European Commission

BATTERIES EUROPE

Strategic Research Agenda for batteries

2020

EUROPEAN **TECHNOLOGY** AND **INNOVATION** PLATFORM

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EXECUTIVE SUMMARY

In Europe, within this decade, where it is technologically and economically viable, **everything that can be electrified will be electrified,** thus making battery technology one of the most important key enablers for the green energy transition facilitating existing and new technologies. Applications will vary widely from most vectors in the transport sector (including: electric bikes, scooters, motorcycles, passenger cars, vans, trucks, buses, boats, ships, trams, heavy duty machinery, robotics, drones and currently unseen vectors), to battery energy storage technologies supporting and strengthening the power grid to facilitate greater intermittency. The energy transition is vital to significantly reduce GHG emissions. *Globally the transportation and power sectors contributed to, respectively, 16% and 23% of global emissions worldwide in 2017.* In the European Union, emissions from transport are considered to be approximately 25%, with 60% of this from light duty vehicles. *By enabling electrification of transport and the use of renewables as a reliable source of energy, the use of battery technology has the enormous potential to reduce global emissions by roughly 30%*[1] *by 2030 in addition to contributing to numerous UN Sustainable Development Goals.*

However, the pace of this disruptive energy transition depends partially on the availability of battery cells, currently procured in large quantities as commodity components from Asia. Indeed battery-powered systems change the value proposition for Battery Electric Vehicle (BEV) applications made in Europe, where the battery is a high value component which currently represents approximately 30% of value creation. This is also true for other battery powered applications. It is particularly important that Europe significantly ramps up production of batteries for the automotive sector to ensure the continued economic sustainability of this sector which currently employs 13.8 million Europeans either directly or indirectly and representing 6.1 % of total EU employment[2]. Furthermore, environmental sustainability must be at the heart of European battery production, so to address the ambitions of the green energy transition.

Research and Innovation are a major cornerstone to building any lasting competitive technology-based industry, and is necessary to gain competitive advantage, sustainability and to develop the necessary expertise and skills sets to take products and processes from concept to market readiness. With the urgent need to set up large scale battery cell production in Europe, comes **the requirement to immediately prioritise battery research, with a holistic approach across the entire battery value chain** supported from all relevant stakeholders including European, National and Regional R&I funding agencies. **Investments in battery research and associated research infrastructure must be both significant and continuous over time, covering both short-term and long-term research priorities**. To be competitive internationally, Europe will need cutting edge research, from concept to product to market introduction, improving **sustainability, reducing costs and ensuring high quality and safety** of products and processes. Failure to invest in research, development, as well as **skills & training**, immediately risks a detrimental effect not only to our fledgling domestic battery industry but also to the many connected industries including the automotive sector.

Within this Strategic Research Agenda, the experts of Batteries Europe ETIP have clearly identified the key topics which must be addressed across the entire battery value chain and the urgency with which these topics need to be addressed. In addition, Key Performance Indicator tables have been prepared which detail current performances and the key performance targets expected within specific

[1] World Economic Forum Report
http://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf
[2] EU Commission
https://ec.europa.eu/growth/sectors/automotive_en#:~:text=The%20automotive%20industry%20is%20crucial,of%20EU%20employment%20in%20manufacturing

timeframes. These targets are subject to variation and will be highly dependent on the level of research, investment and commitment by all parties in the battery R&I ecosystem.

To support the **upcoming short-term needs of the battery industry, it is imperative that generation 3 (optimised Li ion), then generation 4a (solid state Li ion) and generation 4b (solid state Li metal) are addressed now**, with a view to having new differentiating European battery technology on the market from 2025. The applications of these battery chemistries will also be variable and tailorable from high power to high energy requirements thus boosting the variety of industries which can be supported by break though research on these generations of battery chemistries. It is especially important to focus on both materials and cell manufacturing to enable effective and cost competitive upscaling. Battery manufacturing is one specific part of the value chain to which extra research efforts must be focused as this is currently a significant weakness in Europe.

Simultaneously, it is important that a high level of continuous research is focused on longer term ambitious research goals, so Europe maintains market leadership to 2030 and beyond. The European battery industry will need to make continuous advancements to satisfy customer demands, and to facilitate new applications beyond todays scope of knowledge. New concepts and new battery chemistries beyond generation 4 need to be explored focusing on performance, cost and sustainability of batteries (and ethical sourcing), including their production and afterlife. This requires a steady stream of innovation. Furthermore, the development of game changer innovations for the battery industry can be envisaged, however such innovations are born out of well-established and coordinated research environments in which extensive competence is build up over years.

One of the primary differentiators for batteries produced in Europe will be sustainability, with a low carbon footprint and optimised circular economy approach in all steps of the value chain. Research will address economic, social and environmental sustainability to provide a holistic understanding to the impact of innovations from material extraction & processing, cell & battery manufacturing, use, end of life second use and recycling. Sustainable battery technology will be strongly supported by the EU regulatory framework. In order to fulfil a circular economy approach to battery technology, active research on sourcing, extraction and processing of both primary and secondary raw materials is necessary along with an approach to materials traceability. Furthermore, in the context of a growing battery industry and increased manufacturing in Europe, research on new closed loops and recycling technologies are needed.

Batteries Europe considers that a **cross-cutting enabling role will be played by digitalisation** which provides a host of opportunities to significantly accelerated developments across the battery sector from accelerated materials discovery to optimised cross sectorial use of battery systems to support the energy grid. **Digital twins and big data analytics** will be crucial for the advancement of battery managements systems (BMS), battery materials traceability, manufacturing, 2nd life applications and recycling and hence will play an essential role also for mobile and stationary applications.

Strong Coordination will be essential if Europe is to meet its ambitious goals of establishing a large scale competitive battery industry supported by world leading research which is relevant, timely and impactful as set out in this Strategic Research Agenda. All relevant stakeholders including industry, research providers, universities and supporting networks and agencies in Europe will need to continue and intensify their work together focusing research efforts on effective value creation and communicating successfully advancements and further research needs via participation in Batteries Europe and related initiatives.

ACKNOWLEDGEMENTS

Batteries Europe ETIP is only made possible by the participation of its many experts. We wish to acknowledge the huge efforts that have been put in to producing both the Strategic Research Agenda (SRA) and related documents. In particular, we wish to acknowledge the dedication and perseverance of the Working group leaders and the Task Force leaders in the preparation of this document along with the guidance and input of the governing board. Finally, we wish to thank the European Commission for the support of the Batteries Europe ETIP under Tender **ENER-2018-453-A7**.

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INTRODUCTION

Batteries Europe is the European Technology and Innovation Platform (ETIP) dedicated to the entire battery value chain. It brings together all key stakeholders from the public and private sectors namely industry, start-ups, research providers and academia from all over Europe, and national and regional representatives in addition to relevant representatives from the European Commission. The Batteries Europe platform is supported by the European Commission and participating experts/members do not pay a membership fee to participate. The ETIP has a holistic and scientific approach to identifying the R&I needs across the entire battery value chain.

The Batteries Europe SRA has been elaborated with the involvement of approx. 500 experts in 6 different working groups and 4 different task forces, including upstream and downstream elements in the value chain representing Industrial stakeholders, Research and Technology providers, Universities and Policy/Regulatory authorities. The work has been carried out during Spring and Summer of 2020 in a host of telco meetings with the backdrop of the Covid-19 global pandemic. The work identified both the long-term and short-term R&I needs for Battery technology.

The Batteries Europe SRA, starting point looks at the forthcoming needs and the required research to enable multiple end users in a variety of sectors from stationary storage to a variety of transport modes. This is followed by addressing needs within battery manufacturing of cells and systems and advanced materials through to the areas of sustainable raw materials processing and to identifying the research efforts required to develop and support efficient, sustainable, and safe recycling. The SRA also addresses the important area of New and Emerging technologies in which Europe's top experts indicate the most promising and innovative battery chemistries, which can be the key to the European competitive edge in the future. The Batteries Europe SRA also draws the attention of the reader to transversal aspects including skills and education, safety, sustainability, and digitalisation and describes the necessary actions required to address these areas. This is essential to ensure a thriving battery R&I ecosystem.

The Batteries Europe ETIP SRA is a tool to be utilized collectively by the European Commission, the National Member States and industry when developing their research programs. It provides a holistic view and scientific guidance, including current and target key performance indicators.

Batteries Europe ETIP collaborates closely with all other European initiatives and in particular those under the umbrella of the European Battery Alliance, with each initiative having a distinctive yet complementary role. The ETIP also has a close link to the Battery Partnership with key members of Batteries Europe involved in the establishment and work of the Battery Partnership which ensures clear consistent communications and alignment. The Battery Partnership is a public private partnership with the European Commission, which focuses on supporting the battery industry via the Horizon Europe framework research program. While Batteries Europe has a broad platform and takes a holistic view of the battery value chain, the Battery Partnership has a narrower scope, addressing the most vital core parts of the value chain.

Batteries – A key enabler for European competitiveness and decarbonisation

1.1 Current status of the battery industry

The main contributor to the rising demand for Li-ion batteries is the electric vehicle (EV) market. The stationary storage market is also expected to experience significant growth in the next decades. The total global battery demand is expected to reach nearly 1000 GWh per year by 2025 and exceed 2600 GWh by 2030.[3] In Europe, the demand for EV batteries is expected to surpass 200 GWh per year by 2023 and reach around 400 GWh by 2028, creating at least 3-4 million jobs in the process.[4]

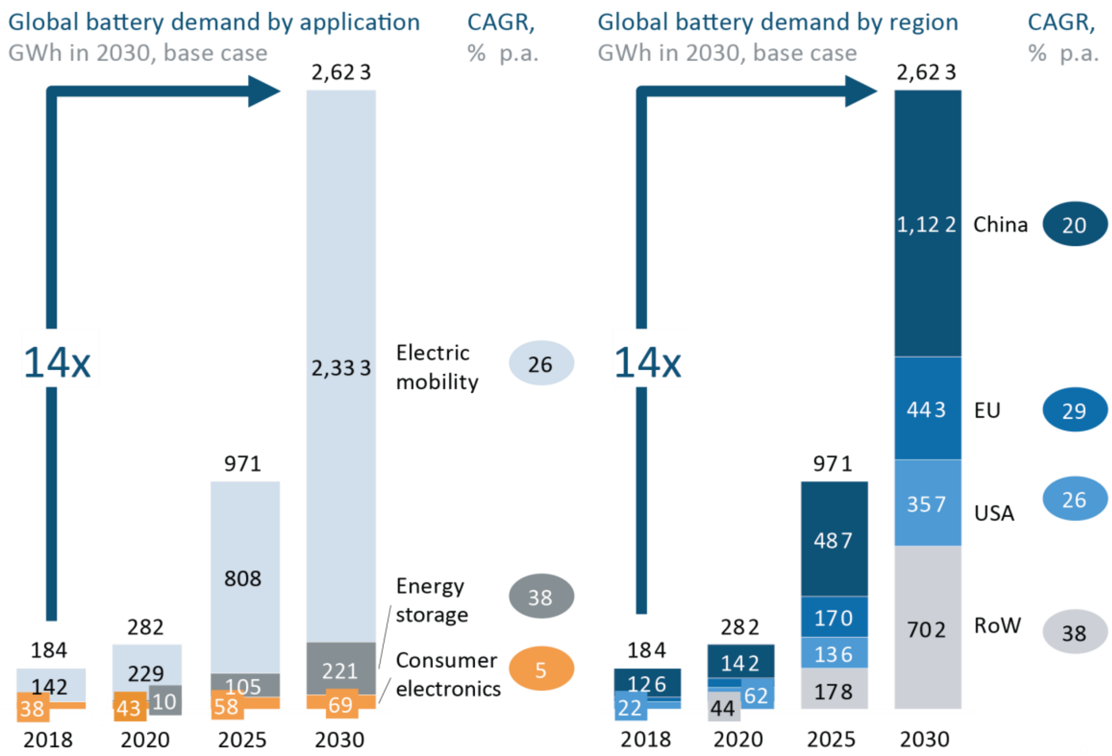

Figure 1: Current and predicted global battery demand.[3]

Expansion in EV – In 2019 about 7.2 million EVs were on the road globally, and 2.1 million of these were sold in 2019 alone, constituting a 6% growth from the previous year and a 2.6% of the total passenger car market share. Both China and the US experienced reduced EV sales in 2019, partly due to reduced purchase subsidies. In Europe, the EV sales increased by a notable 50% in 2019, achieving a new record market share of 3.5%.[5] Here, the Nordic countries, Netherlands and Portugal are leading the trend. Norway and Iceland have passed the 50% mark, while Sweden, Finland, Netherlands and Portugal have reached the 10% milestone in 2020.[6] Europe also saw an increase of more than 100% between 2018

[3]World Economic Forum, M. analysis. A Vision for a Sustainable Battery Value Chain in 2030 Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation. http://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf (2019)
[4] https://www.eesc.europa.eu/en/our-work/opinions-information-reports/opinions/strategic-action-plan-batteries-report
[5] Global EV Outlook 2020. https://www.iea.org/reports/global-ev-outlook-2020
[6] https://www.eba250.com/europes-shift-to-electric-vehicles/

and 2019 in newly registered electric buses.[7] The European growth can to some extent be explained by the implementation of new purchase incentive schemes in i.e. Germany and Italy in 2019 or early 2020.[5] However, in the long term it is expected that regulatory policies will be the main driver for further EV implementation, rather than subsidies. Europe is currently strengthening its CO_2 emissions standards, thus indirectly supporting a move towards EV.[5] To further incentivise the market, France adopted the phase-out of internal combustion vehicles by 2040s, while another 17 countries announced similar intentions targeting a 2050 timeframe.[8]

Stationary energy storage – In 2017 global cumulative installed capacity of electrochemical energy system storage was at 3.5 GWh. This is expected to rapidly increase to approximately 400 GWh by 2030 and further to 1300 GWh by 2040.[9] By 2030 it is forecasted that PV will contribute to more than half of the installed capacity, while frequency regulation, transmission, distribution and others account for the remaining.[10] The growing stationary storage market also opens up for 2nd life battery applications. However, used EV batteries will only be able to fill a small part of the market demand. [11]

Batteries for Maritime & Aviation – Globally, around 250 vessels are currently operating with batteries on-board, and over 150 more are in the pipeline.[12] Many of these vessels are passenger ferries, with the first electric ferry being launched in 2015, demonstrating the rapid transition and adaptation of battery technology in this sector. Other types of vessels are following this trend, and the first hybrid cruise ship was introduced in 2019 by Color Line, allowing for full electric operation in and out of the ports.[13]

The key limitation for implementation of electric aircrafts is the energy density. Current LiB technology allows small aircrafts with up to 4 passengers to operate distances up to 100 km. According to Rolls-Royce, “the world’s most energy-dense flying battery pack,” is currently at 160 Wh/kg.[14] This is however far from matching the energy density of jet fuels at 11,890 Wh/kg. Although new promising technologies are being developed (sodium/magnesium ions), which might reach up to 750 Wh/kg and thus enable small-scale commercial aviation, it may be another 20 to 25 years before this becomes a reality.[15]

Global battery cell production – Europe lags far behind Asia in terms of Li-ion battery cell manufacturing, and more than 90% of the world's production currently takes place in China, Korea and Japan.[16] However, there is a serious ramp-up plan of production over the next 5 to 10 years, as shown in Figure 2. It is expected that as soon as 2022, global production capacity will increase by a factor of 2.5-4, with the greatest growth rates expected for Europe reaching 8% by 2022, and servicing between 7 - 25 % of global demand by 2028. Thus, the European market potential might reach EUR 250 billion annual levels in 2025.[17]

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7 1990 new buses in 2019.
8 https://www.iea.org/reports/global-ev-outlook-2020
9 (https://publications.jrc.ec.europa.eu/repository/bitstream/JRC113360/kjna29440enn.pdf)
10 IRENA, “Electricity Storage and Renewables. Costs and Markets to 2030,” 2017.
11 H. E. Melin, “The Lithium-Ion battery end of life market - a baseline study,” Global Battery Alliance, 2019.
12 DNV-GL Alternative Fuel Insight’. https://afi.dnvgl.com/
13 https://www.colorline.com/about-us/worlds-largest-plug-in-hybrid-ship
14 https://cleantechnica.com/2020/01/29/rolls-royce-claims-its-latest-electric-airplane-battery-has-the-highest-energy-density/
15 https://www.vox.com/2019/3/1/18241489/electric-batteries-aircraft-climate-change
16 https://publications.jrc.ec.europa.eu/repository/bitstream/JRC113360/kjna29440enn.pdf
17 https://ec.europa.eu/commission/sites/beta-political/files/report-building-strategic-battery-value-chain-april2019_en.pdf

1.2 Batteries made in Europe

1.2.1 Current status of the European Battery Manufacturing

The European automotive industry is driving the demand for batteries which today is the fastest growing market in the world for plug-in vehicles. Strong strategic alliances along the value chain between OEMs and Battery producers has resulted in ongoing construction of two fully European Gigafactory's for battery cell production namely Northvolt Ett in Sweden and MES HE3DA factory in Czech Republic. In addition, leading Asian and US companies (Tesla, LG Chem, CATL) are following their European customers and investing in production capacity in Europe. The European Battery Alliance reports that there are a total of 25 announced projects on Li-Ion factories in Europe ranging from pilot plants to Gigafactory's which if realised will add a total of approximately 500GWh production capacity for Europe by total in 2030. An overview of these initiatives, the estimated start date and planned production capacity are highlighted in Figure 2. It is foreseen that Europe will have a 16% share of the 2550 GWh global battery market by 2029 compared to just under 6% of todays 450 GWh.[18]

