EUROBAT 2030

BATTERY INNOVATION ROAD MAP

WHITE PAPER
BATTERY INNOVATION
ROADMAP 2030

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TECHNICAL ANNEX

Pb Li Ni Na

Contents

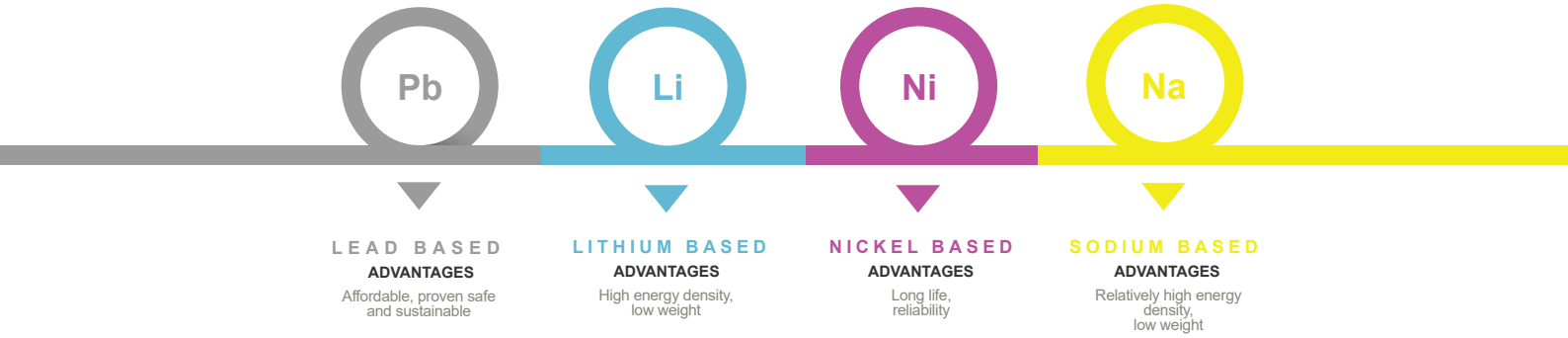
Scope And Purpose Of The Technical Annex

This Technical Annex to the EUROBAT White Paper 'Battery Innovation Roadmap 2.0' provides the reader with more in-depth technical background on the state-of-play and innovation potential of the mainstream lead-, lithium-, nickel- and sodium-based batteries, as well as on promising future battery technologies with a horizon up to 2030. The Annex consists of two main parts.

The first part analyses the state-of-the-art and potential for improvement of each identified battery technology in relation to their intrinsic performance, safety and environmental aspects.

As batteries are designed to be used in particular applications, the second part of the Annex is even more important and analyses the mainstream battery technologies used in critical applications in support of the objectives of the Green Deal. In this part II, the battery KPIs are considered per application as the innovation priority areas for the different mainstream battery technologies are strongly linked to this.

BATTERY TECHNOLOGIES AND APPLICATIONS



Part 1 Identified Battery Technologies and their potential

The battery technologies considered in this White Paper have been selected because of their potential for further improvement and their contribution to meeting the objectives of the European Green Deal and the new Batteries Regulation that is under development.

The first chapter covers today's mainstream battery technologies (lead-, lithium-, nickel- and sodium-based), whilst the second chapter covers the most promising upcoming technologies identified to complement the progress made in the existing technologies.

A. Mainstream battery technologies and their innovation potential

Decades of market-driven R&D has resulted in a wide variety of commercial lead-, lithium-, nickel- and sodium- based battery products. This large variety of products is the result of incremental improvements introduced over decades to fit the specific needs of the applications and their ever-increasing demands.

Today's mainstream lead-, lithium-, nickel- and sodium-based battery technologies still have innovation potential to continue serving further evolving markets. As such, they should be considered as key technologies to further reduce CO_2 emissions and to make Europe less dependent on energy and raw material imports, also by 2030.

This chapter highlights the innovations of each of the various mainstream chemistries. However, it should be stressed that combining battery chemistries within the same application also provides synergies, such as in developments for mild-hybrid EVs or in BEVs, where the HV lithium propulsion battery is supported by the LV advanced lead battery to ensure the functional safety.

A.1. Lead based batteries

State-of-the-art

The lead battery has been the predominant energy storage device for the industrial and automotive markets for over 100 years. Different designs of lead-based batteries are available, with an important choice to be made between flooded or 'vented', requiring maintenance, or maintenance-free valve-regulated (VRLA) batteries. They can be connected in large battery arrangements without sophisticated management systems and are differentiated from the other technologies by a low cost per kWh installed and low cost per kWh electricity throughput.

It is often overlooked that the lead battery has continuously innovated in response to new requirements in terms of functionality, durability and cost. The recent mainstream introductions of absorptive glass-mat (AGM) batteries, enhanced flooded batteries (EFBs), battery monitoring sensors and battery management systems (BMS) are obvious examples of continuous improvement.

Improvement potential

To compete with upcoming electrochemical storage technologies, there is a need to accelerate the pace of innovation. This could be through a better dynamic charge-acceptance at uncompromised high temperature durability or by improving the energy and power densities with improved cycle-life. Specific power could be improved by developing new advanced additives to decrease the internal resistance, while the cycle life could be lengthened through design enhancements, such as corrosion-resistant lead-alloys. More intelligent battery operation modes could also be developed.

Apart from fundamental research to improve the electrolyte, the materials and the components used, other improvements can still be made. These include material innovations on synthetic expanders, nano-based carbon materials, new alloy compositions and improved Thin Plate Pure Lead (TPPL). Also bipolar cell design will be key developments for lead-based technologies to further advance in view of future requirements in a multitude of applications. TPPL and Carbon Enhanced are promising candidates for increased service life, PSOC operation and improved power density.

The outstanding feature in this process is that these improvements have been tailored to the particular application.

Environmental aspects

Occupational exposure to lead is now under control because the battery industry has proactively taken measures to limit the exposure of its employees to blood lead contamination during the manufacturing process. Europe should allow the market to drive change and recent progress on lead battery research should not be discounted. The further development of lead batteries in a variety of enhanced technologies will serve applications that can contribute to the achievement of the zero-emissions targets in the European Green Deal.

Lead-based battery circular economy targets

Recycling targets for lead batteries will be maintained at a very high level, with efficiency over 90% and recycling of active materials at 99%, achieving a circular economy, which will benefit the whole battery value chain and improve Europe's independency on raw materials imports needed to build the batteries.

A.2. Lithium-based batteries

State-of-the-art

Lithium-ion (Li-ion) is considered the leading lithium technology for automotive and industrial applications and will remain so in 2030. Lithium is currently deployed in mass-produced standard cell types in different applications – a strategy driven by cost and safety reasons. The major requirement for higher energy densities to achieve increased driving range is directly linked to e-mobility. This results in a development roadmap for 2030 that mainly considers the lithium-based technologies based on modified nickel cobalt manganese oxide (NMC) materials, from NMC 111 to NMC 811, with increased nickel and reduced cobalt content in combination with high capacitive anode materials with carbon/silicon composites. Solid state technology should also be targeted to increase the energy density and improve the safety aspect. The Li-ion technologies considered in this Roadmap consist of a combination of the following available anode and cathode materials:

Anode	- C:	350 – 360 mAh/g
	- Si(SiOX)/C:	400 – 900 mAh/g
	- LTO:	150 mAh/g
Cathode	- NMC 111:	160 mAh/g
	- NMC 532:	175 mAh/g
	- NMC 622:	180 mAh/g
	- NMC 811:	175 – 200 mAh/g
	- NCA:	200 mAh/g
	- LFP:	150 mAh/g
	- LMO:	105 – 120 mAh/g

Tabulation: Specific capacities of anode and cathode materials of Li-ion batteries covered in this Roadmap

Improvement potential

The development roadmap for Li-ion, Ni-rich NMC positive electrode materials and new materials for the negative electrode (e.g. Si/C composite) considered for future development are:

- **Generation 2a:** NMC 111 / 100% C
- **Generation 2b:** NMC 523 - 622 /100% C
- **Generation 3a:** NMC 622 / C + Si (5-10%)
- **Generation 3b:** NMC 811 / Si/C composite

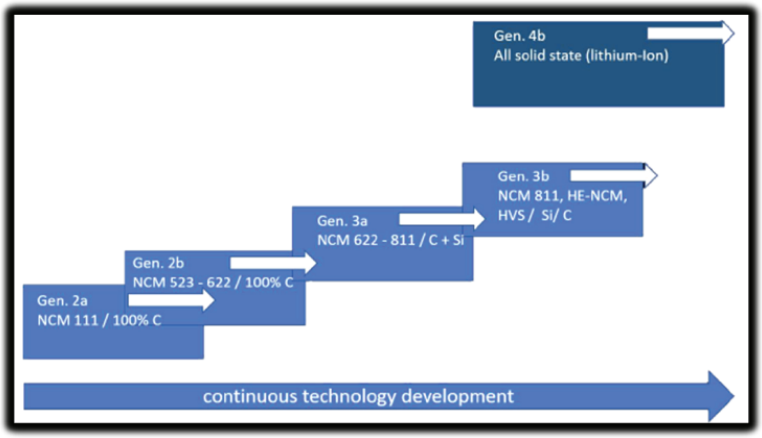


Chart: Generation of lithium materials considered for further development by 2030

Due to the variety of possible combinations of cathode and anode materials, the resulting Li-ion batteries show specific and individual performance characteristics suitable for different kinds of applications. The development of Li-ion technologies suitable for industrial and automotive applications is still a challenge in terms of material research process, production, development, recycling, safety and transportation.

Requirements for cathode materials

- High specific energy (mAh/g)
- Safety
- Stability (cycle and calendric)
- High voltage
- Low polarisation
- Low price
- Low content of rare materials (e.g. cobalt)
- Low CO_2 footprint at production
- Environmentally and ethically harmless
- Easy processing
- Availability
- High power capability

Economic and safety requirements

- Low price
- Easy processing
- Environmentally safe and ethical
- Operationally safe

Challenges identified

- Production processes
- Recycling processes
- Transportation

Environmental aspects

In order to reduce the environmental impact and improving the availability of lithium battery components, a strong push is expected in research aimed at reducing the content of rare materials (Cobalt), at researching alternative materials, activating extraction processes environmentally safe and ethically sound mining and manufacturing, and also a development of low-carbon manufacturing processes.

Lithium based battery circular economy targets

Recycling targets for lead batteries will be maintained at a very high level, with efficiency over 90% and recycling of Recycling targets for lithium batteries will be maintained at the current level of 50%, but active material recycling is expected to increase from 65% to reach 85% by 2030. The recovery of nickel, cobalt and lithium will also be fully commercially viable in future.

A.3. Nickel-based batteries

State-of-the-art

Nickel-based batteries are the technology of choice for applications used in extreme climate, cycling or fast charging conditions. Different designs are available: pocket, sintered, plastic-bonded, nickel foam and fibre electrodes. Cells are prismatic or spiral wound, flooded (or 'vented') or valve regulated, the latter also being maintenance free. Thanks to decades of safe use under the most extreme operating conditions and continuous development, nickel-cadmium is mostly used in special and niche applications.

Improvement potential

Using innovative materials, this technology can be further developed for existing applications and as a replacement solution with its key performance properties in extreme conditions having the potential for further improvement. Nickel-based batteries are among the electrochemical storage systems that should be considered for industrial applications over the next decade.

Environmental aspects and circular economy targets

Recycling efficiency should increase from the current 79% (active materials at 50%) to 80-85% (active materials at 55-60%) by 2030 to reach a break-even business model

A.3. Sodium-based batteries

State-of-the-art

In contrast to other battery types, high-temperature batteries consist of liquid-electrodes and a solid electrolyte, usually an ion-conducting (e.g. Na+) ceramic. These batteries require relatively high operating temperatures of >300°C to keep the sodium-based electrode in the liquid state and to increase the conductivity of the solid electrolyte.

Commercially available representatives are sodium nickel chloride (NaNiCl), also known as the 'Zebra' battery (Zero Emission Battery Research Activities), and the sodium-sulfur battery (NaS).

Sodium nickel chloride batteries: The cathode mainly consists of a porous nickel matrix as a current conductor with nickel chloride ($NiCl_2$), which is impregnated with sodium aluminum chloride ($NaAlCl_4$). The anode is made of sodium. Ceramic β-aluminum oxide is used as the separator and electrolyte, but the sodium ions do not allow electrons to pass between the anode and cathode. The operating temperature of this type of battery is between 270°C and 350°C so that the electrodes (active material) are in the liquid state (melted) and the ceramic separator achieves high conductivity for sodium ions. The specific energy of the cells is approximately 120 Wh/kg at a nominal voltage of 2.3V to 2.6V. Advantages over the sodium-sulfur battery are the inverse structure with liquid sodium on the outside, which allows the use of inexpensive rectangular steel housings instead of cylindrical nickel containers. The assembly is simplified in that the battery materials can be used in the uncharged state as sodium chloride and nickel, and the charged active materials are only generated in the first charging cycle. Sodium nickel chloride batteries are used in small series of electric vehicles in fleets and for stationary storage applications.

Sodium-sulfur (NaS) batteries: The cells consist of an anode made of molten sodium and a cathode made of graphite fabric soaked with liquid sulfur in order to achieve electrical conductivity, as sulfur is an insulator. As in the case of the NaNiCl battery, the solid electrolyte β-aluminum oxide is used as the electrolyte, which becomes conductive for Na+ ions above a temperature of approx. 300°C. The optimum temperature range is between 300°C and 340°C. During the discharge process, positively charged sodium ions enter the solid electrolyte from the liquid sodium, releasing electrons. The sodium ions migrate through the electrolyte to the positive electrode, where they form sodium polysulphides. The cell voltage is 2V. This process is reversed during charging. A major advantage of the sodium-sulfur battery is that the internal resistance of the cell is almost independent of the state of charge. It only rises sharply towards the end of the charge because there is a decrease in sodium ions in the electrolyte.

The required operating temperature is maintained in normal operation by the power dissipation of the cells themselves; in stand-by operation it is achieved by an additional electric heater, which increases the battery's own consumption.

The NaS battery has a volumetric energy density of about 367 Wh/l and gravimetric energy density of 222 Wh/kg. One advantage of this battery is the high cycle stability of over 4,500 cycles and a long calendar life of over 15 years. The technology has been commercialising since 2002, mainly for large scale storage with more than 1 MWh of energy.

