EUROBAT 2030

BATTERY INNOVATION ROAD MAP

WHITE PAPER
BATTERY INNOVATION
ROADMAP 2030

Version 2.0 - June 2022

An update of the original version from June 2020 to take into account the latest developments in the EU's policy objectives and the latest technological realities and potential of the best available battery technologies. The new version includes

- An update on the four mainstream battery technologies
- Identification of future promising battery technologies
- Fine-tuned & new end-user applications
- New aspects on sustainability, circularity, recycling and raw materials

Pb Li Ni Na

WHAT IS EUROBAT?

EUROBAT is the leading association for European automotive and industrial battery manufacturers, covering all battery technologies, and has more than 50 members. The members and staff work with all policymakers, industry stakeholders, NGOs and media to highlight the important role batteries play for decarbonised mobility and energy systems as well as all other numerous applications. **www.eurobat.org**

MORE THAN
30
battery manufacting plants

16
research centers

MORE THAN
50
manufacturers and Associate members from across the value chain

APPLICATIONS

AUTOMOTIVE

Batteries contribute to the decarbonisation of the European transport sector - reducing CO_2 emissions via start/stop batteries and innovative solutions in xEVs

STATIONARY ENERGY

Batteries are indispensable for storing renewable stationary energy coming from solar and wind farms in on grid and off grid solutions.They also contribute to a more stable and reliable grid.

MOTIVE POWER

MATERIAL HANDLING

Batteries are a perfect fit for powering industrial vehicles such as forklifts and cranes, while also reducing noise and emissions.

MOTIVE POWER

OFF-ROAD TRANSPORTATION

Batteries are widely used in rail, marine and air transportation. The concepts of smart charging of road vehicles to support the energy system is also relevant for off-road because their wide deployment and large energy capacities

ALL BATTERY TECHNOLOGIES

EUROBAT represents the manufacturers of all four existing battery technologies: **Lead-, Lithium-, Nickel- and Sodium- based**. Each chemistry has its own advantages and is best suited for specific applications.

Pb
LEAD BASED
ADVANTAGES
Affordable, proven safe and sustainable

Li
LITHIUM BASED
ADVANTAGES
High energy density, low weight

Ni
NICKEL BASED
ADVANTAGES
Long life, reliability

Na
SODIUM BASED
ADVANTAGES
Relatively high energy density, low weight

Contents

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Executive Summary

The Battery Innovation Roadmap 2.0 is an update of the original publication (from June 2020) to account for the latest technological developments and changes in the EU's policy objectives, primarily the proposal for a Batteries Regulation (released in December 2020). It reflects the technological realities and potential of the best available battery technologies and how they can contribute to the EU's policy objectives.

The updated Roadmap includes:

- An update of the innovation potential of mainstream battery technologies
- New electro-chemistries, such as post Li-ion and post-lithium technologies
- New and fine-tuned end-user applications, such as mild- and full HEVs, off-road industrial vehicles, electric aviation and off-grid energy storage applications
- New aspects with regard to circularity and critical raw materials

The key points addressed in the Roadmap are:

The European Green Deal and Batteries Regulation represent the key legislative drivers for battery innovation to meet the EU's objectives in the coming years.

- The Green Deal, presented in December 2019, is one of the main drivers to further electrify end-user applications and **decarbonise transportation, the energy system, telecoms, off-road industrial vehicles and many other applications.** Innovations in battery technologies are recognised as one of the key enablers to make this happen.
- **The Batteries Regulation will be the main driver to further reduce the environmental and societal lifecycle impact of batteries. Not all mainstream technologies are at the same level of maturity and further battery R&D is required.**

Each mainstream battery technology – lead-, lithium-, nickel- and sodium-based – has a substantial developmental potential, **driven by the requirements of different applications.** No single battery chemistry or technology can meet all the challenges of end-user **demand in a multitude of applications, combining high power and energy density, long life, low cost, excellent safety and minimal environmental impact. Improvements in service life, performance and safety will be enabled by using innovative materials and cell components in the electrochemical system, as well as applying advanced battery management systems.** The outstanding feature in this process is that these improvements are always tailored to the needs of a specific application.

The European battery manufacturing industry (all chemistries) is committed to meeting the EU's objectives, in accordance with the Green Deal and Batteries Regulation. The industry is committed to increasing its investments in innovation and to scaling up battery production in line with future demand for batteries and requirements related to performance, safety and the circular economy.

Europe needs a regulatory landscape that treats all battery technologies equally:

- *To maximise existing capabilities*
- *To allow all mainstream technologies to evolve and innovate in line with future requirements, to meet the carbon-neutral objectives of the Green Deal and to make Europe less dependent on fossil fuel imports*
- *To make Europe less dependent on imports of materials and, therefore, less vulnerable to shortages (by utilising different technologies and developing the circular economy)*

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Introduction Scope and purpose of the Roadmap

Why this update?

The EUROBAT Battery Innovation Roadmap 2030, released in June 2020, complemented the EUROBAT Election Manifesto 2019-2024, aiming to provide policy-makers with factual information on the contributions and innovation potential of the current mainstream battery technologies present in the market.

The Battery Innovation Roadmap 2.0 considers the latest technological developments and changes in the EU's policy objectives, primarily the proposal for a Batteries Regulation, in order to reflect the technological realities and potential of the best available technologies currently on the market and how they can contribute to the EU's objectives. In this sense, this Roadmap should be seen as a living document, to be reviewed every two years to account for these evolutions in technology and policy goals.

As the Roadmap 2.0 addresses both policy-makers and the European R&D community, it consists of a main document and a Technical Annex

- The main document is a mid-term review to inform policy-makers about the current state-of-play and innovation potential of the mainstream battery technologies currently on the market and how they help achieve the climate neutrality targets of the Green Deal. It also has a new focus on how batteries can contribute to the sustainability objectives laid out in the Batteries Regulation and how industry can support Europe's Action Plan on Critical Raw Materials by improving the recovery and recycling of battery materials, in line with upcoming legislative requirements relating to the environment

- The Technical Annex addresses the European R&D community, providing more in-depth background information on the innovation potential of mainstream and future battery technologies, towards 2030 and beyond.

What is new compared to the original version?

- An update on the state-of-the-art and innovation potential of the mainstream battery technologies (lead-, lithium- and nickel-based) covered in the original Roadmap, as well as the addition of sodium-based batteries
- A chapter describing the most promising future technologies and how they will impact the market by 2030
- An update on the end-user applications covered in the original Roadmap, as well as four additional applications that can significantly contribute to the EU's Green Deal targets:
    - Automotive: Mild- and full-hybrid electric vehicles
    - Motive power: Off-road industrial vehicles and aviation
    - Off-grid energy storage in rural areas in developing countries or on small islands
- An extended chapter on sustainability and the circular economy, addressing the topics in the Batteries Regulation, to demonstrate how the European battery industry can contribute to Europe's strategic autonomy

Batteries are designed for use in specific applications. As such, t**his Roadmap emphasises the importance of considering each application independently when channelling R&D into advancing battery technologies**. The battery features and targets selected in the EU's Strategic Energy Technology Plan (SET Plan) strongly focus on plug-in HEV/EV propulsion batteries and second life electric vehicle (EV) battery use, which resulted in R&D targeting the most suitable technologies for these application profiles. However, there are many other emerging battery markets, each of which can contribute to transforming the EU's economy in support of the 2050 climate neutrality goals.

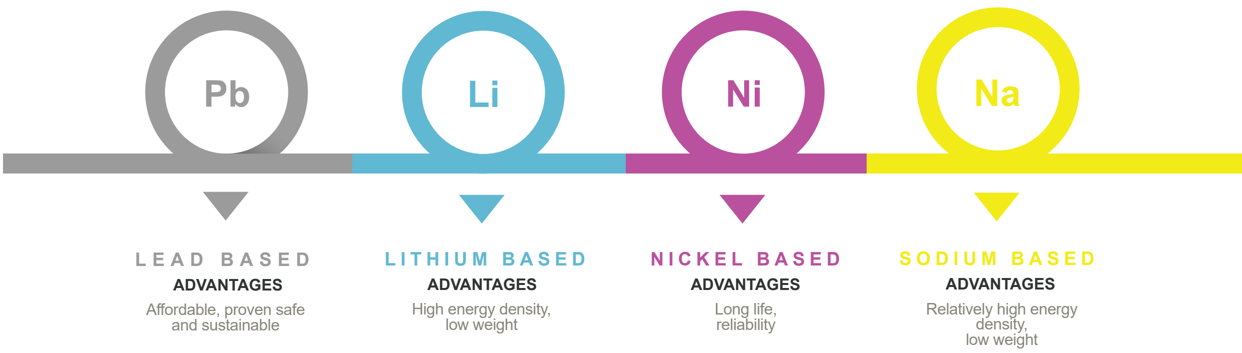
Consequently, this Roadmap focuses on a variety of critical applications, identifying the key battery performance to improve in order to meet future requirements for the applications they will serve. It concludes with a set of research and innovation objectives per application, demonstrating the necessity and complementarity of different battery technologies, which all have a role to play and offer significant potential for development.

The end-user applications are examined in this white paper to provide the technical background for why different battery technologies are needed. It demonstrates how the different battery technologies and chemistries each have their specific role and developmental potential in order to anticipate the shifting demand from the continuous innovation in automotive, motive and stationary storage applications.

This white paper aims to provide a direction on current technical battery requirements and what we believe is feasible to target by 2030. With this market-oriented approach, battery experts have identified the key performance indicators per technology to prioritise in R&D in order to meet the above-mentioned shifting demand towards low emission mobility and power generation.

The mainstream battery technologies considered are lead-, lithium-, nickel- and sodium-based technologies.

BATTERY TECHNOLOGIES AND APPLICATIONS



3

Overall context – Drivers for Battery Innovation

3.1 Battery markets and predictions

There are many credible sources predicting different battery market trends in different scenarios. For EUROBAT, a realistic scenario for the evolution of the total worldwide battery market is a five-fold market growth, from 645 GWh in 2020 to 3,495 GWh in 2030. The chart below represents the worldwide battery market per technology. This shows that lead and lithium batteries will remain the dominant technologies in the market through to 2030, with volumes of lead and lithium batteries on the world market reaching 495 GWh and 3,000 GWh, respectively.

