

EUROBAT E-MOBILITY
BATTERY R&D
ROADMAP 2030

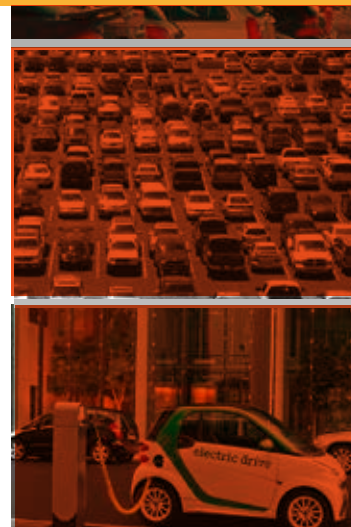
**BATTERY
TECHNOLOGY**
FOR VEHICLE APPLICATIONS



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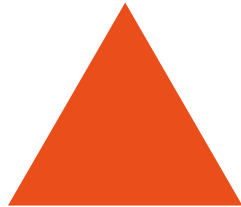


EUROBAT

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 forty 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 including e-Mobility and renewable energy storage

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Executive summary

EUROBAT supports the European Union's objective of reducing CO₂ emissions in the transport sector by 60% and of eliminating the use of fossil fuels in cars by 2050. Among a portfolio of other technologies available for road transport, vehicles based on hybrid and electric powertrains are the most promising option for achieving these targets. Further improvements to the competitiveness and performance of the different battery technologies used in hybrids and electric vehicles are needed to fully contribute to these targets.

E-mobility could bring considerable opportunities in terms of job creation, economic growth, energy security, health and environmental protection. Batteries are at the very heart of this shift and EUROBAT is convinced that they should receive support at the European and national levels. In this Roadmap, we outline the European battery industry's vision of which technical improvements should be prioritised for e-mobility batteries, from now until 2030.

EUROBAT's Roadmap focuses on three existing battery technologies (advanced lead-based, lithium-ion and sodium nickel chloride batteries), which we believe have the greatest potential for further technological improvements over the next decade. All battery technologies have specific performance profiles that serve a well-defined purpose in automotive applications, and therefore, replacing one technology with another will have an impact on overall performance and/or on vehicle cost that must be evaluated before undertaking development processes.

EUROBAT members identified the following R&D priorities: performance, cost, systems integration, production processes, safety and recycling. Significant research and innovation efforts should be organized at the EU, Member State and global levels in order to address all R&D priorities. Concrete priorities in these areas are identified for each battery technology:

- Advanced lead-based batteries – improve performance and lower cost for the mass Micro-Hybrid vehicle market.
- Lithium-ion batteries – overall, the primary objectives are to increase energy density and power density and to lower cost, with different performance priorities for each application.
- Sodium nickel chloride batteries – improvements in production process and systems integration, as well as cost reduction, are the primary targets for this technology.

Particular attention is also devoted to the implications for the new skills needed in the battery industry workforce as a consequence of the shift towards hybrid and electric vehicles. Both government and the battery industry should address this skills gap with specific funding programmes.



1 Introduction

The decarbonisation of the transport sector and the electrification of the European fleet are absolutely necessary for achieving our goals of energy security, energy efficiency and a sustainable, low-carbon and climate-friendly economy. The transport sector is today responsible for more than 30% of final energy consumption in Europe.

EUROBAT, the Association of European Automotive and Industrial Battery Manufacturers, co-signed a letter with other key stakeholders to highlight the importance of the shift towards e-mobility.¹ EUROBAT supports the EU's objective of reducing domestic greenhouse gas emissions by at least 40% below 1990 levels by 2030,² reducing CO₂ emissions from the transport sector by 60% compared with 1990 levels and eliminating the use of fossil fuels in cars by 2050.³ We also believe that the Energy Union Strategy is a unique opportunity to directly address the key issue of decarbonising the transport sector.⁴

Among a portfolio of other technologies available for road transport, vehicles based on hybrid and electric powertrains are the most promising option to achieve these targets. Further improvements to the competitiveness and performance of the different battery technologies used in hybrids and electric vehicles are needed to fully contribute to these targets. The objective of this roadmap is to address these targets, outlining the European battery industry's vision of which technical improvements should be prioritized from now until 2030.

E-mobility could bring considerable opportunities in terms of job creation, economic growth, energy security, health and environmental protection. Several reports have already proved that the shift towards an electrified transport sector can be extremely rewarding for the countries that decide to follow this path. A good

¹ *Electrification of transport within the European Energy Union Communication*, 2 February 2015, www.transportenvironment.org/sites/te/files/publications/TE%20JointLetter_electrification%20energy%20union_V4%20final_com.pdf

² *Council Conclusions of 23/24 October 2014*, www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf

⁷ *Nachhaltige rohstoffnahe Produktion*, Fraunhofer Institut für Chemis-

che Technologie (2007).

³ *Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system*, 28 March 2011, <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0144&from=EN>

⁴ *A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy*, 25 February 2015, http://ec.europa.eu/priorities/energy-union/docs/energyunion_en.pdf

example is the 2013 report, *Fuelling Europe's Future*, which calculated an increase of up to 1.1 million net jobs in Europe by 2030 and 2.4 million by 2050 as a consequence of the decarbonisation of Europe's fleet of cars and vans.⁵ The report highlights a sensible boost for the competitiveness of European car and battery industry, with the additional advantage of moving resources from industrial sectors with low labour-intensity, such as the petro-chemical industry to the high labour-intensity sector of car manufacturing. Above all, e-mobility can be extremely beneficial for the environment, with a 93% reduction in CO₂ emissions from cars and vans, 85% in NO_x and 73% in soot particles by 2050.

