

# EUROBAT

Association of European Automotive  
and Industrial Battery Manufacturers



## WHITE PAPER

**Battery Energy Storage Solutions for Electro-mobility**

**An Analysis of Battery Systems and their Applications in  
Micro, Mild, Full, Plug-in HEVs and EVs**

By EUROBAT Automotive Battery Committee:  
Taskforce II on "Mild, Full and Plug-in HEV and EV Applications" and Taskforce I on "Micro HEV Applications"

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## 1. Introduction

Electro-mobility first appeared at the dawn of the automotive industry. The first cars were electric vehicles. A fleet of electric taxis, for example, produced by Electric Carriage & Wagon Company began to circulate in New York City in 1897. In 1899, an electric vehicle reached the speed of 100km/h for the first time.

Since the 1990s, the R&D for electro-mobility gained importance in view of concerns over increased emissions, in combination with the rapid growth of emerging economies. In addition, the volatility of crude oil prices and fears of future scarceness pushed government authorities and companies to consider alternative solutions and promote electrification of vehicles on the roads.

Looking ahead, mobility will continue to increase globally. In 2011 over 60 million road vehicles were sold on the world market. By 2020 it is expected that this number will increase to 100 million, and up to 200 million by 2050.

However, although cars are often cited as the most significant contributor to man-made CO<sub>2</sub> emissions, they contribute around 12% of total CO<sub>2</sub> emissions in Europe, with overall transport producing 26%<sup>1</sup>. Therefore, while a major challenge, it is clear that vehicle emissions are just one piece of a much larger jigsaw. This paper will therefore focus on battery energy storage systems for the different road vehicle architectures and categories that contribute to green transportation.

This paper aims to enhance knowledge about batteries and the contribution they can make to help meet Europe's ambitious targets with regard to energy efficiency and reduction of Greenhouse Gas (GHG) emissions. It will thus outline the commitment, contribution and vision of the Battery Industry on the current and future development of electro-mobility, both with regard to the vehicles and to the infrastructure required to power them.

The automotive market is currently undergoing an important transformation in the way cars are built and designed, which directly concerns the battery industry and affects not only automotive batteries but also battery technologies used for other applications (fork-lifts, stand-by power such as UPS, telecommunication, hospitals, etc...). This extends the role of the battery industry beyond transport to technologies related to the re-charging of vehicles and the use of renewable energies, as well as on-grid and off-grid renewable energy storage applications. In this regard, EUROBAT is very optimistic about the contribution of batteries to the electrification of mobility.

In this paper, we focus on passenger cars, light commercial and heavy commercial vehicles falling under the following international classification:

- Category 2: N 1, 2, 3: commercial EV and trucks
- Category 1-2: M 2-3: bus
- Category 1-1: M1: electric passenger vehicles and city EVs, with or without range extender and with or without plugs.

Other market segments are also significant in terms of market size and their contribution to greener transportation:

- Light Electric Vehicles, categories L1e, L2e, L3e, L4e and L5e, such as: E-motor-cycle, E-motor pedelec, E-bike and E-light quadri-cycle
- Other transportation modes: E-trains, E-boats, E-ships and more electrified airplanes.

While these vehicles are not considered in this position paper they are of interest to EUROBAT because of their potential in reducing GHG emissions.

More detailed information on the definition and outlook of the different vehicle architectures, as well as battery technology fact sheets and battery case studies related to electro-mobility can be found in Annex 1 "Electro-mobility outlook, battery technology fact sheets and case studies", which can be downloaded from the EUROBAT website at <http://www.eurobat.org/position-papers>.

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<sup>1</sup> Source: EC DG Move



## 2. About EUROBAT

EUROBAT represents European Automotive and Industrial Battery Manufacturers and the supporting supply chain, including 40 global and regional companies producing battery energy storage systems.

The European Battery Industry is committed to continuously develop viable technical solutions to tackle climate change and reduce CO<sub>2</sub> emissions in the fields of transportation and efficient energy storage. More specifically, it is already active in this domain through the manufacturing of batteries for a wide range of applications, such as Start-Stop Micro-hybrid, Mild, Full and Plug-in Hybrid Electric Vehicles and Electric Vehicles.

