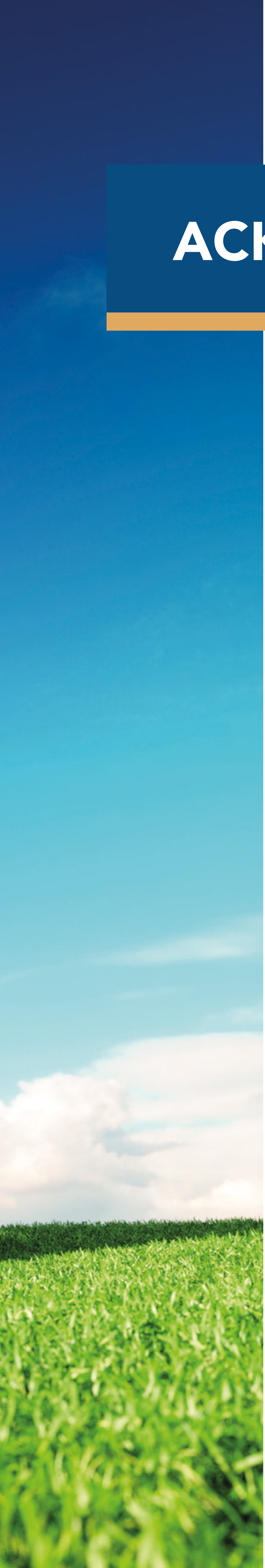
# STRATEGIC RESEARCH & INNOVATION AGENDA

**February 2024**

BATT4EU
Batteries European Partnership

European Partnership

Co-funded by the European Union



# ACKNOWLEDGEMENTS

**This Strategic Research and Innovation Agenda** is a co-creation by the European Commission and the Batteries European Partnership Association (BEPA). In the development of the SRIA, BEPA has worked closely together with the Batteries Europe Secretariat. The Batteries Europe Secretariat is a EU-funded project that has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement N. 101069676. **BEPA and Batteries Europe** have collected input from the wider European Batteries R&I Community by organising six Working Groups and several Task Forces, of which the total attendance figures reach in the hundreds. BEPA and Batteries Europe thank all battery experts who have voluntarily joined these Working Groups and Task Forces. **This SRIA would not be the same without your valuable input**. We would specifically want to thank the beneficiaries of the Battery 2030+ project for their input on the long-term research needs. Battery 2030+ has received funding from the European Union's Horizon Europe research and innovation programme under grant number No. 101104022. The BATT4EU logo and visual identity are a product of AdGrafics Design Studio. The final design of this document was prepared by Nailea E. Gómez Estévez.

Batteries + Europe

BEPA Batteries European Partnership Association

Contributing to The European Batteries R&I Community

Batteries Europe Secretariat is a EU-funded project that has received funding from the European Union's Horizon Research and Innovation Programme under Grant Agreement N. 101069676

# CONTENTS

# EXECUTIVE SUMMARY

Europe is at a crossroads to make good on its goal to establish a competitive European value chain for batteries. Big strides have been made to encourage battery manufacturing plants to be established in Europe. The first gigafactory has been brought online by Northvolt in Sweden, with many more initiatives coming down the pipeline. Market demand for batteries is also on the rise, not only from the EV market, but also for use in other mobility applications and for stationary storage. Recent developments, both on this continent and overseas, however, mean that Europe needs to realign its industrial strategy to meet rising demand and achieve its objectives for the battery value chain
.

The European batteries R&I community has been dedicated to support the establishment of this industrial value chain in Europe, aided by public funding, including by the European Union. The establishment of the BATT4EU Partnership under Horizon Europe in 2021 was a key milestone, but funding for battery R&I is also heavily supported by national and regional governments, as well as individual research originations and private industry, partially under the umbrella of the Important Projects of Common European Interest (the IPCEIs). Given the global geopolitical developments, the potential that batteries hold for reaching the Green Deal objectives, the strategic importance of the battery sector, and the constantly changing nature of this rapidly developing technology, strategic alignment between the actors in Europe is of the utmost importance to deliver on the goals and avoid duplication of efforts or gaps in funding.

This document, which replaces the BATT4EU SRIA of 2021 and the Batteries Europe SRA of 2020, lists the key strategic actions outline that the European Batteries R&I Community that can benefit from collaborative research projects put forward by the BATT4EU Partnership. The SRIA builds heavily on the Roadmaps which have been published by Batteries Europe and Battery 2030+ and is the results of the combined inputs of hundreds of European battery experts.

**WHILE BUILDING ON THE GENERAL DIRECTION AS LAID OUT IN THE PREVIOUS DOCUMENTS, THIS NEW SRIA POINTS TO THE FOLLOWING SIX IMPERATIVES WHICH ARE NECESSARY TO HELP THE COMPETITIVE BATTERY VALUE CHAIN IN EUROPE TAKE ROOT AND DELIVER ON ITS PROMISE:**

**Ensure that (BATT4EU) research results reach gigafactories and the markets,** through pilots, demonstrators and improved decision making aided by digital tools.

**Increase the strategic autonomy of Europe by reducing the reliance on foreign critical raw materials** by supporting local and circular supply chains and support research into different battery chemistries, including sodium-ion technologies.

**Improve battery affordability to accelerate the green transition and keep the European industry competitive** by improving batteries based on materials that are more abundant and pushing for better integration into end-use applications.

**Improve the flexibility of battery manufacturing and recycling systems** to reduce lock-in effects and respond quickly to changes in a rapidly developing industry.

**Implement a safe and sustainable by design framework for batteries,** which plays to European strengths, and which will help reduce emissions and use of substances of concern, improve safety and allow for the integration of smart functionalities.

**Support the continuity of excellent European battery research and academic-industrial cooperation** by improving access to research facilities and pilot lines, use research projects to build up a skilled workface, and by avoiding gaps in research through continued funding, which will bind talented researchers to Europe.

# LIST OF ABBREVIATIONS

| | |
|---|---|
| **BEPA** | Batteries European Partnership association |
| **BESS** | Battery Energy Storage System |
| **BIG-MAP** | The Battery Interface Genome – Materials Acceleration Platform |
| **BMS** | Battery Management System |
| **BTM** | Behind-the-Meter |
| **C2A** | Cell-to-Airframe |
| **C2C** | Cell-to-Chassis |
| **C2V** | Cell-to-Vehicle |
| **CRM** | Critical Raw Material |
| **CRMA** | Critical Raw Materials Act |
| **CSA** | Coordination and Support Action |
| **EASE** | European Association of Storage of Energy |
| **EBA** | European Battery Alliance |
| **EERA** | European Energy Research Association |
| **EMIRI** | Energy Materials Industrial Research Initiative |
| **EMS** | Energy Management System |
| **ETIP** | European Technology and Innovation Platform |
| **FTM** | Front-the-Meter |
| **HLM** | High-Lithium Manganese |
| **IRA** | Inflation Reduction Act |

| | |
|---|---|
| **JRC** | Joint Research Centre |
| **LCA** | Life Cycle Analysis |
| **LCI** | Life-cycle Inventory |
| **LFMP** | Lithium Iron Manganese Phosphate |
| **LI-ION** | Lithium-Ion |
| **LTMO** | Layered Transition Metal Oxides |
| **NMC** | Mickel Manganese Cobalt |
| **NRMM** | Non-Road Mobile Machinery |
| **NZIA** | Net Zero Industry Act |
| **PBAs** | Prussian Blue Analogues |
| **PFAS** | Per- and Polyfluoroalkyl Substances |
| **PWAs** | Prussian White Analogues |
| **SET PLAN** | Strategic Energy Technology Plan |
| **SIB** | Sodium-Ion Battery |
| **SRA** | Strategic Research Agenda |
| **SRIA** | Strategic Research and Innovation Agenda |
| **SoC** | State of Charge |
| **SOH** | State of Health |
| **TRL** | Technology Readiness Level |
| **VPP** | Virtual Power Plants |

# INTRODUCTION

Over the past years, the European Union, European industry and researchers have worked together to establish a competitive battery manufacturing chain in Europe. The European Battery Alliance was launched in October 2017 with the aim to reduce the EU's dependency on battery imports and enhance its competitiveness in the global battery market. The EBA aimed to bring together various stakeholders, including industry, research institutions, and governments, to collaborate on research, innovation, and policy initiatives related to batteries. The activities involving research and innovation were channelled through various initiatives, including Battery 2030+ and the ETIP Batteries Europe, and with support of the Horizon 2020 framework programme.

With the launch of Horizon Europe, the European Commission explored the possibility of establishing a European partnership on batteries as part of Horizon Europe. To this end, the European Commission worked together with a group of European associations (EMIRI, RECHARGE, EUCAR, EASE and EERA) to develop the framework of the Partnership. Individual members of these associations formed a Partnership Shadow Group, which included industry and research actors representing different segments of the battery value chain. Together with the European Commission, these actors established a Strategic Research and Innovation Agenda (SRIA) over the course of 2020, which functions as a guideline for the R&I priorities for batteries under Horizon Europe, and the battery calls for the '21-'22 Horizon Europe Work Programme. In June 2021, BATT4EU was officially launched as a co-programmed Partnership under Horizon Europe and the Horizon Europe battery calls for '21 and '22 were published. The first SRIA was officially adopted in September 2021[1].

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1 *https://bepassociation.eu/our-work/sria/*
2 *https://eur-lex.europa.eu/eli/reg/2023/1542/oj*
3 *https://climate.ec.europa.eu/news-your-voice/news/fit-55-eu-reaches-new-milestone-make-all-new-cars-and-vans-zero-emission-2035-2023-03-28_en*
4 *https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act_en*

A lot has changed since 2021. There have been many changes in the policy landscape, including the adoptions of the new Regulation (EU) 2023/1542 concerning batteries and waste batteries[2] and the regulation allowing only zero-emission vehicles[3], an increased drive to achieve strategic autonomy on net-zero technologies, as enshrined in the Net-Zero Industry Act (NZIA)[4] and the Critical Raw Materials Act (CRMA)[5]. The invasion of Ukraine and the following geopolitical changes have increased the importance of energy independence and the need for the deployment of more stationary energy storage, both focal points of the REPowerEU agenda[6]. While these regulations, acts and other policy measures have a scope that is wider than research and innovation, they all need the right accompanying research to achieve their goals. In addition, a 2023 special report by the European Court of Auditors has concluded that there is a need to have a better overview of EU funding for the battery value chain and that the coordination and targeting of EU funding for the battery value chain needs to be improved. Both the changing policy landscape and the recommendations of the Court of Auditors[7] show the need for an updated SRIA that both realigns the implementation strategy of the BATT4EU Partnership and form a starting point for coordinating the funding provided for the European battery value chain.

Another reason for an update of the SRIA is the rapid development of battery technology and increased industrialisation of the battery industry in Europe and abroad. Spurred on by the roadmap of the European Battery Alliance, European manufacturing capacity is being developed with plans of many gigafactories being announced in the past years.

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[5] *https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1661*
[6] *https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en*
[7] *https://www.eca.europa.eu/en/publications?ref=SR-2023-15*

This wave of industrialisation in Europe is now being matched in North America by the introduction of the Inflation Reduction Act, which has stimulated investment in the battery value chain in the United States and its neighbouring countries.

Lastly, on the organisational side there have been many developments since the early months of 2020. BEPA, the association gathering the European research and industry actors that want to contribute to BATT4EU, has grown to a thriving organisation consisting of over 220 members. Under BEPA, a system of expert of working groups has been set up to channel inputs from the entire European value chain into the strategic documents like the Horizon Work Programme. In addition, with the continuation of Batteries Europe and Battery 2030+ as Coordination and Support Actions (CSAs) funded under Horizon Europe, and sustained efforts to increase collaboration between these two initiatives and BEPA, have streamlined the institutional landscape and reduced the amount of overlap in activities. As a concrete result, the expert working groups of Batteries Europe and BEPA have been replaced by a single set of joint working groups, the Batteries Europe Strategic Research Agenda (SRA) and BATT4EU SRIA have been replaced by a single SRIA (the document before you) and there are better agreements in place how information from other documents such as the Roadmaps of Batteries Europe and Battery 2030+ relate to each other and the SRIA. This SRIA reflects the new, more inclusive, way of working and incorporates feedback from the actors along the value chain more directly. The relation between the current set of documents are as follows:

The Battery 2030+ Roadmap provides an in-depth assessment of the research actions that can be undertaken to radically change the way battery research is being conducted. The Battery 2030+ Roadmap does not focus on specific chemistries but tries to harness disruptive (digital) technologies to accelerate the research on the material science, the manufacturing and the recycling of all the different chemistries which are on the horizon.

The Batteries Europe Roadmap provides a broad overview of research activities that need to be addressed in Europe in the short, medium and long-term (the latter partially building on the Battery 2030+ Roadmap). This overview is holistic and provides recommendations that should be implemented not only on European level, but also in national and regional programmes.

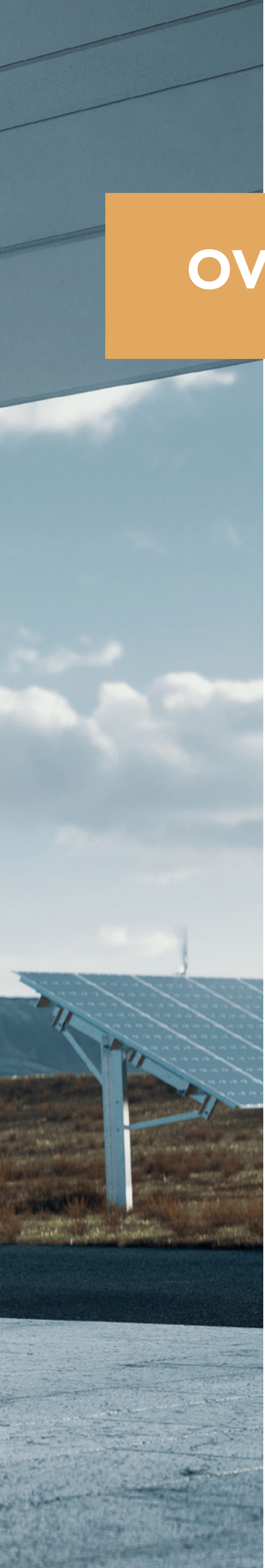
## THE BATT4EU SRIA COVERS THE FOLLOWING ASPECTS

- An update on the current context that the European value chain has to work with, including how new EU policy objectives and measures interplay with the research needs outlined in the Batteries Europe roadmap.
- An update of the identified R&I areas that are within scope of the Partnership.
- A multi-annual agenda and implementation plan and timeframe for each R&I activity identified, which is an assessment on which research projects will benefit from funding under the BATT4EU umbrella.

## THE ANNEXES CONTAIN ADITIONAL INFORMATION ON:

- A full set of Key Performance Indicators that quantify the current state-of-art of battery research in Europe and that sets the targets for the short and midterm.
- The objectives the BATT4EU Partnership. Its strategic objectives and expected impacts.
- The operational aspects of the BATT4EU Partnership. The budget, governance, openness and transparency of the partnership; synergies with other initiatives.


ENERGY STORAGE
Lithium ion battery system



# OVERALL CONTEXT

## 1.1 EU OBJECTIVES

The EU aims to be a climate-neutral economy with net-zero greenhouse gas emissions - by 2050. This objective is at the heart of the European Green Deal and in line with the EU's commitment to global climate action under the Paris Agreement. Under the European Climate Law, the EU has further committed to reduce its net greenhouse gas emissions by at least 55% by 2030.[8]

To achieve the Green Deal objectives, Europe has to implement an accelerated transition from fossil fuels to renewable energy sources. Over three-quarters (76.7%) of greenhouse gas (GHG) emissions are due to fuel combustion. This includes fuel combustion to generate electricity and heat; produce goods; construct buildings and infrastructure; and move freight and persons.

This transition towards a carbon neutral society relies on electrification of key industrial sectors – transport and energy – and batteries are a key enabling technology for both sectors.

While carbon-neutrality is a key driver for the large-scale adoption of battery technology, it is not the only driver. In addition to the achievement of decarbonization targets, the shift towards electrification also provides an opportunity for the European Union to reduce its dependency on foreign fuels and be more strategically autonomous in the field of its energy needs.

The following paragraphs will outline more specifically what the ambitions and challenges are on a European level and how this will impact the development of the battery value chain. Simultaneously, legislation is being developed on a European level that affects (part of) the battery value chain to achieve other important goals like transparency, circularity and the reduction of toxic materials. Lastly, there are policies pushing forward technologies that will impact battery research and deployment, for example, policies to advance digitalisation.

8 *https://eur-lex.europa.eu/EN/legal-content/summary/european-climate-law.html*

1.1.1

## Decarbonisation and zero-emissions: mobility

While the aforementioned European Climate Law set the targets, the implementation of how to achieve this is put forward in a set of acts and regulations collectively known as the 'Fit for 55' legislative proposals.

Passenger cars and light commercial vehicles contribute approximately 12% and 2.5% of the EU's total carbon dioxide ($CO_2$) emissions. Effective from January 1, 2020, Regulation (EU) 2019/631[9] set $CO_2$ emission performance standards for new passenger cars and vans, superseding previous regulations. The legislation introduced EU-wide emission targets for 2020, 2025, and 2030, along with incentives for adopting low- and zero-emission vehicles.

Since the new targets took effect in 2020, the average $CO_2$ emissions from new passenger cars registered in Europe have declined by 12% compared to the previous year, with a notable increase in electric car adoption. To accelerate this trend, an update, Regulation (EU) 2023/851[10] was adopted by the European Parliament and Council to further enhance $CO_2$ emission standards for new passenger cars and light commercial vehicles, aligning with the EU's heightened climate goals. Notably, this amendment strengthens the 2030 targets and establishes a 100% reduction goal from 2035 onward.

These changes aim to achieve a minimum 55% reduction in greenhouse gas emissions by 2030 and eventual climate neutrality by 2050, in line with the European Climate Law. The amended regulation is expected to promote the deployment of clean and affordable zero-emission vehicles, stimulate innovation in emission-reduction technologies, and bolster employment within the EU's automotive sector.

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Other parts of interest of the Fit for 55 package of legislation are the ReFuelEU Aviation Regulation[11] and the FuelEU Maritime Regulation[12]. The aviation and maritime transport sectors account for 14.4% and 13.5% of EU GHG emissions respectively. The ReFuelEU Regulation aims to decarbonise the aviation sector through the creation of a level playing field for sustainable air transport. While focusing on Sustainable Aviation Fuels, the legislation also looks ahead at further electrification, with the Commission expected to report on the future use of electricity in the aviation fleet in 2027. The FuelEU Maritime Regulation is aimed at reducing the carbon intensity of large vessels (>5 000 gross Tonnes) by at least 80% by 2050. It also contains an obligation for these vessels to connect to an onshore power supply when moored, unless they use another zero-emission technology. Both options will drive a future demand for storage solutions, either onboard or on land.

The emission reduction targets outlined in the above-mentioned regulations are supported by a fourth piece of legislation, the Alternative Fuels Infrastructure Regulation (AFIR)[13]. While not directly pushing the drive for electrification, AFIR contains mandatory targets for the deployment of electric recharging infrastructure for the road sector, for shore-side electricity supply at ports (both maritime and inland), and for electricity supply to stationary aircraft. AFIR also intends to improve the experience of end-users, by ensuring full price transparency, common minimum payment options and coherent customer information across the EU. In this way, the AFIR intends to take away barriers that might impede the rapid electrification of the transport sector and indirectly stimulate the demand for electric mobility and therefore batteries.

9 *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32019R0631*
10 *https://eur-lex.europa.eu/eli/reg/2023/851*
11 *https://eur-lex.europa.eu/eli/reg/2023/2405*
12 *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0562*
13 *Alternative Fuels Infrastructure Regulation*

14 ***COM/2022/230 final - 'REPowerEU Plan',*** *EU Commission Communication to EU Institutions, 2022.*
15 ***EU Proposal (COM/2023/148 final)*** *for Amending Electricity Market Design Regulations and Directives, 2023.*
16 ***EU Commission Recommendation (2023/C 103/01)*** *on Energy Storage for a Decarbonised and Secure Energy System, 14 March 2023.*

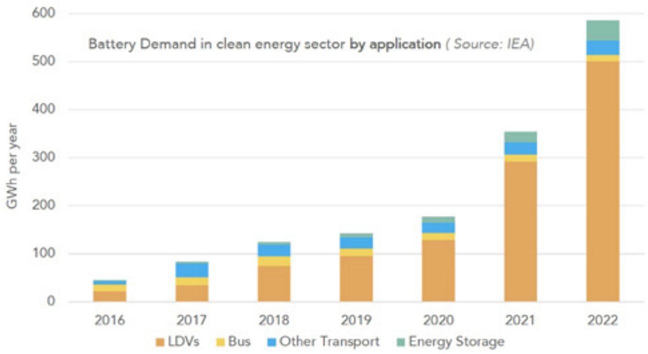
## 1.1.2
# Decarbonisation and zero-emissions: energy supply

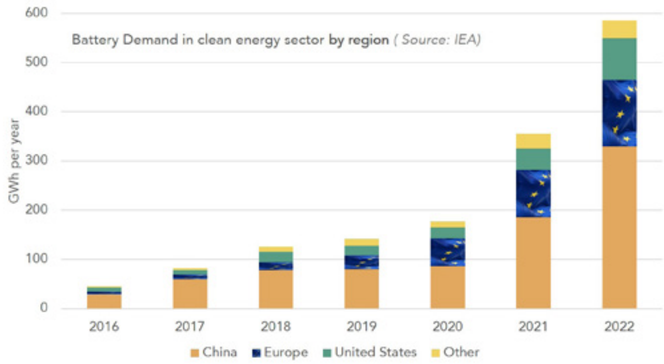
In 2019, the EU updated its energy policy to shift from fossil fuels to cleaner energy through the Clean Energy For All European package, highlighting benefits and EU leadership against global warming. The challenge lies in maintaining constant energy supply from intermittent renewables. Pumped hydro storage dominates now, but battery capacity is expected to grow by 2030, along with importance of hydrogen and e-fuels. Of the mentioned storage solutions, Batteries are unbeatable from the efficiency point of view and present key assets for energy storage such as cycle life and costs.