Similarly, the recent report, *Fuelling Britain's Future*, shows that the shift to low-carbon vehicles could bring substantial benefits to the UK in terms of average avoided spending on fuel (£600 annually per motorist, £13bn for the entire UK), avoided CO₂ emissions (30million tonnes annually), NO_x (1 13,000 tonnes annually) and particulates (3,000 tonnes annually).⁶

Batteries are at the very heart of this shift. Technological improvements and development of advanced lead-based, lithium-ion and sodium nickel chloride batteries will further improve the performance, affordability and reliability of hybrid and full electric cars. When asked how batteries should improve and what they should deliver, governments, car manufacturers and drivers have similar requirements for batteries: they should last longer, charge faster and be cheaper and lighter; they should also be safe, technically reliable and easily recyclable.

In order to meet these requirements, EUROBAT members identified the following R&D priorities where improvements are most needed: performance, cost, systems integration, production processes, safety and recycling. Concrete priorities for advancing in these areas are identified for each battery technology. It is our intention that this vision be used to formulate forthcoming EU-level research and innovation programs into e-mobility battery technologies, especially within the Horizon 2020 European Green Vehicles Initiative.⁷

This Roadmap thus covers vehicles from those with a low degree of electrification (start-stop vehicles) to full-electric vehicles. For additional information on automotive applications, please refer to the EUROBAT report *A Review of Battery Technologies for Automotive Applications*.⁸

EUROBAT's Roadmap focuses on three existing battery technologies: advanced lead-based, lithium-ion and sodium nickel chloride batteries. EUROBAT predicts that these technologies will have the greatest potential for further technological improvements over the next decade and that they will have the most important role to play in further decarbonising Europe's road transport sector over the next decade. In the future, other novel battery technologies (e.g., zinc-air, lithium-sulphur, lithium-air) may become competitive and as a result may be employed in electric vehicles. However, these technologies are still in the early phases of development, and thus are not considered in this Roadmap.

⁵ *Fuelling Europe's Future, June 2013*, www.camecon.com/EnergyEnvironment/EnergyEnvironmentEurope/FuellingEuropesFuture.aspx

⁶ *Fuelling Britain's Future*, 9 March 2015, www.camecon.com/FuellingBritainsFuture.aspxpdf

⁷ The European Green Vehicles Initiative Association is an international non-profit making association aimed at promoting and

facilitating pre-competitive research on road transport systems within the European Research Area. It focuses on technologies and the process chain, with the goal of improving energy efficiency.

⁸ *A Review of Battery Technologies for Automotive Applications*, 19 May 2014, <http://www.eurobat.org/substitution-battery-technologies-would-impact-significantly-passenger-cars-says-new-study-19-may-20>



2 Overview of batteries for e-mobility

A wide range of vehicle types is now available on the European market, featuring increased degrees of hybridization and electrification. This Roadmap is focused on e-mobility, covering all vehicles with a certain degree of hybridization and electrification, from start-stop vehicles to full electric vehicles. Each vehicle type places a different set of demands on the installed battery⁹

2.1 E-mobility – vehicle types

1. **START-STOP VEHICLES**

The internal combustion engine is automatically shut down under braking and rest. The alternator is deactivated during vehicle acceleration and switched on during deceleration (passive boosting). Former belt-driven aggregates are electrified to run according to requirement only.

The installed 12V automotive battery must provide higher deep cycle resistance and charge recoverability than in conventional vehicles, in order to deal with the frequent stops and starts in the start-stop system. Power performance is of primary importance, with minimal energy requirements.

Appropriate technologies: Advanced lead-based batteries like AGM (Absorbent Glass Matt) or EFB (Enhanced Flooded Batteries).

2. **MICRO-HYBRID, ADVANCED MICRO-HYBRID AND MILD-HYBRID VEHICLES**

Start-stop systems are combined with regenerative braking, where stored energy is then used to boost the vehicle's acceleration.

Appropriate technologies: Advanced lead-based batteries (AGM or EFB), lithium-ion batteries

⁹ For additional information on battery technology for automotive application, cfr. *A Review of Battery Technologies for Automotive Applications*, 19 May 2014, <http://www.eurobat.org/substitution->

[battery-technologies-would-impact-significantly-passenger-cars-says-new-study-19-may-20](http://www.eurobat.org/substitution-battery-technologies-would-impact-significantly-passenger-cars-says-new-study-19-may-20)



3. FULL-HYBRID ELECTRIC VEHICLES (HEVS)

Equivalent characteristics to mild-hybrid vehicles, but the stored energy within the battery is also used for a certain range of electric driving.

The battery is recharged frequently during driving, and so the required capacity is low (1-2 kWh), with high power performance more important than energy capacity. Hybrid batteries operate under a “shallow cycle” for charge and discharge, and are designed to provide up to 300,000 micro-cycles over their lifetime.

Appropriate technologies: Nickel-metal hydride batteries, lithium-ion batteries

4. PLUG-IN HYBRID ELECTRIC VEHICLES (PHEVS)



The larger capacity battery (10-25kWh) is used as the main source of energy for daily trips (i.e., 50-100km), and can be charged with off-board energy. Once depleted, the battery takes on HEV functions for power assisting, with the PHEV running from its internal combustion engine. As a consequence, the battery requires a balance of energy and power performance (or both shallow cycle and deep cycle durability).

Appropriate technologies: Lithium-ion batteries, sodium nickel chloride batteries (for heavy duty vehicles)

5. ELECTRIC VEHICLES (EVS)

The battery is used as the vehicle’s only energy source for 100km+ trips, with no internal combustion engine. A higher energy capacity is therefore required (but there are lower power requirements), with the Nissan Leaf, for example, featuring a 24kWh battery pack. EV batteries are fully discharged and charged (with off-board electricity) during operation, and are expected to provide 2,000-3,000 deep cycles.