NaNiCl and NaS batteries have a service life of around 4,500 cycles and an efficiency of 75% to 86%. If necessary, thermal losses due to heating necessary to maintain the cell temperature must be taken into account, if there are longer periods of time between charging and discharging. This can be influenced within certain limits through a corresponding effort in thermal insulation.

Environmental and circular economy targets

NaNiCl battery production is relatively energy-intensive and therefore has the highest share of environmental impact (depending on the heat supply source). Other factors are the high demand for nickel and the complex modular construction (insulation). The nickel content in the battery can be recovered, which can be used in the steel industry. The ceramic content in the cells, as well as the salt collected in the resulting slag, can be used in road construction. Regarding the manufacturing process, the production of the β-aluminum oxide solid electrolyte is considered to be energy-intensive. NaS batteries also contain large proportions of steel and aluminum, which can be recycled accordingly, leading to a reduction in the possible environmental impact.

B. Future battery technologies and their potential

In the frame of further improvements in performance requirements of batteries in real life applications and driven by durability, safety, sustainability and affordability, industry experts have reached consensus on which promising future technologies to consider in the current roadmap. With sustainability as a key driver with the purpose of producing batteries at the lowest possible environmental impact, materials that have been obtained in full respect of social and ecological standards, are long lasting and safe, and that can be repaired, reused or potentially repurposed should be used. In this sense the essential electrochemical storage systems identified are listed hereunder.

B.1. Lead bipolar battery technology

While bipolar and monopolar designs share the same lead-based chemistry, they differ in that in bipolar batteries, the cells are stacked in a sandwich construction so that the negative plate of one cell becomes the positive plate of the next cell. The cells are separated from each other by the bipolar plate, which allows each cell to operate in isolation from its neighbour. Stacking these cells next to one another (figure hereunder) allows the potential of the battery to be built up in 2V increments. Since the cell wall becomes the connection element between cells, bipolar plates have a shorter current path and a larger surface area compared to connections in conventional cells. This construction reduces the power loss that is normally caused by the internal resistance of the cells. At each end of the stack, single plates act as the final anode and cathode. This simpler construction leads to reduced weight since there are fewer plates and bus bars are not needed to join cells together. The net result is a battery design with higher power than conventional monopolar lead-based batteries.

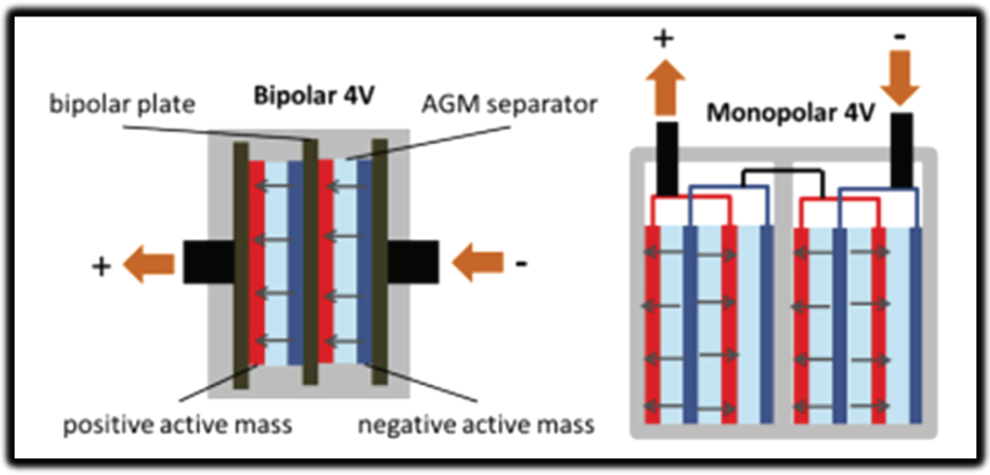


Figure: Bipolar design - the cells are stacked in a sandwich construction

Until recently, the main problem limiting the commercialisation of bipolar lead-acid batteries was the availability of a lightweight, inexpensive and corrosion resistant material for the bipolar plate, and the technology to properly seal each cell against electrolyte leakage.

Architectural advantages are:

- Direct current path = low impedance
- Uniform current density = high material utilisation
- Thin active material and separator = high power
- Pb-Bipolar technology = increased energy density: 50 – 63 Wh/kg

B.2. Sodium-ion room temperature batteries

In comparison to the state-of-the-art high temperature sodium batteries, the upcoming new sodium-ion battery technology is operating at room temperature. The sodium-ion battery has a similar working principle to the Li-ion battery. Sodium ions also shuttle between the cathode and the anode to store and release energy. As sodium resources are cheap and widely distributed and considering the technological similarities with existing Li-ion batteries, the industrialisation process of sodium-ion batteries will be accelerated.

For cathode materials, the most important part of sodium-ion batteries, Prussian blue analogue, layered metal oxides, and NASICON (sodium (Na) Super Ionic Conductor), each has its own advantages in different aspects.

Based on potential application scenarios, higher energy density, longer cycle life and better low temperature performance are the most critical indicators. In total, the cost and safety advantages of sodium batteries will gradually gain in prominence. Therefore, it is likely that sodium-ion batteries will be used as traction batteries in two-wheeled vehicles, such as e-scooters, 12V starter applications, A0 and A00 passenger vehicles for A-level EV charging, and electrical energy storage (EES), as an effective supplement to Li-ion batteries.

The specific capacities of anode and cathode materials are:

Anode:

- C: 300-500 mAh/g
- Sn: 500-1,000 mAh/g

Cathode:

- Prussian Blue Analogue: 120-160 mAh/g
- Layered Metal Oxide: 100-180 mAh/g
- NASICON: 100-140 mAh/g

Sodium-based battery circular economy targets

Recycling targets for sodium-ion batteries will be maintained at the current level of 50%, but active material recycling is expected to increase from 50% to 90% by 2030.

Generations of sodium materials considered for further development by 2030 are:

State-of-the-art	NaS, NaNiCl
>2023	Na-ion (RT)
>2025	High Energy Density Na-ion (RT)
>2030	All Solid State

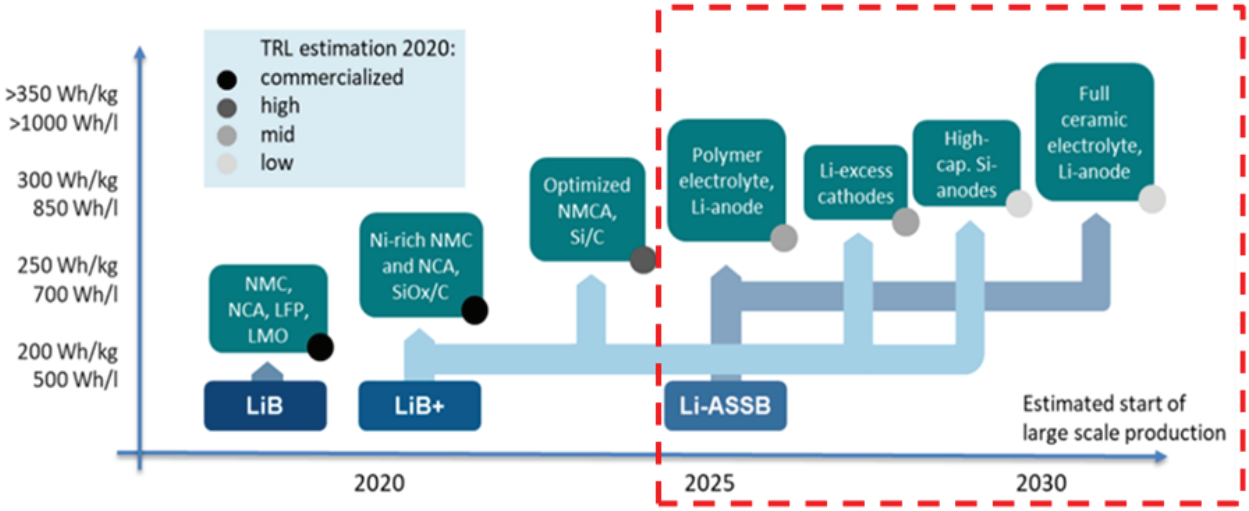
Sodium based technologies - key performance parameters for state-of-the-art in 2023 and targets for 2030:

	Sodium-ion 2023	Sodium-ion 2030
Recycling Rate (%)	50	90
Calendric Life (years)	15	30
Energy Throughput (FCE)	4000	6,000-12,000
Fast Recharge Time (min)	30	5
Volumetric Power Density (W/l)	500	600-850
Gravimetric Power Density (W/kg)	300	380-700
Volumetric Energy Density (Wh/l)	310	350-700
Gravimetric Energy Density (Wh/kg)	160	200-450

B.3. Post Li-ion battery technologies

Inexpensive and environmentally friendly metals such as sodium and polyvalent light metals should one day replace lithium battery technologies. A major challenge, however, is the development of durable and stable electrodes with high energy density and, at the same time, fast charging and discharging rates.

Lithium Technology Roadmap



Battery Generation	Electrode active materials	Cell Chemistry / Type	Forecast Market deployment
Gen 3b	➢ Chathode: HE-NMC, HVS (High Voltage Spinel) ➢ Anode: Silicon / Carbon	Optimised Li-Ion	2025
Gen 4a	➢ Chathode: NMC ➢ Anode: Silicon / Carbon ➢ Elektrolyte: Solid Electrolyte	Solid State Li-Ion	2025
Gen 4b	➢ Chathode: NMC ➢ Anode: Lithium Metal ➢ Elektrolyte: Solid Electrolyte	Solid State Li Metal	>2025
Gen 4c	➢ Chathode: HE-NMC / HVS (High-Voltage-Spinel) ➢ Anode: Lithium Metal ➢ Elektrolyte: Solid Electrolyte	Advanced Solid State	2030
Gen 5	➢ Li/O2- Lithium air /Metal Air ➢ Conversion Materials (primarily Li/S) ➢ New Ion based systems (e.g. Mg, Al)	New cell Gen: Metal-Air / Conversion Chemistries / New Ion-based insertion Chemistries	> 2030

Figures: Lithium technology Roadmap (> 2025): Gen.3. advanced Li-Ion; Gen. 4. Solid-state; Gen. 5 post-Li-ion

Lithium all-solid-state (Gen. 4)

Solid state batteries use an electrolyte made of solid material instead of the usual liquid electrolyte. The electrodes are also made of solid material. With solid state batteries, there is the possibility that part of the solid electrolyte can be incorporated into the electrodes. For example, lithium metal anodes can also be used, which further improve performance. The main advantages of future solid state batteries are that the energy density of the cells will increase significantly in the future and the risk of fire will also decrease due to the less pronounced flammability of the electrolyte. The use of cobalt can also be significantly reduced.

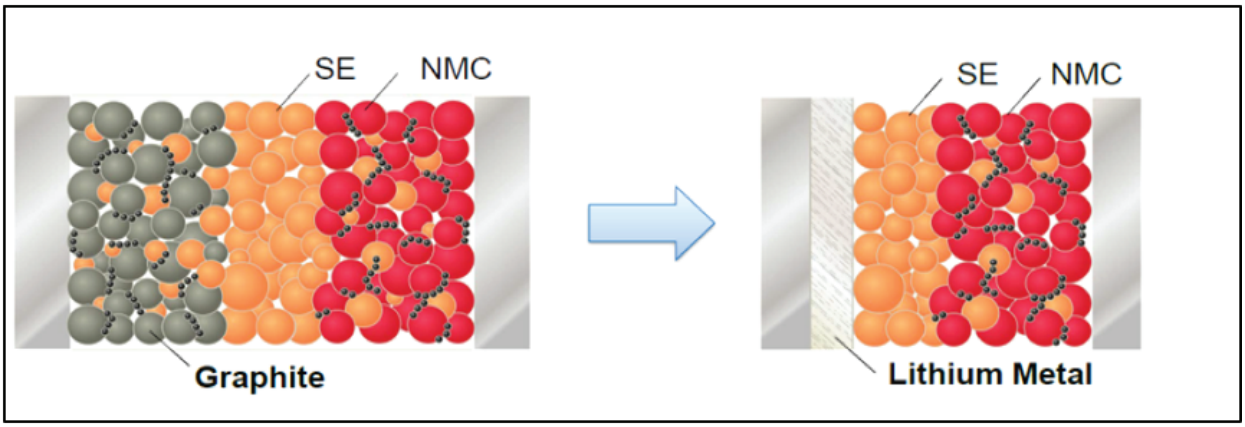


Figure Gen. 4a:
Specific Energy ~ 280 Wh/kg

Figure Gen. 4b:
Specific Energy ~ 450 Wh/kg

The actual increase in energy comes only through the elimination of the graphite by the metallic Li anode, i.e. through the transition from the Li-ion solid state (Gen 4c) cell to the Li solid state cell – Gen 4b. In this case (NMC) by a factor of 1.5.

Advantages of solid state batteries in comparison to liquid electrolyte cells are:

- Higher energy density than Li-Ion
- Safety – instead of flammable organic liquid electrolyte, use of a solid state electrolyte (ceramic, polymer)
- No electrolyte leakage
- Solid polymer Li-ion cells can be made as thin as 0.1 mm or about one-tenth the thickness of the thinnest prismatic liquid Li-ion cells
- Lower manufacturing cost potential
- Excellent shelf life

Disadvantages of solid state cells compared to liquid electrolyte cells are:

- Power limited by low ionic conductivity of electrolyte
- High interfacial resistance
- Poor interface contacts
- Costly manufacturing process when using vapour deposition process

The solid state cells use different polymeric electrolytes: crystalline and glass electrolytes.

Lithium-sulfur

Lithium-sulfur batteries (LiSB), using lithium metal as the anode, an organic liquid electrolyte and sulfur composite as the cathode, could have a high theoretical capacity (1675 $mAh.g^{-1}$) and specific energy (2567 $Wh.kg^{-1}$).

Lithium-sulfur (Li-S) batteries have been proposed and investigated since the 1960s as an effective energy storage device via reversible electrochemical reactions. As the fast development and commercialisation of Li-ion battery technologies kept moving forward, critical technical issues facing Li-S batteries have not been solved since then. In the 2000s, Li-S batteries again attracted significant research interest owing to their low-cost advantages and high theoretical specific energy of 2600 Wh kg^{-1}, which is at least 3 times higher than the current Li-ion technology. The low cost and high abundance of sulfur (i.e. the active cathode material), make Li-S batteries more appealing than Li-ion given the fact that the latter use critical materials such as cobalt and nickel in the manufacturing of the cathodes. Moreover, the high energy and low cost features make Li-S batteries a promising energy storage technology in practical applications, such as portable devices, electric vehicles and grid storage when coupled with the harvesting of renewable solar or wind energy. The ultimate goal of achieving 500 Wh kg^{-1} for Li-S battery will make it more competitive for widespread commercialisation.