Following the global energy market disruption caused by Russia's invasion of Ukraine in 2022, the European Commission published the REPowerEU plan. This plan aims to end EU dependency on Russian fossil fuels while doubling down on its commitment to decarbonize the energy system. This will take place through energy savings, diversification of energy supplies, and an accelerated roll-out of renewable energy. This last point will have an impact on the demand for electricity storage in the grid. As the REPowerEU communication acknowledges that energy storage plays a significant role in ensuring flexibility and security of supply in the energy system. Concretely to promote the development of electricity storage capacities, the Commission proposes to consider storage assets as being in the overriding public interest and facilitate permitting for their deployment.[14]

In March 2023, as part of a bigger policy package called the Green Deal Industrial Plan, the European Commission put forward a proposal for the reform of the EU electricity market design. The proposal aims, amongst other things, to improve the flexibility of the power system. If the proposal gets accepted, Member States will have the possibility to introduce new support schemes especially for demand response and storage. Batteries are a very promising solution to complement existing ancillary services for grid stabilization and will receive a boost once the Member States accept and act on this opportunity.[15]

**The Commission also recommends that Member States continue to invest in research and innovation on energy storage, specifically on topics like long-term energy storage, hybrid storage solutions, behind-the-meter solutions for consumers and the utilisation of electricity stored in electric vehicle batteries for grid purposes.[16]**



## 1.1.3

# European competitiveness and resilience

Driven by the ongoing clean energy transition and the uptake of zero-emission mobility, demand for batteries is growing rapidly and the market for batteries and its components has risen to be of strategic importance on a global level. The European Commission has proposed that the European industry takes up the challenge of becoming a global leader in sustainable battery cell and pack manufacturing, able to compete with current manufacturing bases, mostly located in Asia. Thus, in October 2017 the European Commission launched the European Battery Alliance[17] as a cooperation platform and in May 2018 endorsed the Strategic Action Plan on Batteries[18] as part of the "Europe on the Move" package. The action plan aims to put Europe on a steady path towards leadership in this key industry, supporting jobs and growth in a circular economy, while ensuring cleaner mobility and an improved environment and quality of life for EU citizens. Within this action plan, the Commission proposed to explore the feasibility of a public-private partnership to accelerate European battery R&I. In the European Green Deal[19], the Commission announced that it would "continue to implement the Strategic Action Plan on Batteries" and thus continue with developing the Batteries European Partnership.

In line with the priorities of the New Industrial Strategy for Europe, in May 2020, the industry proposed an Acceleration Plan set to create up to 1 million jobs in a European battery ecosystem worth EUR 250 billion by 2022. The European Investment Bank has also supported battery projects along the entire value chain: loans amounting to EUR 1 billion having so far been allocated by the bank, leveraging EUR 4.7 billion in total.

The COVID-19 crisis has further highlighted the importance of the rationale behind the European Partnership in R&I – to bolster Europe's resilience and strategic autonomy in critical industrial sectors and key, game-changing technologies. Moreover, the Commission's Recovery Plan published in May 2020 underlines the importance of the battery value chain several times and states: "the Commission will also focus on unlocking investment in clean technologies and value chains, notably through the additional funding for Horizon Europe."[20]

While the above-mentioned policies, have pushed the European battery value chain forward and have led to a growing European battery ecosystem, the European Court of Auditors concluded in their 2023 special report that there are still risks that could stop the final production capacity from meeting the rising demand and help achieve the targets of the European Union.[21] The Court of Auditors concluded that the EU-wide industrial policy on batteries has been effective, despite shortcomings in monitoring, coordination and targeting. The report also singles out the fact that access to raw materials remains a major strategic challenge for the EU's battery value chain.

As outlined in the reply of Commission to the special report, part of the challenges will be tackled by the two acts that form the Green Deal Industrial Plan: The European Critical Raw Materials Act (CRMA) and the Net-Zero Industry Act (NZIA). These two acts aim to address these gaps as well as address the risk of planned investments not materializing, due to better incentives provided elsewhere, notably after the introduction of the Inflation Reduction Act in the United States.

The Critical Raw Materials Act aims to provide support for the extraction and processing of CRMs in Europe, which can be an opportunity for the battery raw material sector. The fast tracking of lengthy and costly permitting processes and barriers can encourage more investment in exploiting the raw materials available in Europe. Sustainability and circularity are just as much of a focus however, with emphasis given to recycling and reuse technologies. The regulation could help grow the market and technological maturity of battery recycling, as well as second life use, in order to maximize the value and use of existing raw materials and reduce the need for new materials.

**The CRM act and the NZIA go hand in hand to cover the value chain and contain generally similar measures. Both are aimed at streamlining permitting procedures and bypassing regulatory barriers, and both leave a lot of the implementation up to Member States. This is in contrast to the IRA in the US, which is more focused on financial incentive through tax credits.**

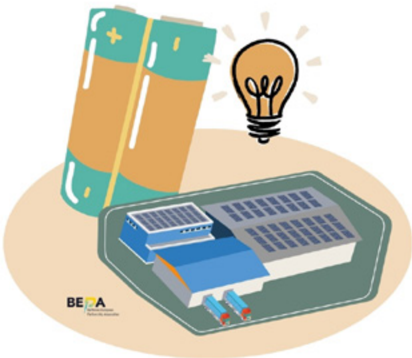
17 *https://www.eba250.com/*
18 ***COM(2019) 176 final Strategic Action Plan on Batteries***
19 ***(COM(2019) 640 final)***
20 *https://ec.europa.eu/info/sites/info/files/communication-europe-moment-repair-prepare-nextgeneration.pdf*
21 *The EU's industrial policy on batteries New strategic impetus needed*

The focus is to increase strategic autonomy by boosting domestic production and reducing import dependence, rather than funding the outright deployment of clean energy to meet goals. In other words, it aims to raise the floor rather than the ceiling, by building up the domestic base of raw material production and manufacturing capacity.

Addressing the gap in skills and education of the workforce has also been taken seriously, as considerable parts of both CRMA and NZIA cover this. Moreover, the accompanying texts of the NZIA in particular highlight the European Battery Alliance, not only as a source for much of the input and information about the battery aspects of the regulation, but also a success story of a European skills academy, which will act as the basis for similar academies that will be created for other domains.

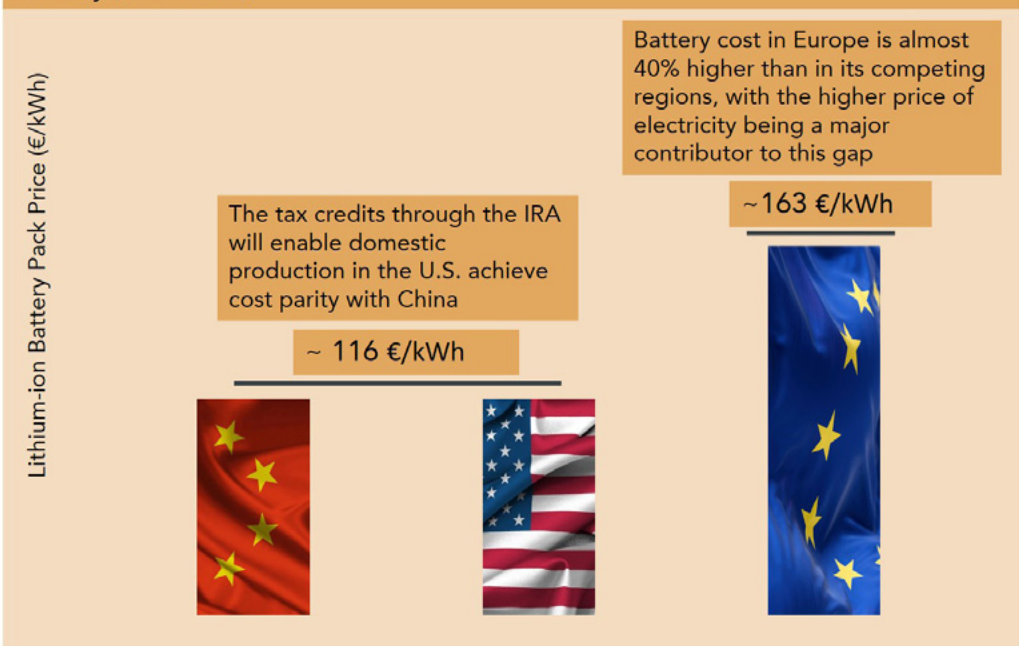
Other initiatives that were launched at the end of 2023 and early 2024 to boost competitiveness are the Innovation Fund call that targets battery manufacturing and the creation of the EBA Raw Materials Fund, which will provide capital for scoping and feasibility studies for strategic raw materials.

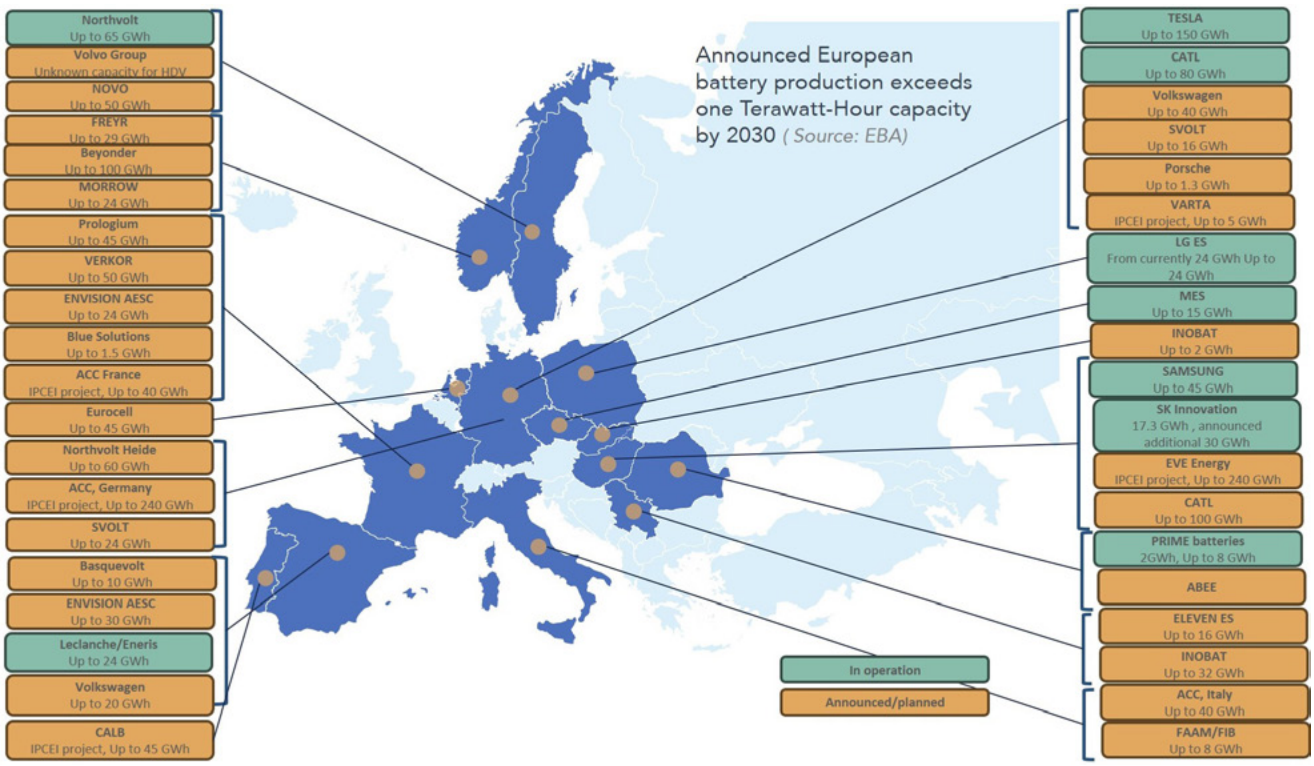
## NET-ZERO INDUSTRY ACT



- Targets **40% of domestic production** for strategic technologies by 2030
- Focus on **key technologies** for net-zero energy production
- **€600 Billion:** Annual global market for net-zero technology by 2030
- **Skills Enhancement** through Net-Zero Academies for training
- Emphasis on **Battery and Storage Technologies** advancement

Impact of the Inflation Reduction Act on the Competitiveness of the European Battery Industry *(Source: EBA)*






### 1.1.4

# The Batteries and Waste Batteries Regulation: towards a circular economy

In July 2023, the European Union adopted a new Regulation on Batteries and Waste Batteries[22] which will replace the Batteries Directive from 2006 following an evaluation of the latter in 2019. The new Regulation aims to create a circular economy for the batteries sector by targeting all stages of the life cycle of batteries, from design to waste treatment. This initiative is of major importance, particularly in view of the massive deployment of electric vehicles, for which the demand is projected to grow by more than 10-fold by 2030.

**The Batteries Regulation lays down several targets, including for material recovery and recycling efficiency. For the recovery of lithium, the targets are as follows:**

- **50% lithium recovery** from waste batteries by end of 2027.
- **80% lithium recovery** from waste batteries by end of 2031 (amendable based on market/technological factors).

**The following recycling efficiency targets are being mentioned in the Regulation:**

- **80% recycling efficiency** for nickel-cadmium batteries by end of 2025.
- **50% recycling efficiency** for other waste batteries by end of 2025.

The Battery regulation also provides mandatory minimum levels of recycled content for industrial, SLI batteries and EV batteries. The initial Minimum Recycled Content levels for industrial and EV batteries are 16% for cobalt, 85% for lead, 6% for lithium and 6% for nickel.

The regulation further introduces an electronic "battery passport", which allows for the digital storage of labelling and other required information on the battery's components and recycled content. The information stored in the battery passport should be accessible through a simple QR code. In order to give the Member States and economic actors on the market enough time to prepare, labelling requirements will apply by 2026 and the QR code by 2027. The improved transparency aims to improve the functioning of the internal market for batteries and ensure fairer competition by allowing easy access to information on safety, sustainability and other labelling requirements.

The drive for a circular battery economy in Europe is further strengthened by the European assessment framework for 'safe and sustainable by design' chemicals and materials, as laid out in Commission recommendation in 2022.[23] The recommendation states that the Commission will incentivize Member States, industry and other stakeholders to prioritise innovation for substituting, as far as possible, substances of concern across sectors, including the battery sector. The 'safe and sustainable by design' framework is a concrete implementation of the "Chemicals Strategy for Sustainability" adopted in 2020. This strategy has announced a phase-out of the use of per- and polyfluoroalkyl substances (PFAS) in Europe "unless it is proven essential for society". The use of PFAS in battery manufacturing will therefore come under particular scrutiny in the review of REACH secondary legislation to happen by 2024. The battery R&I community will play a crucial role in accompanying the industry with these possible regulatory evolutions. The Commission has previously announced in the Chemicals Strategy for Sustainability (COM(2020) 667 final)[24] that R&I activities will be funded under Horizon Europe to develop innovation to substitute PFAS where needed.

## 1.1.5 Digitalisation

The transition to a carbon-neutral society is not the only transition that the world is facing. The rapid development of digital development heralds new opportunities, but also new challenges as digital technologies can have substantial environmental footprints that go against the targets of the green transition. A report from the JRC in 2022 warns that the two simultaneous, or 'twin', transitions are not automatically aligned, but can reinforce each other in many areas, if managed carefully. [25] The report argues for an integrative approach to managing the twin transitions is a key to ensure the successful implementation of both. The Strategic Foresight Report, which was published in 2022 and is based on the JRC's twin transition report, identifies 10 key areas of action where the digital and green transitions intersect and can, and should, reinforce each other: [26]

1. **Strengthening resilience** and open strategic autonomy in sectors critical for the twin transitions.
2. **Stepping up green and digital diplomacy,** by leveraging the EU's regulatory and standardisation power, while promoting EU values and fostering partnerships.
3. **Strategic management** of the supply of critical materials and commodities.
4. **Strengthening economic and social cohesion** through regional development strategies.

22 *https://eur-lex.europa.eu/eli/reg/2023/1542/oj*

23 *EU Commission Recommendation (EU) 2022/2510, 'European Framework for Safe and Sustainable Chemicals and Materials', C/2022/8854, 8 December 2022*

24 *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:667:FIN*

25 *Muench et al., 'Towards a Green and Digital Future', EU Publications Office, Luxembourg, 2022, doi:10.2760/54, JRC129319*

26 *EU Commission's 2022 Strategic Foresight Report on Green and Digital Transitions in New Geopolitical Context (COM/2022/289 final)*

5. **Adapting education and training systems** to match a rapidly transforming technological and socio-economic reality
6. **Mobilising additional future-proof investment** into new technologies and infrastructures with cross-country projects key to pooling EU, national and private resources.
7. **Developing monitoring frameworks** for measuring wellbeing beyond gross domestic product and assessing the footprints and enabling effects of digitalisation.
8. **Ensuring a future-proof regulatory framework** for the Single Market by constantly reducing administrative burdens, updating our state aid policy toolbox or by applying artificial intelligence to support policymaking and citizens' engagement.
9. **Stepping up a global approach** to standard-setting and benefitting from the EU's first mover advantage in competitive sustainability.
10. **Promoting robust cybersecurity and secure data sharing framework** to ensure, among other things, that critical entities can prevent, resists and recover from disruptions, and ultimately, to build trust in technologies linked to the twin transitions.

The battery passport requirement as set out by the Regulation on Batteries and Waste Batteries will be a leading example of how the battery value chain can pioneer the alignment of the twin transitions.

## 1.1.6 Socio-economic aspects

The transition to an electrified economy amounts to a societal transformation.

**According to a report by the World Economic Forum, the battery value chain will generate a total of 10 million jobs worldwide by 2030, mainly linked to the emergence of electric vehicles.[27]**

EIT Raw Materials and Fraunhofer estimate that around 10% of the total will be generated in the EU alone, estimating that at least 100 direct and 300 indirect jobs will be created per GWh along the entire battery value chain.

Important work has already been done on this topic, existing education activities have been mapped and the European needs, new job roles, learning objectives and education concepts for the sector have been examined and categorised.[28] Updates are required, but there are many activities running in Europe to educate people and future workers. This education, skilling and re-skilling of workers must consider all the levels, from blue-collars and vocational levels to professionals to master and PhD students and post-doc.

[27] ***World Economic Forum Report:*** *A Vision for a Sustainable Battery Value Chain in 2030 Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation, 2019.*
[28] *https://batterieseurope.eu/wp-content/uploads/2023/09/Batteries-Europe_Research-and-Innovation-Roadmap-2023_.pdf*

## 1.2 IMPLEMENTATION OF THE INTEGRATED SET PLAN

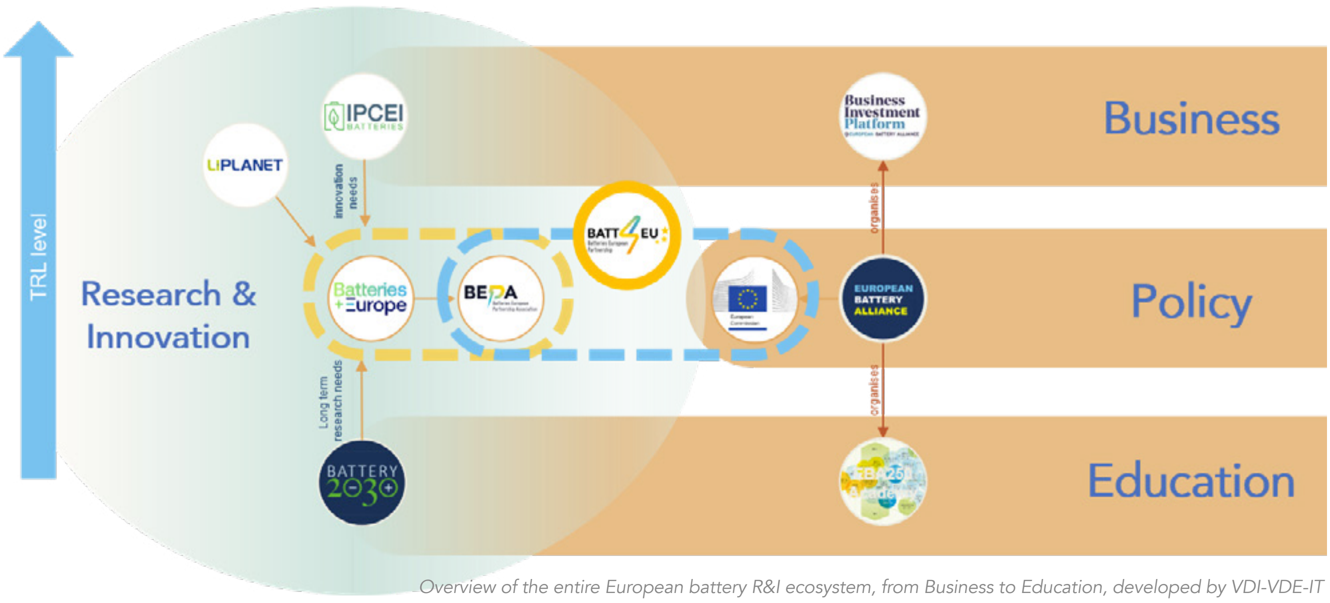
In 2023, the European Commission revised the Strategic Energy Technology (SET) Plan, aligning it with the European Green Deal, focusing on the Net-Zero Industry Act and REPowerEU agenda.

