BATTERIES EUROPE
EUROPEAN **TECHNOLOGY**
AND **INNOVATION** PLATFORM

BATTERIES EUROPE SUGGESTED R&I TOPICS SPRING 2020

DETAILED SUMMARY

INTRODUCTION AND BACKGROUND

In recent years, Europe has become a leader in the fight against global warming. In order to be able to achieve the objectives of decarbonisation, the European Union has set major targets for the reduction of greenhouse gas emissions. These objectives are being accompanied by very concrete actions, such as research and innovation programmes for the development of renewable energies, smart energy systems and electric mobility.

These actions are all the more important given the level of ambition encompassed in the European Green Deal and urgent necessity to boost research and innovation so to strongly support European industries with competitive advantage in the wake of the Covid-19 impact. Batteries have a key role to play in reaching the EU’s 2030 and 2050 decarbonisation objectives. They are of direct relevance to the recent major EU initiatives, including energy sector integration through electrification of transport, just energy transition, the Clean Energy for EU Islands initiative, consumer empowerment and the ‘renovation wave’ (to make our buildings smarter).

The European Commission, as part of a global approach, has recognised the absolute necessity to develop the European battery sector to integrate renewable energies and create a competitive technology, fit for purpose to decarbonise the transport system. It also acknowledged the strategic importance of nurturing the entire value chain in order to reduce European dependency and ensure security of supply. Indeed, batteries are a key enabling technology in the functioning of everyday society from the well-established use in portable consumer electronics, power tools and medical devices to the more recent applications in enabling IoT (Internet of Things) devices, electromobility and stationary energy storage.

It is in this context that the European Battery Alliance (EBA) was created, in October 2017, by the Vice President of the European Commission, Maroš Šefčovič. The European Commission recognised the need to bring together stakeholders from research, academia and industry to discuss and map out strategic needs, in terms of research and innovation (in the short, medium and long term) for the entire battery value chain.

Batteries Europe - European Innovation and Technology Platform (ETIP) was thus launched, in June 2019, as an open platform engaging high level industrial and academic experts. It aims 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. The platform is tasked with creating the European Strategic Research and Innovation Agenda (SRIA) 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. Furthermore, the Batteries Europe hosts a National and Regional Coordination Group (NRCG) which provides a communication and cooperation forum between Member States and Associated Countries, which reduces the duplication of research efforts and results in synergetic effects.

THE DEVELOPMENT OF THE R&I TOPICS DOCUMENT

Recently, the Batteries Europe has defined **short term R&I priorities for the entire battery value chain**. The document provides a condensed overview of key topics and is the result of a long and comprehensive stakeholder's consultation process throughout the entire value chain in order to define short term R&I strategic guidance for policy makers and funding authorities.

The contributions from this document came from the Batteries Europe's thematic working groups, composed of experts representing the battery ecosystem from industry, research and associations and which provide vision and guidance for the development of the integrated research and innovation roadmap. The experts are divided in six Working Groups (WGs) and represent strategically important parts of the battery value chain:

- WG1 – New and emerging technologies
- WG2 – Raw materials and recycling
- WG3 – Advanced materials
- WG4 – Cell design and manufacturing
- WG5 – Application and integration: mobile
- WG6 – Application and integration: stationary

Each of the thematic WGs were requested in November 2019 to begin preparing descriptions and prioritisations of research and innovation topics they deemed of highest importance. A bottom up process was facilitated by the WG chairs and Co-Chairs, in which all the working group experts at a series of face to face meetings, had the possibility to contribute and bring forward their ideas. This was followed by a consolidation step where, in some cases, topics which were found to be overlapping were merged in to a single topic. Following agreement each group contributed between 3 - 6 main research topics, which consider the specific challenge, scope, expected impact and KPIs. Some WGs proposed also a number of additional topics, which they considered important even if not being classified as 1st priority topics.

The document represents the cumulative inputs from 557 battery technology experts working in Europe. A total of **30 R&I topics** spanning the battery value chain have been detailed. All these subjects are deemed as top priority and essential in order to develop the competitive knowledge base, the intellectual property and educated workforce Europe needs to succeed and thrive in this rapidly developing and expanding market.