Li–S batteries are promising because of the high energy density, low cost and natural abundance of sulfur. However, these advantages can be achieved only when the Li–S battery uses elemental sulfur as the cathode active material and the sulfur approaches the theoretical capacity with low process cost. In recent years, great improvements in the cycling performance of Li–S batteries have been made. However, all these achievements are obtained in exchange for the energy density and process cost. Nanostructured sulfur composites based on various types of carbon materials

and conducting polymers have driven the specific capacity of sulfur to a level approaching the theoretical value with acceptable cycling efficiency and cycle number. However, syntheses of these composites are very costly and, furthermore, the cathodes using these composites contain low sulfur content (< 60%) and low sulfur loading (< 2 mg/cm2), which dramatically reduces the energy density of Li–S batteries. On the other hand, Li–S batteries are fundamentally a liquid electrochemical system, in which elemental sulfur must dissolve into the liquid electrolyte in the form of long-chain PS and serve as the liquid catholyte. Dissolution of PS in the liquid electrolyte on the one hand facilitates the electrochemical reactions of insulating sulfur species, and on the other hand causes severe redox shuttle and parasitic reactions with the Li anode.

Lithium-air

A lithium–air battery contains a lithium electrode and porous air electrode separated by a membrane and an electrolyte (aqueous, aprotic or solid). Lithium-air batteries possess great potential for efficient energy storage applications to resolve future energy and environmental issues. Although lithium-air batteries attract much research because of their extremely high theoretical energy density, there are still various technical limitations to be overcome before their full transition. Major draw-back right now is the low round trip efficiency. It is well-recognised that the performance of lithium-air batteries is governed mainly by electrochemical reactions that occur on the surface of the cathode. Widespread interest in various carbons and their applicability as cathode materials in lithium-air batteries arises as a result of their highly specific surface area and porosity, their light weight and their low production cost.

Part 2 Battery end-user application R&D focus area

The selection of the key battery performance indicators (KPIs) for innovation (such as gravimetric and volumetric energy and power densities, fast recharge time, energy throughput, calendar life and recycling rate) is strongly dependent on the application in which the battery will be integrated.

A total of 15 end-user applications are selected in 4 areas:

- Automotive mobility applications
- Motive power material handling and logistics applications
- Motive power off-road transportation applications
- Stationary Energy Storage applications

In all these areas, batteries have been recognised as key enablers to significantly contribute to Europe's decarbonisation strategy and to make Europe less dependent on fossil fuels.

Part II of this Annex provides a direction on the current technical battery requirements for these applications and what we believe is feasible to target by 2030. With this market-oriented approach, battery experts identified the KPIs per technology to prioritise R&D to meet the shifting demands in these end-user applications.

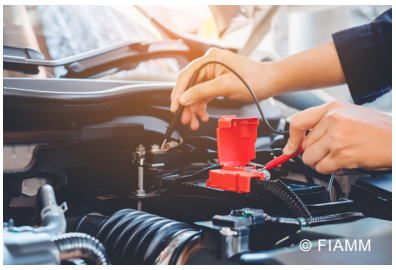
A. R&D AREA - automotive mobility

The road transport sector is responsible for 20% of the EU's total CO_2 emissions, but has a strong potential for decarbonisation, with batteries as key enablers for increasing the energy efficiency of vehicles (all drivetrains). Consumer pressure and regulatory drivers are forcing changes in vehicle technology. Today, there is a strong focus on battery electric vehicles (BEV), but there is wide potential for the role of batteries to evolve further. The Worldwide Harmonised Light Duty Vehicles Test Procedure (WLTC) brought a shift to using real driving data to assess fuel consumption and emissions and the main challenge for automotive batteries is to capture the car's kinetic energy for the different degrees of hybridisation and electrification, from start/stop to mild hybrid, plug-in hybrid and full electric vehicles. The different battery types should continue to co-exist as they all have the potential to contribute considerably to the realization of the Green Deal zero-pollution targets by 2050.

Besides 12V SLI and 12V auxiliary batteries, we also present in this automotive area the Heavy Commercial Vehicle stand-by battery, the mild-HEV and full HEV, as well as the full BEV.

A.1. Automotive 12V auxiliary batteries

Application profile



Auxiliary batteries are regarded as to starter batteries with a nominal voltage of 12V, used as an auxiliary storage/power source in vehicles featuring several levels of electrification and having a range of scopes, such as: 12V board-net voltage stabilisation or full support during events, low voltage electrical load support during cranking of the main battery, supply peaks or backup demand related to 12V based loads, including vehicle functions relevant for safety or autonomous driving features, key warm cranking during S&S (ISS) events, not limiting the functionality to SLI applications.

Auxiliary 12V batteries are used in automotive vehicles at all levels of hybridisation. From micro, mild, full and plug-in hybrids to electric cars, the battery's main function is to support the 12V loads and to ensure the quality of the on-board net, as well as to ensure the safety manoeuvrings in case of emergency. Furthermore, start- stop functionality, cyclability and cranking are tailored to the specific vehicle architecture, although the cranking feature might disappear in future.

The further market penetration of micro, mild, full and plug-in electric vehicles will increase the 12V auxiliary battery market in the next 10 years as vehicles are all already equipped with these batteries.
The dominant battery technology today is lead. Together with lead, lithium can also compete in this category to fulfil future requirements.

In the automotive sector the role of 12V batteries will remain dominant in all vehicle architectures, with 12V Li-ion having a very small market share by 2030.

Description of the battery features

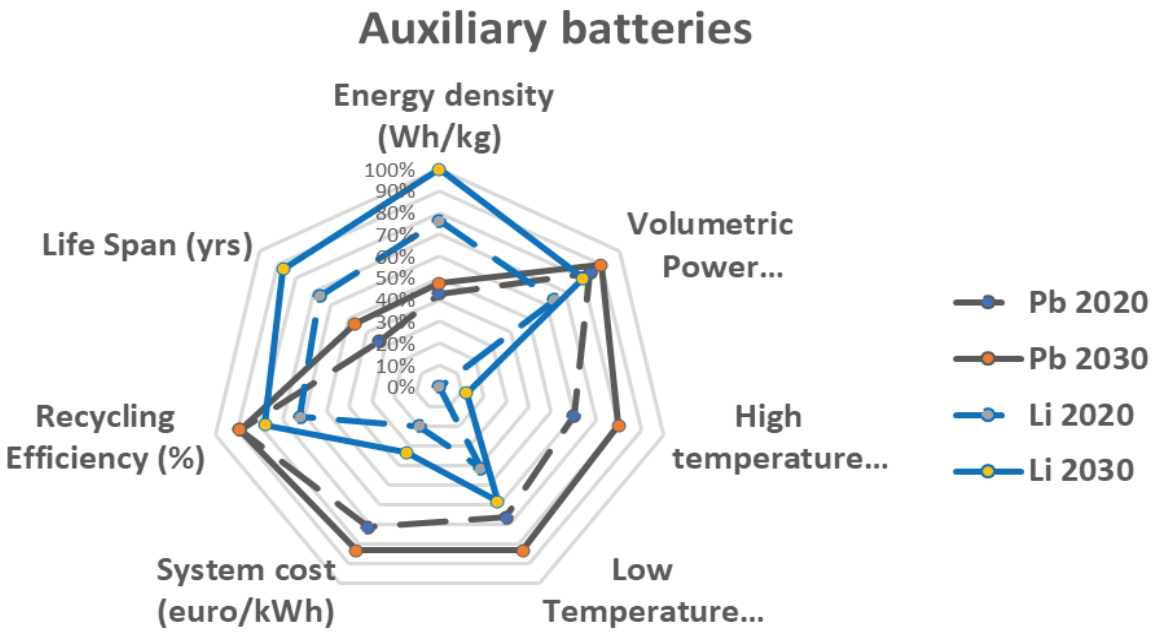
Lead and lithium technologies are complementary in terms of performance, recycling and cost. For auxiliary applications, lead batteries are advantageous for their high temperature life, low temperature performance, recycling efficiency and cost, but there are improving opportunities for what concerns energy density and life span. The advantage of Li-ion batteries, however, is in their energy and power densities and durability at ambient temperatures. However, high cost, safety and recyclability, as well as extreme temperature performance, must be improved in order to become competitive with lead batteries in this application.
Enhanced flooded (EFB) and absorbent glass mat technology (AGM), will generally be preferred. For lithium-based batteries, lithium iron phosphate (LFP) and lithium titanate oxide (LTO) will be the chemistries of use for such applications.

Research and innovation scope

Key Performance Indicators (KPIs) selected for auxiliary automotive applications in all hybridisation types, from micro HEVs to full EVs, are:

- Energy density, expressed in Wh/kg
- Volumetric power density, expressed in W/l
- High temperature life, expressed in units performed
- Low temperature power performance, expressed in multiple Cn (A) ensuring suitable voltage level at -30°C for safety manoeuvring required by the application
- Recycling efficiency (%)
- System cost in €/kWh
- Life span (years)

The spider diagram hereunder on the key performance indicators for 12V auxiliary batteries provides an overview of the state-of-the-art and objectives by 2030 for innovation in the mainstream lead-based and Li-ion technologies.



Spider chart: KPIs for 12V Auxiliary Batteries

Today, lead batteries exceed lithium in the different KPIs, in particular with regard to high and low temperature performance, recycling efficiency and system cost, whereas lithium batteries overperform lead in energy density and life span. The same trend will also be observed through to 2030.
The dominant technology for this application today is lead, both flooded and AGM. Together with lead, lithium, mostly LFP, will also fulfil future requirements. Opportunities for technology improvement could be found in energy density and life span for lead batteries and in extreme temperature performance, recyclability and system cost for lithium batteries.

Sustainability, safety and standardisation aspects

As the safety aspect for the auxiliary services is also crucial, lead will generally remain the preferred option, both flooded and AGM battery types. For lithium-based batteries, LFP and LTO batteries will become the anode chemistry of choice for such applications.
No international standard is currently available for auxiliary batteries. However, IEC TC 21 WG2 of TC 21 is working on a standard for this battery type (both lead and Li-ion batteries) focusing on test methods and requirements, dimensions and functional safety / diagnosability.

European production capacities

European production for lead batteries is currently 90 GWh. We assume lead will remain the dominant technology for auxiliary Batteries.

A.2. Automotive 12V Start-Lighting -Ignition batteries (SLI batteries)

Application segment

Micro and mild-hybrid road vehicles run with a 12V lead starter battery because of the battery's ICE cranking function. Opportunity charging to capture the kinetic energy of the car will be key to improving energy efficiency. High voltage (HV) and low voltage (LV) Li-ion systems are developing further, but lead can also support the capture of excess energy. 'Dynamic charge acceptance' is a key innovation for batteries in such applications. **Based on the EN-50342-6 standard**, the target of 1.25 A/Ah is expected for the next years and needs to be balanced carefully against high temperature durability and water loss of the electrochemical system. **With an increasing number of micro and mild hybrid vehicles on the road and the replacement market to serve for many years after, this application is a key enabler for Europe to meet its CO_2 reduction targets**.

Application profile

Cranking a thermal engine within a wide ambient temperature range is the main feature of the 12V SLI battery, as well as providing energy to power the lights and other accessories in the car when the engine is not running, or when the engine is running but the energy demand is higher than the alternator can supply. Cranking the thermal engine and providing energy to multiple accessories when the engine is not running has become the major challenge to meet the ever-increasing demands of the widespread start-stop micro hybrid architectures that are introduced in the original equipment market (OEMs).

Mainstream battery technologies

The dominant technologies today are lead AGM and EFB. Together with lead, lithium will also fulfil the requirements in future. Both lead and lithium technologies will co-exist in this category in the future, although lead will remain the dominant technology for the next decade.

In the lead battery market, flooded batteries will retain a substantial market share, although EFB and AGM will have a growing share.

Key performance indicators and innovation potential

With the successful introduction of start-stop micro hybrid architectures, which are becoming increasingly powerful with longer stop phases and higher currents during vehicle stand-still, for example when cutting the engine before the car stops, the requirements of this application are increased high cycle life and energy/power densities.

The key performance indicators for the innovation are increased vibration endurance, energy and power density, system cost, energy throughput, dynamic charge acceptance (DCA) to ensure that recent progress is maintained, improving the operating temperature range and recycling rate, whilst ensuring no trade-off in key parameters such as the CCA and water loss.

Opportunity charging to capture the kinetic energy of the car will be key to improving energy efficiency. High voltage and low voltage Li-ion systems are developing further, but lead can also support the capture of excess energy. Dynamic charge acceptance is a key innovation in such applications. The priority is to increase this dynamic charge acceptance fivefold to 1.25A Amps/Ah already by 2022 to meet market demand.

Sustainability, safety and standardisation aspects

The EN-50342-6 standard on dynamic charge acceptance is key for the innovation to capture the energy from regenerating systems when braking or slowing down.

European production capacities

Today's annual European production for lead batteries is 60 GWh, which is forecast to reach 70 GWh by 2030. Lithium, however, is 0.5 GWh today and expected to reach 5 GWh by 2030.

The European battery industry is currently a leader in the worldwide market as well as in the standardisation process with the International Electrotechnical Commission (IEC), and already has Giga- manufacturing capacities – approximately 90 GWh at present.

A.3. Heavy commercial vehicle stand-by batteries

Application segment

In many cities today, trucks are not allowed to run in idle overnight when loading or unloading and in some Member States further legislation is being developed that will not allow cars to stay in idle for longer than a few minutes. Legislative changes have led to new battery requirements and resulted in **a completely new market developing, in particular for Heavy Commercial Vehicle stand-by batteries (HCV stand-by batteries)**.

Application profile

The purpose of these batteries is to ensure a high energy supply when both the engine is not running and electric energy demand is high. This requires deep-cycle performance, which cannot be achieved with existing conventional starting or dual-purpose lead batteries. Today, only lead is in this new market, but in future lithium might also break through. However, the temperature- window and the total cost of ownership for lithium will be a challenge, suggesting only limited market penetration by 2030 and continued lead dominance in this application.

