an alternative for use in SLI, start-stop and micro hybrid applications has been undertaken, and been shown to be effective under certain conditions. However, ACEA et al. explain Li-Ion solutions to require improvements in order to be considered a viable mass market alternative.

Nonetheless, it is understood from other stakeholders that current development of Li-Ion batteries has already overcome some of the obstacles mentioned by ACEA et al. and that they have already been applied in first models available on the EU market. As the consultants understand such batteries to currently be most advanced in terms of providing an alternative for Pb-based batteries, more detail is provided concerning such technologies in the following subsection. Other technologies are only mentioned in this report, where this is understood to be relevant for establishing the application range of lead based batteries in vehicles at present. Further information provided by stakeholders concerning other battery technologies can be viewed in the various online contributions made to the stakeholder consultation. Such information is not reproduced here, as these technologies were deemed not to have potential for substituting lead based batteries¹⁶⁸.

6.1.3.1 Lithium-ion Batteries

A123 Systems, Fraunhofer, LG Chem and Samsung SDI have made a joint contribution, explaining that there are three dominant chemistries applicable for automotive Li-Ion batteries. These are lithium-iron-phosphate (LFP) cathode/graphite anode, lithium manganese cobalt oxide (NMC) cathode/ graphite anode, and NMC cathode/lithium titanate (LTO) anode.¹⁶⁹

¹⁶⁷ See http://www.eurobat.org/sites/default/files/rev_of_battery_executive_web_1.pdf

¹⁶⁸ See Exemption 5 consultation page available under

¹⁶⁹ A123 et. Al. (2014), Joint contribution of A123 Systems, Fraunhofer, LG Chem and Samsung SDI (2014), Contribution submitted to ELV Stakeholder Consultation Concerning Ex. 5, submitted

- **“LFP/Graphite cells** have a voltage of 3.3 V, a good energy density and a good durability. The cells have a good high temperature durability: a storage test at 25 °C with SOC (state of charge) = 100 % results after 12 weeks in 100 % capacity retention; at 70 °C this value corresponds to 90%. The cold-cranking and power is good, the cells have a wide usable SOC range. A drawback may be the difficult BMS (battery management system) algorithm due to a very flat voltage profile. The preferred application of the LFP/graphite chemistry would be the 12 V single battery. Standard 20 Ah products are compatible with lead-acid size standards.
- **NMC/Graphite cells** show a higher voltage of 3.7 V and therefore a superior energy density. The power is 6kW/kg (11kW/l). Good high temperature performance is shown in a storage test at 70 °C with SOC = 60 %, where after 12 weeks 95 % of the initial capacity is retained. The advantages of this cell chemistry are the compactness through high power and energy density, low cost per unit of energy due to high cell voltage, and common usage with HEV chemistry. Due to the incompatibility with the 12V system the preferred application is the 48 V dual battery (100-400 Wh, 8-12 kW).
- The cell chemistry with **NMC/LTO** has the lowest voltage of all systems: 2.2 V resulting in an only fair energy density. Due to the stability of the LTO, the durability of the cells and the high/low temperature performance is superior, which makes the system suitable for a simplified cooling system and under-hood applications. The capacity retention in a storage test at 70 °C with SOC = 60 % after 28 weeks was 100 %. The advantages are the excellent durability over a wide temperature range, the high charge power at low temperature, and the safety. High costs due to a low nominal voltage have to be taken into account. The preferred application is the 12 V dual battery system (30-100 Wh, 2-3 kW), and the 48 V dual battery system. Standard 10 Ah products are compatible with lead-acid size standards.
- It is also possible to use mixed cell chemistries in one battery system. So, for example, the charge/discharge curve of the lithium-ion battery can be fine-tuned by combining three graphite-LPF (4.5 Ah) cells and one graphite-NMC cell with a larger capacity cell (6Ah).¹⁷⁰

12V systems of current interest include a lithium-ion battery for the replacement of a lead-acid battery (a 12V single battery system), and an additional lithium-ion battery for better recuperation of energy (a 12V dual battery system). A 12V single battery system is currently considered primarily for luxury cars, owing to a relatively high cost per kWh. On the other hand, a 12V dual battery system keeps a conventional lead-acid battery and employs a small lithium-ion battery as a supplementary energy

17.12.2014, available under
http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_5/20141217_A123_et.al.2015_ELV_exemption_5_review_-_Li-ion_stakeholders.pdf

¹⁷⁰ Cited in A123 et. al. (2014) as G. Kamitani, Lithium-ion battery for dual battery system in a car utilizing conventional technology, AABC Asia 2014

storage system. In this 12V dual system, the lead-acid and lithium-ion technology complement each other, and the combination is expected to be an economically viable 12V storage system. 48V systems have also drawn much attention in recent years. Several OEMs plan to put vehicles with a 48V system on the market by 2016.¹⁷¹

Depending on automakers' needs for pack location and systems design, their interest in cell chemistry varies from conventional carbonaceous anodes, to LTO anodes, to LFP cathodes. For 12 V battery systems, both a battery with LFP cathode and carbonaceous anode materials (LFP cells) and a battery based on an LTO anode (LTO cells) meet a voltage range of the conventional 12 V power networks. LFP and LTO cells require 4 to 6 cells connected in series for voltage compatibility. LFP cells have an advantage of higher energy density, but LTO cells have a wider range of operational temperatures, and better durability. LFP cells have been used in some vehicles as a 12V single system replacing lead acid batteries, and LTO cells have been utilized as a supplementary battery on the market. For 48V systems, all three chemistries could be applied.¹⁷²

For use in SLI, start-stop and micro hybrid applications, ACEA et al. claim that Li-Ion batteries still require improvements in cold cranking ability and economic packaging (including cost level) in order to be considered as a viable mass-market alternative to lead-based batteries. The further advancement and development of Li-Ion batteries could allow an opportunity for their use in limited SLI applications, albeit primarily as a performance option when weight saving is a sufficient driving factor that increased cost and their lower performance in cold conditions can be accepted. ACEA further explains that the operation of Li-Ion batteries is restricted to a specific temperature and voltage range. If operated at temperatures or cell voltages outside of the operational window the battery no longer provides services, with potential risk to its surroundings.¹⁷³

A123 agrees that cold cranking amperage (CCA) is the most important performance metric for a starter battery, and explains that the perceived deficiency of Li-Ion cold crank performance is likely the most discussed topic with regard to usage in 12V lead-acid starter battery applications. However, it is further explained that Li-Ion battery performance at cold temperatures has improved dramatically. EN-50342, VDA-LV124¹⁷⁴ and SAE-J537 are all commonly recognized automotive specifications which outline cold crank requirements for 12V starter batteries. These specifications do not define specific CCA for a particular battery capacity, rather only test setup and

¹⁷¹ Op. cit. A123 et al. (2014)

¹⁷² Cited in A123 et. al. (2014) as W. Jeong, Lithium-Ion Battery Technology for Low-Voltage Hybrids: Present and Future, AABC Asia 2014

¹⁷³ Op. cit. ACEA et al. (2014)

¹⁷⁴ EN-50342: British Standard European Norm 50342-1, 2006

VDA-LV124: MBN LV124-1 & -2, Electric and Electronic Components in Motor Vehicles up to 3,5t – General Requirements, Test Conditions and Tests

parameters such as temperature, duration, and minimum voltage drop allowed during the cranking pulse. The target CCA is left to the manufacturer to define. Without specific CCA targets with which to compare the performance of Li-Ion to lead-acid it is reasonably assumed that the industry's expectation for cold crank performance is reflected in the CCA rating indicated on battery labels for production advanced lead-acid (AGM) batteries. A123 et al. compare data on performance of various Pb-based and Li-Ion batteries and conclude that modern Li-Ion batteries have reached parity in cold crank performance against lead-acid batteries used in the same application at -18°C, which is the temperature at which automotive 12V starter batteries are often specified and labelled. Today's Li-Ion batteries are said to also meet those industry standards in which cold cranking requirements are specified at -25°C (LV124). A123 et al. explain that many OEMs have their own specifications for cold crank requirements at temperatures as low as -30°C, for which modern Li-Ion batteries have not reached parity with lead-acid, though it is estimated that such performance shall be achieved throughout the next 3–5 years.¹⁷⁵

EUROBAT et al.¹⁷⁶ estimate that significant resources will continue to be spent on improving the performance, cost, systems integration, production processes, safety and recyclability of high-voltage Li-Ion battery systems for hybrid and electric applications. Large performance and cost improvements are expected through developments in cell materials and components (i.e. anode, cathode, separator and electrolyte). Lower cost cell design is expected by 2025, along with improvements in materials properties and the gradual scaling up in production of large cell formats. These improvements will increase the competitiveness of Li-Ion batteries in other applications. It is expected that by 2025, Li-Ion batteries will be implemented in some 48V dual-battery systems together with a 12V lead-based battery in order to further increase fuel-efficiency in advanced micro-hybrid and mild-hybrid vehicles.

A123 et al.^{177, 178} provide information regarding various vehicles in which Li-Ion battery systems are already applied in vehicles. A few vehicle models are mentioned in which single Li-Ion batteries are applied in vehicles available on the EU market, in some cases to support micro-hybridization and in others with light-weighting being the main driver. Furthermore, examples are provided of vehicles with dual batteries, which are available on the global market, some using Li-Ion technology. For details, see referenced documents as well as Appendix A.5.0.

¹⁷⁵ Op. cit. A123 et al. (2014)

¹⁷⁶ Op. cit. EUROBAT et al. (2014)

¹⁷⁷ Op. cit. A123 et al. (2014)

¹⁷⁸ A123 et al. (2015a) Joint contribution of A123 Systems, Fraunhofer, LG Chem and Samsung SDI, Answers to Questionnaire Clarification: Exemption No. 5, submitted per email 6.3.2015

6.1.3.1.1 Super-capacitors coupled with Li-Ion Batteries;

Olife has developed a new car battery claimed to provide the first full substitute for lead acid batteries. The technology combines LFP chemistry with super-capacitors, which is said to guarantee high cranking power at temperatures as low as -50 °C. The Li-Ion batteries continuously refill the super-capacitors, thus serving as a source of Reserve Capacity. The battery has a low value of self-discharge and it will stay ready to start even after two years out of operation. Unlike batteries, super-capacitors store and release electrical energy as electric charge and not in the form of bound chemical energy. This means that the release of electric current does not require a chemical reaction. The super-capacitors thus provide the necessary cranking current, while at any normal vehicle driving temperature (from -30 °C to +50 °C), the Li-Ion batteries will continuously refill the super-capacitors. They also serve as a reliable source of necessary reserve capacity. The super-capacitors further level out all current peaks during normal operation of the car battery, giving the Li-Ion cells ideal protection and maximising battery life. The Olife battery is said to be 7–10 kg lighter than a lead acid battery (depending on the LAB and vehicle type), which is reported to enable significant carbon savings. The production technology procedure development has recently been finalised and Olife is currently undergoing verification of the production technology by producing a limited number of batteries. The aim is to launch full commercial production at the end of 2015. Planned production capacity is hundreds of thousands of pieces per year.¹⁷⁹

6.1.3.2 Nickel-metal Hydride Batteries

An overview of the use of NiMH batteries in automotive applications is provided by EUROBAT et al. (2014):

“NiMH batteries have been the technology of choice in the HEV market over the last decade, due to their design flexibility, good energy density, high power performance and better environmental compatibility. This was the technology selected by Toyota when the Prius HEV was introduced in 1997. NiMH batteries are still significantly more expensive than lead-based batteries, and have not been considered for use in SLI functions because of their inferior cold-cranking performance and other limitations.

NiMH batteries are primarily used in mild-hybrid and full-hybrid vehicles, where they have been the technology of choice over Li-Ion batteries because of their durability and lower cost...For plug-in HEVs and EVs, NiMH batteries have been an important technology while Li-Ion batteries develop to reach a sufficient maturity. However, their heavier weight, lower energy density and lower deep-cycling capability mean that they will not be able to compete with Li-Ion batteries for the next generation of plug-in HEVs and full EVs. This is apparent in Toyota’s decision to use lithium-ion batteries for their plug-in

¹⁷⁹ Olife (2014a), Response to the consultation on the “8th Adaptation to scientific and technical progress of exemptions 2(c), 3 and 5 of Annex II to Directive 2000/53/EC (ELV)”, http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_5/Ex_5_Contribution_17122014_OLIFE_response_to_ELIV_consultation_161214-Public.pdf

hybrid Prius model...their potential for further market penetration is limited by the increased performance and reduced cost of Li-Ion batteries. Because they have already reached a high degree of technological maturity, limited improvements are expected between now and 2025.

At end of life, and in compliance with the Batteries and ELV Directives, all NiMH batteries from automotive applications are collected and recycled. The metals are used predominantly in the steel industry.” ¹⁸⁰

¹⁸⁰ Op. cit. EUROBAT et al. (2014)

Table 6-1: Summary of Alternative Battery Chemistries

	Li-Ion			Supercapacitors coupled with Li-Ion batteries	NiMH
	LFP cathode / graphite anode	NMC cathode / graphite anode	NMC cathode / LTO anode		
Cell voltage	3.3 V	3.7 V	2.2 V		
Preferred application	12 V system (4 cells in series)	48 V system. Full-hybrid electric vehicles.	12 V system (6 cells in series), and also the 48 V system. Simplified cooling systems and under hood applications.	Claimed to be first full substitute for lead acid batteries.	Full hybrid electric vehicles (used in Toyota Prius since 1997).
Energy density	Good	Superior (6 W/kg)	Fair (low voltage)		
Storage				Low self-discharge (ready to start after 2 years out of operation).	
Advantages	High energy density / power. Good cold cranking. Wide usable SOC range.	Superior power / energy density, and in turn low cost per unit energy and also compactness. Good high temperature performance.	Wide range of operational temperatures. High charge power at low temperatures. Superior cell durability. Safety.	High cranking power at temperatures as low as -50 °C. Current peaks levelled out (battery protection). Weight advantage over lead acid battery.	Good design flexibility. Reasonable energy density / high power performance. Good environmental compatibility. Good durability. Low cost.
Disadvantages	Difficult battery management system algorithm due to a flat voltage profile. Less wide range of operational temperatures / worse durability [than NMC / LTO].	Incompatibility with 12 V system.	High costs due to low nominal voltage.		Heavier weight / lower energy density (than Li-Ion). Still significantly more expensive than lead-based batteries. Inferior cold-cranking performance (not used in SLI functions). Reduced deep-cycling capability.
Common disadvantages / notes	Increased cost and lower performance in cold conditions compared to lead acid batteries. Historic cold cranking amperage performance (for starting), but this has improved dramatically and parity with lead-acid is expected even at temperatures as low as -30 °C in 3-5 years.				

6.1.4 Possible Alternatives that May Reduce the Use of Lead in Batteries

A123 further explain that there are paths to the reduction of lead usage in batteries, which are also economical. As explained above, dual battery architectures utilize a low-cost lead-acid battery for cold cranking and a small Li-Ion battery to supplement the system performance, particularly during energy recuperation. The incremental cost of this secondary Li-Ion battery is proportional to its size and when considering total system cost it is possible to engineer a dual battery system, which is somewhat less costly than a single Li-Ion starter battery. The economics of the dual battery approach make it commercially viable to at least limit the capacity of lead-acid batteries in future vehicles.¹⁸¹

6.1.5 Stakeholder Justification for Exemption Renewal

EUROBAT et al.¹⁸² explain that currently several battery technologies are installed in European vehicles, from automotive batteries for internal combustion engine cranking (SLI) and start-stop functionalities to industrial traction batteries for hybrid, plug-in hybrid and electric vehicles. Where a single battery system cannot cope with all requirements at the same time, different combinations of several battery types are installed to allow operation at different voltage levels. For example, all hybrid, plug-in hybrid and electric vehicles are currently equipped with both an industrial traction battery and an auxiliary lead-based automotive battery which is used to support the on-board electronics and safety features.

ACEA et. al.¹⁸³ argue that the substitution of lead-based batteries in automotive vehicles is still not possible, estimating that they are vital to ensure mobility on European roads for [at least] the next 10-15 years. In particular, the cold cranking properties of Pb-based batteries are said to make these battery types essential. At low temperatures, no other commercially available battery system, ready for volume production, is able to meet the required performance or demand (starting ability at temperatures around -30°C required).

EUROBAT et al.¹⁸⁴ estimate that 12V lead-based batteries will continue to be the essential mass-market system in Class 1 vehicles for the foreseeable future, while also continuing to be used as auxiliary batteries in Class 2 and 3 vehicles. By 2025, they are expected to provide extra services in micro-hybrid vehicles to increase the internal combustion engine's fuel efficiency (i.e. stop-in-motion, voltage stabilisation). Therefore, their cycle life, power density and charge acceptance will be further improved. Lead-carbon batteries are expected to be commercialised in the near future, and will provide high performance in terms of charge acceptance and through

¹⁸¹ Op. cit. A123 et. Al. (2014)

¹⁸² Op. cit. EUROBAT et al. (2014)

¹⁸³ Op. cit. ACEA et al. (2014)

¹⁸⁴ Op. cit. EUROBAT et al. (2014)

their ability to operate at partial states of charge in start-stop and micro-hybrid vehicles. Dual batteries using lead-based batteries and other technologies at different voltages will also see accelerated commercialisation in the next decade.

6.1.6 Stakeholder Justification for Lead-acid Battery Phase-Out and Revoking of Exemption 5

The automotive industry considers lead-based battery systems to be essential in automotive applications for the foreseeable future. ACEA et al. claim that despite ongoing industry R&D efforts on enhanced energy storage systems no feasible mass market alternatives to lead-based batteries are currently available.¹⁸⁵

However, other stakeholders have submitted information regarding the applicability of Li-Ion alternatives for various automotive applications, claiming that state of development would allow at least a partial phase-out of lead acid batteries in automotive applications.