The modifications encompass the incorporation into the European Research Area framework, the establishment of fresh priorities addressing cross-cutting concerns, and a broader coverage extending to all key renewable energy technologies. Additionally, the plan emphasizes hydrogen utilization, cooperation with industrial alliances, and specific initiatives, including the promotion of onshore wind energy, advancements in geothermal technologies, energy storage enhancement, building renovation projects, heat pump integration, battery manufacturing initiatives, carbon capture strategies, and the development of small modular reactors.

Priority 4 of the SET Plan, addressing EU competitiveness in the global battery sector for e-mobility and stationary storage, emphasizes achieving self-sufficiency by 2030. The overarching goal is to drive advancements in battery technologies, support workforce development, and promote sustainable energy solutions. The 17th SET Plan Conference in November 2023 highlighted the need for diverse energy storage solutions, emphasizing regional variations.

## 1.3 EUROPEAN R&I SUPPORT LANDSCAPE

To support the implementation of the new regulatory framework and achieve the ambitions of the EBA, the policy goals of the European Union and the goals of the SET-Plan, the European battery R&I community has organised itself in various interlinking initiatives. These initiatives cover the entire battery R&I community ecosystem, with a wide range of fields representing different R&I interests across the battery value chain. Over the past years, these initiatives have intensified their cooperation to form a well-structured ecosystem of complementary organisations which are summarised below.




*Overview of the entire European battery R&I ecosystem, from Business to Education, developed by VDI-VDE-IT*

To support the establishment of a competitive battery value chain in Europe and to answer the demands of the industry across this new value chain, several institutional initiatives have been set up, aiming to unite the involved stakeholders and ensure a structured support from basic research to industry application. These organisations work together towards a single goal and are aware that they represent and support a single community. To emphasise this, the entities have united under the banner of the "European Batteries R&I Community" and have agreed on using a common visual identity that is used to express this single objective.

Energising The European Batteries R&I Community

Below, a short overview of the different initiatives and their current roles are given.

Batteries Europe was launched as a European Technology and Innovation Platform (ETIP), established with support of the European Commission in 2019. Since its inception it has evolved to be an open and inclusive think tank that aims to represent the entire battery value chain by bringing together experts from research, industry and academia. The aim of the think tank includes preparing KPI targets and roadmaps for battery R&I community and beyond, while considering technology developments both inside and outside of Europe. BE also participates in the implementation of the SET plan Action 7 on Batteries and works closely with BEPA to develop the Strategic Research and Innovation Agenda for Europe. Batteries Europe also has a focus to develop and implement a uniform Reporting Methodology across Europe and eventually globally so to support the definition of a unified language for researchers in the sector.

Battery 2030+ was set up in 2017 to provide a long-term perspective on the battery research needs in Europe, with a focus on the digital technologies that will create smarter, better, and longer-lasting batteries and that will change the way battery research is being done. Battery2030+ has been key in clustering innovative European projects to create a European community of excellent scientists, who all agree on certain methodologies and the use of FAIR (Findability, Accessibility, Interoperability, Reusability) data. Battery 2030+ also provides a clear long-term perspective through a roadmap of its own, which underpins some of the longer-term recommendations in this Roadmap and the SRIA.

IPCEI is the abbreviation of "Important Project of Common European Interest". It's a transnational project with an important contribution to the growth, employment and competitiveness of the European Union industry and economy funded by state aid. Part of the implementation programme to mark the kick-off for the development of the European battery industry, are the two IPCEIs; the first one on Batteries and the second IPCEI on European Battery Innovation (EuBatIn). They are designed to bring together the public and private sector and undertake large-scale projects that provide significant benefits to the Union and its citizens.  More than 50 companies from 12 EU Member States are developing new technologies along the entire battery value chain and bringing them into first industrial deployment. The participating EU Member States are providing up to 6.1 billion euros in funding. In addition, up to 14 billion euros in private investments are being made available. To create a European battery ecosystem, the funded companies are encouraged to establish European supply relationships and share knowledge in spill-over activities. The first IPCEI on batteries is coordinated by the French government, while the second IPCEI on European Battery Innovation (EUBatIN) is coordinated by the German government and its project management agency, VDI/VDE Innovation + Technik GmbH. The IPCEI instrument gives EU Member States the opportunity to fund large-volume projects aimed at setting up production facilities for innovative products. The EU Commission sets the framework conditions and monitors compliance with these. The Member States are allowed to fund projects within this framework, but each project must be notified individually by the EU Commission. This ensures compliance with international trade rules.

## 1.3.1 The BATT4EU Partnership

The initiatives under the partnership will support the European Union's recovery, aimed at building a more sustainable, competitive and resilient economy.

As part of the Horizon Europe framework programme, the Commission and stakeholders from the battery value chain launched BATT4EU in 2021. BATT4EU is a public-private partnership, whose main aim is to ensure that the up to 925 million earmarked in Horizon Europe for research on batteries is spent in the best way possible. To this end, specific goals for the battery value chain have been set out in a Strategic Research and Innovation Agenda (SRIA), which guides the development of the calls in the Work Programmes under Horizon Europe. The partnership will also support other activities, like standardisation efforts and the development of the battery regulation, ensuring a wide dissemination of the research results and contributions to the education and upskilling of the workforce. The battery value chain is represented by BEPA, an association of over 220 members as of July 2023, uniting industry and research actors across the value chain. The BATT4EU Partnership cooperates with other partnerships to cover the whole value chain, such as raw materials extraction and production with European Raw Materials Alliance or with application-oriented initiatives, namely 2Zero (road transport), ZEWT (waterborne), Clean Aviation and Europe's Rail. Other collaborations with more cross-cutting topics like manufacturing, processing and digital technologies are also being explored.

To create a continuous workflow between the road mapping exercises by Batteries Europe and the preparation of the Horizon Europe Work Programme by BATT4EU, the expert working groups of BEPA and Batteries Europe have been integrated with a joint governance structure and shared strategy to gain efficiency and synergies among the initiatives. For more information on the Partnership, see Annex 4.1 and 4.2.

### 1.3.2
## Innovation Fund

In order to help BATT4EU scale-up, close cooperation is foreseen with the Innovation Fund. The Innovation Fund is financed through the revenues of the European Emissions Trading System (ETS). As of the Work Programme '23-'24, the projects developed under the BATT4EU Work Programmes are explicitly asked to take the Innovation Fund into account for financing the scale-up and deployment phases in their exploitation plans. The Innovation Fund is establishing a proven record on financing battery innovation. For example, in the third call for large projects saw 4 battery projects (out of 41 in total) receive financing by the Innovation Fund. On December 6th 2023, the European Commission announced a dedicated instrument for the battery value chain under the Innovation Fund, possibly amounting to 3 billion Euros in support. No details were announced before the finalisation of this SRIA.

### 1.3.3
## European Innovation Council

The European Innovation Council (EIC), operating under the EU Horizon Europe program with a budget of €10.1 billion, supports innovative projects across various stages, from early research to technology transfer and startup scale-up. EIC Program Managers lead the funding efforts, focusing on innovation and technology breakthroughs within their expertise for up to 4 years. One distinctive aspect of the EIC is its provision of funding, both as grants and investments, to individual companies, primarily startups and SMEs. Investments are managed by the EIC Fund and include direct equity or quasi-equity investments.

The EIC has specific projects in the area of battery research, including topics covered by the EIC Pathfinder grants such as AI-guided development of vanillin-based flow batteries, high-performing zinc-air batteries for mid-term energy storage, and redox-mediated hybrid zinc-air flow batteries for integrated power systems.

Under the EIC Accelerator, energy storage projects encompass various battery-related topics, such as batteries for hybrid and electric vehicles and sustainable mobility more broadly, innovative manufacturing processes, predictive analytics for battery optimization, and advancements in lithium-ion battery production. The overarching goal is to develop cheaper and more efficient batteries using common and safe raw materials.

# RESEARCH AND INNOVATION PRIORITIES ACROSS THE BATTERY VALUE CHAIN

Based on the developments of the overall context for batteries and the specific objectives of the legislation, the SET Plan and the BATT4EU partnership, nine distinct R&I areas have been identified as key to achieving a competitive, sustainable European industrial battery manufacturing capability and enabling zero emission mobility and renewable energy storage integration. Seven R&I areas focus on the different parts of the value chain. The eighth R&I area covers transversal activities which affect the entire value chain, such as sustainability, education, safety, and digitisation. The ninth and last R&I area covers the coordination efforts needed to support the work emanating from the other eight areas and to support the European Union in achieving it's set targets.

The Strategic Actions below have been developed by the six Working Groups which are operated jointly by Batteries Europe and BEPA. The transversal activities have been suggested by selected cross-cutting Task Forces that Batteries Europe and BEPA also jointly run. The final selection and prioritisation of the activities has been prepared by the members of BEPA in their official function as Partners other than the Union within the framework of the BATT4EU Partnership and has been reviewed by the European Commission. However, all members of the free to access Working Group and Task Force sessions hosted by Batteries Europe have been able to provide their initial input, ensuring a wide base for input and external validation.

To ease interpretation, each area contains a timeline to represent, in a simple way, the cascade effect of R&I activities for each strategic action identified in the SRIA until 2030 and beyond. The horizontal arrows in the timelines indicate the TRLs that the strategic action is aiming to achieve and the timeframe within which they should be achieved.


# 2.1 RAW MATERIALS

## 2.1.1 Vision

European efforts to boost (lithium-ion) battery production to supply European car makers are bearing fruit, with (planned) investments in gigafactories on the rise. However, these battery manufactories are still mostly dependent on imported materials. The investments in sourcing raw material in Europe are developing at a slower pace than those in manufacturing, because of a wide set of reasons (the naturally slower development of the mining industry, the risks associated with the investments, permission procedures, etc). It will take time for the already planned investments to become operative. With the rapidly increasing electric vehicle fleet in Europe, the number of batteries in European cars will increase rapidly forming a fast-growing demand in the use of raw materials, that become available for recycling at a later stage (10 years of more) for recycling (even longer, when a second-life use is implemented).

**To safeguard European strategic autonomy, efforts to boost European raw material processing capacity remain necessary. These efforts also need to consider the raw materials needed for other chemistries than lithium-ion. Investment in research on secondary raw materials (including waste from mining and manufacturing) will be needed to boost the use of recycled material before large streams of recycled materials will make it back to the battery manufacturing supply chain.**

Efforts to improve the recycling of batteries to re-inject materials into the European supply chain are covered in the chapter on dismantling and recycling.

## CRITICAL RAW MATERIALS ACT:
## 2030 targets for domestic production of critical raw materials

- **10%** Extraction
- **40%** Processing
- **25%** Recycling

- **Streamline Permitting: reduced administrative burden for critical raw materials projects**
- **Permitting Timeframes: Extraction permits capped at 27 months; processing and recycling permits capped at 15 months**

# Review of R&I activities

**Since the start of the BATT4EU Partnership in 2021, the following calls have been issued under the umbrella of the Partnership to address the above-mentioned challenges:**

**Call: HORIZON-CL5-2021-D2-01-01**
**Topic:** Sustainable processing, refining and recycling of raw materials.
**Projects:**

| | | |
|---|---|---|
| **ENICON** | Sustainable processing of Europe's low-grade sulphidic and lateritic nickel/cobalt ores and tailings into battery-grade metals. | June 2022 to May 2026 |
| **LICORNE** | Lithium recovery and battery-grade materials production from European resources. | Oct. 2022 to Sep. 2026 |

**Call: HORIZON-CL5-2022-D2-01-01**
**Topic:** Sustainable processing and refining of battery grade graphite
**Projects:**

| | | |
|---|---|---|
| **GR4FITE3** | Graphite resilience for lithium-ion battery anodes through a sustainable European end-to-end supply chain. | May 2023 to April 2027 |
| **SOURCE** | Sustainable routes for synthetic graphite production for high-performance Lithium-Ion battery anodes. | May 2023 to April 2026 |

**Call: HORIZON-CL5-2023-D2-01-01**
**Topic:** Technologies for sustainable, cost-efficient and low carbon footprint downstream processing & production of battery-grade materials.
**Projects:**

| | | |
|---|---|---|
| **STREAMS** | Sustainable technologies for reducing Europe's battery raw materials dependence. | Starting in 2024 |
| **CICERO** | MSA-based circular hydrometallurgy for sustainable, cost-effective production of NMC cathode materials. | Starting in 2024 |

2.1.3

## Scope of actions

**Considering the context, the vision and ongoing research activities, the following research actions are proposed:**

**Strategic Action 1 - SUSTAINABLE PROCESSING AND REFINING OF BATTERY RAW MATERIALS**

The scope of this strategic action is to develop processing solutions for the most crucial elements needed for battery production, which are to be applied to both domestic and imported raw materials. The activities are not only expected to cover lithium-ion battery chemistries over the next ten years (including the processing of Li, Ni, Co, Mn, Gr), but also the supply chain necessary to establish a sodium-ion battery production ecosystem in Europe. Research activities on carbonous materials are also needed for a wide variety of chemistries. The substitution of synthetic graphite from oil distillation with bio-based carbonous graphite anodes to reduce the attributed environmental emissions is a rather overlooked European potential, where the valorisation of biostock feeds is considerably more mature and sustainable compared to the rest of the world.

The research activities developed under these actions are expected to support the implementation of new technologies in the processing of battery raw materials to reduce carbon emissions and harmful chemicals, increasing energy and resource efficiency and raw material flexibility. They also need to help minimize waste and discharge during the refining of raw materials and processing of battery chemicals including energy cascading and water valorisation.

Many research activities listed in the 2021 BATT4EU SRIA under this action have been implemented in the Work Programmes of BATT4EU up until 2024. Research activities which still need to be addressed and can be included in future Work Pogrammes are:

**SUSTAINABLE PROCESSING AND REFINING OF BATTERY-GRADE RAW MATERIALS FOR LITHIUM-ION BATTERIES**

- Development of cost and energy-efficient Cathode Active Material production technologies
- Development of cost and energy-efficient Anode Active Material production technologies.

**SUSTAINABLE PROCESSING AND REFINING OF BATTERY-GRADE RAW MATERIALS FOR SODIUM-ION BATTERIES**

- Development of cost and energy-efficient Cathode Active Material production technologies
- Development of cost and energy-efficient Anode Active Material production technologies

### UTILISING BIO-BASED RAW MATERIALS FOR BATTERY ELECTRODE MATERIALS

- Given the identification of graphite and silicon as Critical Raw Materials (CRM), realization of the opportunities in producing anode materials from alternative sources such as bio-stock is necessary
- Develop methods to ensure consistent quality for the material, even if produced from feedstock with varying properties. Increasing the heterogeneity of the bioresources will secure a resilient supply chain for carbonaceous battery electrode materials through the processing of biomass waste (agricultural, forestry, food and so on …) and circularity of battery industry.
- Produced bio derived carbonaceous materials could be applicable to any battery technology (Li-ion, Na-ion, Li-S, ...):
  - Battery grade graphite as Li-ion battery anode material (high purity, crystallinity, sphericity, …).
  - Disordered carbon-based materials for Na-ion batteries (hard and soft carbons).
  - Carbonaceous materials with high specific surface areas to be used as sulphur host cathodes in Metal-S batteries.

## Strategic Action 2 - INTEGRATION OF SECONDARY RAW MATERIALS

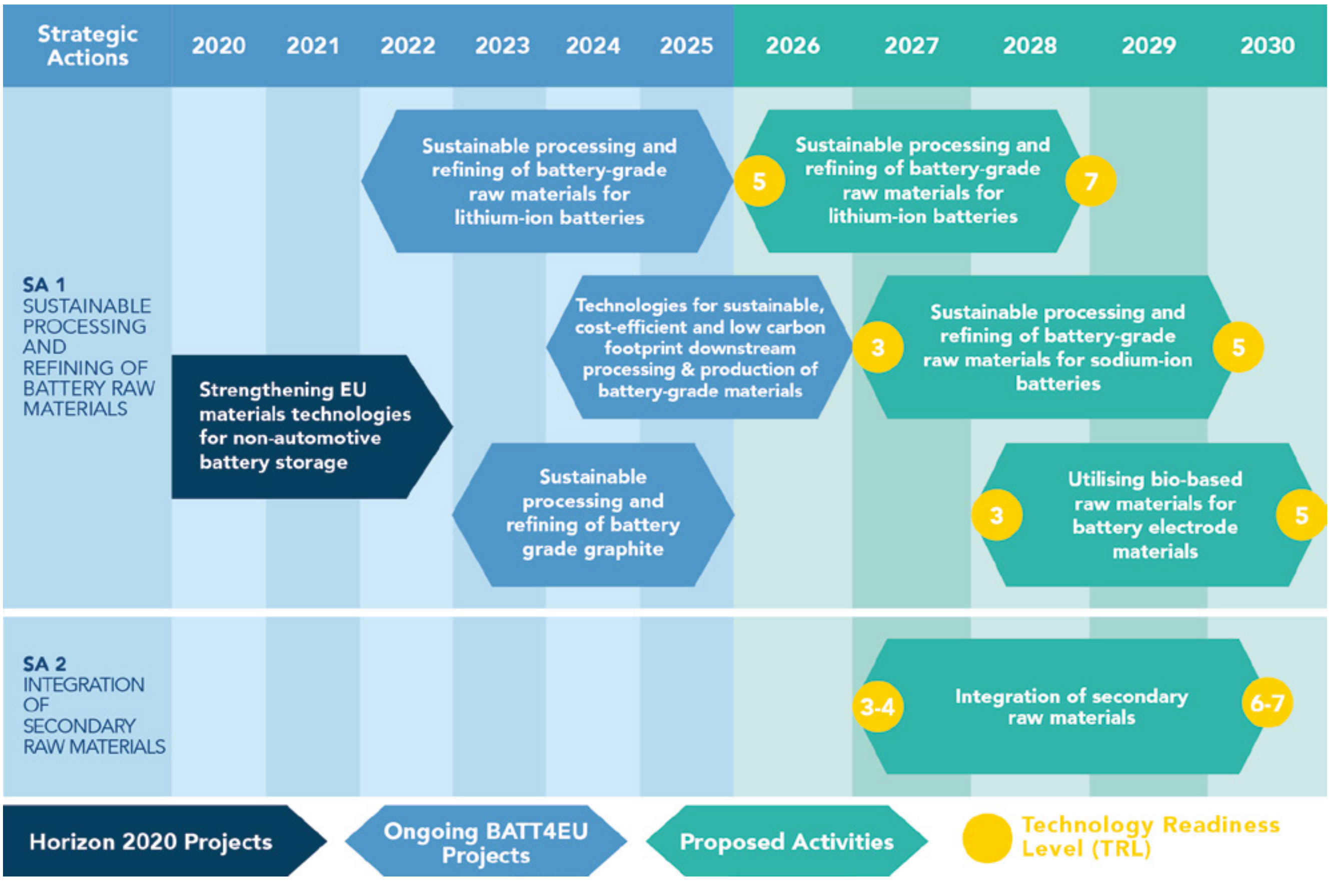
The recovery of metals and chemicals from new sources such as industrial or urban wastes was listed as a possible longer-term activity in the 2021 BATT4EU SRIA. The rise of battery manufacturing capabilities in Europe, coupled with the need for recycled content in batteries as per the Batteries Regulation, have put this topic more in the spotlight. Some aspects of this activity have been included in Horizon Europe call HORIZON-CL5-2023-D2-01-02, but there are many more research areas that should be tackled and so this subject warrants its strategic action. Included in this strategic action are the recovery and production of battery-grade materials from mining and industrial wastes (e.g., manufacturing scrap, tailings, slags, sludges, etc.) for reintroduction into the battery value chain. Research activities which should be addressed in the upcoming years are:

- Development of novel cost and energy-efficient recovery methods and processes.
- Application of the near-zero waste approach, whereby the waste stream is completely utilized after extraction of valuable materials, or at the least can be safely backfilled as a non-hazardous material.
- Demonstration of developed recovery technologies.
- Identification of opportunities of processing intermediate concentrates/ precipitates containing CRM.
- Induction of engineering & operative synergies between mining-refining and recycling-refining of battery CRM-rich feedstocks.

2.1.4

## Strategic action timeline

The figure below summarises the key strategic research and innovation actions between now and the end of the Horizon Europe projects in 2030 and beyond, related to the processing of battery-grade primary and secondary raw materials. The activities highlight the goal of improving European independence in terms of raw materials for batteries.