When charging or discharging trucks in cities when the engine is turned off, a very high energy supply is needed to serve the heavy electric loads. This requires specifically designed high-energy batteries with deep-cycle performances.

Mainstream battery technologies and key performance indicators

The dominant technology for this application is lead. Together with lead, lithium could also function in this category to cater for future requirements.

Key performance indicators for innovation are energy and power density, total cost of ownership, energy throughput, vibration robustness and recycling rate.

Deep-cycle lead batteries have the potential to improve through increasing the charge acceptance and decreasing the total cost of ownership. The current conventional starting or dual-purpose lead batteries cannot meet such deep-cycle performances. Today, only lead is in this new market, but in future lithium might also break through, although the temperature window and total cost of ownership will be challenges.

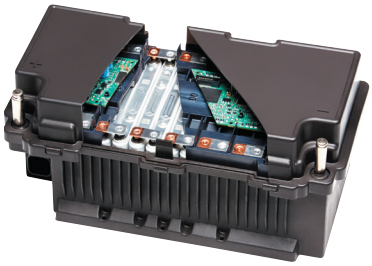
Sustainability, safety and standardisation aspects

Vibration resistance and harsh road conditions by either off-road applications or frame-mounted battery trays provided by the EN 50342-1 V levels also drive the design into a very robust layout. The V4 vibration performance level was added to represent real-life vibration duty observed by the OEMs, which is best provided by lead batteries in the next years.

European production capacities

The annual production of lead batteries in Europe today is 10 GWh, which is estimated to reach 18 GWh by 2030.

A.4. Automotive Hybrid Electric Vehicle propulsion batteries (HEVs)



© CLARIOS – 48V Mild HEV Battery

Application segments and battery features

- 48V – 144V mild hybrids
- The full HEV application (< 2 kWh to stick with the EC classification)

The hybrid electric vehicle segment is considered to range from 48V applications (< 2 kWh, 10-20 kW) to full-HEV applications (< 2 kWh, 30-40 kW). Compared to the power-to-energy ratio (P/E) of pure electric vehicles and plug-in hybrid electric vehicles (e.g. PHEV 12 kWh, 70 kW Peak), the P/E ratio of mild-to-full HEVs is considerably higher P/E = 10-20 compared to 2-8 for EVs, which drives a different system integration factor as well as cell and electrochemistry design.

The contribution to the zero pollution targets of the European Green Deal is lower for mild-HEVs (~10% fuel efficiency gain) and full-HEVs (~25% fuel efficiency gain) compared to PHEV and EVs (up to 100% fuel efficiency gain, though still not GHG CO_2 eq neutral).

Mainstream battery technologies and key performance indicators

The main electrochemistry for mild-HEV and full-HEV applications is Li-ion, preferably with NMC | C and LFP | C compositions.

Since the P/E ratio is less demanding for usable energy content, dopands on the anode side, such as Si-additives to improve specific energy content, are less expected than in PHEV and BEV applications. Solid state technology may also be expected to be introduced after BEVs are equipped with this breakthrough step, especially since solid state electrolytes (all-solid-state batteries (ASSB)) may face a disadvantage in specific power requirements due to the lower conductivity of the electrolyte compared to liquid solutions.

Description of the battery market

EU market demand in 2022 is 2.2 GWh and is expected to grow with a 17% annual growth rate until 2030, with a majority share in the 48V segment compared to the full-HEV.

Over the last two decades, the vast majority of HEVs use the NiMH electrochemistry, with one dominant player in the hybrid fleet. While NiMH will play a role within the next couple of years, by the end of this decade only Li-ion technology will be used in new vehicles. Outside of the EU27, we may still see alternative technologies like NiMH being used.

Safety and sustainability aspects

Safety, circularity and recycling aspects are very similar to high voltage Li-Ion battery systems as mandated in the new EU Batteries Regulation. Recovery rates of specific metal components, as well as overall recycling efficiency, should be tied to the new EU Batteries Regulation.

EU production capacity

European production capacity is closely linked to the proliferation of Giga-factories, due to the similarities and synergies in the manufacturing process compared to BEV battery systems.

A.5. Automotive Battery Electric Vehicles (BEVs)

Application segment and profile

BEV automotive requirements differ due to a large variety of vehicle sizes and applications. Passenger cars vary from small size sports cars to premium large SUVs. Also, light commercial vehicles have different space and business needs, whereas heavy-duty trucks and buses have different use profiles.

Nevertheless, for road BEVs in general, the emphasis is on strong power and high energy needs as longer range and faster charging are required. The environmental, safety and security aspects also play a crucial role for this application.

Mainstream battery technologies and key performance indicators

The technologies of choice are Li-ion batteries with nickel manganese cobalt oxide (NMC) and lithium iron phosphate (LFP). Lead technologies are not suitable for the propulsion of PHEV/EVs but they still have a role to play to maintain the quality of the on-board net and to ensure the safety functions of the main battery.

The challenge of the lithium propulsion battery today is still the high cost and limited range of the EVs compared to ICE-powered vehicles. Also, faster charging, combined with safety and security aspects, are still key performance indicators to target for innovation. To meet these challenges, the industry is seeking materials to increase the volumetric and gravimetric density, as well as to maintain the safety and security aspects of the batteries. NMC and solid state technologies are targeted in this respect.

The mainstream technology today is lithium NMC/LFP, while NMC and solid state technologies will be targeted for development by 2030.

Key performance indicators for innovation, driven by the market demand and regulation are:

- Energy and power density
- System cost
- Energy throughput
- Charge acceptance
- Operating temperature range
- Recycling rate

EV batteries need faster charging regimes and to develop their energy application in order to extend the range. In this respect, the EV application requires material research in order to continue to increase the volumetric and gravimetric energy densities. Solid state technology will help to increase cell voltages and thus the energy content. At the same time, it will contribute to the security and safety aspects by preventing thermal runaway in the batteries as a result of an accident or other high physical stress.

Research at pack level will also be necessary to achieve the targets, as well as support for new chemistries:

- Cell to pack design
- “Structural battery” – battery integrated into the vehicle body
- Thermal management
  - Higher efficiency systems and downsizing
  - Coolant selection and flow, system design, including submerged cells
- Advanced pack materials
  - e.g. for pack enclosures
  - Materials for enhanced thermal management

To manage the battery system, research into controls and software will also be necessary:

- Fast charging
- Health and diagnostics

- Range prediction
- Advanced modelling and machine learning

Subsegment: Commercial vehicles

Heavy Commercial vehicles

In addition to the KPIs above, batteries for heavy commercial vehicles have additional demands for high energy density and long cycle life. They have a wide variation in operation profiles and therefore require multiple solutions

Specific research will be needed on packs to support the specific requirements of commercial vehicles:

- Dedicated thermal management solutions
- Advanced materials for commercial and heavy duty vehicle design
  - For pack enclosures
  - For thermal management solutions

Light Commercial vehicles

The key performance indicators of BEV light duty vehicles are highlighted in the ETIP Batteries Europe roadmap (cfr. tabulation hereunder) and the Strategic Research and Innovation Agenda (SRIA) of the Batt4EU partnership.

Road transport: Light duty BEV*Typical Battery Size : 20-100 kWh (today), 40-120 kWh (in the future)					
KPI	Operating conditions	System/Pack/ Cell level	Unit	2020	2030
Cell/pack weight ratio		Pack	%	70	80
Cell/pack volume ratio		Pack	%	60	75
Operating lifetime expectation	Minimum guaranteed lifetime (equivalent 80% DOD)	Pack	km	~150,000 (~Vehicle lifetime)	
Gravimetric Power density **	180s, SoC 100%-10%, 25°C	Cell	W/kg	750	1,000
Gravimetric Energy density	C/3 charge and discharge, 25°C, charging with CC and CV step	Cell	Wh/kg	~250	~450
Volumetric energy density	C/3 charge and discharge, 25°C, charging with CC and CV step	Cell	Wh/L	~500	1,000
Volumetric power density**	180s, SoC 100%-10%, 25°C	Cell	W/L	1,500	2,200
Cycle life	80% DOD, 25°C	Cell	cycles	1,000	2,000
Hazard level		Cell	-	<=4	<=4
COST					
Cost		Pack	€/kWh	200	85
Cost		Cell	€/kWh	125	70
MARKET					
Market size	Source: Avicenne Energy, 2019; IEA Global EV Outlook 2020		GWh/year	~40	~1,000-2,500

Tabulation: KPIs for road transport light Duty BEVs (Source: ETIP Batteries Europe Roadmap)

Sustainability, safety and standardisation aspects

Recycling rates are today at 50%, but progress is expected by 2030 to make it more economically viable. Also, second life, re-use and re-purposing will help to reduce the footprint of EV batteries.

Recycling requirements will be defined mainly by the Batteries Regulation – currently under consideration. Research will be required on materials, cells and pack design to meet the future targets for increases in:

- The recycling efficiency of batteries
- The material recovery targets for cobalt, copper, lithium and nickel

The importance of the entire battery value chain for the further deployment of BEVs is recognised and supported by the European Commission, with many initiatives under the European Battery Alliance (EBA), as well as the battery features and targets being directly introduced in the EU's SET Plan to target the application

The CEN/CENELEC e-mobility coordination group, which is currently coordinating the EC mandate M/568 "Charging of EVs" has been appointed to initiate coordination of the work on the EC mandate M/579 on battery standardisation with regards to performances, safety and sustainability.

European production capacities

Annual European production of EV lithium batteries today is between 5 and 15 GWh and is estimated to reach 200-400 GWh by 2030, depending on the market scenario used. For commercial vehicles, currently 0.5 GWh, production will reach 25 GWh by 2030

B.
R&D AREA - Motive power material handling and logistics applications

Application segment

Logistics is an important part of supply chain management. There are different vehicle categories and a wide variety of forklift types with distinct applications, features and benefits. These include order pickers, reach trucks, rider pallet trucks, narrow aisle forklifts, high-capacity forklifts and side-loaders, but also automated guided vehicles (AGVs) and state-of-the-art robotic forklifts.

Battery market

Traction and semi-traction batteries for material handling, such as in forklift applications, is an older market in which lead batteries currently have around a 90% market share. Lithium is only in the early stages of starting to penetrate this market. The worldwide battery forklift market is rated at 32 GWh, with around 8% annual growth. Pushed by noise and emissions legislation, battery forklifts are steadily replacing ICE-types types, with the market predicted to reach 67 GWh by 2030. This high market growth will include both lead- and lithium-based technologies.

Battery features

One advantage for lead is the need for a counterweight, especially for sit-down and high-reach forklifts. Another advantage is the fact that, in one-shift regimes or when using battery swap infrastructures on location, there is enough charging time available. Moreover, in operations with opportunity and fast charging, the advanced lead batteries of the future will also offer increased flexibility and higher availability.

Lithium has entered the market for smaller forklifts and shows advantages in multiple shift operations, which are more energy-demanding and where battery charging time is limited. This is because lithium is less affected by opportunity charging, thus offering an extra advantage for 24/7 machine use. In some applications and niche markets with intensive use, the total cost of ownership could become lower than for lead. However, lithium batteries still face issues such as cost, functional safety and high mass energy density.

Nickel-based batteries represent a smaller part of the market, but also have a crucial role to play as they are used in extreme temperature conditions, such as in drive-in freezers

Application profile

Material handling vehicles are used in warehousing and distribution for loading and unloading, handling pallets, and picking and storing inventory. For this reason, the application requires high power charge and discharge rates, high energy content, cycle life and operating times.

Research and Innovation scope

The three mainstream technologies, lead, nickel and lithium, are complementary and all have the potential for innovation in these applications.

The general technical requirements for energy storage systems in material handling are high charge and discharge rates, high energy content, cycle life and operating times, high recyclability, low investment cost and the need to meet strict safety requirements. Other increasingly important requirements are high capacities (increased truck dynamics), namely the power density, high temperature performance and energy efficiency, in particular for multiple shift operations with improved PSOC cycling or opportunity charging, and need for low maintenance.

As for lead batteries, **lowering the TCO is key. This can be done by increasing the cycle life and recharge time, and producing maintenance-free batteries. Other R&D areas for innovation are digitalisation and charging innovation**.

Lithium technologies face a number of issues, such as cost, safety and high mass energy density. R&D should focus on these features so that these batteries can penetrate the market.

C. R&D AREA - Motive power off-road transportation

The motive power battery markets are very diverse, covering propulsion batteries for AGV/AGCs, off-road industrial vehicles with multiple purposes, railway rolling stock, and marine and aviation applications.

C.1. Batteries in off-road industrial vehicles

Application segment

This segment covers a wide range of different applications that cannot be addressed in the previous material handling and logistics application categories. We distinguish the following sub-segments:

- **Sweeping/cleaning machines** used in factories, malls and supermarkets for cleaning purposes, as well as **wheelchairs** to assist people with disabilities and the elderly. Here, a different number of 6 to 12V monoblocs with different dimensions and stored energy are typically used, connected in parallel and series.
- **Construction/demolition machines**, such as mini-loaders and scissor-lifts, used in places like production facilities and construction sites. Batteries used in this segment are the same as those used for material handling.
- **Golf carts and small carts** used for leisure or light human transportation, such as in the airports.
- **Automated guided vehicles and carts (AGVs and AGCs)**: These transport systems are characterised by the fact that they are suitable for lifting, stacking and storing loads on shelves, can pick up and unload automatically within a company's premises without human interaction and generally use electric drives.
- **Other applications not included in the categories above**, such as harvesting trolleys used into greenhouses and other small machines.

Battery features and key performance indicators

Applications for these segments require high energy content, cycle life, operating time and operating temperature range. Since most of the applications do not ask for peak current, high power in charge and discharge rate are typically

not required. **For industrial off-road vehicles with high loads and heavy-duty use profiles, major requirements are exceptionally high cycling capability, particularly in partial state of charge (PSOC) operations, extremely low internal resistance, high power density, fast charging capability (15-20 minutes), high charge acceptance, low maintenance intervals to reduce the total cost of ownership and mechanical and electrochemical stability**.

Mainstream technologies

Lead-based batteries are currently dominant in most of these market segments, which is likely to remain the case in future years, especially for such application where the initial investment is low.

Lithium, with high energy and power densities, is now entering the powering market because of restricted battery compartments and higher currents due to the heavy loads, hence the need for increased volumetric energy density and cyclability, which are key performance indicators for innovation.