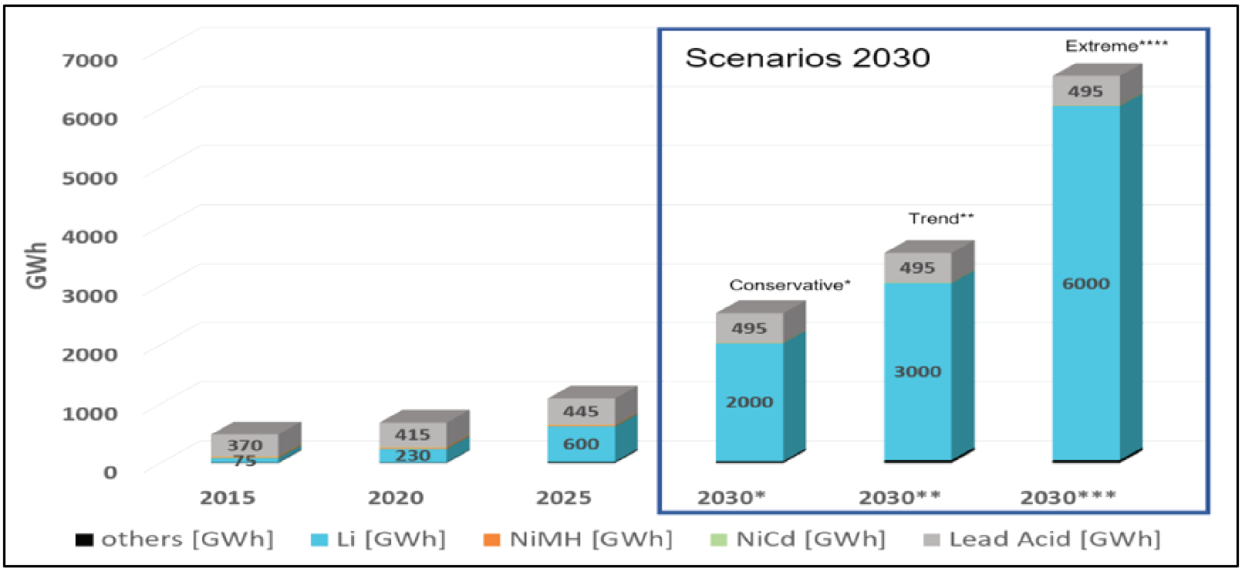


Chart: Worldwide B2B battery market – technology segments - EUROBAT best estimates

Further segmentation of the lead and lithium battery market is provided in the chart below.

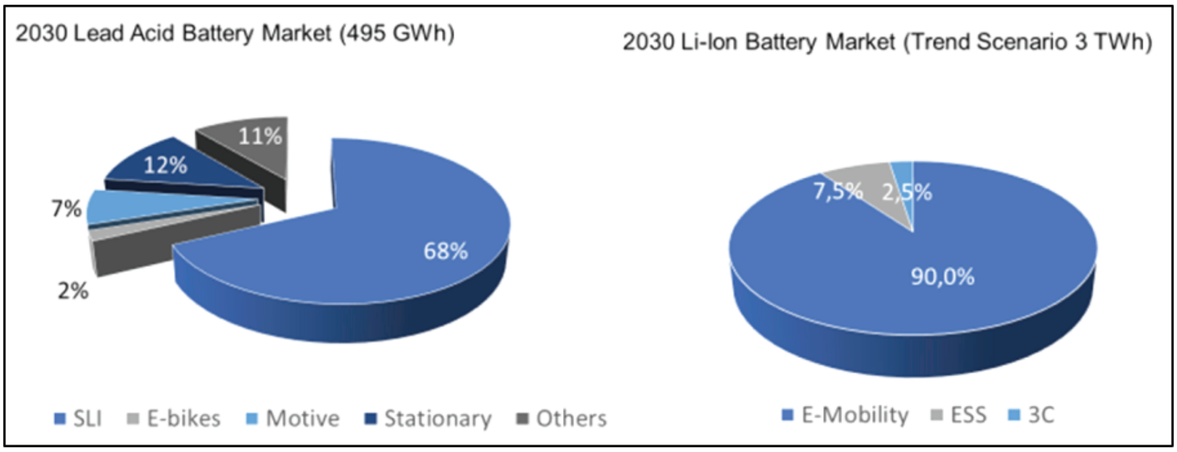
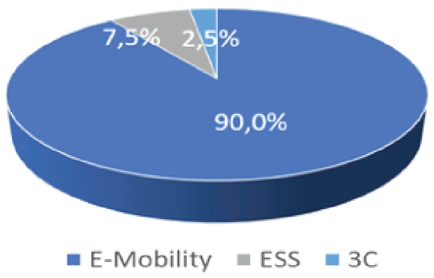


Chart: Lead and Lithium based Worldwide B2B battery markets – EUROBAT best estimates

These charts give a first indication that the mainstream battery technologies will remain complementary through to 2030:

- Lead batteries (495 GWh) will serve the 12V SLI and 12V auxiliary automotive applications, followed by specific applications in motive power and stationary energy storage, in particular UPS and telecom markets.
- Lithium batteries (3,000 GWh) will largely serve the e-mobility automotive power segments (xEV batteries), representing 85-90% of the total volume, but also energy storage markets, which will reach 150-225 GWh by 2030, of which 41 GWh will be behind-the-meter (BTM), 138 GWh front-of-the-meter (FTM) and 31 GWh for residential storage (see chart below).



		Li – Ion [GWh]	
E-Mobility		2.550 - 2.700	
ESS		150 - 225	
	BTM		~ 41
	FTM		~138
	Residential		~31
3C		60 - 75	

Chart: Worldwide lithium battery market mainly driven by e-mobility – EUROBAT best estimates

It should be noted that current predictions on large-scale ESS do NOT take into account the European Commission's recently announced RePowerEU Plan in response to global energy market disruptions. REPowerEU was initially created to end the EU's dependency on fossil fuel imports and will reinforce the Commission's Fit for 55 plan to cut emissions by at least 55% by 2030.

The synergy of both plans will considerably accelerate the building of Europe's clean energy infrastructure. In this context the Commission is proposing to increase the EU's 2030 target for renewables from the current 40% to 45%, which would bring the total renewable energy generation capacities to 1,236 GW by 2030 (compared to 1,067 GW by 2030 under Fit for 55). These new objectives will impact our market projections for the stationary storage battery markets and, in particular, for large-scale ESS.

3.2 Drivers for battery Innovation

The large variety of products that co-exist on the market today is the result of incremental improvements introduced over many decades to fit the specific needs of the applications and their ever-increasing demands.

Battery innovation has historically been market driven, primarily by **the end-user applications. This explains the very wide range of specific battery products, sizes, technologies and chemistries today. The European industry has been strong for decades in serving both mass and niche markets by leading national and international standardisation and by contributing innovative products to the development of a multitude of applications**.

The European Green Deal and the Batteries Regulation will be the main legislative drivers for further R&D on batteries:

The policy objectives of the European Green Deal, the Fit-for-55 Plan and the REpowerEU plan

The Green Deal and the Fit-for-55 Plan promote increased electrification, thereby pushing innovation across automotive, motive and stationary energy markets. The mainstream battery technologies are strong contributors to the decarbonisation of all modes of transportation and to support the energy transition. All the mainstream battery technologies still have potential for improvement and will continue to play a key role through to 2030 and beyond.

EUROBAT is member of the BEPA Batt4EU partnership private side association and the ETIP Batteries Europe, which are the main contributors to shaping the EU's R&D agenda on batteries in order to help Europe to meet the objectives of the Green Deal.

The sustainability objectives in the Batteries Regulation and other EU legislation

The **Batteries Regulation**, which is reaching its final stage of the legislative process, aims not only to improve battery development but also the production processes in Europe. In addition, as part of the European Green Deal, the proposal for a Regulation on Eco-design for Sustainable Products will set new sustainability rules for **almost all physical goods** on the EU market, including batteries, **throughout their whole lifecycle** from the design phase to end use, repurposing and end-of-life.

With this in mind, the battery industry will take further steps towards a circular economy, which will also strengthen Europe's access to raw and secondary materials due to recycling existing batteries.

To ensure the long-term growth and sustainability of the battery value chain in Europe, it is essential to maintain the competitiveness and leadership of the European battery industry.
In this context, a fit-for-purpose and well-balanced legislative framework is needed to create a level playing field in which all battery technologies are treated equally in order to further develop a strong, sustainable and diverse European battery supply chain for the benefit of all European citizens.

4

R&D areas and potentials per battery technology

The demand for batteries has continuously grown, and the performance of batteries improved, due to increased electrification across a multitude of applications. With the aim to achieve climate neutrality, further electrification of the most carbon-intensive sectors – transport and energy – is pushing the boundaries of batteries even further. In addition, to remain competitive and catch up in emerging areas, Europe has put environmental sustainability at the heart of European battery production. This also addresses the ambitions of the green energy transition, including securing access to raw materials through recycling and the circular economy.

To support a multi-target strategy, the **European Battery Alliance (EBA)** was launched in 2017 by the European Commission, EU Member States, industry and the scientific community. Furthermore, in 2018, **the Commission adopted a Strategic Action Plan for Batteries**, setting out a framework of regulatory and non-regulatory measures to support R&D&I and industrialisation for maximum impact.

Batteries that are sustainable over their entire lifecycle will be key to achieving climate neutrality, as well as to ensuring the sustainable competitiveness of the industry and to making Europe less dependent on energy imports. In addition, the new Batteries Regulation framework should also help to reduce the EU's dependence on imported materials to build batteries that are crucial for achieving the climate goals, as a lot of that material could come from recycling existing batteries.

Besides the mainstream technologies (lead-, lithium-, nickel- and sodium-based), EUROBAT industry experts made a selection of the most promising future upcoming battery technologies, based on their current innovation potential and technology readiness level, that can be brought to market and effectively contribute to the EU's sustainability and carbon neutrality objectives.

The developmental potential of the technologies considered in this white paper depends on their technological readiness level. However, for each technology considered, the optimisation of an individual parameter has a direct impact on the other parameters. Therefore, an improvement in one parameter can be accompanied by the decline of another. This makes it necessary to develop electrochemical storage technologies tailored to the requirements of a specific application.

4.1 State-of-the-art of the four mainstream technologies in the market

4.1.1. Lead-based batteries

Pb

Lead-based batteries have been on the market since a century because they are affordable, safe and sustainable. 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 innovation 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-carbon targets in the European Green Deal.

