Stakeholder Consultation Questionnaire: Exemption No. 5
"Lead and lead compounds in components: Batteries"

Industry contribution of ACEA, JAMA, KAMA, CLEPA, ILA and EUROBAT.

Please find below the answers to the stakeholder contribution concerning exemption 5. Input is based on results of a working group consisting of OEMs and suppliers as well as the International Lead Association ILA and EUROBAT.

Question 1

Please explain whether the use of lead in the application addressed under Exemption 5 of the ELV Directive is still unavoidable so that Art. 4(2)(b)(ii) of the ELV Directive would justify the continuation of the exemption.

Please clarify what types of vehicles your answer refers to, i.e., conventional vehicles and various types of hybrid and electric vehicles and which functionalities are covered (starting, ignition, lighting and other points of consumption).

The use of lead in the application addressed under Exemption 5 of the ELV Directive is still unavoidable and therefore that Art. 4(2)(b)(ii) of the ELV Directive should justify the continuation of this exemption.

The answers to this and the following questions regarding exemption 5 of the ELV Directive represent the views of the following Associations:

- The European Car Manufacturers Association (ACEA)
- Japan Car Manufacturing Association (JAMA)
- Korea Car Manufacturing Association (KAMA)
- The European Association of Automotive Suppliers (CLEPA)
- The International Lead Association (ILA)
- The Association of European Automotive and Industrial Battery Manufacturers (EUROBAT)

The information referred to in the following responses is an elaboration of the last review of exemption 5 under the ELV, and represents extensive work and data collection from 2010 until February 2014. It should also be noted that all the existing arguments made during the last ELV stakeholder consultation still apply. The work of this group has also involved the publication of the following 4 study reports, which explains why the exemption should to be continued:

- ***A review of battery technologies for automotive applications.*** This report concludes that for technical and socio-economic reasons, 12 V lead-based batteries will continue to be mass market systems in virtually all vehicles (Conventional vehicles with combustion engines (ICE), Hybrid-Electric and Electric Vehicles) for the foreseeable future. The document can be found here http://www.eurobat.org/sites/default/files/rev_of_battery_executive_web_1.pdf.
- ***The availability of automotive lead-based batteries for recycling in the EU.*** This document concludes that 99% of lead-based batteries in the EU are collected and recycled. The document can be found here http://www.eurobat.org/sites/default/files/ihs_eurobat_report_lead_lores_final_2.pdf

- ***Resource availability of metals used in batteries for automotive applications.*** This document concludes that there are no current or future resource availability issues with the materials used to manufacture lead-based batteries. It highlights some future resource availability issues for other battery technologies such as lithium-ion batteries. The document can be found here http://www.eurobat.org/sites/default/files/resource_availability-final_long_version.pdf
- ***Life-cycle assessment of lead-based batteries for vehicles.*** This document highlights the significant CO_2 savings gained from the use of advanced technology batteries. It also concludes that the high recycling rates of lead-based batteries reduces the overall environmental impact of the battery throughout its lifecycle, and that the battery's overall environmental footprint during manufacturing is negligible in comparison with the manufacture of the vehicle as a whole. The document can be found here: http://www.acea.be/uploads/publications/LCA_of_Pb-based_batteries_for_vehicles_-_Executive_summary_10_04_2014.pdf

Lead batteries are essential for vehicles – conventional ICE vehicles, all hybrid vehicles (mild, micro and Plug-in-HEV, PHEV) and full electric vehicles (EV). Our answer therefore refers to all these vehicle types.

Lead-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 (starter-lighting-ignition). Its excellent cold-cranking capability, with decades of proven reliability, low combined cost and compatibility with these vehicles' 12 V electrical system set the lead battery apart from other battery technologies in conventional vehicles. As such, the lead-based 12 V battery will continue to be the mass market battery for the foreseeable future.

Furthermore, advanced lead-based batteries (AGM[1] and EFB[2] 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)[3].

Lead-based batteries are also 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.

A 12V lead-based battery powers the following functionality: (non-exhaustive)

- Starter, lighting, ignition
- Emergency flashers
- Electronic locks
- Airbag control units

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[1] Absorbent-Glass Matt (AGM) Battery
[2] Enhanced Flooded Batteries (EFB)
[3] Life Cycle Assessment – LCA of Lead-based Batteries for Vehicles (PE International, 2014)

- ABS (anti-lock braking system) control units
- ESP (Electronic Stability Control) control units
- Defrost systems
- Displays for car information
- Power steering
- Electric windows levers
- Audio/stereo systems
- DVD systems
- Heated seats

In addition to the functions listed above, 12 V batteries for hybrid and electric vehicles also provide the following functions:

- Battery management system

  The lead battery powers the battery management system, which is an electronic system that manages another battery (e.g. a battery powering an electric/electrified vehicle), such as by protecting the battery from operating outside its Safe Operating Area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and/or balancing it. Essentially a battery powering an electric/electrified vehicle (e.g. hybrid vehicles which include electric power trains, plug-in hybrid vehicles and full electric vehicles) could not function without a battery management system, which is provided for in all such vehicles by a 12 V lead battery.

- Range extender

  A Range extender is an auxiliary power unit built-in or externally attached to all-electric or plug-in hybrid electric vehicle to increase its all-electric range (AER). The most commonly used range extenders are internal combustion engines that drive an electric generator which in turn supplies the battery and electric motor with electricity. These range extenders are powered by a 12 V lead battery in all such vehicles.

Question 2

If the substitution of lead is still not possible, please explain the efforts your organisation has undertaken to find and implement the use of lead-free alternatives in the manufacture of batteries for automotive uses. In your answers please refer to alternatives, which reduce the amount of lead applied or, which eliminate its necessity altogether. Please refer among others to candidates identified in the past such as:

- **Lithium-ion batteries;**
- **Supercapacitors coupled with a lead-acid battery;**
- **Hybrid lead-acid batteries such as the PbC® battery or the UltraBatteryTM;**

As explained in question 1, the substitution of lead-based batteries in automotive vehicles is still not possible.

Lead batteries are vital to ensure the mobility on European roads at least for the next 10-15 years. Lead batteries are established components and standardised worldwide. During the last years the efficiency and the design has been improved e.g. by absorbent glass mat technology (AGM) as used for micro hybrid systems or enhanced flooded batteries (EFB). In particular the cold cranking properties of lead based batteries make these battery types essential. At low temperature no other commercially available battery system for volume production is able to meet the required performance or demand (Starting ability at temperatures around -30°C required). The Circular Economy is already a fact for lead based batteries, after long service life an already established and well-functioning closed loop recycling economy provides resources for the production of new batteries in Europe within the EU market with high proportions.

