EXECUTIVE SUMMARY- Comparative Life Cycle Assessment of Batteries for Automotive Applications

sphera

Study commissioners:

European Automobile Manufacturers Association – ACEA
Japan Automobile Manufacturers Association – JAMA
Korea Automobile Manufacturers Association – KAMA
Association of European Automotive and Industrial Battery Manufacturers – EUROBAT
International Lead Association – ILA

On behalf of Sphera Solutions Inc. and its subsidiaries

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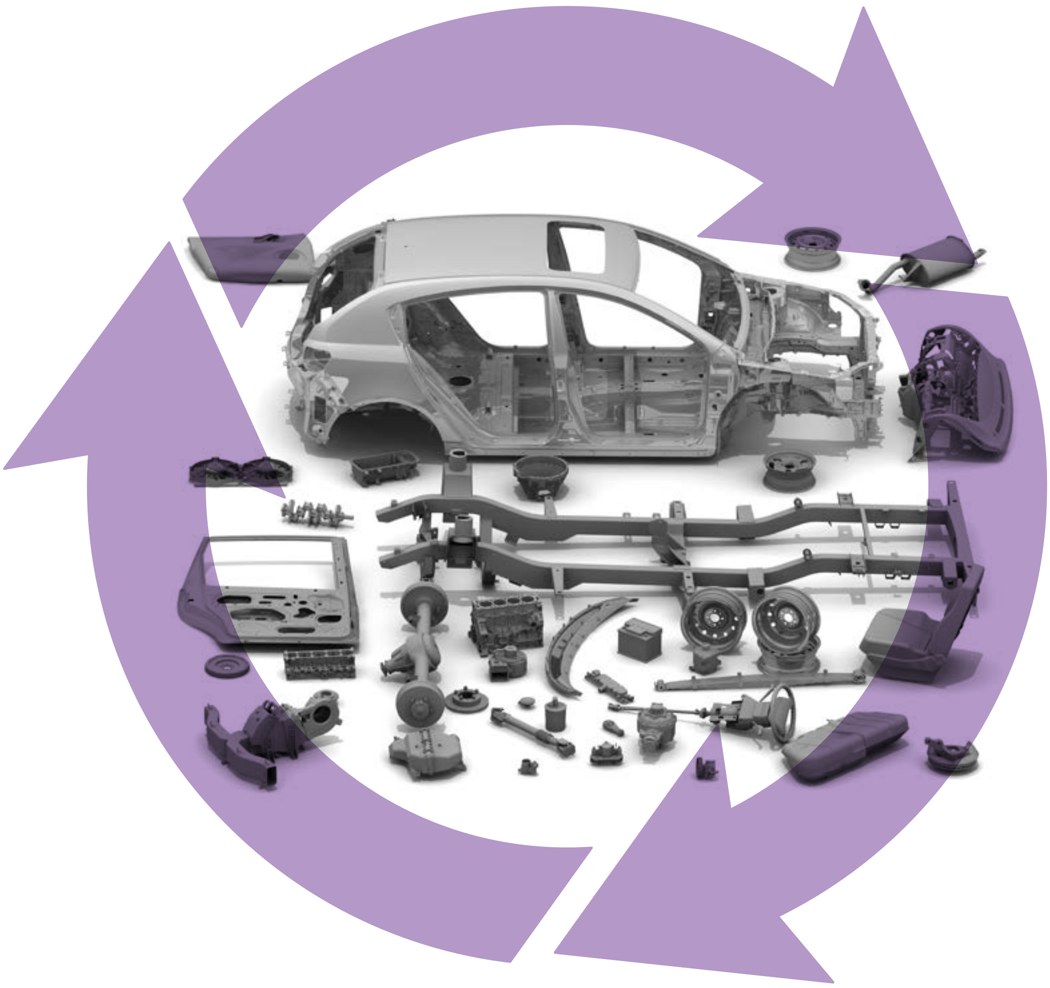

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EXECUTIVE SUMMARY

Comparative Life Cycle Assessment of Batteries for Automotive Applications

The independent consultant Sphera (formally Thinkstep) was requested to undertake a comparative cradle to grave life cycle assessment (LCA) to evaluate the environmental impacts of 12V lead and lithium iron phosphate (LFP) batteries used for automotive applications.

"Over the complete life cycle from cradle-to-grave the difference between all batteries assessed for most impact categories is small with benefits derived from the fuel savings obtained from using batteries in start-stop and the micro-hybrid applications dominating . However, under the baseline scenario the environmental impact of LFP battery manufacturing is currently around a factor 6 times higher than the impact of manufacturing equivalent lead batteries."