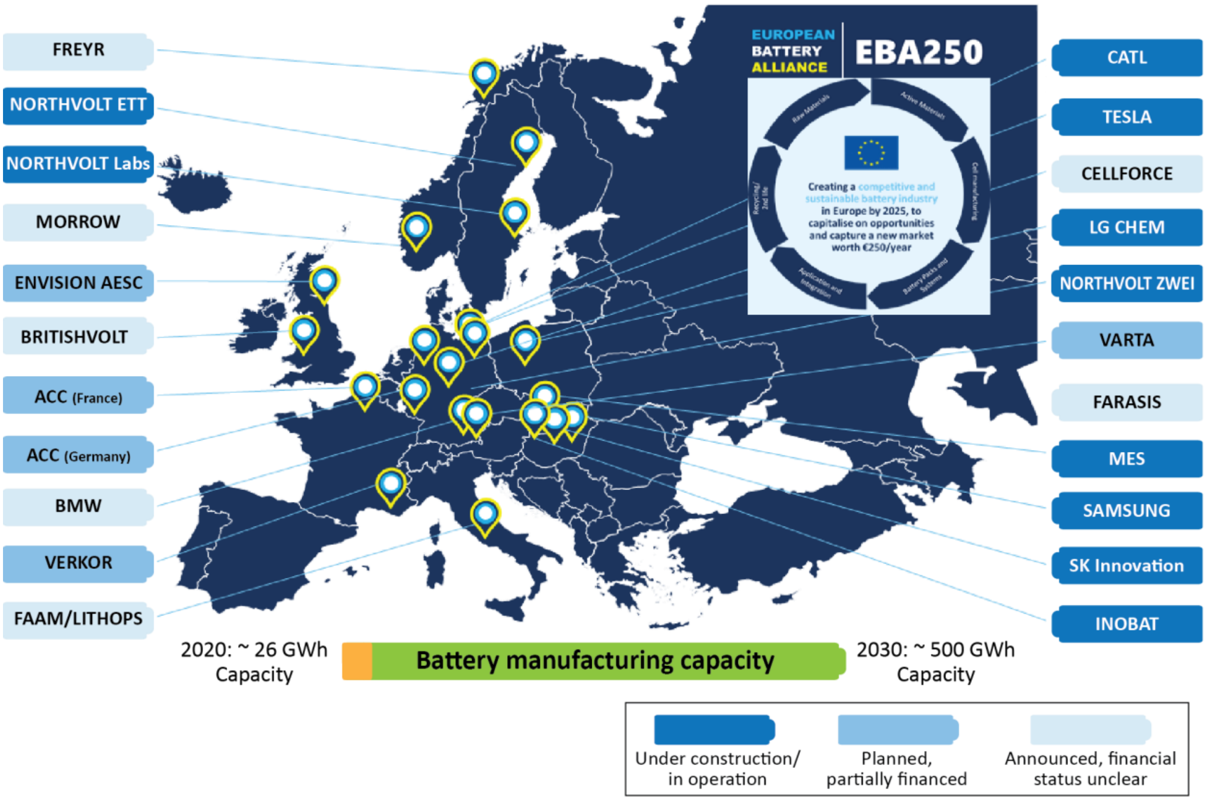

Figure 2: Planned Li ion Battery factories in Europe[19]

[18] Benchmark Minerals, May 2020
[19] European Battery Alliance, 2019

Details for Figure 2:			
FREYR	Announced, planned start 2023, up to 32 GWh	CATL	Start 2022, up to 70 GWh
NORTHVOLT ETT	Under construction, Start 2021, up to 40 GWh	TESLA	Start 2021, up to 40 GWh
NORTHVOLT Labs	In operation, 0,5 GWh	CELLFORCE	Announced, up to 1 GWh
MORROW	Announced, planned start 2021, up to 32 GWh	LG CHEM	Start 2018, up to 64 GWh
ENVISION AESC	1,9 GWh in operation, planned ramp-up to 32 GWh	NORTHVOLT ZWEI	Start 2021, up to 20 GWh
BRITISHVOLT	Announced, planned start 2023, up to 30 GWh	VARTA	IPCEI project, start 2021, pilot plant
ACC (France)	IPCEI project, Start 2021, up to 24 GWh	FARASIS	Announced, up to 15 GWh
ACC (Germany)	IPCEI project, Start 2021, up to 16 GWh	MES	Start 2020, up to 15 GWh
BMW	Start 2022, pilot plant	SAMSUNG	Start 2018, up to 30 GWh
VERKOR	Start 2023, 16 GWh with plans to ramp-up to 50 GWh	SK Innovation	Start 2021, up to 18 GWh
FAAM/LITHOPS	Announced, 200 MWh	INOBAT	Start 2021, up to 10 GWh

There are also considerable European investements along the entire battery value chain from raw materials, active materials, cells, packs and integration through to recycling. Many materials companies are in the process of further developing and up scaling their battery materials production processes.

In summary, Europe sees investments along the entire battery value chain and has the highest global growth in battery cell production capacity.

1.2.2 A new regulatory framework for batteries

The European Commission will publish its proposal for a revision of the Battery Directive 20006/66/EC) before the end of this year. A rapid growing battery industry in Europe with new battery technologies, applications and sustainability requirements, to use and recycle batteries proved the need to update the current regulation. Already in the Strategic Action Plan on Batteries (2018) the European commission announced its intention to design an innovative and future-proof regulation, covering the entire value chain. This has been followed by the Green Deal communication that aims to deliver a legislative proposal in support of the Strategic Action Plan on Batteries and the circular economy within 2020.

Through an assessment of the current situation a number of measures, along the value chain (Figure 8) have been identified. The proposed measures are currently undergoing an impact assessment. If not carefully designed some of the measures might have an impact on future R&I topics and it is therefore paramount to secure technological neutrality and innovation for future technologies.

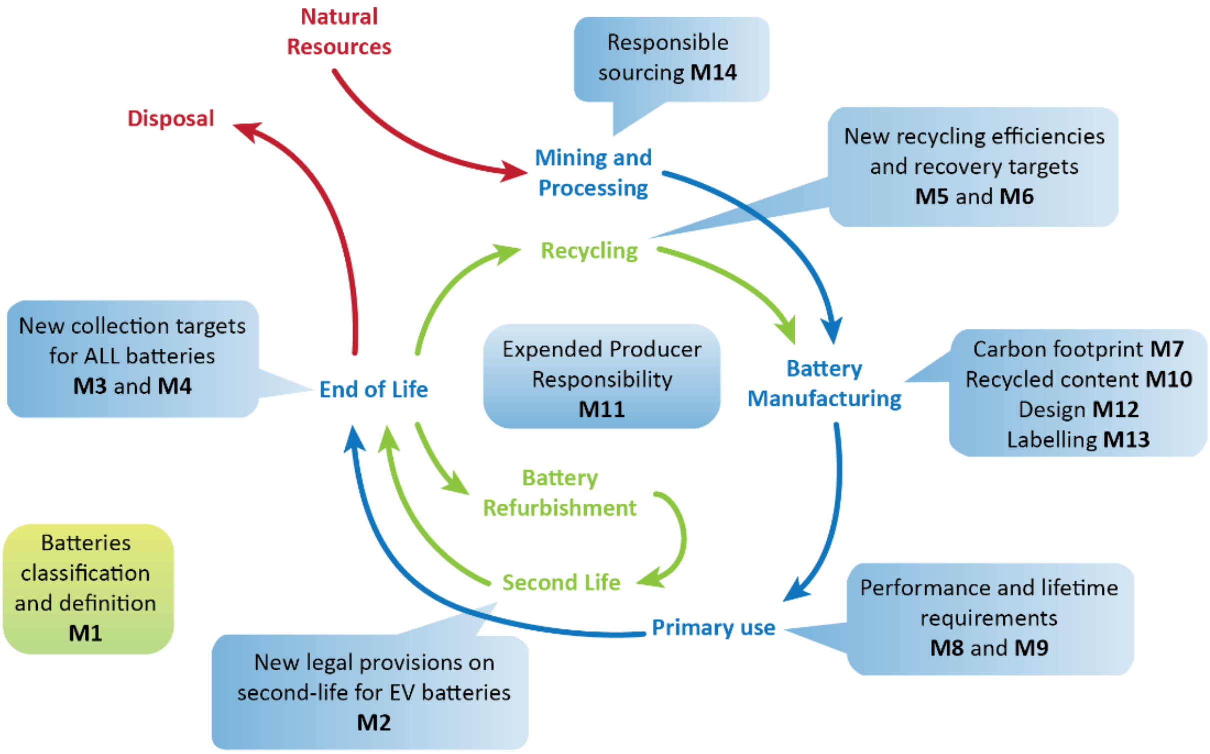

FIGURE 3: A NEW REGULATORY FRAMEWORK FOR BATTERIES -POTENTIAL MEASURES TO BE TAKEN AS HIGHLIGHTED BY THE COMMISSION

The creation of a Battery Passport: To avoid inefficient separation, it is suggested to introduce standardized labelling systems for all Li-ion batteries. Labels (or international accepted serial number system, or barcoding or QR coding) should enable fastest possible automated sorting and provide necessary data for all battery handling parties, including collectors, refurbishments centres or recycling facilities. Data such as battery type, chemistry, raw materials content, weight, dimensions, voltage, capacity, manufacturer etc. should possibly be coded into the label which could be somehow connected with battery passport database which is under consideration between battery industry and EU authorities.

This would significantly support efficient SoH diagnostics and 2nd use stream separation and, perhaps most importantly, accurate separation of batteries according to their chemistries and composition before further recycling treatment.

1.2.3 Vision for the European Battery Industry

Battery technology will be a key enabler for the green energy transition and by 2050, it is not unreasonable to expect that most major transport modes will be electrified. In addition, the share of renewable energy technologies and patterns of use will require the utilisation of electrochemical energy storage. Europe is expected to have a considerable share of the global battery cell manufacturing market and this will result in a ripple effect supporting industries along the value chain. This will create and secure employment throughout the member states and contribute both considerable reduced carbon emissions and improved the security of energy supply in Europe. In order for Europe to build up a leading battery manufacturing industry, extensive research and education involving the entire value chain is imperative.

1.3 Why battery research matters

The market for batteries is growing exponentially, driven globally by both societal and governmental goals to implement the green energy transition. In this highly competitive market environment with huge growth potential, only the most cost competitive and sustainable solutions will achieve market acceptance. While we are witnessing growing uptake of batteries in the automotive sector it is well know that cost reduction and improved performance are necessary to drive down costs, this requires intensive research. Furthermore, there are a host of new potential applications for which batteries have been identified as a potential solution, however, to make this a reality, batteries fit for purpose must be developed.

It is also crucial to ensure that battery technology is a truly sustainable solution.

R&I is needed to provide the European industry with the required technological advances along the value chain:

- to achieve best-in -class performance with lowest cost
- to offer sustainable product solution with a differentiating low carbon footprint
- enabling manufacturing of cells, batteries and systems in high-volume, high efficiency, automated, digitalized industrial processes
- enabling manufacturing and recycling industries to scale up to the needed volumes
- to create and develop fit for purpose battery technology to enable new applications
- to create a workforce with the necessary skills along the full battery value chain as well as excellent scientists

Research and Innovation will be imperative to provide the European battery industry with competitive advantage enabling both sustainability and competitiveness simultaneous.

1.4 Overview of European Battery Research Landscape

The availability of high-performing and sustainable batteries is a prerequisite to achieve a successful transition to a fossil-free society. The need for efficient batteries – for transport, power and industrial applications – is growing fast and at an increasing pace.

A European battery production is therefore a strategic imperative for both the clean energy transition and Europe's competitiveness. Moreover, the European Commission's industrial policy strategy' goal is to make the EU the world leader in innovation, digitalisation and decarbonisation and to create resilient strategic value chains.

To address this industrial challenge in a coordinated manner, the European Commission launched, in October 2017 the European Battery Alliance. The various initiatives, networks and projects working under the umbrella of the European Battery Alliance are shortly described in the following paragraphs.

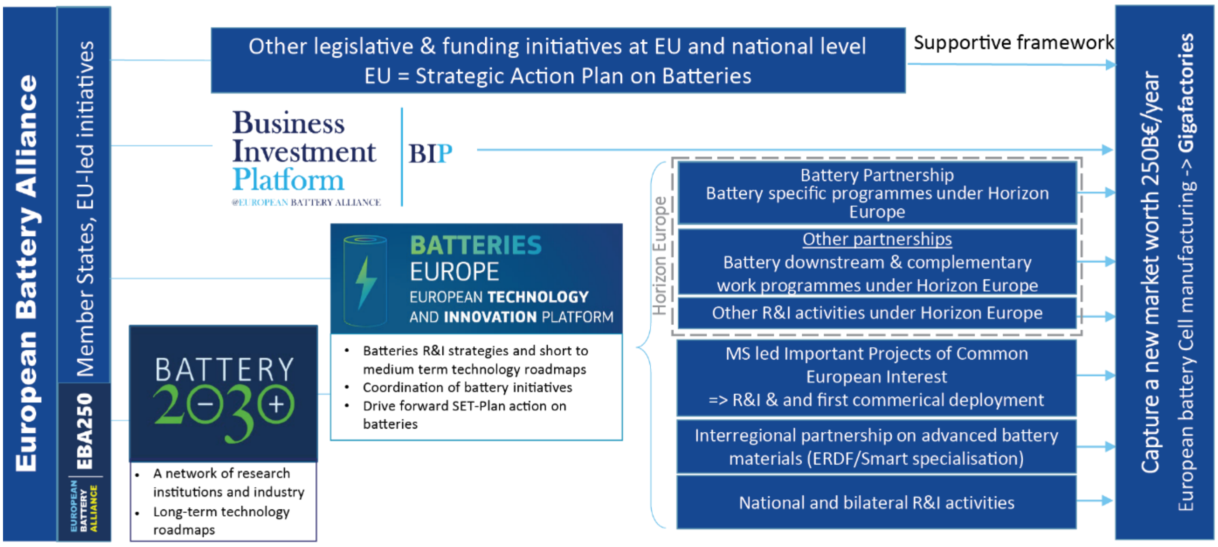

FIGURE 4: OVERVIEW OF THE EUROPEAN BATTERY ECOSYSTEM UNDER THE UMBRELLA OF THE EUROPEAN BATTERY ALLIANCE

The European Battery Alliance:

To reach the goal of capturing a market worth 250B€/year by creating a competitive and sustainable battery cell manufacturing value chain in Europe, European Commission Vice President Maroš Šefčovič launched in October 2017 a collaborative strategy, the European Battery Alliance (EBA). The immediate objective of the EBA was to create a competitive manufacturing value chain in Europe with sustainable battery cells at its core. By combining European cutting-edge competences, financial strength and a cross-industrial approach, a competitive and sustainable production capacity is clearly within reach, even if more needs to be done to accelerate this development. The Commission works on developing future-proof regulations and standards for batteries produced in and imported to Europe. The need to foster research and innovation in the field of batteries to achieve the objectives identified is acknowledged by policy-makers, industrial partners and research centres alike.

Industrial initiatives and networks under the European Battery Alliance:

EBA250

EBA250 is the industrial workstream of the European Battery Alliance. This cooperative ecosystem with more than 500 members gathers the European Commission, interested EU countries, investment institutions and key industrial, innovation and academia stakeholders. EIT InnoEnergy has been trusted by the European Commission to drive forward and promote EBA250 activities, acting as network manager and project facilitator.

Business Investment Platform, EBA BIP

The Business Investment Platform, EBA BIP, has been developed by EIT InnoEnergy, together with financial institutions – public and private – and several core industrial partners with the purpose to enhance the robustness of the investment cases along the entire battery value chain. It is estimated that a total of 70B€ of frontloaded investment in batteries is required to meet peak European demand by 2023. The objective of the BIP is to bridge the gap between investors and investees by reducing business and investment risk thereby accelerating transactions between investee and investor. Investments are typically in the >€5.0bn range.

Research and innovation initiatives under the European Battery Alliance

Batteries Europe ETIP

A European Technology and Innovation Platform (ETIP) are generally recognised as key industry-led communities to develop and implement the SET Plan R&I priorities, with the aim to foster innovation in low-carbon energy technologies and bring such new technologies to the market. They provide consensus-based strategic advice on the SET Plan covering technical and non-technological aspects (e.g. innovation barriers, need for specific research activities, potential for international and interregional cooperation and education) and addressing linkages with other sectors in view of increased system integration. European Commission launched in 2019, the European Technology and Innovation Platform on Batteries, Batteries Europe. The platform was created to accelerate the establishment of a globally competitive European battery industry, driving the implementation of battery-related research and innovation actions of the Strategic Energy Technology (SET) Plan and the Strategic Transport Research and Innovation Agenda. This Strategic Research agenda takes a holistic view of the requirements for research across the entire Battery value chain and is one of the key outputs of the Batteries Europe ETIP. Batteries Europe has a federating role in the battery R&I ecosystem and is closely working together on interdisciplinary and overlapping issues with other R&I platforms, such other ETIP's as well as upcoming partnerships under Horizon Europe, to ensure R&I processes on a high level of expertise and a continual knowledge transfer. Through its national and Regional Stakeholder Group it also serves as an information platform between member states and national projects.

