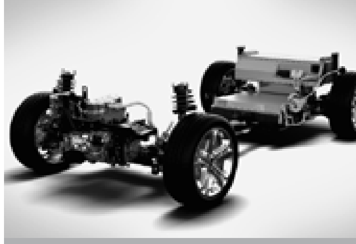

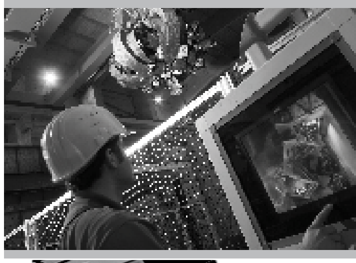

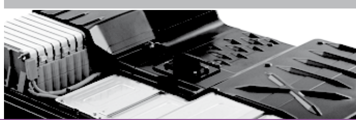

RESOURCE AVAILABILITY OF METALS USED IN BATTERIES FOR AUTOMOTIVE APPLICATIONS

EXECUTIVE SUMMARY

EUROBAT

ACEA

JAMA
JAPAN AUTOMOBILE MANUFACTURERS ASSOCIATION, INC.

KAMA
한국자동차산업협회
Korea Automobile Manufacturers Association

ila
International Lead Association

A joint industry analysis of the current and future availabilities of resources and materials used in a range of battery technologies

EUROBAT, the Association of European Automotive and Industrial Battery Manufacturers, acts as a unified voice in promoting the interests of the European automotive, industrial and special battery industries of all battery chemistries. With over 40 members comprising over 90% of the automotive and industrial battery industry in Europe, EUROBAT also works with stakeholders to help develop a vision of future battery solutions to issues of public interest in areas like e-Mobility and renewable energy storage.

The European Automobile Manufacturers Association (ACEA), founded in 1991, represents the interests of the fifteen European car, truck and bus manufacturers at EU level. Its membership consists of the major international automobile companies, working together in an active association to ensure effective communication and negotiation with legislative, commercial, technical, consumer, environmental and other interests.

Japanese Automobile Manufacturers Association (JAMA) is a non-profit industry association which comprises Japan's fourteen manufacturers of passenger cars, trucks, buses and motorcycles. JAMA works to support the sound development of Japan's automobile industry and to contribute to social and economic welfare.

Korean Automobile Manufacturers Asssociation (KAMA) is a non-profit organization, representing the interests of automakers in Korea. KAMA is also dedicated to the sound growth of the automobile industry and the development of the national economy.

International Lead Association (ILA) is a membership body that supports companies involved in the mining, smelting, refining and recycling of lead. The ILA represents the producers of about 3 million tonnes of lead. ILA's work has a broad focus, covering all aspects of the industry's safe production, use and recycling of lead.

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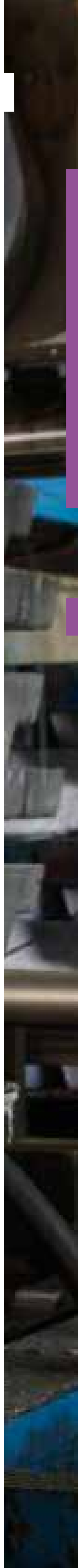

INTRODUCTION

This document provides a joint industry analysis of the current and future availability of resources and materials used in a range of battery technologies. The document focuses on automotive batteries, and does not cover other battery technologies that are not currently used for this application

The report aims to answer the following questions:

- Are there any current resource availability issues associated with the manufacture of automotive battery technologies?
- Are the any future issues that could affect the resource availability associated with the manufacture of automotive battery technologies?

Nonetheless the challenge of meeting the ever-increasing demand for batteries in vehicles remains significant. The production rates for new vehicles are growing rapidly. Estimates of current rates are on the order of 70 million new vehicles every year, and it has been estimated that this rate could rise to about 100 million by 2020 and 140 million by 2030[1].

The information contained in this report is intended to be used to inform the current and future regulatory discussions on the feasibility of substituting different battery technologies currently in use.

[1] Wilson, "Lead: A bright future for the grey metal?", 2011

LEAD-BASED BATTERIES

Based on the information contained within the resource availability document, it can be concluded that there are no resource availability issues associated with the materials used in the manufacture of lead-based batteries.

Currently, all vehicles (conventional and start-stop vehicles, the different grades of hybrid vehicle, and plug-in hybrid and electric vehicles), require a 12V lead-based battery in a Starter, Lighting, Ignition (SLI) type application. 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 95% of which are recycled at the end of life[2]. This means that the existing market for lead-based batteries can be predominantly met with recycled material; because of this circular economy, the demand and requirement for lead reserves from mining sources 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 therefore comfortably meet the projected growth in demand for automotive batteries.

LITHIUM-BASED 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 its use in new applications, such as a range of hybrid and electric vehicles, 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 currently less than 1% of lithium is recycled[3], and the recycling of lithium batteries is in its infancy. One reason for this is due to the widely differing chemistries of different types of lithium batteries. Recycling of lithium-ion batteries can be more difficult than, for example, recycling of lead-based batteries, a situation in which all batteries (automotive and industrial) have the same fundamental chemistry, which allows recycling of all batteries of this type to be conducted using a single process.