Introduction

Life cycle assessment (LCA) is one of the tools that is increasingly being used to examine the environmental impact of a product through its entire life cycle

In 2014 a cradle to grave LCA was presented that compared the environmental impacts of the three most common 12V lead-based batteries used in vehicles in Europe[1]:

- **Standard technology batteries:** These are flooded lead-based batteries used in conventional vehicles, for starting the internal combustion engine (ICE), lighting and ignition systems - commonly known as starting, lighting and ignition (SLI).
- **Improved technology batteries:** These are enhanced flooded (EFB) or Absorbent Glass Matt (AGM) lead-based batteries used in vehicles with a start-stop system, which allows the ICE to automatically shut down under braking and rest and then to restart.
- **Advanced technology batteries:** These are EFB or AGM lead-based batteries used in vehicles with a micro-hybrid system, which combines start-stop functionality with regenerative braking (a system to recover and restore energy from braking), and other micro-hybrid features that require higher deep-cycle resistance and charge recoverability from the battery.

1 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

The study concluded that the production of lead contributes most dominantly to the environmental impacts from battery production whereas the battery manufacturing and assembly processes do not have a such a significant footprint. Moreover, whilst Improved and Advanced technology batteries use more lead, this is more than offset by the savings that they enable in Global Warming Potential when installed in passenger vehicles.

However, this original LCA study did not include other battery technologies and as such it could not be used to assess relative environmental impacts. This has now been rectified and the new study now compares cradle-to-grave life cycle environmental impacts of the available lead-based 12V batteries with an equivalent lithium iron phosphate battery.

Methodology-Scope of the Comparative LCA

LCA is a technique for analysing the environmental aspects and potential impacts of products by:

- Compiling an inventory of energy and material inputs and outputs (including emissions) for the product
- Identifying the potential impacts associated with the specified inventories of the product
- Evaluating the results to assess the product's overall environmental performance across different indicators

The study updated the previously conducted life cycle inventory of the three lead battery types; Standard 12V, 70Ah SLI, Enhanced Flooded (EFB) and Absorbent Glass Matt (AGM) and compared their cradle to grave environmental impacts with a 12V, 60Ah lithium ion equivalent.

Li-ion batteries for 12V service generally use lithium iron phosphate (LFP) cathodes rather than nickel-manganese-cobalt (NCM) cathodes because their cell voltage (3.2V per cell) allows a good match to vehicle electrical system voltage of ~15V max, when combined with carbon a s a negative material (5 cells in series). The comparisons were made across three battery applications; standard for internal combustion vehicles (ICE), vehicles with start-stop and micro- hybrid systems, which combines start-stop functionality with regenerative braking.

The system boundaries for the comparison are illustrated in figure 1 and included raw material extraction and/or processing, inbound transport to the production facility, battery materials manufacturing, battery assembly, use stage of the battery over the lifetime of the vehicle, and end-of-life treatment.