BATTERY 2030+

Investments in disruptive new knowledge and technologies are essential for inventing the sustainable batteries of the future and will give benefits to European industry both in the short and long-term. To address this challenge, the European Commission launched Battery 2030+. The large-scale research initiative BATTERY 2030+ is an ambitious European programme for long-term research on ultrahigh-performance, sustainable, and batteries with smart functionalities. The initiative aims to continuously provide European battery industry with new tools and breakthrough technologies. By gathering high standing researchers within academia, institutes and industry across Europe in a collaborative effort, the initiative focuses on research areas that will transform the way Europe discover and develops new battery technologies. The long-term vision and approach of BATTERY 2030+ complements well more short term initiatives and the content is described in the BATTERY 2030+ roadmap[20].

Batteries IPCEI's

To further accelerate the upscaling of pre-commercial projects along the battery value chain the Commission launched a call for IPCEI's in the battery field in 2019. An Important Project of Common European interest is a tool to support research and innovation in the battery value chain project under specific EU State aid rules. The rules have a specific provision for Member States to fund disruptive and ambitious research and development, as well as the first industrial deployment of the technology in case of market failure. In order to qualify for support under the IPCEI Communication, a project must fulfil several criteria. One of those criteria is to contribute to strategic EU objectives. The clear overall strategy for batteries (Commission Action Plan) was a prerequisite for a speedy assessment and adoption of the two Batteries IPCEI's that now are under development under the lead of DG COMP.

In the beginning of December 2019, the European Commission approved a first IPCEI on batteries. The project has a funding capacity of up to €3.2 billion, was jointly notified by Belgium, Finland, France, Germany, Italy, Poland, and Sweden. The integrated project comprises 4 workstreams covering the

[20] BATTERY 2030+, *Inventing the sustainable batteries of the future – Research needs and future actions* (2020). https://battery2030.eu/digitalAssets/860/c_860904-l_1-k_roadmap-27-march.pdf

battery value chain, namely raw and advanced materials, cell and modules, battery systems, repurposing, recycling and refining.

The Battery Partnership

Given the rapid growth of the Battery sector in Europe and in the world, the implementation of recommendations and inputs provided by Batteries Europe and the other platforms, the European Commission decided to propose a European Partnership on Batteries with the objective to propose concrete R&I actions for Horizon Europe.

Other Related R&I Platforms

All together, these battery related platforms will collaborate together and with other relevant platforms (ETIP SNET, 2Zero, Waterborne etc…) to build a coherent and comprehensive R&I ecosystem in Europe willing to support a competitive and sustainable European Battery value chain in line with Green Deal objectives.

Initiatives addressing Skills and Education under European Battery Alliance

LiPlanet

LiPlanet is Coordination and Support Action under Horizon 2020 that was established in 2020 with the overall objective to create a European innovation and production ecosystem and reinforce the position of the European Union (EU) in the Li-ion cell manufacturing market. This will be achieved by forming a network of Li-ion cell pilot lines integrating industrial stakeholders. The LiPlanet will aaccelerate innovation, create synergies, favour collaboration with the industry and academia and further the production of battery cells towards industrial scale in the EU and thereby increase the basis of trained experts.

ALBATTS

The Alliance for Batteries Technology, Training and Skills (ALBATTS) is a 4-year program under the Blueprint for Sectoral Cooperation on Skills with the purpose to gathers demand and supply sides of competences in the battery value chain. The project started 2020 and is co-funded by the Erasmus+ programme. ALBATTS aims at developing strategic solutions for the battery and electromobility sector through identification of skills needed, developing adapted or new VET opportunities, building business-education-research partnerships and promoting agreements on the recognition of sectoral qualifications and certifications.

There are also other initiatives supported by the European Commission to enhance the training of master and PhD students: some examples are the Marie Cure MESC program and the newly established co-fund program DESTINY just to mention some of the rich flora of training schemes.

Each of these bodies and initiatives has an independent and necessary role in the Ecosystem. All of them allow to cover industry needs to build a competitive, innovative and sustainable value chain and also to cover the short, medium- and long-term priorities to become world leader and to keep its leadership in the sector.

1.5 Batteries Europe ETIP Scope

The Batteries Europe ETIP is supported by a Secretariat that coordinates the work of six thematic Working Groups, populated by European battery research experts from industry and Academia. Furthermore, the ETIP hosts a National and Regional Coordination Group (NRCG) which provides a communication forum between Member States and Associated Countries, which reduces the duplication of research efforts and results in synergetic effects. The executive branch of the Platform is represented by its Governing Board, composed of industry and research members and is chaired by Saft.

The ETIP Batteries Europe has its roots in the work done within the SET Plan Implementation Plan - action 7, and most of the experts from the SET Plan Temporary Working Group are now strongly involved in the ETIP. The platform is tasked with creating this European Strategic Research Agenda (SRA) along with corresponding Research Roadmaps covering all parts of the battery value chain, in addition to facilitating a unique forum for addressing cross-cutting topics such as education and skills, sustainability, safety and the role of digitization in battery technology.

Batteries Europe is a major hub for European collaboration and information exchange for battery research in Europe, working towards a sustainable, competitive, and self-sufficient value chain and is a natural place to for different initiatives to interconnect proactively and create synergies.

1.6 Implementation of the Integrated SET Plan

In the SET plan, Europe has declared its renewable energy ambitions. With its implementation plans it provides a framework to accelerate the development and deployment of cost-effective low carbon technologies. A specific Implementation Plan for batteries 21 was prepared and published by the Temporary Working Group (TWG) on Action 7 and has been followed up and operationalised largely through prioritised of R&I activities in the European Horizon Framework program. Through its annual reporting of ongoing activities on EU as well on national level it also helps identifying topics that needs special attention and helps avoiding duplication of research efforts. Cooperation is crucial if Europe with limited resources for research is to become and stay competitive in the battery value chain.

The implementation of the SET Plan is followed up with a number of target ambitious key performance indicators. The targets are differentiated into performance, cost and manufacturing targets for lithium-ion batteries and future technologies for use in automotive and stationary storage applications. A number of non-quantifiable targets (safety, reduction in the use of critical materials, reduced environmental impact etc.) have also been identified.

Key Performance Indicator tables can be found in Chapter 8.

1.7 Categorisation of Battery Technology

Battery research and development covers a diversity of cell chemistries and how to enable their successful implementation. A categorisation of the different classes of Li based battery chemistry was

[21] https://setis.ec.europa.eu/sites/default/files/set_plan_batteries_implementation_plan.pdf

introduced by the German National electromobility platform22 and subsequently by the European Commission's Joint Research Centre (JRC)23. Further classification is detailed in EMIRI Roadmap (2019)24. This categorisation system is regularly referred to throughout this document. Below Table 1 provides an overview of the categories.

TABLE 1: BATTERY GENERATIONS CATEGORISATION

Battery Generation	Electrodes active materials	Cell Chemistry / Type	Forecast market deployment
Gen 1	• Cathode: LFP, NCA • Anode: 100% carbon	Li-ion Cell	current
Gen 2a	• Cathode: NMC111 • Anode: 100% carbon	Li-ion Cell	current
Gen 2b	• Cathode: NMC523 to NMC 622 • Anode: 100% carbon	Li-ion Cell	current
Gen 3a	• Cathode: NMC622 to NMC 811 • Anode: carbon (graphite) + silicon content (5-10%)	Optimised Li-ion	2020
Gen 3b	• Cathode: HE-NMC, HVS (high-voltage spinel) • Anode: silicon/carbon	Optimised Li-ion	2025
Gen 4a	• Cathode NMC • Anode Si/C • Solid electrolyte	Solid state Li-ion	2025
Gen 4b	• Cathode NMC • Anode: lithium metal • Solid electrolyte	Solid state Li metal	>2025
Gen 4c	• Cathode: HE-NMC, HVS (high-voltage spinel) • Anode: lithium metal • Solid electrolyte	Advanced solid state	2030
Gen 5	• Li|O_2 – lithium air / metal air • Conversion materials (primarily Li|S) • new ion-based systems (Na, Mg or Al)	New cell gen: metal-air/ conversion chemistries / new ion-based insertion chemistries	>2030

[22] A Roadmap for an integrated cell and battery production in Germany (*Roadmap integrierte Zell-und Batterieproduktion Deutschland) - Nationale Plattform Elektromobilität, Jan. 2016*

[23] Steen, M., Lebedeva, N., Di Persio, F. and Boon-Brett, L., *EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions*,EUR 28837 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-74292-7, doi:10.2760/75757, JRC108043.

[24] : EMIRI, *Advanced materials for clean and sustainable energy and mobility* (2019).

RESEARCH AND INNOVATION PRIORITIES ACROSS THE BATTERY VALUE CHAIN

The Strategic Research Agenda is built based on an approach which first looks at the research requirements of the applications of batteries, as these demands ie. desired KPIs as expressed in Chapter 3, have the ultimate ripple effect down the whole value chain. After addressing the application requirements, the research required for manufacturing and advanced materials developments are addressed in Chapter 4 followed by the research needs with respect to raw materials in order to ensure a circular economy approach in Chapter 5. This chapter also considers recycling. In Chapter 6, the longer-term perspective is addressed, which details what research topics are key to ensuring the development of a competitive edge in the long term. Chapter 8 provides KPI tables with current state-of-the-art values and target KPIs which were developed by both the participants of Batteries Europe in collaboration with other relevant stakeholders.

1.8 OVERALL KEY RECOMMENDATIONS

In this Strategic Research Agenda, details of the specific research needs, along with target KPI's across the entire value chain are indicated in chapters 3 through to 6. In addition, to these specific research needs the Batteries Europe stakeholders have identified 8 overarching key recommendation. The recommendations provided below are of equal importance and have not been weighted in any particular order.

Key Recommendation of Batteries Europe ETIP

- Urgent prioritisation of Battery Research to support the European Battery Industry
- Ensure Continuity and Amplitude of Battery Research & Innovation
- Holistic approach to supporting R&I across the Battery Value Chain
- Provision and Coordination of Battery Research Infrastructures
- Develop, support and Implement Reporting Methodologies
- European Development of International Battery Standards
- Enhance Regulatory and Policy Framework to drive sustainability and competitive advantage
- Mutual engagement of battery industry and end users to prepare for new technological advances

Urgent prioritisation of Battery Research to support the European Battery Industry

Europe is in the process of the green transition and a domestic European battery industry is essential to implement this change and create European jobs. To become and stay competitive it is imperative that Europe's battery industry leads the way. Immediate investment in the next generation (Gen 3b and 4) battery research and in addition longer-term innovation is required to ensure Europe can manufacture and upscale competitive battery technology by 2025 and thereafter remain a forerunning in the industry. Failure to invest in research, development, as well as skills-training, immediately risks a detrimental effect not only to our fledgling domestic battery industry but also to the many connected industries including the automotive sector. We strongly recommend both European and National authorities immediately prioritise and strongly support next generation as well as long-term battery research and innovation to ensure the industry remains in Europe.

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Ensure Continuity and Amplitude of Battery Research and Innovation

Battery research and development requiring a continuous stepwise progression from concept to commercial product maturity and utilisation. To establish long term industrial technology leadership, continuous research is a prerequisite, necessary to being technologies to maturity. Regional, National and European R&I funding providers, grant the means to the successful creation, development and deployment of new competitive technology. A continuous strategic focus on research across the full battery value chain will enable a solid foundation of knowledge essential for uninterrupted growth of the European Battery Industry. *We strongly recommend a continuous sustained, European and national strategic focus on battery research and innovation, to allow technologies to be brought from concept to maturity, ensuring full value creation is achieved and benefit realised within Europe*. In addition, it is necessary to provide financial instruments that facilitate investment in battery related start-ups, including guarantees and public investment matching and longer-term investment regardless of short-term profitability.

We strongly recommend a continuous sustained, European and national strategic focus on battery research and innovation, to allow technologies to be brought from concept to maturity, ensuring full value creation is achieved and benefit realised within Europe.

Holistic approach to supporting R&I across the Battery Value Chain

To build a strong "future-proof" battery value chain, research and innovation across the entire value chain is essential. European, Regional and National funding mechanisms are diverse with respect to TRL level development, segment of the value chain addressed and approach. We recommend European, National and Regional stakeholders supporting battery research, provide information of both ongoing research projects and an overview of their strategic focus areas in the field, in the framework of the SET Plan reporting. This will facilitate the identification of gaps in the research and any neglected topics, which if not addressed could lead to weakness in the value chain and thus a loss in industrial momentum. We recommend that research and development of all key parts of the battery chain are addressed adequately, utilising all relevant European, National and Regional funding programs.

We recommend European, National and Regional R&I stakeholders supporting battery research, provide information of both ongoing research projects and an overview of their strategic focus areas in the field, in the framework of the SET Plan reporting. Furthermore, we recommend that research and development of all key parts of the battery chain are addressed adequately utilising relevant European, National and Regional funding programs.

Provision and Coordination of Battery Research Infrastructures

Battery Research from materials discovery to building cells on pilot lines, to testing, developing charging technology and recycling requires considerable infrastructure. Meanwhile, the battery industry is in a significantly accelerated growth phase in which the development of research facilities is not a first priority. Providing the means for relevant infrastructure is necessary to facilitate the building of a strong European knowledge base, enable education and skill development, in addition to empowering cutting-edge research which will result in European competitive advantage. We recommend that national and regional authorities invest in and support the establishment and advancement of open research infrastructure for battery research within Universities and Research & Technology Organisations (RTOs). Co-innovation pilots and prototypes should drive decisions and actions for a massive deployment while still benefitting from continuous learning and sharing best practices.

We recommend national and regional authorities invest in and support the establishment, advancement and collaboration of open research infrastructures for battery research within Universities and Research & Technology Organisations (RTOs).

Develop, Support and Implement Reporting Methodologies

The benchmarking of new battery developments is very challenging due to the lack of uniform reporting methodologies used in both project reports and scientific publications. This challenge becomes even more complex in the case of new novel technologies where it is even difficult to formulate clear KPIs. Often the reporting highlights some given advantages while neglecting to report other key parameters, thus resulting in a lack of understanding of the key innovation. This frequently leads to duplication of research efforts which is both costly and time consuming, in addition to the difficulties in comparing technologies. However, this situation can be improved, in particular for technologies with a Technology Readiness Level of 4 or higher, by applying some basic reporting requirements. The Batteries Europe ETIP is in the process of developing reporting methodologies which is intended to support this action. We recommend that in the future, agencies and stakeholders which require reporting on research projects implement uniform reporting methodology requirements to facilitate comparison of results and clear definition of KPIs.

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European Development of International Battery Standards

Intensive research within Europe in the coming years will yield new battery technologies with improved properties and new applications, along with sustainable production and recycling methods. While it will be necessary to maintain a high degree of freedom and flexibility in particular in upstream parts of the value chain, there are areas in particular downstream of the value chain, where Europe would benefit significantly from developing International standards for the industry. We recommend the European Commission and Member States actively mandate the development of clear standards in applicable parts of the battery value chain to support market uptake, enhance European competitiveness and promote innovation.

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Enhance Regulatory and Policy Framework to drive sustainability and competitive advantage

Regulatory and Policy frameworks implemented both on National and European level can have a significant impact on R&I prioritisations. Careful consideration of the coincidental effects of such decisions needs to be accessed to prevent the stalling of innovation. We recommend that technologies enabling sustainability as a differentiator for batteries made in Europe are strongly supported. Policy and Regulatory frameworks should drive research towards sustainable solutions especially in the case of raw materials and recycling while ensuring this simultaneously provides economic advantage for European industry. Additionally, the clear definition of terms is vital to the understanding and interpretation of Regulation and Policy. We recommend consultation between regulators, policy makers and a wide range of battery stakeholders, in order to anticipate potential impacts and create clear definitions before, during and after implementation of regulation and policy changes.

We strongly recommend that technologies enabling sustainability as a differentiator for batteries made in Europe are strongly supported. Policy and Regulatory frameworks should drive research towards sustainable solutions.

Mutual engagement of battery industry and end users to prepare for new technological advances

Significant developments are on the horizon for battery technology as is indicated in the target KPI's set out in this document. These advancements will enable battery integration in many technologies where it is not optimal or even imagined today. An open dialogue will facilitate both the communication of new developments and the requirements which must be met to facilitate new applications and thus create a new market. We recommend end uses including mobility, heavy duty and stationary energy storage companies and battery industry stakeholders closely collaborate to create synergies and take advantage of new pioneering innovations in battery technology.

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1.9 Addressing Transversal Aspects

1.9.1 Skills and Education

European based companies have a rapidly growing and sustainable demand for skilled workers along the entire Battery Value Chain which must be addressed to lay the foundations of a world leading industry. According to a number of sources, estimations of the job market impact of the establishment of a 32GWh battery production facility is expected to employ between 2900 – 5800 people directly and approximately 3.7 – 7.5 times more indirectly[25].

FIGURE 9: CROSS CUTTING SKILLS OF BATTERY RESEARCH

Accordingly, it can be estimated that the educational needs in the next 5-10 years will be of several hundreds of thousands. **The development and expansion of different educational segments must be rapidly invested in and implemented**, including Academic, Professional, Vocational and Public/User segments along with measures that stimulate gender balance in all areas. This transversal approach should focus to provide a workforce with the necessary span of competencies and depth of knowledge required to elevate the European Battery Industry. The expected needs and benefits of the European Battery industry are clear, thus European education providers need to increase capacities within existing education platforms and creation of new specialized courses along the Battery Value Chain. Though **industry needs to be continuously engaged and express identified needs for reskill and upskill of current workforce.** Already there are several initiatives and projects aim at supporting the growth of competitive Battery Industry in Europe and some of them focus on Battery related education such as Alistore-ERI, EIT InnoEnergy, ALBATTS [26] and Battery 2030+.