For new cars in development it is evident that more and more electric power is needed to provide for the functioning of all electronic systems. Systems like mobile car communication, intelligent electric steering systems instead of hydraulic or mechanical systems and new customer expectations will increase demand for electrical energy. Despite every effort to design efficient vehicle electric power systems the demand for storage and provisioning of electrical energy is increasing. A wide variety of different national, European and worldwide R&D projects are conducted. The aim is to develop energy storage systems with higher energy density and lower weight suitable even for harsh climatic conditions.

By no means exhaustive examples of recent projects in Table 1, providing evidence that the automotive industry has many intense on-going research programs for new energy storage systems (in Germany alone more than 600 Mio € are provided by the NPE research program for research on battery systems). On the other hand it illustrates, that these systems are not yet available for the Automotive Industry and that the results of these research projects needs to be further developed and tested in pilot applications to verify if these systems are able to meet the criteria for volume serial production

It should be noted, that higher availability of energy has additional safety advantages. It can be assumed that different mobile energy storage components will ensure active redundancy in cases of malfunction at a component level in the future. Already today all available Electric Vehicles in volume serial production with high voltage Li-batteries have additional 12 V Lead batteries to ensure SLI (Start, Lightning and Ignition) and additional safety functions. This dual energy storage concept of the combination of different battery technologies for different purposes (cold cranking ability and recuperation) is in focus of several development projects.

In summary the Automotive Industry confirms, that lead-based battery-systems are essential and necessary in volume serial production for the foreseeable future and that the industry is conducting intensive R&D efforts on enhanced energy storage systems.

Table 1: Examples for actual R&D projects (public founded projects)

PROJECT EXAMPLES	DURATION
NATIONAL D[4]	
Verbundvorhaben SHELION (Safe High Energy Lithium-ION):	1.1.2014- 31.12.2015
Entwicklung und Charakterisierung von Nanomaterialien für neuartige Kathoden von wiederaufladbaren Li-Ionen-Batterien (NanoSiLiKat)	1.9.2013- 31.8.2015
DriveBattery2015; (LiIon & Lead batteries covered)	1.8.2013- 30.06.2017
Verbundprojekt MULTIBAT: Multikalenmodelle und Modellreduktionsverfahren zur Vorhersage der Lebensdauer von Lithium-Ionen-Batterien	1.7.2013- 30.6.2016
Li-EcoSafe - Entwicklung kostengünstiger und sicherer Lithium-Ionen-Batterien	1.6.2013- 31.5.2016
Intelligente Datenbuskonzepte für Lithium-Ionen Batterien in Elektro- und Hybridfahrzeugen - IntLiIon;	15.5.2013- 14.5.2016
Entwicklung temperaturoptimierter Batteriemodule mit instrumentierten Zellen - TopBat;	1.5.2013- 30.4.2016
Integrierte Komponenten und integrierter Entwurf energieeffizienter Batteriesysteme - IKEBA;	1.5.2013- 30.4.2016
Hochtemperatur- und Energiematerialien	1.6.2013- 30.6.2016
Automatische Lithium-Ion Batterie-Modul-Assemblierung, Johnson Controls Hybrid and Recycling GmbH, ALiBaMA	1.1.2013- 31.12.2015

[4] Source: http://doku.uba.de;

Alpha Laion - Hochenergie-Lithium Batterien	1.9.2012-31.8.2015
Projektierung qualitätsorientierter, serienflexibler Batterieproduktionssysteme (ProBat);	1.8.2012-31.7.2015
SafeBatt - Aktive und passive Maßnahmen für eigensichere Lithium-Ionen Batterien	1.7.2012-30.6.2015
Produktionstechnik für Lithium-Ionen-Zellen (ProLIZ);	1.1.2012-31.12.2014
Lissi - Entwicklung von Lithium-Schwefel/Silicium Batterien mit hoher spezifischer Energie für die Fahrzeuganwendung	1.7.2011-30.6.2014
SMILE KB2220 Li-Batterien	1.9.2014 31.8.2017
Verbundvorhaben DESIREE	
SafeBatt- Aktive und passive Maßnahmen für eigensichere Li Ionen Batterien Teilprojekt 2.3.5. Toxikologische Bewertung	1.7. 2014 – 30.06.2015
EUROPE EU FP 7 & Horizon[5]	
MEMLAB - Melt Spun and Sintered Metal Fibre Networks for Lead-Acid Battery Advancement	Start date: 2012-11-01, End date: 2014-10-31
LISSEN - Lithium Sulfur Superbattery Exploitating Nanotechnology	Start date: 2012-09-01, End date: 2015-08-31
EUROLIS - Advanced European lithium sulphur cells for automotive applications	Start date: 2012-10-01, End date: 2016-09-30
ENERGY CAPS - Development of a sustainable and safe hybrid supercapacitor with high specific energy and maintained high specific power and cyclability	Start date: 2011-12-01, End date: 2015-11-30

[5] Source CORDIS.europa.eu/search/advanced-en ;

Since 2010, European OEMs have continued their efforts to evaluate the benefits and limitations of alternative technologies that reduce or eliminate the use of lead in automotive batteries. This includes the testing of vehicles during the research and development of future vehicle models. This is a continuation of the product development cycle and whilst there is some promise that the new technologies may supplement, improve or possibly replace lead-based SLI batteries in some vehicles it must be stated that they are still a considerable way from becoming a mass market technology.

As explained, Lead-based batteries are the only technologically viable mass-market option for conventional vehicles, as well as for start-stop and micro-hybrid vehicles. Their excellent performance in cold and hot conditions and their low cost sets them apart from other battery technologies. This combined with their low self-discharge rate, unmatched reliability, safety and the well-established European manufacturing and recycling industry, establish them as the most practical option for the foreseeable future. Lead-based batteries are also 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 safety controls, comfort features and redundancy (as described in detail in question 1).

For reference with the following information, the average battery weight of a lead-based battery can vary between 18 kg and 20 kg, from a standard SLI battery to an advanced lead battery used in a micro/mild hybrid (lead and lead compounds are approximately 60% of the total weight of the battery). The average lifetime of these batteries will range from 5-7 years[6]. However, it should be stressed that battery life will depend upon real world conditions (temperature, usage etc.), and battery life can exceed those mentioned.

Successful efforts have been made to increase the efficiency of the lead-based battery by reducing the amount of lead needed to meet the required performance. However, the increasing amount of electrical components in cars and additional functions that the battery is required to cover (as details in question 1) has imposed extra requirements on the automotive battery (i.e. deeper and more frequent discharge). This has meant that there has not been a corresponding reduction in battery weight for AGM and EFB batteries. In addition, it should be stressed that although the amount of lead has not decreased in lead-based batteries, the use of improved and advanced lead-based batteries (EFB and AGM) more than offset this by the environmental savings they enable when installed in passenger vehicles. These batteries are integral to start-stop and micro hybrid engine systems which result in lower fuel-consumptions than regular engines. For example, PE international conducted a life cycle assessment of lead-based batteries in Europe in 2014[7]. This report concluded that over the lifetime of a vehicle, these systems resulted in savings of between 700-1600 kg CO_2 eqv. This can be seen more clearly in the figure below, which demonstrates the significant CO_2 savings gained by use of improved and advanced lead-based batteries.