The collection and recycling of lead batteries is well-established and ensures a minimum impact. The EU has a mature process of collection and recycling that is both efficient and cost-effective and operates within an established infrastructure that ensures a circular economy. Batteries are collected by recognised companies and recycled within specialised recycling facilities (secondary lead smelters) in a closed-loop system that operates under strict environmental regulations. From an end-of-life perspective, this process reduces the need to produce additional virgin materials, such as primary lead and plastics, which have the biggest environmental impact in the lifecycle of the product. Today, an astonishing 99% of end-of-life lead batteries are collected and recycled. This is because only lead battery recycling generates a net income across the entire value chain.

Recycling targets for lead batteries will be maintained at a very high level in 2030, with 90% efficiency and recycling of active materials at 99%, achieving a circular economy and benefiting the whole value chain.

More information on the state-of-the-art status and the improvement potential of lead-based batteries is available in the Technical Annex.

4.1.2. Lithium-based batteries

Li-ion technologies have a high energy density and low weight. The technologies considered in this Roadmap consist of a combination of specific anode and cathode materials. Economic and environmental requirements are: low content of critical materials (e.g. cobalt), easy processing availability, environmentally safe and ethical, operationally safe and low carbon footprint during production.

Recycling is undertaken through pyrometallurgy or hydrometallurgy, more recently, by direct recycling, and some newly installed capacities are currently under development. End-of-life cells and modules, as well as production scraps, are not crushed but treated directly. Valuable metals are recovered for conversion into active cathode materials for the production of new batteries. Lithium represents a small fraction of what is recovered and is not currently reused in the battery value chain.

Production processes, recycling processes and transportation have been identified as challenges to recycling.

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 85% by 2030. The recovery of nickel, cobalt and lithium will also be fully commercially viable in future.

More information on the state-of-the-art status and the improvement potential of lithium-based batteries is available in the Technical Annex.

4.1.3. Nickel-based batteries

Nickel-based batteries have a long life and are very reliable. 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.

Partnerships between producers, logistics companies specialised in the transportation of hazardous waste and fully permitted EU-based recyclers ensure that industrial end-users can dispose of their spent industrial NiCd batteries in an easy manner. This enables proper recycling of used batteries, the reuse of their components to manufacture new batteries or other industrial goods and the protection of the environment in a closed loop.

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.

More information on the state-of-the-art status and the improvement potential of nickel-based batteries is available in the Technical Annex.

4.1.4. Sodium-based batteries

Na

The high-temperature sodium-based batteries have a relatively high energy density and low weight. Technologies available on the market are sodium nickel chloride (NaNiCl) and sodium-sulfur (NaS). The production of the NaNiCl battery is relatively energy-intensive and therefore has a higher environmental impact, depending on the heat source. Other factors are the high demand for nickel and the complex modular construction. The nickel content in the battery can be recovered and used in the steel industry. The ceramics in the cells, as well as the salt collected in the resulting slag, can be used in road construction. NaS also contains large proportions of steel and aluminum, which can be recycled accordingly to further reduce its environmental impact.

More information on the state-of-the-art status and the improvement potential of sodium-based batteries is available in the Technical Annex.

4.2 State-of-the-art of the most promising future technologies

EUROBAT is a supporting organisation of the BATTERY 2030+ initiative, which has a chemistry-neutral approach to facilitating the invention of the batteries of the future in order to support the implementation of the European Green Deal, the European Action Plan on Batteries and the European SET-Plan.

The following future battery technologies are selected because their improvement potential and their potential to meet the EU's sustainability objectives, **meaning that they can be produced** with the lowest possible environmental impact, using materials that have been obtained in full respect of social and ecological standards and are long-lasting, affordable, safe and can be repaired or reused and repurposed in future. More technical background on the innovation potential and the timeline for market introduction for each identified technology can be found in the Technical Annex.

Lead-based bipolar battery technologies

As 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, resulting in a uniform current density, higher material utilisation and an increased energy density.

More information on lead-based bipolar battery technologies is available in the Technical Annex.

Readiness for the mass market is expected as of 2023.

Sodium-ion room temperature battery technologies

Sodium-ion batteries have a similar working principle to Li-ion batteries. As sodium resources are cheap and equally distributed worldwide (2.75% of the earth's crust is sodium, compared to 0.0065% for lithium) and considering the technological similarities with existing Li-ion batteries, the industrialisation process of sodium-ion batteries will be accelerated. 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 in two-wheeled vehicles, 12V starter applications, A0 and A00 passenger vehicles, and electrical energy storage (EES) as an effective supplement to Li-ion batteries.

More information on sodium-ion room temperature battery technologies is available in the Technical Annex.

Readiness for the mass market is expected as of 2023.

Post Li-ion battery technologies

Inexpensive and environmentally friendly metals, such as sodium and polyvalent light metals, should one day replace the current Li-ion 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. **Hereunder is the technology roadmap, which indicates the timeline of the readiness level for mass-market introduction for the proposed technologies:**

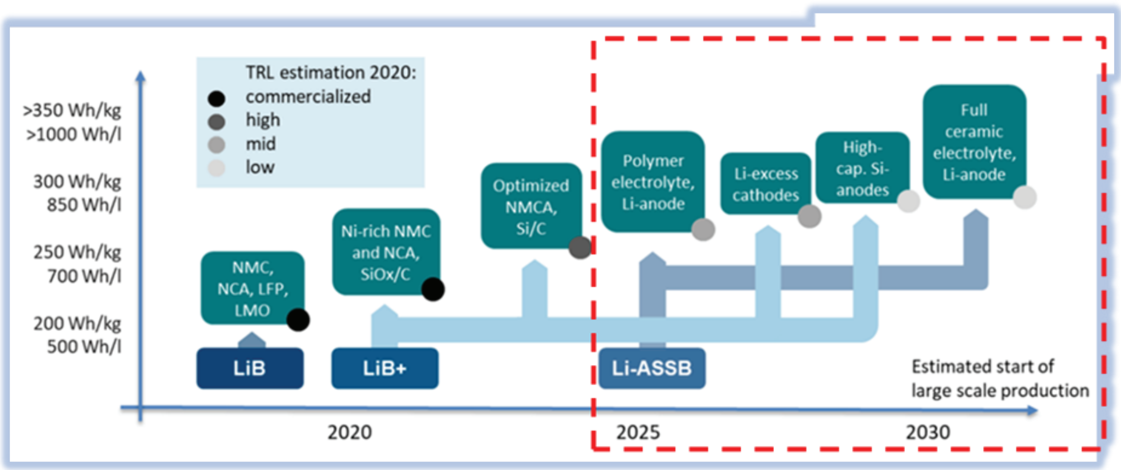


Figure: Li-technology Roadmap > 2025: Gen.3. advanced Li-Ion; Gen. 4. Solid-state; Gen. 5 post-Li-ion

Lithium all-solid-state battery technologies (Li-ASSB – Gen. 4b and 4c)

Solid state batteries use an electrolyte made of solid material instead of the usual liquid electrolyte. The main advantages of future solid state batteries are that the energy density of the cells will increase significantly, the risk of fire will also decrease due to the less pronounced flammability of the electrolyte and the use of cobalt can be significantly reduced.

More information on the lithium all-solid-state battery technologies is available in the Technical Annex.

Readiness for the mass market is expected after 2025 (4b) and as of 2030 (Gen 4c).

Lithium-sulfur battery technologies (LiSB)

The low cost and high abundance of sulfur (i.e. the active cathode material) make LiSB more appealing than Li-ion batteries 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 make LiSB 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 energies. LiSB are promising because of the high energy density, low cost and natural abundance of sulfur.

More information on LiSB technologies is available in the Technical Annex.

- Readiness for the mass market is expected after 2030.

Lithium-air battery technologies

Lithium-air batteries possess a great potential for efficient energy storage applications to resolve future energy and environmental issues. The extremely high theoretical energy density is attractive, but there are still various technical limitations to overcome. 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.

More information on lithium-air battery technologies is available in the Technical Annex.

- Readiness for the mass market is expected after 2030

In conclusion

- The future promising technologies presented in this Roadmap are not all at the same technology readiness level – sodium-ion room temperature batteries are the most promising in terms of earliest entry into the market.

- Considering the projected timeline for innovations to enter the market and the upscaling of production capabilities, as well as the market projections from different credible sources, we can conclude that Li-ion and lead-based batteries will remain the dominant technologies in 2030:

„ By 2030, lithium-ion and lead-acid batteries will be the dominant technologies."

	Pb	Li	Ni	Na
State of the Art	Flooded & VRLA Pb-C, Thin Plate Pure Lead	NCM, LFP , LMO,NCA, LCO (C; LTO; Si/C)	NiCd, NiMH	NaS, NaNiCl (Hightemp.)
>2023	Pb-Bipolar			Na-Ion (RT)
>2025		Solid State		
>2028		All Solid State		
>2030		Li-Sulfur		
		Li-Air		

5

Battery R&D in end-user applications

To demonstrate the developmental potential of the current mainstream battery technologies, we selected key applications grouped around four areas: **automotive mobility, material handling and logistics, off-road transportation and stationary energy storage**. The list of applications is not exhaustive and other key markets exist where battery R&D is strongly driven by innovation in the application. This is particularly true for military and medical applications.

This chapter features battery developments and highlights their innovation potential in relation to the end-user applications they serve. 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 end-user application in which the battery will be integrated.

Five end-user applications in each of automotive mobility, motive power traction and stationary energy storage have been selected, in which batteries are recognised as key enablers to significantly contribute to Europe's decarbonisation strategy and make **Europe less dependent on fossil fuels**.

The purpose is to demonstrate the developmental potential of the mainstream technologies in each of these applications, with Li-ion and lead-based technologies remaining the dominant technologies through to 2030. Battery technologies will continue to co-exist because of the diversity of end-user applications, as well as their complementarity in the marketplace.

More information on the state of play and innovation potential of the mainstream battery technologies in relation to these 15 end-user applications is available in the Technical Annex.

5.1. Area 1
Automotive Mobility

EUROBAT is a member of the EGVIA private-side association of the co-programmed 2ZERO Horizon Europe Partnership and a member of the ERTRAC working group on Energy & Environment to accelerate the transition to carbon-neutral European road transport by 2050.