The robust nickel-based technology NiCd, with its broad operating temperature range (-40°C to 60°C), has traditionally been the choice for applications in extreme environments, although lead-based batteries retain the largest share in today's markets, such as for AGV/AGCs.

These batteries are derived from the traction batteries for material handling applications, and they still share several features with them.

Target technologies are low maintenance or maintenance-free technologies. In the future, lithium is expected to take a higher market share (for higher power applications in particular) and it is likely to become dominant in the construction/demolition markets and in segments where emissions and potential liquid spillages are not allowed (e.g. airports and supermarkets).

Other important aspects driving innovation are safety, circularity and increasing recycling rates.

Lithium is also entering the market successfully to meet increased requirements in terms of volumetric energy and power density, operating temperature range and cyclability.

C.2. Batteries in railway applications

Rail infrastructure is the most efficient transportation mode in Europe with regard to CO_2 emissions and safety. It is, therefore, of great importance that we develop higher performance batteries to support innovations in both vehicles and the infrastructure to further increase the performance and energy efficiency of the systems. Europe's Rail Join Undertaking (Rail JU) and the Batt4EU partnership are investigating the development of joint calls on battery R&D to meet the new battery needs in this sector.

Railway batteries are located in the rolling stock and infrastructure. The mainstream technologies used are nickel-based, in particular NiCd, flooded and sealed lead-based, and lithium based batteries. For the rolling stock, we differentiate 'city traffic' (suburban railway and underground trains), 'regional traffic' (railway passenger carriages) and 'long-distance traffic' (railcars with ICEs), where batteries are used to serve different applications, such as for lighting and emergency power supply, delivering auxiliary services and starting diesel engines. For railway stand-by applications, we differentiate between batteries for 'trackside line signaling', 'street traffic control', 'signal and control boxes and enclosures' and 'wayside energy'.

Application profile

New upcoming applications for battery systems are the **hybridisation and electrification of rail power traction**, mainly for commuter and metro trains, which require high energy, power density and cyclability.

A large proportion of the lines currently operated with diesel vehicles are non-electrified sections "well under 100

kilometers" long. Battery-electric vehicles have the potential in local rail passenger transport to substitute the diesel engines and to make a significant contribution to the net-zero pollution target.
The requisite high energy, power density and cyclability for such applications can be covered by lithium systems in particular, which are expected to be the fastest growing battery segment due to benefits such as being maintenance-free and having a longer lifetime. For batteries used to power auxiliary functions, as well as lights and fans in high speed and metro trains, the nickel-based chemistry is the preferred technology. In this sector, there is growing demand for batteries, especially driven by far east Asian markets. **Due to development trends for on-board units with smaller footprints, weight restrictions and constant reliability needs, the future requirements for energy storage systems consist mainly of improvements to volumetric energy density, lifetime and operating temperature range**.

Mainstream battery technologies and key performance indicators

The dominant technology is lead, both flooded and sealed, but nickel and lithium also have a significant share of the market.

The development trends for on-board units favour lithium. For the **hybridisation and electrification of rail power traction**, mainly for commuter and metro trains, the requisite high energy, power density and cyclability is clearly an advantage for lithium batteries, which also ensure maintenance-free and longer lifetime operations. **To power auxiliary functions**, as well as lights and fans in high speed and metro trains, the nickel-based chemistry is the preferred technology because it can function in rush operational conditions.

As for further developments in infrastructure, different battery technologies will co-exist given the variety of applications, including lead batteries, both flooded and sealed.

Due to development trends for on-board units with smaller footprints, weight restrictions and constant reliability needs, the future requirements for energy storage systems consist mainly of improvements to volumetric energy density, lifetime and operating temperature ranges.

Mainstream technologies by 2030:

- For traction: Lithium-based
- For auxiliary: Lead-based and NiCd

C.3. Batteries in Marine applications

The marine sector is a strong contributor to CO_2 emissions and pollution in Europe and worldwide. Batteries are enablers that contribute to the transformation of maritime fleets in oceans, seas and inland waters, as described in Strategic Research Agenda from the Zero Emissions Waterborne Transport partnership, which is discussing new battery needs in this sector.

The transport sector contributes to almost a quarter of Europe's greenhouse gas (GHG) emissions. Compared to other sectors, such as agriculture or energy industries, it is the only sector with emissions higher than that of 1990. Waterborne transport emissions represent around 13% of the overall EU greenhouse gas emissions from the transport sector. Moreover, waterborne transport emissions could increase by between 50% and 250% by 2050 (4) under a business-as-usual scenario, undermining the objectives of the Paris agreement. The challenge for a large-scale adoption and implementation of batteries for waterborne transport is mainly related to the high cost of the battery systems and cells.
Maritime is therefore to be included in the ETS system and position of EU industry to include maritime in the EU Green Deal and blue economy strategy.

There is an **urgent need to electrify all forms of boat and marine transport, which is an opportunity for both lead and lithium batteries** as they can both contribute and have their place in these markets. Lithium, due to higher energy densities and cycle life, is well-suited to the needs of propulsion, while lead batteries are more suitable for on-board auxiliary services, to ensure the on-board safety and security functions and to crank the diesel engines.

For larger ships and ferries, there are different degrees of hybridisation of the powertrains. Some long-distance cruise ships have thermal engines that charge the batteries via generators to power the electric propulsion engines and reduce fuel consumption and emissions when running at full power for long periods, while they can also operate on pure electric mode during short periods, for example when entering sea ports. Batteries can also be used for feeding excessive loads (peak-shaving).

For the propulsion of smaller vessels, other hybrid electric systems have been developed, including the integration of solar and wind energy. There are also full electric plug-in architectures developing with charging infrastructure at ports where on-board battery systems, once they are fully charged, allow vessels to run autonomously without any fuel consumption or emissions during use. Standardisation is a challenge to reduce costs and meet the high safety requirements of the systems that are used on-board.

For smaller boats, 48V propulsion batteries are used. To increase the propulsion power and range, the potential for innovation is in the gravimetric/volumetric energy densities.

Application segments

We distinguish four maritime application segments, each with their specific application profiles:

- BEV smaller boats (canal, river and lake vessels, integrated fleet with onshore charging infrastructure)
  - 48V propulsion batteries
- BEV and HEV ships: off-shore-, drilling-, fuel cell vessels, etc.
  - Power batteries from 100 kWh to several hundreds of MWh
- BEV and HEV ships: Cruise liners, ships and ferries, etc.
  - Energy batteries from 500 kWh to several hundreds of MWh
- Other batteries in the marine application located on-board and in the infrastructure
  - 12V auxiliary and 12V SLI battery markets for sail boats, etc.
  - On-board stand-by and motive power battery applications in marine (including UPS an TLC), typical harsh climate/weather conditions

BEV smaller boats – 48V propulsion batteries

Application segment

Smaller battery electric boats, such as canal, river and lake vessels, are boats propelled by mechanical systems consisting of an electric motor turning a propeller to reduce noise and operate with zero emissions. Battery electric boats are often integrated into a fleet of vessels with an onshore charging infrastructure in place.

Mainstream battery technologies and key performance indicators

The dominant technology today is lead, both flooded and sealed. Lithium NMC and LFP are also breaking through in this market.
The market for small electric propelled vessels will increase considerably in future to meet demand. Due to high safety requirements for on-board system use with severe ventilation requirements, a reduced need for maintenance, high vibration resistance and horizontal inclination aspects, we predict that both lead and lithium batteries will co-exist. Lead batteries will shift towards valve regulated technologies, both AGM and EFB, and lithium batteries towards NMC, but also LFP, for safety reasons.

Key performance indicators for innovation are energy and power density, energy throughput, charge acceptance, operational temperature range and recycling rate.

Apart from R&D, further battery standardisation is an opportunity to increase reliability and safety, as well as to reduce the total cost of ownership.

BEV and HEV ships: off-shore-, drilling-, fuel cell vessels, etc.

Application segment

Off-shore ship applications with typical power batteries with capacities from 100 kWh to several hundreds of MWh.

Mainstream battery technologies and key performance indicators

Lithium technologies are the best available technologies for the take up of this market.

The key performance indicators for such typical power batteries and targets by 2030 are listed in the ETIP Batteries Europe Strategic and Innovation Research Agenda and are listed hereunder.

Waterborne transport: battery electric or hybrid electric ship with power battery (offshore vessel, drilling vessel, hybrid fuel cell, ...) Typical battery size: 100 kWh - several hundreds of MWh						
KPI	Operating conditions	Description	System/ Pack/Cell level	Unit	2020	2030
PERFORMANCE						
Cell/ESU weight ratio		Full ESU (Including rack, gas exhaust system, BTMS, BMS)	Energy storage Unit (ESU)	%	60	70
Cell/ESU volume ratio		Full ESU (Including rack, gas exhaust system, BTMS, BMS)	ESU	%	30	60
Operating lifetime expectation		10 years of operation	ESU	hours	~50,000-80,000h (<ship lifetime)	
Volumetric energy density	1C charge and 3C discharge, 25°C		Cell	Wh/L	200	400-500
Gravimetric energy density (Wh/kg)	1C charge and 3C discharge, 25°C		Cell	Wh/kg	~100	200
Cycle life (number of cycles)	70% DOD, 25°C, 1C charge and discharge		Cell	cycles	25,000-50,000	>80,000
Hazard level		EUCAR cell-level safety performance	Cell		< = 5	< = 2
COST						
Cost			Cell	€/kWh	300	150
Cost		Full ESU (Including rack, gas exhaust system, BTMS, BMS)	ESU	€/kWh	1,300	600-700
MARKET						
Typical market size	Source: Fincantieri, Saft internal studies			GWh/an	~0	~2.5

Tabulation: KPIs for typical power batteries - targets by 2030 (source: ETIP Batteries Europe SRIA)

BEV and HEV ships (cruises, ships and ferry's...)

Application segment

Off-shore ship applications with typical energy batteries with capacities from 500 KWh to several hundreds of MWh.

Mainstream battery technologies and key performance indicators

Lithium technologies are the best available technologies for the take up of this market.
The key performance indicators for such typical energy batteries and targets by 2030 are listed in the ETIP Batteries Europe Strategic and Innovation Research Agenda and are listed hereunder.

Waterborne transport: battery electric or hybrid electric ship with energy battery (cruise, ship, ferry, ...) Typical battery size: 500 kWh - several hundreds of MWh						
KPI	Operating conditions	Description	System/ Pack/Cell level	Unit	2020	2030
PERFORMANCE						
Cell/ESU weight ratio		Full ESU (Including rack, gas exhaust system, BTMS, BMS)	Energy storage Unit (ESU)	%	60	70
Cell/ESU volume ratio		Full ESU (Including rack, gas exhaust system, BTMS, BMS)	ESU	%	30	60
Operating lifetime expectation		10 years of operation	ESU	hours	~50,000-80,000h (<ship lifetime)	
Volumetric energy density	1C charge and 3C discharge, 25°C		Cell	Wh/L	400-500	800-1,000
Gravimetric energy density (Wh/kg)	1C charge and 3C discharge, 25°C		Cell	Wh/kg	~180	350
Cycle life (number of cycles)	70% DOD, 25°C, 1C charge and discharge		Cell	cycles	5,000-8,000	>10,000
Hazard level		EUCAR cell-level safety performance	Cell		< = 5	< = 2
COST						
Cost			Cell	€/kWh	150	75
Cost		Full ESU (Including rack, gas exhaust system, BTMS, BMS)	ESU	€/kWh	600-700	250-300
MARKET						
Typical market size				GWh/an	~0.2	~4

Tabulation: KPIs for typical energy batteries - targets by 2030 (source: ETIP Batteries Europe SRIA)

Other batteries in the marine application located on-board or in the infrastructure of shipping ports

A variety of batteries are present, such as:

- 12V auxiliary and 12V SLI batteries for sail boats and other vessels
- On-board stand-by and motive power battery applications, including UPS and TLC for harsh climate/ weather conditions

The market is typically dominated by lead, with niches for NiCd and lithium also entering this market.

C.4. Batteries in Aviation applications

Application profile

In aviation, batteries can be utilised for auxiliary services in airliners or to power smaller aircraft. Today's electrification of the power train is concentrated on smaller aircraft, such as helicopters, vertical take-off and landing drones (VTOL) and air taxis sized to carry a maximum of seven people or equivalent cargo.

In 1884, one airship called La France powered by a 435 kg Zn//Cl_2 battery took to the air near Paris, which was the first aerial vehicle to complete a controlled, powered round trip flight (8km). This attempt inspired researchers and engineers and paved a way for electric propelled flights. Currently, the weight of the batteries needed to power commercial aircraft is roughly 30 times higher than the weight of jet fuel, meaning that, even when taking into consideration the higher efficiency of an electric engine, full electric propelled commercial aircraft are not an option today.

Today, the Li-ion power battery technology is used for the propulsion and boosts the development of smaller aircraft for both passenger and freight transport, especially that of electric vertical take-off and landing vehicles (eVTOL), which can be used in different applications, from short-haul urban transport to information platforms and emergency medical services. Compared with the battery electric vehicle (BEV), eVTOL can not only get rid of traffic congestion, but also consumes lower energy. For eVTOL, the current energy density of Li-ion is to a certain extent satisfied, although safety is still a concern for the application.

Mainstream battery technologies and key performance indicators

Auxiliary batteries in airliners are undergoing the transition from conventional batteries (nickel-cadmium and lead-based) to Li-ion batteries with higher energy and power densities and a longer lifespan.