Appropriate technologies: Lithium-ion batteries, sodium nickel chloride batteries (for heavy duty vehicles)

		Vehicle category				
		Micro HEV	Mild HEV	HEV	Plug-in Hybrid	EV
Function	Start / Stop					
	Regen. Brake					
	Power assist					
	Electric Drive			+/- 100m	+/- 10km	Up to 200km
Electrical specifications	Operating Voltage	12V  750V				
	Energy level	0,3kWh  200kWh				

Each vehicle type places a different set of demands on the installed battery or batteries, according to the e-mobility services that must be provided. A portfolio of different battery technologies is required to fulfil these demands.

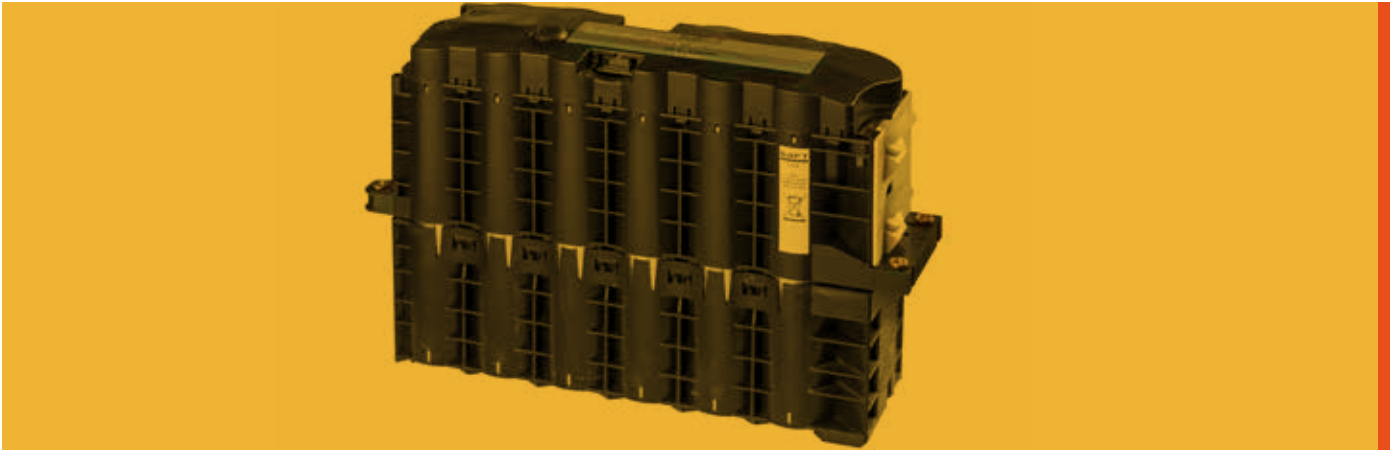
In all electrified powertrains, an auxiliary 12V lead-based battery is used for Starting-lighting-ignition (SLI) functions, including support to on-board electronics and safety features. Due to their excellent cold-cranking capability, with decades of proven reliability, low combined cost and compatibility with these vehicles' 12V electrical system, the lead-based 12V battery will continue to be the mass-market battery for the foreseeable future.

BATTERY TECHNOLOGIES COVERED IN EUROBAT ROADMAP

In this context, EUROBAT's Roadmap focuses on three existing battery technologies, which we predict will have the greatest potential for further technological improvements over the next decade, in order to improve their competitiveness in e-mobility applications:

- Advanced lead-based batteries – for start-stop vehicles and micro-hybrid vehicles
- Lithium-ion batteries – for electric vehicles and all types of hybrid vehicles
- Sodium nickel chloride batteries – for heavy duty electric vehicles and plug-in hybrid vehicles

Although nickel-metal hydride batteries have been an important technical resource, contributing to the rise of hybrid and electric vehicles, their potential for further market penetration has been reduced as a consequence of the increased performance and reduced cost of lithium-ion batteries. Because they have already reached a relatively high degree of technological maturity, it is expected that there will be only limited performance and cost improvements between now and 2030. Therefore, they are not focused upon in this Roadmap.



2.2 Technical Roadmap

A. ADVANCED LEAD-BASED BATTERIES

Over the last decade, the European battery industry has established a position of global leadership in the manufacture of advanced lead-based batteries like AGM and EFB for start-stop and micro-hybrid vehicles. In the period from now until 2030, a significant development for the European and global battery industry will be the projected mass-market roll-out of start-stop and micro-hybrid vehicles. Already in 2014, a high percentage of new vehicles being offered in the European market contained start-stop systems using advanced lead-based batteries, with Navigant Research, for example, estimating 59 million units for the global micro-hybrid market by 2024.¹⁰ In 2014, EUROBAT members sold more than 13.5 million advanced lead-based batteries within the EU. This represented over 25% of the total number of automotive batteries sold in that year.¹¹

This early market uptake, compared with US and Asian markets, has encouraged European battery manufacturers to be at the forefront of technological developments for advanced lead-based automotive batteries. Europe's global leadership also means it is well-equipped to fulfil demand in other areas of the world, with automotive lead-based battery exports from the EU increasing significantly over the last five years.¹²

New valve-regulated lead acid (VRLA) batteries containing enhanced levels of carbon in the negative plate are being developed for micro-hybrid electric vehicle applications. This work has successfully shown that these advanced designs can adequately cope with this vehicle type's duty cycle and exhibit excellent reliability. On the other hand, the advent of a higher voltage (48V) boardnet offers considerable possibilities for designing VRLA batteries with higher charge acceptance, greater active material utilisation and with a potential to run at a higher state-of-charge.

¹⁰ Navigant Research, 2015, *Stop-Start Vehicles: Onboard Energy Storage, Lead-Acid Batteries, Lithium Ion Batteries, and Ultracapacitors: Global Market Analysis and Forecasts*, www.navigantresearch.com/research/stop-start-vehicles

¹¹ EUROBAT data. It includes new cars and aftermarket sales.

¹² From 2011 to 2012, for example, exports increased by 13% (from €480,000,000 to €550,000,000).

This in turn could result in smaller, lighter batteries, further enhancing the attractiveness of an advanced lead-acid solution.