In the automotive mobility area, the evolution of battery technologies in the five end-user applications is clear:

- The 12V auxiliary, 12V SLI and HCV commercial vehicle stand-by battery markets will remain mostly lead-based up to 2030
- For mild and full HEV batteries, as well as for BEV propulsion batteries, the market will be exclusively lithium-based. The e-mobility-driven lithium battery market will grow to 2,700 GWh by 2030

5.1.1. 12 Volt auxiliary batteries

12V auxiliary 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 the safety manoeuvrings in case of emergency. Furthermore, start-stop functionality, cyclability and cranking are tailored to the specific vehicle architecture. However, the cranking function may disappear entirely in future.

Battery market

The 12V SLI and 12V auxiliary battery market in Europe (EU27 + EFTA) is currently 51 GWh with an expected annual growth rate of >1% to reach 59 GWh by 2030[(2)]. The increase in market size is also due to the use of auxiliary batteries in all vehicle architectures from mild, full and plug-in HEVs to full EVs. **The further market penetration of micro, mild, full and plug-in EVs will increase the 12V auxiliary battery market in the next 10 years as vehicles are all already equipped with these batteries**.
The dominant technology for this application today is lead, both flooded and AGM. Together with lead, lithium (mostly LFP) will also fulfil some 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.

Innovation potential

KPIs selected for auxiliary automotive applications in all hybridisation types, from micro HEV to full EVs, include energy density, volumetric density, power density, recycling efficiency, system cost and life span.

More information on the battery features for innovation in this application is available in the Technical Annex.

► **12V Auxiliary - Dominant Battery Technology by 2030**:
- Lead - advanced AGM and EFB steadily taken over from flooded
- Li-ion (LFP and LTO) can also compete but very small share

Pb >97%

Li <3%

5.1.2. 12V starting-lighting-ignition batteries (12V SLI)

Micro and mild hybrid road vehicles run with a 12V lead starter battery because of the battery's ICE cranking function. 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). Opportunity charging to capture the kinetic energy of the car will be key to improving energy efficiency in vehicles. **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 CO2 reduction targets.**

Battery market

Today, the worldwide 12V SLI battery market is >300 GWh/year and will grow by 1-2% annually to reach >340 GWh/year by 2030. Lead (mainly AGM and EFB) will continue to dominate this market because of its specific features. Lithium will have a moderate penetration of 1-2% by 2030[(2)].

A potential lead ban by the EU and/or China for SLI batteries in 2025 is a low probability, but with a 70% aftermarket share[(1)], it would not directly affect the total market in the next years to come.

Europe already has giga-factories and today's annual European production for lead batteries is up to 90 GWh. Lithium production, however, is only >0.5 GWh and expected to reach >5 GWh by 2030.

Innovation potential

Start-stop micro hybrid architectures 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 KPIs for innovation are increased vibration endurance, energy and power density, system cost, energy throughput and dynamic charge acceptance. 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.

More information on the battery features for innovation in this application is available in the Technical Annex.

► **12V SLI Battery - Dominant Technology by 2030**:

- Lead - mainly AGM and EFB
- Li-ion - can also compete but very small penetration

Pb >98%

Li <2%

5.1.3. Heavy commercial vehicle stand-by batteries (HCV stand-by batteries)

In many EU Member States, legislation is being developed that does not allow cars to stay in idle for longer than a few minutes. Such legislative changes have led to new battery requirements and resulted in a new market developing, in particular for heavy commercial vehicle stand-by batteries. 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. 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.

Battery market

Today, only lead is in this new market, but lithium may also break through in future. 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 within this application.

The annual production of lead batteries in Europe today is 10 GWh, which is estimated to reach 18 GWh by 2030[1].

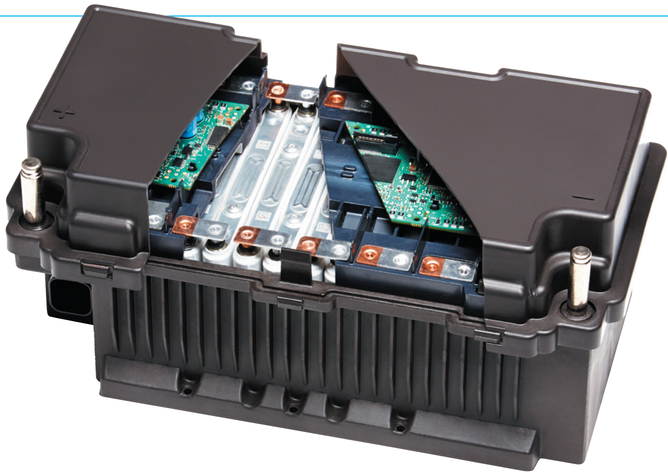
Innovation potential

KPIs 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.

More information on the battery features for innovation in this application is available in the Technical Annex.

►**HCV Truck Stand-by Batteries- Dominant Technology by 2030**:
- Lead to continue dominating the market
- Li-ion – difficult to compete with moderated penetration

Pb >98% Li <2%



© CLARIOS – 48V Mild HEV Battery

5.1.4. Mild & full hybrid electric vehicle propulsion Batteries (HEV Batteries)

Hybrid electric vehicle energy storage solutions are 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 PHEV and BEVs (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 emission targets in the European Green Deal is lower for mild HEV (~10% fuel efficiency gain) and full HEV (~25% fuel efficiency gain) compared to PHEV and EVs (up to 100% fuel efficiency gain, though still not carbon neutral).

Battery market

EU market demand in 2022 is 2.2 GWh, which is expected to grow 17% annually until 2030 with a majority share in the 48V segment compared to full HEVs[(1)]. Over the last two decades, the vast majority of HEVs have used the NiMH electrochemistry, with one dominant player in the hybrid fleet. While NiMH will play a role over the next couple of years, only Li-ion technology, with NMC | C and LFP | C compositions, will be used in new vehicles by end of this decade. Outside of the EU27, we may still see alternative technologies like NiMH being used.

European production capacities are closely linked to the proliferation of giga-factories because of the similarities and synergies in the manufacturing process compared to BEV battery systems.

Innovation potential

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

More information on innovation in this application can be found in the Technical Annex.

▶ **Mild & Full HEV propulsion Battery Technologies by 2030:**

- Exclusively lithium based

Li **100%**

5.1.5. Battery electric vehicle propulsion batteries (BEV propulsion batteries)

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

For road BEVs, 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.

Battery market

The current BEV worldwide market will increase considerably and will be the main driver for increased lithium production in Europe. Worldwide lithium propulsion batteries for the BEV application are expected to rise to 2,700 GWh, representing 85-90% of the total lithium battery market share by 2030[1]. Market drivers include favourable government policies and subsidies, rising concerns about emissions and the further development of charging infrastructure, including bi-directional vehicle-to-grid systems (V2G) in order to support grid-functionalities. 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 mainstream technology today is lithium NMC/LFP, while NMC and solid-state technologies will be targeted for development by 2030.

Innovation potential

KPIs for innovation, driven by market demand and regulation, are energy and power density, system cost, energy throughput, charge acceptance, operating temperature range and recycling rate. Pack research (e.g. cell pack design, thermal management, advanced pack materials, etc.) will also be necessary to achieve the targets and to support the EU's environmental objectives, such as increasing the recycling efficiency, recovering cobalt, copper, lithium and nickel, and reusing or repurposing EV batteries.

Furthermore, specific additional research on heavy and light commercial vehicles will be necessary, as specified in the ETIP Batteries Europe roadmap and the SRIA of the Batt4EU partnership.

More information on the battery features for innovation in this application is available in the Technical Annex.

► **BEV propulsion Battery Technologies by 2030**:
- Exclusively lithium-based (NMC / LFP)

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5.2. Area 2

Motive power material handling & logistics

Motive power battery markets are very diverse, covering propulsion batteries in many off-road industrial vehicles for multiple purposes as well as in railway rolling stock, marine and, more recently, aviation applications.

The worldwide industrial motive power battery market in 2030 will reach an estimated 67 GWh, with the major market related to material handling and logistics applications, such as forklift trucks.

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, high cycle life and long operating times. 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.

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. Nickel-based batteries are in niche markets with harsh conditions. The three mainstream technologies – lead, nickel and lithium – are complementary and all have the potential to contribute to innovation in these applications.

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, with the market predicted to reach 67 GWh by 2030[(1)]. This high market growth will include both lead- and lithium-based technologies.

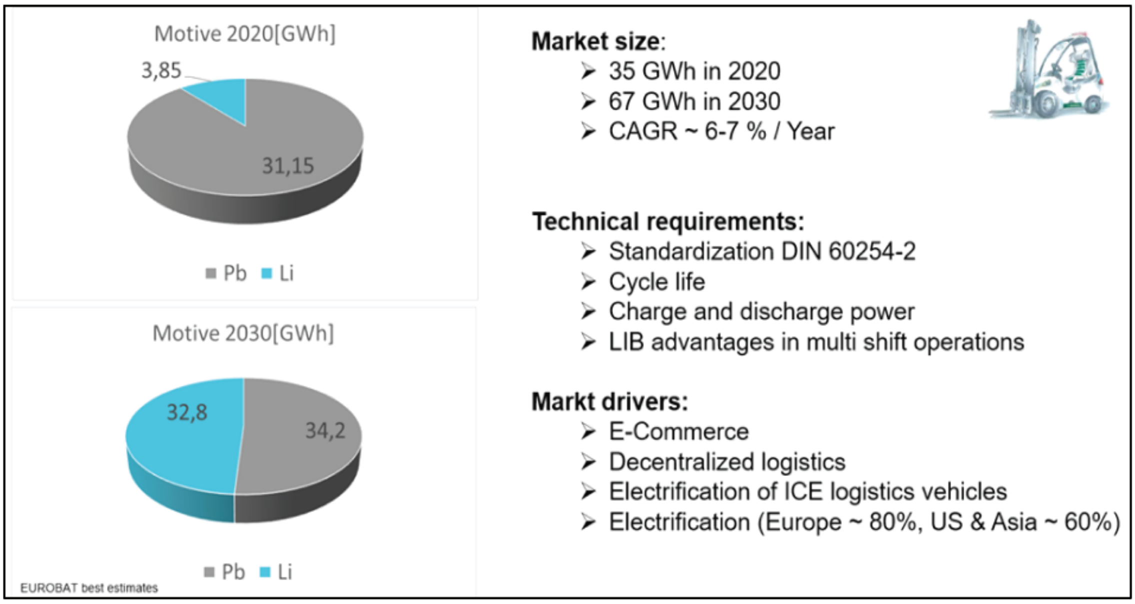

Chart: Worldwide B2B Motive Power Material Handling battery market demand – EUROBAT best estimates

Innovation potential

Lithium has entered the market for smaller forklifts and has advantages in multiple shift operations, which are more energy-demanding and where battery charging time is limited. 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.