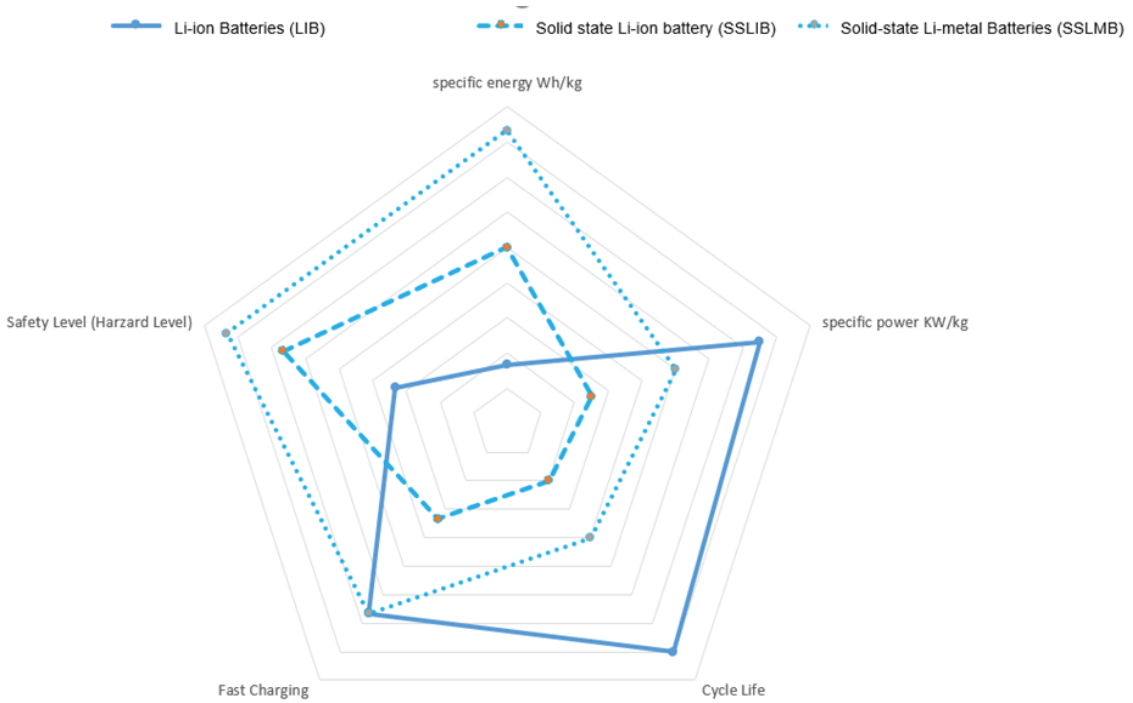
Pursuing batteries with higher energy densities invariably leads to metal anodes. Rechargeable metal batteries, especially lithium metal batteries (LMBs), are key enablers for high cell voltage and storage capacity in order to increase the energy density. To power business aeroplanes, the ideal specific energy of a battery should be much higher (1,000 Wh/kg) than what we can reach with today's Li-ion technologies, so novel materials are needed in future. Safety is the first priority for aviation batteries, which demands exceedingly high interfacial stability between the lithium metal anode and electrolyte, so solid state lithium metal batteries (SSLMB) are moving to the forefront.

As for eVTOL traction, besides the mainstream Li-ion technology, the two most promising future solid state technologies are:

- Solid state Li-ion battery (SSLIB), with a graphite/silicon anode
- Solid state lithium metal batteries (SSLMB)

Hereunder is a spider chart in which the positions of the three technologies are represented, grouped around five key performance indicators selected for the application, namely the specific energy and power, fast charging, cycle life

and the safety level of the batteries (according to the EUCAR safety classification levels (Hazard levels), which are currently used to gauge the level of danger associated with handling batteries and the outcome of performed tests on the cells according to specific test standards).



Spider chart: KPIs for the traction e-VTOL application with regards to current Li-ion and future SSLIB and SSLMB

The balance between stability, safety and energy density is key for SSLMB, while corresponding processing technology need to be developed, which is different for liquid state LMB. However, some challenges for promoting SSLMB in aviation cannot be avoided, among which poor rate capability and short cyclic lifespan are most evident. The undesired rate capability is partly originating from the low bulk ionic conductivity of solid electrolyte, but principally from the poor wettability in the solid-to-solid interface (sluggish interfacial kinetics). As for the short cyclic lifespan, besides electrochemical reasons such as short circuit, mechanical stress will be electrochemically generated inside the lithium metal anode, so the physical contact is lost during cycling.

On the solid electrolyte side, in future, novel solid electrolyte materials with a wide electrochemical stability window, high ionic conductivity, outstanding interfacial compatibility and excellent mechanical property need to be explored for desired rate capability, high-stability, cost-effectiveness, and high-yield SSLMB. Besides, attention should be paid to a more stable and reliable LMB as well through developing new liquid electrolytes with better lithium stripping/plating behaviour and more sophisticated battery management and safety forewarning systems.

Europe's CLEAN Aviation Joint Undertaking (Aviation JU), in coordination with the Batt4EU partnership, is further developing R&D topics on batteries to meet new requirements in this sector to reduce the greenhouse emissions from aviation.

D. R&D AREA - Batteries for stationary energy storage

The stationary battery markets cover the UPS, telecom, residential and commercial storage after the meter, grid-connected utility grid-scale energy storage and the off-grid energy storage applications.

D.1. Batteries for uninterrupted power supply (UPS)


© EXIDE Technologies

Application profile

Batteries for uninterrupted power supply (UPS) take action when utility power fails in order to ensure that critical equipment can safely shut down to protect the operation. There are various applications from small single computers to big data centres, buildings and power plants. There is a tendency to use energy storage devices for other purposes, for example UPS as a reserve and peak load looping. Virtual power plants and new big data centres are further driving the demand for UPS. UPS contributes to zero pollution targets through longer bridging times, grid stabilisation (instead of building additional power plants) and in combination with renewable energy sources.

The growth of the market is due to increased use of big data and the associated need for new data storage centres and the implementation of distributed energy resources (DER). Another driver will be the growth of emerging economies, requiring significant UPS capacity, with Europe as a leading battery supplier.

Mainstream battery technologies and key performance indicators

The dominant technologies used today are valve regulated lead acid batteries (VRLA) with absorbent glass mat technology (AGM) and nickel cadmium batteries (NiCd). Li-ion batteries are also entering the market with lithium iron phosphate (LFP), lithium metal polymer (LMP) and nickel manganese cobalt (NMC) cathodes combined with carbon anodes. The technology target by 2030 is NMC with carbon-silicon anodes.

Increasing the power density is particularly necessary because of the further electrification of critical loads, which require greater output from the battery. Also, as new UPS batteries should provide additional value, such as peak-shaving, there is a need to work on the charge acceptance and energy throughput of the batteries. In parallel to the demand for increased power density, there is the need to reduce the operational expenditures (OPEX) of these applications through reduced climatisation as one of the main cost drivers and thus the heat exposure to the battery will rise and the batteries must be able to cope with it.

Key performance indicators for this application, as typical back-up time is between 5 and 15 minutes, are energy and power densities, system cost, operating temperature range and reduced cooling. Increases in the power density are required because of the further electrification of critical loads, which require more output from the battery. This affects both lead and lithium technologies. The UPS stand-by application is expected to extend its usage beyond uninterruptible power in order to generate more value, for example UPS and peak-

shaving and UPS as reserve power (UPSaaR). An additional key performance indicator for UPS with such multiple functions will be the energy throughput.

Another development is the connection of smaller UPS batteries in one network to form a larger UPS system or even to form a virtual power plant (VPP). This will become possible thanks to the development of 5G and artificial intelligence to allow distributed energy production, storage and consumption. Such VPPs could include traditional commercial and industrial UPS batteries from data centres and base transceiver stations, but also batteries from EVs, forklifts, utility grid-scale and batteries behind-the-meter.

Because of these innovations, it will be necessary to work on the charge acceptance of the UPS batteries and their robustness to higher temperatures from faster charging, increased power density and reduced climatisation. The extended usage will also require a considerable increase in energy throughput.

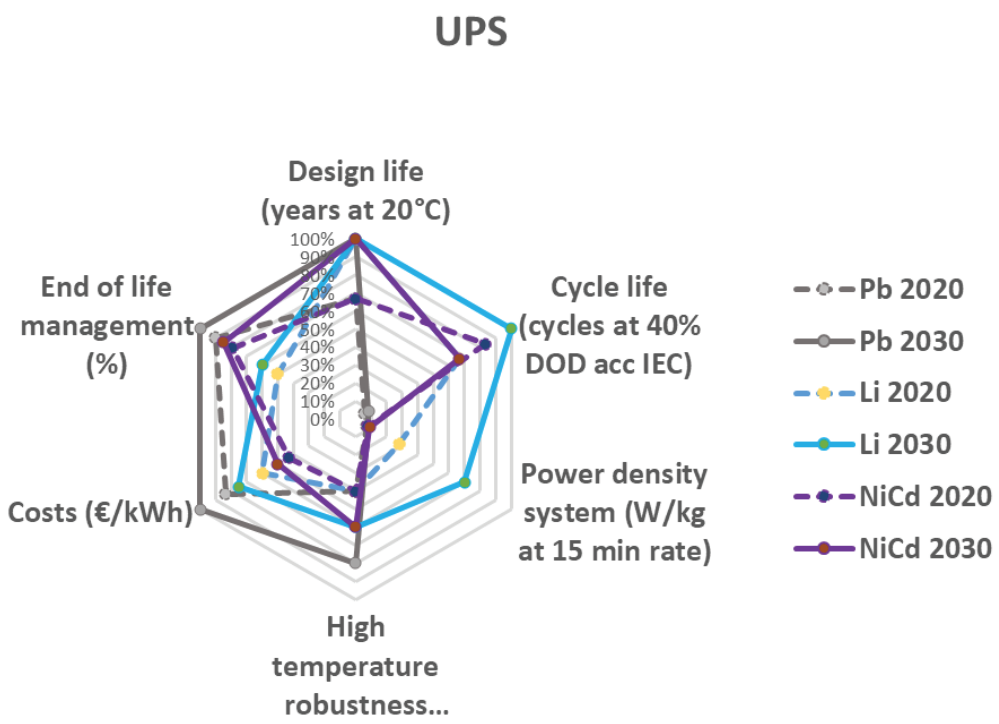
The technology of choice for the user is not only related to the type of load but also to the climate (temperature robustness), quality of the grid and configuration of the UPS, as well as the energy throughput.

Despite the emerging new requirements, there will still be pure stand-by applications with a demand for back-up power only and, of course, the requirements for these use cases are less demanding.

Cost and safety are and will remain key factors. While the cost of Li-ion batteries has already been reduced significantly in the last 15 years and is now closer to lead batteries, there are still safety concerns for Li-ion. This is attributed to the potential risk of mistreatment by over-charge and discharge that could cause a thermal event that would release a high amount of energy in a short period of time causing a fire and release of hazardous gases. In order to prevent this, a battery management system (BMS) is a mandatory support item for Li-ion batteries. This is not required for lead batteries.

In addition to cost and safety, there will be a stronger focus on end-of-life management and, therefore, the recycling targets and content of recycled material in the battery will become more important. This is part of the new EU Batteries Regulation. Due to its maturity, lead battery recycling processes have developed and improved over a long time and are nowadays highly efficient and economically valuable. It is possible to recycle a lead acid battery to 99%. The recycling of Li-ion batteries is more complex due to the different chemistries (LFP, NMC, LTO, organic electrolytes) and battery housings that demand different physical and chemical treatments.

Hereunder is a spider diagram including the six key performance indicators (KPIs) selected for the application, namely end-of-life management, design and cycle life, high temperature, power density and cost factor.



Spider chart: Key performance indicators for the UPS Application with regards to lead, Li-ion and NiCd

R&I scope and strategic actions

Lead batteries: Increase the volumetric power density to 200 W/l, improve the charge acceptance to 40 A / 100 Ah, increase the cycle life at 40% DOD to >500 cycles, increase the calendar life on float at 20°C from 10 to 15 years and float life at 40°C from 3 to 4 years, cost reduction to 150 $/kWh.

Li-ion batteries: Increase the volumetric power density to 1,000 W/l and increase the cycle life at 40% DOD to 8,000 cycles.

Strategic actions for lead batteries: Increase the mass utilisation, use corrosion resistant alloys and improve the cycle life

Strategic actions for Li-ion batteries: Development new anode and cathode materials (NMC, silicon + graphite), cost reduction actions and improve the safety of products (LFP, aqueous electrolytes)

UPS applicable standards are IEC 60896-21 (LAB), IEC 62619-2017 (LIB) and IEC 62620-2014 (LIB)

European production capacities

Today, annual European production of lead batteries is 2.4 GWh, while lithium is forecast to rise from 0.05 GWh to 0.5 GWh by 2030.

D.2. Batteries for Telecom (TLC)

Application profile

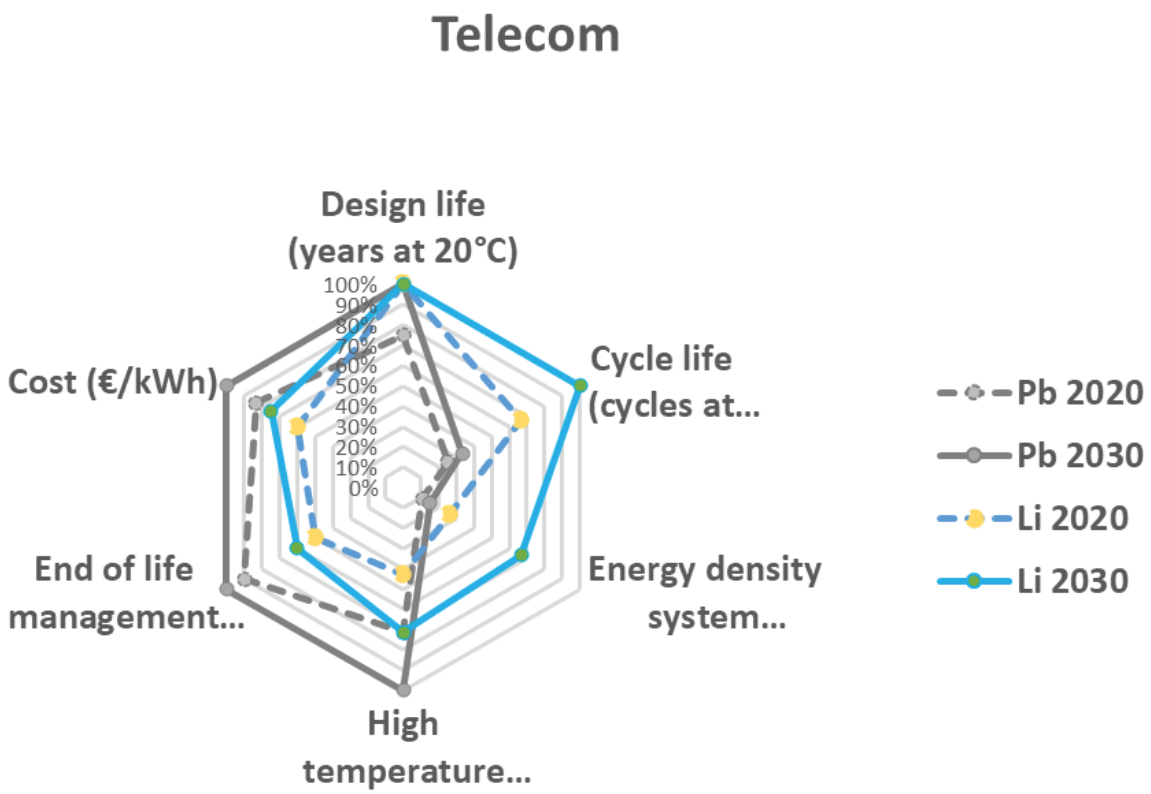
Telecom batteries are cells, blocks or modules connected to form a 48V direct current (DC) energy storage system able to supply electricity to an information and communication technology or telecom site when the main power source is unavailable or insufficient. A telecom unit is an information and communication technology or telecom site with critical loads. In case of unavailability or insufficiency of the main power source, telecom batteries provide instant and continued DC voltage power to all redundant equipment to ensure that the telecom application continues to function until a diesel generator or in future a fuel cell can take over. Despite this classical use case, there are more and more off-grid telecom towers combined with renewable energy sources or other hybrid systems, especially in emerging countries with a lack of grids or in remote areas. In these cases, the batteries provide electricity when the energy from renewable sources is not sufficient or not available, for example from solar panels during the night.