[6] *A review of battery technologies for automotive applications* Joint industry analysis 2014
[7] *Life-cycle assessment of lead based batteries for vehicles* PE International 2014

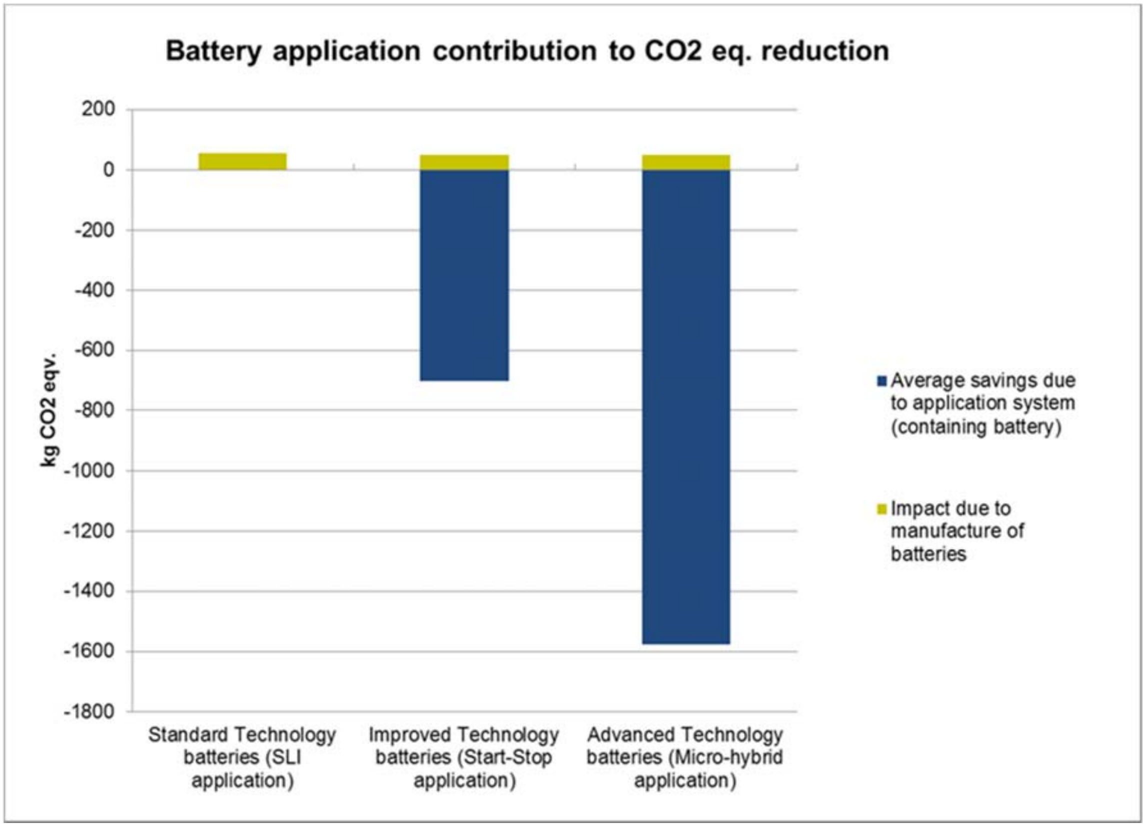

Figure: Net impact and savings associated with lead batteries over 1 vehicle's lifetime

AGM Batteries

During the last ELV consultation for exemption 5, it was stated that Absorbent Glass Mat (AGM) batteries were crucial for the technology and may permit a reduction in fuel consumption and CO_2 emissions by 10%. It was recommended that further research in this field may allow even further emission reductions and environmental benefits. At the time, it was stated that the product was still under development, but that AGM technology may offer even future chances for improving the environmental compatibility of batteries and vehicles. Both AGM and EFB are now widely used in start-stop technologies and are commercialised in several mass market car models, with Pike Research estimating that there will be 37 million units in the global car market by 2020[6]. It has also been reported that these technologies reduce fuel consumption by 5-10%[7]. It should, however be stressed that 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. These batteries are able to meet the extra requirements demanded by start-stop and basic micro-hybrid vehicles whilst providing higher performance efficiency and longer lifetimes.

Alternative technologies-lithium-ion batteries

For the use in SLI, start-stop and micro hybrid applications, lithium-ion batteries still require improvements in cold cranking ability and the economic packaging (including cost level) to be considered a viable mass market alternative to lead-based batteries[8]. The further advancement and development of lithium-ion batteries could permit an opportunity for their use in limited SLI applications, albeit primarily as a performance option when weight saving is a sufficient driving factor to accept increased cost and their lower performance in cold conditions. European OEMs are continuing R&D efforts to evaluate the benefits and limitations of lithium-ion technologies in real applications, in order to develop further insights on this topic. The authors could not identify any mass market use of lithium-ion batteries in SLI, start-stop and micro hybrid applications which could one-to-one replace a lead battery.

Alternative technologies-nickel-based batteries

Research has been conducted investigating the use of nickel-based batteries for SLI, start-stop and micro hybrid applications. However, these batteries are not considered as a viable alternative due to their inferior cold cranking performance and other limitations. For example, Nickel Iron batteries are not considered suitable in this application due to their low cycling ability, high self-discharge rate and permanent hydrogen gassing[8].

Alternative technologies-sodium based batteries

There are no manufacturers of sodium SLI batteries for automotive applications. Being mostly an energy battery type, the classic SLI or start-stop and micro hybrid applications are not considered a realistic application for sodium based batteries[8]. For example, sodium-based technologies are required to operate at internal temperatures above 250°C to keep components in a molten state, which requires a thermal insulation. In periods without electrical use, external heating is required to keep the battery ready to operate. Therefore this battery technology is not suitable for SLI applications.

Supercapacitors coupled with a lead-acid battery; Hybrid lead-acid batteries such as the PbC® battery and the UltraBatteryTM;

In order to cope with increasing power requirements and expand the capabilities of micro-hybrid vehicles, European manufacturers have been examining how to refine battery design to optimise deep-cycle resistance and charge recoverability. Research projects from the Advanced Lead Acid Battery Consortium (ALABC) have also demonstrated the successful use of advanced lead-based battery systems in mild-hybrid vehicles, either individually or in 48V/12V dual battery.