More information on the battery features for innovation in this application is available in the Technical Annex.

5.3. Area 3

Motive power – Off-road transportation

5.3.1. Batteries in off-road industrial vehicles

This segment covers a wide range of industrial applications that cannot be allocated to the previous material handling and logistics vehicle categories. We identify the following sub-segments:

- **Sweeping/cleaning machines** used in factories, malls and supermarkets for cleaning purposes, as well as **wheelchairs.** Here, a different number of 6-12V monoblocs with different dimensions and stored energy are typically used, connected in parallel and in series.

- **Construction/demolition machines**, such as mini-loaders and scissor-lifts, used in places like production facilities and construction sites – batteries are similar to those used in the previous application.
- **Golf carts and small carts** used for leisure or light human transportation, such as in 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 and generally use electric drives.
- **Other applications not included in the categories above**, such as harvesting trolleys used in greenhouses and other small machines.

Battery market

We target these market segments because of their high potential to contribute significantly to the zero emission targets of the European Green Deal and we estimate market demand in 2030 to be 3.3 GWh[1].
Lead-based batteries are currently dominant in most of these market segments. This is likely to remain the same in future years, especially for applications where the initial investment is low. Lithium is entering the powering market because of restricted battery compartments and higher currents due to the heavy loads, in particular for construction/demolition vehicles. Nickel-based technology (NiCd), with its broad operation temperature range, has traditionally been the choice for extreme environments, but currently it covers only a very niche market for this segment.

Innovation potential

KPIs for innovation in these segments are high energy content, cycle life, operating time and operation 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. Other important aspects driving innovation are safety, circularity and increased recycling targets.

More information on the battery features for innovation in this application is available in the Technical Annex.

► Motive Power Off-road Industrial Vehicles - Mainstream Battery Technologies by 2030:

- Lead will remain dominant In most of the off-road segments
- Lithium to replacing larger ICE, ex. in building/demolition
- Nickel to serve niches for extreme environment

Pb Li Ni

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5.3.2. Batteries in railway applications

Rail infrastructure is the most efficient mode of transport in Europe in terms of CO_2 emissions and safety. Europe's Rail Joint Undertaking (Rail JU) and the Batt4EU partnership are investigating the development of joint calls on battery R&D to meet new battery needs in both the vehicles and the infrastructure to further increase the performance and energy efficiency of the system.

Battery market

The railway segment is a very fast-growing market, driven by increasing populations and increased demand for rail transport around the world. Asia is highly active in the sector and expected to have a significant impact on the train battery market in Europe. The overall battery market has high growth potential, with annual growth until 2025 for Li-ion, Nickel-Cadmium and lead forecast to be 25%, 5% and 4%, respectively. Lead and advanced lead batteries, with increased cycle and service life and low temperature tolerance, will be the main technologies for commuter trains in 2025 with a market share of more than 35%. Lead, both flooded and sealed, may be the dominant technology, but nickel and lithium (LTO mainly) also have a significant share of the market.

Innovation potential

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. 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 make a significant contribution to the net-zero emission target.

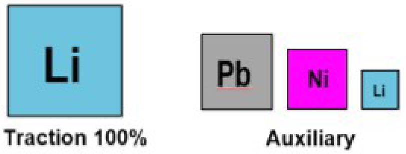
Hybridisation and electrification of rail power traction is the fastest growing battery segment for railway applications. High energy, power density and cyclability suit lithium systems best.

Key areas for development are volumetric energy density, lifetime and operating temperature range.

More information on the battery features for innovation in this application is available in the Technical Annex.

► Motive Power Railway Mainstream Battery Technologies by 2030:

- Traction is exclusively li-ion
- Auxiliary: NiCd mainly and lead based, lithium also penetrating



5.3.3. Batteries in marine applications

The marine sector is a strong contributor to carbon emissions and pollution in Europe and worldwide, but batteries are enablers that contribute to the electrification of maritime fleets in oceans, seas and inland waters. The Zero Emissions Waterborne Transport partnership, together with the Batt4EU partnership, is seeking solutions for the new battery needs in the marine sector.

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

► BEV smaller boats: canal, river and lake vessels, integrated fleets 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 standby and motive power battery applications (including UPS and TLC), typically for harsh climate/weather conditions

Battery market

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 both technologies can contribute and have their place in these markets. Lithium batteries have higher energy densities and cycle life, 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. In all these segments, the market for electric propelled vessels is increasing to meet future demand. For BEV smaller boats, lead 48V propulsion technologies, both flooded and sealed, are dominant today. Lithium NMC and LFP are also breaking through in this market, while for the propulsion of BEV and HEV medium to large ships, the market is exclusively lithium.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Innovation potential

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 density.

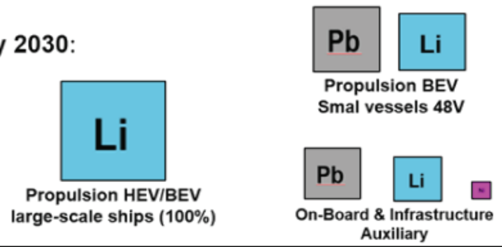
Key performance indicators for a large-scale adoption and implementation of batteries for waterborne transport are energy and power density, energy throughput, charge acceptance, operational temperature range and recycling rate. More information on the KPIs can be found in the ETIP Batteries Europe SRIA.

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

More information on the battery features for innovation in this application is available in the Technical Annex.

► **Motive Power Marine Mainstream Battery Technologies by 2030:**

- Propulsion of large-scale schips (ferry's, cruises and other off-shore): 100% Li
- 48V propulsion smaller vessels batteries for eVTOL: exclusively Li-ion
- Auxiliary: Lead-based, NiCd for niche, lithium penetrating



5.3.4. Batteries in aviation applications

According to the International Energy Agency, the aviation industry produces annually over 1,000 Mt CO_2 worldwide. Electric aircraft have been discussed in the last decade in the context of the EU Emissions Trading System (EU ETS) and climate targets. However, with current battery energy densities, it is not yet possible to electrify the propulsion of commercial aircraft. Potential hybridisation and the development of eVTOL is a first step to reduce the greenhouse gas emissions of this sector. Europe's CLEAN Aviation Joint Undertaking (Aviation JU), in coordination with the Batt4EU partnership, is developing R&D topics on batteries to meet new requirements in this sector.

Battery market

Short-range VTOL vehicles will bring value as personal air vehicles, air taxis and cargo carriers to replace helicopters, which are noisy, mechanically complex and expensive to maintain. Electric, multi-rotor, distributed-propulsion solutions are in the making. Over 100 firms worldwide have announced work on 1-7 seat short-range urban air mobility vehicles. It is predicted that by 2050 there will be over 160,000 eVTOL-vehicles flying worldwide. Meanwhile, the development of eVTOL will further boost other battery markets. Apart from reducing fuel burn and related carbon emissions, other market drivers are noise reduction and a significant improvement in competitiveness with other mobility types. In today's markets, aircraft batteries are used for many other 'non-propulsion' functions (e.g. **ground power, emergency power, improving DC bus stability and fault clearing**). Small private aircraft use lead-based batteries, while commercial and corporate aircraft use nickel-cadmium (NiCd) thanks to a **high cycling capacity that ensures long life** and reduced maintenance and low weight and size. Lithium can also compete with such auxiliary batteries and is increasing its market share.

Innovation potential

Currently, auxiliary batteries in airliners are undergoing a transition from conventional batteries (nickel-cadmium and lead-based) to Li-ion batteries, with high energy and power densities and a longer lifespan.

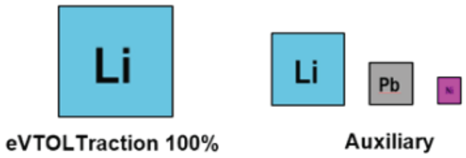
For eVTOL propulsion batteries, Li-ion, with the highest energy density, is most suitable, but safety needs to improve. Further improvements for developing light, compact and safer HV batteries capable of powering eVTOLs is to be found in the design and integration aspect (light weight, thermal management, etc.) and in developing other chemistries to increase the specific energy and power density (e.g. LMB, SSLMB, SSLIB with graphite/silicone anode).

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. Furthermore, there should be investigations into more stable and reliable LMB, developing new liquid electrolytes, more sophisticated battery management and better safety forewarning systems.

More information on the battery features for innovation in this application is available in the Technical Annex.

▶ Motive Power Aviation Mainstream Battery Technologies by 2030:

- Propulsion batteries for eVTOL: exclusively Li-ion (LTO...
- Auxiliary: Lithium to take over NiCd and lead-based



5.4. Area 4
Stationary energy storage

5.4.1. Batteries for Uninterrupted Power Supply (UPS Batteries)

When utility power fails, Uninterruptible Power Supply (UPS) ensures 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 demand for UPS. UPS contributes to zero emission targets through longer bridging times, grid stabilisation (instead of building additional power plants) and in combination with renewable energy sources.

Battery market

UPS is an established market in which lead-based batteries have been the dominant technology for decades and are expected to remain so by 2030. The global market production capacity was 15 GWh in 2019 and will grow to 25 GWh in 2030. This growth is due to increased use of big data and the associated need for new data storage centres, as well as 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.

The EU market share in 2020 of the total world market was 28%, which will decrease to 21% in 2030. China, India and others will grow by 11% over this time[(2)].

The dominant technologies used today are valve regulated lead acid batteries (VRLA) with absorbent glass mat technology (AGM) and li-ion batteries, while nickel-cadmium (NiCd) has a minor share. The expected annual growth rate for lead and lithium is 1.6% and 12% (in value), respectively. Lithium penetration will increase from 10% in 2020 to 30% in 20301 depending on further cost reduction, safety issues and regulatory implications[(1)].