A cross disciplinary approach is also recommended to create a large number of highly educated and qualified engineers, managers, consultants, entrepreneurs and policy makers. Education should cover five main elements as seen in **Schematic #** (Science and Technology; Integrations and Applications; Digitalisation Environment and Economics; Processing and Safety; and Social Impact). A particular key challenge is to **increase the workforce and collective knowledge on the large-scale production of batteries** which can be achieved by professional education incorporating all five main elements mentioned, and by vocational training which is important for the specific work in the Battery Value Chain. This provides an opportunity to adapt skilled workforce from non-green energy related jobs towards green energy related jobs. It is important to note that vocational education within the Battery Industry differs from other industries in terms of capital investment. Infrastructure for training facilities and necessary equipment can be particularly capital intensive, but the expected benefits are evident and tangible.

[25] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC108043/kjna28837enn.pdf
[26] https://www.project-albatts.eu/en/home

Education of the general public and policy makers is of great importance to provide a basic understanding of batteries, the major advantages of transitioning to electric-based transport and energy storage, and the basic knowledge to ensure safe operation and disposal of batteries. Based on challenges and needs, several recommendations are given in order to build up a European Battery Economy.

Currently, there is a lack of sufficient academic education in battery technology, which must be developed and implemented in the future (for instance digitalisation, circular economy, IPR, training on cells and battery packs behaviour among others). **Industry should be strongly encouraged to engage in education process more actively** by providing academic staff with concrete and pertinent manufacturing insight and offering more opportunities for internships. Additionally, **policy stakeholders need to facilitate and enable coordination efforts between industry and academia in order to adapt educational systems and curricula** to the up-coming needs of the battery industry. Lastly, **EU could create a platform for exchange of skilled personnel and programs in order to expand knowledge on ongoing or completed activities** and on Member States level **the educational system needs to be supported and the creation of cross-regional educational programs needs to be enabled.**

Proposed measures and actions will enable increased number of people with adopted qualification profiles tailored for the upcoming needs of industries along the value chain. The impact of these recommended actions can take a few years, however with proper coordination between individual MS and by expanding current programs the impact can be visible sooner. In order to implement and coordinate all actions and skills and education level, consortium supportive actions would be required to homogenize activities and all levels in different places.

A more detailed overview of the Skills and Education white paper can be found at the Batteries Europe Website [27]

2.2.2 Safety

Most research efforts focus on improving battery performance and durability; however, battery safety is paramount to ensure confidence and widespread adoption of e-mobility and electrical energy storage in our society. Battery research outcomes are increasing, and further usage-state development are quickly reached. All these advances need to be foreseen and aligned with safety protocols or processes in order to provide safe and quick solutions to the battery market. Accordingly, standardization bodies like, ISO, IEC, SAE, CEN-CENELEC, etc. provide the needed standards to proceed safely with battery solutions.

However, safety needs to be seen from the **whole battery chain perspective.** The improvement of safety at any specific level on the value chain, for example at material level, should be beneficial for all levels. Safety does not only embrace the safety of the battery product during its intended use. It must be considered in a much larger scope along the value chain of batteries, and include:

[27] See "Publications" section at https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications_en .

- Material handling, components processing, cells, modules and system manufacturing/assembly, installation of battery systems.
- Use, maintenance, repair and second life of the product in its application environment.
- Dismantling, handling, transport and storage of waste, damaged and defective batteries.

Whereas we can consider today's **battery systems have reached a good level of safety,** it must be noted that this level comes along with substantial efforts at different system levels to detect and mitigate possible hazards. Further improvements of battery safety, in particular those impacting the intrinsic safety of the electrochemical components, do not only enable even higher levels of safety, but in particular can decrease the effort, cost and risk (*)[28] related to other measures currently required to ensure battery safety.

New advances in battery technology such as solid-state batteries or batteries with aqueous based solutions, replacing flammable electrolyte or other volatile components can result in a major improvement of safety and significant impact on the cost of battery systems. Self-healing technology can serve as well to avoid dangerous degradation events. In addition, sensor technology which provides direct feedback to battery management systems can enhance safety. Novel advancements can result in fewer components, less cost and less overall risk.

Automatization of the processes and robotics might play a key role in several parts of the battery value chain such as; manufacturing, handling, transport, recycling and storage of waste and damaged or defective batteries. For example, the development of safe automatized procedures can be used to safely produce batteries, avoiding any kind of human interaction. In addition, processes to disassemble packs and modules, to identify cells suitable for 2nd life or to separate cells that have potential defects can also be automatized. The development of and automatized process for disassembly will broaden **the re-use of second life cells** in stationary applications. By implementing those procedures, the necessity for personnel in close proximity to possible dangerous situations will be decreased.

The **creation and adaptation of existing standards** to encompass the whole battery chain is of importance. At material level for example, the development of a safety assessment methodology is needed. At manufacturing level, methodologies to improve the safety management would be very beneficial, considering, for example, material nano-particle manipulation, upscaling processes and the development of safe designs. The **adaptation of the already developed standards and strategies for the battery management systems** (BMS, BTMS) needs to be continuously updated. Existing standards and management strategies should be kept updated to follow new coming technologies so to prevent critical faults by the adoption of early detection and mitigation measures for each technology. Their development has to be supported by continuous research. In addition, in order to avoid safety testing to become the bottleneck of the industry, continuous work on test protocols, to make it more appropriate and decrease tests durations, should be encouraged. All these actions would increase safety of LIBs and will accelerate the market access.

A more detailed overview of the Safety white paper can be found at the Batteries Europe Website [29]

[28] *(*) nb: any safety device or measure is linked to a risk of not being effective, e.g. failure of electronic protection, intended or unintended violation of safety procedures, malfunction of safety barriers.*

[29] See "Publications" section at https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications_en .

2.2.3 Sustainability

Sustainability in its three dimensions will be a major differentiation factor of EU battery technologies within the international competitive landscape. R&D is not only needed to achieve ambitious KPI's at product and process levels, but also to implement methods, indicators and rules across the industry to ensure the desired impact. This also needs close cooperation with policy makers to establish the adequate regulation framework to ensure competitiveness in the European industry.

Tools and methodologies to perform **environmental and social life cycle analysis (LCA and S-LCA) to quantify sustainability performance of batteries must be further developed** from a holistic perspective. R&I actions are needed to develop data sources and expand methodologies to cover to cover the broad range of sustainability aspects and ensure transparency and comparability in sustainability aspects between all types of batteries as well as other energy storage technologies. Innovation must also address the fact that sustainability is a cross cutting issue with many conflicting objectives. Multi Criteria Decision **Analysis (MCDA) can address the different dimensions of sustainability to analyse and evaluate future technologies.**

Economic sustainability

Technical R&I activities will contribute to technical development and cost decrease in battery production, as key enabler to electrification. Design and development must also consider **economic sustainability such as criticality of raw materials, recyclability, geopolitical sensitivities in material and component value chains, competitiveness related to import of battery cells, components and raw materials to Europe and development of new business models for battery applications.**

Social sustainability

R&D&I activities must also contribute to increased social sustainability in the battery value chain, **address the need for skills & training, consider use of materials and components with critical risks related to worker's rights and ethical aspects and new tools and mechanisms must be developed to ensure transparency, traceability and risk mitigation in the value chain.**

Environmental sustainability

Future research and development activities on batteries must also address environmental sustainability by **developing methodologies and technologies to optimize battery production, minimize resource and energy use and strive to achieve the lowest possible environmental footprint of batteries**. As batteries are energy intensive products, today heavily depending on fossil energy, there is a clear need to minimize use of fuels, water, chemicals and raw materials to improve environmental performance and stimulate use of renewable energy across the value chain. The technologies of today are also in many cases depending on the usage of hazardous substances. Efforts across the value chain is needed to ensure safe management of hazardous materials, substitution of hazardous materials with safer alternatives if feasible and reduction of hazardous materials where possible. The environmental performance of batteries and access to raw materials is also heavily depending on end-of-life management and recycling technologies. **Business-, social-, technical-and environmental aspects of recycling must be developed and assessed in a holistic approach, from design to end-of-life.**

A more detailed overview of the Sustainability white paper can be found at the Batteries Europe Website [30]

2.2.4 Digitalisation

Digital technologies will optimize the value that battery storage systems can bring to the energy markets, thereby enabling opportunities for new energy stakeholders, creating new jobs for the circular economy, and bring Europe to the forefront of leadership in the fight against climate change.

Digitalisation of **Europe's battery assets** will:

- enable the **sharing economy** and increase **social participation** in the evolving ownership relation between people, processes and products;
- unlock **all layers** of a highly **dynamic energy system** for energy & industries and their customer operations;
- support Europe's goal of a **battery industry** that is more **sustainable**, **safer** and less dependent on foreign-sourced **raw materials**.
- enhance the social impact for **jobs** and the **competitive edge**
- **Data intelligence** and **digital customer services** will increase exponentially with a predominant role of global IT companies. Data will have a major technical and commercial value, to create services for society and industry with added value.
- Digitalisation covers the **entire value chain** and helps to **interconnect** different **cycles**, involves complex data science models using heterogenous data from various sources and phases, while **big data** circulates across systems and processes.

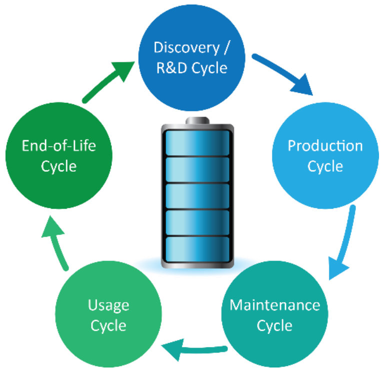

FIGURE 10: BATTERY LIFECYCLE

Digitalisation of Europe's battery assets requires **tailored digital technologies** that will enable several "use cases" across the value chain.

The development of **digital technologies** is required to improve the industrialization of new batteries and shorten the time to market. The design of **machine learning algorithms** will accelerate the discovery of materials and the development of AI orchestrated characterization of battery materials and battery cells. Combining **computer aided engineering** tools and experimental measurements will help develop understanding of and predict battery performance. The utilisation of such tools and methods will be essential for a competitive industry in Europe. **Digital Twins** can be used during the discovery, R&D, production and usage cycles to improve battery performance, lifetime, safety, manufacturability and recyclability. Big **data analytics** methods can be developed to feed the digital twins, while IoT-based data analytics improve the maintenance cycle. The **design of experiments methodologies** can benefit from digital twins to accelerate the industrialization of new batteries. Finally, the development of a **battery data infrastructure** will help each actor to access the needed information and facilitate safe

[30] See "Publications" section at https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications_en .

battery recycling. Data gathered during the usage cycle, using wireless communication technologies can provide information on performance and aging (e.g. SoC, SoH) to the consumers.

The **automated materials discovery** aims to increase the pace of development of new battery chemistries (see the BATTERY 2030+ roadmap[20]). Others will leverage the flexibility and competitiveness of European **battery cell production** by making use of advanced Industry 4.0 concepts. All stakeholders in the supply chain will benefit from a transparent and fraud-proof traceability of the full life cycle, from the raw material to the end-of-life, in form of a **digital battery passport** and **advanced SoC/SoH monitoring** based on sensors and the use of big-data analytics.

Digital interconnection of centralized and decentralized storage systems by **hybridization and multiuse of battery energy storage systems (BESS) into flexible portfolios** will be an important step towards democratized energy systems. Empowering the consumer will be a vital aspect of the new energy economy. By democratizing and expanding the battery storage sector, new demands will be generated within the market and will give rise to a new generation of innovative services and companies.

The digital initiatives ranging from managing the performance of assets and real-time platforms, to integrating energy storage and customer solutions, will **impact** strongly on **Europe's future**. Main impacts are: **value creation**, disruption in the **energy market** and forging **new jobs**.

The primary goal is to improve system flexibility and enable higher renewable energy penetration rates in Europe, by:

- Facilitating robust research, innovation, and deployment of software solutions that are required to monetize BESS by providing multi-services through the creation of flexibility pools, hybridization, and opening access to multiple energy markets.
- Ensuring interoperability through the alignment of existing standards from the utility and ICT domains, across devices/assets and systems to enable innovative BESS services.

A large stakeholder community is involved in this topic. Batteries Europe ETIP will further engage with experts from the digital European ecosystem (from industry to associations to EC DGs) to support alignment on global digital technologies development.

A more detailed overview of the Digitalisation white paper can be found at the Batteries Europe Website [31]

[31]See "Publications" section at https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications_en .

BATTERY APPLICATIONS

1.10 BATTERIES FOR MOBILITY AND HEAVY DUTY / INDUSTRIAL APPLICATIONS

Vision & Challenges for 2030

The different transport modes (road, waterborne, airborne, rail) represent together around 25% of total CO_2 emissions in the EU[32]. Significant efforts have led to efficiency improvements (for example, the average emissions from new passenger cars[33], measured in g[CO_2]/km, decreased by 30% between 2000 and 2018). However, transport demand continues to grow, and the sector remains the only one which has not been able to reduce its CO_2 emissions (the EU transport emissions have increased by around 20% compared to 1990 levels, while the EU total emissions have decreased by around 20% in the same period). Decarbonizing the transport sector is therefore a crucial issue, which can be addressed by several complementary technology options, including batteries, hydrogen, synthetic fuels and sustainable biofuels[34], next to measures for overall efficiency improvement.

One of the main advantage of batteries is the very high energy efficiency of battery electric transport modes, up to 75%[35]. Batteries are playing an increasingly important role for decarbonizing light-duty transport[36] (in particular, passenger cars and vans, which represents around 50% of current EU transport sector CO_2 emissions). Batteries can also contribute to the decarbonisation of heavy-duty transport (trucks, trains, ships, planes, etc.) and non-road mobile / industrial machinery (construction, agriculture, mining, etc.). However, batteries suffer from a much lower energy density than gas or liquid fuels[37]. Therefore, for heavy-duty or long-distance transport, batteries will mostly be used in hybrid power sources.

It should be noted that integrating batteries into vehicles will not only enable the deep decarbonisation of the transport sector, but will also play a major role to support the shift towards more renewables in the power sector thanks to vehicle-to-grid energy storage.

In this context, research and innovation in the field of batteries for transport applications is strongly needed. The application requirements, hence the battery key performance indicators (KPIs), vary from one application segment to the other; hence the KPI tables (see Chapter 8) are defined for each of the main application segments. Nevertheless, the different application segments in the transport sector share the same **key challenges**, namely:

- battery performances and cost,
- battery safety,
- fast charging,
- environmental sustainability (including the circular economy principles).

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32 European Commission, *EU energy in figures – statistical pocket book* (2019).
33 European Environment Agency, www.eea.europa.eu
34 Environmentally sustainable biofuels (in terms of life-cycle carbon footprint) can be obtained from feedstocks such as energy crops, agriculture or forest residues, and waste.
35 Transport & Environment, *How to decarbonise European transport by 2050* (2018); The Royal Society, *Sustainable synthetic carbon fuels for transport: Policy briefing* (2019); J. Krause et al., *EU road vehicle energy consumption and CO2 emissions by 2050 – Expert-based scenarios* (2020).
36 IEA, *Global EV outlook* (2020).
37 The Royal Society, *Sustainable synthetic carbon fuels for transport: Policy briefing* (2019)

Battery **performances** (energy density in Wh/kg and Wh/L, power density in W/kg and W/L, cycle and calendar lifetime, reliability, etc.) have to be improved, while **cost** (in €/kWh) has to be reduced. It will allow electrified transport to offer the same or better usability than fossil-fuel based transport at a similar or reduced total cost of ownership. In particular, road transport requires batteries with higher energy densities and hence longer driving range. Other transport modes (waterborne, airborne and rail transport) would also strongly benefit from increased battery energy densities.

Ensuring battery **safety** is a mandatory requirement for all applications, although the required level of safety (and the corresponding operating conditions) strongly depends on the application sector. The development of battery technologies with a higher level of safety is urgently required, in particular for very demanding applications such as airborne, waterborne or rail transport.

Fast charging[38] is a key enabler for improving the usability of all electrified transport modes. In the case of road transport, fast charging is needed in combination with standard charging: daily needs can generally be met by standard charging (especially if the chargers are located where the electric vehicles spend most of their time, e.g., at work or at home), while fast charging is used occasionally (typically for long-distance trips, or for some use cases in urban area).

Finally, improving **environmental sustainability** (i.e., lowering the carbon and raw material footprints of batteries over their full life cycle) is absolutely required in the framework of the European Green Deal[39], for protecting our environment, reducing the European dependency on raw material imports, and providing the European industry with a key differentiating asset in the global competition. A better environmental sustainability can be reached by applying the principles of a circular economy ("reduce, reuse, and recycle").