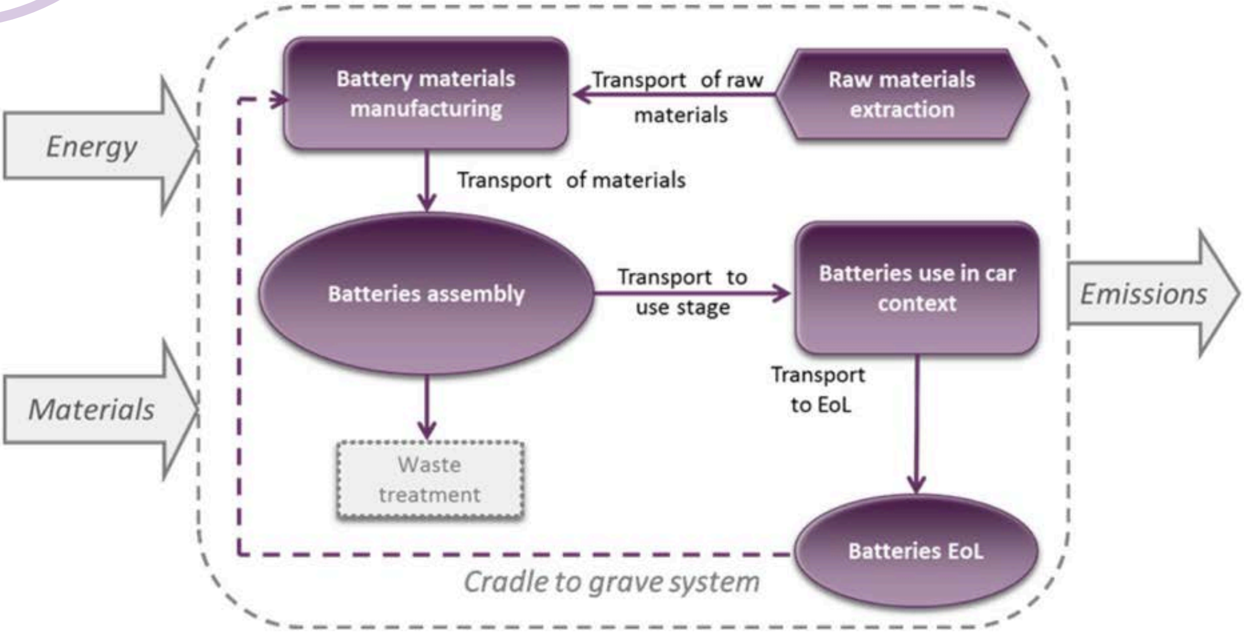

Figure 1: System Boundaries for Battery LCA

The functional unit for the study was: Rechargeable storage of energy to fulfil the service lifetime of a vehicle (10 years / 150.000 km)

The following battery criteria were selected per functional unit

Lead Battery Application	Weight (kg)	Capacity (Ah)	Lifetime (years)	Number of batteries per vehicle lifetime	Lithium ion battery type	Weight (kg)	Capacity (Ah)	Lifetime (years)	Number of batteries per vehicle lifetime
Standard 12V	18	70	5	2	LFP	12	60	8	1.25
Improved/Start-Stop	19	70	5.5	1.82	LFP	12	60	8	1.25
Advanced/micro-hybrid	20	70	6	1.66	LFP	12	60	8	1.25

Table 1: Battery reference flows per Functional Unit (the "baseline scenario").

The results of the study represent lead battery production in Europe, lithium ion cell production in Asia with assembly in Europe and recycling of both technologies in Europe.

To account for the complete life cycle, the use and EoL phases of the batteries were modelled in the study. The use phase modelling accounts for differences in battery weight and includes a best- case assumption for the associated fuel savings due to start stop and micro hybrid applications. An EoL collection rate of 97.3 was used for both battery types based upon an analysis of EU collection and recycling of Lead based automotive batteries during the period 2015-2017[2] . For LFP batteries two EoL scenarios were considered: one that includes the incineration of the cell (with energy generation) and recycling for electronics and passive components and one where a recycling scenario involves recovery of the Lithium in form of Lithium Carbonate.

Main Findings

Over the complete life cycle from cradle-to-grave the difference between all batteries assessed for most impact categories was small. However, under the baseline scenario that is considered to most accurately reflect the current situation, lead battery manufacturing has a lower environmental impact than LFP (Table 2).

	Conventional ICE		Start-Stop		Micro-hybrid	
Life Cycle Stage	PbB	LiB-LFP	PbB	LiB-LFP	PbB	LiB-LFP
Manufacturing stage	45	254	35	254	47,8	254
Use stage	44	0	-970	-1030	-1990	-2060
EoL	-6	-12	-4	-12	-2	-12
Total Life Cycle	**83**	**243**	**-938**	**-788**	**-1944**	**-1818**

Table 2: Global Warming Potential [kg CO2 eq.]

2 IHS Markit (2020) An Analysis of EU Collection and Recycling of Lead Based Automotive Batteries During the Period 2015-2017

In the manufacturing stage, for both batteries, the raw materials are the main / dominant contributor with around 70% of the GWP for the lead and 50% for the LFP batteries. A further big contributor in the LFP manufacturing impact is the Battery Management System (BMS) that is required to ensure functional safety in the vehicle.

The environmental impact of LFP battery manufacturing is currently around a factor 6 times higher than the impact of manufacturing equivalent lead batteries (Table 2). An advantage of lead batteries is that 75% of the raw material present in the battery is recycled lead-thus reducing the environmental impact. In contrast, LFP batteries are currently manufactured using primary raw materials with no opportunity to recover battery grade materials at end-of-life.

The environmental benefit of lead batteries is maintained in the baseline scenario during the full life cycle for conventional ICE vehicles. However, the fuel savings benefits derived from use of both battery chemistries in start stop and micro hybrid applications means that in these vehicles the complete life cycle from cradle-to-grave differences between the battery types for most impact categories are small (Figure 2).