# 2.2 ADVANCED MATERIALS

2.2.1

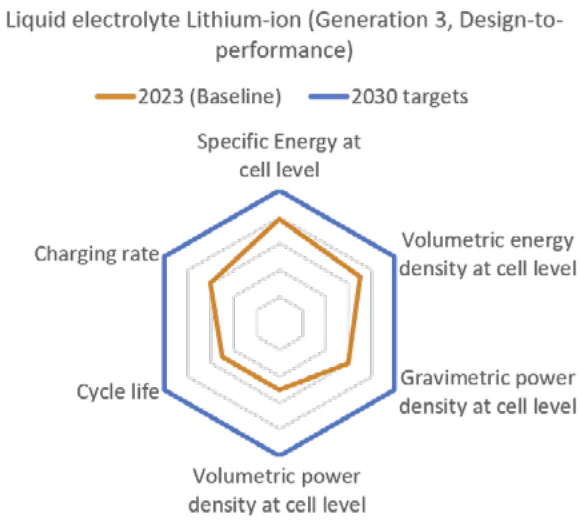
## Vision

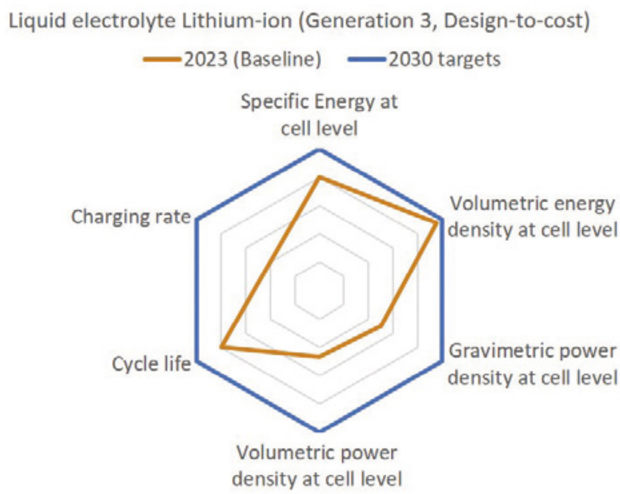
The focus of the European projects in advanced materials has been on maximizing the performance of the batteries while aiming for lower costs. To that end, safe materials that exhibit high capacity and high voltage (i.e., high-nickel NMC cathodes with silicon-carbon composite anodes) are considered both short to mid-term materials of choice, while at the same time several European projects target generation 4 lithium-ion batteries (i.e., solid electrolytes with/without metallic lithium anode) as long-term candidates of the industry that present a significant potential both in terms of performance and cost. The investment on R&I for these chemistries should be followed with the sense of necessity of continuity and avoidance of knowledge gap, ensuring the European competitiveness in the medium to long run by bringing these technologies to the market.

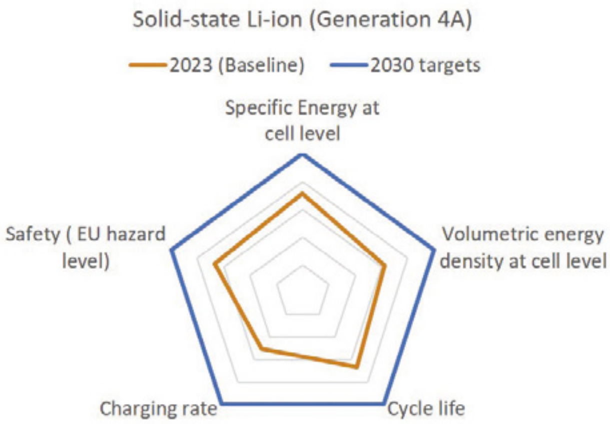
**Increasing the energy density remains a central driving force in advancing battery research and innovation, especially for aviation and high-performance on-road applications. However, disruptions in supply chains, rising raw material costs, and the need for Europe to secure critical raw materials have highlighted the importance of diversifying development of advanced materials for specific use cases.**

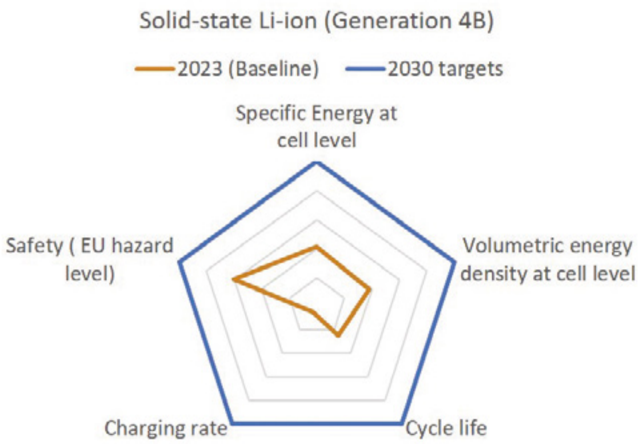
The development of lithium-ion chemistries such as LFMP and LFP, and perhaps even sodium-ion chemistries, also have the objective to obtain higher energy densities, but with a clear eye on ensuring cost-effectiveness and reduced reliance on critical raw materials. By giving more thought to affordability, these approaches can support the widespread electrification of transport by offering cheaper alternatives.

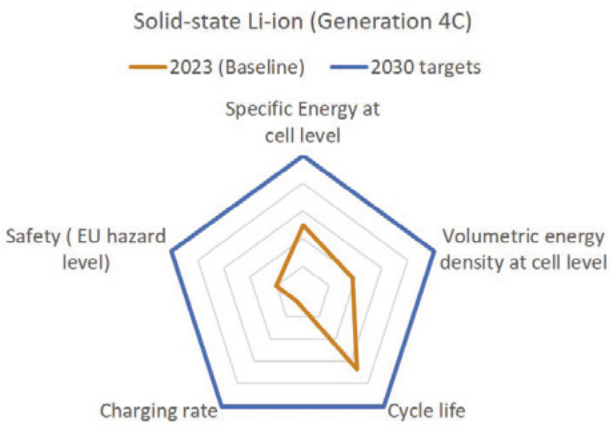
Ambitious targets have been set for all of the above-mentioned chemistries, which can be explored in depth in the KPI tables attached to this SRIA as Annex I. Even though there are battery systems on the market that fulfil the definition of Generation 3, these are not performing to the levels that are expected in 2030 and there is a need for research development to achieve these targets. The spider graphs below show the expected room for progress for the different generation 3 and generation 4 lithium-ion chemistries towards their specific targets.

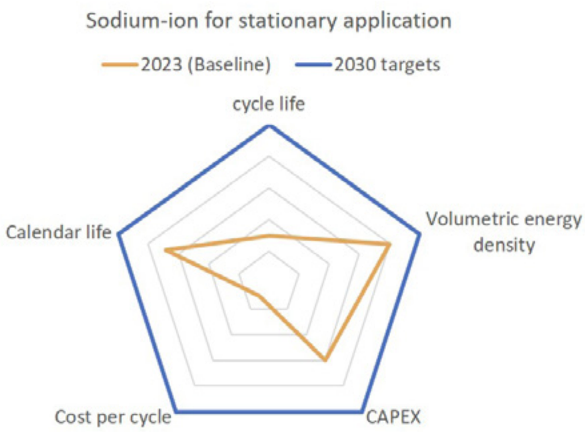


The complementary approach foreseen in the SRIA is investment in the long-term research on emerging sustainable generations of chemistries that target ambitious energy density targets (e.g., metal-air and metal-sulfur) and/or cost competitive alternatives that satisfy the requirements for electrification of a variety of transport modes. The development of advanced materials for stationary storage also requires specific focus. Here the trade-off between performance indicators is shifting in favour of cost-effectiveness and longevity. These objectives require further research on chemistries which rely on abundant and cheap main elements, have long lasting components and can operate reliably at wide range of conditions. The area includes higher TRL technologies, primarily sodium-ion and vanadium redox flow batteries, to low TRL chemistries including but not limited to aqueous (flow) batteries, metal-air and multivalent systems.

Incorporating sustainability as a critical criterion for the development of advanced materials for batteries is imperative. Alongside the pursuit of higher energy density, cost-effectiveness, and extended longevity, due consideration must be given to sustainability. This entails a comprehensive assessment of not only performance and cost-effectiveness but also environmental impact, human safety, durability, and lifecycle considerations through guidelines outlined by safe and sustainable by design farmwork (see design chapter). The objective is to ensure that selected materials not only fulfil immediate performance needs but also align with long-term sustainability goals. This approach aims to proactively address any potential environmental, safety, or recycling concerns that may arise as these materials become adopted in the market.

| Battery Technology Generations and Component Materials Overview[29] | |
|---|---|
| **Liquid electrolyte lithium-ion battery (Generation 3)** | |
| **Design to cost** | Low-cost, long-lasting materials with moderate voltage and energy density. E.g., phosphate-based cathodes (LFMP, LFP) and lithium-rich manganese materials. |
| **Design to performance** | High voltage/high energy (Li-rich) NMC with silicon-based anodes (Si>10%). |
| **Solid-state lithium-ion battery (Generation 4)** | |
| **Generation 4a** | NMC cathode + C/Si composites + Solid electrolyte. |
| **Generation 4b** | NMC cathode + Li metal + Solid electrolyte. |
| **Generation 4c** | High voltage/high energy cathode (HE NMC, Li-rich NMC, LMNO) + Li metal + Solid electrolyte. |
| **Sodium-ion battery** | |
| **Generation 3** | Liquid-electrolyte Sodium-ion batteries. |
| **Generation 4** | Solid-state sodium-based batteries. |

*29 The table is intended to illustrate the distinction in components of different technologies and builds upon a system used in the previous SRIA and Horizon Europe work programmes. It is not an exhaustive representation of all the chemistries discussed herein and the absence of a specific chemistry in the table does not imply its exclusion from the broader discussion in this chapter and the SRIA.*

2.2.2

## Review of R&I activities

**Since the start of the BATT4EU Partnership in 2021, the following calls have been issued under the umbrella of the partnership to address the advanced materials research:**

**Call: HORIZON-CL5-2021-D2-01-02**
**Topic:** Advanced high-performance Generation 3b (high capacity / high voltage) Li-ion batteries supporting electro mobility and other applications.
**Projects:**

| | | |
|---|---|---|
| **SIGNE** | Composite silicon/graphite anodes with Ni-rich cathodes and safe ether-based electrolytes for high capacity li-ion batteries. | Sep. 2022 to Aug. 2026 |
| **Intell iGent** | Innovative and sustainable high voltage li-ion cells for next generation (EV) batteries. | Sep. 2022 to Aug. 2025 |
| **HighSpin** | High-voltage spinel LNMO silicon-graphite cells and modules for automotive and aeronautic transport applications. | Sep. 2022 to Aug. 2026 |
| **NEXTCELL** | Towards the next generation of high performance li-ion battery cells. | Jan. 2023 to Dec. 2026 |

**Call: HORIZON-CL5-2021-D2-01-03**
**Topic:** Advanced high-performance Generation 4a, 4b (solid-state) Li-ion batteries supporting electro-mobility and other applications.
**Projects:**

| | | |
|---|---|---|
| **AM4BAT** | Gen. 4b Solid State Li-ion battery by additive manufacturing. | July 2022 to June 2026 |
| **SEATBELT** | Solid-state lithium metal battery with in situ hybrid electrolyte. | July 2022 to June 2026 |
| **HELENA** | Halide solid state batteries for electric vehicles and aircrafts. | June 2022 to May 2026 |
| **PSIONIC** | High voltage, room temperature single-ion polymer electrolyte for safer all solid-state lithium metal batteries. | July 2022 to June 2026 |

| | | |
|---|---|---|
| **ADVANGEN** | Development of advanced next generation solid-state batteries for electromobility applications. | Aug. 2022 to July 2026 |

**Call: HORIZON-CL5-2022-D2-01-02**
**Topic:** Interface and electron monitoring for the engineering of new and emerging battery technologies
**Projects:**

| | | |
|---|---|---|
| **OPIN-CHARGE** | Operando analyses and modelling of interface dynamics and charge transport in lithium-ion batteries. | June 2023 to May 2026 |
| **UltraBat** | Capturing ultrafast electron and ion dynamics in batteries. | Sep. 2023 to Aug. 2027 |
| **OPERA** | Development of operando techniques and multiscale modelling to face the zero-excess solid-state battery challenge. | June 2023 to May 2026 |

**Call: HORIZON-CL5-2023-D2-02-01**
**Topic:** Advanced materials and cells development enabling large-scale production of Gen4 solid-state batteries for mobility applications.
**Projects:** TBD

**Call: HORIZON-CL5-2023-D2-02-02**
**Topic:** New approaches to develop enhanced safety materials for gen 3 li-ion batteries for mobility applications
**Projects:** TBD

**Call: HORIZON-CL5-2024-D2-02-02**
**Topic:** Post-Li-ion technologies and relevant manufacturing techniques for mobility applications (Generation 5).
**Projects:** TBD

**Call: HORIZON-CL5-2024-D2-02-05**
**Topic:** Furthering the development of a materials acceleration platform for sustainable batteries (combining AI, big data, autonomous synthesis robotics, high throughput testing).
**Projects:** TBD

2.2.3

# Scope of actions

**Considering the context, the vision and ongoing research activities, the following research actions are proposed:**

## STRATEGIC ACTION 1 - LIQUID ELECTROLYTE LITHIUM-ION BATTERIES (GEN. 3)

Previous research calls under Horizon Europe have focused on better performing and safer materials for lithium-ion batteries for batteries. The strategic activities proposed in the SRIA promote, on the one hand, more focus research on a new wave of lower-cost chemistries and the next step for high-performance Li-ion chemistries on the other.

### DEVELOPMENT OF DESIGN-TO-COST CHEMISTRIES

The focus of this activity is the development of advanced materials with the primary aim of reducing cost while lowering the share of critical raw material (CRM), including by "design-for-recycling" strategies. Research to enhance safety and lifetime in exchange for lower energy density are also possible. Examples of chemistries covered by this activity include, but are not limited to, high-safety phosphate-based materials (e.g., LFP and LFMP), high safety manganese rich HLM-based materials and high safety and low-cost nickel-rich cathodes. The cost leverage should not hinder the previously established standards for low carbon manufacturing processes, compatibility with sustainable production methods (e.g., dry manufacturing) and materials sourcing alignments with Critical Raw Materials Act objectives.

### DEVELOPMENT OF DESIGN-TO-PERFORMANCE CHEMISTRIES

Developing advanced materials enabling higher energy/power density thanks to higher capacity and/or operating at a higher voltage. **Priorities include:**

- Developing high voltage cathodes with reduced degradation rate and high cycling stability.
- Developing high content (>10%wt) Si-based anodes with controlled volume changes during charge/discharge cycling, and simultaneously targeting competitive and sustainable manufacturing of Si-rich anodes.
- Developing sustainable and recyclable inactive materials such as binders and electrolyte additives that maintain good stability with silicon and high voltage cathode materials.
- Cathode materials (positive active materials and inactive materials) designed for organic solvent-free or dry production processes manufacturing.
- Strong reduction of critical raw materials.
- Enabling fast charging, particularly for deployment in high-rate applications.
- Developing self-healing materials and corresponding triggering mechanisms.

## STRATEGIC ACTION 2 - SOLID-STATE LITHIUM-BATTERIES (GEN. 4)

Accelerated scale production of solid-state batteries by the end of the decade and uptake of the chemistry by the mobility sector strongly depends on innovations in the battery materials area. Accordingly, the focus is on developing solid-state electrolytes, cathode materials, and anode materials (including additives) that exhibit enhanced thermal and electrochemical stability. The goal is to achieve higher energy/power densities, enable fast charging, improve cyclability, and enhance overall safety. Materials intended for solid-state electrolytes should ideally prioritize full sustainability, refraining from the use of critical raw materials (CRMs). It is advisable for these materials to be designed with an emphasis on recyclability and ease of manufacturing.

**Short-term priority is to build on the results of the ongoing research on the following areas:**

- Developing solid-state electrolytes, cathode materials and anode materials (including additives) for generation 4.c.
- Enabling higher thermal and electrochemical stability while targeting higher energy/power densities.
- Fast charging capabilities.
- Cyclability and improved safety.
- Low-cost electrode processing and electrolyte deposition.
- Enhanced compatibility analysis, by co-development of materials and cell design.

Developments should range from using conventional materials (Gen. 4a) to using Li metal-based anode with(out) high voltage cathode materials (Gen. 4b and 4.c). Given the previous fundings on generation 4.a and 4.b, and as the scope of the Horizon Europe programme (TRL≤7) implies reaching to demonstration of cell production at pilot level, these materials should also provide the corresponding compatibility and manufacturability characteristics, while maintaining (and improving) the sustainability goals followed by incumbent generation 3. cells. In addition, maximizing the potential of sharing generation 3 production processes, through tailored choice of materials, and exploring using low-cost cathodes (e.g., LFP and LFMP) are of remaining challenges.

## STRATEGIC ACTION 3 - DEVELOPMENT OF NEXT GENERATION SUSTAINABLE BATTERIES FOR MOBILITY

The goal of this action is to enable future of e-mobility by developing various chemistries (currently at TRL≤4) to deliver on safety, cost, performance, sustainability and recyclability, with clear prospects for the feasibility of scale-up of the manufacturing processes. The development of new chemistries for safety-critical mobility applications will also be considered under this activity. Research activities under this goal will also include building on the main findings from the 2024 Horizon Europe topic "Post-Li-ion technologies and relevant manufacturing techniques for mobility applications (Generation 5)".

Sodium-ion based chemistries are now covered in more depth by Strategic Action 5.

## STRATEGIC ACTION 4 - NON-LITHIUM-ION BATTERIES (DRIVEN BY STATIONARY STORAGE)

The aim of this strategic action is to develop various safe and sustainable systems to enable beyond Li-ion batteries to deliver features fit for stationary storage, including extended cycle and calendric life, low cost, and a reduced dependence on critical raw materials. Various technologies are considered under this strategic action, ranging from technologies that are close to the market, such as vanadium flow batteries, to more novel battery material systems, such as organic flow batteries and aqueous batteries.

### ENHANCED MATERIALS FOR VANADIUM REDOX FLOW BATTERIES TARGETING HIGHER PERFORMANCE AND SUSTAINABILITY FOR LOWER COST

**The objectives aim at improving the properties of several vanadium flow battery components:**

- Improved cost-effectiveness and sustainability of membranes, both with and without fluorine.
- Creating custom electrodes with enhanced catalysis and topology.
- Implementing strategies to improve energy density using solid mediators or complexing agents.
- Reduction of critical elements and design for recycling.

### DEVELOPMENT OF NEXT GENERATION BATTERIES FOR LONG DURATION STORAGE

The aim of this activity is to develop promising sustainable battery material systems with minimized amount of critical raw materials that can provide storage services for the grid from 10 hours to seasonal timeframes. The research on this activity will aim to develop chemistries that demonstrate an optimal trade-off between energy density, capital cost, operating cost, round-trip efficiency and lifetime, making them the reliable electrochemical storage systems on the path to reaching the targets in adoption of renewable energy sources, outlined by REPowerEU. The activity is focused on advancing technologies that are presently at an early or low Technology Readiness Level, indicating that they are still in the nascent stages of development. Examples range from metal-air chemistries to aqueous batteries. The full list and elaborate description of R&I needs for these technologies are provided in the Batteries Europe Roadmap under "New and Emerging Technologies"[30].

### DEVELOPMENT OF NEXT GENERATION BATTERIES FOR HIGH-POWER APPLICATIONS IN GRID

Development of sustainable next generation high-power battery technologies for use in power grid and other stationary applications; to be used as stand-alone solutions or in a hybrid with other sustainable long-term energy storage solutions, with the goal of covering a critical gap of ultrafast and fast storage. Technologies developed should contain minimum to no critical raw materials and offer an optimal trade-off between power density, capital cost, operating cost, round-trip efficiency and lifetime. Possible use-cases could cover a combination with power2x, hydropower, use in fast-charging environments etc. Examples range from metal-air chemistries to aqueous batteries. The full list and elaborate description of R&I needs of these technologies are provided in the Batteries Europe Roadmap under "New and Emerging Technologies".

## STRATEGIC ACTION 5 - SODIUM-ION BATTERIES (DRIVEN BY MOBILITY AND STATIONARY STORAGE)

The developments on sodium-ion technology, the possible benefits for the reduction of CRMs and the current capabilities in Europe support a broad Strategic Action on this topic. The main objective of the action is developing safe and sustainable materials systems to enable low-temperature sodium-ion batteries (SIBs) to deliver on energy density, long cycle life and low cost, combined with a reduced dependence on critical raw materials. They include generation 3 (liquid electrolyte batteries with carbonaceous or Ti-based anode) and generation 4 (polymer, sulfide and oxide solid-state electrolyte batteries with carbonaceous, Ti-based and Na metal-based negative electrodes). The positive electrode materials include layered transition metal oxides (LTMO), Prussian blue/white analogues (PBAs/PWAs), and polyanionic compounds. Choice of the materials depends on the corresponding KPIs and type of application. Both liquid electrolyte (Gen.3) and solid electrolyte (Gen4.) sodium-ion batteries are considered under this action.

## STRATEGIC ACTION 6 - BIOMIMETIC MATERIALS WITH SELF-HEALING FUNCTIONALITIES

**Development of biomimetic self-healing materials, targeting increased lifetime of batteries:**

- Biomimetic separators for controlled charge transfer, ion selectivity and/or trapping of degradation products or parasitic materials.
- Microcapsules with repairing agents that can be triggered upon demand.
- Establishing metrics and qualifying standards of self-healing in the context of batteries.
- Including both autonomous and externally triggered concepts.
- Self-healable binders, separators and/or electrolyte systems having self-healing functionalities derived from bio-inspired materials.
- Bio-inspired architectures for active materials.