A123 et al.¹⁸⁶ have provided information to demonstrate the latest developments in Li-Ion battery technology (see also Section 6.1.3.1 above). They claim that Li-Ion solutions in plug-in hybrid electric vehicles and full electric vehicles could already be used to replace LAB based solutions in vehicles for which cold cranking performance is not a relevant requirement. They elaborate on this statement in order to clarify the relevance for various types of vehicles:

- *“In the case of an **electric vehicle (EV)**, sometimes called a battery electric vehicle (BEV), there is no internal combustion engine installed and no such vehicle has an engine cranking requirement. In an EV, a 12V lead-acid battery is typically still installed to support vehicle electronics which are common with other vehicle types and still operate at 12V. We are aware of no valid argument why the use of lead in this application is not immediately avoidable.*
- *Another relevant class of vehicle is a **plug-in hybrid electric vehicle (PHEV)** which is generally designed to drive on electric power until the battery energy is consumed and then operation switches over to power from a combustion engine. As with a fully electric vehicle (EV), there is generally a 12V lead-acid battery on-board. When operating conditions require starting of the combustion engine in a PHEV, it is technically possible to crank the engine using power from *either the high-voltage lithium-ion battery or the 12V lead-acid battery*. While the members of this response group are not experts on the architecture of every PHEV in the market, we are aware that some use the lithium-ion battery to crank the engine, thereby relieving the lead-acid battery of that responsibility. In the cases where the lead-acid battery is not involved*

¹⁸⁵ ACEA et al.(2015a), Industry contribution of ACEA, CLEPA JAMA, KAMA, ILA and EUROBAT, Answers to Clarification Questions, submitted 27.3.2015 per email

¹⁸⁶ A123 et al. (2015b), Joint contribution of A123 Systems, Fraunhofer, LG Chem and Samsung SDI, Answers to Clarification Questions Following the Stakeholder Meeting of 10.4, submitted per email

in engine cranking, we are not aware of any technical reason that a lithium-ion alternative could not be introduced immediately.

- *Finally, we should mention the **conventional hybrid electric vehicles (HEV)** as well. This class of vehicle is quite similar to a PHEV in terms of electrical architecture but the high voltage lithium-ion battery typically has a smaller capacity. Generally speaking, HEVs are designed to drive on electric power from the high voltage battery for very short distances and only at low speeds. Therefore, the vehicle relies on operation of the combustion engine more often. Despite this difference from a PHEV, conventional hybrids also have a mix of engine cranking strategies wherein some crank with the lithium-ion battery and others crank with the 12V lead-acid battery.”*

Furthermore, as already explained in Section 6.1.3.1.1, Olife has developed a new car battery claimed to provide the first full substitute for lead acid batteries. The technology, combining Li-Ion energy storage with super capacitors, is in production verification stages, with a full commercial launch planned for the end of 2015.¹⁸⁷

6.1.7 Economic Aspects

Though economic arguments do not suffice to justify an exemption under the terms of the ELV Directive, it is noted that various cost aspects have been mentioned by stakeholders.

EUROBAT et al. provide information regarding the prices of various battery chemistries in the context of different vehicle classes. The data is compiled in Table 6-2 below.

Table 6-2: Cost Data Compilation for Various Battery Chemistries in Different Class Vehicles

Battery Chemistry / Vehicle Class	Lead Based	NiMH	Li-Ion
Class 1 Conventional *inc. Start-stop and micro-hybrid vehicles	50-150 €/kWh 6-18 €/kW	700-1400 €/kWh 90-180 €/kW	600-1200 €/kWh 118-236 €/kW
Class 2 Hybrid	100-200 €/kWh 10-20 €/kW	800-1400 €/kWh 27-47 €/kW	800-1200 €/kWh 30-75 €/kW
Class 3 EV	100-250 €/kWh 10-25 €/kW	400-500 €/kWh 910-1140 €/kW	300-450 €/kWh 100-200 €/kW
Class 3 PHEV	(not given)	(not given)	800-1200 €/kWh 30-75 €/kW

EUROBAT et al. (2014), pages 26, 35 and 43

¹⁸⁷ Op. cit. Olife (2014a)

ACEA et al.¹⁸⁸ explain that there is no experience of the use of other batteries as SLI batteries, and thus it is not possible to assess the cost per vehicle. However, they do provide information to allow a partial comparison: Pb-based batteries remain by far the most cost-effective and durable battery technology for SLI applications in conventional powertrains (in the region of 50-150 €/kWh). On top of their lower cell-level cost, they do not require heat shielding, active cooling, or a battery management system.

This is an important consideration for consumers and the automotive industry, due to the higher financial burdens that a more expensive alternative battery system would place on them. On a cell level, the upfront costs of Li-Ion batteries remain significantly higher than those of equivalent lead-based batteries. System level cost is further increased by the required battery management system, shielding and housing (with total upfront system cost ranging from 600-1200 €/kWh). ACEA et al. state that although some of these high upfront costs could eventually be distributed over the Total Cost of Ownership (TCO), they remain another barrier against Li-Ion batteries being considered as a viable alternative to Pb-based batteries for use in mass-market conventional vehicles with a single 12V battery with SLI function.

In this regard, Olife¹⁸⁹ state that cost *“is mainly a commercial issue but should be calculated over the lifetime of the vehicle. For the ELV directive, the cost of batteries over the lifetime of the vehicle is the true representative cost. In this case a high initial cost would not be a limitation if the battery life is long enough.”* The anticipated selling price for the Olife battery is likely to be about double the retail price of an equivalent AGM LAB. The anticipated life of the Olife battery—particularly in micro-hybrid applications—is estimated to be four times that of lead acid.

In a later document Olife¹⁹⁰ further explains that: *“The whole life cost of the Olife technology is superior to lead acid for the consumer in terms of lower emissions from reduced weight and the use of modern stop-start technology; the longer service life, approximately eight times that of lead acid and the lack of toxicity in the products of manufacture. However, the aftermarket is price driven and there might be reluctant to accept the product with higher absolute price. This is despite the fact that the life service cost is significantly below currently used the lead acid products”*

A123 et al. agree that compared to lead-acid batteries Li-Ion technology is more expensive on a kWh basis. Currently, a Li-Ion starter battery with 1 kWh of energy capacity costs less than 500 € for [manufacture of]¹⁹¹ more than 10,000 pieces per year. However, this cost is set to fall dramatically in the near future due to improvements in technology and higher production volumes. As cold cranking power continues to improve, various vehicle manufacturers are already developing

¹⁸⁸ Op. cit. ACEA et al. (2014)

¹⁸⁹ Op. cit. Olife (2014a)

¹⁹⁰ Olife Energy (2015), Answers to Oeko-Institut Clarification Questions, sent per email on 27.3.2015

¹⁹¹ Consultant's addition.

production vehicle programs and meeting their cold cranking requirements with less than 1 kWh of Li-Ion capacity. A123 et al. state that several Li-Ion vendors are offering fully compliant starter batteries below 300 € for annual volumes of less than 500,000 units starting in 2017. Furthermore, the industry has additional potential to improve, particularly as volumes increase.

For a complete analysis, it has to be considered that a Li-Ion battery with 60 Ah capacity can replace a 95 Ah lead-acid battery in a micro hybrid application. While the lead-acid battery may cost approximately 80 €, it weighs nearly 15 kg more. While different vehicle manufacturers value mass reduction at various levels, a typical OEM would pay as much as 100 € to achieve such mass savings [per vehicle]¹⁹².

Furthermore, a Li-Ion battery will last at least twice as long as a lead-acid battery in the same application, so one must count twice the lead-acid cost when comparing the cost of competing Li-Ion technology. However, even this assessment is too generous to lead-acid because the consumer pays much more for the replacement lead-acid battery than the vehicle manufacturer paid for the one initially installed in the vehicle.¹⁹³

A123 et al. state that although Li-Ion starter batteries have already been introduced into the market for luxury and sports cars, improvements have to be made with respect to the costs to allow a break-through in the mass market.¹⁹⁴

A123 et al. explain that Li-Ion batteries have a further advantage. As noted above, Li-Ion technology offers charge acceptance that far exceeds that of the best lead-acid technologies. When a vehicle manufacturer installs a Li-Ion starter battery, relatively little system engineering is required in order to use the battery's superior charge acceptance to reduce emissions through a stronger recuperation strategy.

To illustrate the value of this benefit, assume that the vehicle manufacturer is slightly above the 2015 requirement of 130g CO₂/km and that the more aggressive recuperation strategy enabled by the Li-Ion battery yields a modest improvement of 3% or 4g CO₂/km. In 2015, a manufacturer who is 4g over the limit must pay a fine of 140 EUR per vehicle. Of course, vehicle manufacturers already have strategies to meet the 2015 emissions requirements but these requirements are becoming steadily more stringent and the penalties for non-compliance will grow dramatically in the next several years. When evaluating only life and mass advantages, Li-Ion technology will become cost competitive over the next few years and the incremental ability to enable emissions reductions provides a compelling business case independent of the ELV exemption under consideration here.¹⁹⁵

¹⁹² Consultant's addition.

¹⁹³ Op. cit. A123 et. al. (2014)

¹⁹⁴ Op. cit. A123 et. al. (2014)

¹⁹⁵ Op. cit. A123 et. al. (2014)

6.1.8 Environmental Arguments

Although the intention of the ELV Directive is to “*minimise the impact of end-of life vehicles on the environment*” (recital (1)), it does not directly require the comparison of applications using ELV substances and their possible alternatives in terms of possible environmental impacts in the context of exemption justification.

Nonetheless, ACEA et al. have drawn attention to various aspects relevant to automotive batteries in terms of environmental impacts, shortly summarised below.

Information was provided regarding the recyclability of lead acid batteries (see Section 6.1.2.3) to show the advantages of lead acid batteries at the End-of-Life phase over possible alternatives. As for the recyclability of Li-Ion batteries, though ACEA et al.¹⁹⁶ state that the “recycling of lithium batteries is in its infancy”, A123 et al.¹⁹⁷ provide some information regarding the recycling processes of Li-Ion:

“Such recycling processes are already available from companies such as Umicore and Toxco, although not yet in mass volume since the production volumes do not yet warrant such a scale. Lithium and other components are relatively benign with regard to toxicity to humans when compared to lead. All batteries will be dismembered and recycled at end of life for economic and social reasons. But in the case of lithium-ion batteries, there is far less concern with regard to toxic waste and thus recyclability is generally not considered a market barrier for this technology.

Lithium-ion battery recycling is being scaled as needed to match increasing market demands of lithium-ion batteries because the process is relatively simple and efficient. The basic procedure involves feeding the materials into a high temperature smelter where some of the metals (i.e. cobalt, nickel, copper, and iron) are gathered as an alloy for further refining into reusable battery materials. The other elements (i.e. aluminium, lithium, calcium) end up in an oxidized slag form which can be reused in other industries and applications. Most of the energy needed for the recycling process comes directly from the battery materials themselves (i.e. graphite, plastics, electrolyte, aluminium.) Only the materials containing fluorine (less than 3%) need to be landfilled responsibly.”

Concerning manufacture with attention to recyclability, Olife has said about its batteries:

“Olife considers recycling part of our responsibility as well as compliance with the legislation. A proposed model is emerging from consideration of the existing technologies... Olife can make its batteries more recyclable by implementing changes to its products. Prior to full production, Olife plans to discuss the battery design with a recycling facility... and other facilities along with researchers in this field in order to obtain technology and product design recommendations and collaborate to adjust the batteries accordingly in order

¹⁹⁶ Op. cit ACEA et al. (2014)

¹⁹⁷ Op. cit. A123 et al. (2014)

to make the whole process as economically-efficient as possible... At the moment there is not a Li-Ion- battery recycling infrastructure in Europe in terms of collection, logistics and recycling. What exists is based on the voluntary efforts of individual companies who intend to bring this new product to the market. Lithium as an energy source for electric vehicles is a new technology that is growing but the recycling infrastructure is yet to be built. Today, there are a number of projects that aim to overcome the challenges in lithium recycling.

*One initiative, which is particularly interesting, is the Lithorec II project: On the Way to an “Intelligent” Recycling of Traction Batteries. The objective of the LithoRec project is to find answers to these questions and to show a way of “intelligent” recycling with a very high recovery rate and very high energy efficiency. Therefore, almost the entire life cycle of lithium ion batteries—from the demounting of the batteries from the (electric) vehicle to the preparation of new battery cells out of recycled materials—is being researched within the LithoRec project. The project is funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and coordinated by the Automotive Research Centre Niedersachsen (NFF) and 12 partners take part in this project”.*¹⁹⁸

EUROBAT et al.¹⁹⁹ explain that:

“When recycling lithium-ion batteries, a high recovery rate of materials is challenging in comparison with lead-based and nickel-based batteries. This is primarily due to the wide varieties of chemical components and system complexity. Several industrial recycling processes have begun to be established, and research projects are ongoing to recover a wider range of components, with nickel, cobalt and copper the most interesting constituents”.

It is further understood that the identification of Li-Ion batteries in the sorting stage needs to be further developed to ensure that batteries are directed to the correct treatment facilities. In this regard, Olife²⁰⁰ mention the following possible changes that could be made in coordination with recyclers in the design of their product to facilitate recyclability in the future:

“Inclusion of labels or other distinguishing features — Various labelling technologies could help to categorize the battery chemistry at the collection or initial sorting stage such as:

- *Bar code*
- *RFID chips*

¹⁹⁸ Op. cit. Olife (2015)

¹⁹⁹ Op. cit. EUROBAT et al. (2014)

²⁰⁰ Op. cit. Olife (2015)

➤ *Paint colour or type (e.g., visible under black light)”*

A life cycle analysis was also provided by ACEA et al., comparing various aspects of lead-acid chemistry alternatives (e.g. flooded lead-based batteries, enhanced flooded lead-based batteries (EFB) and absorbent glass matt (AGM) lead-based batteries)²⁰¹. However, the LCA study does not cover battery types, which have been mentioned as potential candidates to replace lead batteries. Against this background, details of the LCA based comparison provided by ACEA et al. are not further specified here. For further details, see the LCA Executive Summary²⁰².

6.1.9 Road Map for Substitution

ACEA et al.²⁰³ explain that a wide variety of different national, European and worldwide R&D projects are conducted with the aim of developing energy storage systems with higher energy density and lower weight, suitable even for harsh climatic conditions. Nonetheless, ACEA concludes that these systems are not yet available for the automotive industry and that the results of these research projects need to be further developed and tested in pilot applications in order to verify if these systems are able to meet the criteria for volume serial production.

To accommodate a completely different battery technology into new vehicle models, European OEMs estimate that the required installation and ramp up of the technology would, as a worst case, require an implementation time of over 10 years. Under this worst-case timescale, if a technology were already available as a technical substitute for 12V batteries used in conventional vehicles, it would not be until at least 10 years later that it could be implemented into new vehicles being released onto the European market.

ACEA et al. differentiate in this regard between the component level of development of an alternative and the later development of applications at the vehicle level. Before focussing at vehicle level, component development needs to be considered. After research at component level is completed, and elementary component tests have characterised their properties, the next step towards vehicle specific integration can be assessed and developed. It has to be clear that efficient use of new mobile energy storage devices needs specific electronic control units embedded in the software and energy management of a vehicle's board-net design. Pilot applications will deliver the necessary knowhow needed to start development for volume production including safety and reliability aspects. ACEA et al. provide a non-exhaustive overview of different development tasks at component and vehicle level, as presented in

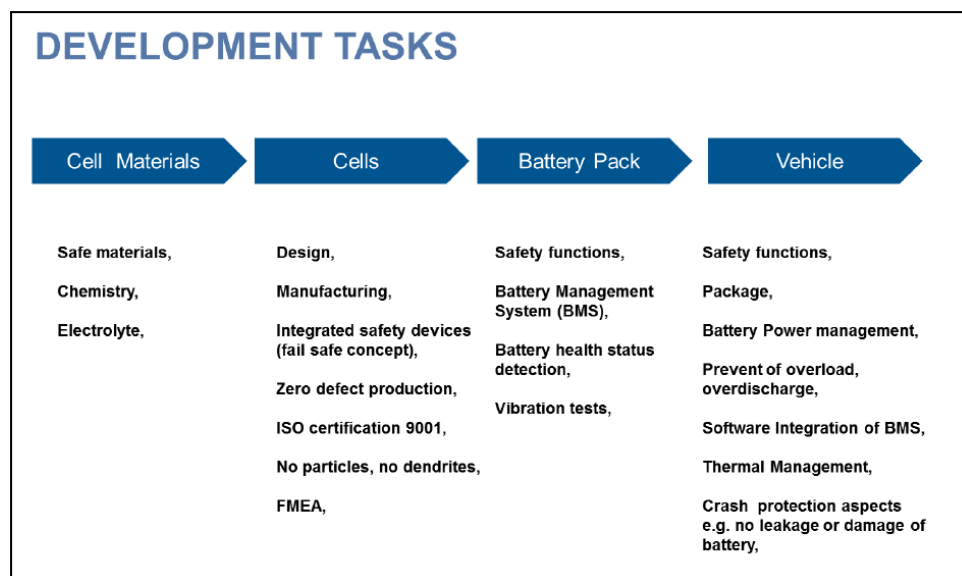
²⁰¹ Usbeck, V. C., Kacker, A. and Gediga, J., PE International (2014), Life Cycle Assessment of Lead-based Batteries for Vehicles, prepared for EUROBAT, ACEA, KAMA, JAMA & ILA, Executive summary available under: http://www.acea.be/uploads/publications/LCA_of_Pb-based_batteries_for_vehicles_-_Executive_summary_10_04_2014.pdf

²⁰² See link in footnote 201

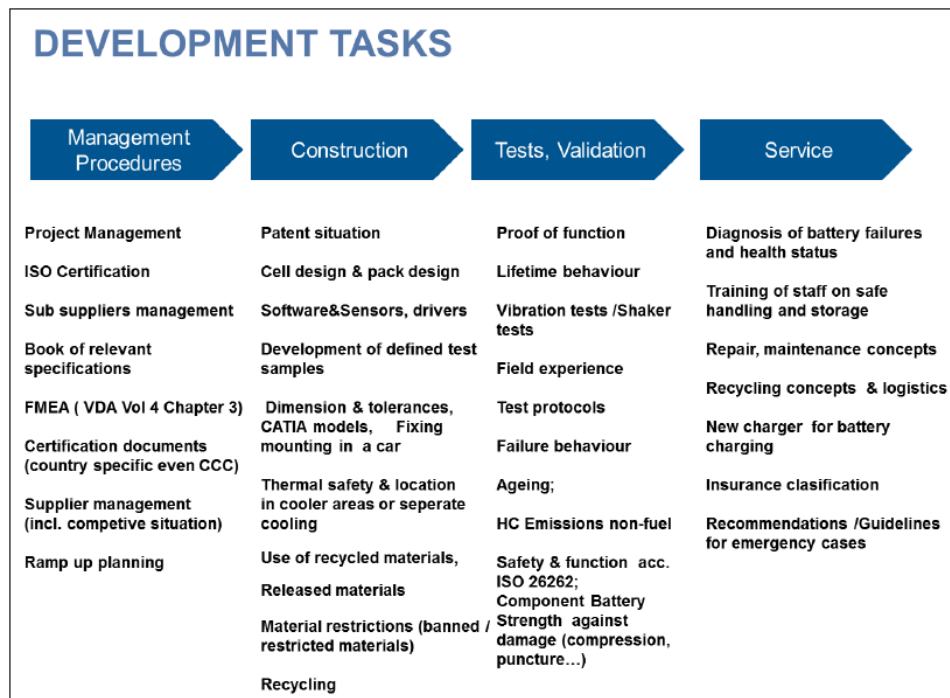
²⁰³ Op. cit. ACEA et al. (2014)

Figure 6-2 below, further elaborating on some of the aspects in their submission (see Appendix A.6.0)²⁰⁴.