The document will provide a basis for the discussions on the next research program of Horizon Europe, which will take place in partnership with the industry. Due to budgetary limitations not all topics will necessarily be covered in the context of work programs specifically covering battery technology. If the topics are not covered in the Horizon Europe calls specific to batteries, they will be proposed to other funding mechanisms such as national and bilateral programs. Some topics may be applicable to other domains of the Horizon Europe funding mechanisms, such as European Research Council or European innovation Council. There are also plenty of possibilities to implement R&I projects through the European Regional Development fund, as well as new funding instruments to be created under the Recovery Plan: "Repair and prepare for the next generation"[1].
Last but not least, considerable R&I funding on batteries research will be channelled through the so-called Important Projects of Common European Interest (IPCEI).

[1] https://ec.europa.eu/commission/presscorner/detail/en/ip_20_940

The current report provides a brief summary of the main topics enlisted in the full R&I document, which can be grouped in seven macro areas.

FROM SUSTAINABLE SOURCING TO SECURING THE SUPPLY OF RAW MATERIALS

Europe is facing an increasing challenge to ensure secure and cost-efficient access to essential/critical raw materials for batteries.

Currently the level of extraction and processing of battery raw materials in Europe is marginal. For lithium, hard rock mine projects do exist in Europe, with a collective currently planned capacity corresponding to about 10% of the estimated global demand by 2027. 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.

Accessing untapped European deposits and improving yields and purity of recovered product, reducing the number of processing steps and the volume of tailings are all very necessary developments which will require research efforts to achieve. This must be accompanied by significant reductions in the energy consumption and the CO_2 footprint of raw materials processing to achieve sustainable battery material production and processing in Europe.

To answer these challenges, Batteries Europe identified the *Sustainable Processing of Battery Raw Materials* as a priority. The aim is to develop technologies of extraction and processing of battery raw materials. In particular (but not solely), the targeted materials are lithium, nickel, cobalt and graphite. As many unit processes for battery raw materials already exist in Europe, there is an increasing demand for optimized and integrated processing solutions to supply sustainable raw materials to European battery manufacturers.

Lithium: R&I should be pursued in terms of mineralogy of hard rock lithium deposits to foresee how the mineral mix could be better understood and processed. Water and energy conscious processing methods are needed in addition to secondary product recovery, minimizing tailings and gangue production, is needed as well. Availability of renewable energy sources near lithium processing units and/or mines that can readily be taken into use are essential. Lithium processing should be prioritized as Europe has some own resources, which are still not utilized.

Nickel and cobalt: Nickel and cobalt need to be recovered from the low grade and challenging material streams, which are currently uneconomical to be treated. The development of new technologies for these challenging material streams will significantly widen the metal base in Europe. The product purity will be increased to meet the needs of battery applications.
Graphite: Given the limited availability of natural graphite in the area, synthetic graphite offers the best alternative for sustainable European production, if key challenges are overcome.

Firstly, existing process flow based on petroleum coke must be improved to improve battery grade material yields and performance, whilst reducing energy intensity (and such specific CO2 emissions), and environmental pollutant discharges. Secondly, the use of recycled anode material, EU available carbon options (e.g. available natural graphite qualities in EU) and by-products from anode material production as raw materials for synthetic graphite should be developed. As a longer-term option, bio carbon alternatives to petroleum coke should be developed to ensure long term sustainable supply.

Exploring advanced materials potential for boosting energy storage performance in both mobility and stationary applications

Decarbonisation is one of the crucial tasks for today's society in order to reduce greenhouse gases (GHG) emission and thus the negative impact on our climate. All over Europe transportation accounts for almost 25% of total European CO_2 emissions. In order to reduce GHGs for transportation, the market share of electric vehicles (EV) has to be increased. Lithium-ion batteries (LIBs) are the key technology for electromobility and the implementation of a competitive battery value chain within Europe is an urgent matter.