29 https://batterieseurope.eu/results/technology-roadmap/researchandinnovationroadmap-2023/

**STRATEGIC ACTION 7 - ACCELERATED BATTERY MATERIAL DISCOVERY THROUGH MULTI-MODAL CHARACTERIZATION**

Autonomous closed-loop materials discovery through the use of artificial intelligence to orchestrate data acquisition and analysis from multiscale computer simulations, experiments and testing is crucial. It includes the development of autonomous high throughput synthesis robotics and experiments, also utilising the European large-scale characterisation infrastructures such as synchrotron and neutron facilities. Activities under this action are building on the successful BIG-MAP project of Horizon 2020 and ongoing projects and calls furthering the work on interface engineering and development of the fully-automated material discovery platform.

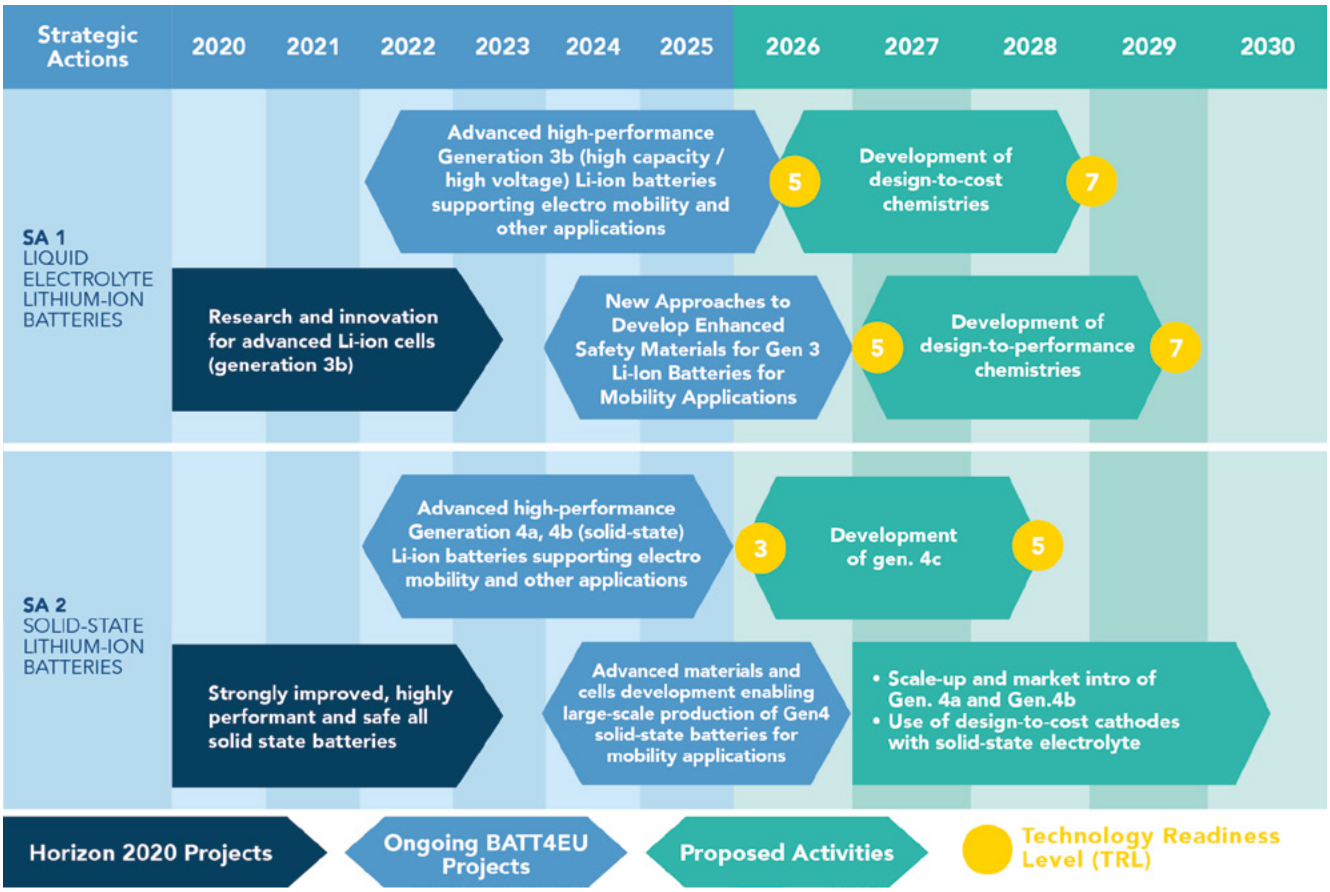
**The groundwork that has already been laid can be capitalised upon by supporting the following topics:**

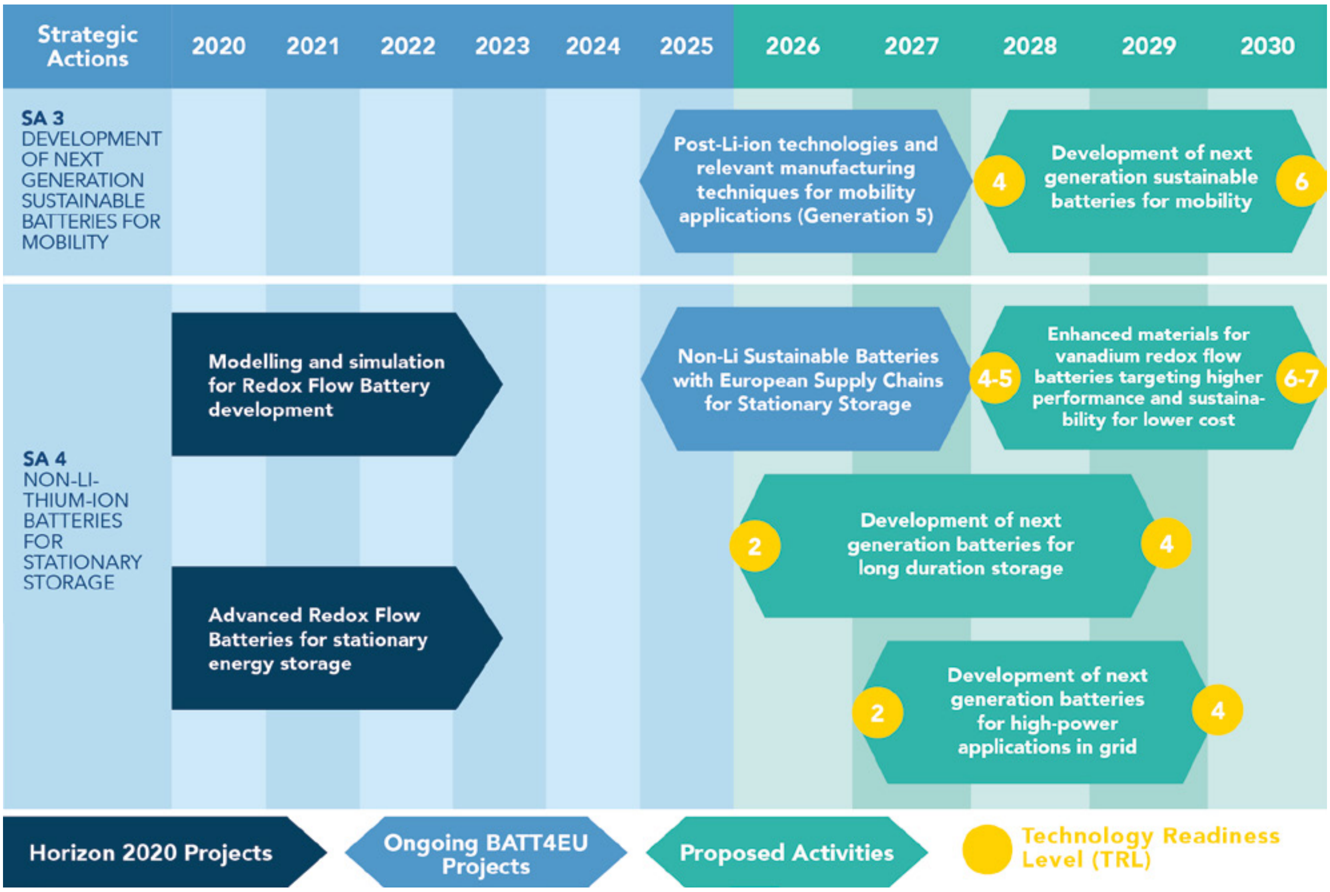
- The expansion of the materials acceleration platform (MAP) to allow for other chemistries including organic and the development of standardised and correlative multi-modal characterizations.
- Application of multi-techniques and multiscale advanced (in operando) characterisation of battery materials to push the development of solid-state batteries towards market-ready products.
- To accelerate the roll-out of multi-techniques and multiscale advanced characterisation, a streamlined access to the European network of synchrotrons is necessary. For example, a battery meta-hub could pool synchrotron access and establish a collaborative platform for community-organized experimental programs, based on sharing of methods and data, which will allow to utilise these methods on a larger scale.

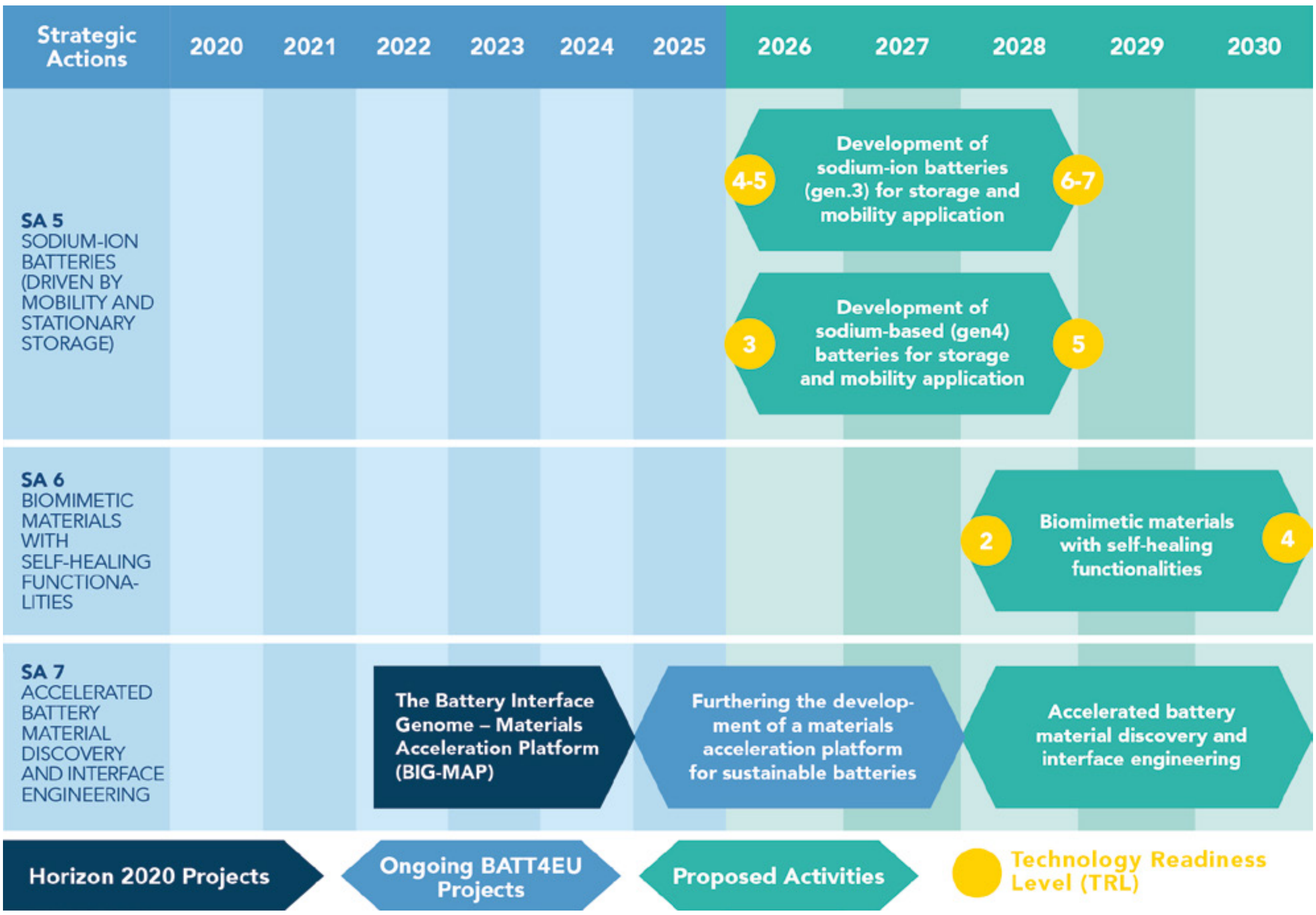
## 2.2.4

# Strategic action timeline

**The figure below summarises the key strategic research and innovation actions between now and the end of the Horizon Europe projects in 2030 and beyond, related to the advanced materials.**




Strategic Actions
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
SA 3
DEVELOPMENT OF NEXT GENERATION SUSTAINABLE BATTERIES FOR MOBILITY
Post-Li-ion technologies and relevant manufacturing techniques for mobility applications (Generation 5)
4
Development of next generation sustainable batteries for mobility
6
SA 4
NON-LI-THIUM-ION BATTERIES FOR STATIONARY STORAGE
Modelling and simulation for Redox Flow Battery development
Non-Li Sustainable Batteries with European Supply Chains for Stationary Storage
4-5
Enhanced materials for vanadium redox flow batteries targeting higher performance and sustainability for lower cost
6-7
2
Development of next generation batteries for long duration storage
4
Advanced Redox Flow Batteries for stationary energy storage
2
Development of next generation batteries for high-power applications in grid
4
Horizon 2020 Projects
Ongoing BATT4EU Projects
Proposed Activities
Technology Readiness Level (TRL)


Strategic Actions
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
SA 5
SODIUM-ION BATTERIES (DRIVEN BY MOBILITY AND STATIONARY STORAGE)
4-5
Development of sodium-ion batteries (gen.3) for storage and mobility application
6-7
3
Development of sodium-based (gen4) batteries for storage and mobility application
5
SA 6
BIOMIMETIC MATERIALS WITH SELF-HEALING FUNCTIONALITIES
2
Biomimetic materials with self-healing functionalities
4
SA 7
ACCELERATED BATTERY MATERIAL DISCOVERY AND INTERFACE ENGINEERING
The Battery Interface Genome – Materials Acceleration Platform (BIG-MAP)
Furthering the development of a materials acceleration platform for sustainable batteries
Accelerated battery material discovery and interface engineering
Horizon 2020 Projects
Ongoing BATT4EU Projects
Proposed Activities
Technology Readiness Level (TRL)


## 2.3 DESIGN

Battery cell and system design do not only impact directly the properties of the batteries produced, but they have the capacity to shape the entire value chain, from raw material production to the expected lifetime of the battery and the ease of recycling. It is also in the design phase that the need to comply with current and upcoming legislation is first felt. In order to cut time-to-market of new cell designs, designers need to have a toolkit at hand that allows them to quickly adapt to new regulations. To remain competitive in a dynamic global system, European producers need to harness European strengths in digital cell design and the embedding of smart functionalities and self-healing properties. Improved performance and energy density of the batteries at the cell level also significantly addresses the resource efficiency of the sector, contributing to the Critical Raw Materials Act targets. This could be tackled through innovative designs such as bipolar stacking while also conceptualising and designing the next generation of cells for upcoming chemistries.

## 2.3.1
# Review of R&I activities

**Since the start of the BATT4EU Partnership in 2021, the following calls have been issued under the umbrella of the partnership to address the above-mentioned challenges:**

**Call: HORIZON-CL5-2022-D2-01-06**
**Topic:** Embedding smart functionalities into battery cells (embedding sensing and self-healing functionalities to monitor and self-repair battery cells).
**Projects:**

| | | |
|---|---|---|
| **HEALING BAT** | Advanced sensing, monitoring and self-healing mechanisms to self-repair batteries. | June 2023 to May 2027 |
| **SALAMANDER** | Smart sensors and self-healing functionalities embedded for battery longevity with manufacturability and economical recyclability. | May 2023 to Oct. 2026 |
| **PHOENIX** | Building more reliable and performant batteries by embedding sensors and self-healing functionalities to detect degradation and repair damage via advanced battery management system. | May 2023 to April 2027 |

## 2.3.2
# Scope of R&I actions

**Considering the context, the vision and ongoing research activities, the following research actions are proposed:**

**STRATEGIC ACTION 1 - SAFE AND SUSTAINBLE BATTERIES BY DESIGN**

The adoption of the Safe and Sustainable by Design framework is pushing battery cell producers to develop methodologies to apply the framework to the realities of battery manufacturing. This need is spurred on further by Article 6 of the Batteries Regulation and the proposed ban on PFAS.

**Topics under this action should:**

- Translate the Safe and Sustainable by Design framework into practicable guidelines for the battery sector by defining common principles, tools and methodologies for evaluation of design for circularity
- Evaluate battery design and materials from a reuse, recycle and repairability perspective
- Aim for a reduction of substances of concern as well as CRM by substitution and/or alternative battery designs
- Intensify use of the available digital toolsets, such as virtual reality, machine learning and artificial intelligence.

## STRATEGIC ACTION 2 - FUNCTIONAL CELL AND BATTERY DESIGN

Embedding smart sensing functionalities and/or functionalities enabling battery self-healing inside battery cells will significantly enhance the performances, lifetime, reliability and safety of the whole battery system. Sensors integrated into battery cells will communicate real-time data to the battery management system (BMS) for a better diagnosis and prognosis of the cell status. Furthermore, the BMS will be able to react to the sensor outputs and trigger active self-healing processes at the cell level. This action encompasses the development and integration of non-invasive sensing and/or self-healing mechanisms inside battery cells, as well as the coupling sensing and active self-healing functionalities via the BMS. Sensors and self-healing functionalities need to be adapted to the detection of the critical ageing processes. A link with the activities related to accelerated battery material discovery and interface engineering can be established. Activities under this action should build on the results of ongoing Horizon Europe projects, pushing cells with smart functionalities towards demonstration and production.