This market growth will create an increased demand for advanced lead-based batteries. In order to further expand the capability of start-stop and micro-hybrid vehicles, advanced lead-based batteries will have to provide:

- Increased charge recoverability from present about 0.3A per Ah up to 2A per Ah at low temperatures (energy recuperation)
- Stabilization of charge recoverability level over battery lifetime
- Improved cycling ability at partial state of charge (due to new and more demanding charge and discharge profiles)
- Increased capacity (due to additional energy demand at idle periods)
- Superior material utilization, mainly through an approximate 20% lead weight reduction, by 2030 under improvement of specific values for energy storage capacity and power output

This will allow for micro-hybrid engines to turn off while approaching a stop (at speeds <20 km/h), rather than only at complete vehicle standstill, as is the case today. Micro-hybrid vehicles will also begin to provide “stop-in-motion” functionality, where the engine is turned off at higher speeds whenever acceleration is not needed. Advanced lead-based batteries should eventually be employed to provide power assist to the vehicle for short periods, delivering a further increase in fuel efficiency.

A.1 PRIORITY AREAS TO IMPROVE TECHNOLOGICAL PERFORMANCES

These priority improvements will be brought about by several expected developments in battery chemistry and system design.

Battery chemistry

- Carbon nanotechnologies – the development of new types of additives will improve the conductivity of active materials within the battery
- High surface area doping materials – to increase charge acceptance, while avoiding hydrogen evolution (gassing)
- Low-cost catalysts – to recombine hydrogen and oxygen produced at regenerative brake events

Battery design

- Lighter-weighting solutions – the use of lighter materials as a conductive substrate (Cu, Al, C, etc.)
- Advanced battery designs (Bipolar, Spiral wound, etc.) – to enhance energy and power density

A.2 PRIORITY AREAS TO LOWER COST

Battery manufacturers also continue to implement design and process improvements across the lifecycle for reducing the cost of automotive lead-based batteries, from a current reference level of €50-100/kWh:

- Use of high-volume cost-optimised carbon materials as additives
- Development of fully automated processes for new advanced designs (bipolar, spiral wound, ultra)
- Increased usage of secondary materials (lead and polypropylene) in new batteries
- Lifecycle approaches to optimise battery design for end-of-life recycling and remanufacturing



A.3 PRIORITY AREAS TO IMPROVE SYSTEMS INTEGRATION

- Advanced thermal solutions – to enable a wider range of operating conditions with constant temperature loads up to 60°C and beyond for the battery, with reduced system complexity
- Battery management systems – electronic devices to adjust the state of charge to real working conditions

A.4 PRIORITY AREAS TO OPTIMISE PRODUCTION PROCESS

The production process of automotive lead-based batteries is already highly automated. There are, however, some areas of the process that still have room for improvement, such as:

- Active material preparation (batch-wise to be converted to continuous paste mixing)
- Cureless plate production (using nano-additives to avoid long curing times >24h)
- Closed-loop formation (with an electrolyte recirculation system that could reduce by 2/3 the total process time)

A.5 PRIORITY AREAS TO OPTIMISE SAFETY PARAMETERS

Lead-acid batteries are very safe, due to their use of a non-flammable electrolyte. Using VRLA batteries with AGM or gel technology prevents a possible acid leak in the case of a container rupture and avoids the release of charging gasses. Both have already been introduced in high-end vehicles, but are still not fully deployed for micro-hybrid vehicles, as many original equipment manufacturers (OEMs) still prefer for cost reasons the so-called EFB design.

A.6 PRIORITY AREAS TO DEVELOP RECYCLING PROCESSES

The collection and recycling of automotive lead-based batteries is already an efficient and cost-effective process that operates in a well-established infrastructure. Used automotive lead-based batteries are typically returned to the point of sale or to recycling businesses or metal dealerships. In all cases, they are then sent on to collection points. The batteries are then picked up at the collection points by specialized companies that transport and deliver the batteries to secondary recycling facilities (smelters) operating under strict environmental regulations.

Within the EU, close to 100% of lead-based batteries are taken back and recycled in a closed-loop system – a rate of recycling higher than any other mass-market consumer product, leaving virtually no room for improvement.¹³

From an end-of-life perspective, these sophisticated take-back and recycling schemes, as set up by the European lead-based battery industry, dramatically reduce the need for the production of additional primary lead – the most important cause of environmental impact in the life cycle of the product.

¹³ IHS, *The availability of automotive lead based batteries for recycling*, 2014, www.eurobat.org/sites/default/files/ihs_eurobat_report_lead_lores_final.pdf



EUROBAT Recommendations

In general, EUROBAT recommends that public research into advanced lead-based batteries should retain a focus on materials research and development.

Demonstration projects for new advanced lead-based battery concepts should continue to be undertaken by the industry, through partnerships between battery manufacturers and European OEMs for commercial and passenger vehicles (as well as for two- and three-wheel vehicles) over the next decade. However, current lead-based technologies remain too heavy and bulky for use in electric vehicles. As a consequence, research and innovation efforts are to be focused at the EU, Member State and global levels in order to improve performance and lower costs for the mass micro-hybrid vehicle market.

Case Study Advanced Lead-acid Battery Consortium (ALABC)

The Advanced Lead Acid Battery Consortium (ALABC) has since 2000 been demonstrating Valve Regulated Lead Acid batteries (VRLA) containing enhanced levels of carbon in the negative plate in hybrid electric vehicles.

Different R&D projects on micro- and mild hybrid segments are running under the ALABC' Vehicle Demonstration program. There are promising results and they are demonstrating the high values that low-voltage lower-cost lead batteries create in such hybrid segments. More and coordinate research will be needed at European to complement these efforts.