Li-ion generation 3b batteries for mobility applications

To achieve a high market diffusion of EVs, especially purely battery electrified vehicles (BEVs), increased driving range, greater cycling life and reduced charging times are of major importance, along with developments which will result in cost reductions while improving sustainability for the battery pack and hence for the cells and materials, respectively. To do so, Europe will need to invest in and carry out research on advanced Li-ion batteries for mobility applications such as generation 3b, both high voltage and high capacity, and solid-state lithium batteries with conventional materials but also Li-metal based anode batteries (generation 4a and 4b). Hence, the topic *Li-ion generation 3b batteries for high voltage mobility applications* addresses these challenges with the aim of reaching higher energy densities, developing high voltage (HV) cathode materials concomitantly avoiding or significantly reducing the contents of critical and/or high-cost elements such as cobalt. On the other hand, the topic *Li-ion generation 3b batteries for high capacity mobility applications* has the scope to boost current Li-ion batteries for e-mobility close to their fundamental limits in terms of energy densities and capacity. Such a drastic improvement of performance must be achieved through the development of advanced materials covering cathode, anode, binders, separators, electrolyte, current collectors and packaging materials as to enable new Li-ion batteries, with a focus on generation 3b High Capacity.

Li-ion generation 4a and 4b batteries for mobility applications

The deployment of electric vehicles is today a reality with more and more PHEV[2] and EV's on the market. This is the result of the successful development of Li-ion batteries, however safety issues arise with the liquid electrolyte with the trends to increase cell voltage and fast-charging rates, and this requires the replacement of flammable electrolytes with solid state electrolytes with better intrinsic thermal and electrochemical stability. The main challenge is to achieve fast charging solid state batteries, increase power density without reducing the cyclability, the energy density, and improved safety. This will imply designing new materials derived from conventional chemistries adapted to the solid-state concept. The topic *Li-ion generation 4a batteries (Solid State with conventional materials) for mobility applications* will aim to optimize the solid state battery cells and components, developing low DCR (Direct Current Resistance) active materials, reducing anode thickness, developing thin solid electrolyte with high ionic conductivity, manufacturing new solid electrolyte interlayers, improved interface design to ensure efficient charge-transfer and electrochemical stability and improved cell mechanical stability.

[2] Plug-in hybrid electric vehicles

Considering the global competition, the rush for better technology implies also the need for a better traction battery technology as a key enabling technology whereby improved Li-Ion batteries are expected to remain the main choice for several decades to come. Europe must regain its competitiveness in markets that nowadays are dominated by non-European countries. This could occur by developing a new European owned battery technology. The topic *Li-ion generation 4b batteries (Solid State with Li metal-based anode) for mobility applications* tackle the development of new materials and/or chemistries to increase the energy densities and safety beyond the state of the art of batteries used in automotive applications. Technologies will be developed to enable Li metal with interface-controlled systems.

Sodium-ion (Na-ion) stationary batteries

Stationary energy storage has become a growing global concern over the last decades in view of the increased energy demand of the modern society and increasing share of variable renewables in electricity production. The use of battery energy storage systems has gained increasing interest for providing grid support, local load peak shaving and optimization of local RES exploitation (self-consumption). As previously mentioned, Li-ion batteries have conquered the portable electronic market and currently are the principal candidate to power the electrical vehicles. However, for domestic and grid applications, the high cost, the scarcity and technical constraints such us extreme sensitivity to high temperature, overcharge, etc. are major drawbacks. This opens opportunities for other electrochemical energy storage solutions. Following in-depth assessment of different technological options, Batteries Europe has identified as strategic topic the *Development of Sodium–ion (Na-ion) stationary batteries for domestic applications*. Development of the next generation of sodium-ion batteries offers a multidisciplinary/interdisciplinary approach needed to consider actions from synthesis and characterizations of materials (cathode, anode, electrolyte), towards their integration into novel sodium-ion pouch cell battery. The goal is to develop a battery that reaches higher performances and lower cost at pre-industrial pouch cell prototype level than current commercial batteries for domestic applications. The developed system should be maintenance free and environmentally friendly.