## 3. Commitment of the EU Battery Industry to the EU Climate Change Package

The European Battery Industry can make a significant contribution to help meet the targets set out in the EU Climate Change Package, which include:

- a binding target to reduce EU emissions by 20% by 2020, regardless of progress made in international negotiations for a post-Kyoto agreement;
- a binding target to have 20% of the EU's overall energy consumption coming from renewables by 2020;
- a target for each member state to achieve 20% savings in energy consumption vs projections for 2020.

The EU decided to focus on reducing CO<sub>2</sub> emissions from cars to 120g/km in 2012 and 95g/km in 2020 on average. This led the battery industry to develop battery solutions aimed at helping car manufacturers reach this objective.

The European Commission also proposed strict targets to cut urban use of Internal-Combustion-Engine (ICE) vehicles by half by 2030 and "phase them out by 2050" according to the EU Roadmap on Transport (March 2011). These objectives will also play a role in achieving the more comprehensive target of cutting CO<sub>2</sub> emissions from transport by 60% by 2050. The objective of ICE-vehicle-free cities by mid-century is to be pursued through fiscal measures, promotion of alternative transport systems, and building of the necessary infrastructure to move to a widespread use of more electric, clean cars.

EUROBAT understands the European Union's need for sustainable solutions in the field of transportation and the ambitious objectives regarding the reduction of CO<sub>2</sub> emissions. We are in regular contact with the EU to explain that there is a range of advanced battery technologies currently available on the market that are already contributing to decreased CO<sub>2</sub> emissions. The battery industry is continuously working to improve its products and to develop new technologies. Start-Stop Micro-hybrid, Mild, Full and Plug-in Hybrid Electric Vehicles and Electric Vehicles are experiencing strong development. Through these technologies, the industry is seeking to come up with solutions that will both meet the needs of civil society for a cleaner environment and of consumers for high performance products produced in a sustainable manner with a minimal impact on the environment, and available at reasonable prices.

EUROBAT is in regular contact with other European associations such as EUCAR (European Council for Automotive Research), EARPA (European Automotive Research Partner Association) and UNIFE (Association of the European Rail Industry) as well as with European Technology Platforms such as the European Road Transport Research Advisory Council (ERTRAC) and European Rail Research Advisory Council (ERRAC). In these contacts EUROBAT explains the role of Battery Energy Storage ('BES') as a key element for energy sources and management inside the vehicle.

EUROBAT members are also contributing or directly participating to several EU FP7 projects. EUROBAT is part of the Board of Advisors of the EU Project ELVA (Advanced Electric Vehicle Architectures), which will focus on the development of three detailed vehicles, is co-convenor of the Batteries Project Team within the CEN-CENELEC Focus Group on Electro-Mobility and is actively involved in the EU-US dialogue on similar topics, proposing a stronger transatlantic collaboration on electric vehicle standards.



## 4. Vehicle Architectures

There are currently a wide range of different vehicle concepts covering automotive needs:

- Micro Hybrid Electric Vehicles (HEVs), also referred to as start-stop systems because the engine turns off when the vehicle stops, and starts automatically when the car is powered,
- Mild Hybrid Vehicles, which includes the storage and re-use of braking energy
- Full Hybrid Electric Vehicles which use the electrical storage system for relatively short distances,
- Plug-in HEVs (PHEVs), which combine the advantages of an electrical vehicle with those of a vehicle using a combustion engine, and,
- Electric Vehicles (EVs), which are operated with electrical power only.

The evolution of the different vehicle architectures and their markets will depend both on incentives and technological evolutions. According to well-informed consulting companies (IHS, Roland Berger) and some major stakeholders (ERTRAC, ACEA), different vehicle architectures will eventually co-exist and the Internal Combustion Engine (ICE) will remain important in the coming decades, even up to 2050.

The development of the vehicle market is driven by both political decisions and consumer demand. The battery industry can deliver solutions that meet both political objectives aimed at reducing dependency on fossil fuels and GHG emissions, and consumer expectations.