Figure 6-2: A Non-exhaustive Overview of Different Development Tasks at Component and Vehicle Level



²⁰⁴ ACEA et al., (2015b), Industry contribution of ACEA, CLEPA, JAMA, KAMA, ILA and EUROBAT. to additional questions for clarification after stakeholder meeting on 10 April 2015, amended version submitted 13.5.2015 per email



Source: Op. cit. ACEA et al. 2015b

Technology development and integration for automotive products typically occurs in three phases:

- 1) Advanced engineering;
- 2) Product development; and
- 3) Platform development;

A simplified project plan for the research, development and required test-phases for a new battery system is presented in Figure 6 in Appendix A.6.0.²⁰⁵

Nonetheless, ACEA et al. explain that:

“As OEMs and the supply base is already active in research and to some extent advanced engineering for the 12V SLI battery application there are some applications for which Li-Ion could enter the advanced engineering stage earlier. These applications would, as absolute minimum requirements, have to:²⁰⁶

- *Accept some degradation on winter performance (both cranking and recharging: e.g. luxury cars that are unlikely parked outdoor under harsh winter conditions and have a fuel fired heater that can warm up the battery);*
- *Provide a package location that avoids temperatures above 60 °C;*

²⁰⁵ Op. cit. ACEA et al. (2015b)

²⁰⁶ Op. cit. ACEA et al. (2015b)

- Provide a package location outside crash zones; and
- Not require any significant platform/architecture modifications.”

6.1.10 Conflicting Views Regarding the Performance of Li-Ion Batteries and their Suitability as a Substitute for Lead-acid Batteries

The automotive industry considers lead-based battery systems to be necessary in volume serial production for the foreseeable future, explaining that no feasible mass market alternatives to lead-based batteries are currently available²⁰⁷. Although the alternative technologies described by Olife and A123 et al. are recognised as having a number of positive attributes they are, however, still considered to be immature.

OEMs cannot be confident that the technologies will deliver the required functionalities and considerable time is required to determine whether these alternative technologies are suitable for the applications discussed. ACEA et al. further explain that for a battery technology to be technically feasible it has to meet technical and safety requirements at a component level in full, then meet the specifications for a prototype vehicle at the next level, before finally meeting all of the requirements for an on-road vehicle capable of volume production and proven reliable service.²⁰⁸

ACEA et al. point out the following limitations and requirements to support this view. Each point is followed by relevant information provided by other stakeholders to clarify within context where conflicting views are apparent.

- **Market availability and road experience:** ACEA et al. state that they:

“disagree with the statement [that] ‘a number of Li-Ion alternatives are already available on the market at the component level for use as a single battery’. It should be stressed that vehicles using single 12 V Li-Ion batteries equate to 0.001% of the current fleet of vehicles. Lead-based batteries are used in the remaining 99.999% of vehicles. It would be more accurate to say that a very small number of Li-ion batteries are being offered for SLI applications for special applications... this is a very small and expensive market segment and the vehicles in question are high performance sports cars.

Based on the limited experiences available today, these applications need to be assessed as not suitable for any volume production... More development efforts are essential as well as sufficient field experience at least over one model cycle, before any decision on volume production is possible...A123 quote a figure of 4 years field experience but this refers to a supercar with less than 400 cars built which is significantly different to a typical on-road vehicle. The other vehicles using these single Li-Ion batteries have two years or less field

²⁰⁷ Op. cit. ACEA et al. (2015a)

²⁰⁸ Op. cit. ACEA et al. (2015b)

experience, which is not sufficient to assess the applicability of the technology.”²⁰⁹

Regarding road experience with Li-Ion applications, A123 et al.²¹⁰ specify that:

“The first series production of a lithium-ion starter battery occurred in Europe in 2011. That program started the development and validation testing phases in 2009. Additional applications from additional vehicle manufacturers entered the European market in 2013”.

For the Olife technology:

“Prototype production processes are established and prototypes have been successfully on trial this year in start-stop vehicles... Full-scale production is targeted for the end of Q2 2015. Equipment procurement for production and process scaling is underway, in collaboration with an industry partner in the Czech Republic.”²¹¹

In a later document, Olife further elaborates:

“The initial sales and market penetration is expected to provide a first year production of 10,000 batteries by the end of 2016. With successful market acceptance and favourable customer response, a growth of approximately 200,000 units per annum for the subsequent five years is forecast. To reach a turnover of one million units, it would require approximately 9 to 12 months to build a factory which could produce at this level.”²¹²

➤ **Drop-in applicability of alternative technologies:** ACEA et al. explain that:

“In a minority of these vehicles, OEMs offer a Li-Ion battery as an option for racing conditions due to the weight savings. In these cases, the vehicle is specially designed to enable replacement of the lead battery with a Li-Ion battery. However, drop-in of 12 V Li-Ion batteries would not be possible in other vehicles without significant and expensive re-design. It should also be mentioned that the Olife package that contains both a Li-Ion battery and a super-capacitor could, in our opinion, not be available as a drop-in alternative... Whilst super-capacitors are not as affected by temperature, independent tests have found that in order to support the required cranking time and energy, the capacitor banks have to be relatively large and very costly and, due to their self-discharge characteristics, require management to isolate them when the vehicle is switched off so as to avoid a flat battery.”²¹³

²⁰⁹ Op. cit. ACEA et al. (2015b)

²¹⁰ Op. cit. A123 et al. (2015b)

²¹¹ Op. cit. Olife (2014a)

²¹² Op. cit. Olife (2015)

²¹³ Op. cit. ACEA et al. (2015b)

A123 et al.²¹⁴ also state that they:

“dispute the conclusion that the currently available solutions cannot be a drop-in replacement. While the present examples in series production in Europe still have a relatively low sales volume, the vehicles using those solutions were not redesigned to accept a lithium-ion starter battery. In these present examples, the vehicle manufacturers also concluded through validation testing that the lithium-ion alternative was already sufficient to meet the vehicle’s cold cranking requirements... No additional equipment is necessary to introduce lithium-ion starter batteries in series production and generally speaking, the size of a lithium-ion alternative is equal to or smaller than the lead-acid solution it replaces.” Information as to vehicles available on the market with a single Li-Ion battery is presented in Appendix A.5.0.

Though the technology is not yet available, Olife say that theirs is a drop-in substitute:

*“Because the Olife technology is designed as a direct replacement for the 12 volt LAB it can be incorporated into the energy management system with no adjustments. Additionally, the engine managements systems contain safeguards, which prevent batteries being over discharged or overcharged... The Olife prototype battery has been tested in commercially available passenger vehicle BMW type 630i with start/stop system. The test was conducted with the aim to simulate all possible vehicle situations (urban, off-urban, long-standing, different operating temperature ranges etc.). The test duration has been 13 months, so far.”*²¹⁵

➤ **Development of Technical Standards:**

From the information provided by ACEA²¹⁶, it can be understood that standards are developed by the various appropriate organisations, also involving representatives from industry; Standards for batteries are regularly updated with full participation of OEMs and the battery industry especially in European standardisation committees (Cenelec). The Automotive Industry Association (Verband der Automobilindustrie - VDA) is also said to have been active in issuing new standards for lead-acid automotive batteries as vehicle requirements have changed, and requirements developed by UNECE also have to be respected.

ACEA et al. state in this regard:

²¹⁴ Op. cit. A123 et al. (2015b)

²¹⁵ Op. cit. Olife (2015)

²¹⁶ Op. cit. ACEA et al. (2015b)

“For Li-Ion batteries, technical standards are not yet developed and for lead-acid SLI batteries, the requirements are defined in EN 50342-1 and for lead-acid batteries for stop and start applications... by EN 50342-6 which is not yet published. The EN 50342 family of specifications does not reflect requirements for Li-Ion batteries... A new EN standard is required to specify requirements for Li-Ion starter batteries. Requirements derived from the vehicle application, such as capacity, high-rate cranking capability, vibration resistance and so on may be similar to EN 50342-1... new tests specific to Li-Ion characteristics may be included. Accelerated life tests specific to Li-Ion batteries require extended field experience on failure modes. Such investigations on the road have scarcely been started... According to the experiences of OEMs...” It has taken 6 years to get ISO 12405 (“Electric road vehicles – Test specification for Li-Ion traction battery systems”) completely published (from May 2008 to May 2014).²¹⁷

➤ **Thermal environment for batteries:** ACEA et al. state:

“The life time of Li-Ion batteries depends to a high degree on efficient thermal management. If the thermal load on these batteries is too high very fast ageing will occur and the battery will fail prematurely. Internally generated heat from the component during charging and discharging over the battery life time is important and also the local ambient temperature levels are important. If temperatures are too high, additional specific cooling systems become necessary and this has to be considered in the component, location, package and vehicle design... It should be noted that the requirement for cold cranking at -30°C is not changed but lead-acid batteries are not damaged at -40°C and will continue to operate. Unless and until Li-Ion batteries can provide robust performance over a full temperature range, they cannot be specified to replace LABs without significant restrictions.”²¹⁸

In this regard A123 et al. explain:

“All starter batteries are known to have shorter operating lives in hot environments and this is true for lithium-ion as well. The maximum operating temperature of a lithium-ion battery varies by supplier but safe operation in ambient temperatures up to 70 °C can be assured. Due to the cost increment of lithium-ion technology in starter battery applications, vehicle manufacturers often set life targets for the lithium-ion alternatives, which exceed the life requirements defined for lead-acid. To achieve superior life, lithium-ion starter batteries are typically installed where they are not directly exposed to engine temperatures. In most series production applications to date, prior

²¹⁷ Op. cit. ACEA et al. (2015b)

²¹⁸ Op. cit. ACEA et al. (2015b)

versions of the vehicle had already located the lead-acid battery away from the engine so the lithium-ion alternative was installed in the same location. In cases where the current battery location is adjacent to the engine, vehicle manufacturers can install a heat shield made of sheet metal to extend life of the lithium-ion battery and/or install the battery further from the heat source.”²¹⁹

According to Olife, Lithium batteries are able to operate over a wide temperature range of at least -20 °C to +70 °C:

*“Recent developments by various manufacturers are extending the operating range; values of -50 °C to +80 °C are now being quoted. Olife has conducted successful field trials in hot climates with under hood temperatures exceeding +60 °C. Independent testing by TUV will be carried out to determine the maximum safe operating range.”*²²⁰.

➤ **Battery crash and safety aspects:** ACEA et al. state:

*“The battery needs to be resistant to mechanical damage in the form of compression, shock and puncture. To comply with product responsibility with regard to crash behaviour, methods to avoid fire and explosions have to be considered... for Li-Ion batteries. For batteries defined as rechargeable energy storage systems (REESS), there should be no leakage to the battery during the crash test and no thermal runaway. The car industry would therefore have to locate Li-Ion starter batteries in a non-crash-sensitive area... This is a packaging issue and generally a full redesign of the vehicle platform is required... Reinforcing the car body area to establish a crash safe cage for a component needs to be implemented in the total crash behaviour design of a vehicle. This is a key concern of all OEMs, and no vehicle can be offered for sale until crash safety has been correctly established... There are two very important restrictions. The first, in case of a crash, is that the battery should not catch fire and the second is that during normal operation the battery should not be destroyed or ruptured by heating. In the vast majority of European cars starter batteries are installed in hot installation spaces; i.e. in the engine compartment or in the vicinity of the exhaust pipes... the operating temperatures at up to peaks of 100 °C are limitations for a safe installation of any available batteries working with an organic electrolyte (e.g. Li-Ion batteries or high capacity electrolytic capacitors).”*²²¹

A123 et al. agree that:

²¹⁹ Op. cit. A123 et al. (2015b)

²²⁰ Op. cit. Olife (2015)

²²¹ Op. cit. ACEA et al. (2015b)

*"It is generally preferred to install a lithium-ion battery outside of the vehicle zones which are designed to deform in a vehicle collision. Nevertheless, multiple vehicle manufactures are currently studying installation of a lithium-ion starter battery in such so-called "crush zones". Furthermore, there are vehicles in the field today wherein a high voltage lithium-ion battery of an EV or HEV has been safely installed in a vehicle crush zone. Large capacity, high voltage lithium-ion batteries by their nature introduce greater safety risks than lithium-ion starter batteries. Therefore, the engineering knowledge in the market today is more than adequate to ensure that vehicles containing lithium-ion starter batteries are safely constructed."*²²²

➤ **Battery management system (BMS):** ACEA et al. state:

*"Lithium batteries require a more complex BMS for reliability and safety reasons, which for example has to communicate current and voltage limits as functions of temperature, state of charge, and ageing, to control thermal management in terms of absolute and relative temperature limits, to disconnect the battery in case of severe failure. Existing BMS for high voltage batteries cannot be carried over because of different functionality, package, and cost requirements... Development of a BMS for li-ion starter batteries that would be feasible and fully qualified for mass production is a substantial engineering and verification task on its own. Verification and validation have to be foreseen both on system (battery) and vehicle integration level."*²²³

Concerning the above aspects generally and further specific design aspects, ACEA et al. summarise:

*"OEMs specify a number of requirements for battery technologies used in mass market vehicles... that Li-Ion batteries would need to comply with in order to be applied in mass market vehicles. Examples of these are: a) Cold cranking; b) Safety; c) Durability at high temperatures; d) Positive charge balance at low temperatures; e) Sustainable Recycling; f) Cost. In particular, all the requirements have to be met simultaneously. For example, LFP batteries with improved high temperature robustness usually show degraded cold cranking performance. These trade-offs have to be eliminated by technology breakthroughs before LFP or any other alternative can even be considered for replacing lead-acid in the vast majority of car applications... While the supply base is making progress, it is still too early to predict when these breakthroughs will be achieved and robustly implemented in cells capable of mass manufacture, irrespective of pack and vehicle integration and prove-out."*²²⁴

²²² Op. cit. A123 et al. (2015b)

²²³ Op. cit. ACEA et al. (2015b)

²²⁴ Op. cit. ACEA et al. (2015b)

The information above is relevant for the possible use of Li-Ion batteries as SLI batteries. However, the information provided by EUROBAT et al. suggests that the use of lead-acid batteries for propulsion in dual battery systems could be banned. Regarding future trends of battery applications, EUROBAT et al.²²⁵ explain that:

- In Class 2, hybrid electric vehicles (including advanced micro-hybrid, mild-hybrid and full hybrid vehicles): lead based batteries are *“Primarily expected to be used as an auxiliary battery to support the board-net. Increased industrial potential of advanced lead-based batteries [is expected]²²⁶ in micro-hybrid and mild-hybrid applications.”*
- In Class 3, plug-in hybrid electric vehicles and full electric vehicles: lead based batteries are *“Expected to be used only as auxiliary battery to support the board-net and for supply of an active redundancy safety mechanism.”*

ACEA et al. were thus asked to explain on what basis the main battery of such dual battery systems cannot already be excluded from the scope of Exemption 5. ACEA et al. explain:²²⁷

- **Class 2: Hybrid electric Vehicles:** *“Due to the need for high energy density, this segment is currently dominated by high voltage Li-Ion battery systems, due to their superior energy density, fast recharge capability and high discharge power... research and development is on-going to assess the suitability of both Li-Ion and lead based batteries as the main 48 V battery in these applications... Advanced designs of lead-acid batteries are available that will meet the 48 V battery specifications using lead-carbon, bipolar constructions and special electrode structures. These all share the low cost materials, simplicity of construction and recyclability of this chemistry.*

For the reasons quoted above, and given the short timescale to meet new emissions standards and achieve a phase out of lead batteries in 48 V applications, this could lead to a decrease in the uptake of these vehicles and make it difficult to meet emission targets. Phase-out may become an option in the future as new platforms are introduced with a safer place to install the Li-Ion battery and if it can be demonstrated that they can meet the desired functionality. It would be wrong to jeopardise the use of lead-acid batteries in dual battery solutions considered above as these systems have the potential to realise lower carbon dioxide emissions at less cost and in shorter timescales than would be achieved with only Li-Ion batteries being permitted as the second battery.”

- **Class 3 - Plug-in hybrid electric vehicles and full electric vehicles:** As in the case of Class 2, the main battery referred to in Class 3 is considered as a traction or propulsion battery and therefore very different from the 12 V

²²⁵ Op. cit. EUROBAT et al. (2014)

²²⁶ Added by consultants to make sense of the sentence.

²²⁷ Op. cit. ACEA et al. (2015b)

batteries under discussion in these answers. Due to the need for high energy density, this segment is currently dominated by high voltage Li-Ion battery systems, due to their superior energy density, fast recharge capability and high discharge power. The functionality and the requirements of these batteries are very different to those of 12 V batteries used as an auxiliary battery and therefore cannot be compared.

In comparison, A123 et al.²²⁸ believe that where the functions of the lead-acid battery do not include engine cranking, the use of lead is avoidable today. This statement is relevant for:

- Hybrid and electric vehicles, in which an auxiliary lead-battery is used to support the conventional vehicles electronics (such as the radio, gauges, window motors, etc.);
- In premium start / stop systems, in which some vehicles currently use two lead-acid batteries to support start / stop functionality. While the first battery is used for cranking the engine, the role of the second battery is to protect the vehicle electronics from the brief decline in voltage that normally happens during engine cranking. This second lead-acid battery could be replaced by a lithium-ion alternative;
- Micro-hybrids – such vehicles can use dual battery systems with one lead-acid battery used mainly for engine cranking and another energy storage device used for basic hybrid functionality at either the 12V or 48V level. Here too the second battery can be specified as a lead-free alternative.