Research Topics 2020-2030

In order to tackle the above-mentioned key challenges, research is needed along the whole battery value chain (from raw materials to advanced materials, cells, systems and end-of-life management). At the battery system level, several **research topics** have been identified, namely:

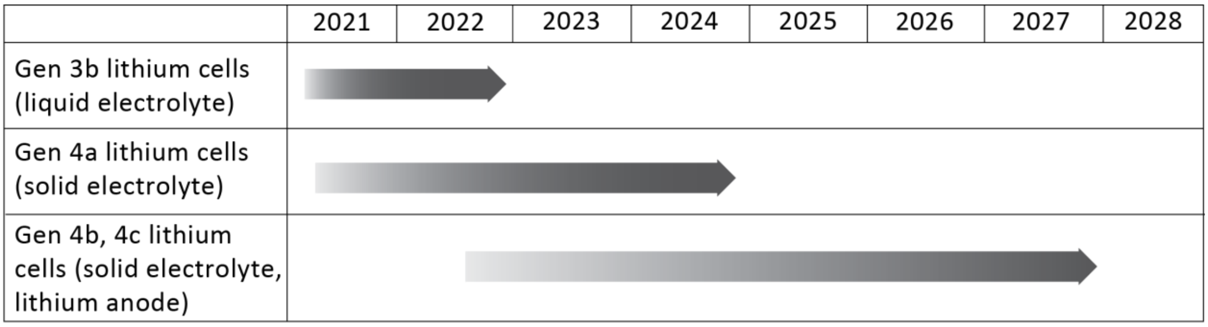
- battery systems (for cells and battery system design and related manufacturing processes, considering mechanical, electrical and thermal aspects),
- battery management (knowledge and data-based battery management, considering algorithms, software and hardware, and including topics related to sensor integration, standardization, interoperability[40] with systems inside or outside the vehicle, and vehicle-to-grid),
- digital twins (for battery design, manufacturing, and battery management in the field), new methods and tools for assessment of battery performance and safety (new approaches, including the combination of physical and virtual testing, for a faster and more accurate assessment of battery lifetime, reliability and safety).

[38] *Fast charging* can be defined either in terms of C-rate (relevant for material and battery development) or in terms of power (more relevant for applications). High C-rate does not necessarily mean high power (and vice versa). *Fast charging* and *ultra-fast charging* correspond to C-rates higher than 1C and 3C, respectively. The car industry considers that *fast charging* and *ultra-fast charging* correspond to power higher than 50 kW and 350 kW, respectively.
[39] European Commission, *The European Green Deal*, COM(2019)640.
[40] Interoperability refers to data management (digitalisation) and implies facilitating the seamless exchange of data between products and systems.

Research topic	Impact on key challenges				
	Performances	Cost	Safety	Fast charging	Sustainability
#1 Battery systems	+++	+++	+++	+++	+++
#2 Battery management	+++	++	+++	+++	+++
#3.a Digital twins for battery system design and manufacturing	++	+++	+	+	+++
#3.b Digital twins for battery management	+++	++	+++	+++	+++
#4 Methods and tools for assessment of battery performance and safety	++	+++	++	+	+++

+++: large impact; ++: significant impact; +: low/no impact.

Those research topics at battery system level can be supported over time by focusing successively on the integration n of different generations of lithium battery cells (in particular generations 3b, 4a, 4b and 4c)[41].



Beyond 2030

Beyond 2030, new battery markets would emerge, and batteries would be used for even more demanding applications (for example, robotics). It would require the development of new generations of batteries with ultrahigh performances, and a paradigm shift in the way we develop, design and intelligently manage batteries, as suggested for example in the roadmap developed by the EU-funded BATTERY 2030+ initiative[20]. The use of disruptive battery materials and design could allow to combine high energy and power density. A very strong coordination with lower TRL activities of Batteries Europe will be needed to ensure a smooth uptake of solutions currently under investigation.

1.11 Batteries for stationary energy storage applications

Energy Storage is a key enabler[42] **for achieving European Green Deal**[43] **targets**. As decarbonisation of the power generation coupled with electrification of the final consumption will be crucial for reaching a net-zero emissions in a Sustainable Development Scenario, with Variable Renewable Generation rising globally up to 57% in 2070 [44] , stationary storage will contribute to the **security of the electricity supply** in EU[45], while improving grid flexibility and allowing further RES penetration. Energy Storage will be deployed whether behind-the-meter coupled with Residential and Commercial & Industrial Solar PV, or in front of the meter, in large utility scale power generation plants and standalone storage plants for

[41] EMIRI, *Advanced materials for clean and sustainable energy and mobility* (2019).
[42] ETIP SNET R&I Roadmap 2020-2030
[43] European Commission, *The European Green Deal*, COM(2019)640.
[44] IEA -Energy Technologies Perspectives 2020
[45] Study on Energy storage – Contribution to the security of the electricity supply in Europe

avoiding grid congestion. Electric vehicle batteries could provide additional short-term storage through V2G technologies.
In this vision, different energy storage technologies will coexist applied to the most suitable use case, where batteries are a winning option for many applications[46].

Vision & Challenges for 2030

The stationary storage battery main markets will be grid services (domestic, industrial and utility scale), telecom, back-up, power quality and micro-grid (on-grid and off-grid)47, where mature chemistries together with innovative ones holds room for market opportunities.

Distributed renewable generation use-cases. Batteries might growth as the preferred option for the ever most present DG (Distributed Generation) option if ambitious targets are reached, in terms of **longer lifetime (>15000 cycles)**, **cost (< 80 €/kWh)** and maximum **safety (fire / fault proof systems),** as a highlight by market research[48].

Medium- to Long-term storage use-cases (arbitrage, others) with BESS (Battery Energy Storage System) will not only take advantage of the cost reduction in the mobility industry but also has an opportunity with other chemicals competing with next generation Lithium batteries (solid state, lithium sulfur, metal-air) and other technologies (Na-ion, sustainable redox flow batteries, etc). **Low cost (<50€/kWh at least) with still comfortable roundtrip efficiency (>70%)** will unlock new business cases in terms of renewable generation curtailment reduction and grid congestion avoidance.

Open access, Interoperability 40, Multi-Services and Digital Twins are also essential factors that will allow massive deployment of BESS, unlocking new market segments to every kWh of sharable battery, in a more economically efficient way.

In order to achieve such targets, it's crucial to continue supporting a **competitive BESS EU manufacturing industry** for stationary storage industry[49] taking a market-oriented approach, while focusing in creating an environmentally **sustainable** circular value chain for BESS, leveraging on second life batteries and promoting an efficient process for recycling end of life batteries.

Research Topics 2020-2030

In order to tackle the above-mentioned key challenges, several **research topics** have been identified:

i. Battery systems with improved **Cost**, **Longer Life** and **Performance**
ii. **Safety** requirements for stationary electrical energy storage systems
iii. **Open Access** battery management systems using standard procedures for monitoring state of health, and other key performance parameters.
iv. **Interoperability40 and Digital Twin** for Stationary Battery Energy Storage Systems for the Advancement of **Multi-Service** Flexibility and Hybrid Solutions
v. Battery systems with improved **Sustainability:** recyclability, second life, etc.
vi. Battery systems for **medium- to long-term energy storage**

[46] IRENA. (2017) Energy Storage Outlook
[47] The rechargeable battery market and main trends 2017-2030, AVICENNE, AABC Europe, January 2019
[48] https://www.iea.org/commentaries/battery-storage-is-almost-ready-to-play-the-flexibility-game
[49] Battery Innovation roadmap 2030, EuroBat 2030

In the following table the expected impact on key challenges by researched topics are summarized:

Research topic	Impact on key challenges				
	Flexibility	BESS EU industry	RES penetration	Grid Security	Decarbonisation
Cost, Longer Life and Performance	+++	+++	+++	+++	+++
Safety	+	+++	+++	++	+
Open access	++	++	++	++	+
Interoperability Multi-Service, Digital Twin	+++	+++	+++	+++	+
Sustainability	+	+++	+++	++	+++
Medium- to long-term energy storage	++	++	+++	++	++

+++: large impact; ++: significant impact; +: low/no impact.

Strategic Topic 1: Innovative technologies and components to decrease the cost of batteries for stationary applications, improve calendar and cycle life and ensure optimal performance

The main challenges for battery **performance** such as energy density in < Wh/L (or specific energy in Wh/kg), power density in W/L(or specific power in W/kg), cycle and calendar lifetime, Depth of Discharge, c-rate etc. have to be improved, while key **cost** KPIs (CAPEX, OPEX, LCoS and TCO) have to be reduced. Such improvements will allow battery energy storage to provide a valuable and affordable solution enabling European targets for a green and sustainable provision of energy, while still ensuring the highest level of service required by a reliable electricity system. Such advanced performances represent a key element in order to qualify the raising **EES EU manufacturing** value chain for battery industry, and have it competitive since the beginning. As further key element for competitiveness, **Sustainability** shall be promoted for the European battery energy storage system industry, throughout the entire supply chain, by mean of proper design for reuse and recycle.

- **Impact:** improved performance, and namely energy density, cycle and calendar life of batteries, will make batteries a cost-competitive and affordable option for stationary storage applications to be deployed at a large-scale, enabling the transition to a carbon-neutral energy system in a scenario of high penetration of variable RES in power generation.

- **KPIs:** FEC (Full Equivalent Cycle) Life for stationary applications depending on the applications increased to 15.000 cycles or Calendar life of stationary battery modules increased to 30 years; C-rate capability up to 8C/8C for power-oriented services; self-discharge rate at 0,10% of SoC per month; discharge duration over 10 hours.

- **Resources:** 50 M€

Strategic Topic 2: Technologies, methodologies and tools to enhance safety in stationary electrical energy storage systems

Safety aspects associated with stationary energy storage systems - due to their dimension scale and installation (e.g. in buildings) - are key issues to be tackled to support a large-scale market up-take of batteries in stationary applications.

Advanced and energy dense battery storage systems shall be **intrinsically safe**, and this both by means of proper design of components and system for active containment of possible issues, but also by means of SW for advanced modeling for degradation and monitoring during operation, enabling active fault prevention and prediction. Ensuring **safety** will remain over time as a challenge to develop methods for risk assessment and define safety in order to allow for development of European regulations globally accepted and supporting the market.

- **Impact:** the expected impact is the increase of the overall safety of stationary electric energy storage plants through suitable regulation and innovative technologies and methods. This will remove obstacles to BESS growth by reducing incident costs as well as increasing lifetime by over 20%.

- **KPIs:** OPEX for maintenance and operation of BESS related to safety aspects decreased by 20%; number of reported incidents decreased by 90%; a consistent regulatory framework and technical standards in place

- **Resources:** 50 M€

Strategic Topic 3: Open access and interoperable advanced Battery Management Systems

Open access to BMS information and standardization of data and formats is necessary to get performance and historical information for external systems, and to define telecommunication standards allowing third parties to control and communicate with the storage system. Third party access is crucial as well for second life applications allowing an efficient, safe, and economic reuse of the batteries. A trustworthy and transparent methodology will facilitate a reliable estimation of the state of life and prediction of the remaining lifetime for new uses. Relevant historical information about the way in which the system has been used, like extreme temperatures, equivalent cycles and many others will contribute to an optimal reuse of the elements and fair markets.

- **Impact:** open and interoperable BMS will support the creation and up-take of a second-life applications market for EV batteries at the end of their first-life, thus contributing to the overall sustainability and competitiveness of batteries. Advanced and interoperable BMS will also allow the hybridization of the system contributing to a wider extent to smart energy integration. Innovative HW and SW for battery management are key to ensure an extended battery lifetime and optimal performance

- **KPIs:** cycle life >15.000 cycles by 2030. Increase of use of batteries (massive deployment), increase on the second-life batteries use, reduction of cost due to higher concurrence (30%).

- **Resources:** 30 M€

Strategic Topic 4: Interoperability, Digital Twins and Multi-Services

Interoperability[40], Digital Twins and Multi-Services are key enablers for improving the usability and competitiveness of battery-based energy storage systems (BESS and HESS). Interoperability will enable cost reduction through higher competitiveness, and a more efficient use of systems enabling machine to machine collaboration. Digital Twins will make possible reliable simulation studies, and consequently the inclusion of storage in grid-planning process facilitation a wide use of BESS and HESS on grid use-cases. Energy storage still needs an improvement in cost and calendar life to compete with other alternatives. A shared use based on Multi-Service storage systems can be the way for putting the batteries in the market sooner. Without it, implementation costs will be higher, time to market will be longer, and system benefits for EU electricity and battery industries will be delayed.

- **Impact:** Digitisation of BESS is expected to allow an increasing number of new BESS-based energy services to come to the market, helping the development of cost-effective and sustainable BESS and HESS ecosystems, and an optimal management of storage resources at the grid level.

- **KPIs:** Interoperability Level 3 reached in 2024, LCoS per cycle - Cost for stationary applications requiring deep discharge cycle (€/kWh/cycle) < 0,01 € at2030

- **Resources:** 50 M€

Strategic Topic 5: Sustainability and Second-life stationary applications for EV batteries

Sustainability and Second life use of batteries, is absolutely required in the framework of the European Green Deal[50], It is estimated that there will be 29 GWh of used EV batteries available in 2025. Of this, almost a third may be utilised for second life as stationary storage (10GWh), bringing the cumulative total to 26 GWh in 2025. This is one of the optimal ways to decrease the carbon footprint of batteries. However, there are still (i) a number of significant challenges to be addressed to allow an uptake of second-life applications, such as: durability and performance of second-life batteries and safety risks due to aged batteries; (ii) effective business-models are to be demonstrated and (iii) cost-effective technologies and eco-design for the dismantling the battery packs and repurposing for second life are to be developed.

- **Impact:** a reliable, safe and sustainable use of second-life batteries improves the LCA of batteries, contributing to lower their carbon footprint and ensure a circular economy. Second-life applications can also improve the competitiveness of battery packs and support availability of batteries for storage applications in the peak phase of the automotive demand.

- **KPIs:** Percentage of re-use of 2nd life batteries in 2030: 20% of available batteries. Increasing the Recycling efficiency of all kind of batteries.

- **Resources:** 50 M€

[50] European Commission, *The European Green Deal*, COM(2019)640.

Strategic Topic 6: Medium-to long term EES

Medium- to long-term EES opens a new ever seen opportunity to fast track to ambitious cost reduction to below 5 cents €/kWh/cycle. The spread of renewable and sustainable energy sources in the framework of the decarbonisation of energy at continental level requires the availability of energy storage in periods when primary sources, e.g. solar and wind, are inadequate.

The challenge is to develop cost-effective systems and technologies for medium (>5 hours storage)- to long-term storage (some weeks to some months) for back-up, arbitrage, and renewable sources generation shifting, among other uses.

- **Impact:** Low cost battery system (<50€/kWh) with still high round trip efficiency (>70%) will enable massive storage of energy from Renewable Generation meanwhile avoiding grid congestions, enabling European ambitious targets of penetration of Renewable generation, even >50% in 2030
- **KPIs:** self-discharge rate (SDR) for medium-term storage: ≤ 2% per month; self-discharge rate (SDR) for long-term storage: ≤ 0.5% per month; cycle life (CL): ≥ 15,000; levelized cost of storage (LCoS) at EPR ≥ 10 hour ≤ 0.01 €/kWh/cycles in 2030
- **Resources:** 60M€

Beyond 2030

Beyond 2030, new battery technologies with lower cost and better safety levels would emerge[51] for stationary energy storage for domestic, industrial and commercial as well as for utility scale applications as expected from the BATTERY 2030+ roadmap[20].

[51] The rechargeable battery market and main trends 2017-2030, AVICENNE, AABC Europe, January 2019

BATTERY MANUFACTURING AND ADVANCED MATERIALS

1.12 BATTERY MANUFACTURING

Vision & Challenges for 2030

Ensuring a competitive European battery manufacturing industry through digitalisation and technical development

To support the rapid transition toward the electrification, battery cells, such as lithium batteries, are the key enabling factor to foster the competitiveness and sustainability of a wide range of European Industries and battery value chains (e.g. E-mobility, stationary systems, consumer electronics, industrial applications, busses). A large-scale production demand of innovative battery cells is therefore an important element to increase the competitiveness of Europe as a business location. Europe's ability to further develop novel battery cells and produce them flexibly in medium to large series is the long-term guarantee for competitiveness and independence. Therefore, a deep understanding of manufacturing processes, as well as the development of energy-efficient processes and production equipment, represents a major opportunity to strengthen European Industries along the value chain.

Research and development in the field of cell production faces a multitude of **challenges** in today's battery systems, but especially in those of the future:

- **Sustainability and energy efficiency** of plants and processes
- **Cost competitiveness** via enhanced productivity and flexibility in production
- **Highest quality, safety and performance** at cell level
- **Full digitalisation** from cell design to manufacturing lines for enhanced efficiency, quality control and process optimization.

Research Topics 2020-2030

To successfully tackle these challenges, several strategic research actions are identified and prioritized:

Strategic Topic 1: Research in innovative cell components and designs and its manufacturing processes

As the state of the art in battery sector evolves, there is an increasingly fast availability of new advanced materials and components with improved performance. These must be implemented into real environment like battery cell systems that may substantially challenge previous conceptions of cell design and configuration. The design for intrinsic safety and recycling should be considered at the conception phase of the cells.

- **Impact**: Increase energy density, facilitating manufacturability, disassembly, recovery of components and recyclability.
- **KPIs**: Increase of battery cell energy density and intrinsic safety by 40%. Reduction of carbon intensity of 25% CO2/kWh through lower inactive materials use at cell level. Reduce the production costs by at least 20% vs. current lithium battery cell production.
- **Resources:** 90M€

Strategic Topic 2: Cell design digitalisation

Structure-property relationship, degradation models and large-scale data driven testing are required to reduce development times and costs and to improve the final cell designs. For this purpose, substantial progress in advanced multiscale models, electrochemical performance as well as ageing mechanisms need to be developed and to be combined with large-scale data harvesting.