We are now at a turning point where car manufacturers and the entire supply chain are moving in a new direction to scale up and improve different electric concepts from start-stop micro, mild, full and plug-in HEVs to full EVs, which are all in a state of constant evolution. Eventually, a range of diverse solutions will be made available to meet the different driving-profiles (urban transport, use of motorways, commuter, fleet operation).

As it has become clear that Europe will take leadership in CO<sub>2</sub> reduction, it should also be the place to launch large scale vehicle demonstration projects to test how the new concepts work and fit. Start-Stop Micro is increasing applied as a standard in all new passenger vehicles. The mild, full and plug-in HEVs and EVs may initially have small market shares but will increase after a certain period. With regard to standardization and manufacturing, Europe should act in a coordinated way in order to move fast.

Details about the different vehicle architectures can also be found in the [Annex 1](#).

## 5. About Battery Energy Storage

A rechargeable battery is an electricity energy storing system, based on electrochemical charge/discharge reactions. The amount of electrical energy stored in a battery directly relates to the chemical energy used.

There are numerous varieties of rechargeable batteries, in different shapes and sizes – from small button cells to very large batteries used as back-up energy storage in industrial applications. Several different combinations of chemicals are commonly used, deriving from the four battery technology families currently dominating the market: Lead, Lithium, Sodium and Nickel, as explained in chapter 6 below.

Energy can be stored in different forms as compressed air (pneumatic), flywheels (kinematic), thermal storage (heat), hydrogen (chemical). Battery Energy Storage ('BES') systems should be distinguished from other storage devices for a number of reasons. First and foremost, they are highly flexible and can be adapted to high power and/or high energy applications. When correctly selected or tailored, they are also highly efficient both during use and on stand-by. BES systems increase the overall efficiency of road vehicle applications – both current and future.



## 6. Battery Energy Storage Technologies for Automotive Applications

The battery technology for electric mobility has evolved tremendously over the last decade with the introduction of lithium-based batteries complementing the lead-based, nickel-based and sodium-based technologies. These technologies will all continue to have a significant impact on electro-mobility as they may give cost and/or performance advantages for specific applications, for example as start-stop and hybrid solutions.

A broad range of different electrochemical battery technologies exist. However there are four which are usually considered as those technologies that can effectively contribute to the efficient and sustainable use of electrical energy storage:

Battery Technologies:	Characteristics:
Lead based (Pb)	Proven in application, low production cost
Nickel based (Ni)	Proven off-shore & harsh environments, long life
Lithium based (Li)	High energy density, small and light
Sodium based	High energy density, light

The battery technology is selected depending on the user's requirements with regard to performance, life, safety and cost of a given application. Given the diversity of possible operating modes, there is no single battery system or technology covering the entire range of needs adequately. On the contrary, different BES technologies exist and each of them has a role to play in the future as best solution to the needs of a system depending on their specific attributes:

- Lead-based: Starter Lighting Ignition and onboard batteries as well as start-stop micro application, up to mild HEVs. For HEV, Plug-in HEV and EVs applications these batteries can extend considerably the autonomy of the main battery by providing the electricity necessary to power applications, such as air-conditioning, heating, power steering, entertainment etc...
- Nickel-based: for the propulsion of HEV applications only
- Lithium-based: for the propulsion of HEV, plug-in HEV and full EVs
- Sodium-based: for the propulsion of Plug-in HEV and full EVs.

Each battery technology is detailed in the [Annex 1](#) with a description of their current status of market deployment.

## 7. Future Battery Systems and Prospects

Besides the battery technologies presented earlier, there are a few other electro-chemical systems which are currently drawing a lot of attention because of their potential to enable significantly higher energy storage densities than Li-Ion batteries. For example, with a Lithium-Sulphur system it may be possible to reach specific energy levels of up to 500 Wh/kg. This electro-chemical system is still in the state of infancy, the main challenge facing its introduction being its endurance in terms of capacity and lifespan.

Another technology which offers a high potential to drastically improve the energy data is systems based on air cathodes. Up to now, these systems have suffered from problems with recharging and low efficiency. With alkaline Zn/air cells specific energy data up to 300 Wh/kg have already been demonstrated in the past. However, the biggest potential for a future high energy battery is seen with the employment a Li-Air based system. Specific energy with Li-Air may even exceed the threshold of 1000 Wh/kg.