Redox flow stationary batteries

Additional energy storage is needed in Europe to ensure the large-scale penetration of renewable energy. Redox flow batteries (RFB) show potential for renewable energy management due to their scalability between storage capacity and power, short response time, good cycling capability and long discharge time. However, currently used RFB are relatively costly. The challenge is therefore to reduce the cost and increase sustainability by combining different innovations taking advantage of advanced materials. *Redox flow stationary batteries for utility scale applications* aims to develop and validate new redox flow batteries based on new materials (new designs, components, redox couples and electrolytes) that are more price competitive, environmentally sustainable, having higher energy/power density and with greater durability.

Establishing Europe as a leader in battery manufacturing

Sustainable processing for electrode and cell component manufacturing

One of the most crucial aspects of battery development which Europe needs to build competencies and a world leading knowledge base is on battery component and cell manufacturing. Between 2014 and 2019 there was but one EU Horizon call in which Battery manufacturing was in focus. Environmentally sustainable and cost-effective manufacturing will be essential to give Europe the competitive edge. The suggested topic *Environmentally sustainable processing techniques applied to electrode and cell component manufacturing* proposes electrode coating techniques completely without organic solvents as slurry dispersing media. Advanced –higher solids content- coating or completely dry coating techniques will be developed with the aim to reduce production cost, increase battery performance and ultimately result in increased efficiency and better cycle life.

Intelligent electrode and cell production machinery

The battery market is highly competitive with the global manufacturing hub currently in Asia. However, as Europe prepares for large scale local production, game changing manufacturing equipment will be crucial to ensure sustainability and competitiveness. In the development of battery manufacturing machinery, important aspects for success include minimising energy consumption, eliminating air and water pollution, and integration of intelligent control processes to minimise scrap, thereby reducing costs and environmental impact of the production process. In addition, such machinery must operate at very high productivity levels while incorporating intelligent quality control systems. To achieve these goals, efforts should be made to improve resource efficient and intelligent electrode and cell production machinery. Further requirements in this area are the digitalisation of cell design development and optimisation, including degradation models and large-scale data driven testing. The development, analysis and implementation of digital twins along battery cell production lines can be a game changer with respect to improving sustainability and reducing costs as it provides a virtual mirror where changes to the production process can be virtually tested in real time. The topic *Resource efficient and intelligent electrode and cell production machinery* addresses this issue.

Digital twins development along battery cell production lines

Digitalisation and smart battery design procedures combined with the utilisation of large amount of experimental data will help the EU develop a strong position in the world market of lithium-ion batteries. For this purpose, a focus on optimization of the design process combined with digitalisation data driven methods and artificial intelligence methods are required.

In order to increase battery manufacturing competitiveness, it is important to optimize the resources needed to design, optimize and produce cells for which an analysis of the production lines is required. Thus, battery manufacturing needs to take advantage of high-performance computational tools. Digital twins can provide a virtual mirror to the entire production process chain and factory and are the basis of cyber-physical systems (industry 4.0). The digital twins predict the effect of process chain design and process parameters on production efficiency, costs and CO_2-footprint as well as on material structure and cell quality. They are needed for optimum process chain design and best process parameter setup and can be adapted to specific requirements in real time control of production, answering what-if questions and reducing trial & error approaches in the manufacturing process. Thus, the use of a digital twin will increase competitiveness and sustainability and reduces design, development and test time during process optimization and thus improve plant efficiency. The topic *Analysis and Implementation of digital twins along battery cell production lines* focuses on this matter.

Battery manufacturing factory plant value chain integration

Triggered by huge efforts both from the private and public sector, Europe is gradually strengthening its battery cell manufacturing value chain by building-up its own cell-manufacturing capabilities in the Member States. When it comes to sourcing process equipment, however, manufacturers still rely to a large extent on an Asian supply-chain. European machinery and plant engineering companies are offering innovative process equipment, but this has often not yet been implemented in giga-scale production lines. For sustainable success, the horizontal integration of the European supply chain for battery process equipment into the growing production of giga-scale battery cells is a major challenge. Hence, Batteries Europe identified a need to close the gap between (i) industrial-scale cell manufacturing and (iia) battery process equipment companies, (iib) material and other industrial sectors potentially benefitting from sector coupling with cell manufacturing (e.g. grid power or material suppliers), as mentioned in the topic *Towards integration battery manufacturing factory plant value chain - from upscaling and innovation of battery process equipment, to energy efficient material and energy flow ecosystems integration*. More specifically, this proposed topic suggests a Coordination Support Action (CSA) aimed at enabling deeper collaboration in the network, providing an essential element for the competitiveness of the European battery value chain.