### DEMONSTRATION, PRODUCTION AND APPLICATION OF SMART FUNCTIONALITIES IN BATTERY CELLS

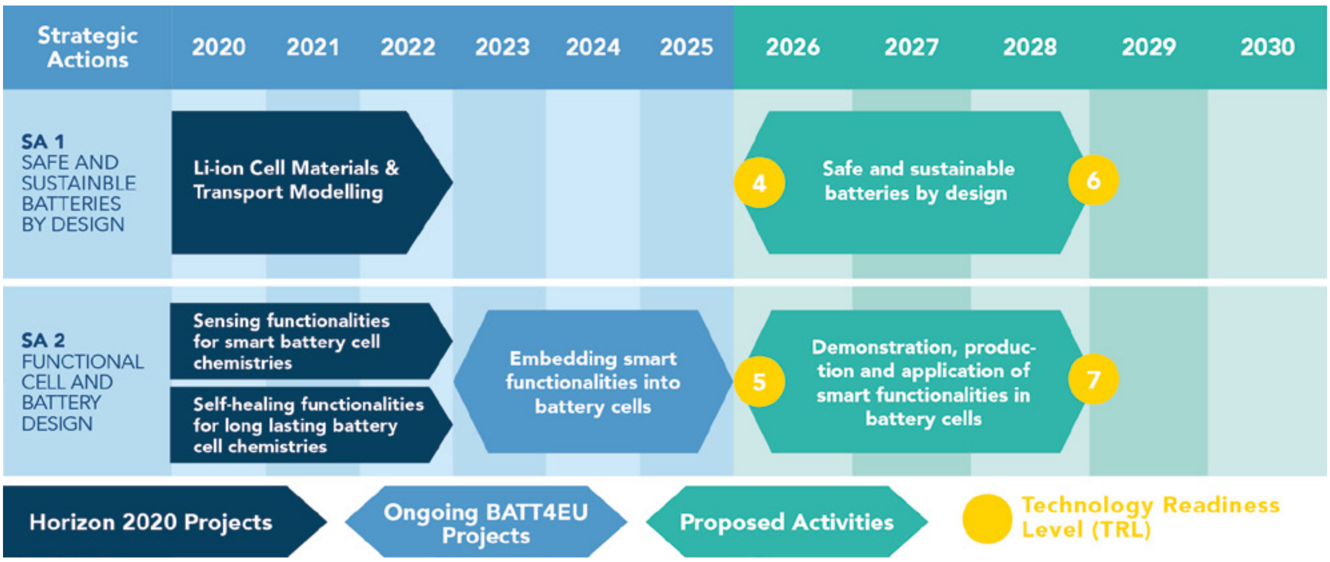
The activity is not aimed at developing advanced materials with self-healing functionalities, rather to implement the functionalities of developed agents in order to reach TRL>4 by building on the results from the 2022 topic "Embedding smart functionalities into battery cells (embedding sensing and self-healing functionalities to monitor and self-repair battery cells)" and/or by:

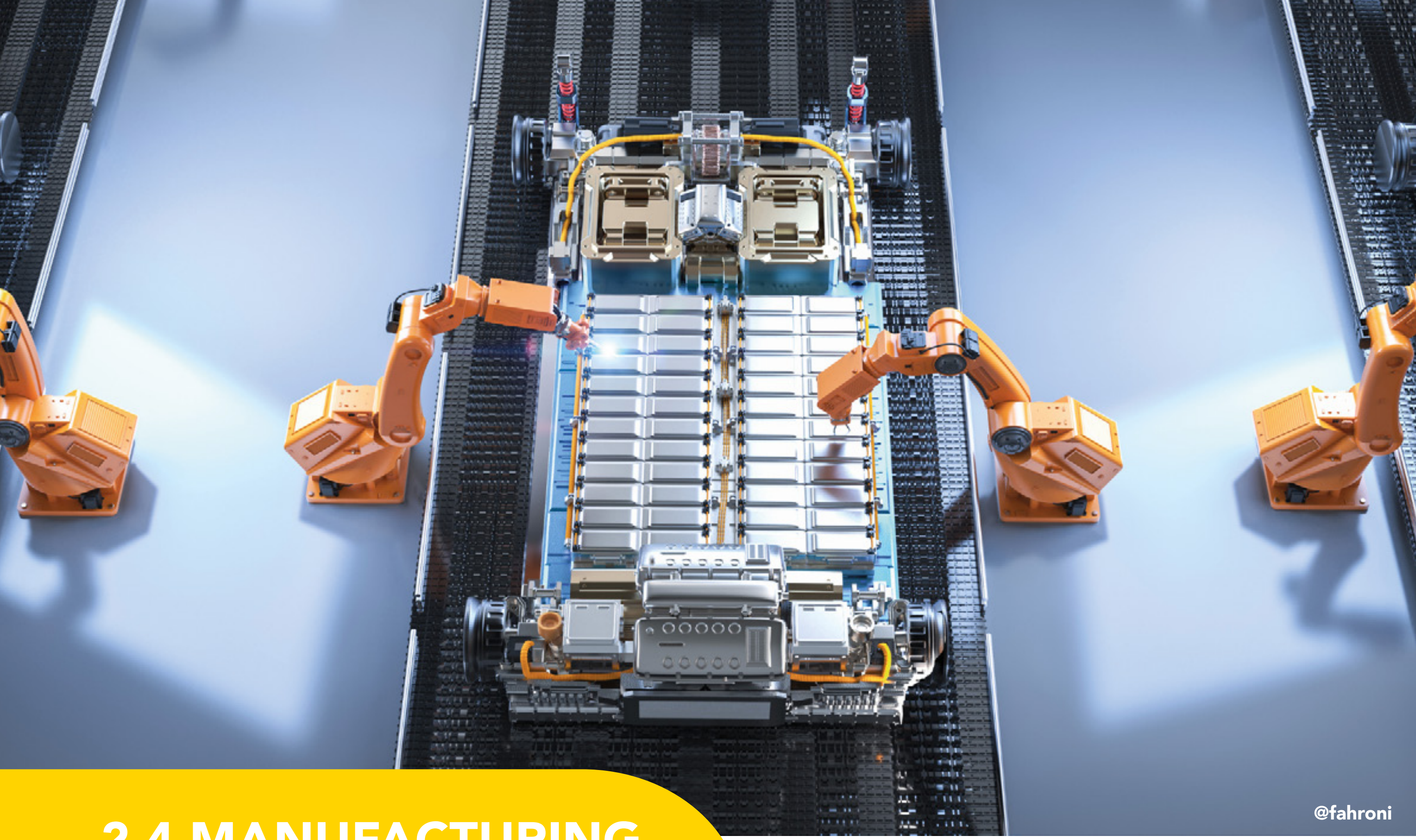
- Scale-up production of self-healing materials and battery cells containing thereof. And studying the proper recycling methodologies for the embedded smart functionalities.
- Digital models for optimizing sensor placement and efficient sensor communication technology.
- Demonstration of manufacturability of cells with embedded functionalities at pilot leve.

2.3.3

# Strategic action timeline

**The figure below summarises the key strategic research and innovation actions between now and the end of the Horizon Europe projects in 2030 and beyond, related to battery design.**





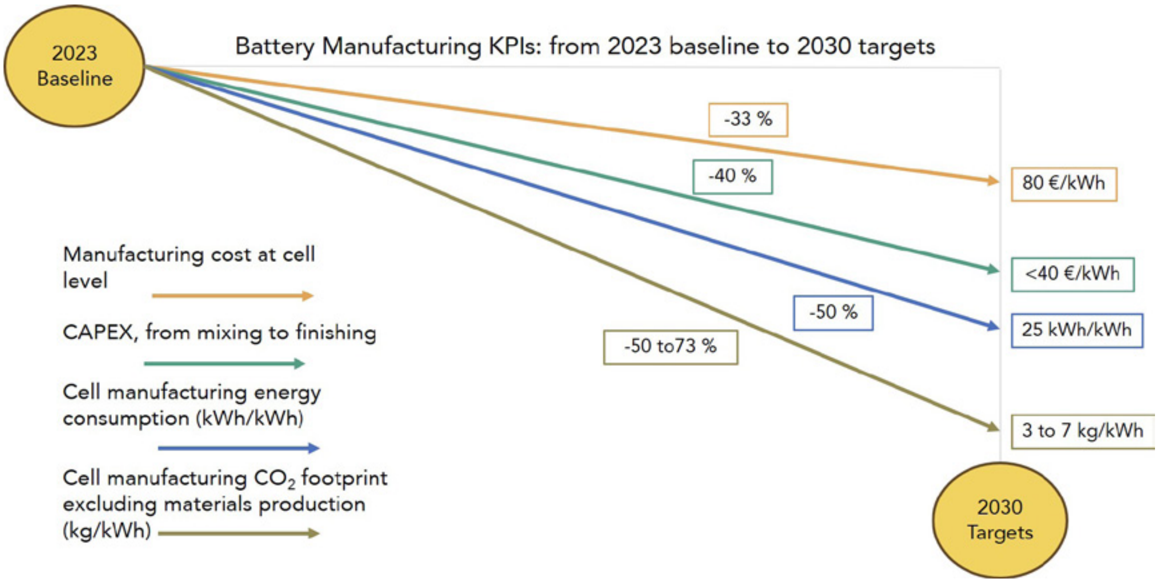

# 2.4 MANUFACTURING

As European cell production continues to thrive, research and innovation initiatives should prioritize two key directions. Firstly, the focus should be on devising solutions that reduce energy costs, carbon emissions, and enhance productivity, primarily through enhanced digitization and sustainability practices for manufacturers of conventional generation 3 lithium-ion batteries. This will enhance the competitiveness of the sector while it is trying to get off the ground. Secondly, efforts should be directed towards adapting these solutions to accommodate the increasing diversity of battery chemistries and applying existing high-efficiency methods to emerging technologies. To ensure the competitiveness and rapid industrialization of these new chemistries, knowledge transfer is a must. Ongoing projects aimed at constructing an integrated value chain and harmonizing processes should leverage these collaborations to establish a comprehensive value chain for the mass production of future technologies, like solid-state batteries.

To effectively meet the long-term demands of the value chain within European research and innovation projects, it is crucial to enhance the flexibility of production lines. This objective ensures production resilience during disruptive scenarios, such as fluctuations in energy and raw material costs. Adaptable production lines facilitate the creation of customized products for a wide array of applications, while also enabling the seamless incorporation of changes to accommodate emerging technologies, such as sodium-ion batteries, within existing processes.

Enhancing the sustainability of battery production has been a central goal in battery manufacturing projects. For instance, several projects are currently exploring innovative processing methods aimed at eliminating toxic solvents. This, in turn, reduces the environmental footprint of cell products and yields significant cost savings. These findings should be complemented by further research to implement these sustainable practices on a larger scale within European gigafactories' production lines. Another critical aspect involves applying these results to upcoming chemistries like solid-state batteries while simultaneously exploring opportunities to manufacture with lower energy consumption and reduced $CO_2$ emissions, particularly for emerging advanced materials.

A similar trend of activities and objectives can be observed in the digitalization of production lines. Ongoing efforts to develop the first generation of digital twins necessitate validation at the pilot level, with the subsequent step involving the transition from prediction to implementation, demanding both hardware and software innovative solutions.




## 2.4.1

# Review of R&I activities

**Since the start of the BATT4EU Partnership in 2021, the following calls have been issued under the umbrella of the partnership to address the above-mentioned challenges:**

**Call: HORIZON-CL5-2021-D2-01-04**
**Topic:** Environmentally sustainable processing techniques applied to large scale electrode and cell component manufacturing for Li-ion batteries
**Projects:**

| | | |
|---|---|---|
| **NoVOC** | Eliminating VOC from Battery manufacturing through dry or wet processing. | Sep. 2022 to Aug. 2026 |
| **BatWoMan** | Carbon neutral European battery cell production with sustainable, innovative processes and 3D electrode design to manufacture. | Sep. 2022 to Aug. 2025 |
| **GREEN SPEED** | Green and sustainable processes for electrode production. | July 2022 to Dec. 2025 |
| **GIGA GREEN** | Towards the sustainable giga-factory: developing green cell manufacturing processes. | Sep. 2022 to Aug. 2026 |

**Call: HORIZON-CL5-2021-D2-01-05**
**Topic:** Manufacturing technology development for solid-state batteries (SSB, Generations 4a - 4b batteries).
**Projects:**

| | | |
|---|---|---|
| **SPINMATE** | Scalable and sustainable pilot line based on innovative manufacturing technologies towards the industrialisation of solid-state batteries for the automotive sector. | Aug. 2022 to July 2026 |

| | | |
|---|---|---|
| **PULSE-LiON** | Pulsed laser deposition technology for solid state battery manufacturing supported by digitalization. | Sep. 2022 to Aug. 2026 |
| **SOLID** | Sustainable manufacturing and optimized materials and interfaces for lithium metal batteries with digital quality control. | Sep. 2022 to Aug. 2026 |

**Call:** **HORIZON-CL5-2022-D2-01-04**
**Topic:** Towards creating an integrated manufacturing value chain in Europe: from machinery development to plant and site integrated design.
**Projects:**

| | | |
|---|---|---|
| **GIGABAT** | Sustainable and digitalized gigafactory for battery production with made-in-Europe machinery. | July 2023 to Dec. 2026 |
| **BAT-MACHINE** | Boosting Europe's sustainable battery cell industrial manufacturing value chain by developing an optimised machinery with intelligent control processes to minimise costs, scrap and energy consumption. | June 2023 to Nov. 2026 |

**Call:** **HORIZON-CL5-2023-D2-01-03**
**Topic:** Advanced digital twins for battery cell production lines.
**Projects:**

| | | |
|---|---|---|
| **BATTwin** | Flexible and scalable digital-twin platform for enhanced production efficiency and yield in battery cell production lines. | Dec. 2023 to May 2027 |
| **BatCAT** | Battery Cell Assembly Twin. | Jan. 2024 to June 2027 |

**Call:** **HORIZON-CL5-2024-D2-02-01**
**Topic:** Sustainable high-throughput production processes for stable lithium metal anodes for next generation batteries.
**Projects:** TBD

2.4.2

# Scope of R&I actions

**Considering the context, the vision and ongoing research activities, the following research actions are proposed:**

## STRATEGIC ACTION 1 - SUSTAINABLE PRODUCTION OF CELLS & BATTERIES

### ENVIRONMENTALLY SUSTAINABLE PROCESSING TECHNIQUES APPLIED TO LARGE-SCALE MANUFACTURING FOR GEN.3 AND GEN.4 LI-ION BATTERIES

- Reduce specific energy consumption and emissions, minimise the use of chemicals and improving process safety, reduce cost and increase efficiency.
- Validation of sustainable production processes in view of giga-scale application.
- To build on the findings of the ongoing projects specially Horizon Europe projects under the topic "Environmentally sustainable processing techniques applied to large scale electrode and cell component manufacturing for Li ion batteries" and to upgrade the degree of integration of sustainable manufacturing processes into the existing/ future lines.
- If possible, showcasing applicability of innovative solutions to similar battery production lines like sodium-ion systems.

## STRATEGIC ACTION 2 - FLEXIBLE PRODUCTION TECHNOLOGIES

### FLEXIBLE PILOT LINES FOR CURRENT AND NEXT-GEN TECHNOLOGIES

- Innovative multi-purpose production line development, encompassing the creation of machinery compatible with diverse chemistries, cell format/design, process technologies, and more. This development includes pilot-level validation and simulation to assess its applicability to mass production scale
- Enhance the capacity of existing Lithium-ion battery giga-factories to accommodate upcoming new chemistries and advanced production concepts and machinery. Additionally, fortify production lines to withstand various disruptive scenarios, ranging from energy source variability to supply chain disruptions. To achieve these objectives, required actions include conducting sensitivity studies on current equipment to assess their response to different scenarios, followed by designing potential tools or upgrades for improved resiliency and adaptability.

## STRATEGIC ACTION 3 - DIGITAL TWINS FOR SUSTAINABLE DESIGN AND MANUFACTURING OF BATTERIES

### UPTAKE OF ADVANCED DIGITAL TWINS IN LI-ION BATTERY PRODUCTION LINES

- Optimisation of sensors and on-line measuring
- Validation of digital twins at pilot level to optimise production processes, implement automatic corrections, reduce commissioning time and mitigate project risk

- To focus on implementation of the Horizon Europe projects under the topic "Advanced digital twins for battery cell production lines ", and move forward from prediction to optimisation/correction in real-time for existing production lines.

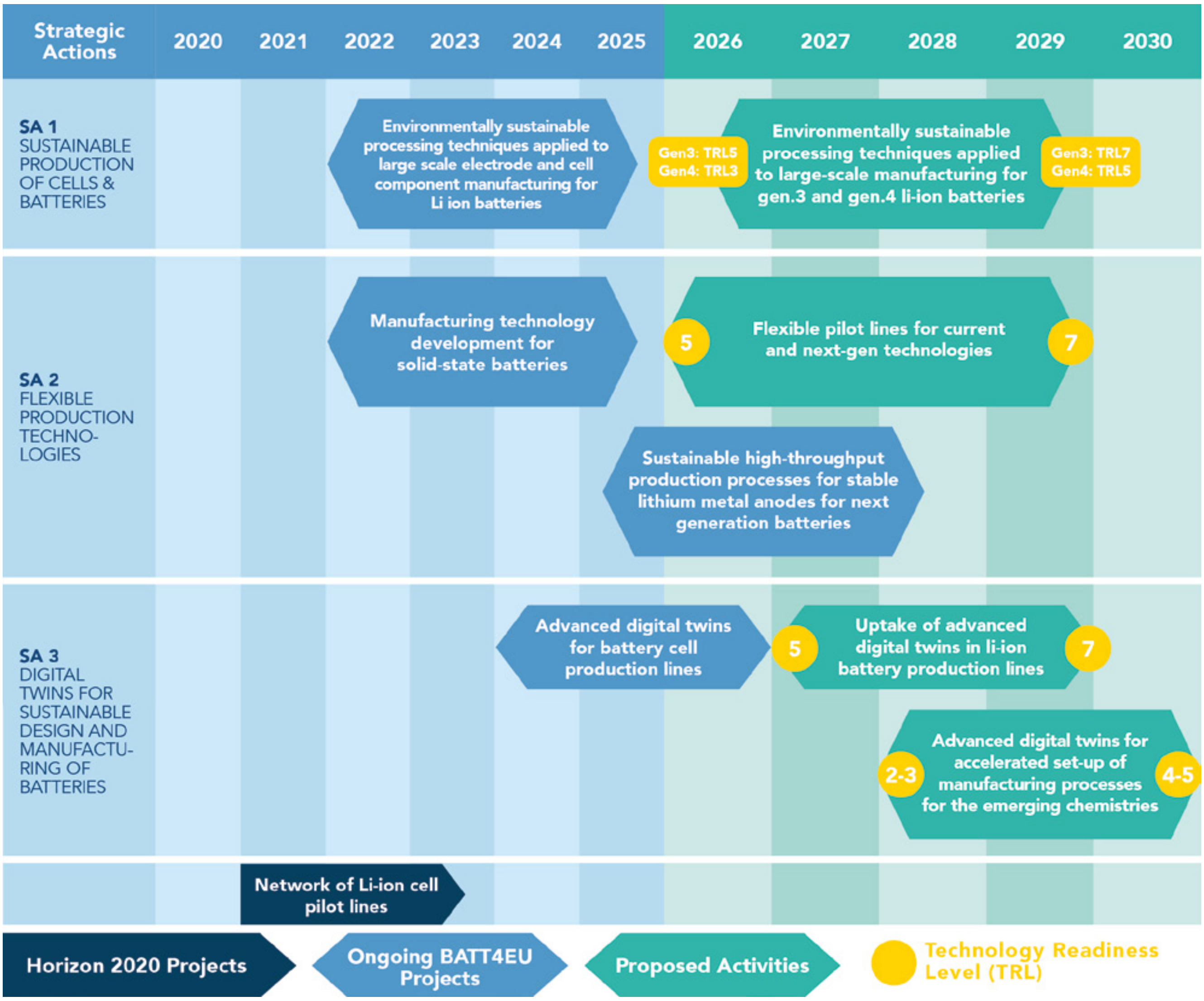
**ADVANCED DIGITAL TWINS FOR ACCELERATED SET-UP OF MANUFACTURING PROCESSES FOR THE EMERGING CHEMISTRIES**

- Development of 1st generation digital twins for emerging chemistries.
- Develop an integrative modelling approach ("smart digital twin") able to simulate and optimise fabrication processes of this new generations of battery technologies.
- Model- based cell design of manufacturing processes.

### 2.4.3

## Strategic action timeline

**The figure below summarises the key strategic research and innovation actions between now and the end of the Horizon Europe projects in 2030 and beyond, related to the battery manufacturing.**



# 2.5 APPLICATION: MOBILITY

The rapid development of battery technologies is a cornerstone of achieving the objectives set by the European Green Deal. Not only the energy transition supported by stationary batteries, but also the decarbonisation of transport, and transition to electric mobility applications. These advancements are aimed at addressing some of the key challenges associated with electric vehicles, such as limited range, lengthy charging times, costs and concerns about battery durability and safety. The European battery industry is at the forefront of these developments, and as many European countries are already set to ban internal combustion engines within the next decade, safe and affordable batteries are crucial to enabling this transition. Many similar regulations are in place in ports, fjords, and inland waterways, requiring zero emission from ships. Whether for primary propulsion or auxiliary power, batteries are playing an increasingly important role in all transport modes. This effort is also needed to give to the European transport sector and industry the boost it needs to remain competitive on a global scale.

The challenges of the battery industry are nowadays mainly driven by the automotive industry, however, extend beyond this industry, encompassing aviation, waterborne, rail, and off-road transport. Each of these modes bring unique criteria to meet and emphasize different performance requirements. Further research and innovation is needed to make most fitting/tailormade battery solutions more widely available. By pushing the boundaries of battery technology, the European battery industry aims to overcome the barriers that have historically limited the widespread adoption of electric mobility options. These advancements contribute to a cleaner and more sustainable transportation sector by reducing greenhouse gas emissions and reliance on fossil fuels.

Many challenges related to electric mobility are currently being addressed by projects under Horizon Europe, bringing the needed technology closer to market ready. However, there is still work to be done in the final years of Horizon Europe, and the strategic research actions below intend to guide this. Battery performance aspects, such as rate of discharge can open batteries to a wider range of use cases. Cost efficiency is more and more important, to remain competitive with batteries from Chinese producers entering the European market. Improvements in thermal management is still needed for newer chemistries, and batteries for off-road applications, particularly in harsh use and extreme weather conditions.

2.5.1

## Review of R&I activities

**Since the start of the BATT4EU Partnership in 2021, the following calls have been issued under the umbrella of the Partnership to address the above-mentioned challenges:**

**Call: HORIZON-CL5-2022-D2-01-05**
**Topic:** Next generation technologies for High-performance and safe-by-design battery systems for transport and mobile applications.
**Projects:**

| | | |
|---|---|---|
| **EXTENDED** | Next generation of multifunctional, modular and scalable solid state batteries system. | June 2023 to May 2026 |
| **NEXTBAT** | Next generation technologies for battery systems in transport electrification based on novel design approach to increase performance and reduce carbon footprint. | June 2023 to Nov. 2026 |
| **TEMPEST** | Next generation multiple architecture battery systems for industry. | May 2023 to April 2026 |
| **VERSA-PRINT** | Versatile printed solutions for a safe and high-performance battery system. | May 2023 to April 2026 |

**Call: HORIZON-CL5-2022-D2-01-07**
**Topic:** Digitalisation of battery testing, from cell to system level, including lifetime assessment.
**Projects:**

| | | |
|---|---|---|
| **AccCellBaT** | Accelerated cell and battery testing – for automotive and stationary. | April 2023 to March 2026 |
| **FASTEST** | Fast-track hybrid testing platform for the development of battery systems to TRL6. | |
| **THOR** | Innovative methodology for battery testing. | |

**Call:** **HORIZON-CL5-2022-D2-01-09**
**Topic:** Physics and data-based battery management for optimised battery utilisation.
**Projects:**

| | | |
|---|---|---|
| **NEMO** | Next generation models for advanced battery electronics. | June 2023 to May 2026 |
| **BATMAX** | Battery management by multi-domain digital twins. | May 2023 to Oct. 2026 |
| **NEXTBMS** | Advanced BMS to enhance modelling approaches. | June 2023 to Nov. 2026 |
| **ENERGETIC** | Next generation BMS based on data rich digital twin. | June 2023 to Aug. 2026 |

**Call:** **HORIZON-CL5-2023-D5-01-022**
**Topic:** Innovative battery management systems for next generation vehicles (2ZERO & Batt4EU Partnership).
**Projects:**

| | | |
|---|---|---|
| **InnoBMS** | Situationally aware innovative battery management system for next generation vehicles | Jan. 2024 to June 2027 |
| **iBattMan** | Smart, Connected and Secure Battery Management System Enhanced by Next Generation Edge and Cloud Computing, Sensors and Interoperable Architecture. | Jan. 2024 to June 2027 |

**Call:** **HORIZON-CL5-2024-D2-02-03**
**Topic:** Size & weight reduction of cell and packaging of batteries system, integrating lightweight and functional materials, innovative thermal management and safe and sustainable by design approach.
**Projects:** **TBD**

2.5.2

## Scope of R&I actions

**Considering the context, the vision and ongoing research activities, the following research actions are proposed:**

**STRATEGIC ACTION 1 - HIGH-PERFORMANCE, COST-EFFICIENT AND SAFE BY DESIGN BATTERY SYSTEMS**

### ADVANCED THERMAL MANAGEMENT TECHNOLOGIES FOR BATTERIES IN HARSH-USE AND EXTREME CONDITIONS

- Progress on the batteries' thermal management, advanced cooling systems, and digital twin models for improving performance understanding under sustained fast and super-fast charge cycles, while informing the end-user on optimal usage profiles (driving/charging) for minimal capacity and performance degradation.
- Waterborne systems are not anticipated to encounter significant regenerative conditions but will be subjected to continuous discharge with a power requirement close to peak power. Therefore, reliability and thermal management are crucial, such as direct liquid cooling (either partial or full immersion).
- Development of reliable thermal management systems capable to operate under extreme environmental conditions supported by advanced models
- Development of novel cooling solutions, including new cooling agents for battery pack.