Progress with all future battery systems will strongly depend on the progress with active storage materials. But future achievements with materials and components needed for passive components (electrolyte, separator, housing etc.) are also regarded as key to achieve technical solutions. Overall electro-mobility may become an acceptable replacement for the fossil-based energy storage and conversion technology in vehicles which have been the choice for vehicles platforms for more than one hundred years.

## 8. Electro-mobility and Energy Infrastructure

In the context of the ongoing structural transformation of electricity supply, a growing demand for decentralized storage facilities is expected to increase substantially the share of intermittent renewable sources to feed power into the medium and low voltage level of the electricity grid. The development of advanced industrial battery solutions will offer more possibilities than currently used to obtain primary and secondary spinning reserves, which are necessary to compensate for continuous power fluctuations in the grid.

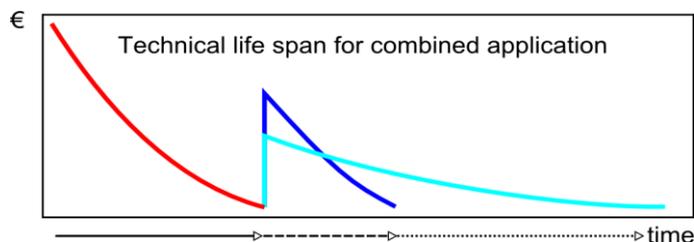
The increase of electro-mobility and of the numbers of vehicles connected to the grid to charge during the day or overnight (fast charging or slow sharing) will have an impact on the grid, which will be managed by the electricity grid operator. In the future, smart grids with bi-directional communication and energy flows, as well as the battery of the connected vehicle could assist to partly solve grid perturbations. The new transmission system operators' business model for grid expansion will have to take this into account.

Considering that the majority of the parked pHEV/EV cars will be plugged in during the day or overnight, its batteries might also play a positive role in balancing grid fluctuations in future smart grids. Such 'stationary use' of pHEV/EV batteries is currently in a demonstration phase. The large EU demonstration project 'Green e-motion' will consider this and is part of the EU Green Car Initiative. Currently there are no real business cases yet on such grid support, but in principle the vehicle-to-grid (V2G) functions could give an added value to the batteries that are installed in electric vehicles, i.e. when connected to the grid.

In addition, the second life use of pHEV/EV batteries is under consideration because of the positive impact it would have on the life-cycle and the end-of-life value of the pHEV/EV battery. Second life use for such batteries could be found depending on whether a battery is fixed or removable. It could then be an essential element in the total cost and viability of the electric vehicle technology.

It is assumed that once battery capacity has decreased to a level that is no longer suitable to power electric vehicles, the battery is technically depreciated for use in vehicles but may still have a commercial and technical value in other applications, which would extend life-cycle and thus have a positive impact on the final purchase price. This would support the business case of plug-in hybrid and battery electric vehicles.

**Fig. 1:** Second life would result in more gradual depreciation due to the two value chains



However, a lot of R&D is still required for V2G and "second life" of electric vehicle batteries in order to solve major problems related to mechanical and electrical interfaces and data transfer integration such as:

- Differences in wear of used battery packages;
- Inconsistency of battery packages with each other to form one storage module;
- Overall control to harmonise battery packages.



## 9. Battery Solutions and Employment Aspects

The European battery industry is a dynamic industry employing thousands of people across the continent and upon which thousands of other jobs in related industries depend. The industry is committed to producing sustainable batteries in Europe for the European and world markets, guaranteeing a safe and controlled manufacturing of batteries but also effective treatment of end-of-life batteries. It is worth noting that the European battery industry widely uses recycled materials, including large amounts of materials sourced from end-of-life batteries, in the production of new batteries.