ENABLING MOBILITY

Transport in general and the automotive sector in particular will dominate growth in demand for battery cells in the mid-term, as it is already the case today. This will play a key role in driving down costs, thanks to significant economies of scale. However, many challenges are ahead to meet the technological needs of the future European transport sector.

Design and manufacturing of battery modules and packs

Batteries Europe considers the design and the manufacturing of battery modules and packs as an indispensable issue to be tackled in the short term. Indeed, packs in modular design can be used for a wide variety of mobile applications. Module and pack eco design, considering the process from production via maintenance, repair, dismantling and recycling, is gaining more importance as well. Europe needs to aim for environmental sustainability, module standardization, designs for low-cost maintenance and automated manufacturing processes, supported by different simulation approaches – including digital twin. The topic *A System approach: Design and manufacturing of battery modules and packs* aims to define innovative design (optimising both mechanical and electrical designs) as well as related manufacturing processes, to reduce development time and cost and to increase performances, all the while considering sustainability aspects, e.g., recyclability and carbon footprint.

Thermal management performance

Thermal management is an important aspect in future acceptance of electrified transport, in particular considering fast charging. It supports the safety and reliability of the battery system which is also decisive for acceptance and breakthrough of e-mobility in general. Batteries Europe proposes the topic *Advanced thermal management performance* to develop improved thermal management while reducing costs (and when relevant volume and/or weight), and increase efficiency, reliability, lifetime and security of the battery system.

Advanced battery management for optimised battery utilisation

Compact, high energy density battery cells, modules and packs such as those used in automotive applications are complex, and potentially dangerous if not correctly controlled. To tackle these issues, the development of better advanced battery management is a way to ensure the optimisation of battery utilisation. Indeed, secure, real-time, data-based battery management will ensure optimised and safe utilisation during all modes of operation. The topic *Advanced battery management for optimized battery utilization* aims to develop knowledge and data-based battery management systems to lower the overall cost of battery systems, ensure an optimized and safe utilization during all modes of operation, and provide an accurate classification for a "Second Life".

Digital twins of battery modules and packs for development, manufacturing processes and battery management

The battery module & pack development and production for mobile applications occur based on experimental know-how and large numbers of trials. In order to reduce the cost, speed up the development process and increase the reliability of battery modules and packs during development and production, it will be necessary to use a digital twin for the representation of the real physical product and simulation of manufacturing processes and system designs. Therefore, Batteries Europe proposes the topic *Digital twins of battery modules and packs for development, manufacturing processes and battery management.* It tackles the development of a digital twin creation and development for the representation of the real physical product and simulation of manufacturing processes and system designs. This will speed up the development process and increase the reliability of battery modules and packs during the development and production.

Methods and tools for battery safety, performance, reliability and lifetime assessment

Existing methods and tools for assessing battery safety, performance, reliability and lifetime are usually time-consuming and costly (for example, assessing battery safety is performed today only via destructive/abusive testing of sample cells). These methods are costly both in terms of test samples and test infrastructure, and do not enable industrial battery pack assessment at a high throughput, at the end of the production phase or later during battery lifetime. Moreover, the cell-level assessments performed today are usually not detailed enough to anticipate the performance, safety, durability and reliability at the pack level. Hence, the topic *New methods and tools for assessment of battery safety, performance, reliability and lifetime* was proposed as an important topic. Relevant R&I should address the definition of new methods and tools, for cross industry validation, based on various techniques, such as characterization, virtual and live testing, simulation or a combination of these. The main goal should be to substantially reduce the cost (at least 20%-30%) and/or the duration (at least 20%-30%) of battery assessment, as well as enhance its quality.