### HIGH PERFORMANCE AND COST EFFICIENT SAFE-BY-DESIGN BATTERIES

- Increase the cell energy and power density performance, while avoiding/replacing critical materials (e.g. Co) and reducing costs, including module and pack cost accounting for materials, connection technologies, peripherals and housing functional to the demonstration of battery operation.
- Highly efficient, compact, and lightweight cell-to-pack integration technologies (including multi-functionality of materials and components, where applicable and depending on the end-user applications).
- Multi-type cell arrangements (e.g. high-voltage LNMO / high-capacity NMC), high-voltage and current (i.e. above 800 V and/or 500 A), increasing performance through enhanced integration (i.e. Cell-to-Chassis (C2C), Cell-to-Vehicle (C2V), Cell-to-Airframe (C2A)). Interfaces to other systems (e.g. fuel-cell stacks) for joint operation can be considered (link to Clean Aviation/Clean Hydrogen).
- Fast charging capability is a key enabler for the electrification of transport. Most prominent limiting factors to adoption and further development of fast charging are cell degradation (i.e. cycling capacity fade) and heat dissipation. R&I in the area of fast charging is expected to focus on cells, modules and battery pack design capable of increasing the charging power while limiting degradation (by increasing voltage), targeting to double the actual charging speed, i.e. from 10-to-80% battery pack SoC increase in about 15 minutes, for road transport applications. As a further example, fast charging (high-voltage/parallel charging), i.e. from 10-to-95% battery pack SoC increase in about 15 minutes is expected for airborne applications.

- Pack design including flame retardant materials to prevent thermal runaway, explosion, and toxic gas release during crash and handling and recovery of crashed batteries. Investigate new battery architectural and housing designs ensuring repairability and fail-safe operation (such as containment of thermal runaway). Safety considerations are also the main cost driver for several applications, with corrosion resistant materials playing a large role in the cost of batteries for waterborne applications for example.

## STRATEGIC ACTION 2 - CLOUD BASED BATTERY MANAGEMENT FOR MULTI-APPLICATION INTEGRATION

BMS development has been widely funded. However, aspects like design and implementation of a comprehensive sensing strategy, integration of multi-purpose/multi-functional sensors capable of quantifying safety (i.e. probability of fatal event to occur), early diagnostics sensors, cloud-based machine learning algorithms and distributed intelligence instead of centralized BMS are open topics that could significantly enhance the value and the utilization of the battery. This is an activity that needs to be supported in conjunction with the delivery of a demonstrator.

### CLOUD BASED DATA MANAGEMENT FOR MULTIPLE APPLICATIONS

- Advanced Battery Management Systems (BMS), embedding sensors for diagnostics and early failure prediction, remote upgrade, and maintenance (ensuring cyber security for remote and cloud-based functions), lifetime-optimized operation management, (capitalizing on fleet-learning, artificial intelligence). Different level of sensorisation (e.g. per module, per-cell, on- or in-cell, depending on the transport modes and use-case can be adopted).
- Decentralized (virtual) BMS design for battery packs, with advanced algorithms and data analysis for more accurate SoC, SoH, SoX. Cloud data storage facilitating optimization of battery performance. Advanced user interaction for more informed decision making and optimized performance of multiple battery systems.
- Cloud-connected BMS to enable use of advanced algorithms and models, improving battery safety and functionality by exchanging data with the cloud. Can also be connected to battery passport.
- Cloud aggregation of battery assets in multiple storage units/vehicles, and provide fleet-management, or virtual storage capacity aggregation towards grid flexibility services.
- Advanced battery integration concepts, such as multi-functional energy storage structures with embedded multi-purpose sensing capabilities.
- Demonstration in relevant environment (e.g. test-bed with environmental control capabilities) of integrated and continuously-operated battery cell/module/pack sensors capable of multi-functional monitoring.

## STRATEGIC ACTION 3 - ACCELERATED MULTIPHYSICAL AND VIRTUAL TESTING AND DEVELOPMENT

### MULTIPHYSICAL TESTING FOR ACCELERATED VALIDATION AND VERIFICATION

- Shortening the development time and costs of battery cells and battery systems by minimising the experimental testing effort and thus reducing the time to market and increasing innovation cycles as well as accelerating sustainability targets.
- Fostering innovations in the eco-system battery through accelerated and more reliable verification and validation of advanced solutions contributing to increased use acceptance (safety & costs) and competitiveness of the European battery value chain.
- Development of virtual methods to reduce the complexity of testing sample to sub-system DUTs (device under test) while full system is validated by virtual methods using the results from physical sub-system test.
- Standardisation of battery system testing & validation approaches focusing on the fusion of physical and virtual test methodologies.
- Development of simplified test strategies, reducing the number of test and their complexity while improving battery safety and reliability.
- Understanding and describing the impact of multi-physical operational loads, failure modes, ageing and mis-use on battery reliability and safety highlighting the dependencies between them in order to design the most adequate testing methods and parameters.

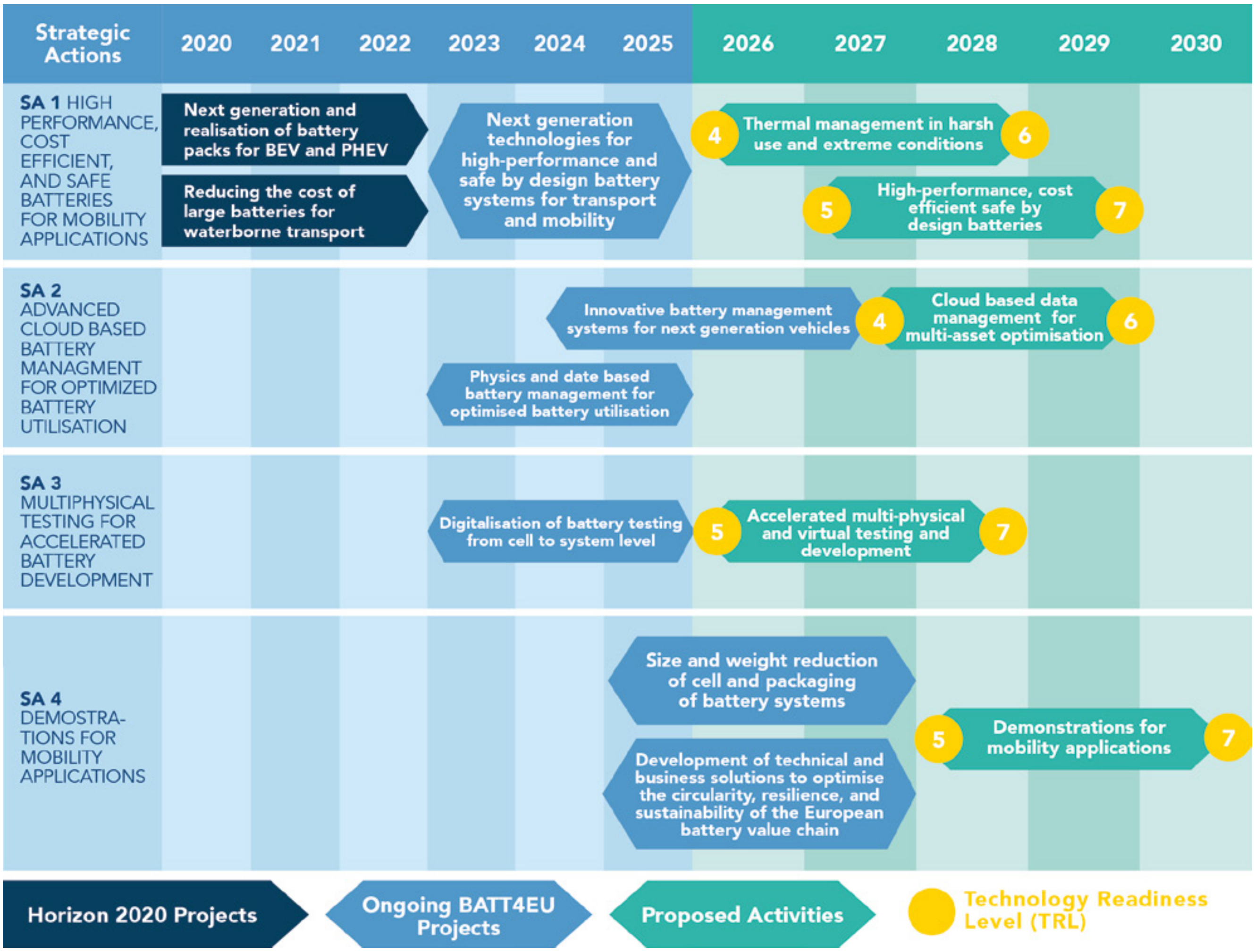
## STRATEGIC ACTION 4 - DEMONSTRATIONS FOR MOBILITY APPLICATIONS

High TRL activities for multiple transport modes where demonstrations are needed to move a technology forward and closer to market. These may or may not be funded by Batt4EU, but are nevertheless included here to communicate the need from the battery perspective.

- Design and prototype safe, light weight and airworthy battery modules and packs (including cooling systems, BMS, in/on-cell sensors, including digital twin), fit for the high voltage and power requirements of reference airframes (e.g., high C-rates for power boost in take-off and go-around scenarios), including their integration in relevant electric architectures and interface with electric conversion systems.
- Demonstration of electrification of off-road and non-road mobile machinery (NRMM). Battery solutions for the electrification of mines, construction sites, ports, industrial sites where cargo or material is moved. Demonstration can integrate multiple applications.
- Battery swapping (use cases can be aviation, inland shipping or short distance ferries, besides EVs).
- Battery for rail application as on-board energy storage system with improved charging times, regenerative braking capability, and to be able to power train on short to mid distances in case main of power supply failure. Virtual demonstration or demonstration paired with other demonstrations (i.e. hydrogen powered train) can be covered.

## 2.5.3
# Strategic action timeline

**The figure below summarises the key strategic research and innovation actions between now and the end of the Horizon Europe projects in 2030 and beyond, related to the mobility application.**




# 2.6 APPLICATION: STATIONARY STORAGE

As an essential piece in both energy efficiency and renewable energy use, the market for battery energy storage systems is growing significantly. Battery energy storage systems (BESS) enable efficient time-shifting of excess renewable energy production, manage peak energy demand, and enhance grid stability by responding quickly to frequency fluctuations. They contribute to a more reliable and resilient electricity grid, supporting the integration of renewable energy sources and helping to address supply-demand imbalances, while offering backup power during emergencies. The end user is equally versatile, from grid operators at the Front of the Meter (FTM) side, down to individual consumers at the Behind the Meter (BTM) side. Several transversal areas also converge here, with sustainability, safety, digitalization, and hybridization each having important roles due to this versatility.

Because of the versatility of uses, research in this area focus significantly on integration, interoperability, and optimization of BESS, rather than chemistry or composition of the cell or system. Using second-life batteries or several batteries of different chemistries can enable the further growth and sustainability of the industry, but brings challenges with the management and operation of such units, and as such is seen as a key research area. Long duration energy storage is also a key area, to significantly enhance the potential of BESS in all of its uses. While research on these topics is ongoing in some cases, field demonstrations and other advancements are needed to bring the industry forward in Europe.

While the stationary storage market has come a long way, there is still much to be done regarding research and innovation. Early in 2023, the green deal industrial plan was unveiled, which included a reform of the European electricity market. This has important implications, as the market reform included mechanisms to further incentivise grid operators to procure units providing flexibility to the energy grid, a role that BESS can fill well.

**R&I is still necessary to improve asset utilisation and capability, especially for new chemistries, long duration energy storage, 2nd life batteries, and hybrid storage systems.**

The Batteries Regulation, unveiled in August 2023, adds some new requirements as well, specifically with the battery passport and relevant implications for BMS and second life battery use. The described areas below see to address these challenges, by building upon the earlier projects and filling in any gaps, and moving these technologies toward demonstration level.

## 2.6.1
# Review of R&I activities

**Since the start of the BATT4EU Partnership in 2021, the following calls have been issued under the umbrella of the Partnership to address the above-mentioned challenges:**

**Call: HORIZON-CL5-2023-D2-01-04**
**Topic:** Battery management system (BMS) and battery system design for stationary energy storage systems (ESS) to improve interoperability and facilitate the integration of second life batteries.
**Projects:**

| | | |
|---|---|---|
| **BIG LEAP** | Next generation of battery management systems to increase interoperability, bridge the gap between 1st and SL-BESS, extend adaptability and empower battery value chains. | Starting in 2024 |
| **Battery2Life** | Battery management by multi-domain digital twins. | Starting in 2024 |

**Call: HORIZON-CL5-2023-D2-01-05**
**Topic:** Hybrid electric energy storage solutions for grid support and charging infrastructure.
**Projects:**

| | | |
|---|---|---|
| **SMHYLES** | Safe, sustainable and modular hybrid systems for long-duration energy storage and grid services. | Starting in 2024 |
| **HAVEN** | High-performance hybrid energy storage system for multi-service provisioning. | Starting in 2024 |

**Call: HORIZON-CL5-2024-D2-01-02**
**Topic:** Non-Li Sustainable batteries with European Supply Chains for Stationary Storage (Batt4EU Partnership.
**Projects:** TBD

2.6.2

## Scope of R&I actions

**Considering the context, the vision and ongoing research activities, the following research actions are proposed:**

### STRATEGIC ACTION 1 - LONG DURATION ENERGY STORAGE

#### DEVELOPMENT OF ADVANCED BATTERY TECHNOLOGIES FOR LONG DURATION ENERGY STORAGE

- Develop next-generation long duration storage (>10h, up to 100h or more) technologies to ensure their commercial viability by the time the deployment of variable renewable resources reaches saturation in the 2030.
- Innovative consolidated battery technologies and adapting them to long duration storage through improved electrochemistry and hybridization.
- Demonstrate multi-purpose grid-scale long duration BESS with advanced management systems supporting the creation of solid business cases.

### STRATEGIC ACTION 2 - BATTERY MANAGEMENT FOR OPTIMISED BATTERY UTLISATION

#### DEMONSTRATION OF ADVANCED BATTERY MANAGEMENT SYSTEMS IN THE FIELD

- To follow up on the results from the 2022 topic "Physics and data-based battery management for optimised battery utilisation" by demonstrating the functionality in the field, proving the adaptability to various cell sensors and embedded functionalities.
- New and flexible BMS systems that are usable for a variety of chemistries including upcoming technologies and are applicable to hybrid solutions.
- Enhanced use of digital twins to enable the integration of real-time data.
- Development of standardization of BMS architecture, to facilitate universal compatibility and scalability towards EMS.
- BMS adaptation to next generation of grid services more related to fast response due to intermittency of renewable energy sources. EMS-BMS connected assets with battery to optimise data exchange between assets. Promote and develop enhanced EMS-BMS interaction, minimising hardware and software incompatibilities and inefficiencies.
- Reliability and safety of BMS functionality, continuous improvement of SIL level in framework where new assets are introduced continuously, including both new battery chemistries and used batteries.
- BMS matching to the ongoing battery passport needs, and the increased complexity of data sharing and methods of sharing (i.e. cloud, blockchain).

### STRATEGIC ACTION 3 - INTEGRATION OF STATIONARY BATTERY STORAGE

#### DEVELOPMENT OF INNOVATIVE SOLUTIONS TO OPTIMIZE BATTERY UTILISATION, RENEWABLE ENERGY INTEGRATION AND MULTI-SERVICE USE

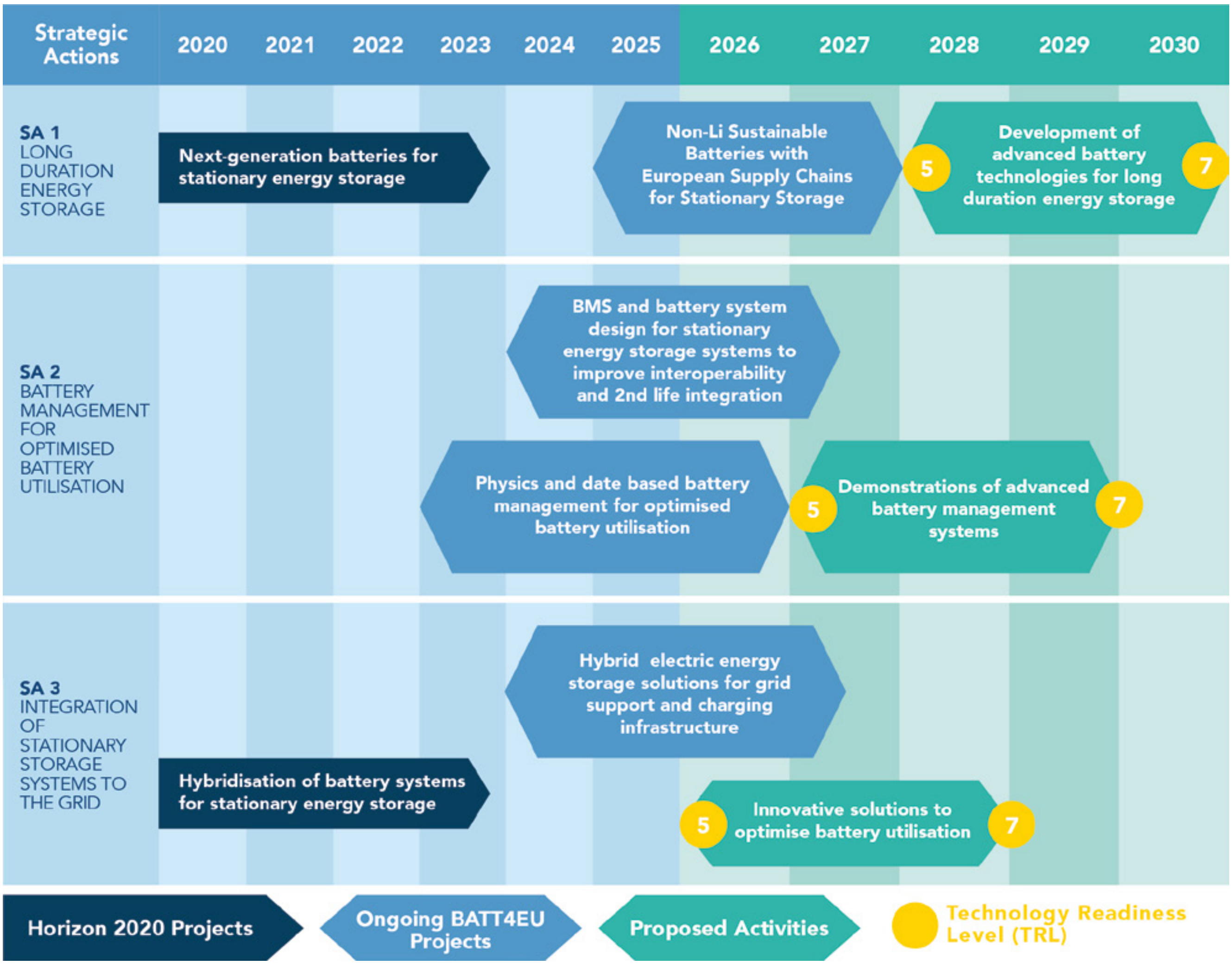
- Adaptive algorithms to optimize the combined use of several energy storage systems and provide multiple services.
- Strategies to optimize the operation and integration of battery storage across different energy sectors.