The transfer to Virtual Power Plants (VPP) is also demanding a higher energy throughput from the batteries involved and the profile is changing from a floating to a cycling application, very often at partial state of charge (PSOC). Due to a variety of different and new applications and the difference in geographical fluctuations of power outages, the battery performance has to meet these customer requirements. This means, for example, that a battery in a pure stand-by function has a significantly lower energy throughput in areas with very stable grids than in areas with very unstable grids. Customer can select the most appropriate solution for their application and consider a valuable ratio between costs and benefits.

Mainstream battery technologies and key performance indicators

The dominant technology used today is the valve regulated lead acid battery (VRLA) with absorbent glass mat technology (AGM) for reliable grids and VRLA with gelled electrolyte (GEL) in poor or off-grid areas. The predominant lithium technologies are lithium iron phosphate (LFP) and nickel manganese cobalt (NMC) cathodes with graphite anodes to target NMC graphite-silicon composite anodes by 2030. Due to cost and safety reasons, there is currently a trend towards the LFP technology.

The main features of batteries for telecom applications are energy and power density, energy throughput and hot temperature robustness. Otherwise, safety, cost and end-of-life management are also key aspects (see spider chart hereunder).



Spider chart: Key performance indicators for the TLC Application with regard to lead and Li-ion technologies

While lead batteries are intrinsically safe and very robust against abuse, a Battery Management System (BMS) is required to prevent Li-ion batteries from damages caused by over-discharge or over-charge. In terms of product cost lead batteries are the most attractive solution and will remain the cheapest solution in 2030. However, the price decrease for lithium batteries will continue and the gap between lead and lithium will become smaller. This will also depend on the future electrode chemistry of lithium batteries and the availability of required raw materials like cobalt, manganese and nickel.

Important aspects of end-of-life management are product collection, recycling and circularity. The collection rate for the different battery technologies is very similar and already on a very high level. With respect to recycling, lead batteries are amongst the products with the highest recycling efficiency worldwide. Recycling processes are established and recycling plants are well distributed. Recycling of lithium batteries is not yet mature and the recycling efficiency and economy needs to be developed. Due to the usage of different electrode chemistries like LFP and NMC, different recycling processes are required because of the different chemical behavior. The new Batteries Regulation is putting a strong emphasis on circularity and demands that batteries must contain recycled materials by 2030, with a target of 85% for Lead and 4% for lithium.

Description of the R&I scope and strategic actions

The main drivers in this application are the extension of WiFi and the strong network expansion in China, India, eastern Europe and South America, as well as the introduction of 5G. Further actions to reduce the cost of diesel consumption and emissions, especially in countries and areas with unstable grids, will have the consequence of a higher energy throughput for the battery. One of the main drivers for OPEX reduction is the downsizing or elimination of air conditioning that will expose the battery to higher environmental temperatures.

Lead batteries: In order to be able to meet new market needs (linked for example to 5G), an increase of gravimetric energy density at system level to 40 Wh/kg is to be expected, together with an increased volumetric power density, always at system level, to 30 W/l. Cycle life performances should be increased to 2,000 cycles at 40% DOD and an extended battery life to 10 years at 40°C or more than 20 years at 20°C in order to improve the TCO. The calendar life in off-grid and VPP applications might be significantly shorter and would require further improvements in endurance. These new features are expected to be reached working on increased mass utilisation, the use of corrosion resistant alloys, improved cycle life, more maintenance free or reduced maintenance solutions and further cost reduction

initiatives like increased content of secondary raw materials and a higher level of production automation.

Li-ion batteries: An increase in the gravimetric energy density at system level to 350 Wh/kg linked to an increased volumetric power density to 100 W/l is to be expected, together with an increase in cycle life at 40% DOD to 8,000 cycles in order to improve the TCO significantly. The main area of action for Li-ion technologies will involve the development of new anode and cathode materials (NMC, silicon + graphite), cost reduction actions and an improvement in the safety of products (LFP, aqueous electrolytes).

European production capacities

Annual European production of lead batteries today is 3 GWh. Production of both lead and lithium is expected to increase by 2030.

D.3. Batteries for residential and commercial energy storage behind the meter

Application overview

The residential and commercial sectors are responsible for 12% of the EU's total CO_2 emissions. More than 4 GWh of additional capacity per annum is predicted by 2022 [(4)], resulting not only from increased numbers of units sold but also because the increased demand for larger storage systems will increase self-consumption. The use of different electro-chemistries provides an overall benefit to the decarbonisation of the residential sector and batteries are key enablers for making this happen.

Stationary batteries for storing energy from renewable sources behind the meter are used both in residential and commercial buildings (offices, SMEs, etc.) where they can also fulfil additional roles, such as peak-shaving or UPS.

The primary task of these batteries is to supply the load when electricity cost is high or renewable power output too low and offer consumers a level of independence from grid supplied energy. In addition to the cost benefits, additional drivers for residential and commercial storage are increased levels of self-consumption with less reliance on grid-based power, combined with reserve to ensure power continuity. Residential storage batteries should be designed and sized according to the location and local power needs.

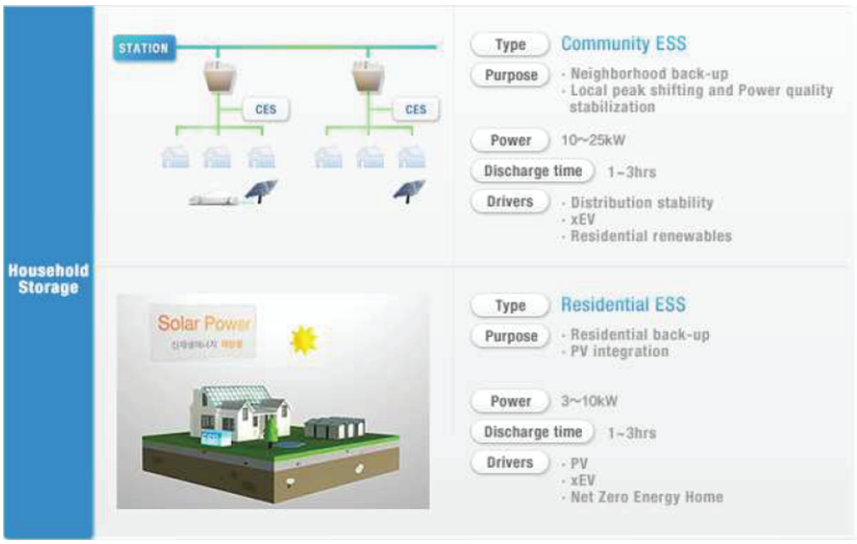


Figure: Residential and Community Household Energy storage profiles (Enersys)

Mainstream battery technologies and key performance indicators

Both lead and lithium-based technologies can support the requirements in this market, each with their own features and characteristics. Inevitably, there is a trade-off between technology capability and cost, which is tied to the market conditions for cost / kWh of grid supplied energy. This can be very country specific and home owners need to evaluate a number of factors including purchase cost, cost per delivered kWh (from the storage system) and payback time linked to financial incentives, i.e. subsidies vs feed-in tariff rates (FIT), to determine the economic viability to invest in such systems.

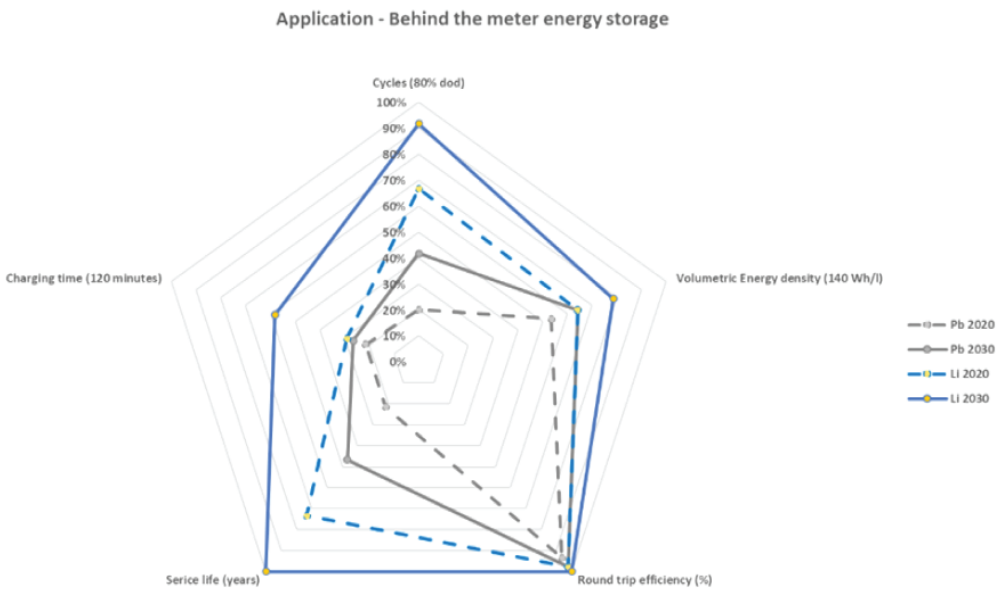
Lithium-based storage solutions currently dominate in this market space. Lithium-based solutions have an advantage regarding space, weight and cyclic performance, but safety is a consideration to be further improved for in-house storage applications. For lead batterie, bipolar technology can increase the energy density and advanced chemistries, such as carbon loaded negative designs, can improve cyclic performance and energy throughput, particularly in partial state of charge operations. One soft aspect to consider for end users is the aesthetics of any battery system that is on offer. Li-ion batteries typically have attractive packaging that may be important where installations can be on prominent display.

Lead today is not only fully recyclable, but also has economies of scale in place that work without any subsidies. For Li-ion, there are still improvements to be made to make recycling more economically viable by 2030. Life cycle (energy throughput) advancements for both technologies will be required to reduce the TCO for the end user. The PSOC cycles of the batteries, according to the European reference test standards, should increase by a factor of 1.6 by 2025.

Lithium technologies are dominant in the market today and are expected to remain so. Lead batteries are less present, but with advancements in energy density and cyclic performance could make lead-based solutions a more attractive proposition to serve this market and compete with NMC solid state designs.

A comparison of the current and future (2030) attributes of the technologies used in behind the meter storage applications (spider chart hereunder) suggests R&I development should be focused on improving cycle life, or more appropriately, increasing life-time energy throughput (kWh) across the full range of depth of discharge (particularly for lead), which could provide inherent TCO benefits. Associated KPIs relating to improving charge efficiency and higher energy density are also desirable, though not critical. For Li-ion solutions, advancements in recyclability, coupled with improvements in safety (move to solid state) and less reliance on BMS, are identified as potential KPI developments.

Improving the roundtrip efficiency is also a key parameter in future to align with the Energy Efficiency Directive, as well as the productisation and configuration to customise batteries to power conversion and control systems.



Spider chart: KPI diagram current / future state battery technology attributes for behind the meter applications

European production capacities

Across all application sectors, it is anticipated that lead battery demand will remain relatively constant with lead-based technologies dominant in 12V automotive and stationary applications (UPS and telecom), whilst there are significant

growth expectations for Li-ion, mainly driven by EV applications with Li-ion expected to become the dominant technology in residential and commercial storage behind the meter. Lead-based manufacturing capacity in Europe is sufficient to meet demand expectations. Whilst Li-ion demand is heavily reliant on imports today, by 2030 it is expected that there will be an almost 40-fold increase in capacity that will be able to meet demand even at optimistic growth expectations. Ultimately, a surplus of capacity vs European demand will be in place based on forecasts[1].

D.4. Batteries for utility grid-scale storage (large-scale ESS – in front of the meter)

Application profile and overview

Utility grid-scale energy storage for grid-functionalities is a market where batteries compete with other storage technologies, such as hydro-power and fuel cells. However, batteries have considerable advantages as they are easy to install on location and scalable to the power and capacity needs of the application.

Batteries can provide grid stability in multiple ways. They can store energy quickly or feed in, in milliseconds, for grid compensation to avoid frequency instability and compensate deviations caused by fluctuations in generation and load. Batteries also provide reserve capacity for the grid to take on the role of spinning reserves provided by conventional power plants. Battery energy storage is also required to restart after a complete power failure (black start) or to supply energy to an island power grid integrated with renewables.

Due to their short response times, in the millisecond range, battery storage systems are also suitable for providing control energy down to the minute range. The provision of control power from pooled, decentralised battery storage is already economical today. The creation and use of local flexibilities to support the network is the key to optimising the use of distribution grid capacities.

Large scale energy storage batteries cover a large variety of operational ranges, depending on the grid function they will fulfil. Hereunder is a tabulation including the application profiles for some key grid functions, such as voltage/ frequency regulation, arbitrage, black-start, back-up, investment deferral and grid independent power supply (GIPS).