A123 et al.²²⁹ further contend that from a technical vehicle integration perspective, the space currently used for the dual battery system would suffice to support the space needs of a single Li-Ion battery and its required supporting equipment. Since the lithium-ion alternative is already equal in size or smaller than a single lead-acid battery, any vehicle, which already has two batteries represents the easiest transition. A123 et al., however, note that the share of vehicles with two batteries in the market today is rather small and that restricting the use of LAB as proposed above could have the unintended effect of vehicle manufacturers using one larger lead-acid battery in some cases rather than keeping the second battery and converting it to a new technology.

²²⁸ Op. cit. A123 et al. (2015b)

²²⁹ Op. cit. A123 et al. (2015b)

6.2 Critical Review

6.2.1 Scientific and Technical Practicability of Lead Substitution in Automotive Batteries

The information available concerning various automotive battery applications reveals a complex situation. As shall be explained in the points below, it is apparent from various vehicles already on the EU market that battery technologies other than lead-acid can be applied in some cases. Nonetheless, reaching conclusions as to the applicability of the various alternatives to the specific vehicle classes and types that are part of the vehicle market range requires considering multiple factors.

6.2.1.1 Aspects of Relevance to Lead-Acid Starter Battery Replacement

The points raised in Section 6.1.10 are discussed in the following:

Market availability and road experience:

ACEA et al. present the view that Li-Ion alternatives are not yet available on the market at the component level for use as a single battery.

This statement cannot be accepted, as it is clear that first vehicles have indeed been placed on the market in which Li-Ion batteries are in use as a single battery (see Appendix A.5.0). The consultants understand this to be an attempt to dismiss the experience with Li-Ion single battery systems, in terms of its applicability to more conventional vehicles, as well as in terms of the availability of a mass-market alternative. The consultants understand that the vehicles, in which single Li-Ion battery systems are applied, have particular characteristics, making the further implementation of such systems in other vehicles less straightforward, and thus possibly time consuming.

ACEA et al. state²³⁰ in this regard that:

“Car manufacturers have to follow strictly defined development processes in order to get to robust and safe vehicle implementations. This applies as well for Li-Ion SLI batteries, considering the impact of Li-Ion technology on vehicle safety with regard to both component safety (hazards caused by the battery as well as the impact of abuse or accident to the battery) and vehicle safety in general (e.g. functional safety of electrified chassis or driver assistance systems affected by power supply failure).”

Regarding vehicles where Li-Ion starter batteries are already installed in the first vehicles on the market, ACEA et al. continue to explain that:

“Those cars that are presently equipped with Li-Ion starter batteries have run through modified pilot processes which are not applicable for mass volume production. Hence, applications are restricted, for example, to moderate climate markets because of the limitations of Li-Ion technology already

²³⁰ Op. cit. ACEA et al. (2015b)

described. The current field trials feature over dimensioned Li-Ion batteries with a very high cost impact and very high integration efforts, linked with functional limitations and are only feasible in order to obtain first long-term field experience. Furthermore volumes are kept very low, with the customer vehicles being closely monitored by OEMs.”

Though it is explained that such vehicles go through modified pilot processes not applicable to mass volume production, the consultants assume that as consumer products they must also adhere for example to vehicle safety regulation and further requirements that would also be relevant for more conventional vehicles. Experience with these vehicles is thus understood to provide the basis for learning what modifications would be needed in other vehicle types and models.

As the ACEA et al. contributions indicate that on-road experience with alternatives is paramount, before wider phase-in can be considered, the consultants wonder what field experience would be considered to be relevant and sufficient for determining the suitability of alternative battery technologies. Detailed information as to how such experience is collected in practice and how many years of relevant field experience would suffice for OEMs to be able to consider application in various types of conventional vehicles is not clear.

Drop-in applicability of alternative technologies:

ACEA et al. explain that Li-Ion batteries to be used as a single battery in further automotive applications would require significant and expensive re-design.

This view is not shared by A123 et al. on the basis that current vehicles using such batteries did not require redesign to accommodate the Li-Ion alternative. Nor is the view shared by Olife, who claim their Li-Ion super-capacitor alternative to be a drop-in solution.

In line with the information provided by A123 et al., the consultants would expect there be additional models, aside from luxury-sport vehicles, in which the transformation from LAB to Li-Ion could be easier. ACEA was thus asked if there were vehicle types in which implementation of such alternative battery systems could be more manageable in terms of the needed redesign, in light of a higher availability of space for battery system supporting equipment, and in light of suitable operational conditions (temperature). A detailed answer was not provided, with ACEA explaining that: *“such an approach would require world standard vehicles, but even the various vehicle models of one producer are quite different in their design, equipment and package.”*²³¹

The consultants agree that various vehicle models differ from one another, possibly requiring significant time to screen OEM vehicles relevant for the EU market in order to provide a comprehensive answer. However, from the consultants’ experience, the battery location may differ from vehicle to vehicle (see in the following paragraphs), and it is thus expected that phase-in efforts could be easier in some vehicles,

²³¹ Op. cit. ACEA et al. (2015b)

assuming technical requirements are fulfilled. As for the Olife alternative, as promising as it may be it is not yet commercial, as according to the makers: *“The Olife battery is anticipated to be ready for commercial use by the end of 2015. The initial sales and market penetration is expected to provide a first year production of 10,000 batteries by the end of 2016.”*²³² The consultants cannot accept the conclusion that the lead-acid battery technology has become avoidable on the basis of a technology which is not yet available on the market.

Development of Technical Standards:

ACEA et al. claim that: *“the development of Li-Ion batteries for 12 V SLI applications is at an early stage and they are not yet able to meet all the requirements of this application”*. The associations explain that standards are yet to be developed for Li-Ion starter batteries, providing an in-exhaustive list of requirements used by OEMs at present to evaluate Li-Ion starter batteries. The actual required performance is partially detailed only for a few aspects (such as cold cranking capabilities and thermal environment aspects), explaining that performance requirements may differ between various vehicles and models.

The consultants conclude that the process of developing standards is time consuming and is to be based on sufficient field experience. Nonetheless, the current lack of dedicated standards does not explain why the various performance requirements cannot be detailed, explaining the range of minimal performance that Li-Ion starter batteries or other technologies need to fulfil. Despite recurring requests for detailed information,, ACEA et al. did not confirm the list of aspects of relevance, they had been provided to be exhaustive. In their contributions, they explain, in relation to aspects that had been mentioned, that the improvement of one indicator may result in the deterioration of others. However, the minimal performance is not presented clearly for each aspect and would not allow an actual evaluation of such aspects in relation to possible alternatives, nor of how the performance of specific aspects is to relate to others.

It may be argued that it is difficult to provide an exhaustive list in light of the Li-ion starter battery being at the development stage. However, OEMs provide such specifications to their suppliers, for which we must assume that supplied products fulfil the requirements. Li-Ion starter batteries are already applied in a number of models available on the market, and it is thus presumed that such specifications would have had to be developed to a degree sufficient to allow their implementation in first vehicles.

Thermal environment for batteries:

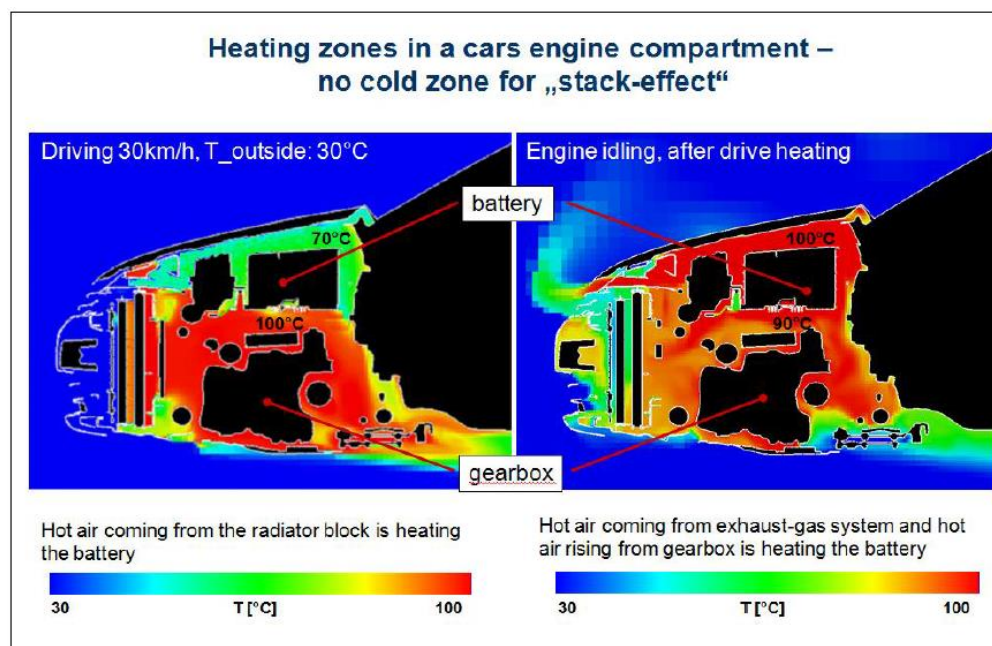
As explained by ACEA e al., the performance and service life of Li-Ion batteries depends on efficient thermal management, with fast aging occurring when the thermal load is too high.

²³² Op. cit. Olife (2015)

A123 et al.²³³ support this view, explaining that the maximum operating temperature can vary between suppliers, but also stating that safe operation in ambient temperatures up to 70°C can be assured. Li-Ion starter batteries should typically be installed where they are not directly exposed to engine temperatures, whereas when the current battery location is adjacent to the engine, a heat shield made of sheet metal can be installed to extend the life of the Li-Ion battery. A123 et al. further claim that no additional equipment is necessary to introduce Li-Ion starter batteries in series production. The size of a Li-Ion alternative is said to be equal to or smaller than the lead-acid solution it replaces. The consultants understand this size factor to be mentioned in order to clarify that where Li-Ion batteries are to be installed the space would suffice for adding heat shields where this is needed.

In the consultants view, the ease of replacing a lead-acid battery may vary from vehicle to vehicle, in light of the location of the battery at present. ACEA et al. provide thermal-images of an engine compartment to show that the thermal environment may be an obstacle for Li-Ion starter batteries (see Figure 6-3 below).

Figure 6-3: Thermal Environment in a Vehicle Engine Compartment Showing the Battery Temperature under Different Conditions.



Source: Op. cit. ACEA et al. (2015b)

However, a quick search of the internet suffices to show that some vehicle models do not have the battery installed in the engine compartment to begin with²³⁴. It is

²³³ Op. cit. A123 et al. (2015b)

²³⁴ See for example battery location in the Volkswagen Touareg. In some models a single battery system is installed and in others a dual lead-acid system. In both cases, batteries are not installed in the engine compartment but either below the driver's seat or under the luggage compartment: See

presumed that such models would allow substitution more easily in this respect in light of the larger distance from heat zones and in light of additional space-availability should the battery need to be equipped with additional safety equipment. The conflicting views do not allow for a clear view on what changes may be needed to accommodate the Li-Ion battery with a sufficient battery management system, nor if such changes would require additional space and design changes, nor what time might be needed for their implementation.

The thermal environment aspect also regards operation of the battery (and subsequently of the vehicle) under extremely cold temperatures. It is understood that the requirement for cold cranking of Li-Ion starter batteries is -30°C. A123 et al. have explained that today's Li-Ion batteries can meet industry standards in which cold cranking requirements are specified at -25 °C and that research and development are focused on further improvements in this area. They expect Li-Ion battery technology to fully close this final gap in the next three to five years.

In this regard ACEA et al.²³⁵ explain that the vehicle market is global in nature and that obviously temperatures can range widely from country to country, as is the case in Europe. Customers expect to be able to operate their vehicle in all conditions irrespective of the model they purchase. For this reason, cold cranking capabilities are required as part of OEM vehicle specifications to ensure cranking function can be provided in very cold weather conditions as low as -30 °C.

The consultants conclude that the cold-cranking performance of Li-Ion starter batteries has not reached this specification; however, it can also be concluded that further developments over the next few years may allow parity to be achieved at the -30 °C level.

For example, Olife²³⁶ explained that their technology does not have problems with the cold cranking requirement: *"The supercapacitors operate independently of the temperature and will function at near 100% capability below -30C. The combination of supercapacitors and a Li FePO4 battery enable cold cranking performances comparable to, or better than, lead acid batteries"*. Though this technology is not yet available on the market, such cold cranking performance would solve what has been communicated in the past as one of the larger obstacles for Li-Ion batteries in automotive applications.

Battery crash and safety aspects:

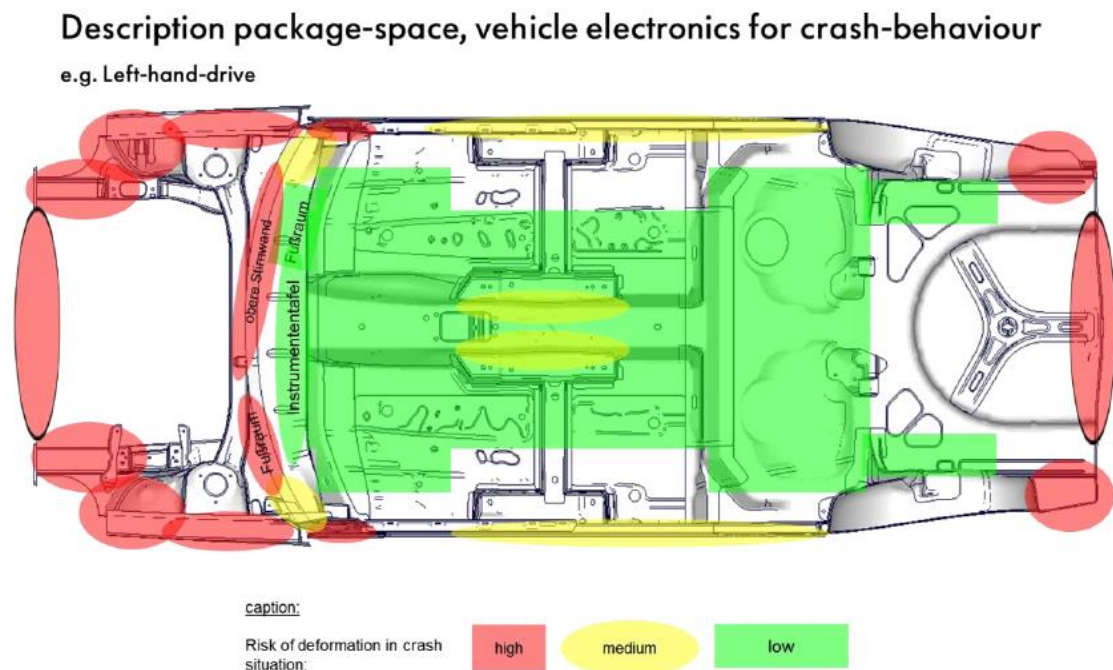
both http://vwts.ru/electro/touareg/tou_27_eng.pdf and <http://www.clubtouareg.com/forums/attachment.php?attachmentid=10758&d=1289554571>, both last accessed 10.06.2015.

²³⁵ Op. cit. ACEA et al. (2015b)

²³⁶ Olife Energy (2014b), Answers to Specific questions from report of Oeko Institute dated 28 July 2010, Chapter 4.5 Exemption No 5, submitted 17.12.2014, available under: http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_5/Ex_5_Contribution_17122014_Olife_Specific_questions_from_report_of_Oeko_Institute_dated_28_July_2010.pdf

ACEA detailed various safety requirements such as resistance to mechanical damage in the form of compression, shock and puncture, consideration of fire, and explosion prevention. It recommended locating Li-Ion starter batteries in a non-crash-sensitive area, which would generally require a full redesign of the vehicle platform. In this respect, Figure 6-4 clarifies which areas of a vehicle are understood to be the crush zones.

Figure 6-4: Package Space for Vehicle Electronics Considering Crash Behaviour



Source: Op. cit. ACEA et al. (2015b)

A123 et al. generally agree with the need to install Li-Ion starter batteries away from the crush zone. They explained, however, that there is experience with the installation of high voltage, Li-Ion batteries in a vehicle crush zone, whereas these batteries are said to introduce greater safety risks than Li-Ion starter batteries.

It can be concluded that safety requirements would make replacing LABs with Li-Ion starter batteries challenging in some cases, requiring time for redesign and testing. However, here too it is understood that there are certain vehicles on the market in which the battery is currently located away from crush zones. Such models are thus understood to allow substitution more easily.

6.2.1.2 Aspects of Relevance to Lead-Acid Replacement in Dual Battery Systems

The information provided by the various stakeholders clarifies that in class 2 and class 3 vehicles a dual battery system is usually implemented in which one battery (the main battery) provides the propulsion functionality while a second battery (the auxiliary battery) is used to support the conventional vehicles electronics, while in some cases also used for engine cranking.

EUROBAT et al.²³⁷ have detailed in this respect that in Class 2 vehicles, LABs are primarily used as the auxiliary battery, while in Class 3 vehicles they are expected to be used only as the auxiliary battery.

A123 et al. contend that in these vehicles, where the functions of the lead-acid battery do not include engine cranking, the use of lead is avoidable today. They explain that the lead acid battery can be replaced in hybrid and electric vehicles, in which cranking of the engine is not required of the auxiliary battery. In micro-hybrid vehicles and in premium start/stop systems in which a dual battery system is in use, it is explained that the battery that is not used for cranking the engine could also be specified with a lead-free alternative.

Furthermore, from a technical vehicle integration perspective, A123 et al. claim that the space currently used for dual battery systems would suffice to support the space needs of a single Li-Ion battery and its required supporting equipment. It is noted that the share of vehicles with two batteries in the market today is rather small. Thus, A123 et al. mention that restricting the use of LAB as proposed above could have the unintended effect of vehicle manufacturers using one larger LAB in some cases rather than keeping the second battery and converting it to a new technology.

ACEA et al. agree that both the Class 2 and Class 3 segments are currently dominated by high voltage Li-Ion battery systems, used as the primary battery, also including a lead-acid auxiliary battery. However, for Class 2 vehicles, it is argued that research and development is on-going to assess the suitability of both Li-Ion and Pb based batteries as the main 48 V battery in these applications. In this regard, for example, ACEA et al.²³⁸ explain that research projects from the Advanced Lead Acid Battery Consortium (ALABC) have demonstrated the successful use of advanced lead-based battery systems in mild-hybrid vehicles, either individually or in 48V/12V dual battery.