Dual Board-nets and Hybrids

A dual board-net allows for batteries of different voltages to be integrated in vehicles, without having to change the voltage of on-board electronics. 48V/12V systems are beginning to be considered for increasing fuel efficiency in micro- and mild-hybrid vehicles. Such a configuration involves a conventional 12V network using a lead-based battery, but adds an additional 48V network powered by a 48V battery (lithium-ion, lead-based etc.). It should be noted that the maximal charge voltage (c.f. the legal limit of 60V) is still being defined by OEMs.

[8] *A review of battery technologies for automotive applications* Joint industry analysis 2014

In this setup, the 12V network continues to handle traditional SLI loads (lighting, ignition, entertainment, audio systems, electronic modules), while the 48V system supports the vehicle's active chassis systems, air conditioning compressors, and regenerative braking. This has the potential to further increase fuel efficiency in mild-hybrid vehicles[9].

This has involved research into the use of EFB and AGM batteries with enhanced carbon in the negative plate (lead-carbon batteries). Where increased electrical functionality is required (as explained in question 1), lead-carbon designs have been introduced to inhibit the negative plate sulphation frequently observed in the battery's partial state-of-charge operation. Various lead-carbon batteries have been introduced to the market in recent years including the PbC® battery and Ultrabattery®, as well as those with carbon blended into the negative active material. The three main approaches comprise:

1. Blending carbon with the standard negative lead paste that is used in negative electrodes;

2. Developing split-electrodes in which half of the negative electrode is lead and the other half is carbon (UltraBattery);

3. Completely replacing the lead-based negative electrode with a carbon capacitor electrode assembly (PbC). Therefore, this setup has a sloping capacitor voltage characteristic, not the typical stable battery voltage characteristic[9].

Through these developments, lead-based batteries can provide higher performance both in terms of charge recoverability and by their capability to operate at partial states of charge. These improvements will increase their competitiveness in micro-hybrid and mild-hybrid vehicles[9]. These batteries are still in developmental phase and more time and investigation is needed to assess these batteries. 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 than those in a standard lead-based battery. This information is further explained in "A review of battery technologies for automotive applications"[9.]

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[9] *A review of battery technologies for automotive applications* Joint industry analysis 2014

Question 2a

Please compare alternatives with lead-based batteries to clarify on a quantitative basis how alternatives perform in relation to the lead-based batteries currently in use in various vehicles in respect of requirements such as:

The comparison of lead-based batteries and alternative technologies is comprehensively covered in the study "A review of battery technologies for automotive applications". This can be found here http://www.eurobat.org/sites/default/files/rev_of_battery_executive_web_1.pdf. Information in the answers below is taken from this document.

Lead-based batteries are the only technologically viable mass-market option for conventional vehicles, as well as for start-stop and micro-hybrid vehicles. Their excellent performance in cold and hot conditions and their low combined cost sets them apart from other battery technologies. This combined with their low self-discharge rate, unmatched reliability, safety and the well-established European manufacturing and recycling industry, establish them as the most practical option for the future. Lead-based batteries are also 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.

As discussed in question 2, 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.

Supercapacitors coupled with a lead-acid battery would not substantially reduce the size, or lead demand, of the main battery. Hybrid lead-acid batteries are still in developmental phase but by their very concept 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 than those in a standard lead-based battery.

Research into Lithium-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, lithium-ion batteries still require improvements in cold cranking ability and the economic packaging (including cost level) in order to be considered a viable mass market alternative to lead-based batteries[10].

Cold cranking;

Cold cranking is defined as the battery's ability to effectively start an engine at low temperatures (down to -30°C). The vehicle's electric cranking motor requires high currents to convert electrical energy into sufficient mechanical energy. The battery's ability to provide high currents with stable voltage decreases with low temperatures, and consequently higher cold-cranking amperes (500 to 1000 CCA) are requested as part of OEMs' vehicle specification, to assure cranking function can be provided in very cold weather conditions. In order to recharge the battery, charge acceptance at very low temperatures is

[10] *A review of battery technologies for automotive applications* Joint industry analysis 2014

also required (i.e. -10°C to -30°C). The recommended temperature range to operate a lead-based battery is between -30 and +75°C[11].

Lead-based batteries have a volumetric power of approximately 800 W/l at temperatures below -18°C, for a period of more than 10 seconds. At the end of its service life, the battery's power performance in cold temperatures will still be above 450W/l. Consequently, lead-based batteries are able to reliably start a vehicle's combustion engine at low temperatures, something that has traditionally set them apart from other technologies. Their cranking capability is ensured even at lower temperatures down to -30°C, as required in regions of Northern and Eastern Europe and as specified by vehicle manufacturers. Reliable cold cranking performance is also secured in start-stop applications when advanced EFB and AGM designs are used[11].

Nickel Metal Hydride (NiMH) batteries would need to be considerably oversized if they were to provide the necessary cold-cranking amperage to start an engine, in comparison with a lead-based battery for the same type of vehicle. In 2010, Roland Berger estimated the oversizing factor to be approximately 30% at temperatures down to -18°C; corresponding with a weight increase of 10% for the NiMH battery, and increased overall costs. Power capability at lower temperatures down to -30°C is not ensured[11].

Specially designed lithium-ion batteries are technically capable of satisfying a conventional vehicle's cold-cranking requirements down to the reference temperature of -18°C. However, at lower temperatures down to -30°C, lithium-ion batteries still have significantly inferior discharge characteristics. Furthermore, a limited recharge rate at low temperatures must be taken into account[11].

Being mostly an energy battery type, the classic SLI is not today a realistic application for sodium-based batteries: the technology has not been developed or considered for this purpose[11].

Typical service life;

Calendar life is one of the essential requirements that automotive SLI batteries are required to fulfil. Current SLI batteries can be expected to have a calendar life of 5-7 years before replacement becomes necessary[9].

Lead-based batteries are highly durable, with their calendar life not significantly affected by high/low temperatures (although self-discharge and water evaporation from the electrolyte does increase). Lead-based batteries can be placed under the hood of the vehicle (close to the starter motor) without need for a heat-shield or a cooling system. The average calendar life of a lead-based SLI battery is 5-7 years. 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). Although such duty profiles typically generate electrolyte stratification for flooded battery designs, lowering capacity and accelerating ageing, this effect is mitigated when the electrolyte is immobilised, as in AGM battery designs[11].

The calendar life of NiMH traction batteries used in full-hybrid vehicles is approximately 8-10 years. There is no experience of using them as a starter battery, but it can be assumed their calendar life would

[11] *A review of battery technologies for automotive applications* Joint industry analysis 2014

be reduced significantly due to the high temperatures in the engine compartment. Even the use of a thermal management system (with a further cost for the overall system) cannot overcome this issue, as the heat after engine stop continues to warm up the battery even as the cooling is deactivated[12].