SUPPORTING THE DEPLOYMENT OF STATIONARY ENERGY STORAGE AND INTEGRATION OF E-MOBILITY

Safety requirements for stationary electrical energy storage systems

An important prerequisite for the expansion of electrical energy storage systems is their verified safety along the entire value chain. So far, it hasn't been addressed sufficiently. Safety measures exist on the different levels from material level to the cell and also on application levels for the various storage applications from portable devices to electronic vehicles. However, standards are largely still missing for stationary EES applications. In order to increase the use of electrochemical energy storage (EES) in stationary systems e.g. in power storage stations of large dimensions and high energies safety is key. The topic *Safety requirements for stationary electrical energy storage systems* aims at identification of risks and minimum safety requirements through R&I, considering their specific conditions, e.g. grid interfaces, buildings, rescue systems etc. Knowing the state of safety will enable to increase the overall safety in stationary EES applications and thus will open up these fields for the re-use of batteries (Second life) on a large scale. Europe must lead the safety challenges of new energy storage systems to both promote more reliable deployments and prevent the entry into the market of non-compliant solutions.

Open access battery management systems

Advanced battery storage systems will play a major role in the future energy sector. They will allow the continuous deployment of solar and wind energy sources, support the utilization of industry 4.0, and boost the development of small robotised devices dedicated to the industry or private households. One major challenge with current battery storage systems is that their status of life (which includes state of health, state of function and security aspects) decreases with time and use due to electrochemical degradation of the cells. This state of life needs to be estimated via the Battery Management System (BMS). In the case of Hybrid Energy Storage Systems (HESS), where several batteries are combined to perform as a single Battery Energy Storage System (BESS), the knowledge of the battery state of life is crucial to leverage the synergies of the chemistries. The challenge is to establish standard procedures to determine the state of life indicators of the system. In addition, third parties must have access to all necessary battery system information, battery condition, operational modes and condition of interoperability. The topic *Open access battery management systems using standard procedures for state of life determination* proposes to develop solutions allowing for an increased battery lifetime and to demonstrate non-discriminatory methods to diagnose and prognosticate the state of life of battery systems. This can be achieved, for example, through advanced BMSs with real-time algorithms and innovative instrumentation, as well as offline solutions using historical data and benefiting from high computational capabilities.

Interoperability for Stationary Battery Energy Storage

Interoperability and multiservice operations are key pillars in which Battery energy storage systems can outperform other competing energy storage technologies. It is also important for using flexibility of EVs. Aligning interoperability with appropriate standards, business models, and technical solutions need to be a part of BESS, Hybrid Energy Storage Systems (HESS) and EV development to achieve multi-service flexibility. The topic *Interoperability for Stationary Battery Energy Storage Systems for the*

Advancement of Multi-Service Flexibility, Hybrid Solutions, and EV development suggests developing technology to enable the seamless utilization and monetization of BESS and EV flexibility within an interoperable environment by developing interoperability and seamless real-time data sharing, through aligning existing standards from the utility and ICT domains, across the devices and systems to enable innovative BESS and EV services.

Battery energy system for medium to long term storage

To facilitate the transition of the European continent to a zero-emission energy system by 2050 as set out in the Green Deal, the availability of cost efficient, reliable and sustainable energy storage is key. Developing fit for purpose electrochemical energy storage systems (ESS) which facilitate a range of services is necessary. Furthermore, it not the batteries alone that requires development but the systems as a whole with its electronic components, managements systems and advanced software that is necessary to obtain a final marketable solution. The topic *Battery energy systems for medium to long term storage* address the necessity to develop and demonstrate real life large scale solutions for longer term energy storage (10+ hours), which could have a positive impact on the penetration of not programmable and intermittent wind and PV green energy. Daily peak shifting is a great business opportunity for European companies that might find a gap to compete against other world areas with proprietary technology, both at chemistry and system level. The market for grid support, load shifting, and arbitrage well justify the effort to support European based solutions providers.