- Impact: Shortening the time-to-market of new cell designs with reduced development times and costs, as well as environmental impact.
- KPIs: Battery cell development cost reduction by at least 20%, reduction of number of experiments by factor 3-5, by referring to the SoA of Li-ion battery cells.
- Resources: 50 M€

Strategic Topic 3: Innovation in manufacturing machinery and processes

For the improvement in terms of process capability, reduction of material waste, energy efficiency and product consistency to deliver state-of-the-art cells, but also to fit new processes oriented to new battery cell technologies – i.e. solid-state cells -, circularity and digitalisation concepts.

- Impact: Allow production competitiveness of the European Giga Factory, flexibility, and overall reduction in energy consumption.
- KPIs: Increase in production rate by 10-15% vs. SoA Li ion, increase cell production Overall Effectiveness Efficiency (OEE) > 90%; reduce the cost of equipment capital investment per GWh down to 80 M€ by retrofitting; reduce energy consumption by 25%.
- Resources: 100 M€

Strategic Topic 4: Digitalisation for process integration and plant operations

Manufacturing data analytics to monitor the production performance will enable the continuous improvement of the manufacturing lines and preventive troubleshooting. Digitalisation will assist in two levels: (i) at the production line level, supported by machine learning and artificial intelligence, and (ii) at the plant level within its local energy and materials flow ecosystems integration supply ecosystem, i.e. sector coupling.

- Impact: Avoiding trial and error at production line level, energy and materials flows optimization with savings in logistics costs and CO_2 impact, plus added security and consistency of supplies.
- KPIs: Increase in production rate by 10-15% ; reduce energy consumption by 25% vs. current Li-ion cell production.
- Resources: 60 M€

Beyond 2030

In the mid and longer term there will be a need for R&D for all systems at the same time from manufacturing perspective, both to be state-of-the-art electrode and cell designs and production processes, as well as new battery cell chemistries/technologies. The battery technologies that we will be manufacturing tomorrow, as it is the case of today, do not follow each other but are present next to each other, each one suiting better different, complementary application niches.

Having this picture in mind, we can anticipate Battery Cell Design and Manufacturing needs beyond 2030 as:

1. **Continuous improvement in current manufacturing processes (today at medium and high TRL)**, machinery, state-of-the-art battery technologies (in 2030), i.e. Gen3b Lithium ion, Gen4 SSB, redox flow batteries, etc.
2. **Manufacturing of new promising battery technologies (today at low TRL)**, and the need to upscale to manufacturing plant, implementation of self-healing concepts and its sensing and actuators, e.g. coming out of Battery 2030+ strategic approach.
3. **Radically new manufacturing approaches** like molecular level cell design and manufacturing i.e. for atomistic level interfaces
4. **Further development of digitalisation** and digital tools and at all levels. Democratization of simulation, from atomistic scale to better understand and predict the behaviour of battery electrodes and cell.

1.13 ADVANCED MATERIALS FOR BATTERIES

With about 70% of the cost of a battery cell being the cost of the cathode, anode, separator and electrolyte materials, it is obvious that advanced materials are key to further cost reduction and market uptake. Ongoing R&I in advanced materials allows indeed the development of more cost-efficient, better performing, safer and more sustainable battery cells. The main driving force behind R&I in battery materials deals with increasing the energy density of battery cells to enable better performance and cost-competitiveness of the specific applications. Various battery chemistries exist and are being further developed nowadays. These battery chemistries may differ depending on the application focus being mobility or stationary usage. In the mobility space, it is all about Li-ion battery chemistries, R&I is on liquid-state batteries (generation 3) with a drive towards solid-state batteries (generation 4) while R&I is also conducted on generation 5 battery chemistries. In the stationary storage space, next to Li-ion batteries, there are numerous developments focusing on Na-ion batteries, redox-flow batteries and metal-air batteries. For all these battery chemistries, further R&I is needed to develop the most appropriate advanced materials as detailed below. This chapter will solely focus on R&I needed in Advanced Materials for further key improvements expected in Li-ion techs. Generation 5 battery chemistries and novel systems for stationary storage are dealt with in the chapter “European competitive edge”.

Research Topics 2020-2030

Strategic Topic 1: Research & innovation on Generation 3 Li-ion batteries for mobility applications

- **Challenge:** Developing advanced materials enabling higher energy / power density thanks to higher capacity and/or operating at higher voltage. Focus is on adapting the cathode materials (high-nickel NMCs for capacity, spinels / Li-rich Mn NMCs for voltage), the anode materials (graphite containing Si(Ox)), the electrolytes (stabilized formulations), the binders … and their interplay.
- **Impact (KPIs):** Gravimetric, volume energy density at cell level of 350-400 Wh/kg, 750-1000 Wh/l respectively. For high voltage application, operation at 4.7+ Volt. 3000+ and 2000+ deep cycles for high capacity and high voltage applications respectively. Cost at pack level < 100 euro/kWh
- **Time to market & resources needed:** 2025(+) / 100 M euro

Strategic Topic 2: Research & innovation on Generation 4 Li-ion batteries for mobility applications

- **Challenge:** Developing solid state electrolytes, cathode materials and anode materials enabling higher thermal and electrochemical stability while targeting higher energy / power densities, fast charging, cyclability and improved safety. Developments should range from using conventional materials to using Li metal-based anode with(out) high voltage cathode materials)
- **Impact (KPIs):** Gravimetric, volume energy density at cell level of 400+ Wh/kg (Generation 4a), 800+ Wh/l to 500+ (Generation 4b & 4c), 1000+ Wh/l respectively. Cycle life up to 3000 and ability to operate at charging rate of 3-5C. Cost at pack level down to below 75 euro/kWh
- **Time to market & resources needed:** 2030(+) (depending on tech.) / 200 M euro

Strategic Topic 3: Research & innovation on Li-ion batteries for stationary storage applications

- **Challenge***:* Develop the various materials systems (cathode, anode, electrolyte, binders …) to enable stationary Li-ion batteries to be used in utility scale applications (> 100 MW, P/E < 1/3) and in commercial high-power applications (< 100 MW, P/E > 4). Material strategies are very diverse and range from improving conductivity, energy density, lifetime in utility-scale applications, while improving conductivity and capacity for high-power applications
- **Impact (KPIs):**
  For commercial high-power applications - Volumetric energy density of 500+ Wh/l, lifetime of 6000+ cycles, rate capability of 5-6 C.
  For utility-scale applications - Volumetric energy density of 500+ Wh/l, lifetime of 10000+ cycles, cost <0.05€/kWh/cycle
- **Time to market & resources needed:** 2030 / < 100 M euro

Strategic Topic 4: Research & innovation on advanced materials to reduce weight of EVs (battery packaging, drive train, car body)

- **Challenge:** Developing new lightweight materials based on glass fibers, carbon fibers, new plastics, high strength steels … and demonstrating high strength-to-weight ratio suitable for structural and functional automotive parts

- **Impact (KPIs):** Total weight reduction EV car body of 40%, weight reduction battery packaging of 70 %, attain lightweight materials (HSS, Al, plastics…) share in EV's of 65%, drive train cost reduction of 30%, durability improvement of 30%, driving range 700 km, recyclability of 99%

- **Time to market & resources needed:** 2025(+) / < 50 M euro

Strategic Topic 5: Research & innovation on advanced materials to enable ultra-fast charging

- **Challenge***:* Developing the various materials systems enabling user-friendly, safe and reliable ultra-fast charging stations with power transfer capability exceeding 350 kW
- **Impact (KPIs):** Charging time below 10 minutes, power transfer capability at 350+ kW and low energy losses due to ohmic resistances during charging process, energy loss < 2%
- **Time to market & resources needed:** 2025 / < 50 M euro

Beyond 2030

By 2030, Li-ion technologies will remain the dominant technology in mobility applications due to successful market uptake, an established industrial value chain and continuous improvement of the technology. The focus of the R&I will be on solid-state batteries (generation 4) and generation 5 (beyond Li) will receive stronger attention, leading to some inroads in specific application segments. For stationary, next to Li-ion batteries, we will have a broader choice of technologies. The focus will also be on the development of theoretical and experimental tools to enable future generation batteries and accelerate the finding of new battery chemistries. Beyond 2030, we expect to see several new chemistries behind proposed. Novel AI-based tools and physics-aware models and autonomous synthesis robotics will indeed enable to "learn" the interplay between battery materials and interfaces, providing the foundation to improve future battery materials, interfaces, and cells.

RAW MATERIALS FOR THE CIRCULAR ECONOMY

1.14 SUSTAINABLE PROCESSING OF BATTERY GRADE PRIMARY AND SECONDARY RAW MATERIALS

In the following text we understand primary raw materials being materials, which are produced based on mined materials, and utilized first time in products. With secondary materials we understand materials, which have been in use and returned back to the raw material cycle after end of life. Mining residues and other industrial wastes, from where the materials may be beneficially recovered at a later phase are also considered as secondary raw materials. Raw materials represent a major part of battery value and carbon footprint. Therefore, the raw materials have a high impact on overall batteries and therefore R&I work is critical and imperative. To reach the goal of the European Battery Alliance – 300 GWh/a of battery production in Europe – will require approximately 270 000 tons of battery grade graphite and 30 000 tons of Silicon for the anode, and 225 000 tons of Class 1 high purity nickel, 29 000 tons of cobalt, 84 000 tons of manganese and 59 000 tons of lithium for the cathode. Currently the level of extraction and processing of battery raw materials in Europe is marginal. For Lithium, hard rock mine projects exist in Austria, Portugal, Serbia and Finland, with a collective planned capacity of 11 000 t Lithium Carbonate Equivalent (LCE), corresponding to about 8% of the estimated 2027 world demand. For Cobalt and Nickel, the European mine production from a Finnish operation is expected to be 1900 tons of battery grade cobalt and 56 000 tons of nickel in the next few years. Europe is a large producer of primary silicon, and also produces both natural and synthetic graphite but not in the vast quantities needed. It must be noted here, that as secondary material based recycling of batteries and other related materials is going to support the material supply in the future, there is still a gap of available materials, which have to be filled by using increasing amounts of primary, mine based materials, too.

The dependency on imported materials not only poses a strategic supply risk for European battery manufacturers but also a branding issue as the sustainability and traceability of raw materials from non-European sources are very difficult to define. Building up European capacity in extraction and processing would serve the diversification of supply chains, thus, limiting supply risks; but also serves future recycling of batteries as the recycled materials can gradually be integrated into the existing primary processing facilities.

These goals require Europe to be in the frontline of technological development of metallurgical production, where innovations in processes and unit processes are required. These should aim at improved yield, better process control, flowsheet flexibility, improved product purity and quality, improved impurity removal, and improved recovery from secondary streams. These innovations are in some places complementary unit processes to existing process flow sheets, while in others like European Li or pCAM production, completely new flowsheets. This is expected to bring added value for the European battery metals production.

Vision & Challenges for 2030

Europe's global leadership in automotive and battery industries is built on a solid supply of transparently and sustainably extracted and processed raw materials from both European and non-European sources.

This vision is built on three cornerstones i.e. Strategic Topics. The proposed projects are presented in more details in the ETIP Road Map for Raw Materials and Recycling[52] and the various Projects are presented here in a very short list. It is mandatory to invest on R&I to reach the visions.

Current projects:

- 3-5 new battery raw material mines in operation (Lithium, cobalt, graphite) by 2027;
- Number of new pilot plants, demonstration units or prototypes;
- Volume / number of tailings or other side products taken into use;
- Reduction of processing steps in add-on for old processing, e.g. leaching steps.

By 2030:

- Zero Liquid Discharge in battery grade raw materials processing;
- 25% increase in energy efficiency in graphite, battery chemical and pCAM (precursor cathode active materials) processing against current state of art;
- 50% reduction of CO2 emissions in lithium extraction and processing compared to current state of art;

  25% of LCE used by European battery manufacturers produced from European own sources.

Strategic Topic 1: Sourcing, sustainability and traceability of raw materials

Synthesis: "It is most important that the European battery industry can rely on a harmonized and straightforward way to source metals in the currently complex and intertwined global extraction supply chains".

TABLE 2: STRATEGIC TOPIC 1 FOR RAW MATERIALS, SHORT AND MEDIUM TERM

Short term (0-5 years)
• Harmonized approach for estimating the resource/reserve basis in Member States • Understanding of sustainability requirements for raw materials sourced outside of EU • Responsible sourcing and traceability across the global supply chains • Development and evaluation of tracing and labelling technologies, digital ledger technologies
Medium term (5-10 years)
• Tracing and labelling of the certified materials through the whole life cycle (cradle-to-grave)

Strategic Topic 2: Sustainable extraction and refining of battery grade raw materials

Synthesis: "Developing processing solutions for Li, Ni, Co, Mn and graphite to be used to both domestic and imported raw materials".

[52]See "Publications" section at https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications_en .

TABLE 3: STRATEGIC TOPIC 2 FOR RAW MATERIALS, SHORT AND MEDIUM TERM

Short term (0-5 years)
• Solutions to a sustainable Lithium value chain • Development of continuous processes for pCAM to replace the currently used batch processing • Zero Liquid Discharge processing in battery chemical and pCAM processing, including energy cascading and waste valorisation • New recoverable reagents for battery metal leaching and extraction • European graphite production – with vertical integration into the European battery production • New business models for co-processing and process integration • New smelting and slag engineering technologies to address Ni and Co losses in smelting • Process modelling competence combined with environmental impact evaluation (incl. LCA analysis) for individual primary processes
Medium term (5-10 years)
• Recovery of metals and chemicals from new sources as industrial or urban wastes • Development of an economically feasible process for Mn recovery (from base metal solutions) • Substitution of petroleum-based feedstock in synthetic graphite production • Secondary product recovery to attain a consensus flowsheet • Substitution of fossil fuels and use of smart and / or renewable energy solutions at battery raw material processing units and/or mines • New silicon production methods (Si/C composite up to 20 %) • Working on silicon rich anodes using novel strategies/materials such as porous silicon (anode density to more than 1200 mAh/g).

Strategic Topic 3: Raw Material LCA and material Flow Analysis

Synthesis: "Greater environmental sustainability via new holistic and applicable quantitative tools of circular batteries. Reliable holistic LCA tools, reduced carbon footprint, new approaches to recycling and reuse and greater understanding of societal sustainability and coherent measurement of the SLCA".

TABLE 4: STRATEGIC TOPIC 3 FOR RAW MATERIALS, SHORT AND MEDIUM TERM

Short term (0-5 years)
• Open access LCI data of raw materials • Ecolabel of batteries (sustainability requirements) • Use LCA in an early design process • Harmonized energy source declaration of material producing companies from exploration to final products • Harmonized Material Flow Analysis for raw materials for batteries • Reliable raw materials (including chemicals and precursors) LCI • Reliable recycling LCI data • Understand the full sustainability (not focus only on one indicator) • Scrutiny of primary and secondary materials (in terms of energy, costs and other impacts).
Medium term
• Regionalized LCA for mining, LCI data and LCA of next generation batteries • Social Life Cycle Assessment (S-LCA) methodology development and use in Battery value chain, especially related to raw materials

1.15 Recycling

With the rapidly increasing electrical vehicle fleet in Europe also the amount of batteries in European cars will increase rapidly forming a fast growing stock in use of raw materials, which are later an remarkable source of raw materials and available for recycling (after the possible second life use). Currently, the Li battery recycling industry in Europe is mainly concentrating on the Li batteries coming to end-of-life (EoL) from electronics and portable instruments, which have a large challenge in collection and reverse logistics. Also, the chemistry of these batteries is varying a lot, challenging the processing and recovery of the materials. However, the materials in these batteries are already now valuable to be recycled and recovered, to support the growing Li ion battery manufacturing in Europe. The need to develop better technologies to recycle the materials contained in batteries is also important due to the upcoming Battery Directive (see Section 1.2.2), which will set totally new targets for the collection of batteries and recovery efficiencies in recycling processes.

At the same time, the recycling industry is preparing for the future challenges to be ready when large amounts of EV batteries are available to be recycled, which means also a growing need for bigger scale processing units. However, not only will the market for batteries and recycling of batteries grow in Europe. In the context of a growing battery industry and increased manufacturing in Europe, it must be noted here, that we refer to a wider scope of recycling. New closed loops and recycling technologies are needed for a circular battery industry in Europe. New potential is to be explored in industrialised closed loops and recycling systems, for example to return and recover low-value chemicals from the battery manufacturing processes to high-value input products for the industry.

Vision & Challenges for 2030

Europe to become the No. 1 recycler of Li-ion battery raw materials i.e. all the important raw materials imported into Europe in batteries or installed in batteries in Europe are collected and processed in Europe to recover the materials without down cycling when technically, economically and environmentally beneficial.

This vision is built on two cornerstones i.e. Strategic Topics. The proposed projects are presented in more details in the ETIP Road Map for Raw Materials and Recycling[53] and the various Projects are presented here in a very short list. It is mandatory to invest on R&I to reach the visions. These two corned stones are supported by studies on new business models, sustainability and safety not to forget the circular economy related second use phase before final EoL recycling.

The proposed KPIs for these topics are summarized together with the primary raw materials related KPIs in Chapter 8. It must be noted here, that the New Battery Directive will call for more efficient recycling and that the targets and the KPIs for recycling will be updated when the Directive is effective. Thus the following KPIs shall be considered preliminary.