The calendar life of lithium-ion traction batteries used in hybrid vehicles (and PHEVs/ EVs) is approximately 10 years. These vehicles still however require a 12 V lead-based battery to provide controls, comfort features, redundancy and safety features (as explained in question 1).

<u>• Reliability requirements;</u>

Lead-based batteries have an unmatched reliability in vehicle applications. At present, SLI batteries are often placed in the engine compartment (to minimise cable resistance) and may operate at high temperatures. Services and cell stability must be maintained in all reasonable conditions. Lead-based batteries are regarded as intrinsically safe systems, both in production and operation, and can be operated within a wide temperature range. This is confirmed by a long history and by practical experience.

Operations of lithium-ion batteries are 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[12]. (N.B.: In single battery architectures including ICE vehicles with start-stop and micro-hybrid features, it is not permitted to disconnect the battery at any time, in order to ensure the operation of essential features such as the hazard warning lights.)

<u>• Average cost per vehicle (for battery system and over the vehicle lifetime, i.e., where the average number of battery replacements is included in calculation);</u>

Cost efficiency is a primary differential for OEMs and consumers, in order to optimise overall vehicle costs and maintain competitiveness. However, as there is no experience of lithium, sodium or nickel based batteries SLI batteries it is not possible to assess the cost per vehicle. Nevertheless, information is provided below for the different batteries on a kWh basis.

At present, lead-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[12].

NiMH batteries for SLI applications would cost approximately 4-5 times more than their lead-based equivalents[11], due to higher cell costs and the additional costs for their battery management system, shielding and housing. This cost differential is too high for NiMH SLI batteries to be considered as a viable alternative technology for use in mass-market conventional vehicles[12].

On a cell level, the upfront costs of lithium-ion batteries remain significantly higher than for 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). Although some

[12] *A review of battery technologies for automotive applications* Joint industry analysis 2014

of these high upfront costs could eventually be distributed over the Total Cost of Ownership (TCO), they remain another barrier against lithium-ion batteries being considered as a viable alternative to lead-based batteries for use in mass-market conventional vehicles with a single 12V battery with SLI function[13].

• Energy density;

The battery's energy density is a primary focus for batteries used for propulsion in advanced micro-hybrid, mild-hybrid and full-hybrid vehicles. The energy content of batteries in this class needs to be high, in order to provide sufficient energy for extended driving on electric power. However, energy density is not a critical requirement for SLI batteries, and therefore is not discussed further here. More detailed information on energy density of batteries used for propulsion in advanced micro-hybrid, mild-hybrid and full-hybrid vehicles can be found in the *A review of battery technologies for automotive applications* Joint industry analysis 2014.

•Power density;

Meeting higher power demands, especially under continuous discharge, affects the battery's life endurance as a thinner electrode configuration must be used. Power density requirements will depend upon the specifications of the vehicle manufacture. Power demands for SLI applications result mainly from starting the vehicle under cold and warm conditions and board net stability requirements. Power densities in the range of 300 to 500 W/kg are required for these applications (e.g. for a 90 Ah battery).

Lead-based batteries with reliable life endurance allow a continuous power-to-energy ratio of 3 kW/kWh. This makes it difficult to serve longer acceleration periods in vehicles with small batteries[13].

High energy NiMH systems provide a continuous power performance of 150 W/kg. A plug-in hybrid with a 10 kWh battery on board would provide about 30 kW, which may be insufficient for a typical mid-size car. A full electric vehicle with a 30 kWh battery will have a typical power performance of greater than 90kW, which will not affect its acceleration ability[13].

Lithium-ion batteries designed for high energy applications in electric vehicles normally provide a peak discharge power performance from 3-10 kW/kWh, which corresponds to approximately 300-1000 W/kg. Even for a small 10 kWh battery system, this results in sufficient power for use in electric vehicles[13].

Power density achievable by sodium nickel chloride batteries is 180 W/kg and 270 W/l at battery pack level[13].

• Typical weight and content of ELV restricted substances;

The average battery weight of a lead-based battery can vary between 18 kg and 20 kg, from a standard SLI battery to an advanced lead battery used in a micro/mild hybrid (lead and lead compounds are

[13] *A review of battery technologies for automotive applications* Joint industry analysis 2014

approximately 60% of the total weight)[14]. This equates to a lead/lead compounds weight of between 10.8 kg-12 kg.

Alternative technologies such as nickel and lithium-based batteries do not contain substances that are restricted by ELV. However, it should be noted that alternative battery chemistries can also contain substances of concern. For example nickel cadmium batteries contain nickel salts and cadmium that have acknowledged adverse health properties and the lithium cathode material that can be used in lithium-ion batteries is lithium cobalt oxide. A number of cobalt salts have recently been included on the REACH candidate list, with some now proposed for prioritisation for addition into Annex XIV of REACH due to health concerns.

• Self-discharge rate;

Lead-based batteries have a self-discharge rate of ~3% per month. NiMH has a discharge rate of ~15-20% per month and Li-ion batteries of ~2-5% per month. This will however depend on the ambient conditions such as temperature[14].

• Temperature range;

This is discussed in the cold cranking section. However lead-based batteries have a volumetric power of approximately 800 W/l at temperatures below -18°C, for a period of more than 10 seconds. At the end of its service life, the battery's power performance in cold temperatures will still be above 450W/l. Consequently, lead-based batteries are able to reliably start a vehicle's combustion engine at low temperatures, something that has traditionally set them apart from other technologies. Their cranking capability is ensured even at lower temperatures down to -30°C, as required in regions of Northern and Eastern Europe and as specified by vehicle manufacturers. Reliable cold cranking performance is also secured in start-stop applications when advanced EFB and AGM designs are used[14].

NiMH batteries would need to be considerably oversized if they were to provide the necessary cold-cranking amperage to start an engine, in comparison with a lead-based battery for the same type of vehicle. In 2010, Roland Berger estimated the oversizing factor to be approximately 30% at temperatures down to -18°C; corresponding with a weight increase of 10% for the NiMH battery, and increased overall costs. Power capability at lower temperatures down to -30°C is not ensured[14].

Specially designed lithium-ion batteries may be technically capable of satisfying a conventional vehicle's cold-cranking requirements down to the reference temperature of -18°C. However, at lower temperatures down to -30°C, lithium-ion batteries still have significantly inferior discharge characteristics. Furthermore, a limited recharge rate at low temperatures must be taken into account[14].

• Safety

At present, SLI batteries are often placed in the engine compartment (to minimise cable resistance) and may operate at elevated temperatures. Services and cell stability must be maintained in all reasonable conditions, and therefore safety is of great importance.

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[14] *A review of battery technologies for automotive applications* Joint industry analysis 2014

Lead-based batteries are regarded as intrinsically safe battery systems, both in production and operation, and can be operated irrespective of ambient temperature. This is confirmed by a long history and by practical experience. Most lead-based batteries are sealed and the evaporation rate of the electrolyte is relatively low. Gas evolution is even more reduced with immobilized electrolyte designs like AGM, and there is even no spilling when the container is cracked e.g. in case of an accident. Specific cooling is not required[15].