The contribution of the battery industry is not limited to the automotive applications. Batteries are also used as power supply in other sectors. For example, they are key elements in systems supporting the supply of Renewable Energy, ensuring energy supply in cases of power failure (UPS, telecommunications, hospitals) and in strategic defence applications. In addition to this, the commercial world relies heavily on batteries to ensure regular power supply in helping transport goods around the globe in aeroplanes, trains and boats. As such, without batteries, life as we know it would not be possible. However, the ability to continue or further increase the deployment of new technologies is highly dependent on a strong manufacturing base for batteries in Europe. This sustainable industrial base is a requirement for continued RTD efforts by companies in Europe, which in turn supports the competitiveness of other European sectors which incorporate batteries as an essential part of their electronic and electrical technology.

As far as employment conditions are concerned, the European battery industry invests significant means in making sure that its workers are not exposed to chemical or physical hazards. It manages its operations in a safe and responsible manner with the aim of continuously reducing the impact of its manufacturing practices on human health and the environment. In addition, it considers compliance with the comprehensive and extensive legislation already in place as simply a baseline, with the battery industry constantly improving the working and health conditions of its workers, going beyond the requirements in the legislation.

Every lead-based and nickel-based battery plant employs occupational health staff to carry out regular health checks of the workers and to advise company management on effective ways of controlling worker exposures to hazardous substances. In addition to this the industry, through EUROBAT, collects statistical information on health related issues, so as to ensure it has a good overall grasp of the situation and to constantly improve its parameters.

## 10. Battery Solutions and Environmental and Transportation Aspects

EUROBAT's members are committed to adapt their products and production processes in order to help the EU meet its objectives for the de-carbonization of transport. This however requires significant efforts in terms of innovation and investment.

When the EU decided to decrease the environmental impact of batteries through the Battery Directive, the European Battery Industry committed to achieve maximal rates of waste prevention and recycling in order to minimize the negative impact of batteries and battery waste throughout Europe – and has today reached a rate of recycling of almost 100% of the collected car batteries. The Battery Industry has exchanged views with the European Commission on issues related to the potential impact of batteries on the environment, including battery production, battery handling and collection, and the end-of-life/recycling of batteries, thereby creating a closed-loop.

The advantage of batteries is that they are highly recyclable, and infrastructure for their collection and recycling exists all over Europe. Moreover, battery manufacturers use a high proportion of secondary materials. As a result, the batteries currently used have a neutral impact on the environment, and we will cooperate with European authorities at all levels to make sure that this continues to be the case with advanced batteries used in EVs.

As mentioned earlier, batteries have become a very efficient and essential tool in decreasing CO<sub>2</sub> emissions from cars, and offer several intermediate solutions in that respect: 'start-stop' batteries, which shut down the engine every time the car stops already contribute to decreased CO<sub>2</sub> emissions, while other advanced batteries, which can be used in hybrids but also in fully electric cars, eliminate CO<sub>2</sub> emissions



altogether at the vehicle level. In addition, lifecycle cost analyses show batteries to be clean, efficient and, in certain configurations, already economically viable when compared with other energy supply options (e.g. directly from fossil fuels, nuclear, renewable).

Research funding and an innovative environment are crucial and it is important to capture what is happening in those Member States who have undertaken interesting initiatives to promote electric mobility. We appreciate the opportunity given under FP7 for battery research, both for basic research in materials as well as in deployment of batteries in projects, for example in the Green e-motion Project. Those are critical projects because they look at the commercialization of e-mobility and how cities can benefit. EUROBAT is also involved in the ELVA project, Advanced Electric Vehicle Architectures, launched in December 2010 as well as in the E-Mobility work plan of the Transatlantic Economic Council and the CEN/Cenelec Focus Group on E-mobility. Within the CEN/CENELEC Focus Group on E-Mobility, EUROBAT was the co-convenor of the batteries team, whose mission was to evaluate the existing standards and advise on the creation of new ones. This CEN CENELEC Group issued a final report in October 2011.

EUROBAT representatives participate in the EU-US Transatlantic Business Dialogue and the UN-ECE Working Party 29 (Committee for Passive Safety) related to standards and safety provisions in electric vehicles. In that context EUROBAT has joined the UN-ECE Working Group for Rechargeable Energy Storage Systems (REESS) and is connected to the US Department of Transport, the European Commission and various industry associations involved.