The end-of-life (EoL) phase has a smaller influence on the total life cycle results (contribution of 1%-18% per impact category) than the manufacturing and use phases

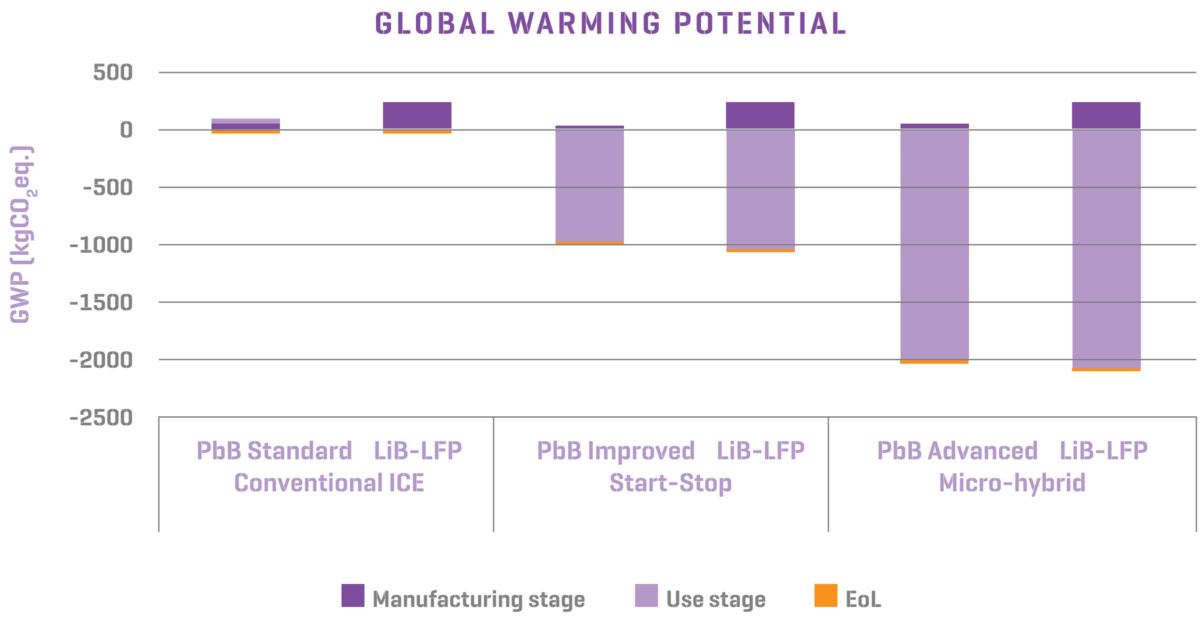

Figure 2: Overall Life Cycle Global Warming Potential per Battery Technology and Type

This study made an attempt to isolate the contribution of the start-stop/micro-hybrid system (of which the battery is an integral part) from other technologies used to improve fuel efficiency within the vehicle i.e. base engine updates, engine downsizing, reduced roll resistance tyres, vehicle weight reduction, and aerodynamic improvements. However, the total fuel consumption is influenced by all these parameters, therefore the assumed fuel reductions have some methodological limitations.

The European Automobile Manufacturers' Association (ACEA) represents the 16 major Europe-based car, van, truck and bus makers. BMW Group, CNH Industrial, DAF Trucks, Daimler, Ferrari, Fiat Chrysler Automobiles, Ford of Europe, Honda Motor Europe, Hyundai Motor Europe, Jaguar Land Rover, PSA Group, Renault Group, Toyota Motor Europe, Volkswagen Group, Volvo Cars, and Volvo Group.

- ACEA works with a variety of institutional, non-governmental, research and civil society partners - as well as with a number of industry associations with related interests.
- ACEA has permanent cooperation with the European Council for Automotive R&D (EUCAR), which is the industry body for collaborative research and development.
- ACEA has close relations with the 29 national automobile manufacturers' associations in Europe, and maintains a dialogue on international issues with automobile associations around the world. **www.acea.be**

EUROBAT is the association for the European manufacturers automotive, industrial and energy storage batteries. EUROBAT has more than 50 members from across the continent comprising more than 90% of the automotive and industrial battery industry in Europe. The members and staff work with all stakeholders, such as battery users, governmental organisations and media, to develop new battery solutions in areas of hybrid and electro-mobility as well as grid flexibility and renewable energy storage. **www.eurobat.org**

ILA is the only global trade association dedicated to representing lead producers and companies with a direct interest in lead and its use. The Association's team of technical, regulatory, environment and health experts work with stakeholders to promote the benefits of lead and the safe and responsible use of the metal in manufacturing and other applications. **https://www.ila-lead.org/**

Japan Automobile Manufacturers Association, Inc. (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. **http://www.jama-english.jp/**

The Korea Automobile Manufacturers Association (KAMA) is a non-profit organization representing the interests of automakers in Korea. We are promoting the sound growth of the automobile industry and also the development of the national economy. **http://www.kama.or.kr/**