[53] See "Publications" section at https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications_en .

Return of batteries

TABLE 5: KPIS FOR RETURN OF BATTERIES

KPI for return of batteries	
Portable batteries (*)	Industrial and automotive batteries (**)
Actual rate: 45% 55% by 2025 65% by 2030	100 % Takeback obligation

(*) Collection target calculated based on the average of portable batteries placed on the market during the last 3 years.
(**) all industrial batteries need to be taken back (100% takeback obligation).

Improved total recycling of battery materials (Subject to change upon upcoming battery directive)

TABLE 6: KPIS FOR IMPROVED TOTAL RECYCLING OF BATTERY MATERIALS, 2020 AND 2030 TARGETS

KPIs	2020	2030 Target
Recycling efficiency* Li ion batteries (by average weight of waste battery)	Overall: > 50% Cobalt > (90%) Nickel > (90%) Lithium > (35%) Copper > (90%)	Overall: >60% Cobalt> (95%) Nickel > (95%) Lithium > (70%) Copper > (95%)
Other batteries chemistries **		50%
The number of recovered products eg. Cu, Al, Li, Co,etc	4-6	6-10
Reduced direct or indirect CO_2 emissions		Consortia to deliver evidence

* Battery pack without housing. Oxygen and hydrogen excluded
** Category representing all other type of battery chemistries (except Li-ion, NiCd and Pb-acid): Alkaline, Zn-C, Li-primary, button cells, NiMH

Strategic Topic 1: Collection, reverse logistics, sorting and dismantling

Synthesis: "To develop comprehensive technologies for safe and effective handling of the growing battery streams before they finally will enter the recycling process". This topic is highly relevant to reach the upcoming Battery Directive targets.

TABLE 7: STRATEGIC TOPIC 1 FOR RECYCLING, SHORT AND MEDIUM TERM

Short term (0-5 years)
• R&I on new technologies and devices for battery SoH assessment. • R&I on standardized diagnostics protocols and cut-off criteria between product (2nd life application) and waste (recycling). • Development of standardized and cost-efficient storage and transportation containers with visual and thermal load monitoring systems and, if necessary, inert atmosphere. • R&I on discharge technologies and devices equipped with energy recovery systems. • Development of standardized battery labelling system and potential integration with battery passport database. • R&I on automated batteries sorting and dismantling technologies.
Medium Term
• Design for sustainable recycling • Modularity: Enabler of automatic dismantling operation • Risk and safety: At all stage of the dismantling chain • Sorting for particular materials: • Assembling method (for example: glue vs. screws)

Strategic Topic 2: Metallurgical recycling processes, industrial integration and secondary material based precursors

Synthesis: "Efficient processing of these batteries to recover the valuable (or hazardous) raw materials with lowest possible environmental footprint and costs ensuring that the recycled materials fulfil the sustainability targets set to the raw materials set by the European battery manufacturers to ensure their competitiveness in Europe but also in global markets."

TABLE 8: STRATEGIC TOPIC 2 FOR RECYCLING, SHORT AND MEDIUM TERM

Short-term (0-5 years)
• LIB and NiMH chemistries and cell formats, which are in large- scale production today • Creation of feasible **holistic recycling processes** that can effectively exploit the vast amounts of EV battery waste reaching its EoL in the next 10 years, as well as the production scrap. Recycling processes recovering the highest amount and value of resources present within these secondary raw materials. The recycling processes will be based innovative combination of optimized unit processes and may also partially utilize existing metallurgical infrastructure. • Downcycling or safe disposal of the non-metallic elements like the electrolyte, separator and electrode binders. • Further development of **metallurgical tools and modelling** enabling techno-economic comparison of the technology alternatives. • Developing **safety protocols** for all recycling process units. • Reduction of **environmental impacts** of the recycling processes • Industrialising **closed loops** to return low-value chemicals from manufacturing processes to high-value and necessary inputs for the battery manufacturing industry

Medium term (5-10 years)
• Development of **centralized, vertically integrated and automated close-loop** processes. • As an alternative, **de-centralized (local or mobilized)** metallurgical treatment units for flexible battery waste treatment to minimize the transportation (Optimal solution may comprise a combination of the centralized and de-centralized unit operations). • **Direct recycling** of battery materials and components should be attempted • **Zero waste recycling** where also the non-metallic elements are recycled back to battery use. • New process concepts piloting.

To realize a rapid and comprehensive response to the current challenge (to ensure full industrial operation in less than 10 years), the unit processes utilized should be based primarily on processes already in industrial use with primary/known raw materials (TRL9), while holistic battery waste recycling process concepts are targeted at TRL3-6/7 level.

Circular economy-based business models

Synthesis: New business models has to be studied and developed to reach the objectives set above. The following R&I activities are proposed:

TABLE 9: CIRCULAR ECONOMY BASED BUSINESS MODELS

Objective	Projects
Securing a sustainable supply of minerals, base metals and in particular Critical Raw Materials	• *Efficient primary mining,* • *Resource assessment* • *Mapping of secondary sources and Valorization of secondaries*
Designing low lifecycle footprint material solutions.	• *Design for sustainable recycling* • *New processes* • *Standards & eco-labels* • *Digital platforms* •
Enabling maximum value usage of products in the economy	• *RE-strategies* • *Ageing management and Monitor as a service*

The Roadmap of WG 2 is available at the Batteries Europe Website [54] - *30/09/20 This document is currently under review and will be available before publication of the SRA*

[54] See "Publications" section at https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications_en .

EUROPEAN COMPETITIVE EDGE

Securing and maintaining a European competitive edge on batteries requires long term research and a clear vision on the actions that have to be taken for an EU climate neutral and green recovery plan. There is an urgent need to find new sustainable materials for cleaner batteries but also new battery chemistries in order to reach this goal, in addition to improving existing battery chemistries with novel sustainable components.

Vision & Challenges for 2030

A long term vision builds on European research excellence and on a deep knowledge of the different components within the battery, the battery system and all parts of the value-chain, to be able to take a leap to realise low cost, sustainable and safe batteries with high performance. Batteries Europe collaborates with the BATTERY 2030+ initiative, where transformational research directions are identified to accelerate the finding of new materials and future battery cell concepts as described in a long-term roadmap[20] .

The vision for long-term research is to provide Europe with the necessary tools and concepts to be in the forefront both in battery production and implementation. In the last 50 years the science of batteries has made dramatic advances, resulting in batteries with higher energy, higher power, longer life and lower cost. Further advances are foreseen for a number of different applications, not all yet realised, even if transportation and large-scale storage for the moment are the prime targets. The long-term vision is to accelerate new concepts where sustainability of batteries (and ethical sourcing), including their production and afterlife, are the focus. The increasing energy density should not be decoupled with improvements in safety, the two having a tendency to go in opposite directions. With the ever-increasing role of batteries in facilitating a transition to a carbon neutral world, it is essential to address these issues, which have been identified as urgent needs for the next generation batteries.

The pathway to cleaner, high performance and sustainable batteries will come the following scientific approaches:

1. Develop battery chemistries that mitigate risks related to critical minerals in the long term.
2. Develop synthesis and production routes that use less energy, lower temperatures, less toxic solvents and minimize risks for workers and environment.
3. Improve battery resistance to fires and thermal runaway. A major breakthrough is needed towards the minimization or replacement of the present flammable electrolytes.
4. Reduce chemicals that can potentially produce toxic materials with the target to remove them in the long term, i.e., beyond 2030.
5. Develop hybrid systems enabling the use of materials and/or devices for multiple intersectoral energy storage.

Research Topics 2020 – 2030

Accordingly, the specific R&D actions described below are expected to accelerate the assessment of the sustainability and safety of batteries providing high energy density, high number of cycles and calendar lifetimes, and low LCoE (for stationary applications).

Overall, to accelerate these developments new theoretical algorithms utilizing the latest digitalisation tools paired with high throughput characterisation are sorely needed in alignment with BATTERY 2030+ initiative advocating the use of artificial intelligence to drastically reduce the battery materials development cycle time through the Battery Interface Genome (BIG) – Materials Acceleration Platform (MAP) initiatives and to develop smart functionalities at the battery cell level. This approach, which is chemistry agnostic and long term, with the goal to enable the different new chemistries suggested in this section is described in the BATTERY 2030+ roadmap[20].

TRL ≥ 2

Substantial improvements regarding sustainability are certainly needed for already developed (if not commercial) battery chemistries.

- **Li metal-based batteries beyond Generation 4, employing innovative high voltage (> 4.8 V)/ capacity (> 500 mAh/g) cathodes and solid state electrolytes** to achieve very high energy densities and full recyclability**; (TRL 2-4)**
- **Zinc-based secondary batteries (intercalation and zinc-air)** for greener and safer energy storage**; (TRL 2-6)**
- **Na-ion batteries with low-cost electrolytes** for Li-free energy storage; **(TRL 2-3)**
- **Greener RFB** combining low cost (CRM-free) active materials and improved energy densities**; (TRL 3-6)**

TRL < 2

More generally, basic research is required to evaluate realistic performance parameters of innovative battery chemistries made of accessible raw materials and avoiding scare elements. Here, low energy and bio-sourced synthesis routes to produce the active material, improve lifetime, self-discharge and energy density, need to be established. The research should address all types of batteries, including redox-flow and high-power batteries for the direct use of extremely abundant, reactive metals.

Finally, basic research (TRL 1-2) is needed to establish the feasibility of other innovative chemistries using metals with high availability:

- **Organic batteries including redox-flow (TRL 1-3)**
- **Metal batteries from sodium metal to multivalent ion-carriers other than zinc, including elemental cathode materials (TRL 1)**
- **Anion shuttle-based batteries (TRL 1)**
- **High power primary regenerative batteries based on reactive metals such as Na, Ca, Al, Zn, …, for seasonal/annual electrochemical energy storage (TRL 1-2)**

Beyond 2030

Given the lower TRL of some of the potentially more promising technologies, further research will be required beyond 2030 on the following topics:

Organic batteries; R&D (TRL 2-6) to scale up, demonstrate and bring this new technology to commercialisation.

Metal batteries employing multivalent ion-carriers; more basic research (TRL 0-2) to evaluate realistic performance parameters (KPIs) to R&D (TRL 2-6) to confirm expectations for scale-up

Anion shuttle-based batteries; from basic research (TRL 1-2) to evaluate realistic performance parameters (KPIs) to R&D (TRL 2-6) to confirm expectations for scale-up

Hybridisation of energy storage solutions from materials to devices to systems; from basic research (TRL 1-2) to evaluate realistic performance parameters (KPIs) to R&D (TRL 2-6) to confirm expectations for scale-up.

FUTURE OUTLOOK / CONCLUSION

The Strategic Research Agenda for battery research contained in this document is the result of the work of over 500 stakeholders, involved in the Platform's thematic Working Groups which focus on a wide, diverse range of battery-related topics that cover the entire value chain. Batteries Europe aims to push it forward as a document that can serve the purpose of being a lighthouse for battery research. Directing the efforts of research in the right directions on all topics related to the battery value chain is an essential coordination work towards making Europe a competitive, sustainable and self-sufficient actor in the global battery production scene.

The five identified key recommendations are rationales that encompass the Strategic Topics that should receive attention on the road to 2030 and beyond. Ensuring **the continuity of battery R&I** is the main prerogative to keep the work that has been done in the past years alive, focusing as well on **appropriate infrastructure and skills**. To facilitate the exchanges and the marketability of European batteries, Batteries Europe also recommends to develop and implement **adequate reporting methodologies and international standards**. European research should be coordinated and **anticipate the evolution of the innovation ecosystem**, embracing and welcoming beneficial synergies. Furthermore, a **holistic approach to support the entire battery value chain** is beneficial for Europe and will pave the way for smaller actors to rise.

Being the hub for battery research in Europe, the Batteries Europe ETIP underlines the need of supportive European and national policy frameworks that should be developed alongside research, following the key recommendations of this document.

KEY PERFORMANCE INDICATORS

In the definition of a strategic research agenda that covers wide applications and the entire battery value chain it is necessary to define current state of the art key performance indicators (KPI's) and target KPIs along with a considered timeframe.

A detailed and comprehensive set of KPIs is herein presented. The information in these tables is a subjective recommendation made by some of the key stakeholders of Batteries Europe and will be open to a further consultation process. Extensive consultation has been limited somewhat due to the restrictions imposed on large scale meetings by the COVID-19 crisis. These data will be reviewed in 2020-2021 by the working groups and experts active in Batteries Europe.

The identified KPIs are tailored to the specific applications and value chain segment, presented in the separate tables. which therefore must be fulfilled in their entirety. It is worth noting, in some cases this is the first time KPI's have been created for specific applications.

Disclaimer

The data contained in this document should not be considered as an official document from the European Commission. The European Commission is not responsible for any errors or omissions, or for the results obtained from the use of this information.

TABLE 10: ROAD TRANSPORT: LIGHT DUTY BEV*TYPICAL BATTERY SIZE

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

*The following specifications do not consider new use cases such as vehicle-to-grid

** Here it is not specified if the pulse is in charge or discharge mode. The operating conditions give 10%-100% as a SoC range in which the 180s power pulse can be applied; obviously for low SoC starting values the pulse should be applied in charge mode, whereas for high SoC starting values the pulse should be applied in discharge mode.

TABLE 11: ROAD TRANSPORT: MEDIUM AND HEAVY DUTY BEV*

Road transport: medium and heavy duty BEV*					
Typical Battery Size: 150-600 kWh (today), up to 1000 kWh (in the future)					
KPI	Operating conditions	System/Pack/ Cell level	Unit	2020	2030
PERFORMANCE					
Cell/pack weight ratio		Pack	%	70	80
Cell/pack volume ratio		Pack	%	60	75
Operating lifetime expectation	Minimum guaranteed lifetime (equivalent 80% DOD)	Pack	km	~750,000 (~Vehicle lifetime)	
Gravimetric Power density**	180s, SoC 100%-10%, 25°C	Cell	W/kg	750	1,000
Gravimetric Energy density	C/3 charge and discharge, 25°C, charging with CC and CV step	Cell	Wh/kg	~250	~450
Volumetric energy density	C/3 charge and discharge, 25°C, charging with CC and CV step	Cell	Wh/L	~500	1,000
Volumetric power density**	180s, SoC 100%-10%, 25°C	Cell	W/L	1,500	2,200
Cycle life	80% DOD, 25°C	Cell	cycles	3,000	6,000
Hazard level		Cell	-	<=4	<=4
COST					
Cost		Pack	€/kWh	~400	~150
Cost		Cell	€/kWh	~140	~75
MARKET					
Market size	Source: Avicenne Energy, 2019, IEA Global EV Outlook 2020		GWh/year	~20	~200

*The following specifications do not consider new use cases such as vehicle-to-grid

** Here it is not specified if the pulse is in charge or discharge mode. The operating conditions give 10%-100% as a SoC range in which the 180s power pulse can be applied; obviously for low SoC starting values the pulse should be applied in charge mode, whereas for high SoC starting values the pulse should be applied in discharge mode.

***EUCAR cell-level safety performance.

TABLE 12: ROAD TRANSPORT: LIGHT DUTY PHEV*

Road transport: light duty PHEV* Typical Battery size (light duty vehicles): 5-15 kWh (today), up to 25kWh (in the future)					
KPI	Operating conditions	System/Pack/ Cell level	Unit	2020	2030
PERFORMANCE					
Cell/pack weight ratio		Pack	%	70	75
Cell/pack volume ratio		Pack	%	60	70
Operating lifetime expectation	Minimum guaranteed lifetime (equivalent 80% DOD)	Pack	km	~150,000 (~Vehicle lifetime)	
Gravimetric Power density**	180s, SoC 100%-10%, 25°C	Cell	W/kg	750	1,750
Gravimetric Energy density	C/3 charge and discharge, 25°C, charging with CC and CV step	Cell	Wh/kg	~200	350
Volumetric energy density	C/3 charge and discharge, 25°C, charging with CC and CV step	Cell	Wh/L	~500	800
Volumetric power density**	180s, SoC 100%-10%, 25°C	Cell	W/L	1,500	3,850
Cycle life	PPT	Cell	cycles		> 2,000
Hazard level ***		Cell	-	<=4	<=4
COST					
Cost		Pack	€/kWh	230	120
Cost		Cell	€/kWh	145	100
MARKET					
Market size	Source: Avicenne Energy, 2019, IEA Global EV Outlook 2020		GWh/year	~5	~100-150

*The following specifications do not consider new use cases such as vehicle-to-grid

** Here it is not specified if the pulse is in charge or discharge mode. The operating conditions give 10%-100% as a SoC range in which the 180s power pulse can be applied; obviously for low SoC starting values the pulse should be applied in charge mode, whereas for high SoC starting values the pulse should be applied in discharge mode.