Storage and DC micro-grid architecture

In the context of stationary energy storage, load and storage devices, as well as electric vehicles, the DC micro-grid concept attracts growing attention thanks to the significant increase in penetration of DC renewable sources. The DC micro-grid presents the possibility of simplifying the grid architecture while reducing energy losses and cost due to of the requirement for fewer converters and other components, in addition to their simplification. DC microgrids technology offers high expectations in LCOS improvement as a remarkable advantage as well as flexibility and hybridisation on storage systems development. The topic *Storage and DC micro-grids architecture & dedicated electronics* focuses on the essential developments which are necessary for the reduction of the cost of installation of battery energy storage systems (BESS). Currently, the high initial cost (CAPEX) and complexity of the electronics and related infrastructure has been identified as a major prohibiting factor in the integration of BESS despite the many functionalities and long-term benefits that can be gained. It is essential this topic is addressed to facilitate increased RES usage.

Modelling and standardisation of second life EV batteries for stationary storage

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. The use of second life batteries for stationary energy storage can yield a host of benefits including considerably reducing the carbon footprint of batteries due to the extension of lifetime. However, significant developments with respect to methods of assessment, reconditioning and battery management are required before the use of batteries for second life can be utilised extensively. These developments are addressed in the topic *Modelling and standardisation of second life EV batteries for stationary storage*. By developing the technology and mechanisms (such as assessment, reconditioning and optimised BMS) to enable reliable, safe and sustainable use of second life batteries significant improvements in the LCA of batteries are expected. The GHG emissions and carbon footprint of batteries should be seen to drop substantially due to delaying end of life by at least 50%. Europe must implement actions and monitoring tools for the end of life of energy storage systems sold on the market. Knowing the value or cost of batteries in a second life scenario is an obligation, and not tackling this problem can have an environmental cost of immeasurable magnitude.

RECYCLING BATTERY MATERIALS

Along with the rapid growth of e-mobility and energy storage industries, a growing stream of Li-ion batteries is entering European markets. In the next 10 years a vast number of EV battery systems are expected to reach end of life (EoL).

Battery materials total recycling

Handling end-of-life battery streams necessitates developing a harmonised system of battery handling across the EU. Hence, tackling collection, handling, sorting, and dismantling of EoL Li-ion batteries are the first necessary steps in getting the materials back into the battery value chain and ensuring proper recycling. More environmentally friendly processes should be developed with the aim of minimising the energy, water and chemical consumption, as well as recycling the chemicals, and minimising the exposure to hazardous materials. *Improved total recycling of battery materials* targets the 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 pre-production scrap. The aim is to build recycling processes recovering the greatest amount (high recovery rate of single elements/material, but also high total overall materials recovery) of resources present within these secondary raw materials.

Collection, reversed logistic, dismantling and sorting

The stream/flow throughout the value chain of Li-ion batteries across Europe is very diverse. The great variety of types, sizes, shapes, connections and chemical compositions of active materials make it very difficult to be handled effectively, at maximum possible takeback rate and with minimum CO_2 footprint. This could be achieved, among others, by re-directing part of streams to second life applications after expert diagnosis and assessment of state-of-health. Sorting technologies are therefore another area to be further developed.

Safety issues during all stages of recycling should also be addressed with appropriate attention. The status of collected EoL batteries is usually unknown at the takeback points and authorized treatment facilities of end-of-life vehicles. When bearing an electric load, the risk of electric shocks should be taken into account. The risk of fire and explosion can appear when short-circuit process or solder /joint impairment starts in a broken battery. These initiate uncontrolled releases of heat which starts a chain reaction (thermal runaway), decomposition and evaporation of electrolyte and organic compounds inside the batteries, leading to even accelerated burning rates and finally explosion with potential for poisonous gas emission. These dangers are particularly significant during handling high-energy batteries from e-mobility or energy storage applications. *Collection, reversed logistics, dismantling and sorting* refers to developing comprehensive technologies for safe and effective handling of the growing battery streams before they finally enter the recycling process. Methodology and technologies for state-of-health (SoH) assessment and sorting (automated and standardized where possible) will be created, to separate potentially dangerous batteries from ones that could be re-used or re-purposed for secondary applications.