The consultants can accept that banning the use of lead-acid batteries in the above cases could impact the current development trends towards dual systems. However, Article 4(2)(b)(ii) of the ELV Directive only allows to “*exempt certain materials and components of vehicles from the provisions of subparagraph (a) if the use of these substances is unavoidable*”. As it is concluded that the use of lead-acid batteries as the primary propulsion battery in Class 2 and Class 3 vehicles is avoidable, an exemption for such applications would not be justified. All the more so, as the use of such chemistries for the primary battery is understood to be fairly uncommon at present. The fact that the suitability of Pb based batteries is under assessment, as the main 48 V battery in Class 2 vehicles is thus understood to be contradictory to the efforts toward the substitution of lead in automotive applications, and contradictory to the ELV ban on lead.

The consultants can agree that in some cases it is possible that the use of lead based technologies may provide environmental benefits that outweigh the benefits of lead free technologies. This aspect is, however, not mentioned in the ELV Directive as a

²³⁷ Op. cit. EUROBAT et al. (2014)

²³⁸ Op. cit. ACEA et al. (2014)

criterion for justifying an exemption, though it is often considered in other legislation restricting hazardous substances (e.g., Directive 2011/65/EU). As in any case, information was not available to enable a comprehensive comparison of the environmental impacts of Li-Ion and Pb alternatives, and therefore such a comparison would at present be inconclusive.

6.2.2 Aspects Related to the Recycling of Batteries

The various stakeholders have provided information concerning the recyclability of different types of batteries.

- Based on this information it can be concluded that the infrastructure for recycling LABs in the EU is quite developed, and provides a good basis for enabling the recycling of lead-acid batteries that are collected. However, the consultants feel that this information does not allow a conclusion to be reached as to the number of LABs placed on the market that are collected and recycled in the EU, as shall be explained below, but only as to the recycled share of collected batteries.
- Regarding other battery technologies, as explained by the various stakeholders, such batteries are already used in some vehicles available on the market; however, their market share in vehicles is still very small in comparison with LABs. Furthermore, in some of these cases batteries shall have a service life comparable to or above that of LABs, and thus, since their application in vehicles is more recent, it is expected that until now much smaller volumes have reached end-of-life.

In this sense, it can be seen that the infrastructure for such battery technologies is still developing. As indicated by some of the stakeholders, it is expected that such systems shall develop as the market share of alternative automotive batteries develops, along with their share in the waste stream. This is also understood to be supported by the ELV Directive, which places the responsibility to increase the share of components that can be recycled primarily on vehicle manufacturers, as well as a responsibility to increase the feasibility of that recycling, for which Member State governments are also obligated to create the necessary framework conditions.

Regarding the possible difference between the number of automotive batteries put on the EU market and the number of batteries collected and recycled, the consultants would like to note that the export of vehicles to non-EU countries may influence the availability of batteries for recycling at end-of-life, as well as the soundness of the recycling of such batteries.

The following information suggests that a significant amount of vehicles are exported, in some cases illegally, and it is assumed that batteries used in these vehicles thus end up being recycled in non-EU facilities. This aspect is relevant to all automotive batteries. However, most of the vehicles on the market are understood to use lead-acid batteries, and as such, these batteries are assumed to have a larger share in batteries that are exported in second-hand vehicles or through illegal export of vehicles (second hand vehicles as well as ELVs).

In 2014, BIOIS et al.²³⁹ concluded an “Ex-post evaluation of certain waste stream Directives”, including a review of the ELV Directive. According to this source, one of the remaining challenges for the Directive is the illegal shipment of ELVs, which hinders the achievement of the environmental benefits of the Directive:

“It is estimated that some 25%²⁴⁰ of all ELVs arising in the EU do not end up in ATFs [authorised treatment facilities]... Member States may be recycling over 90% of ELVs ending up in ATFs but if those ELVs only represent a share of the total number of ELVs arising in Member States, the “real” recycling rates are lower. There is evidence to suggest that considerable numbers of ELVs are exported illegally from EU Member States, predominantly to Africa and the Middle East. This is supported by several press reports as well as by the results of joint activity inspections in the framework of an IMPEL-TFS project completed in 2008, where several cases of illegal shipment of ELVs were reported – mostly to African countries²⁴¹.“

Though it can be understood that some vehicles are exported illegally, it is also worth noting the significant amount of cars exported as used cars. The Austrian Umwelt Bundesamt GmbH (AUBA)²⁴² has compiled data on the export of used cars (see Figure 6-5 below) explaining that over 30% of these are exported to African countries as well as to other countries (see Figure 6-6). The AUBA report also details a few information sources (press reports) showing that illegal shipment of ELVs takes place.

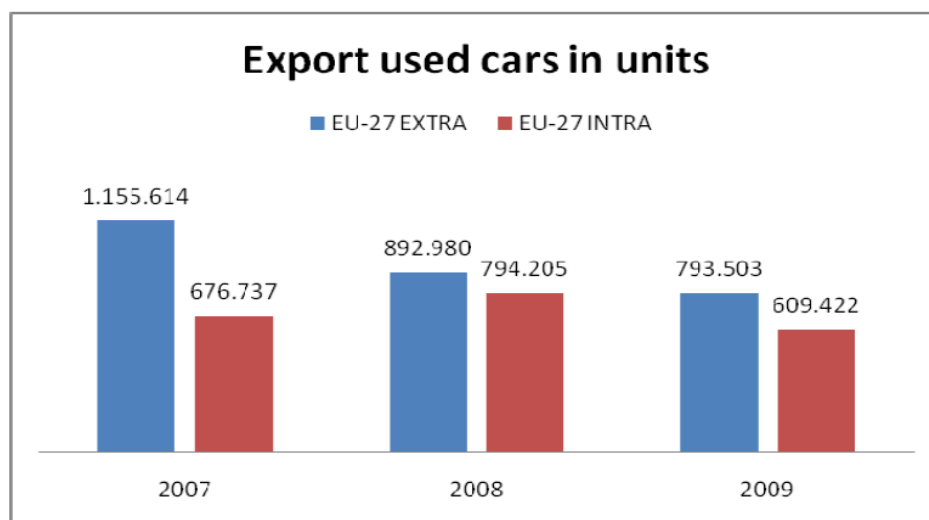
²³⁹ BIOIS et al. (2014) Bio Intelligence Service, Arcadis and the Institute for European Environmental Policy (IEEP) (2014), Ex-post evaluation of certain waste stream Directives, Final report, prepared by Mudgal, S., Fedrigo, D., Kong, M., A., Lambert, S., Lecerf, L., Mitsios, A., Pahal, S., Van Acoleyen, M., and Watkins, E. for the European Commission – DG Environment, dated 18 April 2014

²⁴⁰ This estimation is based on the study Oeko-Institut et al. (2011) European second-hand car market analysis, European Commission

²⁴¹ Cited as European Parliament (2010) End-of-life Vehicles: Legal aspects, national practices and recommendations for future successful approach

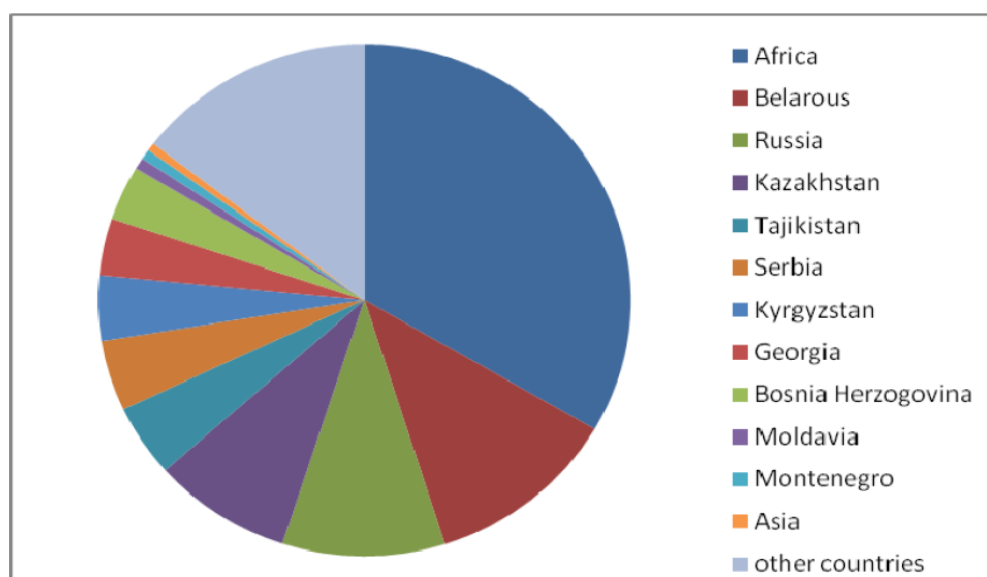
²⁴² AUBA (2010) Austrian Umweltbundesamt GmbH, End of Life Vehicles: Legal Aspects, National Practices and Recommendations for Future Successful Approach, Authors: Schneider, J., Karigl, B., Neubauer, C., Tesar, T., Oliva, J., and Read, B,

Figure 6-5: Export of Used Cars between EU Countries (intra) and to Non-EU Countries (extra) between 2007 and 2009



Source: Op. cit. AUBA (2010) based on data provided by the COMEXT database

Figure 6-6: Main Destinations for Used Cars out of the EU-27 in 2008 (in units)



Source: Op. cit. AUBA (2010) based on data provided by the COMEXT database

This information is not intended to cast doubt on the effectivity of battery recycling operations in the EU, nor of accomplishments regarding lead-acid batteries. However, information concerning battery recycling needs to be reviewed in context, with the understanding that 99% recycling of collected batteries is not to be assumed equivalent with 99% of batteries placed on the EU market. In order to increase the collection rate of vehicles and subsequently of batteries (of all types) illegal exports need to be controlled and as far as possible avoided. The state of battery recycling in some destinations (particularly in Africa) understood to be receiving exported vehicles

(and thus batteries) further raises concerns that these practices are in some cases related to adverse environmental and health impacts.²⁴³

6.2.3 Conclusions

The consultants can follow that the development state of Li-ion starter batteries has changed. Though there are conflicting views, it is understood that this technology has matured and may now provide sufficient performance in relation to some of the OEM requirements. There are conflicting views as to the ease of implementation of this technology as a starter battery in vehicles, as well as regarding the time that this would require. This aspect is considered to be of importance for consideration of a phase-out of lead acid batteries in the near future. However, the fact remains that the cold-cranking performance of Li-Ion batteries still requires improvement to reach the -30°C requirement. Though the Olife technology may solve this problem, it is not yet market mature and thus cannot yet be considered a viable alternative.

In this sense, we conclude that Li-Ion alternatives cannot yet be used as a mass-market alternative starter battery. Subsequently, the use of lead-acid batteries cannot yet be considered avoidable for SLI functions. Nonetheless, the current state of the various alternatives suggests that within a few years, the use of lead-acid batteries may become avoidable, at least in some vehicles, with other vehicles possibly requiring more time for implementation than others.

A future review should thus be carried out within a few years regarding the need for an exemption for starter battery applications, as with the maturing of the various technologies it is expected that estimating the length of the needed transition period shall be possible.

A few points need to be noted in this regard:

First of all, in relation to the possible exemption of certain components from the ELV substance restrictions, a “gradual” phase-in could only be enforced if it were possible to make a clear distinction between components of a certain component group for which the availability of substitutes is different. For example, if one could clearly point out that for batteries of a certain type (e.g., rated voltage) or used for specific purposes (e.g. SLI or propulsion functions) lead batteries had become avoidable. However, one cannot prescribe targets for gradual phase-out within a component group or sub-group through the current exemption mechanism. In other words, it is understood that where it is established that the use of an ELV substance has become avoidable, and the Annex is respectively amended, a phase-out is foreseen for all relevant components starting the expiry date specified in the second column. In exemptions which have expired, it is observed that the only further permission for use of a component containing an ELV restricted substance, is for as spare parts (or replacement parts) for vehicles type approved prior to the change. In this sense, the above reference to a gradual phase-in is only possible on a sub-application basis, but

²⁴³ See for example:

http://www.johnsoncontrols.com/content/us/en/about/our_company/featured_stories/battery-recycling-ghana.html

not in terms of the period over which a phase-in is to occur. The Exemption Mechanism in the Directive does not allow for a gradual phase-in, regardless of the ability of suppliers to make substitutes available in a suitable quantity and regardless of the benefits that a gradual approach may offer.

A second point of importance regards how this limitation affects suppliers of substitutes and more importantly the certainty needed in the research and development community to promote innovations and to lead to their take-up on the market. At development stages, innovators require a minimum certainty as to the possible take-up of their products on the market, in order to be able to raise required capital for further development. According to Coogan et al., technology developers and financiers often refer to the 'valley of death' as an obstacle for innovative technologies to make the leap from the lab to the market. Technologies at early stages (un-proven, proven) and at middle-stages (pre-commercialisation) of development are still viewed by private investors as being too risky, and have difficulties receiving funds.²⁴⁴ This is not to say that exemptions should be amended to promote the uptake of innovation, but only to note the obstacles that the current mechanism creates for developers, in light of the time needed for reaching market readiness and the time needed for upscaling manufacture.

Though some time may be needed to understand the optimal applicability range of substitutes in terms of vehicle classes and types, the current automotive roadmap creates an obstacle that could result in grave impacts on innovation. Without more certainty as to the potential for Li-Ion (or Li-Ion-supercapacitor) starter battery uptake, such initiatives shall have difficulties to make further developments towards OEM needs, as financing shall be limited and in some cases may be withdrawn.

A123 have made proposals for requiring the phase-in of Li-Ion starter batteries within a small share of vehicles by a certain date as a first stage to substitution. This would not only allow a reduction of lead in vehicles and in the future waste stream, but would also support both developers and OEMs in gathering more field experience with alternatives. However, this approach is not supported by the exemption mechanism and could not be recommended as long as a particular component sub-group or vehicle group cannot be addressed.

In the case of alternative starter battery technologies, in the consultants view a few alternatives have reached a certain market maturity. The cold cranking performance of Li-Ion starter batteries has almost reached parity with that of the LAB and is expected to be resolved in the near future. Other obstacles such as the location of these batteries away from crush zones and areas with high thermal stress mainly play a role in vehicles with batteries located in the engine compartment. Here too, integration of BMS and heat protection is expected to be easier and thus more rapidly deployable in some models than in others.

²⁴⁴ Coogan, A, Earhart, R, Eggli, B., Handke, V., Kamburow, C., Krauth, V., Marshall, A. and van Ermen, R., (2007), FUNDETEC - Comparison and Assessment of Funding Schemes for the Development of New Activities and Investments in Environmental Technologies, prepared by European Partners for the Environment, see [link](#)

It follows that the automotive industry cannot commit to a certain timeframe without first surveying all models and without planning the various stages needed to complete and implement the redesign of vehicles. On this basis, it also follows that setting a date for phase-out is not currently possible. However, a long-termed renewal of the exemption could be the death-sentence of possible alternatives, which are understood to provide some qualities that may be advantageous in some vehicle types in comparison with LAB alternatives.

A123 et al. estimate that the cold-cranking of Li-ion starter batteries shall reach parity with LABs within three to five years. A review of the status within a few years shall ensure that obstacles have been overcome, while also giving industry time to perform surveys and consider how much time is truly needed for phase-in in certain vehicle types (sub-groups of vehicle classes). This should allow for the setting of phase-out dates (at least for some vehicle types) in the next review, providing both the Li-ion community and the automotive sector with more certainty as to how the roadmap to substitution can be formed. As a period of 3-5 years is assumed to reach parity, it is recommended to schedule the next review following this period.

Regarding the use of lead-acid batteries in other applications than starter applications, it is apparent that the case is different. LABs are understood to be used as an auxiliary battery in class 2 and class 3 vehicles in which a dual battery system is in use. In most of these cases this battery is still needed for cold cranking and is thus still understood to fulfil starter functions, for which the LAB as above is still considered unavoidable. However, the other than lead-acid battery technologies have been used traditionally for the primary battery in such vehicles. For exemptions to be granted, Article 4(2)(b)(ii) of the ELV Directive requires the use of the ELV restricted substances to be unavoidable. Against this criterion, the consultants view is that an application, for which the use of lead acid batteries is at present still uncommon, would be considered an application in which the use of lead is avoidable. As it is concluded that the use of lead-acid batteries as the primary propulsion battery in Class 2 and Class 3 vehicles is avoidable, an exemption for such applications would not be justified.

As for the auxiliary battery, though it is understood that in some cases this battery does not need to fulfil starter functions, the available information does not show that any field experience has been accumulated for batteries other than lead-based batteries for this application. Though replacement with Li-ion batteries sounds promising, the consultants understand that such substitution would need to at least be tested in pilot vehicles before bringing such vehicles on the market. The same is true for Class 1 vehicles with start/stop functions, equipped with two lead-acid batteries, for which one does not supply starter functionalities. Though the consultants view is that Li-ion batteries are a candidate for replacing lead-acid batteries in this application, first experience should be gathered before deciding on the complete phase-out of Pb in batteries for such applications.

The consultants understand that banning the use of lead-acid batteries in the above cases could impact the current development trends towards dual systems, however, this would not justify an exemption based on the ELV criteria. The fact that the suitability of Pb based batteries is under assessment as the main 48 V battery in Class 2 vehicles would not justify an exemption. Even if such developments could be

shown in the future to be beneficial for the environment, the current legislation does not give weight to such factors.

To facilitate future evaluations, it is further emphasised that the performance requirements relevant for battery alternatives need to be clearly addressed and quantifiable to allow a comprehensive comparison. Such information would need to be public for a comparison to be transparent. It is further conceivable that a life cycle analysis of such alternative battery technologies would assist in verifying the range of environmental impacts and in ensuring that the adverse impacts are not a result of possible future trends. Though such aspects are at present not reflected in the ELV Directive exemption criteria, the information should at least be available to allow decision makers to consider environmental rebound impacts of possible phase-out in the future. This is understood to be particularly of interest in areas where resources are limited as well as in light of the differences of energy consumption relevant for manufacturing and recycling operations.

6.3 Recommendation

Based on the information submitted, the use of lead in automotive batteries cannot be avoided at present, in cases where starter functionality is of relevance.

It is also presumed that in cases where a dual battery system is in use, the use of a LAB as an auxiliary battery would not be avoidable even where starter functionality is not needed. This is based on the understanding that there is a lack of experience with batteries other than LAB for this function, though this could change over the next few years as Li-Ion batteries are understood to provide a suitable candidate for such cases. Three to five years are envisioned to be needed in this case to allow reaching parity of cold cranking performance. As replacement with Li-Ion batteries is not yet implemented in vehicles on the market, it can be followed that more time would be needed to finalise testing and type approval processes, once parity was established.