Nickel-metal hydride batteries are regarded as intrinsically safe battery systems. This is confirmed by a long history and by practical experiences in many applications. As with other aqueous systems there may be natural gas production under abuse conditions (overcharging). This needs some additional care when employing these systems in vehicles and for other applications[15].

Operations of lithium-ion batteries are restricted to a range both in terms of temperature and cell voltage. If operated at temperatures or cell voltages out of the operational window, the battery no longer provides the desired function, with potential risk to its surroundings (N.B.: In single battery architectures including ICE vehicles with Start-Stop and Micro Hybrid features, it is not permitted to disconnect the battery at any time, in order to ensure operation of essential features such as the hazard warning lights). The management system incorporated in the battery monitors and restricts temperature and voltage parameters at cell, module and battery levels. However this increase in technology complexity results in additional costs[15].

• On-board electronic (board-net voltage)

The on-board electronics of vehicles operate at 12V. This includes the lighting for the car as well as control electronics, entertainment, navigation and safety devices like airbags or door lock systems (as described in question 1). 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.

About 10 nickel based cells in series are necessary to be compatible with standardized 12V architectures in vehicles. The voltage characteristics of nickel-based systems are rather flat and for that reason are generally aligned with what is used in the vehicles today. Although the batteries provide an internal gas recombination mechanism, overcharge and over-discharge need to be avoided in order to prevent overheating and battery venting. This is essential for safety and crucial for a long service life. An electronic battery management system must be installed to maintain correct operating parameters. On-board automotive electronics are designed to be able to sustain up to 15 V. A Li-ion cell has an initial voltage of 3,6 V and a charge voltage of 4,2 V.

[15] *A review of battery technologies for automotive applications* Joint industry analysis 2014

Due to the voltage of their cells, the use of Li-ion batteries in SLI applications would require a very significant redesign of on-board electronics[15].

- Manufacturing base and resource availability

The group of Associations listed in question 1 have also considered the long term availability of materials used in a range of battery technologies. This document considered the current and future resource availability of metals used in automotive battery technologies[16]. The document concludes no current or future resource availability issues with lead-based batteries- there are significant global reserves of lead, both primary (i.e. from mining) and secondary (i.e. from recycling) and secondary production currently accounts for more than 50% of total global lead production. In fact, in 2014 100% of US lead production and 75% of European lead production will originate from secondary sources. The high recycling rate for lead is driven principally by lead-based batteries, more than 99% of which are recycled at the end of life[17]. This means that the existing market for lead-based batteries can be predominately met with recycled material and because of this circular economy (i.e. a closed loop) the demand and requirement for lead reserves from mining is low. The anticipated growth in demand for automotive batteries will however likely need to be serviced by primary lead, which will then be available itself for recycling at end of life, and hence enter the circular economy. The existing reserves of lead can comfortably meet the projected growth in demand for automotive batteries.

In contrast, although the report shows that lithium-based batteries have no current resource availability issues, the increasing use of lithium-ion batteries in portable electronics, coupled with use in new applications is expected to result in a substantial increase in demand for lithium. This increased demand would need to be met from lithium reserves via primary production, as recycling of lithium batteries is in its infancy. However, with the increasing number of Li-ion batteries entering the market and with a significant supply crunch, recycling is expected to be an important factor for consideration in effective material supply for battery production. Recycling where the recycled materials are sold back to industry, is likely to help against potential price fluctuation of metals or compounds.

Li-ion batteries have been introduced into the market rather recently; they are highly engineered products incorporating a wide variety of materials. Several different technologies are available, which differ *inter alia* on the choice of active cathode material. These facts contribute to the lower recycling rates observed compared to more established technologies such as lead-based batteries.

Li-ion batteries do, however, meet the average recycling rate of 50% mandated for this family, and recycled materials are reused by other industries where they replace the extraction of primary metals. As this technology is growing fast, recycled material from volumes currently collected - sold at a time when the Li-ion market share was insignificant - do not match the quantities required to manufacture batteries placed on the market today, therefore due to its growth, this segment is currently a net “taker” of raw materials.

[16] *Resource Availability of metals used in batteries for automotive applications* Joint Industry analysis *2014*
[17] *The availability of automotive lead based batteries for recycling in the EU* IHS 2014

There are significant reported resources of lithium, and in 2014 the global mine production was 35,000 tonnes[18]. The most significant use of lithium is in lithium-ion batteries for portable electronics (e.g. cameras, phones, laptops). The growth rates for these uses are predicted to be considerable[13]. In addition to these applications, a new and very rapidly growing market has emerged over the last decade in the form of electric bicycles. Approximately 30 million e-bikes were sold in 2009, and it has been forecast that 466 million electric two-wheelers will take to the road by 2016[19]. These bikes have previously used lead-based batteries, but there is a push to switch to lithium-ion batteries[20], which if pursued, could be expected to consume additional lithium reserves.

As mentioned above, the predominant use of lithium-ion batteries is in portable batteries. However, the use of lithium-ion batteries in some automotive and industrial applications is also expected to rise. There is predicted to be increasing volumes used as traction batteries in PHEV and EVs, as well as certain hybrid segments. They will also be required for large-scale grid-connected energy storage. In addition, the use of automotive lithium-ion batteries in an SLI function in vehicles is being explored as a potential alternative to lead-acid batteries in R&D projects.

If the existing challenges associated with SLI use of lithium-ion batteries were resolved such that they became viable option to lead-acid technology - coupled with the additional demand for lithium in portable electronics, energy storage, e-bikes and other areas of the automotive industry – future resource availability issues for lithium could be expected. As an illustrative example, if lithium-ion batteries were required to gradually replace (over several years) all lead-acid batteries in an SLI function, *ca* 90,000 tonnes of lithium[21] would be required from further increases to primary production. This quantity is almost three times the current reported lithium mine production, and so the required gradual increase in production would be significant.

The increased demand for lithium in new and existing applications could be predicted to present a long-term future challenge to the commodity and their market prices if it is also to be required in new mass-market applications, especially since there is no significant lithium resources primary production in Europe.

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[18] US Geological Survey, Mineral Commodity Summaries, January 2014

[19] Pike Research 2010

[20] William Tahil, cars21.com April 2012

[21] *Approximately 7 million tonnes of refined lead were consumed for use in automotive batteries in 2013. This equates to the production of approximately 700 million lead-acid batteries worldwide for use in automotive applications. It can be assumed that approximately 20% of these batteries would be for new cars, and the remaining 80% would be for replacement batteries[21]. Assuming 0.15 kg of lithium in each lithium-ion SLI battery, 90,000 tonnes of lithium would be required to manufacture 700 million batteries. This change would be gradual over several years, beginning with the installation of lithium-ion batteries as original equipment in new vehicles, and progressing to their sale as replacement batteries on the aftermarket. The above scenario gives an indication of the long-term consequences of forcing such changes to the battery technologies used in automotive applications.