Regarding the transportation of lithium batteries EUROBAT participates in the meetings of the civil airline organization ICAO, and UN bodies on the same subject. EUROBAT proposed solutions regarding the interpretation of approval for batteries transportation. The approval currently varies from country to country and may demand an approval for each single transport. In view of series production and the mass transport including spare part supply EUROBAT is proposing a clarification that batteries and their packaging have to be approved only once, namely, by the appropriate authority of the state of origin. Such approval can be used for each transport until the expiry date or revocation of the approval, and a copy of this approval has to be attached to each transport.



## 11. Conclusions and Recommendations

The Battery Industry has already started innovating and investing in the cars of the future, with the objective of making batteries that meet the different requirements of consumers from a functional, economic and environmental perspective. At the same time however, we need to make sure that we understand the policies that are planned by the EU Commission and Member States at a very early stage, so that we can take them into account when planning future investments. If regulations are developed in fair understanding with the European industry they can be an opportunity rather than a constraint, and can contribute to a healthy development of the battery industry in Europe while at the same time helping EU authorities meet their objectives in terms of the de-carbonisation of transport and the development of e-mobility.

In addition, European authorities and industry need to work together in order to enable the battery industry to develop in a fair and competitive environment, and which may even require cooperation with third countries:

- Access to all raw materials required for the production of batteries in sufficient volumes and at fair competitive prices;
- Revision of the rules related to the air transport of li-ion batteries in order to reflect the specificity of li-ion batteries intended for use in cars;
- Standardization of all the aspects related to the advanced batteries used in EVs;
- Clear safety measures that are applied globally
- Need for more Research & Development
- Improving social awareness and public discussions
- The EU Research program should declare sustainable mobility a priority and promote pre-competitive cooperation between industry and academia.
- Need for security of legislation and incentives that are better adapted to the expectations of the final customer.



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## Glossary of Abbreviations

AC - Alternate current  
ACEA - European Automotive Manufacturers' Association  
ACMARE- Advisory Council on Maritime R&D  
AGM- Absorbent Glass Mats  
ASD - Aerospace and defence Industries Association  
BES - Battery energy storage  
BEV - Battery operated electric vehicles  
CEN-CENELEC – European Committee for Electro-technical Standardization  
CLEPA - European Association of Automotive Suppliers  
DOD – Depth of discharge  
DC - Direct current  
EARPA - European Automotive Research Partners Association  
ELV - End-of-life Vehicle  
ERTRAC – European Road Transport Research Advisory Council  
ERRAC- European Rail Research Advisory Council  
ELVA - Advanced Electric Vehicle Architecture  
EV - Electrical Vehicle  
EU - European Union  
EUCAR – European Council for Automotive R&D  
FC HEV - Fuel Cell Hybrid Electrical Vehicle  
FP7 - Seventh Research Framework Programme  
GHG - Greenhouse Gas  
HEV - Hybrid Electric Vehicle  
ICE - Internal Combustion Engine  
ISO - International Organization for Standardization  
LEV - Light Electric Vehicle  
NREAP - National Renewable Energy Action Plan  
PEM - Proton exchange membrane  
PHEV - Plug-in HEV: Plug-In Hybrid Electric Vehicles  
RES - Renewable Energy Systems  
R&D - Research and Development  
SLI - Starting, lighting and ignition  
UPS – Uninterrupted Power Supply  
VRLA - Valve Regulated Lead Acid  
V2G - Vehicle-to-Grid  
kg- kilogram  
km - kilometer  
mAh – milli Ampere Hour: unity of battery capacity  
NO<sub>x</sub> - Generic term for a group of highly reactive gases  
W - Watt: unity for Power output  
Wh - Watt Hour: unity for energy capacity  
Wh/kg or Wh/L - Energy Density  
Pb -Lead  
Ni - Nickel  
Li -Lithium  
NiCd - Nickel-Cadmium  
NiMH - Nickel-Metal Hydride  
i - Nickel  
Li -Lithium  
NiCd - Nickel-Cadmium  
NiMH - Nickel-Metal Hydride





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