In contrast, in the primary battery of dual systems, where the battery is only needed for propulsion, other chemistries are currently in use, making the use of lead in batteries avoidable. The consultants recommend that the exemption for lead in batteries be reformulated to exclude such primary batteries from its scope.

The use of lead in other battery applications is still considered unavoidable but should be revisited within three to five years, as first alternatives are already in use in vehicles available on the EU market and could become relevant for mass-market applications in the near future. Three to five years are needed to allow Li-Ion alternatives a chance to close the cold cranking temperature gap, at which time the Olife battery is also expected to become commercial.

The consultants would recommend the next review is held within 3 years. Once cold-cranking is established, Li-Ion developers will have difficulty advancing to mass production as long as there is no sign as to when the revoke of the exemption could be expected. Even if cold-cranking is established earlier, it shall not be until after the next review of this exemptions that Li-Ion developers shall be able to estimate possible changes to the market as a means of promoting the next stages of development. In contrast, once cold cranking has been established (and possibly first experience with the Olife alternative is available) the automotive industry shall be

able to estimate more precisely how many years would be needed to complete the various stages needed for phasing-out of the LAB. Such stages may vary for the different vehicle types (e.g., electric, hybrid, and conventional) and could include among others further testing; establishing sufficient safety levels; possible redesign; possible adaptation of standards; and type approval. As these stages are expected to be time consuming, in the consultants view, advancing decisions as to the future of the exemption shall support the further development of these technologies and facilitate the automotive industry in gaining more experience with alternatives. This in turn shall promote with time the possible phase-out of the LAB. Though the promotion of innovation does not justify the revoke of the exemption, it should be taken into consideration in the decision as to when the next review should be carried out.

In parallel, the consultants are aware that establishing parity may take longer (the estimations are of up to five years). The EU Commission may thus also decide to postpone the next review, in order to allow developers more time to achieve cold cranking parity, while also allowing more experience to accumulate within this period in terms of testing of battery applicability. In this case the EU COM could decide to hold the next review after the five year period has passed.

Against this background, the consultants propose a split of the exemption. The split shall differentiate between battery functions in which LABs are currently in use and understood still to be unavoidable, and between other battery functions for which LABs are not applied at present in models on the market, and thus understood as avoidable.

In a discussion held with the EU COM and with representatives of the Automotive industry on 22 July 2015, ACEA et al. were asked to clarify if the terminology used in their documents, referring to vehicles of Classes 1, 2 and 3 and to primary and auxiliary batteries would be suitable for differentiating between the batteries. It was explained that these terms do not conform to type approval terms. After consulting with the EU COM, it was recommended to refer to the voltage classification of batteries and to the propulsion function, understood to be relevant in cases where LABs are not in use. It was also recommended to refer to M1 and N1 vehicles, which are understood to be the only vehicles that may use propulsion batteries and that need to comply with the ELV substance restriction. As it has been stated by ACEA et al. that LABs may still be in use in special purpose vehicles (e.g. for handicapped people, police cars and ambulances)” a longer period is recommended for phasing out lead batteries in propulsion batteries, to allow time to clarify if the exemption would still be needed for such “special purpose vehicles”.

Based on the above considerations, the consultants recommend the following wording and review period for ELV Exemption 5:

Materials and components	Scope and expiry date of the exemption
<i>Lead in batteries:</i> <i>I. in high voltage systems (systems that have a voltage of >75VDC as defined in</i>	<i>I. Vehicles type approved before 1 January 2019 and</i>

<p><i>the Low Voltage Directive (LVD) 2006/95/EC that are used only for propulsion in M1 and N1 vehicles</i></p>	<p><i>spare parts for these vehicles</i></p>
<p><i>II. Battery applications not addressed in paragraph I.</i></p>	<p><i>II. Review to be carried out in 3 to 5 years</i></p>

6.4 References Exemption 5

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- A123 et al. (2015a) Joint contribution of A123 Systems, Fraunhofer, LG Chem and Samsung SDI, Answers to Questionnaire Clarification: Exemption No. 5, submitted per email 6.3.2015
- A123 et al. (2015b) Joint contribution of A123 Systems, Fraunhofer, LG Chem and Samsung SDI, Answers to Clarification Questions Following the Stakeholder Meeting of 10.4, submitted per email
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Appendices

A.1.0 Appendix A.1.0: The History of Exemption 2(c)

The wording for the exemptions covering leaded aluminium alloys in the ELV Directive have changed several times and evolved overall with a trend to a decrease in the thresholds, which specify the allowance for the use of lead in such alloys.

Article 4(2)(b) of the legal text of the ELV Directive published in 2000 required that the Commission evaluate the need for exempting the use of the ELV substances in a number of applications. This included evaluations for a number of specific applications such as the use of lead as an alloy in aluminium in wheel rims, engine parts and window levers.²⁴⁵ Annex II of the original ELV Directive (2000/53/EC) included an exemption for “Aluminium containing up to 0.4 % lead by weight” which was intended to cover the unintentional content of lead in recycled aluminium.²⁴⁶

As a result of a first evaluation, the following exemptions were published in the first revision of Annex II:²⁴⁷

2. a) *Aluminium for machining purposes with a lead content up to 2 % by weight (1 July 2005)*

b) *Aluminium for machining purposes with a lead content up to 1 % by weight*

The 0.4% general exemption was still included in Annex II, though no longer in the table but rather integrated as a footnote specifying that:

“a maximum concentration value up to 0.4 % by weight of lead in aluminium shall also be tolerated provided it is not intentionally introduced.”

In a further footnote it is detailed:

“Intentionally introduced” shall mean “deliberately utilised in the formulation of a material or component where its continued presence is desired in the final product to provide a specific characteristic, appearance or quality”. The use of recycled materials as feedstock for the manufacture of new products, where some portion of the recycled materials may contain amounts of regulated metals, is not to be considered as intentionally introduced.”

²⁴⁵ “Aluminium (in wheel rims, engine parts and window levers) containing up to 4 % lead by weight”

²⁴⁶ Oeko-Institut (2008), Dr. Joachim Lohse et al., Oeko-Institut; Otmar Deubzer, Fraunhofer IZM: Adaptation to Scientific and Technical Progress of Annex II Directive 2000/53/EC, Contract N° 07010401/2007/470145/ATA/G4, final report; Freiburg, 16 January 2008; http://elv.exemptions.oeko.info/fileadmin/user_upload/Background/Final_report_ELV_Annex_II_revision.pdf

²⁴⁷ Commission Decision 2002/525/EC of 27 June 2002 amending Annex II of Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles

As a result of the second revision²⁴⁸, the allowance for lead in aluminium alloys for machining purposes was further reduced:

2(a). Aluminium for machining purposes with a lead content up to 1.5 % by weight (Scope and expiry date of the exemption 1 July 2008)

2(b). Aluminium for machining purposes with a lead content up to 0.4 % by weight

The footnote referring to the general exemption of 0.4 % by weight of lead in aluminium did not appear in the second revision. It was deleted with the Council Decision dated 20 September 2005. A justification for the deletion was not detailed.

In the third revision of Annex II in 2008,²⁴⁹ the exemption evolved to include three entries, only the third (Ex. No. 2(c) as detailed above) is still applicable for use in new vehicles put on the EU market. Based on recommendations of Oeko-Institut²⁵⁰, the wording of the exemption was changed from “Aluminium for machining purposes with a lead content up to 0.4% by weight” by deleting the wording “for machining purposes” in order to (re-)include unintentionally present lead in the scope of the exemption. The Organisation of European Aluminium Refiners and Remelters (OEA) and the European Aluminium Association (EAA) had requested a general exemption of up to 0.4% for the unintentional content of lead in aluminium alloys.

The last review took place in 2009/2010. For Exemption 2(c), a review within five years was recommended on the basis that industry did not provide sufficiently detailed evidence at the time, to clarify that a reduction of lead concentrations in aluminium alloys was not feasible, despite the general availability of lead-free alternatives that had become apparent²⁵¹. The requirement to review Exemption 2(c) in 2015 was published in the fifth revision of Annex II in 2011.²⁵²

²⁴⁸ Council Decision 2005/673/EC of 20 September 2005 amending Annex II of Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles

²⁴⁹ Commission Decision 2008/689/EC amending Annex II of Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles

²⁵⁰ Oeko-Institut (2008), Dr. Joachim Lohse et al., Oeko-Institut; Otmar Deubzer, Fraunhofer IZM: Adaptation to Scientific and Technical Progress of Annex II Directive 2000/53/EC, Contract N° 07010401/2007/470145/ATA/G4, final report; Freiburg, 16 January 2008; http://elv.exemptions.oeko.info/fileadmin/user_upload/Background/Final_report_ELV_Annex_II_revision.pdf

²⁵¹ Oeko-Institut (2010), Stéphanie Zangl et al., Oeko-Institut; Otmar Deubzer, Fraunhofer IZM: Adaptation to scientific and technical progress of Annex II to Directive 2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS), final report; Freiburg, 28 July 2010; http://elv.exemptions.oeko.info/fileadmin/user_upload/Final_Report/Corr_Final_report_ELV_RoHS_28_07_2010.pdf

²⁵² Commission Directive 2011/37/EU of 30 March 2011 amending Annex II to Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles

A.2.0 Appendix A.2.0: List of Relevant Properties and Performance Indicators Related to Exemption 2(c)

Source: ACEA et al. (2015c), ACEA, JAMA, KAMA, CLEPA and EAA, Ex. 2C List of Relevant Properties and Performance Indicators, submitted per email 22.8.2015

Functionality / Property /Performance Aspect	Performance indicator (basis for monitoring the performance and comparing between AI alloys with/ without lead)	Comments - Interrelations
Component level		
#1 Durability/ reliability of part		#1, #18, #10, #12, #7, #9,#3, #9 ,#6
#2 Lightweight (component)		#9, #7,
Material Level / physical chemical, mechanical properties		
#3 Temperature resistance		#1
#4 Heat treatable strength		#1
#5 Eutectic point of alloy		#3,
#6 Shrinkage from liquid to solid phase /residual stress		#1
#7 Microporosity		#1, #12
#8 Elongation		#1
#9 Fatigue strength		#1
#10 Coefficient of friction		#1,
#11Emergency lubrication properties		#1,
#12 Corrosion resistance, especially pitting corrosion		#1,
#13 Electrochemical potential (of additive)		#1, #12
#14 Recycling		
Processing Level		
#15 Tool life and energy consumption during machining of parts		#16, #17
#16 Cutting speeds, lubrication		#15
#17 Chip length (Machining)		#15
#18 Surface accuracy/ finish part precision		#12, #1, #10, #11

A.3.0 Appendix A.3.0 Summary of Test Reports submitted as Annexes to the contribution of ACEA et al. (2014) Concerning Exemption 3

ACEA et al. (2014) submitted 19 Annexes to their contribution. Some of which present test results relevant to the research into substitutions for leaded copper alloys – these results have been summarised in the table below. The Annexes can be viewed at <http://elv.exemptions.oeko.info/index.php?id=60>.

The following Annexes are not test reports but literature studies (E3_[01] and E3_[02])²⁵³ and a compilation of information from material data sheets (E3_[08]).²⁵⁴ Therefore, they are not included in Table 6-3.

The numbers that are indicated under the column “Title at Consultation Page” contain numbers that are given by ACEA et al. (2014); the Annexes are not consecutively numbered.

Table 6-3: Summary of Test Reports submitted as Annexes to the contribution of ACEA et al. (2014)

Title at Consultation Page	Object of Investigation	Lead-free / Lead reduced Alternative used	Summary of Results
E3_[07]_- [Supplier 5]_Industry-Statement.pdf	Manufacturing of clamp sleeve / collet	Lead free alloys in different chemical composition, e.g. CuZn42 and CuZn21Si3P	With existing machine and tool setting, required tool life of the series-production drills was only 3% when manufacturing lead-free copper alloys; cutting forces 1,75 compared to leaded copper alloys; on cooperation with tool suppliers 35 different material of drills and cutters were developed, which are not specified further; test are still ongoing.

²⁵³ E3_[01]_[WE-03]_Literature_Study_completed_2013-09-03.pdf;

E3_[02]_Welter_2014_leaded copper alloys for automotive applications-a scrutiny.pdf

²⁵⁴ E3_[08]_Compilation_Material property data sheets lead and lead free alloys.pdf

E3_[09]_[TE-01]_Messingwerkstoffe Tribologie-englisch3.pdf	Tribological test (pin to disk)	Ecobrass and Blue Brass (Pb > 0.1%)	Ecobrass shows a higher wear resistance compared to the leaded copper alloy Z33 (Pb 3.3%) due to a higher hardness and small precipitates (Cu ₄ ZnSi or Cu ₈ Zn ₂ Si) which acts as points of support; slightly better wear resistance of BlueBrass compared to Ecobrass; main wear mechanism for all specimen is adhesive wear; additional mass of pins after test: BlueBrass reveals the highest amount of products on the pin.
E3_[10]_[BO-02]_Corrosion_Galvanic_CopperCEEf_report.pdf	Galvanic corrosion tests of brass alloys (electrochemical behaviour in NaCl solution compared to aluminum)	CuZn42 (CW 510L); CuZn28As (CW 511L); CuZn21Si (CW 714R)	Order of potentials in NaCl solution: Al < CuZn42 < CuZn38As < CuZn21Si < CuZn39Pb3; galvanic current created by coupling aluminum and brass alloy: CuZn42 (CW510L) > CuZn38As (CW511L) > CuZn21Si (CW724R) ≥ CuZn39Pb3 (CW614N); corrosion current density: CuZn39Pb3 > CuZn42 > CuZn28Si > CuZn38As; corrosion rate at higher potential (> -100 mV / ECS): CuZn42 > CuZn38As > CuZn28Si ≥ CuZn39Pb3.
E3_[11]_[BO-01]_Comparative Stress Corrosion Cracking results_Copper_CEEf_report.pdf	Sensitivity to Stress Corrosion Cracking (SCC)	CuZn42 (CW 510L); CuZn28As (CW 511L); CuZn21Si (CW 714R)	SCC measured by elongation prior to cracking in an aggressive medium compared to elongation in air; corrosion solutions NaCl Na ₂ SO ₄ ; in chloride and sulphide solutions the sensitivity coefficient C _{sc} is 1 for CuZn21Si and CuZn28As irrespective of the surrounding solution; for leaded brass and CuZn42 it drops to 0.3-0.2 depending upon the environment.
E3_[12]_[LU-02]_Micro drilling final.pdf	Micro drilling of copper alloys with diameter of 1 mm	CuZn21Si3P, CuZn38As, CuZn42	Micro drilling: CuZn21Si3P, CuZn38As, CuZn42 worse compared to leaded brass; tool breakage occurred during drilling of CuZn42 and CuZn21Si3P after a few holes for most of the applied strategies; the process was only stable when dividing the cutting process in 10 steps (1 mm each) and moving the tool completely out of the hole after every cut (increase of process time); chip formation: chip breakage of CuZn42 and CuZn21Si3P comparable to CuZn39Pb3; when drilling CuZn38As, slightly longer chips were formed on average; feed forces: for CuZn38As, mean of feed forces was much higher compared to CuZn39Pb3; mean of feed forces of CuZn21Si3P was higher compared to CuZn42 due to high hardness; no increase during drilling process was observed; surface roughness: same or even lower when drilling CuZn38As, CuZn42 and CuZn21Si3P; tool wear: high abrasive wear when drilling CuZn21Si3P led to huge increase of feed forces and early tool breakage.

E3_[13]_[TE-02] 2014-02 Messingwerkstoffe Warmverformung-englishV2.pdf	Tests on deformation behaviour of brass alloys at 150 °C	CuZn21Si3P, CuZn38As, CuZn42	Tensile tests at 150 °C; creep tests; Brinell hardness measurements; testing machines are specified; CuZn21Si3P alloy highest strength; lead free alloys CuZn42 and CuSi21Si3P show much less creep strain compared to the lead containing Z33
E3_[15]_- [supplier 6]_[SO-02]_Pinion.pdf	Test of pinion	CuZn31Mn2 Si1Al1	Continuous operation test with mating gear of Delrin100: greater wear marks at lead free pinion; test parameters such as velocity, hertzian pressure etc. were specified.
E3_[16]_- [OEM 1]_[PA-01]_Shift_forks.pdf	Tests with shift forks	Lead free shift forks; material not specified	High wear of lead-free shift forks already during "standard run"
E3_[18]_- [OEM 1]_[WA-01]_Fittings fuel feeding system.pdf	Tests of fittings to fuel feedings system	Leg62:CuZn 38As; Leg430:CuZn21Si3; Leg57:CuZn 42	Torque experiments at room temperature and at 130 °C; Leg430 showed best results, besides torque decrease (prevail torque at 130 °)
E3_[20]_- [OEM2]_[JA-03]_tire-valve.pdf	Test on valve stems	BZ-5U; Eco-Brass; Pb0.2% brass	Check of adhesive area ratio between rubber and metal under heat and acid conditions; BZ-5U and Eco-Brass failed in all tests.
E3_[21]_- [supplier 3]_[MU-01]_Industry_statement.pdf	Test of crimp contact material	CuZn42	Crimp contacts made of CuZn42 showed cracks which hampers safe contact closure.
E3_[23]_- [supplier 4]_[WE_04]_Crimpkontakte.pdf	Manufacturing of crimp contacts	Lead reduced material CuZn37Pb0,5 ; CuZn35Pb1; CuZn35Pb2; CuZn37Pb2	Technical process not presented, rather results / statement on material properties; material with <2% Pb not applicable; testing requirements not detailed.
E3_[24]_- [supplier 1]_[LA-01]_Batterie klemme.pdf	Manufacturing of battery terminal	CuZn42 and CuZn39Pb2	Higher processing time for CuZn42; shorter tool life; damages in the lead free components (microcracks)

E3_[26]_- [OEM3]_Material_Tests_Japan_StdTest.pdf	Material tests on cutting and drilling	Reduced lead: Pb (ave. %): 0.2; <0.1 (Si-type)	Test Result Summary; testing requirements not revealed; higher cutting and drilling forces and limited cutting time for lead reduced alloys compared to 3.7%Pb alloy.
E3_[29]_- [OEM3]_[JA-02]_Machining_lead_reduced_copper.pdf	Manufacturing of guide for thermostat and of union	Guides: Pb 0.2% and <0.1% (Ecobross) compared to C3604 (Pb 3.2%); unions: lead reduced alloys of 2.2% Pb compared to Pb 3.07%	Guides: byte breakage with Pb 0.2% and <0.1% material because curly sawdust occurred; Unions: lead reduced samples showed rough surface with grooves in the radial direction and a continuous burr on the edge; damage to the cutting tool tip by reduced lead alternative.
E3_[30]_- [supplier 8]_corrosion_journal-bearing.pdf	Corrosion test (8% of bioethanol E100 in oil, 246h)	CW713R (Pb 0.2 – 0.8%) CW507L (Pb 0.05% max.)	Test medium mixture of laboratory aged oil, bioethanol E100 and addition of salts and acids and presence of oxygen; corrosion speed lower for higher leaded CW713R -> better corrosion resistance: lead-free material show intergranular corrosion

A.4.0 Appendix A.4.0: Comparison of Information Provided Related to Ecobrass from the Various Stakeholder, Concerning Exemption 3

The following table compares the different input provided by ACEA et al. and Mitsubishi Shindo Inc.