Points of contact

Advanced Lead Acid Battery Consortium

www.alabc.org

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B. LITHIUM-ION BATTERIES

Historically, lithium-ion (Li-ion) cells have primarily been developed for consumer electronics applications, a segment dominated by Asian battery manufacturers.¹⁴ This ready-made production and supply chain network enabled Asian battery manufacturers to react quickly to the initial demand for high performance nickel metal hydride (NiMH) and Li-ion cells for the automotive market.¹⁵ Japan's early move to the hybrid electric vehicle market through the Toyota Prius developed industry knowledge about integrating the entire energy system into vehicles.

This situation, combined with prolonged government support through R&D subsidies, has allowed Asia to build up an early position of market leadership for NiMH and Li-ion batteries for the automotive market, in competition with European and US industries. Asian companies also dominate further up in the supply chain, with a strong market share in the production of cathode and anode active materials, electrolytes and separators.

In 2015, there are only a limited number of production sites in Europe for Li-ion cells or batteries for automotive applications. However, the market for electric vehicle batteries remains an open playing field in 2014, with several different Li-ion chemistries competing for prevalence, and significant process improvements still to be made across all stages of Li-ion battery manufacture.

Given that the global market for Li-ion batteries is in an early stage of development, it is still possible for the EU to establish a competitive advantage in the production of Li-ion battery cells and systems. Increased levels of public R&D investment should be provided in order to anticipate new products and support pre-competitive research projects. The EU's Horizon 2020 European Green Vehicles Initiative provides a strong foundation, but larger-scale efforts might be required in order to ensure significant improvements.

¹⁴ McKinsey/German Federal Environment Ministry, 2010

¹⁵ Notably LG Chem, GS Yuasa, AESC, Panasonic and Hitachi

Additionally, the specialized electrochemical and engineering skill-set of Europe's workforce must be developed across several industry sectors, in order to compete with the expertise that has been developed in the Asian workforce over several decades.

It should also be emphasized that due to high transportation costs from Asia and market proximity to European manufacturing facilities, cost savings will be made possible by local production of battery technologies close to vehicle assembly lines. Once economies of scale have been realized for Li-ion battery manufacture, this will encourage European OEMs either to develop in-house leadership in battery technology, or to create strong partnerships with nearby manufacturing plants.

Moreover, wherever cell manufacture takes place, further processes such as pack assembly or systems integration can also create significant local value in Europe.

B.1 PRIORITY AREAS TO IMPROVE TECHNOLOGICAL PERFORMANCES

Primarily, battery and vehicle manufacturers will focus on increasing the energy and power density of lithium-ion batteries, thereby improving their performance in hybridized and electrified powertrains, and increasing the overall driving range of electric vehicles.

Energy density

Element Energy have estimated that through the development of high-voltage cathodes or high-capacity cathodes, the energy density of lithium-ion cells has the potential to increase from ~170Wh/kg today to ~290Wh/kg by 2030.

Energy density is being further improved by developing electrode materials with a high specific capacity, or by developing cells using higher voltage chemistry.

This will directly impact electric vehicle driving range, with Element Energy, for example, expecting a medium-size car equipped with a 200kg lithium-ion battery pack to deliver a 250-300km driving range by 2030.

Power density

Battery manufacturers are also working to increase the power density of lithium-ion cells, something that is especially important for plug-in hybrid and hybrid applications. An improvement could be achieved through optimised design, improved manufacturability and high performance current collectors.

Battery lifetime

At present, lithium-ion battery cells can achieve a 10-year lifetime. Manufacturers are working to further improve the battery's thermal management system, which ensures that the cells are kept at optimum temperature ranges. It can be expected that as a result electric vehicle cells will achieve a lifetime of 10-15 years by 2030.

Charge acceptance

Battery lifetime can directly be influenced by material choice, especially of the negative electrode (graphite versus titanate), as well as by an improved understanding of aging processes during cycling and of thermal behaviour.

B.2 PRIORITY AREAS TO LOWER COST

It is generally accepted that the cost of lithium-ion batteries will continue to decrease significantly over the next decade. For example, Element Energy have estimated that packaging costs can be reduced by 70% by 2030, to approximately \$215/kWh (from current levels of \$700/kWh). Half of this development would be through cell improvements, while the remainder would be in lowering packaging costs.

Materials improvements

Research into cell materials should continue to focus on bringing new, cheaper materials into battery cells (i.e., anode, cathode, separator and electrolyte). Technical advances in these areas will also increase the capacity of batteries (110% by 2025 according to McKinsey), resulting in further price reductions.

Mechanical design improvements

Manufacturers are also continuing to develop lower-cost options for battery casings, and to optimise their battery management system design with a focus on low-cost, low-weight solutions.

Another important aspect for future design will be a targeted standardisation of battery sizes. Therefore, modular concepts with a high degree of scalability are in focus, to meet the need for different-sized batteries

Manufacturing at scale

The increase in demand for large-format lithium-ion batteries will improve economies of scale, directly lowering cost. Battery manufacturers are currently working to design simplified systems ready for large automation.

Standardisation

EUROBAT also assumes that standardisation of large-scale lithium-ion cell manufacturing will continue to develop over the next decade.

B.3 PRIORITY AREAS TO IMPROVE SYSTEMS INTEGRATION

Once cells are designed and produced, they need to be included within a battery system. The integration of such systems is a key element in improving efficiency, reliability and safety. EUROBAT members have identified the following priority areas for systems improvement:

Standardisation of interfaces

Standardisation of protocols, mechanical shape and size of the battery management system (BMS) and other components is a priority in order to improve overall system reliability and lower costs.

Improvement of thermal management

Thermal management is of great importance for high-power batteries as well as for the development of high-energy batteries, designed to work in all weather conditions. Battery lifetime and reliability in extreme weather conditions are pending consequences of thermal management and must always be improved.

Safety improvement in electrical components

Manufacturers continue to improve the electrical safety of fuses, contactors and current sensors. This is important for further improving battery safety and systems reliability.