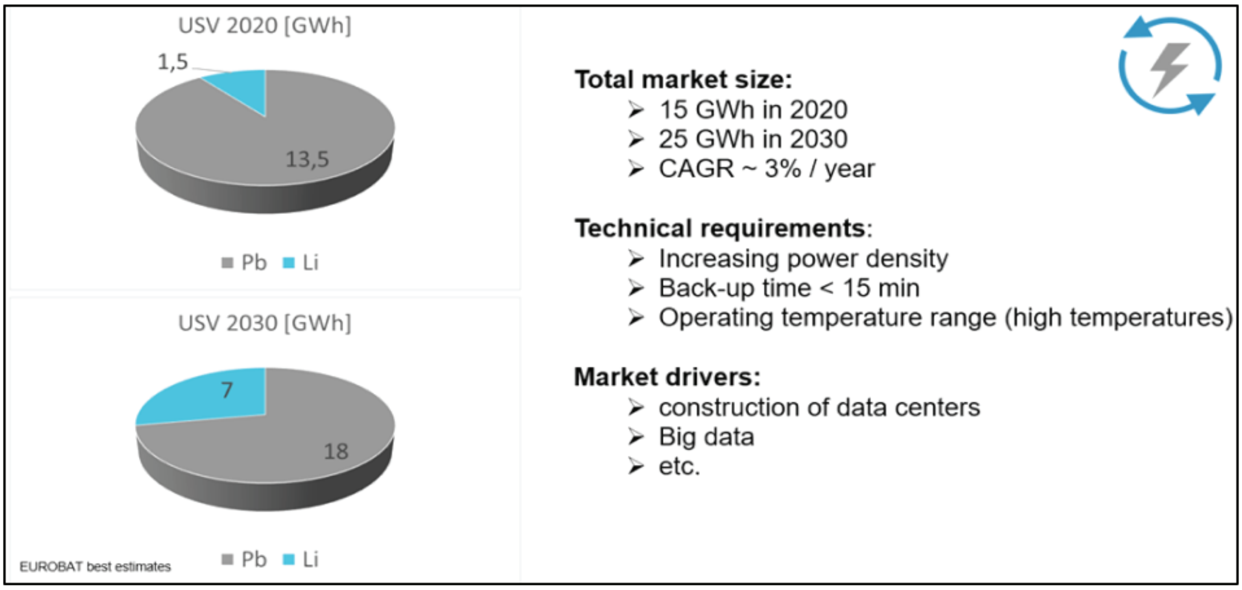


Chart: Worldwide UPS Battery market – market share lead/lithium in 2020 and by 2030

Innovation potential

Increasing the power density is particularly necessary because of the further electrification of critical loads. As new UPS batteries should provide additional value, 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 by reduced climatisation as one of the main cost drivers and, therefore, the heat exposure to the battery will rise and the batteries must be able to cope with it. **As the typical back-up time is between 5 and 15 minutes, KPIs for the application are energy and power densities, system cost, operating temperature range and reduced cooling, as well as safety.**

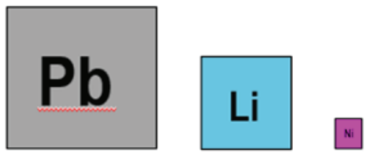
Other developments are the connection of UPS batteries in a single network to form a larger UPS system or virtual power plant (VPP). This will become possible thanks to 5G and artificial intelligence to allow distributed energy production, storage and consumption.

Due to its maturity, lead battery recycling processes have developed and improved over a long time and are already highly efficient and economically valuable, while recycling of lithium batteries is more complex due to the different chemistries and battery housings that demand different physical and chemical treatments.

More information on the battery features for innovation in this application is available in the Technical Annex.

► Stationary Energy Storage UPS Mainstream Battery Technologies by 2030:

- Lead-dominant technology to be maintained (VRLA mainly)
- Li-ion entering the market with LFP and LMP and NMC
- NiCd has minor share to serve niches

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5.4.2. Batteries for telecommunication (TLC Batteries)

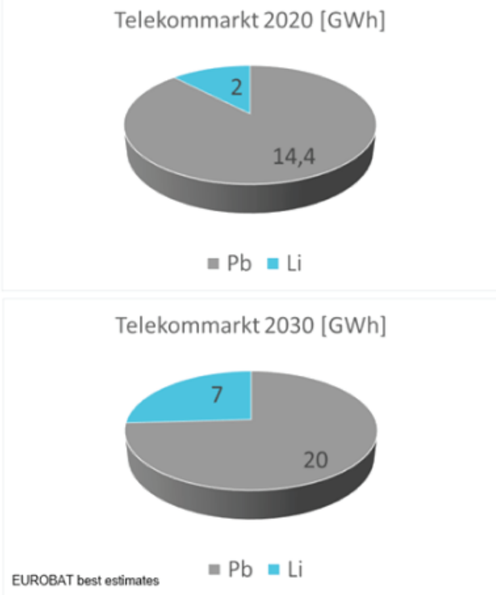
A telecom unit is an information and communication technology or telecom site with critical loads. In case of unavailability or insufficiency of the main power source, telecom batteries provide instant and continued 48 DC voltage power to all redundant equipment to ensure that the telecom application continues to function until a diesel generator or, in future, a fuel cell can take over. In contrast to UPS batteries, telecom batteries serve only telecom applications, connected to the 48V DC electricity supply net.

There are also off-grid telecom towers combined with renewable energy sources or other hybrid systems, such as in emerging countries with a lack of power grids or in remote areas. In these cases, the batteries provide electricity when the energy from renewable sources is insufficient or unavailable. The transfer to virtual power plants (VPP) also demands 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).

Battery market

The dominant technology used today is VRLA with absorbent glass mat technology (AGM) for reliable grids and VRLA with gelled electrolyte (GEL) in poor or off-grid scenarios. The predominant lithium technologies are LFP and NMC cathodes with graphite anodes to target NMC graphite-silicon composite anodes by 2030. Due to cost and safety reasons, there is a trend towards LFP technology.

The global market demand in 2020 was 16.4 GWh, which is expected to grow to 27 GWh in 2030 (4.3% annual growth in volume). The annual growth rate for lead batteries is expected to be 0.5% and for Li-ion batteries it is expected to be 8.5%. In this scenario, lead will remain the dominant technology but the lithium market share will grow to 27%. This is because lithium is more expensive than lead (~2-3x), but with a lower total cost of ownership (TCO) than lead in hot climates because of a higher expected lifetime, especially in high temperatures. The main drivers for this application are the extension of WiFi, strong network growth in China, India, eastern Europe and South America, as well as the introduction of 5G. Other drivers are the further actions to reduce diesel consumption and emissions, especially in countries and areas with unstable grids, which will necessitate higher energy throughputs for the battery.



Total market size

- 16,4 GWh in 2020
- 27 GWh in 2030
- CAGR ~ 5% / Year

Technical requirements:

- Operating temperature range (higher temperatures)
- Lifetime (trickle charge and cycles)
- Safety

Market Drivers:

- Wireless markets
- Expansion of data networks
- 5G building and extending networks.

Chart: Worldwide Telecom Battery market - market share lead/lithium in 2020 and by 2030

Innovation potential

The main features of batteries for telecom applications are energy and power density, energy throughput and hot temperature robustness. In addition, safety, cost and end-of-life management are key aspects. For the end-of-life management, product collection, recycling and circularity are key. With respect to recycling, lead-based batteries are among the products with the highest recycling efficiency worldwide. Recycling processes are established and recycling plants well distributed. Recycling of lithium batteries is not yet mature and the recycling efficiency and economy needs to be further developed. Due to the usage of different electrode chemistries, different recycling processes are required. The new Batteries Regulation will put strong pressure on circularity and demand that batteries must contain recycled materials. The target is 85% for lead and 4% for lithium by 2030.

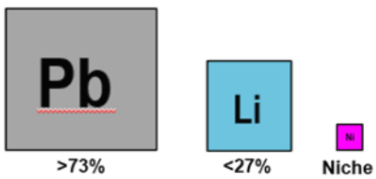
The main targets for lead-based batteries are an increase in the gravimetric energy density at system level, while increasing the cycle life performance at different DODs and extending the battery lifetime to 10 years at higher temperatures to improve the TCO. The calendar life in off-grid and VPP applications 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 from secondary raw materials and a higher level of production automation.

For Li-ion battery technologies, an increase in the gravimetric energy density at system level, together with an increase in cycle life at different DODs, will be needed 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).

More information on the battery features for innovation in this application is available in the Technical Annex.

► Stationary Energy Storage Telecom Mainstream Battery Technologies by 2030:

- Dominant technology: lead
  - In reliable grids: VRLA with absorbent glass mat
  - In poor or off-grid: VRLA with gelled electrolyte (GEL)
- Li-ion entering the market with LFP and NMC
- NiCd to serve niches



5.4.3. Batteries for residential and commercial storage behind the meter

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 cost benefits, additional drivers for residential and commercial storage are increased 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.

Battery market

Lithium technologies are dominant in the market today and are expected to remain so. Lead batteries are less present, but advancements in energy density and cyclic performance could make lead-based solutions a more attractive proposition. Recent studies suggest there will be an 8% annual increase in demand (MWh) for batteries used in energy storage systems(1). Current demand for lead batteries in this application is approximately 700 MWh with Li-ion technologies accounting for around 1,000 MWh. Demand for lead batteries is expected to double in the timeframe up to 2030, with Li-ion solutions expected to increase six-fold over the same period, which means that Li-ion will be the increasingly dominant technology.

Lead-based manufacturing capacity in Europe is sufficient to meet expected demand, whilst Li-ion demand is heavily reliant on imports today. However, by 2030 it is expected that there will be an almost 40-fold increase in European capacity that will be able to meet demand even at optimistic growth expectations. Ultimately, there will a surplus of capacity versus demand in Europe based on current predictions.

Innovation potential

Lithium-based solutions have an advantage in terms of space weight and cycle performance, but safety is a consideration to be further improved for in-house storage applications. The lead-based bipolar technology can increase energy density and advanced chemistries, such as carbon loaded negative designs, can improve cycle performance and energy throughput, particularly in partial state of charge operations. Another aspect to consider for end-users is the aesthetics of the battery system if it is to be prominently displayed at home or in commercial locations.

Lead today is fully recyclable and has the economies of scale in place that work without subsidies. For Li-ion, further improvements are needed to make it economically viable. Lifecycle (energy throughput) advancements for both technologies will be required to reduce the TCO. The PSOC cycles of the batteries, according to the European reference test standards, should also increase. With advancements in energy density and cycle performance, lead-based solutions could become more attractive in future.