Table 6-4: Properties of Ecobrass compared to CuZn39Pb3 / C36000

Properties	ACEA et al.	Mitsubishi
Tensile strength	At 150° 30% better	1.41 Due to the higher tensile strength, thickness and weight of components can be reduced
Relaxation fittings	180% worse	Not specified
Elongation	Not specified	1.50
Cold compression strength	Not specified	1.36
Bending stress	Not specified	1.57
Fatigue limit	Not specified	1.64
Thermal conductivity	Not specified	0.34
Electrical conductivity	320% worse	0.31
Creep resistance / creep strength	The lead free alloys CuZn42 and CuSi21Si3P show much less creep strain compared to the lead containing Z33.	Higher creep strength at 120° and 150°
Wear of copper disc	300% better	(non lubrication) 0.05 (lubrication) 0.02
Adhesion behavior	Similar	Not specified.
Friction coefficient	30% worse	(non-lubrication): 1.29
Corrosion	45% worse	Superior
Stress corrosion cracking	330% better	Superior 0.01
Galvanic corrosion	Leaded brass appears to be more resistant than silicon brass.	ECO BRASS and C36000 galvanic corrosion sensitivity of aluminum are equivalent.

Erosion corrosion resistance	Not investigated.	Superior
Cavitation resistance	Not specified.	Superior

Source: *Op. cit.* ACEA et al. (2014 and 2015a); Mitsubishi Shindo Co., Ltd. (2015a)

A.5.0 Appendix A.5.0 : Information Concerning Vehicles on the Market not Utilising a Lead-Acid Battery System

Source of the below information: A123 et al. (2015a) A123 Systems, Fraunhofer, LG Chem and Samsung SDI, Answers to Questionnaire Clarification: Exemption No. 5, submitted per email 6.3.2015

Below are the production battery programs referenced in our original submission with an additional column for location of vehicle sales when known to this group.

Table 1: Single li-ion battery programs supporting micro-hybrids:

	Vehicle Manufacturer	Vehicle Model	Launch year	Estimated quantity of units in service	Battery manufacturer	Vehicle sales locations
1	Mercedes Mercedes-AMG	S-Class SLS AMG Coupe SLS S63 AMG S65 AMG Coupe	2013	12k	A123 Systems (Li-ion LFP)	Europe
2	BMW	M3	2014	<1k	GS Yuasa (Li-ion LFP)	Europe

Other single li-ion battery programs are in production on McLaren and Ferrari models but are not noted in the table above because light weighting is the driver for these applications, not micro-hybridization. There are 5k additional units in service on these super car models worldwide.

Table 2: Dual energy storage programs supporting micro-hybrids:

	Vehicle Manufacturer	Vehicle Model	Launch year	Estimated quantity of units in service	Energy storage manufacturer	Vehicle sales locations
1	Suzuki	Wagon R	2012	800k	DENSO (li-ion)	Japan
2	Nissan	DAYZ ROOX	2014	30k	Panasonic (NiMH)	Japan
3	Mitsubishi	eK Space	2014	15k	Panasonic (NiMH)	Japan
4	PSA	various	2010+	1-2M	Continental /Maxwell (ultracap)	Europe
5	Mazda	various	2013	10k	Nippon (ultracap)	Global

A.6.0 Appendix A.6.0: Description of Relevant Stages Required as Part of the Development Tasks of Battery Technologies at the Component and Vehicle Levels.

Source of the below information: ACEA et al., (2015b), Submission of ACEA, CLEPA, JAMA, KAMA, ILA and EUROBAT. to additional questions for clarification after stakeholder meeting on 10 April 2015, amended version submitted 13.5.2015 per email

Component level specific R&D issues

The development of Li-ion batteries for 12 V SLI applications is at an early stage and they are not yet able to meet all the requirements of this application. A full programme of research and development needs to be carried out to ensure OEM specifications and technical standards can be met. For Li-ion batteries, technical standards are not yet developed and for lead-acid SLI batteries, the requirements are defined in EN 50342-1 and for lead-acid batteries for stop and start applications, they are being defined by EN 50342-6 which is not yet published.

However, the EN 50342 family of specifications is particular to lead-acid batteries, as its title “lead acid batteries” indicates. Only some EN 50342-1 requirements are derived from the vehicle application, such capacity, high-rate cranking capability and vibration resistance.

Furthermore, many requirements defined in EN 50342-1 address battery characteristics specific to lead-acid, which have been identified over years of operation of lead-acid batteries in vehicles. For example the procedure for forced deep discharge (“over-discharge”) of lead-acid batteries and capability for recovery afterwards.

Li-ion batteries must not be subjected to any deep discharge (“over-discharge”) and therefore are self-protected by disconnection, even if vehicle function may be compromised.

On the other hand, some requirements have not been addressed in EN-50342 as it is common knowledge that there is no need for a particular requirement, either as it is not critical for any lead-acid battery, or the requirement is implicitly covered by another requirement.

As an example, system overvoltage at the 12 V/14 V level, from a transient or a defect of the voltage controller of the alternator, is a quite common failure. Therefore, vehicle manufacturers specify the electronic devices used to be resistant to damage by an overvoltage for a limited period of time, e.g. 1 hour at 18 V. However, EN-50342 does not need to specify such a situation, as it is common knowledge that lead-acid batteries can easily withstand such a situation, even at elevated temperatures, without losing function or being a potential hazard. Some degradation (grid corrosion, water electrolysis) is accepted under such an abuse condition, even if the overall operating period may be somewhat compromised. Implicitly, this topic is also addressed in the water loss test (constant voltage 14.4 V overcharge at 60° C for many weeks).

Li-ion batteries are sensitive to overcharge, especially at high temperatures, and therefore protect themselves by disconnecting, even if vehicle function may be compromised.

Furthermore, there are laboratory tests specified in EN-50342 which have been demonstrated to reflect failure modes similar to failure modes seen in the field over years of experience. Such so called accelerated life tests do not emulate vehicle operating conditions (as this would require years of testing) but failure modes, to allow for a full evaluation after a few weeks.

The procedure for 50% depth-of-discharge cycling is an example. Accelerated life tests of this type are specific to the electrochemical system. Furthermore, extended field experience on failure modes has to be collected, and a robust statistical verification of any new-designed accelerated life test against a full statistical analysis of failure modes is required before specification and implementation of such a test.

All of this indicates that the EN 50342 family of specifications does not reflect requirements for Li-ion batteries, and is not intended to do so. A new EN standard is required to specify requirements for Li-ion starter batteries. Requirements derived from the vehicle application, such as capacity, high-rate cranking capability, vibration resistance and so on may be similar to EN 50342-1. Tests specific to lead-acid may be dropped, while new tests specific to Li-ion characteristics may be included. Accelerated life tests specific to Li-ion batteries require extended field experience on failure modes. Such investigations on the road have scarcely been started. Whenever further design changes of Li-ion batteries are made (or will be made in future), this has to be considered and updated.

EN 50342-1 defines cold cranking requirements for lead-acid batteries, low rate capacity at the 20 h rate, charge retention, corrosion resistance, cyclic endurance, vibration resistance, water loss and electrolyte retention. Water loss and electrolyte retention are specific to lead-acid and would not be applicable to Li-ion. Cold cranking, low rate capacity, charge retention, cyclic endurance and vibration resistance requirements should be equivalent for Li-ion as these are vehicle requirements but the tests may be different as discussed. The charge retention is measured by storage of a fully charged battery at an elevated temperature (40oC) for a period and then measuring its CCA performance. The corrosion test is a high temperature durability test where the battery is held at elevated temperature (60oC) on a constant voltage charge for a period and then measuring the CCA performance. Each period is a unit and durability is measured in number of units before failure. Cyclic endurance is measured on a shallow cycle for 180 cycles and the CCA is checked.

EN 50342-6 is not yet a standard but will define requirements for micro-cycling, dynamic charge acceptance, endurance at 17.5% depth-of-discharge and endurance at 50% depth-of-discharge following a deep discharge. The basic requirements of EN-50342 remain in place. OEMs and battery manufacturers are working on this standard as an expert committee.

As illustrated in Table 1 existing standards can only partly be used as a basis to develop the required standards for li-ion SLI batteries. They have to be modified and adapted to the specific conditions. For some test specifications completely new standards have to be developed.

According to the experiences of OEMs and described above, this is a time consuming process. It has taken 6 years from May 2008 (kick-off meeting for ISO 12405-1) to May 2014 (ISO 12405-3 published) to get ISO 12405 (“Electric road vehicles – Test specification for Li-ion traction battery systems”) completely published.

In addition to the standards in the table there is actually work ongoing for a Li-ion cell safety standard (IEC 62660-3), in which Li-ion cells for starter batteries are not yet in the scope (“Secondary Li-ion cells for the propulsion of electric road vehicles”). This standard as well as the standards in Table 1 has to be developed as a completely new standard for Li-ion cells for 12 V SLI batteries.

Table 1 Comparison of relevant standards and applicability for li-ion SLI batteries (below).

Starter lead acid batteries	Starter Li-Ion batteries
EN 50342-1	Transfer of the EN 50342-1 to Specification for Starter Li-Ion batteries
Lead-acid starter batteries -	
Part 1: General requirements and methods of test	
Cold cranking	Possible
Low capacity rate	Possible
Charge acceptance	Possible
Charge retention	Possible
Corrosion resistance	Not applicable for Li-Ion technology
Cyclic endurance	Possible
Vibration resistance	Possible
Water loss	to be adapted as an electrolyte degradation test for Li-Ion technology
Electrolyte retention	Not applicable for Li-Ion technology
Deep discharge test (7days with bulb)	Possible
Charge recovery after Deep Discharge	Possible
Not needed for lead-acid technology (e.g. jump start from 24V truck)	Additional requirements needed for Lilon (e.g. jump start from 24V truck)
Not needed for lead-acid technology (e.g. Overcharge at 28V/2h)	Additional requirements needed for Lilon (e.g. Overcharge at 18V/1h)
EN 50342-6	Transfer of the EN 50342-6 to Starter Li-Ion batteries
Lead-acid starter batteries -	
Part 6: Batteries for Micro-Cycle Applications	
Micro-hybrid test (MHT)	Possible
Dynamic Charge acceptance test (DCA)	To be adapted for Li-Ion Starter battery
Endurance cycling test with 17.5 % depth of discharge (DoD)	To be adapted for Li-Ion Starter battery
Endurance cycling test with 50 % depth of discharge (DoD) at 40 °C	To be adapted for Li-Ion Starter battery
Water loss	to be adapted as an electrolyte degradation test for Li-Ion technology
High current discharge test at low temperature	Possible
Li-Ion technology	
IEC 62660-1	Transfer of the IEC 62660-1 to Starter Li-Ion Cells
Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 1: Performance testing	
1. General charge conditions	Possible
2. Capacity	Possible
3. SOC adjustment	Possible
4. Power	To be adapted for Starter Li-Ion Cells
4.1 Test method	To be adapted for Starter Li-Ion Cells
4.2 Calculation of power density	To be adapted for Starter Li-Ion Cells
4.3 Calculation of regenerative power density	To be adapted for Starter Li-Ion Cells
5. Energy	To be adapted for Starter Li-Ion Cells
5.1 Test method	To be adapted for Starter Li-Ion Cells
5.2 Calculation of energy density	To be adapted for Starter Li-Ion Cells
6. Storage test	Possible
6.1 Charge retention test	Possible
6.2 Storage life test	Possible
7. Cycle life test	To be adapted for Starter Li-Ion Cells
7.1 BEV cycle test	To be adapted for Starter Li-Ion Cells
7.2 HEV cycle test	To be adapted for Starter Li-Ion Cells
8. Energy efficiency test	To be adapted for Starter Li-Ion Cells
8.1 Common tests	To be adapted for Starter Li-Ion Cells
8.2 Test for cells of BEV application	To be adapted for Starter Li-Ion Cells
8.3 Energy efficiency calculation for cells of HEV application	To be adapted for Starter Li-Ion Cells
Li-Ion technology	
IEC 62660-2	Transfer of the IEC 62660-2 to Starter Li-Ion Cells
Secondary lithium-ion cells for the propulsion of electric road vehicles – Part 2: Reliability and abuse testing	
1. Mechanical test	Possible (but the standard should be extended to Starter Li-Ion Cells)
1.1 Vibration	Possible (but the standard should be extended to Starter Li-Ion Cells)
1.2 Mechanical shock	Possible (but the standard should be extended to Starter Li-Ion Cells)
1.3 Crush	Possible (but the standard should be extended to Starter Li-Ion Cells)
2 Thermal test	Possible (but the standard should be extended to Starter Li-Ion Cells)
2.1 High temperature endurance	Possible (but the standard should be extended to Starter Li-Ion Cells)
2.2 Temperature cycling	Possible (but the standard should be extended to Starter Li-Ion Cells)
3 Electrical test	Possible (but the standard should be extended to Starter Li-Ion Cells)
3.1 External short circuit	Possible (but the standard should be extended to Starter Li-Ion Cells)
3.2 Overcharge	Possible (but the standard should be extended to Starter Li-Ion Cells)
3.3 Forced discharge	Possible (but the standard should be extended to Starter Li-Ion Cells)
Li-Ion technology	
ISO 12405	Transfer of the ISO 12405 to Starter Li-Ion batteries
Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems —	
Part 1: High power applications	
Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems —	
Part 2: High energy application	
Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems —	
Part 3: Safety performance requirements	
	necessity for similar standard for Starter Li-Ion batteries

Thermal environment for batteries

The life time of Li-ion batteries depends to a high degree on efficient thermal management. If the thermal load on these batteries is too high very fast ageing will occur and the battery will fail prematurely.

Internally generated heat from the component during charging and discharging over the battery life time is important and also the local ambient temperature levels are important. If temperatures are too high, additional specific cooling systems become necessary and this has to be considered in the component, location, package and vehicle design.

Figure 2 shows the temperature distribution in the engine compartment of a current vehicle at 30 °C and a velocity of 30 km/h as determined by a major OEM. Temperatures are above 60 °C and in most areas above 80 °C.

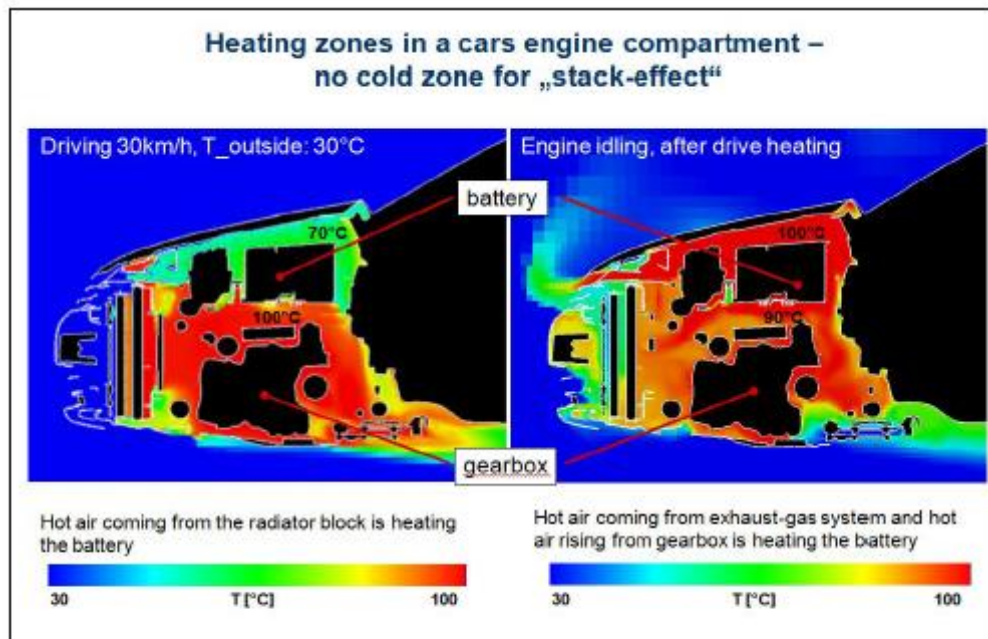


Figure 2 Thermal environment in a vehicle engine compartment showing the battery temperature under different conditions.

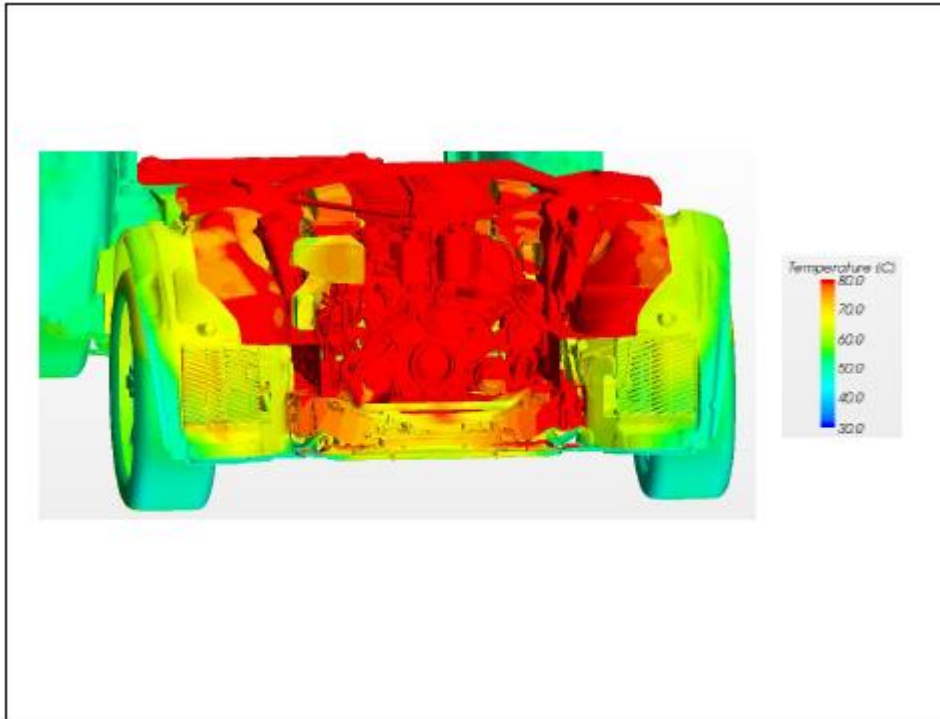


Figure 3 Temperature distribution in a typical vehicle engine compartment.