Light weighting solutions for structural, vibration and safety improvement

Batteries must be lighter and more stress-resistant.



B.4 PRIORITY AREAS TO OPTIMISE PRODUCTION PROCESS

Improvement of the processes used during lithium-ion battery manufacture will result in reducing overall production costs, as well as improving overall consistency and reliability in battery operation. Priority improvements include:

Reducing energy consumption and overall environmental footprint from manufacturing processes and equipment

The energy required to build li-ion cells is significant, although it is possible to store energy and reuse it for the process. Energy consumption can also be lowered through reducing the size of dry rooms and through optimizing process steps, such as instituting a better formation process, but also through the use of improved materials. The materials, at a minimum, must be fully recyclable and would ideally also be biodegradable.

Alternative processes to ink mixing and coating

Today's state-of-the-art positive electrode process uses organic solvent. Dry processes like extrusion, with no need to heat and cool down electrodes, using new binders and active materials, are in development. This will be a real breakthrough, and research programs need to be completed to confirm yields and product performance. Replacing organic solvent with water can be an alternative to "dry" methods. Programs will focus on aluminium foil corrosion, the intrinsic stability of powder in water and the production process.

Functional integration of current electrode and cell manufacturing process steps

Automated control systems during the assembly phase will lead to significant increases in the quality and reliability of products by removing defects before assembly. More robust production processes will help reduce the generation of defects.

Electrical formation

The energy used in this process (heat/cool down, charge/discharge) is currently re-injected into the grid so that consumption is reduced. New cell material will allow batteries to work close to ambient temperatures and thus reduce the energy required.

B.5 PRIORITY AREAS TO IMPROVE SAFETY PARAMETERS

Although a comprehensive set of precautions is taken at each step of their lifecycle to ensure that lithium-ion batteries are protected and secured against hazards, R&D should continue to be directed at developing cells and batteries with improved safety performance.

Development of high-efficiency monitoring functions

Existing BMS provide in real time a great deal of information about the status of each cell of a battery, but the margin for improvement is still quite high for functions such as State-of-Charge and State-of-Health, which depend on the way the battery is used. Research programs will make these estimations more accurate and reliable, and at the same time make batteries cheaper and lighter.

Cell diagnostic and supervision systems to support understanding of aging

Today, li-ion cell models are embedded in the BMS to predict the battery's health and remaining life. Simplifying the model and identifying the key measures needed for reliable prediction are necessary improvements. Knowledge about aging of the electronic boards is also important, as any failure in level may jeopardize all efforts to make prediction more reliable.

Systems design and validation

The complete system requires significant validation efforts. These can be reduced by improving the level of confidence in any concept used in the design.

B.6 PRIORITY AREAS TO DEVELOP RECYCLING PROCESSES

Li-ion batteries have been introduced into the market only recently; they are highly engineered products incorporating a wide variety of materials. Several different technologies are available, which differ inter alia as to the choice of active cathode material. These facts contribute to the lower recycling rates observed when compared with more established technologies such as lead-based batteries. Li-ion batteries do, however, meet the average recycling rate of 50% mandated for this family in the EU Batteries Directive (Directive 2006/66/EC), and recycled materials are reused by other industries where they replace the extraction of primary metals. As this technology is growing quickly 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 new batteries placed on the market today. Therefore, due to its growth, this segment is currently a net “taker” of raw materials.

Because several different lithium-ion battery chemistries are used in hybrid and electric vehicles according to specific needs for energy, power, safety, cost and lifespan, diverse and flexible recycling solutions are required that can process all different types of batteries. In this context, EUROBAT members recommend that the following areas should be focused upon over the next decade:

Value chain principles for design for recycling and remanufacturing

Product recycling starts at the design stage. Dismantling and component separation must be foreseen at this moment. Replacing any component that makes a battery harder to dismantle must become a priority; this can be achieved by anticipation programs that will develop the concepts before they are implemented in industrial products.

Development, in cooperation with the fertilizer industry or other industries, of a use for slags containing metal phosphates

Industrial zero-waste recycling processes at present mainly target the recovery of nickel, cobalt and copper. The recycling of lithium is technically and industrially feasible, but as only a small quantity is used in each battery (between 1 to 2% of total weight), and because only a small number of large-format batteries have reached end-of-life, this has not become economically viable yet. Slag containing lithium is recycled in an open loop for fast-hardening cement and ceramics.

EUROBAT Recommendations

Although the primary objectives remain increasing energy density and power density and lowering cost, EUROBAT members consider that research programs into lithium-ion batteries for Micro Hybrid Vehicles, HEV, PHEV and EV must also include a focus on each of the areas identified in this chapter. Only through such multi-faceted improvements will lithium-ion batteries become fully market competitive, while at the same time fulfilling requirements for safety and sustainability.

C SODIUM NICKEL CHLORIDE BATTERIES

First developed in the mid-1970s with the use of simple active materials as sodium chloride and nickel and with a solid ceramic electrolyte, sodium nickel chloride technology shows solid and proven results for energy storage and clean powering of electric vehicles and marine applications.

Sodium nickel chloride batteries have been commercialized since the 1990s and originally found application in electric vehicles and hybrid electric vehicles, mostly buses, trucks and vans. Today, the use of this type of battery has been broadened to industrial applications, including telecom and back-up markets, as well as on/off-grid stationary energy storage systems as large renewable energy power stations and supply of ancillary services to the electrical grid.

Batteries are available for use as high voltage packs ready for plug in: the packs used for automotive application show typically 20 to 30 kWh in both 300 and 600V Voltage range. Batteries are based on strings of cells enclosed in a stainless steel, case complete with thermal insulation. A proprietary BMS provides thermal management and maintains optimal usage conditions, preventing the possibility of electrical abuse.