The report also investigates resource availability issues associated with materials used in sodium and nickel-based batteries. In contrast to the lithium scenario, no issues were identified for critical elements used in nickel or sodium based batteries. Like lead-based batteries, other battery technologies such as Ni and Na-based batteries have high collection and recycling rates. Nickel batteries are recycled in a well-developed infrastructure, and due to their high recyclability, nickel is reused in the manufacture of a large variety of industrial products, and cadmium is reintroduced in the manufacturing of new batteries. Reserves of nickel and cadmium are also sufficient to satisfy the demand for the metal for decades. Sodium based batteries also have high recycling rates, driven by an economical return of the process.

Question 2b

For alternatives, which still have the potential to develop into a viable candidate, please provide information as to the various research and development stages that are still needed as well as a time range estimation for each stages.

Lead batteries are vital to ensure the mobility on European roads at least for the next 10-15 years. Lead batteries are established components and standardised worldwide. During the last years the efficiency and the design has been improved e.g. by absorbent glass mat technology (AGM) as used for micro hybrid systems or enhanced flooded batteries (EFB). In particular the cold cranking properties of lead based batteries make these battery types essential. At low temperature no other commercially available battery system for volume production is able to meet the required performance or demand (Starting ability at temperatures around -30°C required). The Circular Economy is already a fact for lead based batteries, after long service life an already established and well-functioning closed loop recycling economy provides resources for the production of new batteries in Europe within the EU market with high proportions.

For new cars in development it is evident that more and more electric power is needed to provide for the functioning of all electronic systems. Systems like mobile car communication, intelligent electric steering systems instead of hydraulic or mechanical systems and new customer expectations will increase demand for electrical energy. Despite every effort to design efficient vehicle electric power systems the demand for storage and provisioning of electrical energy is increasing. A wide variety of different national, European and worldwide R&D projects are conducted. The aim is to develop energy storage systems with higher energy density and lower weight suitable even for harsh climatic conditions.

By no means exhaustive examples of recent projects in Table 1, providing evidence that the automotive industry has many intense on-going research programs for new energy storage systems (in Germany alone more than 600 Mio € are provided by the NPE research program for research on battery systems). On the other hand it illustrates, that these systems are not yet available for the Automotive Industry and that the results of these research projects needs to be further developed and tested in pilot applications to verify if these systems are able to meet the criteria for volume serial production

It should be noted, that higher availability of energy has additional safety advantages. It can be assumed that different mobile energy storage components will ensure active redundancy in cases of malfunction at a component level in the future. Already today all available Electric Vehicles in volume serial production with high voltage Li-batteries have additional 12 V Lead batteries to ensure SLI (Start, Lightning and Ignition) and additional safety functions. This dual energy storage concept of the combination of different battery technologies for different purposes (cold cranking ability and recuperation) is in focus of several development projects.

In summary the Automotive Industry confirms, that lead-based battery-systems are essential and necessary in volume serial production for the foreseeable future and that the industry is conducting intensive R&D efforts on enhanced energy storage systems (see also Table 1, page 5-6).

This has involved the testing of some of the products of research and development activities in vehicles. This is a continuation of the product development cycle and whilst there is some promise that the new technologies may supplement, improve or possibly replace lead-based SLI batteries in some vehicles it must be stated that they are still a considerable way from becoming a mass market technology. As such, and as stated at the last ELV exemption, a further 8-10 years would be required to fully assess whether any of these alternative technologies can be scaled up to become commercially viable mass market products offered in type approved vehicles. This is explained further below:

Development time

A survey of European OEMs has estimated that the development time for new vehicles is between 54 and 80 months, depending on the model and its predecessor[22.] However, the lead-in times will be longer if new technologies or components have to be implemented into new vehicles. Specifically, when there is a need to use alternative materials, this can take many years and depends on the type and function of the component. Sufficient field experience is then required to suitably evaluate alternatives under real driving conditions and to detect long term failures or risks. 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. As the automotive trends document has demonstrated[26], no such technical alternative currently exists for the mass-market. Currently there are a high number of R&D projects underway and an exact estimation of development times is not possible.

Manufacturing infrastructure

According to EUROSTAT figures, 70,313,259 automotive lead-based batteries were produced for SLI applications in the EU in 2011, with the vast majority destined for the European market. It is highly unlikely that sufficient manufacturing capacity could be provided to replace this quantity with alternative technologies in the short and medium-term, as this would require:

1. Sufficient financial investment – something not widely available in the current financial crisis

2. Sufficient transition time – the manufacturing processes of one technology are not the same as for another, and existing plants would need to be completely replaced and existing factories re-tooled to a new purpose. In addition, employees would have to be retrained in the new processes and new manufacturing methods[26].

Resource Availability

The long term availability of materials used in a range of battery technologies has also recently been considered, and a report published. This document considered the current and future resource

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[22] *A review of battery technologies for automotive applications* Joint industry analysis 2014

availability of metals used in automotive battery technologies[23]. The document is discussed in detail in question 2a, but the report concludes no current or future resource availability issues with lead-based batteries but raises concerns that the increased demand for lithium in new and existing applications, coupled with a recycling industry in its infancy could be predicted to present a future challenge to the commodity if it is also to be required in new mass-market applications.

Board-net voltage

Another issue would be that on board-net voltage. 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.

This cannot be enforced in Europe in isolation, as the 12V power supply is standardised throughout the world. It would only be possible to change the voltage if all global car manufacturers acted together.

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.

[23] *Resource Availability of metals used in batteries for automotive applications* Joint Industry analysis *2014*

Question 2c

Please clarify what types of vehicles your answer refers to as well as if lead free alternatives could be used to replace the auxiliary 12V lead-based battery used as the secondary battery in hybrid and electric vehicles at present.

Our answers above refer to all types of vehicle, with lead batteries being essential for vehicles with internal combustion engines (ICE), l hybrid vehicles (mild, micro and Plug-in) and full plug electric vehicles.

Lead-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 (starter-lighting-ignition). The excellent cold-cranking capability, with decades of proven reliability, low combined cost and compatibility with these vehicles 12 V electrical system set the lead battery apart from other battery technologies in conventional vehicles. As such, the lead-based 12 Volt battery will continue to be the mass market battery for the foreseeable future.

Furthermore, advanced lead-based batteries (AGM[24] and EFB[25] 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 entry class of braking recuperation and passive boosting (resulting in 5-10% fuel efficiency improvements)[26]. In these applications, lead-based batteries again remain the only technology available for the mass-market. Vehicles in this class will continue to comprise the majority of Europe's car parc for the foreseeable future.