There is predicted to be increasing volumes used as traction batteries in plug-in hybrid vehicles and electric vehicles, as well as certain hybrid segments. High quantities of lithium-ion batteries will also be required for large-scale grid-connected energy storage.

[2] Nachhaltige Rohstoffnahe Produktion, Fraunhofer Institut Chemical Technology (2007)

[3] UNEP report on recycling rates for metals 2011

There are significant reported resources of lithium, and in 2014 the global mine production was 35,000 tonnes[4]. 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. In addition to these applications, a new and very rapidly growing market has emerged over the last decade in the form of electric bicycles (ebikes). Approximately 30 million ebikes were sold in 2009, and it has been forecast that 466 million electric two-wheelers will take to the road by 2016[5]. These bikes have previously used lead-based batteries, but there is a push to switch to lithium-ion batteries[6], 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 in 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-based batteries, as a consequence of pressure from existing and proposed EU environmental legislation[7]. However, this application of lithium-ion batteries is currently has only very minor use in luxury vehicles, and significant technical limitations and cost implications remain for their use in mass-market vehicles[8].

If the existing challenges associated with lithium-ion batteries for SLI functionality in conventional vehicles were resolved such that they became a viable option to substitute lead-based 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.

[4] US Geological Survey, Mineral Commodity Summaries, Jan 2012

[5] *Pike Research 2010*

[6] *William Tahil, cars21.com April 2012*

[7] The End-of-Life Vehicles Directive bans the use of lead in vehicles, with an indefinite exemption for lead in batteries that is reviewed regularly according to technical and scientific progress. The European Commission last reviewed this exemption in 2010, reaching the conclusion that no mass market alternatives were available to replace automotive lead-based batteries.

[8] More information is provided in A Review of Battery Technologies for Automotive Applications (2014), authored by the same group as this report.

As an illustrative example, if lithium-ion batteries were required to replace all lead-based batteries in an SLI function, ca 90,000 tonnes of lithium[9] would be required globally from further increases to primary production. This quantity is almost three times the current reported global lithium mine production, and therefore the required increase in production would be significant.

In addition this report highlights that a significant amount of lithium production, reserves and resources currently originate from Argentina, Bolivia and Chile. Although not discussed in detail this observation suggests the possibility of an additional challenge to future accessibility created by geo-political risk of a raw material that is only available in one specific region. For example, any unrest or instability of the governments in these regions could greatly affect the supply of lithium and have an impact on battery price, and thus application cost.

NICKEL AND SODIUM-BASED BATTERIES

This report also investigates resource availability issues associated with materials used in sodium and nickel-based batteries. In contrast to the lithium scenario, no supply-side concerns were identified for critical elements used in nickel or sodium-based batteries.

The major metals used in nickel-based batteries are nickel, zinc, iron, cadmium and cobalt. These are well-known metals with significant annual production tonnages and known global reserves. Rare Earth metals can be utilised in nickel-based batteries. In the past, concerns have been raised with the export policy of China, the largest producer of rare earth metals (97% of the market). However, significant exploration projects are underway in many countries, and there are substantial known global reserves of the metal. As such, access to rare earth is likely to be an economic issue as opposed to a resource availability issue.

Sodium-based batteries (specifically sodium sulfur) comprise mainly sodium, sulfur, aluminium and nickel. Sodium occurs naturally in vast quantities, sulfur is widely available, and no issues are foreseen with nickel and aluminium. It can therefore be anticipated that the materials used in these batteries can easily meet current and future demand.

[9] 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 used for new cars, and the remaining 80% would be used for replacement batteries. 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.

CONCLUSIONS

In conclusion, this report identifies that there are no resource availability issues for lead-, sodium-, and nickel-based batteries. It also shows no current issues with lithium-based batteries. However, the increasing use of lithium-ion batteries in portable electronics, coupled with their use in new applications, is expected to result in a substantial increase in demand for lithium. If, in addition, lithium-ion batteries were required for other mass-market applications (for example, to replace automotive lead-acid batteries in an SLI function), significant future challenges would be predicted for the global supply of lithium.

The authors of this report therefore recommend that in each automobile application, battery selection should be influenced by the availability of resources to meet demand, as well as the efficiency with which those resources can be recycled and reused at end of life. They also advocate that there needs to be a legislative and regulatory environment that guarantees a fair and technology-neutral competition between automobile battery technologies.

As the most relevant example, the use of lead-based batteries should continue to be encouraged for a number of reasons. The existing market for automotive and industrial lead-based batteries can predominantly be met with recycled material, and the reserves of primary lead can comfortably meet projected future growth in the demand for those batteries. Because this technology is the most competitive option from technical and economic perspectives, its use should be fostered, with any residual risks to human health and the environment being properly managed.

This document provides a joint industry analysis of the current and future availabilities of resources and materials used in a range of battery technologies. The document focuses on automotive batteries, and does not cover other battery technologies that are not currently used for this application. The report aims to answer the following questions:

- *Are there any current resource availability issues associated with the manufacture of automotive battery technologies?*
- *Are the any future issues that could affect the resource availability associated with the manufacture of automotive battery technologies?*

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