Sodium nickel chloride batteries are produced in Europe by the Fiamm group's company, FIAMM SoNick, based in Stabio, Switzerland. FIAMM SoNick has a plant with a 20,000 m² production area, more than 200 employees and an automatized process with an installed production capacity of 100 MWh/year and a potential installed capacity of 300 MWh/year.

The SoNick battery is an energy-oriented battery with about 1.5 peak power/energy ratio. The best applications for sodium-based batteries in the e-mobility world are pure electric and electric-oriented plug-in hybrids, where the pure electric range is wide and energy storage is large enough to make available the peak power necessary for service.

C.1 PRIORITY AREAS TO IMPROVE TECHNICAL PERFORMANCE

To answer the customer's general demand for better performance, life and reduced cost, R&D efforts are focused on overall performance improvement with different projects that include:

Power density

Power density will be improved through working on different factors: reduced Ohmic losses due to improved design and materials in the cell components, research on advanced ceramics with higher conductivity and innovative cell geometry that increases the surface available for ion transfer. Expected improvements of power density are 15% by 2020 and an additional 20-25% by 2030.

Life cycle

The life cycle in general depends on type of usage and will be improved by more advanced thermal management with new cooling systems, by improvement of vehicle integration and energy management and by new cathode composition. Expected improvements to life cycle are 15% by 2020 and an additional 20-25% by 2030.

Energy density

Energy density will be improved through the optimisation of cathode composition.



Expected improvements are 20% by 2020

Developments in chemistry – Basic and applied research programs in electro-chemistry will lead to advanced sodium nickel chloride batteries with improved performance. Current research projects are studying a new positive electrode composition with higher power performance for both charge and discharge, as well as a new Catholite composition with lower resistance and melting point.

The introduction of a new BMS with advanced features, together with a total quality program in the overall production process, will improve the general reliability of sodium nickel chloride batteries.

C.2 PRIORITY AREAS TO REDUCE COST

Cost reduction is a common, key demand from users and manufacturers in order to keep an industrial product profitable. On-going projects to lower costs are focused on improvements to the ceramic electrolyte production process, the introduction of improved materials for thermal insulation, the industrialization of a new ceramic production process with reduced energy demands and the component supply chain optimisation.

C.3 Priority areas to improve systems integration

Deep integration and strong cooperation with vehicle manufactures are key elements for improving systems integration. In this regard, key areas for development are co-design and standardisation, with a strong focus on the mechanical integration of the battery to the vehicle, the development of communication standards among the components of the vehicle and the reduction of the energy necessary to maintain the temperature in the required operational range.

C.4 Priority area to optimise production processes

Resource optimisation in production lines, together with the savings that are achievable through economies of scale are classic approaches to reducing production cost and improving the total quality of a product. The on-going projects in this regard are:

- a lean manufacturing of battery assembly process
- automatic quality control for ceramic assembly

C.5 Priority areas to optimise safety parameters

Sodium nickel chloride technology is already considered to be intrinsically safe, based on four safety pillars:

- Intrinsically safe chemical reactions, with the development, in case of a fault, of solid materials, such as nickel, aluminium and salt, rather than flammable ones.
- Cells are hermetically sealed in a strong metallic case, preventing release of hazardous material.
- Double battery containment prevents cell damage by external physical, chemical or atmospheric hazards.
- Electronic control and safety interlock, preventing and protecting cells against unwanted physical/electro-chemical deviations, leading to hazardous conditions.

In any case, improvements are always possible and desirable, and present efforts are focusing on:

- more efficient cooling systems
- increased tolerance against abuse condition
- continuous product upgrade according to incoming automotive safety standards



C.6 Developments in recycling processes

Recycling is not considered an issue for sodium nickel chloride batteries. The basic materials of a sodium nickel chloride cell are nickel, iron, common salt and ceramic. The cell case and the battery box are made of steel and thermal insulation is provided by a silica-based material. All common materials are unaffected by possible shortages and are easily recyclable.

An exhausted battery can be used in the production of steel: the metallic boxes, the nickel and the iron content become part of the final product, and the salt and ceramic will form the slag in a process-consistent way, with the slag normally used as asphalt for road construction.

The recycling process is set up and available at industrial level. A possible improvement could be to earn value from thermal insulation material through secondary uses.

EUROBAT Recommendations

Projects for the improvement of sodium technology are both in progress and scheduled for the next five years. Sodium-based batteries are energy-oriented batteries, and are more competitive for commercial and professional vehicles, LCV to Heavy-duty, in pure electric and plug-in hybrid configurations or for general use in harsh ambient conditions. Demonstration projects and proofs-of-concept are in progress, in special vehicles and marine applications.

The suggested priority order for R&D and engineering projects of sodium nickel chloride batteries is: production processes, improved systems integration, cost, overall performance, safety, recycling processes, and extra functions.

2.3 EUROBAT Position on Vehicle-to-Grid

Vehicle-to-Grid is a concept that assumes that the electrical storage capacity available on BEV or plug-in HEVs can be used to deliver electrical energy to the grid. The idea is that electric cars are normally parked for a long time during the day and if connected to grid can help to balance grid loads by “valley filling” (charging at night when demand is low), “peak shaving” (sending power back to the grid when demand is high) and “buffer storing” (buffering renewable energy generated by stochastic sources as solar and wind power).

This concept could also provide utilities with new ways to provide regulation services (keeping voltage and frequency stable) and to provide spinning reserves (meeting sudden demands for power).

The flow of power from an electric vehicle can be valuable to the electric grid, and electric vehicle owners could and should be paid for the service. This would require recognition of the value of the several services offered by storage and would necessitate strong integration between the vehicles and the grid (Smart Grid and Smart Vehicles). Additionally, car batteries could have a second life as household storage facilities.

Nevertheless, several regulatory barriers to storage technology are still present at the European level. First and foremost, the lack of a clear definition of storage presents an element of uncertainty. Grid fees, ownership, liability, correct evaluation of ancillary services, access to data and control are all elements that should be addressed by the regulator in order to unlock the potential of household storage, vehicle-to-grid and a second life for batteries.