Fostering new and emerging technologies

Batteries Europe believes that it is important not only to build the competitive EU battery industry but also to maintain competitiveness in the longer term. Therefore, part of the today's research funding should be directed to longer-term objectives.

Multivalent batteries

Among the new emerging energy storage technologies promising to offer high energy and power density while being green, cheap and safe, new multivalent (calcium, magnesium, aluminium, etc.) batteries could have an important role and need to be explored and developed. The multivalent nature of the cation[3] brings added difficulties but holds the promise of higher energy densities by offering more than one electron per cation and the prospects of using metal anodes, in addition to lower costs due to the use of more abundant materials. *Multivalent batteries* addresses the development of green and sustainable multivalent battery concepts. These new energy storage technologies, based on abundant, multivalent anodes such as calcium, magnesium, aluminium, etc., hold the promise of high energy and power densities whilst being green, cheap and safe.

Non-conventional redox flow batteries

In order to boost the introduction of energy storage systems coupled to renewable energy sources at competitive energy prices (€/kWh), breakthrough technologies are needed in Europe. Batteries Europe believes that the modelling, novel cell chemistries, and new cell design for sustainable non-conventional redox flow batteries represents a step in this direction. *Non-conventional redox flow batteries: modelling, new sustainable cell chemistries and cell designs* aims to develop electrochemical models to perform simulations, backed up by experimental results that will allow for a faster and cheaper way to discover the most promising redox couples. This should facilitate the search and choice of molecules to experimentally test as redox flow battery catholytes and anolytes and therefore enable a faster development of high energy density, low price, sustainable and safer systems.

[3] a positively charged ion

Aqueous rechargeable batteries for energy storage

Following the same reasoning, Batteries Europe recommends exploring low cost and safe advanced aqueous rechargeable batteries for energy storage. Their inherent properties in terms of safety, cost, and sustainability could be a significant advantage for the European battery value chain in the coming years. The topic *Low cost and safe advanced aqueous rechargeable batteries for energy storage* will explore aqueous rechargeable batteries (ARBs) that are of particular interest for energy storage due to their inherent properties in terms of low cost, sustainability and safety. New types of aqueous batteries could provide fast charge/discharge at higher round-trip efficiency due to their high ionic conductivities. Electrolyte components can be cheaper and environmentally benign. This technology is relevant for large-scale energy storage but also for other applications where high volumetric energy density is not necessary.

New and emerging technologies monitoring interfaces

While the research of novel chemistries is important, Batteries Europe has also identified interfaces between components in the battery cell as an area of research that needs to be extensively investigated and understood. Chemical reactions at battery interfaces greatly impact the lifetime and the safety of the battery. For these reasons, monitoring interfaces of new and emerging battery technologies in operando to increase our understanding and thus the performance of new batteries should be seen as another priority. The topic *Monitoring Interfaces of new and emerging technologies in operando* has the scope of studying interfaces inside battery cells during their formation and propagation as a function of battery cycling. Modeling is an essential tool to support the understanding of reactions and/or degradation mechanisms and for the assessment of chemical component formation or break down at interfaces. The aim is to deliver proof-of-concepts for the study of interfaces between components in battery cells but also to elucidate the modus operandi of studying degradation mechanisms due to reactions taking place at the interfaces. The new techniques and approaches should lay the foundation for a sound scientific platform on studies of battery interfaces.

Combinatorial approach for new anode materials discovery

Finally, Batteries Europe observed that the available selection of practical materials for battery anodes is extremely narrow and their performance is one of the major obstacles for the further improvement of battery chemistries. Furthermore, the knowledge concerning stability and performance of new and emerging anode battery materials is limited due to insufficient comparable experimentation evidence and available resources. The long-term challenge is to develop a platform which will allow a rapid, high-throughput and reproducible experimental screening of new potential anode materials. The topic *Combinatorial approach for discovery of new anode materials* aims at creating such a platform for the development and testing of potential anode materials. The approach should demonstrate synergies with the autonomous battery Material Acceleration Platform (MAP) of the Battery 2030+ initiative as the initial suggested selection of suitable materials could be achieved through advanced multiscale modelling processes.