R&D&I development should be focused on improving the cycle life and increasing the lifetime energy throughput (kWh) across the full range of depth of discharge (particularly for lead) to provide TCO benefits. Associated KPIs relating to improving charge efficiency and higher energy density are also desirable. 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 round-trip efficiency is also a key parameter in future to align with the Energy Efficiency Directive.

More information on the battery features for innovation in this application is available in the Technical Annex.

► Residential / Commercial Stationary Energy Storage Behind the meter Mainstream Battery Technologies by 2030:

- Li-ion increasingly dominant technology
- Lead is kept in the loop – depending on further R&D results

Li

Pb

5.4.4. Batteries for utility grid-scale energy storage

Utility grid-scale energy storage systems are large storage facilities that can provide grid stability in multiple ways. Depending on the grid function, a large variety of operating profiles are considered, in which, depending on the requirements, all mainstream battery technologies can have a role to play.

Grid functions, such as voltage/frequency regulation, arbitrage, black-start, back-up, investment deferral and grid independent power supply (GIPS), are typically suitable for batteries. Hereunder is a table of application profiles per grid function.

	Segment	Power rate (MW)	Response time	Storage capacity	Charge acceptance	Cycles (#/year)	Efficiency (%)	Energy density	Condition of operation
Regulation	Conventional		<1 min- 60min			250-10 000			
	PV	1-40 MW	15-60min	0,5 - 20 MWh		250 – 1 000			
	Wind		<1 min-60min		Sec.			Low	
	End-users	0.1-10 kW	0,1-15min	na		10-200			
	T&D	na	<1 min-60min						
Arbitrage	Generation				Hours				
	PV integration	0.1-500 MW	<1-6h	0.1->1GWh	Min.	50-250			
	Wind integration								
	Seasonal	10-1000 MW	2-8 h	> 50 MWh up to 10000 MWh	Hours	10-50		Moderate	
	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	

Tabulation: Battery profiles per grid function

Battery market

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 at location and scalable to the power and capacity needs of the application.

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, such as optimising self-consumption through the integration of renewables, and for peak-shaving.

Drivers and trends for grid support applications are the major infrastructure changes in the power supply industry, the integration of renewables, emerging electro-mobility and demand for higher power quality.

Innovation potential

A distinction must be made between energy and power applications. General technical requirements are PSOC cyclability, high power density and wide operating temperature ranges. General technical requirements are high reliability, scalable power supply and low maintenance/service cost. A particular feature for this market is also the projected service life of 20 years, which can be met both with lithium and lead. A potential way of reducing costs for Li-ion systems is the deployment of second-life EV batteries.

The development of the multi-use aspect of ESS will also increase the profitability. 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”).

Research priorities for lead are, in particular, the cycle life, PSOC cycles and the charge efficiency. 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.

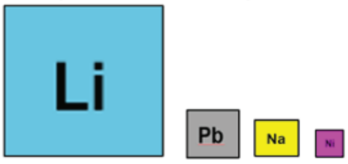
Intelligently combining lead- and lithium-based batteries could also increase the market significantly for lead as it would offer considerable benefits in terms of lower energy reserve costs.

KPIs for utility and renewable energy storage grid functions are lifetime, charging/discharging efficiency and safety. The research priority for lead up to 2030 is cycle life in order to lower operating costs, and for lithium it is primarily safety. Also, improving the round-trip efficiency is key to reducing acquisition and operating costs.

More information on the battery features for innovation in this application is available in the Technical Annex.

► Utility grid-scale Energy Storage mainstream Technologies by 2030 (ESS Batteries):

- Mainly grid functions suitable for batteries
- Mainly li-ion but also niches for lead and sodium HT based technologies
- Nickel-based as niche for harsh environment



5.4.5. Batteries in off-grid configurations

This application segment covers batteries for stand-alone use or in ‘hybrid’ (combined with diesel generators or renewable energy production), off-grid or remote mini-grid systems 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 in developing countries
- Peri-urban areas with weak grids in developing or emerging countries
- Small islands separated from the national grid (e.g. mini-grids)

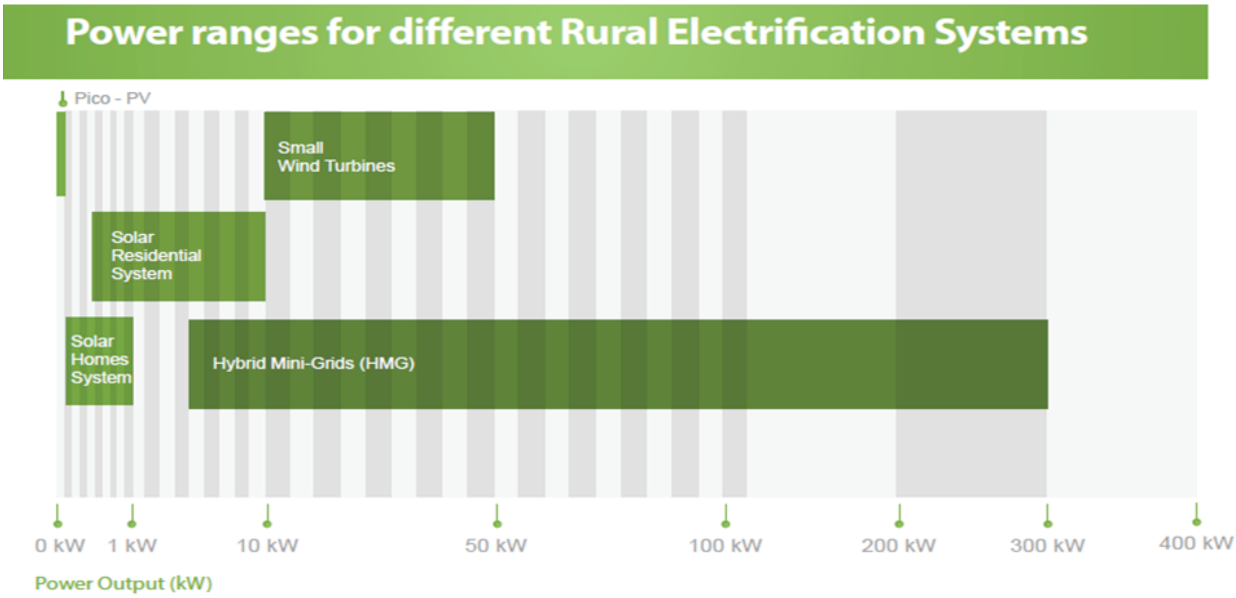


Figure: Power ranges for different off-grid Rural Electrification segments [4]

The main applications are battery energy storage systems (BESS) ranging from pico-PV and domestic solar homes systems over small wind turbines and industrial/commercial hybrid mini-grids to community scale usages and back-up power for telecom towers.

Battery market

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.

Recent studies from the International Energy Agency (IEA) have quantified that off-grid and mini-grid configurations using Battery Energy Storage (BES) is often the most efficient and sustainable way to electrify isolated rural areas or remote commercial and industrial sites (C&I sites). In order to achieve universal energy access by 2030, the IEA estimates that a further 379 TWh of on-grid electricity generation will be needed, along with 399 TWh from mini-grid systems and 171 TWh from off-grid systems. Another market is on small European islands without mainland interconnections where peak production relies on fossil fuel. Nowadays, there is a clear tendency towards the installation of off-grid and mini-grid renewable energy sources instead. Market drivers are the worldwide expansion of fluctuating renewable energy sources like PV and wind. National and multinational funding programmes support these developments. With an increasing global population and despite the growing electrification worldwide, in 2018 there were still 112 million people in central and southern Asia and 548 million people 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-emission targets of the European Green Deal. In addition, electrifying rural areas helps address other societal challenges, both in developed and

developing countries, including remote telecommunication installations, water purification and/or pumping, street lighting and security systems.
The dominant technologies through to 2030 will be lead-based (sealed and flooded) and Li-ion (NMC and LFP). Lead-based technologies still have the major advantage as they are safe and easy to install and to maintain without sophisticated technicians, which is important for rural and remote installations. Sodium-ion (RT) batteries could be an upcoming alternative storage system competing with LFP and lead.

Innovation potential

The main KPIs for the majority of off-grid applications are high performance in rugged atmospheric conditions, low maintenance and affordability.

For lead-based batteries, increased energy throughput and the development of operation strategies by integration of BMS (battery management system) are important. For lithium-based batteries, improving the design life, safety aspects like high temperature operation, cost and recyclability are paramount.

Circularity and recycling are key parameters for further development. Cycle or lifetime performances are measured differently depending on the battery chemistry and the depth and rate of discharge. Cycling profiles are different in each IEC cell chemistry-specific standard, so it is not meaningful to compare results across technologies. Instead, the application-specific standard IEC 61427-1 is the reference to benchmark.

More information on the battery features for innovation in this application is available in the Technical Annex.

► Batteries in off-grid configurations - mainstream Technologies by 2030 (ESS Batteries):

- Lead dominant technology - with 40% sealed, 15% flooded
- Lithium-ion, with LFP to gain from NMC

Pb | Li | niches

6 Cross-cutting – sustainability, safety and standardisation

6.1 The EU Batteries Regulation proposal

The European battery industry is strongly committed to sustainability and safety as it is laid down in the proposal for a Batteries Regulation (introduced in December 2020), which targets the entire battery value chain. More than ever, the recycling and recovery of battery materials is a high priority for meeting the new environmental requirements in the legislative proposal, as well as to make Europe less dependent on imported raw materials for batteries.