From a technical point of view, it must be taken into consideration that the cycling necessary for this service could affect the life of batteries installed on these vehicles, and the cost/benefit ratio needs to be considered in order to develop realistic applications. EVs would also need to be equipped with a grid-tied inverter, resulting in higher vehicle costs. Research projects are in progress to test the technical implications of vehicle-to-grid.





electric drive

3 European Battery Industry, Skills and Jobs

3.1 Competitiveness of the European battery industry

This Roadmap has been developed from the perspective of the European battery industry. EUROBAT's membership considers that the technological improvements prioritised in this report can be achieved through sustained cooperation between European industry, academia and policy makers.

Alongside this technical vision, it is important to consider Europe's global competitiveness in the manufacture of different battery technologies for automotive applications. Although there is a strong, well-established European industrial base for traditional automotive battery technologies, further efforts are required to improve Europe's competitiveness in the production of hybrid and electric vehicle batteries.

The EU automotive and industrial battery sector directly employs around 30,000 workers and has an annual turnover of approximately €6.5 billion. As well as manufacturing sites, many research and development centres are located in Europe. The EU battery manufacturing industry collectively spent €740 million on Research & Development & Innovation-related investments (i.e., infrastructure) over the last five years, with an additional €105 million for R&D&I related expenses (e.g., material costs) and manufacturing-related investments (e.g., pilot lines) of €915 million. EUROBAT members currently operate 16 R&D centres in Europe.

Vehicle manufacturing is a strategic industry in the EU, where 16.2 million cars, vans, trucks and buses are manufactured per year. The European auto industry is a global player, delivering 6.6 million “Made in Europe” vehicles around the world, and resulting in a €92 billion trade surplus. Motor vehicles account for over €385 billion in tax contributions in just 14 EU countries — a vital source of government revenue. The €839 billion turnover generated by the automotive sector represents 6.9% of the EU’s GDP.

The automobile industry employs 12.9 million people, representing 5.3% of the EU employed population. The three million high-skilled jobs in automotive manufacturing represent 10% of the EU’s manufacturing employment. The automotive sector is the EU’s largest investor in R&D, accounting for 25% of total R&D spending. The EU auto industry invests over €32 billion into R&D and applies for 9,500 patents per year.

3.2 Skills

This chapter examines the implications for the skills needed in the battery industry workforce as a consequence of the shift towards advanced hybrids and battery-based electric vehicles.

When it comes to battery manufacturing, many of the skills required for the development of advanced batteries are the same as those that are needed for the manufacture and maintenance of conventional ones. There are, however, a number of new skills that will be needed as different types of batteries are developed and aim at higher CO₂ emissions reduction. Specifically, there will be a need for high-level research chemists to investigate new substances to be used in batteries, or ways of making existing batteries more powerful and efficient.

Research carried out in 2014 by the European Climate Foundation, EUROBAT and other partners identified specific occupations within the battery industry, where new skills might be needed in the future:

- Chemical engineers to develop new batteries; to improve existing battery technology; and to design the equipment and processes needed for manufacturing batteries
- Electrical engineers to design, develop, test and supervise the manufacture of electrical equipment and components, and to design the electrical circuitry needed to charge batteries and to distribute electricity from batteries to the motor
- Industrial engineers to determine the most efficient and cost-effective ways of combining the various factors of production: labour, machinery and materials
- Materials engineers to develop and test new materials
- All the above occupations require people with at least tertiary level qualifications — i.e., university degrees or the equivalent. For tasks involving research, the need is for people with postgraduate qualifications .

Moreover, the battery industry is also facing a challenging skills shortage. For example, there are only a few universities in Europe that provide teaching and research opportunities in the field of lithium ion technology. This might push



companies to look further away for candidates, from India and China. The research mentioned above concludes that tackling skills shortages is a joint responsibility of governments and companies, though ultimately it falls to companies to respond to the prevailing situation. As a result, companies develop graduate programmes to train new recruits in the relevant fields. However, training programmes come at a cost and hiring experienced people who already have the requisite skills is an alternative, even though it may mean paying higher salaries.

In addition, some of the existing workforce may have difficulty in learning the new skills required, either because of the lack of educational background or age, or simply because they are responsible for specific production lines with a precise timetable, so they have less flexibility in terms of time for training.

In the battery industry, besides the specific engineering skills mentioned above, a very important aspect consists of the skill-set of assembly-line workers. In this case, there are two challenges that the battery industry is confronted with: older workers (aged 55 or over), and workers with low levels of education. Neither of these two groups is likely to have the background and interest required for acquiring new skills or learning new tasks relatively easily, which means that training assembly-line workers in the battery industry may sometimes be problematic, e.g., security training for proper handling of the product in different manufacturing phases.

EUROBAT recommends that the European Commission, in close collaboration with national authorities, establish specific transport calls dedicated to lifelong learning skills to bridge the skills gap, foster skills development, anticipate change, secure transitions and promote labour mobility.



4 Conclusion

EUROBAT notes the extreme importance of the efforts to speed up the decarbonisation of the EU transport sector and the electrification of the fleet. Batteries are at the heart of the move towards a decarbonised transport sector, and further research is needed to rapidly advance along this path.

In the near future, advanced lead-based, lithium-ion and sodium nickel chloride batteries have the greatest potential for further technological improvements.

This Roadmap highlighted the R&D priorities where improvements are most needed: the intention of the battery industry is to focus its R&D efforts in the directions illustrated in this Roadmap. At the same time, EUROBAT invites the European Commission and all relevant stakeholders to join EUROBAT efforts and to actively support these R&D priorities for each battery technology.



■ Points of contact

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The decarbonisation of the transport sector and the electrification of the European fleet are absolutely needed to achieve our goals of energy security, energy efficiency and sustainable, low-carbon and climate friendly economy.



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