	Segment	Power rate (MW)	Response time	Storage capacity	Charge acceptance	Cycles (#/year)	Efficiency (%)	Energy density	Condition of operation
Regulation	Conventional	1-40 MW	<1 min- 60min	0,5 - 20 MWh	Sec.	250-10 000		Low	
	PV		15-60min			250 – 1 000			
	Wind		<1 min-60min						
	End-users	0.1-10 kW	0,1-15min	na		10-200			
	T&D	na	<1 min-60min						
Arbitrage	Generation	0.1-500 MW	<1-6h	0.1->1GWh	Hours	50-250		Moderate	
	PV integration				Min.				
	Wind integration								
	Seasonal	10-1000 MW	2-8 h	> 50 MWh up to 10000 MWh	Hours	10-50			
	Residential	2 - 6 kW	1-6h	4 - 10 kWh	Min.	50-250			
	Commercial/ industrial	6 kW - 5 MW		12kWh - 10 MWh	Min.	250-500			
Black-start	Generation	5-50 MW	15-60min	5-50 MWh	Hours	10-20		Moderate	
	Industrial								
Back-up	Small – UPS	5 - 2000 kW	<1-60sec	3 - 1000 kWh	Hours	10-20		Moderate to high	
	Medium and large UPS	50 MW	1-60min	100 MWh	Hours				
	Power continuity	0.5 - 100 kW	0,25-6 h	0,5 - 200 kWh	Hours	5-100		Low	
	Reserves	1-500 MW	2-8 h	1 - 500 MWh	Hours	10-50			
Invest. Deferral	Transmission & Distribution	1-100 MW	1-4 h	2 - 200 MWh	Hours	50-100		Moderate	
GIPS	Community/rural	10-100 MW	2-8 h	40 - 400 MWh	Min.	50-500		Low	
	Residential	0,1-20 kW		1-50 kWh					
	Industrial	0.5 - 15 kW		2 - 50 kWh					

Tabulation: Application profiles for different grid functions

Mainstream battery technologies and key performance indicators

For large storage systems, lithium and lead technologies are considered the reference technologies. Nickel-based batteries were previously preferred for large system storage in low temperature applications. Lithium is relevant for high-current applications like optimising self-consumption through the integration of renewables and peak-shaving (100 kW-5 MW). A distinction must be made between energy and power applications.

Drivers and trends for grid support applications are major infrastructure changes in the power supply industry, the integration of renewables, emerging electro-mobility and demand for higher power quality. **General technical requirements** are PSOC cyclability, high power density and wide operating temperature ranges. **Drivers and trends for off-grid applications** are increased demand for independent power supplies and reduced infrastructure costs. **General technical requirements are** high reliability, scalable power supply and low maintenance/service cost.

The development of the multi-use aspect will increase profitability for the user. Due to their multifunctional capabilities, storage systems are often efficiently used in the form of mixed operating models in which several areas of application are combined ("multi-use storage systems").

Advantages for lithium storage in non-automotive applications were first expected for peak-shaving applications. These advantages consist of a large potential market, low safety risks and a short amortisation time of around five years. Ten years ago, this application was driven by the higher cost of lithium cells. As the cost of lithium cells has fallen, the applications have been upgraded to the extent that lithium cells now compete with larger lead cells.

Other grid applications include frequency regulation, voltage support, black-start, energy time shift and peak-shaving. A particular feature is the projected service life of 20 years, which lowers investment costs. A way of reducing costs for Li-ion systems for peak-shaving and energy time shift for renewables is to deploy second-life EV batteries.

Research priorities for lead are cycle life, up to 6,000 cycles at 70% DOD, 2,500 PSOC cycles according to the European performance test standards, and charge efficiency higher than 95%, according to IEC standards, by 2025. Advanced large industrial VRLA lead batteries (with capacities up to 15 MWh) with carbon additives entered into service recently in Germany. Lead carbon batteries can match the PSOC cycle life of lithium batteries for voltage stabilisation in solar power plants.

Research priorities for lithium are safety, capacity, retention of the negative graphite electrodes and material cost reduction of the positive electrode, e.g. through reduced cobalt and higher nickel content.

Although lead batteries currently represent less than 2% of large utility grid-scale ESS, intelligently combining lead- and lithium-based batteries could increase the market significantly for lead as it would offer considerable benefits in terms of lower energy reserve costs. This could be achieved by installing lead-based and smaller lithium-based batteries for power peaks. Battery systems with strings of Li-ion batteries have already been considered in telecom applications. A lithium battery would deliver almost 100% of the load at the beginning, whereas a lead battery would take charge in the middle and final stages of discharge.

The Primary research priority for lead is to increase the cycle life at 70% DOD from 1,000/3,000 cycles to 6,000 cycles by 2025 and 6,800 cycles by 2030, which is the main economic indicator for energy storage applications.
Today, charge efficiency of AGM batteries, according to IEC standards, is 85-90% and is targeted to reach >95% by 2030.

Key performance indicators for utility and renewable energy storage are lifetime, charging/discharging efficiency and safety. The research priority for lead up to 2030 is cycle life (up to 6,800 cycles at 70% DOD) in order to lower operating costs, and for lithium it is primarily safety. Also, improving the roundtrip efficiency is key to contribute to reducing acquisition and operating costs. Correct sizing of the product and the configuration to customise lead batteries to power conversion and control systems is also a key factor for the overall efficiency of the EES.

The key battery performance indicators for innovation are safety, reliability, power and volumetric energy density, high and low operating temperatures, float life, cycle and calendar life and PSOC cycling.

The dominant technology in 2030 will be Li-ion, with niches for lead and sodium HT based technologies. Nickel will have a niche in harsh environments. Sodium-ion RT and lithium solid state are emerging.

D.5. Batteries in off-grid applications

Application profile

This application segment covers batteries for stand-alone use or in combination with diesel generators or renewable energy production as 'hybrid systems', in off-grid or remote mini-grid systems installed to provide rural electrification at locations were electrical power can be provided most cost-effectively and sustainably with batteries rather than through grid extension. This can include:

- Isolated rural areas, notably in developing countries
- Peri-urban areas with weak grids, notably in developing or emerging countries
- Small islands separated from the national grid (e.g. mini-grids)

The main applications are battery energy storage systems (BESS) in a range from **domestic and industrial/ commercial to community scale usages and back-up power for telecom towers**.

The picture hereunder highlights the typical power ranges for some different rural electrification systems.

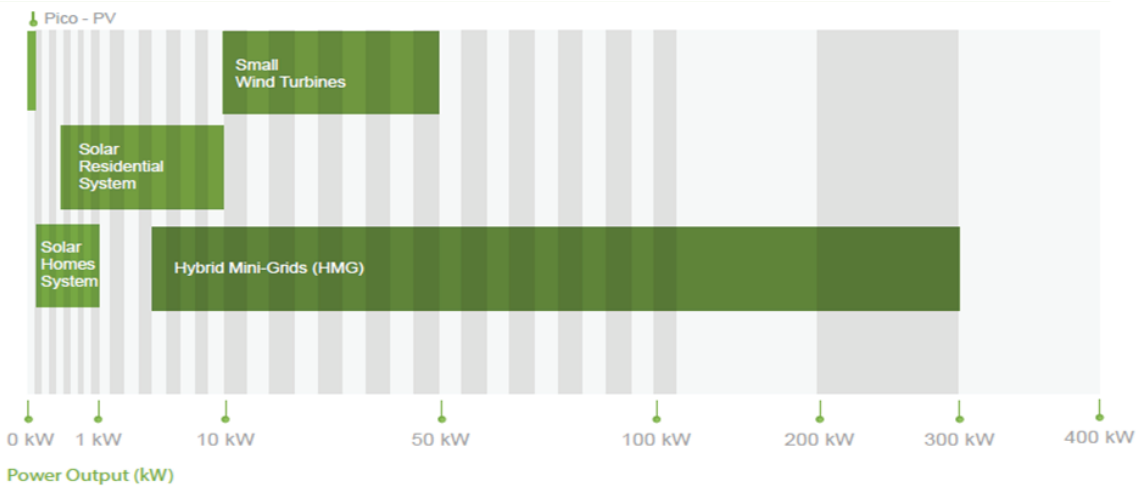


Figure: Typical power ranges for rural electrification systems

Market drivers and evolution

Batteries for energy storage can improve the reliability of power supply from renewable and conventional sources, increase the overall system efficiency and provide economic savings across the system life cycle, for example by fuel savings. Market drivers are the worldwide expansion of fluctuating renewable energy sources like PV and wind. This is supported as well by national and multinational funding programs. Despite the growing electrification worldwide there are still hundreds of million people located in central and southern Asia and in sub-Saharan Africa without direct access to electricity.

Batteries produced in Europe – following European environmental standards – are exported for use in rural areas worldwide. As such, they significantly contribute to the zero-pollution targets of the European Green Deal outside the borders of Europe. In addition, electrifying rural areas helps address other societal challenges, both in developed and developing countries, including:

- Remote telecommunications installations
- Water purification and/or pumping
- Street lighting
- Security systems

EU Market demand

Recent studies from IEA have quantified that off-grid and mini-grid configurations using Battery Energy Storage (BES) are often the most efficient and sustainable way to electrify isolated rural areas or remote C&I sites.
Another market is on smaller European islands without mainland interconnections where peak production relies on expensive fossil fuel. Now there is a clear tendency towards the installation of off-grid and mini-grid renewable energy sources instead.

It is important that the European industry is active with all established technologies to serve these markets.

Description of the battery features

Battery Energy Storage is used across the entire range of off-grid and hybrid mini-grid systems and provides a permanent source of electricity that is independent from variable power generation. It is used to store energy from Renewable Energy Sources and release it when needed at times when RES production is not sufficient. BES is typically sized to keep supplying power for up to 4-10 days. This is necessary to ensure that the application will always be powered should RES be limited for an extended period of time.

The main KPIs are the requirement for high performance in rugged atmospheric conditions, low maintenance, high energy throughput, design life, broad temperature range and affordability (TCO).

Mainstream technologies

Lead-, lithium-, nickel- and sodium-based batteries are complementary technologies that serve the combination of functions in this off-grid segment depending on the system's technical, environmental and situational requirements.

The current dominant technologies are lead-based (sealed and flooded) and Li-ion (NMC and LFP). Lead-based technologies still have the major advantage of being safe and easy to install and to maintain without sophisticated technicians (important for rural and remote installations). If estimated cost targets could be achieved, sodium-ion (RT) could be an alternative storage system competing with LFP and lead in future.

R&I scope and strategic actions

For lead-based systems: Increased energy throughput and the development of operation strategies through the integration of BMS (battery management system).

For Li-ion: Improving the design life and safety aspects like high temperature operation, costs and recyclability.

For sodium-ion (RT), currently in the phase of technology demonstration (TRL 5): The general qualification of the technology has to be demonstrated.

Sustainability, safety and standardisation aspects

Cycle or lifetime performances are measured differently depending on the battery chemistry and its depth and rate of discharge. Cycling profiles are different in each IEC cell-specific standard, so it is not meaningful to compare across technologies. Instead, an application-specific standard like IEC 61427-1 could be used as a benchmark.

Circularity and recycling aspects will be key parameters for further developments

Source references

(1) EUROBAT internal best estimates
(2) ETIP Batteries Europe roadmap
(3) BEPA Strategic Research and Innovation Agenda (BEPA SRIA)
(4) EU funded project elements 'Current direct' (https://www.currentdirect.eu/)
(5) Zero Emissions Waterborne Transport Partnership Strategic Research Agenda (Waterborne SRA)
(6) European Council for Automotive R&D - EUCAR Hazard Levels
(7) Nature Energy, 2020, DOI
(8) Nature Materials, 2021, DOI
(9) International Journal of Aviation, Aeronautics, and Aerospace
(10) International Conference on Transportation and Development
(11) Mineralogical Magazine, 2020, DOI
(12) IEA Tracking report 2019
(13) EUROBAT Guidance document on Rural Electrification
(14) Energy solutions for Off-grid applications, Dena 2017
(15) White Paper on Off-grid access to renewable energy_SER_2020

Authors

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List of Abbreviations

3C: Portable battery market
A0 classification: automotive mini passenger vehicle
A00: classification: automotive small passenger vehicle
AGC: Automated Guided Cart
AGM: Absorbent Glass Mat
AGV:: Automated Guided Vehicle
ASSB: All solid-state Batteries
B2B : Business to Business
BEPA: Batteries European Partnership Association
BAT: Best Available Technologies
BES: Battery Energy Storage
BEV: Battery Electric Vehicle
BTM: Behind the Meter
C&I: Commercial and Industrial
CAGR: Compound Annual Growth Rate
DER: Distributed Energy Resources
DOD: Dept of discharge
EBA: European Battery Alliance
EC: European Commission
EES: Electric Energy Storage
EFB: Enhanced Flooded Battery
EFTA Member States: Iceland, Liechtenstein, Norway, Switzerland
ETIP: European Technology and Innovation Platform
ETS: Emissions Trading System
EV: Electric Vehicle
eVTOL: Electric Vertical Take-off and landing
FTM: Front of the Meter
GBA: Global Battery Alliance
GHG: Greenhouse Gases
GIPS: Grid Independent Power Supply
HEV: Hybrid Electric Vehicle
HCV: Heavy Commercial Vehicle
HV: High voltage

ICE: Internal Combustion Engine
IEA: International Energy Agency
IEC: International Electrotechnical Commission
KPI: Key Performance Indicator
LAB: Lead-acid Battery
LCV: Light Commercial Vehicle
LIB;: Lithium-ion Battery
LFP: Lithium Iron Phosphate
LiSB: Lithium Sulfuric Battery
LMB: Lithium Metal Battery
LMP: Lithium Metal Polymere
LTO: Lithium Titanate Oxide
LV: Low voltage
NiMH: Nickel Metal Hydride
NMC: Nickel Manganese Cobalt Oxide
OEM: Original Equipment Market
OPEX: Operational Expenditures
PSOC: Partial state of charge
PHEV: plug-in HEV
R&D: Research & Development
R&I: Research & Innovation
RT: Room Temperature
SET-Plan: Strategic Energy Technology Plan
SLI: Starting-lighting-Ignition
SRIA: Strategic Research and Innovation Agenda
SSB: Solid-state Batteries
SSLiB: Solid-state lithium-ion Batteries
SSLMB: Solid-state Lithium-metal Batteries
TCO: Total Cost of Ownership
TLC: Telecom
TRL: Technology Readiness Level
UPS: Uninterrupted Power Supply
VPP: Virtual Power Plant
VRLA: Valve Regulated Lead-Acid
xEVs: covers mild HEV, full HEV, PHEV and BEV

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