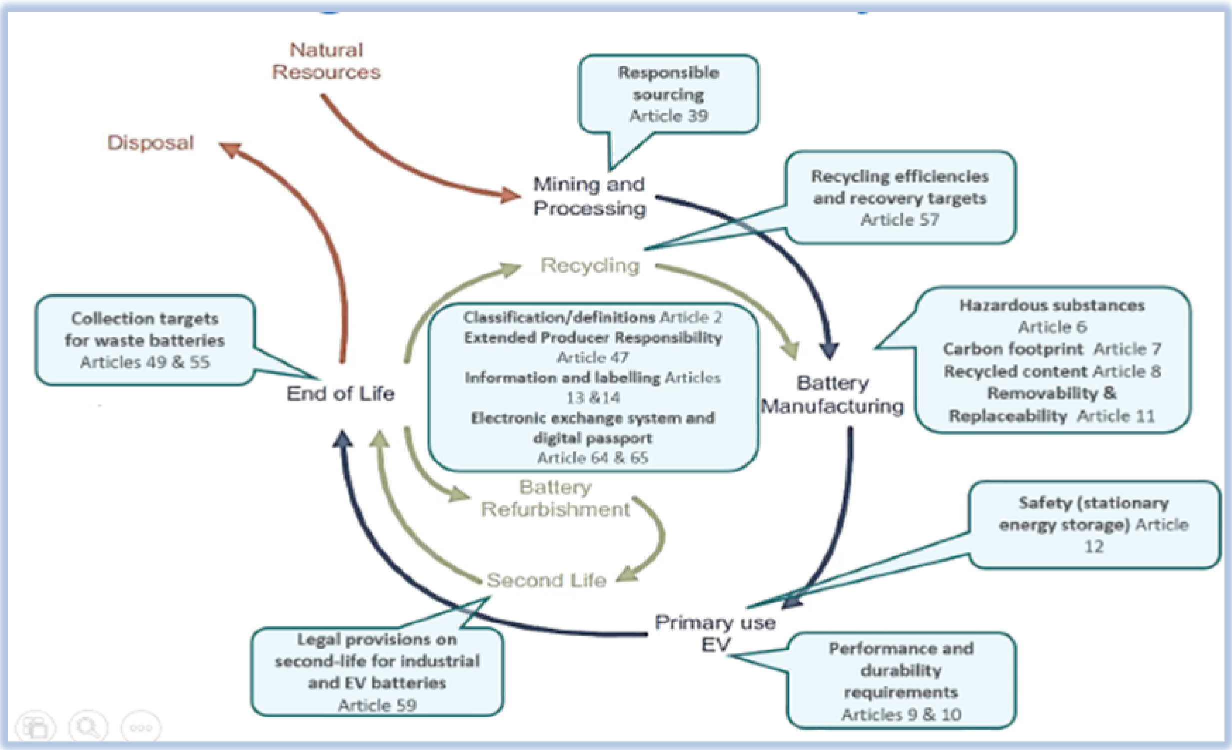


Figure: New EU legislative proposal - targeting the entire battery value chain (source: EC DG Grow).

The product requirements for batteries in the Regulation proposal will cover the following R&D areas:

- Design: restrictions on hazardous substances, performance, durability, safety, etc., but also for recycling, repair and reuse
- Production: carbon footprint, recycled content, etc.
- Information provision: labelling, electronic exchange system, battery passport, state of health, etc.

All mainstream battery technologies have challenges with regard to the safety and environmental requirements laid down in the Batteries Regulation proposal. With this Roadmap, we want to demonstrate that each mainstream technology features battery developments that support the objectives of the Regulation, while significantly contributing to Europe's decarbonisation targets, and making Europe less dependent on imports and less vulnerable to shortages of raw materials for batteries through the transition to a circular economy.

The industry recognises the need for implementing measures and impact assessments to elaborate further on the new Batteries Regulation to ensure more harmonised legislation in the following areas:

- **Collection rate calculations and targets**
- **Recycling efficiencies and material recovery calculation methods and targets**
- **Mandatory recycled content declaration: calculation and target levels**
- **Mandatory carbon footprint calculations and targets**
- **Minimum information requirements with regard to performance and durability**
- **Provision of basic and more specific (encrypted) information to end-users and economic operators through the setting up of an electronic information exchange system for batteries**

In connection with the last point, the setting up of a battery passport scheme for industrial and electric vehicle batteries is a key instrument in which the battery industry is committed to further investigate before implementing it in the market.

6.2 The Battery Passport

The Circular Economy Action Plan is an essential pillar of the European Green Deal and provides a clear indication of the urgent need to **improve the circularity of our economic model**.

A key instrument that the European Commission wants to be fully implemented by 2026-27 is the Battery Passport, initially applying to EV batteries and larger stationary storage batteries only, but with the purpose to extend it to other applications. The Battery Passport is about the digitalisation of product information to ensure interoperability and technicalities in order to facilitate the reuse and repurposing of batteries instead of directly recycling them.

The mainstream and future technologies addressed in this Roadmap have been selected because of their cost-efficiency, sustainability and low-carbon footprint potential. The feasibility studies launched, and to be launched, to assess what is the best architecture for the proposed electronic information exchange system and what services it should deliver, should consider these mainstream technologies because their potential.

The development of the Battery Passport is a challenge, but there are also threats. With this digital transformation, further R&D will be needed on the battery management system (BMS) and battery system design to improve interoperability and facilitate the integration of second life batteries. This should be industry-driven as the industry is in prime position to take into account what is happening internationally and the Battery Passport will need to work worldwide.

Apart from R&D needs, faster uptake of the innovation will also be possible by scaling up standardisation and developing education skills, as well as improving safety.

EUROBAT is a member of the Global Battery Alliance (GBA) because of the international dimensions, such as securing access to raw materials for batteries, standardisation and skills development.

EUROBAT supports cradle-to-grave lifecycle analyses in order to develop and promote sustainability and the circular economy. The industry is implementing and further developing sustainability practices in all phases of the battery product life, during the production, transportation, manufacturing and use phases, as well as recycling and reuse.

At the end-of-life stage, virtually all batteries from the different applications that are available for collection are collected and processed for recycling. The **recycling efficiency levels in the Batteries Regulation can be met independently of the application**.

Today, not all the mainstream technologies are at the same level of maturity with regard to recycling. While lead batteries already have a very well established circularity business model in place, which is economically viable, lithium batteries are at an earlier stage and will need more R&D efforts to develop their models.

In addition to its membership of the Global Battery Alliance, EUROBAT has been a member of the European Battery Alliance (EBA250) since it was founded in 2017.

6.3 Battery Standardisation

Standardisation has been recognised by the European Commission as the foundation of the single market and global competitiveness. It is the key for scaling up the implementation of innovations to maximise the impact in support of the European Green Deal.

The European battery industry has led the way on standardisation for many decades, bringing the European voice into global discussions, resulting in reliable products and quality standards tailored to a multitude of applications. Leading on standardisation and with active production lines in service, the industry has been keen to take improvements from the lab to the market in order to launch new products to serve new demands and requirements. Today, the industry retains a leading position in the European lead-based automotive and motive power markets and, to a lesser extent, in the stationary business. The industry is leading the process on battery standardisation (all technologies) within the framework of the International Electrotechnical Commission (IEC), TC21 and its SC21A.

The European Commission mandate to CEN/CENELEC (M/579) will support future legislation to address new challenges with regard to performance testing, safety and sustainability of all batteries. The existing CEN/CENELEC e-mobility Coordination (eMCG) will be managing the coordination within CEN/CENELEC's existing structure with the aim to provide the Commission with the final report by 31 December 2025.

- The participation of the European IEC TC 21/SC21A leaders, the CLC TC21X leaders and some key European industry associations, such as EUROBAT, will play a crucial role in ensuring the consideration of the international context and the largest European industry players when developing harmonised standards.

- Potential standardisation activities under the M/579 mandate should be industry-driven. **The industry has already developed IEC Standard 62902, which is a worldwide standard on colour codes and QR codes in an attempt to direct the waste stream of the different battery technologies on the market. This standard is currently under review. The IEC TC21 WG, which is in charge of this standard, would be a good basis to start further initiatives to support legislation with further standards.**

- Additional resources will be needed to progress with work related to the M/579 mandate for developing standards and common specifications on the performance and durability of batteries, but also to develop harmonised calculation rules for data collection, the declaration of carbon footprint performance classes and other aspects that are covered in the Batteries Regulation proposal.

7

Concluding remarks and recommendations

7.1 In conclusion

By 2030, both Li-ion and lead-based batteries will remain the dominant battery technologies.

- Li-ion: The fastest growing market with double-digit annual growth up to 2030
- Lead-based: It will maintain its position with single digit market growth every year until 2030

The mainstream established technologies still have innovation potential and, through to 2030, will improve incrementally in order to meet the changing and increasing market requirements in many end-user applications:

- Lead batteries with new technology branches, such as pure lead, lead-carbon and bipolar
- Li-ion batteries, because of the diversity in technologies, have a large variety of KPIs to improve

The EC's RepowerEU Plan could have an additional high impact on energy storage demand, which cannot be covered by only one technology.

Application-specific developments will further push the boundaries for the established technologies, in particular for Li-ion and lead-based technologies.

Mainstream batteries are not yet at the same level of maturity when it comes to developing a circular economy. Each technology has different R&D needs to make progress on this.

New technologies are also required. Sodium-ion room temperature batteries (Na-ion RT) represents the most promising future technology in terms of cost, raw material availability and performance.

Having different manufacturing technologies in Europe's portfolio has strategic advantages with regard to the availability of raw materials.

7.2 Recommendations

The European battery industry, represented by EUROBAT, recognises the importance of developing all battery technologies in order to maximise our contribution to Europe's decarbonisation objectives and strategic autonomy. This Roadmap demonstrates that the different battery technologies, each with their unique features and developmental potential, are complementary and key to supporting the EU's Green Deal agenda.

The presence of different battery technologies in Europe's portfolio is critical to cater to different and evolving battery uses and applications, and helps to hedge against unpredictable movements in the cost of raw and secondary materials. Putting too much emphasis on one technology would represent a strategic risk for Europe's global competitiveness, negatively affect European citizens' buying power and damage the EU industrial knowledge across key markets.

As such, Europe must strive for a level-playing field for all battery technologies as each of the complementary technologies will be needed to transform the EU into a fair and prosperous society with a modern, resource-efficient and competitive economy with net-zero emissions by 2050. A fit-for-purpose legislative framework is needed to promote a strong and sustainable European battery supply chain.

In particular, the Batteries Regulation proposal, the reviews of the End-of-Life Vehicles Directive, REACH Regulation and Waste Shipment Regulation, the Corporate Sustainability Reporting Directive and the Corporate Sustainability Due Diligence Directive, and other proposals in the Fit for 55 package need to be coordinated to promote regulatory visibility.

Future EU R&D public funding activities should be spread more equally among the different technologies by targeting applied research on different applications. Today, battery technologies are still competing or are complementary in different market segments and Europe will benefit if it leaves the door open for all technologies to be able to maximise their market innovations.

8

Technical Annex

The Technical Annex to the Roadmap 2.0 provides the reader with more detailed background on the mainstream and future battery technologies and their potentials for improvement for each application addressed in the roadmap.

Source references

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(9) Energy solutions for Off-grid applications, Dena 2017

Authors

EUROBAT TF Innovation experts

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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