Lead-based batteries are also 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.

[24] Absorbent-Glass Matt (AGM) Battery
[25] Enhanced Flooded Batteries
[26] Life Cycle Assessment – LCA of Lead-based Batteries for Vehicles (PE International, 2014)

Question 3
Eurobat (2014), evaluates the utilisation of lead-based batteries as a possible option for use as the primary battery in hybrid electric vehicles (micro hybrid, mild hybrid and full hybrid) and in plugin-in-hybrid electric vehicles and electric vehicles. Please state, if to your knowledge, lead-based batteries are currently utilised as the primary battery, in such vehicles which are marketed on the European market.

Micro hybrid vehicles are defined by engine stop/start and limited brake energy recuperation, where the recuperated energy is only used for powering the 14 V electrical on-board system but not for active propulsion. Such vehicles have been introduced in large volumes to the European market since 2008, and they typically use a single lead/acid battery (EFB or AGM), sometimes augmented by a second lead based AGM battery for voltage stabilization or by a supercapacitor or small high-power lithium ion battery for enhanced recuperation.

Mild, full and plug-in hybrid vehicles, as well as battery electric vehicles typically utilise NiMH and Li-Ion traction batteries.However, it should be stressed, as explained in earlier questions that both categories still rely on lead-based batteries for the 12V functionality.

In addition, a new category of micro/mild hybrid is currently under development by many of the vehicle manufacturers, which utilise lead carbon batteries. In this category a dual low voltage system is being proposed at 12V for the traditional hotel loads and a nominal 48V primary battery for the regenerative circuit which will allow electrical engine assist and various other functionalities, for instance driving other heavy power users such as pumps and air-conditioning. This is described further in question 2. While certain manufacturers may be looking towards a lithium-ion solution for the 48V battery this is certainly not true across the board. For example two OEMs showcased vehicles at the recent Paris Auto show which utilise a 48V lead-carbon battery as the primary battery. This is a project being run in conjunction with the Advanced Lead Acid Battery Consortium (ALABC).

Furthermore, as well having its own demonstration vehicle, which uses an advanced lead carbon battery as the primary battery, ALABC is working with an OEM and Ricardo[27] and other partners on a dual 12/48V (lead carbon battery) diesel hybrid sponsored by the UK Technology Strategy Board. This so-called ADEPT project is aiming at CO_2 emissions of less than 75g/km.

[27] Ricardo are the lead company in the ADEPT project. The Project is 50% sponsored by what was the Technology Strategy Board - now Innovate and is listed as Project Number 101578.

Question 4

Eurobat (2014), quotes a 2007 Fraunhofer-Institut für Chemische Technologie report, which confirmed that at end-of-life, the vast majority (>95%) of lead-based batteries in Europe are collected and recycled by the battery industry and other smelters in a closed-loop system. Please provide information as to the current recycling rates of batteries covered under Ex. 5. Please explain what the denominator is for such information, specifying if recycled amounts refer for example to all batteries placed on the EU market / to batteries that are coming the market through the sales of new vehicles / to batteries used to replace faulty batteries in automobiles etc.

The collection and recycling of automotive lead-based batteries is an efficient and cost-effective process that operates in a well-established infrastructure. The economies of lead battery recycling, where virtually all the materials are recovered and reused at the end of life in a straightforward production process, means that very high rates of collection and recycling of lead-based batteries are realised.

In 2007 the Fraunhofer ICI published an end-of-life recycling rate for lead-based batteries of greater than 95%. However, this study was based solely on German data, and extrapolated to obtain a European wide figure for end-of-life recycling.

In order to get a more accurate figure for Europe as a whole, consultants IHS, on behalf of EUROBAT, International Lead Association, European Automobile Manufacturers Association, Japan Automobile Manufacturers Association, and Korea Automobile Manufacturers Association, have recently performed a study aimed at assessing the collection and recycling rates for European lead-based automotive batteries (those covered under ELV exemption 5)[28]. This study reported the collection and recycling rate of automotive lead-based batteries in Europe to be 99% over the period 2010-2012. The report also states that the remaining 1% represents the statistical error of the approach and/or movement of stored batteries and batteries with longer lifetimes than estimated in this study rather than batteries being landfilled or incinerated. The above mentioned associations believe this to be a robust and accurate figure for the collection and recycling rates in Europe that is reflective of the current recycling situation.

The IHS collection and recycling rate methodology addressed the number and weight of waste batteries that are available for collection in a given year. This includes all batteries that are available for recycling-automotive batteries recovered within the vehicle lifetime and replaced with new batteries and used automotive batteries recovered from end-of-life vehicles.

The collection and recycling rate was therefore calculated as:

Automotive battery weight collected in a given year, divided by the estimate of the weight of automotive batteries available for collection and recycling in that year.

The batteries collected in a given year were calculated using data gathered from national authorities.

The estimated weight of automotive batteries collected was derived using IHS proprietary parc data and then applying a formula for the battery's expected lifetime within the vehicle, and from EUROSTAT data on End-of-Life vehicles. More information on the methodology can be found in the full report:

[28] IHS The availability of automotive lead based batteries for recycling 2014

http://www.eurobat.org/sites/default/files/ihs_eurobat_report_lead_lores_final_2.pdf

This gives the following results for the current collection and recycling rate for lead-based batteries in Europe:

2010/2012	Europe
Automotive batteries available for collection (Tons)	1,110,730
Automotive batteries collected (Tons)	1,093,645
Automotive lead-based battery collection and recycling rate	99%

*These figures are an average over the period 2010-2012.

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. The batteries are picked up at collection points by specialised companies who transport and deliver the batteries to secondary smelting plants operating under strict environmental regulations.

Once the lead-based batteries arrive at a smelter for recycling, in general the battery is broken down into component parts, these are sorted and processed. The lead-acid battery is an excellent example of a product allowing a complete end-of-life recycling, as all components of a lead-based battery are available for recycling.

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 which are used for hybrid and electric vehicles and, owing to a range of factors such as the high recycling yield of lead batteries, the well-developed collection and recycling infrastructure and the intrinsic economic value of lead, we believe it is reasonable to assume that all batteries collected are recycled.

This means that the existing market for automotive lead-based batteries in the EU can be predominately met with recycled material and, because of this closed loop, the demand and requirement for primary lead reserves from mining is low. And even if the anticipated growth in demand for automotive batteries will need to be serviced by primary lead, this primary lead will itself then be available for recycling at end-of-life, and so will enter the closed-loop system.

In conclusion, our industries request the extension of the exemption 5 under Annex II of the ELV Directive due to the reasons explained above and specified in the referenced reports and to schedule a follow up assessment of granted exemptions not before an eight year period.