Figure 3 shows a similar situation in a different vehicle with the temperature distribution in the engine compartment when the engine is running in normal conditions. It can be seen that in most areas temperatures exceed 60oC and are generally at 80oC.

If an additional cooling system is necessary, energy loss of the system at cold and hot temperatures needs to be taken into account.

One of the North American OEMs operating internationally has provided the following comment: lead-acid batteries will operate over the temperature range from -40oC to 75oC measured internally and will survive excursions to 105oC but Li-ion batteries will switch to open circuit when the temperature, applied voltage or current conditions exceed safe limits.

It should be noted that the requirement for cold cranking at -30oC is not changed but lead-acid batteries are not damaged at -40oC and will continue to operate. Unless and until Li-ion batteries can provide robust performance over a full temperature range, they cannot be specified to replace lead-acid batteries without significant restrictions.

In addition to the thermal environment for the battery crash and safety aspects have to be considered.

Crash and safety aspects

Lead-acid batteries do not pose a major risk of catching fire. In general they are outside the scope of component approval as required by ECE-R 100²⁵⁵. It should be stated that the following section refers only to li-ion SLI batteries, and does not refer to Li-ion traction batteries. Li-ion batteries fully adapted for SLI applications will necessarily have a might have a different power density than those used for traction applications and as a result product safety needs to be carefully evaluated. For example, li-ion SLI batteries will have to be tested against stringent standards to ensure the safety of passengers is not compromised in case of an accident. This is explained further in the following section.

The battery needs to be resistant to mechanical damage in the form of compression, shock and puncture.

To comply with product responsibility with regard to crash behaviour, methods to avoid fire and explosions have to be considered. This is not an issue for lead-acid batteries but cannot not be excluded for Li-ion batteries. For batteries defined as rechargeable energy storage systems (REESS), there should be no leakage to the battery during the crash test and no thermal runaway.

The car industry would therefore have to locate Li-ion starter batteries in a non-crash-sensitive area. This is demonstrated in Figure 4, which highlights the risks of deformation of different areas for vehicle electronics considering crash behaviour.

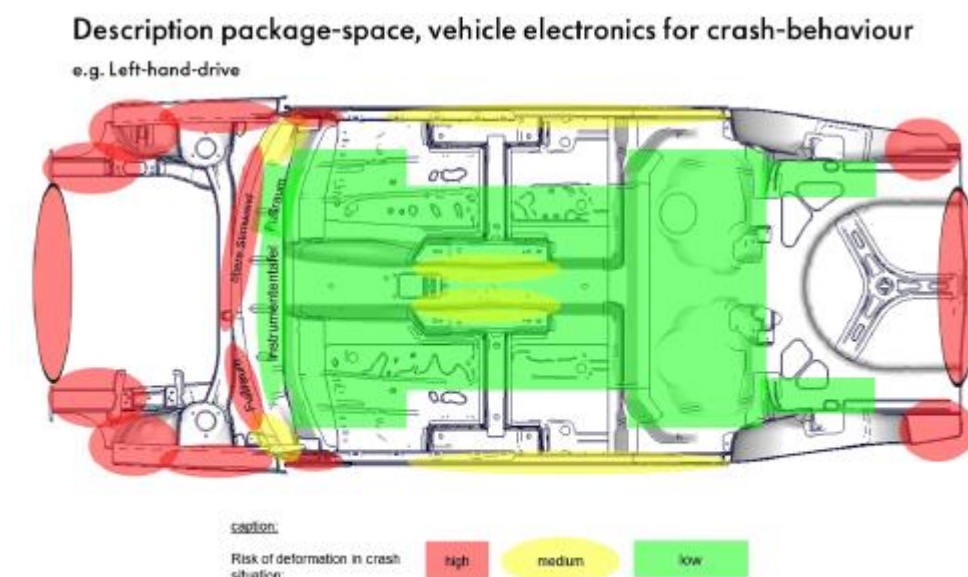


Figure 4 Package space for vehicle electronics considering crash behaviour, demonstrating risk of deformation for different areas of a vehicle (example).

This is a packaging issue and generally a full redesign of the vehicle platform is required.

²⁵⁵ Uniform provisions concerning the approval of vehicles with regard to specific requirements of the electric power train United Nations Economic Commission of Europe (UNECE), Regulation 100, August 2013

Figure 5 demonstrates the impact of a crash on a component in a crumple zone. Reinforcing the car body area to establish a crash safe cage for a component needs to be implemented in the total crash behaviour design of a vehicle. This is a key concern of all OEMs, and no vehicle can be offered for sale until crash safety has been correctly established.

Demonstration, what happens to a battery, if located in the crumple zone of a vehicle



Figure 5 Potential impact of a crash on a component in the crumple zone of a vehicle.

In addition to the overall requirements given in EN 50342 there are special requirements for the implementation in cars; the installation-space issue (“package”). The use of starter batteries in cars is very installation-space sensitive, because there are two very important restrictions. The first, in case of a crash, is that the battery should not catch fire and the second is that during normal operation the battery should not be destroyed or ruptured by heating. In the vast majority of European cars starter batteries are installed in hot installation spaces; i.e. in the engine compartment or in the vicinity of the exhaust pipes. Hot installation spaces typically have a starter battery in the engine compartment and the operating temperatures at up to peaks of 100°C are limitations for a safe installation of any available batteries working with an organic electrolyte (e.g. Li-ion batteries or high capacity electrolytic capacitors).

In addition, batteries containing an inflammable electrolyte are recommended not be located in the crumple zones of the car due to possible risks of thermal incidents in certain crash situations as discussed above. For example positions behind the headlamps or major part of the trunk are crumple zones. Positions such as the passenger cabin are not crumple zones. It is a key requirement that the starter battery has to withstand crash loads without the risk of fire and also that the starter battery has to withstand a thermal environment with temperatures up to peaks of 100°C.

Furthermore, verification is required that the battery will support the electrical requirements of the vehicle throughout the required operational ambient air

temperature range per each particular application and package location. This involves the following:

1) Capability to provide power for engine cranking, electronics support when the vehicle is switched off and back-up support when the alternator or DC/DC converter fails or is switched off.

Robust operation down to -30oC is required which, presently, lithium batteries do not provide. Operation to -25oC is possible but it requires compromise to the engine start function and is typically only achieved by the most expensive lithium options to date. In addition, diesel engines are not supported. Whilst supercapacitors are not as affected by temperature, independent tests have found that in order to support the required cranking time and energy, the capacitor banks have to be relatively large and very costly and, due to their self-discharge characteristics, require management to isolate them when the vehicle is switched off so as to avoid a flat battery. As a result, seamless and direct replacement for a lead-acid battery is not feasible.

2) Capability to sustain power delivery capability throughout assigned drive cycles/use cases performed throughout the required operational temperature range. Due to the recharge limitation of lithium batteries, tests have found that present lithium battery technology, (even those capable of operation to -25oC), do not support short journey operation of vehicles and still maintain the required functionality at temperatures below -10oC as the batteries inevitably move to a lower state-of-charge.

3) Confirmation of robustness of the battery for vehicle operation throughout the temperature range.

This requires a detailed evaluation to ensure that the sensitivity of the lithium battery to fluctuating electrical vehicle loads is well understood. Presently, there is a concern regarding lithium plating occurring due to the transient nature of certain high power vehicle loads (heated windows, suspension pumps, braking systems and other systems). The pulses caused by switching off may cause the battery to be charged at a higher rate than allowed which may cause lithium plating, damage to the electrodes and may lead to short circuits. This, at least, must be evaluated to understand the magnitude of the issue but, additionally, the automated connection and disconnection strategies, which the batteries require are potential weak areas which have the potential to significantly weaken the safety case unless appropriate countermeasures can be developed. Finally, a full component standard will then need to be developed to ensure that the robustness of the battery may be fully verified against the transient load factors, which have been identified.

4) Verified compatibility is between the voltage range required by the battery to maintain safe and robust operation and the range expected by the existing vehicle electrical modules, which are designed for the voltage range provided by lead-acid batteries.

This is an issue if the chemistry of the lithium battery prevents operation in certain voltage ranges expected by the existing electrical system modules and engine control units (ECUs). Functionality may be restricted which then will require redesign of the affected module. The impact will depend upon the battery chemistry used and, as lithium chemistry is not well standardised, may result in complexity, cost and service replacement issues.

5) Verified Compatibility between the vehicle powernet controller and the battery management system especially as regards accuracy and robustness of the battery state estimation signals which are essential to maintain safe operation.

The performance and accuracy of existing lead-acid battery management systems (BMS) is well known and incorporated into existing vehicle designs. Lithium batteries require a more complex BMS for reliability and safety reasons, which for example has to communicate current and voltage limits as functions of temperature, state of charge, and ageing, to control thermal management in terms of absolute and relative temperature limits, to disconnect the battery in case of severe failure. Existing BMS for high voltage batteries cannot be carried over because of different functionality, package, and cost requirements. It should be noted that li-Ion cell suppliers are typically not familiar with and usually not approved for automotive electronics and software development processes. Development of a BMS for li-ion starter batteries that would be feasible and fully qualified for mass production is a substantial engineering and verification task on its own. Verification and validation have to be foreseen both on system (battery) and vehicle integration level. Additionally, high voltage systems cannot be utilised because their design and composition is entirely different to that needed for stand-alone 12 V and the cost impact is huge.

6) Verified robustness of the powernet against the fitment of an incorrect battery. Lead-acid is relatively benign so the fitment of an incorrect battery does not have a significant impact upon the safe operation of the vehicle even though the supported functionality may be affected to some extent. Lithium is a very different chemistry and if charged incorrectly, may cause significant safety issues. As customers are only used to lead-acid batteries then they expect to be able to simply purchase a direct replacement from a shop with the same applying to a battery charger.

7) Compatibility confirmation with manufacturing facility but especially the service infrastructure.

As per the previous issue, dealerships' equipment for charging and diagnosis are only set up for lead-acid batteries. Suitable replacement equipment will need to be identified, proven and sourced at significant cost and, more importantly, this will take time to achieve.

8) Definition and agreement of how to treat 12 V lithium batteries at end-of-life in relation to both the End-of-Life Vehicle and Batteries Directives and, ideally to agree a recycling process. These issues associated with Li-ion recycling have already been discussed at length in our previous submissions.

b. Please include detail of required development stages and the time estimated for their completion (the time needed for each stage). If relevant please refer to differing battery chemistries.

As explained in our previous contributions, there are many obstacles and challenges for Li-ion batteries to overcome before they can be considered as an alternative technology in SLI applications (slide 5 of our presentation during the stakeholder meeting). One of the key challenges remains to ensure the life duration. These obstacles were agreed by A123 in the April 10 meeting. *If* these are overcome, and an alternative technology developed, European OEMs estimate that the required installation and ramp up of the technology would require an implementation time of at least 10 years. Under this timescale, if a technology were already available as a

technical substitute for 12 V batteries used in conventional vehicles, it would not be until about 10 years later that it could be implemented into new vehicles being released onto the European market²⁵⁶.

This process involves many stages, starting with tests on cell level, component tests under a range of different conditions followed by the development of prototype vehicles. If these are successful, summer and winter tests need to be carried out and then pilot applications will be undertaken to ensure correct and reliable operation. Car manufacturers have to follow strictly defined development processes in order to get to robust and safe vehicle implementations. This applies as well for Li-ion SLI batteries, considering the impact of Li-ion technology on vehicle safety with regard to both component safety (hazards caused by the battery as well as the impact of abuse or accident to the battery) and vehicle safety in general (e.g. functional safety of electrified chassis or driver assistance systems affected by power supply failure). Those cars that are presently equipped with Li-ion starter batteries have run through modified pilot processes which are not applicable for mass volume production. Hence applications are restricted for example to moderate climate markets because of the limitations of Li-ion technology already described. The current field trials feature over dimensioned Li-ion batteries with a very high cost impact and very high integration efforts, linked with functional limitations and are only feasible in order to obtain first long-term field experience.

Furthermore volumes are kept very low, with the customer vehicles being closely monitored by OEMs. An additional reason for these very low volumes are the present limitations in service and recycling capabilities. These early adopter applications have to be considered as early field trials rather than as regular series applications.

Technology development and integration for automotive products typically occurs in 3 phases: advanced engineering, product development and platform development. A simplified project plan for the research, development and the required test-phases for a new battery system is presented in the figure below (Figure 6):

²⁵⁶ A review of battery technologies for automotive applications Joint industry analysis 2014

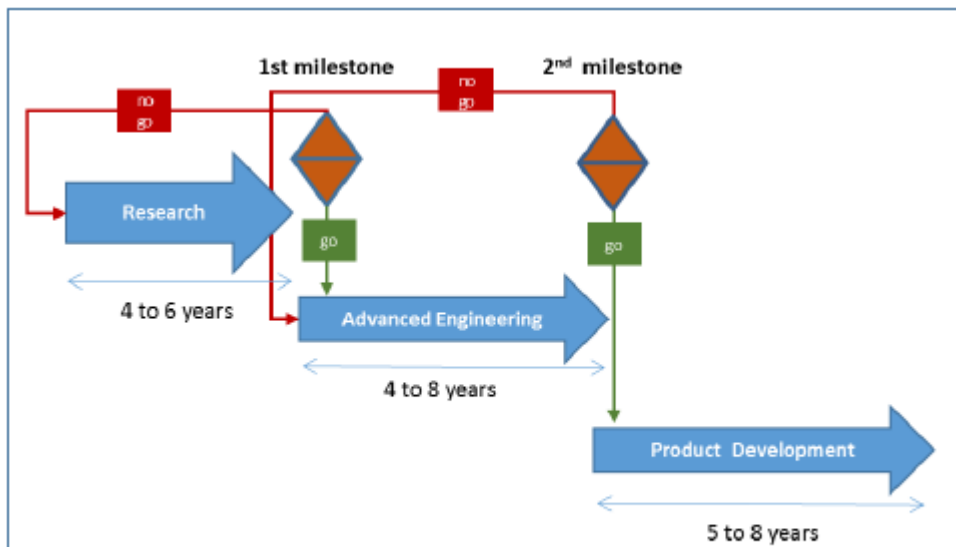


Figure 6 Simplified project plan for a first volume application (for a more detailed overview please refer to ANNEX 1 – “20150427_generic_project_timeline_battery_ACEA.pdf”)

As indicated in Figure 6 milestones have to be integrated to validate the possibilities for further development. In the event of technological problems and drawbacks further development loops have to be considered.

In the attached diagram (ANNEX 1), a best case generic timing plan for a typical first volume application is presented. As a prerequisite for this timeline it is assumed that all obstacles – described in detail in this document and in all previous contributions – are overcome and that the steps of all three phases are concluded successfully. Many of these steps can run in parallel but the total time required is at least 10 years and longer if technical obstacles have to be overcome. For Li-ion batteries for SLI applications the programme would commence when robust batteries become available meeting all the various technical and safety requirements.

Up to now, not even the cell materials used in Li-ion SLI batteries (e.g. electrolyte) can be finalised today that would be required to survive engine bay temperatures without massively deteriorating the winter performance. In consequence, the full timescale including cell research has to be considered.

Further assumptions are as follows:

- The known cell technology available today would not allow an engine bay package which also has crash zone package issues. For these applications, suppliers have still to do fundamental material and cell research and development work, for which 3 years duration is a very optimistic assumption.
- Based on that, the usual A/B/C/D cell pack sample development stages has to be carried out sequentially (further explained in Annex I). No OEM program (with significant volume) can be initiated without pack system A-samples successfully tested.
- In parallel, OEMs would have to investigate and package/protect platform modifications that will include some passive or active cooling. However, it is impossible to move all starter battery locations into cool and crash protected locations for all global platforms.

- Given the high technological risk, fast adaptation for mainstream volumes would require standardisation of requirements, avoiding the need for multiple OEM specific parallel tests and reducing the engineering risk. 4 years is an optimistic timing assumption for this process that will include life tests validation in several iterations. The recent development of EN 50342-6 for 12 V lead/acid micro hybrid-batteries took 4 years from kick-off to decision about the draft for voting (the voting and administrative process steps are still pending and causing another 8-12 months delay before the standard is in force). Notwithstanding this, mass production was already launched several years before and field data is available. Collaborative working relationships between OEMs and the battery supply base have been established for decades. Still, no harmonization with other regions (e.g. North America, Japan and China) was possible within this time frame. In addition, it has taken 6 years from May 2008 (kick-off meeting for ISO 12405-1) to May 2014 (ISO 12405-3 published) to create ISO 12405 (“Electric road vehicles – test specification for Li-ion traction battery systems”).

As OEMs and the supply base is already active in research, and to some extent advanced engineering, for the 12V SLI battery application, there are some applications for which Li-ion could enter the advanced engineering stage earlier. These applications would, as absolute minimum requirements, have to

- accept some degradation on winter performance (both cranking and recharging: e.g. luxury cars that are unlikely parked outdoor under harsh winter conditions and have a fuel fired heater that can warm up the battery),
- provide a package location that avoids temperatures above 60 °C,
- provide a package location outside crash zones,
- not require any significant platform/architecture modifications.

If the available cells are compatible with package and technical requirements of a given vehicle, the research phase can be significantly shortened. This may apply only to a fraction of the vehicles that have the battery at least not packaged in the engine bay. Nevertheless, as outlined in the other parts of this document, roll-out to mainstream applications even if they fulfil the above conditions is far from straightforward. Moreover, in many battery locations outside the engine bay, the 55 to 60 °C temperature limits would still be exceeded, e.g. in the vicinity of the exhaust tail pipe. It was not possible to quantify this fraction more precisely due to the competitively sensitive nature of the information involved.