*** EUCAR cell-level safety performance

TABLE 13: OFF-ROAD MOBILE MACHINERY

Off-Road Mobile Machinery Typical battery size: 20 kWh - 1000 kWh					
KPI	Operating conditions	System/Pack/ Cell level	Unit	2020	2030
PERFORMANCE					
Cell/pack weight ratio (%)		Pack	%	70	80
Cell/pack volume ratio (%)		Pack	%	60	75
Operating lifetime expectation		Pack	hours	~20,000h (~Vehicle lifetime)	
Gravimetric energy density	C/3 charge and discharge, 25°C, charging with CC and CV step	Cell	Wh/kg	200	350
Volumetric energy density	C/3 charge and discharge, 25°C, charging with CC and CV step	Cell	Wh/L	500	800
Cycle life	80% DOD, 25°C	Cell	Cycles	3,000	6,000
Charging time	80% ΔSOC, Minimum impact to lifetime	Pack	Minutes	60-90	20-30
Hazard Level*		Cell		<=4	<=4
COST					
Cost		Cell	€/kWh	150	80
Cost		Pack	€/kWh	>500	200
MARKET					
Typical market size	Source: Northvolt internal studies		GWh/an	1	30

* EUCAR cell-level safety performance

TABLE 14: AIRBORNE TRANSPORT: BATTERY ELECTRIC OR HYBRID ELECTRIC AIRCRAFT WITH ENERGY BATTERY

Airborne transport: battery electric or hybrid electric aircraft with energy battery* Typical battery size: 250 to 1000 kWh					
KPI	Operating conditions	System/Pack/ Cell level	Unit	2020	2030
PERFORMANCE					
Cell/pack weight ratio (%)		Pack	%	70	80-90
Operating lifetime expectation		Pack	years		2
Charging time	Back 80% SoC		minutes		30
Gravimetric energy density (Wh/kg)	2C Discharge - 23 °C	Cell	Wh/kg		500-600
Cycle life (number of cycles)	80% DoD, 23 °C, 3 C charge, 1 C discharge	Cell	cycles	N/A	> 3,000
Hazard level**		Cell		N/A	< or = at 2
COST					
Cost		Cell	€/kWh	N/A	100-200
(€/kWh)		Pack	€/kWh	N/A	200-300
MARKET					
Typical market size	Source: Safran, Saft internal studies		GWh/year	N/A	1

*Typical use case: small-to-medium size conventional aircrafts, powered through a full electric or hybrid architecture

** EUCAR cell level safety performance

TABLE 15: AIRBORNE TRANSPORT: BATTERY ELECTRIC OR HYBRID ELECTRIC AIRCRAFT WITH POWER BATTERIES

Airborne transport: battery electric or hybrid electric aircraft with *power* batteries Typical battery size: 150 kWh					
KPI	Operating conditions	System/Pack/Cell level	Unit	2020	2030
PERFORMANCE					
Cell/pack weight ratio (%)		Pack	%	70	80-90
Operating lifetime expectation		Pack	years		2
Charging time	Back 80% SoC		minutes		20
Gravimetric energy density (Wh/kg)	8C discharge, 23°C	Cell	Wh/kg		450
Cycle life (number of cycles)	80% DoD, 23 °C, 3 C charge, 1 C discharge	Cell	cycles	N/A	> 3,000
Hazard level**		Cell		N/A	< or = at 2
COST					
Cost (€/kWh)		Cell	€/kWh	N/A	100-200
Cost (€/kWh)		Pack	€/kWh	N/A	200-300
MARKET					
Typical market size	Source: Safran, Saft internal studies		GWh/year	N/A	2 to 5

*Typical use case: small-to-medium size conventional aircrafts, powered through a full electric or hybrid architecture

** EUCAR cell level safety performance

TABLE 16: AIRBORNE TRANSPORT: HYBRID ELECTRIC AIRCRAFT WITH HIGH POWER BATTERY

Airborne transport: hybrid electric aircraft with high power battery* Typical battery size: up to 100 kWh					
KPI	Operating conditions	System/Pack/ Cell level	Unit	2020	2030
PERFORMANCE					
Cell/pack weight ratio (%)		Pack	%	70	80-90
Operating lifetime expectation		Pack	years		3
Gravimetric energy density (Wh/kg)	30C Discharge - 23 °C	Cell	Wh/kg		200
Cycle life (number of cycles)	80% DoD, 23 °C, 3 C charge, 1 C discharge	Cell	cycles	N/A	> 3,000
Hazard level**		Cell		N/A	< or = at 2
COST					
Cost ($/kWh)		Cell	$/kWh	N/A	100-200
Cost ($/kWh)		Pack	$/kWh	N/A	200-300
MARKET					
Typical market size	Source: Safran, Saft internal studies		GWh/year	N/A	<1

* Typical use case: short-to-medium range conventional aircraft (A320 type like), battery used for power boost in specific flight phases

** EUCAR cell level safety performance

TABLE 17: WATERBORNE TRANSPORT: BATTERY ELECTRIC OR HYBRID ELECTRIC SHIP WITH ENERGY BATTERY

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

TABLE 18: WATERBORNE TRANSPORT: BATTERY ELECTRIC OR HYBRID ELECTRIC SHOP WITH POWER BATTERY

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

TABLE 19: STATIONARY

Stationary								
Parameter	KPI	Operating conditions	Description	System/ Pack level	Unit	2015	2020	2030
PERFORMANCE								
Battery lifetime	Cycle life	(at 25° temperature)	Cycle life to 70% BoL and 100% DOD	Module level	n. of cycles	1,000-3,000	5,000	15,000
Battery lifetime	FEC - Full Equivalent Cycle	(at 25° temperature)	FEC - Life for stationary applications to 70% BoL and 100% DOD	Module level	n. of cycles	3,000- 4,000	4,000-5,000	15,000
Battery lifetime	Calendar life	(at 25° temperature)	Calendar life considering 70% BoL	Module level	years	8 - 10	15	20
Charge/ discharge	Charging Rate time	(at 25° temperature)	Fast recharge time	Module level	min	30 (10 to 40 min)	22	12
Charge/ discharge	C-rate capability (relevant for power-oriented applications of BESS: grid stabilization etc.)	(at 25° temperature)	C (h^{-1}) Power Rate/Specific Energy. Charge/Discharge	Module level	h^{-1}	1C/3C	4C/4C	8C/8C
Charge/ discharge	Discharge duration (relevant for energy oriented applications/long-term storage systems)	(at 25° temperature)	Energy capacity / rated power	System Level	hours	1-4	4-8	>10
Charge/ discharge	Self discharge rate	(at 25° temperature)	% of SoC per month	System Level	% of SoC per month (%)	30%	2%	0.50%
Charge/ discharge	Roundtrip efficiency DC side	(at 25° temperature) (measured targeting a 1C charge / discharge)	(DC discharged energy/ DC charged energy) for a full cycle at system level	System Level	%	92%	95%	>97%

Charge/ discharge	Roundtrip efficiency AC/DC side	(at 25° temperature) (measured targeting a 1C charge / discharge)	Efficiency of a complete charge/discharge cycle AC/DC/AC (calculated as AC conversion efficiency 98% each way, i.e. equal to 96% roundtrip)	System Level	%	88%	91%	>93%
Response	Response time	(at 25° temperature)	0-100% Power	System Level	0-100% Power (s/ms)	>1	200 ms	<100 ms
Energy density/ power	Gravimetric energy density	(related to 1C)		Module level	[Wh/kg]	85-135	235	>250
Energy density/ power	Volumetric energy density	(related to 1C)		Module level	[Wh/l]	95-220	500	>700 - 800
Energy density/ power	Gravimetric power density			Module level	[W/kg]	330-400	470	>700
Energy density/ power	Volumetric power density			Module level	[W/l]	350-550	1,000	>1,400

COST								
Cost	Battery cost		Battery modules cost for ESS application (including battery modules, racks e BMS)	Module level	€/kWh	180-285	150	70
Cost	LCoS	the KPI is dependent on use-case conditions	Cost for stationary applications (Net Present Value of the Total Cost of Ownership (CAPEX + OPEX) / Net Present Value of the Discharged Energy, over the whole project lifetime)	System Level	€/kWh/cycle			
Cost	CAPEX		Capital cost of the whole system for stationary applications	System Level	€/kWh	600-800	450-350	

TABLE 20: EUROPEAN CELL PRODUCTION CAPACITY

European Cell Production Capacity					
KPI	Description	Unit	2014-2015	2020	2030
Li ion Battery cell production	Automotive (Li-ion and next generation post-lithium) battery cell production in the EU	GWh/year,	0.15-0.20	+25	+350

TABLE 21: SAFETY & SUSTAINABILITY

Safety & sustainability					
KPI	Description	Unit	2015	2020	2030
Safety (E-mobility)	> 10Ah Cell level, EUCAR HL4 (mechanical, electrical, thermal)	ºC	-30 to 60ºC	-30 to 60ºC	-30 to 60ºC
Sustainability	REACH, CRM	%	-	< 10% CRM	No CRM

TABLE 22: TOTAL RECYCLING BATTERY MATERIALS

Total recycling battery materials				
KPI	Description	2023	2028	2030
Recycling, efficiency	Recycling efficiency Li-ion batteries (by average weight of waste battery)	50%	60%	60%
	Metal specific targets	Cobalt: 90% Nickel: 90% Lithium: 35% Copper: 90%	Cobalt: 95% Nickel: 90% Lithium: 70% Copper: 95%	Cobalt: 95% Nickel: 95% Lithium: 75% Copper: 95%
	Other battery chemistries	Pb-acid: 65% NiCd: 75%	50% for all other batteries except: Pb-acid: 75% NiCd: 75%	
Product recovery	Number of recovered products eg Cu, Al, Li, Co, etc	4-6%	6-10%	
Recovered elements	Number of elements recovered from battery waste back to use (Mn, graphite, REEs, electrolytes, F …)			80%
Reduced direct or indirect CO^2 emissions				
Quick addressing of new chemistries	Addressing the recyclability of new battery chemistries (eg. V, Mn, Na, solid state, sulphur)			

TABLE 23: TAKE BACK OF BATTERIES

Take back of batteries				
KPI	Description	2020	2025	2030
Collection		45%	55%	65%
Collection		No specific Take-back target, well implementation of a reporting system		
Overall recycling efficiency			50%	60%
Material recovery targets**			Co, Ni, Cu: 90% Li: 35%	Co, Ni, Cu: 95% Li: 70%

* Take back rate calculated based on the average of portable batteries placed on the market during the last 3 years.

** Material recovery targets are calculated on the quantity of metal equivalent (independently from the actual form(s) of the recovered material)

TABLE 24: SOURCING, SUSTAINABILITY AND TRACKING

Sourcing, sustainability and tracking		
KPI	Description	Value
Sustainability of the value chain. *	Sustainability Standard for Mining. Number of sustainability approaches/certificates in use	1
LCI availability (for raw materials)	Update within 2 years PEF database and identify gaps by material (prioritized). Address gaps and proxy needs	
LCI availability from large scale mining	Environmental information available for battery raw materials	90% by production volume**
ASM data availability	Process based LCA data on battery raw material extraction and processing is made available; ensure data quality is adequate and improve it. Provide guidelines to ensure safety Collect environmental information	Apply PEF DQR; aim to move from 4 to 2 within 2 years;
LCI availability from artisanal mining	Environmental information available for battery raw materials	50% by production volume
Environmental impacts per kg of raw materials	Revisit list from the PEFCR for High Specific Energy Rechargeable Batteries for Mobile Applications	Improve accuracy of data, characterization factors and models
Data sharing	Decentralizing information on industry aggregates for mining site operations and emissions	15% of European mines have decentralized information 50% by 2025
Social impacts	Incorporate social impacts that could be based on the UNEP SETAC guidelines for sLCA. Impacts on health of miners and social indicators (human rights).	Assessment of specific materials by chemistry (CRMs, active materials)

Sourcing, sustainability and tracking		
KPI	Description	Value
Stock and flows, Volumes of batteries placed on market and Raw Material Index	See PROSUM project and Material System Analysis by the European Commission (JRC). Update to the trade codes (PROC, ...) to provide more consistent descriptions of raw materials, components and products	PROSUM project revisited and updated. Improvement in coding to improve the tracking systems. Balanced stocks and flows (only 20% missing flows and stocks)
Share of European raw materials	Increase the share of European primary and processed (imported) raw materials in batteries produced in Europe. Increase the Li recovery in recycling.	1 Scale up pilot for Lithium material refining and recycling
Tracing	Number of tracing technologies/concepts from mine to battery piloted/evaluated	3–5
Tracing	Share of batteries manufactured in Europe where an approved raw material tracing technology has been implemented	90% by 2030

* Sustainability standards exists already. To be defined more precisely which standards are used in Europe. Should also include CO_2 emissions. Sourcing of materials outside Europe should also include transportation. Mining sustainability and sourcing of material are separate issues.

** Shall be more specific which materials we are focusing on and explained in more details. Quality of the data more important than the quantity.

TABLE 25: SUSTAINABLE PROCESSING OF BATTERY RAW MATERIALS

Sustainable Processing of Battery Raw Materials		
KPI	Description	Value
BY 2025		
European extraction of battery metals	Number of new mines in operation for lithium, cobalt or graphite	3-5 (2027)
Battery metal processing	Number of new pilot plants, demonstration units or prototypes	Value to be determined
Valorization of side streams	Number of sites where tailings or other side products taken into use	Value to be determined
Improvement of existing processes	Reduction of processing steps demonstrated in add-on for old processing, e.g. leaching steps	Value to be determined
BY 2030		
Environmental footprint	Liquid discharge from battery grade material processing	Zero
Energy efficiency	Efficiency improvement in graphite, battery chemical and pCAM (precursor cathode active materials) processing against current state of art	25 %
CO2 emissions	Reduction of CO2 emissions in lithium extraction and processing compared to current state of art • 25% of LCE used by European battery manufacturers produced from European own sources	50 %
European sourcing and processing	Share of battery grade lithium (carbonate, hydroxide) used by European battery manufacturers produced from European own sources	25 %

TABLE 26: SECOND LIFE OF BATTERIES, CIRCULAR ECONOMY MODEL

Second life of batteries, circular economy model	
Market data related KPIs* (multi-functional use):	
KPI-1:	Capacity and weight of EV-ITB placed on the market for the first time
KPI-2:	Number/weight of EV-ITB taken back (collected) and sent at EoL directly towards recycling
KPI-3:	Number/weight of EV-ITB taken back (collected) and sent to a contracted remanufacturer (for re-use in the same EV application)
KPI-4:	Number/weight of EV-ITB remanufactured and sent at EoL towards recycling
KPI-5:	Number/weight of EV-ITB taken back (collected) and sent to a contractor for refurbishment/re-purpose (for second life in another application)
KPI-6:	Number of EV-ITB re-purposed and placed on the market for the first time (after refurbishment, i.e; for a second life)
KPI-7:	Number of EV-ITB re-purposed and sent at EoL towards recycling (at the end of the second life)
* KPIs based on rechargeable Industrial Traction Batteries (ITB) from electric vehicles (EV), per EU Member State, and consolidated for total EU.	

9. ACRONYMS:

AC	Alternating current	ITB	Industrial Traction Batteries
ADR	Agreement concerning the International Carriage of Dangerous Goods by Road	KPI	Key Performance Indicator
AI	Artificial Intelligence	LCA	Life-cycle assessment
ARB	Aqueous Rechargeable Battery	LCE	Lithium Carbonate Equivalent
BES	Battery Energy Storage	LCI	Life-cycle information
BESS	Battery Energy Storage Systems	LCoE	Levelized Cost of Energy
BEV	Battery Electrified Vehicle	LCoS	Levelized Cost of Storage
BIG	Battery Interface Genome	LFP	Lithium iron phosphate
BM	Battery Management	Li-M	Lithium metal
BMS	Battery Management System	LIB	Lithium-ion battery
BoL	Beginning-of-life	Li-ion	Lithium-ion
CAPEX	Capital expenditures	MAP	Materials Acceleration Platform
CL	Cycle Life	MCDA	Multi Criteria Decision Analysis
CRM	Critical Raw Materials	MS	Member States (of the European Union)
DC	Direct Current	Na-ion	Sodium-ion
DCR	Direct Current Resistance	NCA	Lithium nickel cobalt aluminum oxide
DOD	Depth-of-discharge	NMC	Lithium nickel manganese cobalt oxide
EBA	European Battery Alliance	NRCG	National and Regional Coordinators Group
EC	Ethylene carbonate	OEE	Overall Effectiveness Efficiency
EC	European Commission	OEM	Original Equipment Manufacturer
EES	Electric Energy Storage	OPEX	Operating expenses
EoL	End-of-life	Pb-acid	Lead-acid
EPR	Energy-to-power ratio	pCAM	Precursor Cathode Active Materials
ESS	Energy Storage System	PHEV	Plug-in hybrid electric vehicle
ESW	Electrochemical Stability Window	PV	Photovoltaic
ETIP	European Technology and Innovation Platform	PV-BES	Photovoltaic and Battery Energy Storage
EV	Electric Vehicle	REE	Rare Earth Element
FEC	Full Equivalent Cycle	RES	Renewable energy sources
FTE	Full time equivalent	RFB	Redox-flow batteries
GHG	Greenhouse Gases	RIA	Research and Innovation Actions
HESS	Hybrid Energy Storage Systems	RTO	Research and Technology Organisation
HE-NMC	High Energy Lithium nickel manganese cobalt oxide	SDR	Self-discharge rate
HSS	High-strength steel	SET	Strategic Energy Technology
HVS	High-voltage spinel	SLCA	Sustainable Life-cycle assessment
IA	Innovation Actions	SoC	State-of-Charge
ICT	Information and communications technology	SoH	State-of-Health
IEA	International Energy Agency	SRA	Strategic Research Agenda
IoT	Internet of Things	TRL	Technology Readiness Level
IP	Intellectual Property	TWG	Temporary Working Group
IPR	Intellectual Property Rights	WG	Working Group
		Zn-air	Zinc-air