- By optimizing BESS designs, materials, and control strategies, and by fostering cross-energy sector coupling, this research activity should seek to contribute to the development of a sustainable, resilient, and efficient multi-energy market that effectively integrates renewable energy sources and maximizes the benefits of advanced battery storage systems.
- Advanced and fast energy management algorithms of hybrid storage (multi-technologies) allocated in the electricity grid (FTM) in order to provide fast response energy services, and to be resilient in the long term. Go further in new multi-grid services and new schemes in the energy market mechanisms. Taking into account VPP (Virtual Power Plants).
- In BTM applications, aggregation of different technologies of batteries to provide energy to consumers and at the same time improve grid quality and stability. Virtual batteries business modelling with advanced EMS.

2.6.3

## Strategic action timeline

**The figure below summarises the key strategic research and innovation actions between now and the end of the Horizon Europe projects in 2030 and beyond, related to stationary application.**



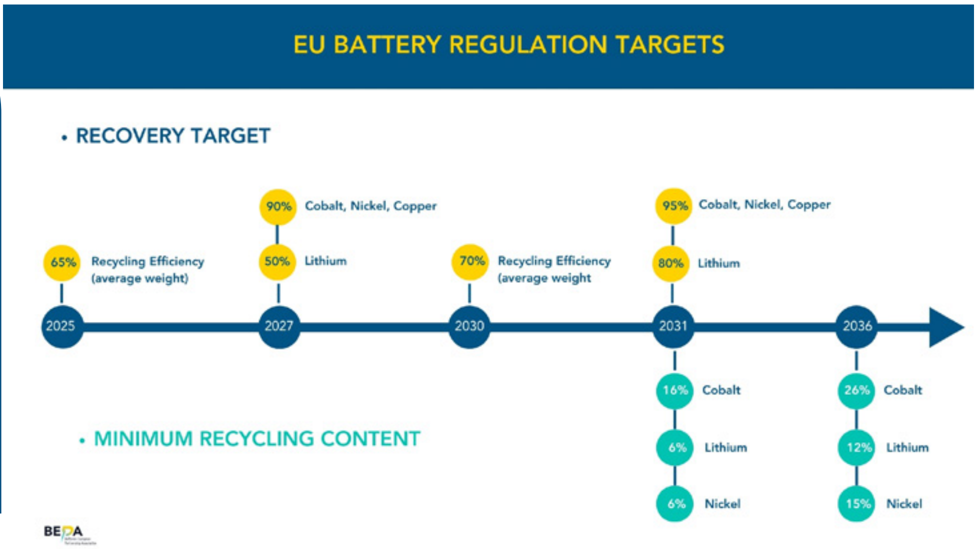

# 2.7 DISMANTLING AND RECYCLING

Even though batteries last longer than initially predicted, the number of End of Life (EoL) batteries from e-mobility and stationary applications are increasing and will continue to increase in the following ten years. This means that both the number and capacity of recycling facilities need to increase. The new facilities need to be automated to reduce costs and reduce safety risks in all parts of the value chain.

Due to the lack of standardisation, data about the form, composition, assembly modes, state of health, etc. are of utmost importance. The battery passport is seen as an enabler in this respect and should be fully developed within this time frame (integration of a battery labelling system within the battery passport).

In line with its importance to create a circular value chain and deliver on the transition to a net zero economy, dismantling and recycling topics have been allocated a significant share of the funds under the BATT4EU Partnership.
There remain, depending on the TRL, activities that are still deserving of public funding, both for the collection, sorting and dismantling of batteries, and the recycling processes.

**Additional focus needs to be put on ensuring enhanced flexibility of recycling facilities. This flexibility will help recyclers to adapt to market developments and future-proof the massive investments needed to get battery recycling capacity off the ground in Europe.**



2.7.1

## Review of R&I activities

**Since the start of the BATT4EU Partnership in 2021, the following calls have been issued under the umbrella of the Partnership to address the above-mentioned challenges:**

**Call: HORIZON-CL5-2021-D2-01-011**
**Topic:** Sustainable processing, refining and recycling of raw materials.
**Projects:**

| | | |
|---|---|---|
| **RELiEF** | Recycling of Lithium from Secondary Raw Materials and Further. | July 2022 to June 2025 |

**Call: HORIZON-CL5-2021-D2-01-06**
**Topic:** Sustainable, safe and efficient recycling processes.
**Projects:**

| | | |
|---|---|---|
| **RESPECT** | Flexible, safe and efficient recycling of li-ion batteries for a competitive, circular, and sustainable European battery manufacturing industry. | July 202 to June 2026 |
| **RHINO-CEROS** | Batteries reuse and direct production of high performances cathodic and anodic materials and other raw materials from batteries recycling using low cost and environmentally friendly technologies. | Sep. 2022 to Aug. 2026 |
| **FREE4LIB** | Feasible recovery of critical raw materials through a new circular ecosystem for a li-ion battery cross-value chain in Europe. | Sep. 2022 to Aug. 2026 |

**Call: HORIZON-CL5-2022-D2-01-10**
**Topic:** Streamlined collection and reversed logistics, fully automated, safe and cost-efficient sorting, dismantling and second use before recycling.
**Projects:**

| | | |
|---|---|---|
| **Batte-Reverse** | A next-generation automated, connected, and standardised process for increased safety, efficiency, and sustainability of li-ion battery reverse logistics. | May 2023 to Oct. 2026 |
| **REBELION** | Research and development of a highly automated and safe streamlined process for increased Lithium-ion battery repurposing and recycling. | June 2023 to Nov. 2026 |

| | | |
|---|---|---|
| **REIN-FORCE** | Standardised, automated, safe and cost-efficient processing of end-of-life batteries for second and third life re-use and recycling. | June 2023 to May 2027 |
| **RECIR-CULATE** | Reuse of batteries through characterisation, smart logistics, automated pack and module dismantling and repackaging and a blockchain enabled marketplace. | May 2023 to April 2026 |

**Call:** **HORIZON-CL5-2023-D2-01-02**
**Topic:** New processes for upcoming recycling feeds.
**Projects:**

| | | |
|---|---|---|
| **RENOVATE** | A circular and chemistry-neutral approach for recycling and recovery of battery waste feeds. | Jan. 2024 to Dec. 2026 |
| **REVITALISE** | Recycling of low value components using high purity pre-treatment, direct recycling and green hydrometallurgical approaches for recycling of lithium ion and sodium ion batteries. | Jan. 2024 to Dec. 2026 |
| **RENOVATE** | A circular and chemistry-neutral approach for recycling and recovery of battery waste feeds. | Jan. 2024 to Dec. 2026 |

**Call:** **HORIZON-CL5-2024-D2-01-01**
**Topic:** Advanced sustainable and safe pre-processing technologies for End-of-Life (EoL) battery recycling.
**Projects:** **TBD**

## 2.7.2
# R&I needs

**Considering the context, the vision and ongoing research activities, the following research actions are proposed:**

**STRATEGIC ACTION 1 - SUSTAINABLE, SAFE AND EFFICIENT RECYCLING PROCESSES**

**DEVELOPMENT OF RECYCLING PROCESSES FOR EMERGING CHEMISTRIES**

- Development and validation of integrated recycling processes for sodium-ion batteries.
- Development and validation of integrated recycling processes for Vanadium Redox Flow Batteries (VRFBs).
- Safe-proof recycling methods for Li-metal batteries.
- Direct recycling of electrode materials.

## STRATEGIC ACTION 2 - ENHANCED FLEXIBILITY OF RECYCLING PROCESSES

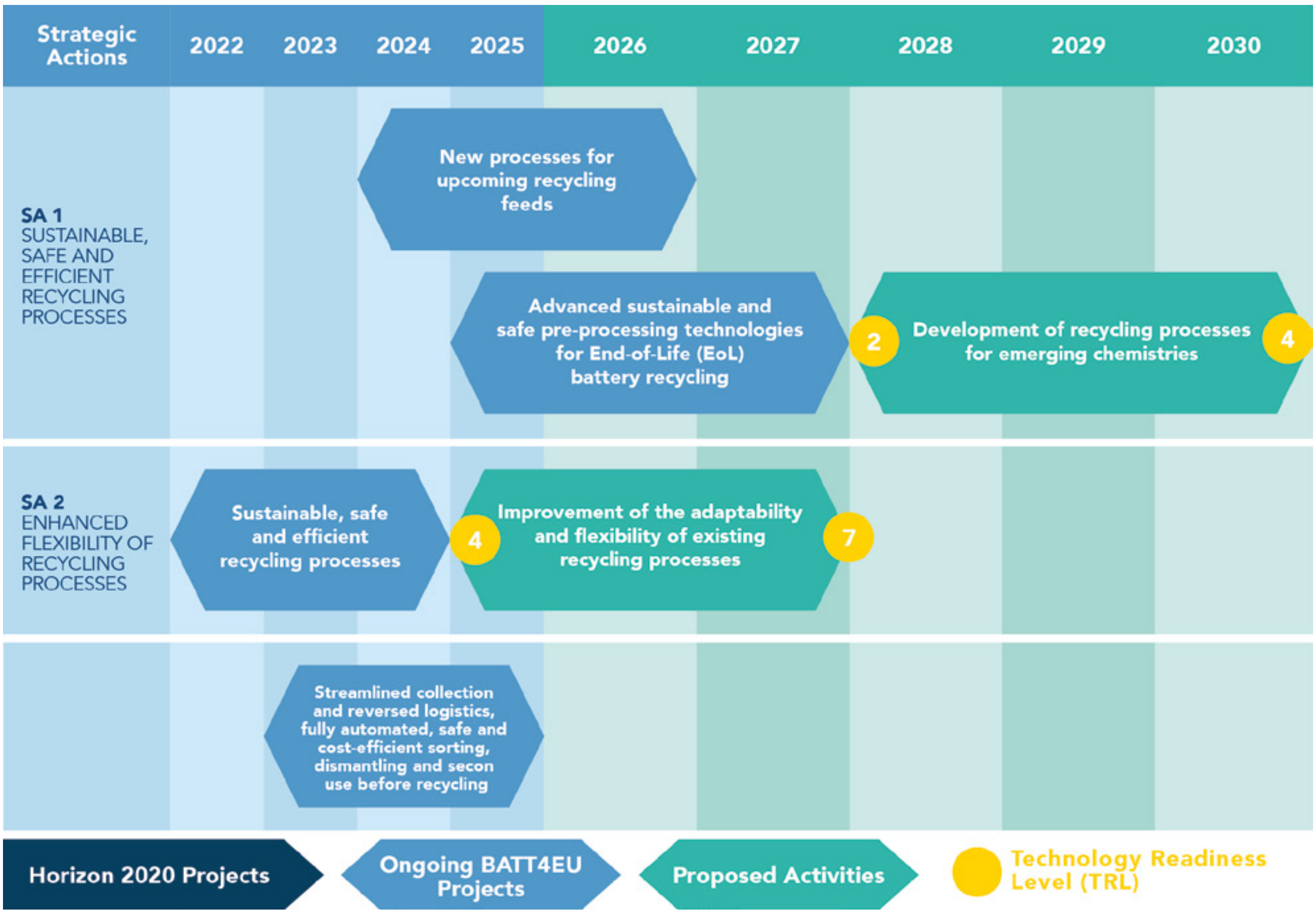
### IMPROVEMENT OF THE ADAPTABILITY AND FLEXIBILITY OF EXISTING RECYCLING PROCESSES

- Development of more flexible and adaptable recycling processes for lithium-ion batteries than current ones will provide a solution for the constantly evolving composition and formulation of cathodes, anodes and electrolytes (e.g., increase in share of Si in Si/C anodes, variations in Ni share in NMC cathodes).
- Provisions for adaption of lithium-ion battery recycling processes to recycling of sodium-ion batteries. As the battery manufacturing and recycling processes for both chemistries share a high degree of similarity, flexible processes that are able to recover materials from sodium-only or mixture of lithium and sodium batteries feeds will be of importance.
- Methods to increase rate of lithium and graphite recovery from gen.3 lithium-ion batteries.
- Improvement of existing lithium-ion battery recycling processes to increase the recovery of electrolyte solvents and salts, binder material, and membranes.

2.7.3

# Strategic action timeline

**The figure below summarises the key strategic research and innovation actions within the Horizon Europe and beyond related to recycling.**




# 2.8 TRANSVERSAL TOPICS

The previous chapters list the R&I actions along the battery value chain which are most in need of a collaborative European push. However, there are certain R&I activities that cut across the value chain and that are equally deserving of being supported by European projects. The chapter below lists three strategic actions, two in the field of sustainability and one to boost battery education efforts, that will cut across the value chain.

In the 2021 BATT4EU SRIA, the highlighted transversal activities covered sustainability and safety. The new activities proposed for sustainability are building on the topics proposed in the 2021 SRIA, and which have been subsequently implemented.

**These are refining the Life Cycle Analysis (LCA) of batteries and ensure the R&I activities necessary to support the implementation of the battery passport as proposed in the Batteries and Waste Batteries Regulation. The suggested activity for education focuses on the need to accelerate practical training across Europe, both for academic and vocational purposes.**

The safety aspects that were described in the 2021 SRIA have found their way into topics for specific parts of the value chain. They have therefore already been covered in the previous chapters on, for instance, advanced materials and recycling. To avoid duplication, the issue of safety is not separately addressed here. This should not be mistaken for a lack of attention to this issue, quite the contrary. Safety remains an important topic across the value chain, as the new strategic area “safe and sustainable by design” in chapter 2.3 Design attests. Furthermore, every topic developed under the BATT4EU Work Programme will be evaluated for its contribution to increasing the safety along the value chain.

Other transversal issues, such as the digitisation of battery production, and the social aspects of European battery production will be continuously taken into consideration during the development of the Work Programmes.

## 2.8.1 Review of R&I activities

**Since the start of the BATT4EU Partnership in 2021, the following calls have been issued under the umbrella of the Partnership to address the above-mentioned challenges:**

**Call:** HORIZON-CL5-2021-D5-01-04
**Topic:** LCA and design for sustainable circularity - holistic approach for zero-emission mobility solutions and related battery value chain (joint 2Zero & Batt4EU partnership call).
**Projects:**

| | | |
|---|---|---|
| **Tran-Sensus LCA** | Towards a European-wide harmonised, transport specific LCA Approach. | Jan. 2023 to June 2025 |

**Call:** HORIZON-CL5-2023-D2-02-03
**Topic:** Creating a digital passport to track battery materials, optimize battery performance and life, validate recycling, and promote a new business model based on data sharing.
**Projects:** TBD

## 2.8.2 R&I needs

### STRATEGIC ACTION 1 - LCA AND LCI DEVELOPMENT FOR NEXT-GENERATION BATTERIES AND STATIONARY STORAGE APPLICATIONS

This strategic action should take the lessons from the TranSesnus project on the LCA of Li-ion batteries for EVs and broaden the LCA methodology so that it becomes applicable to a wide range of batteries, including stationary storage. This call should also target batteries with external storage, as LCAs for this type are short in supply and hinder the implementation of the Batteries Regulation.

### STRATEGIC ACTION 2 - BATTERY PASSPORT DEVELOPMENT FOR BATTERIES WITH EXTERNAL STORAGE

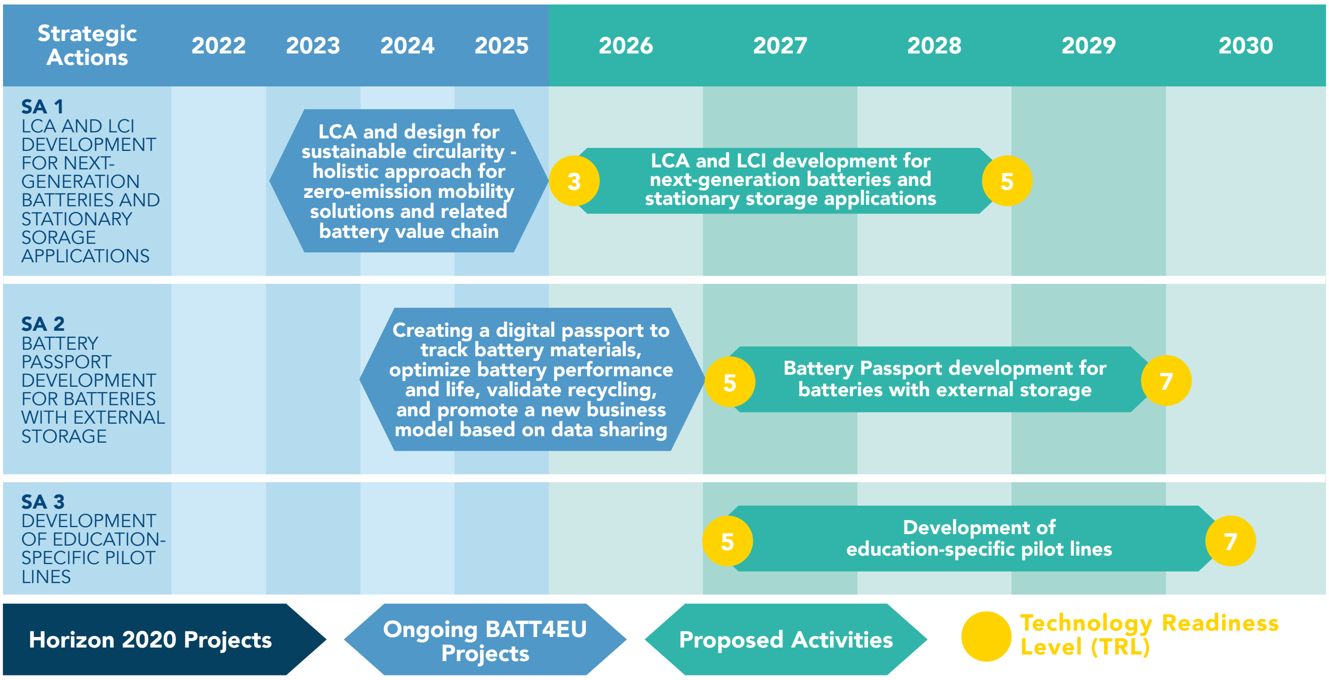
This strategic action should develop a pilot to develop a working and applicable battery passport for batteries with external storage. This project should work with the ongoing Horizon Europe project on the battery passport but ensure that battery passport concept can be adequately adopted by flow batteries, so that the battery passport application does not distort the level playing field between batteries with internal and external storage.

**STRATEGIC ACTION 3 - DEVELOPMENT OF EDUCATION-SPECIFIC PILOT LINES**

The aim of this strategic action is to develop pilot lines specifically designed for educational proposes. A qualified workforce has been described as the true critical raw material in the transition towards an electrified society. One of the key bottlenecks to deliver on the creation of a competitive battery value chains in Europe is providing the people that need to be educated or re-skilled with easy access to a place where they can practice in a real environment. The objective of this strategic action is to develop battery manufacturing pilot lines that are specifically tailored to educational needs. The design of these pilot lines and the accompanying training manuals should be released as blueprints to be rapidly copied across Europe. As the deployment of physical pilot lines are costly and not practically applicable in every scenario, the action should also develop a digital version of the pilot lines which can be used for digital training through, for example, virtual or augmented reality.

## 2.8.3
# Strategic action timeline

**The figure below summarises the key strategic research and innovation actions within the Horizon Europe and beyond related to cross-cutting activities.**



# 2.9 COORDINATION

Europe has been making good progress on the objectives it set out when envisaging a flourishing battery ecosystem in Europe back in 2017. One of the key enabling factors of these positive results has been the contribution of the battery research and innovation community. The robust growth of the battery industry in Europe is built on coordinated, continuous and strategically driven research and innovation across all parts of the battery value chain. As set out in chapter 1.3, to support this coordination, several initiatives have sprung into being, including Battery 2030+, the ETIP Batteries Europe, and the supporting research programmes of the IPCEI. These initiatives, together with BEPA, the private-side association of the BATT4EU Partnership, are providing platforms for the stakeholders in the battery value chain to channel their inputs for policy, to set strategic objectives and to provide roadmaps. The initiatives are also key to promote excellence, improve knowledge exchange between stakeholders.

The years since the publication of the first BATT4EU SRIA in 2021 have seen efforts by the above-mentioned initiatives to improve the coordination of the ecosystem, by better coordinating amongst themselves. After the start of the BATT4EU Partnership in 2021, Batteries Europe and Battery 2030+ have been continued as Coordination and Support Actions (CSAs) under the Partnership and funded through budget set aside for the Partnership. Both initiatives have been operating in line with the coordination priorities that were spelled out in the first BATT4EU SRIA. Both CSAs coordinate their activities with BEPA and with each other to reduce overlap in activities as much as possible, only being limited by their fixed scopes of action as CSAs. Prime examples of these collaboration efforts are the integration of the Working Groups and the Task Forces between Batteries Europe and BEPA, the coordinated work between Battery 2030+, Batteries Europe and BEPA on the roadmapping activities (including for this SRIA) and the joint operation of the National and Regional Coordination Group (NRCG) by Batteries Europe and BEPA, which gives delegates of European states a possibility to directly share information with the ETIP and BATT4EU Partnership

**The relative success of the coordinated roadmapping activities has been acknowledged by the European Court of Auditors in their special report. However, there are also several points of improvement listed, mostly around monitoring and better coordination across funding mechanisms. Future CSAs can play a role in addressing these issues and the input of the Court of Auditors has been instrumental in setting out this chapter.**

The goal of this chapter is not to sketch how the future calls for the CSAs will look like and what their respective scope will be. The aim is to outline the coordination efforts needed to help the European battery community reach its goals. The actual outline of future Coordination and Support Actions will be done during the development of the remaining Work Programmes in Horizon Europe.

## 2.9.1
# 2030 Vision

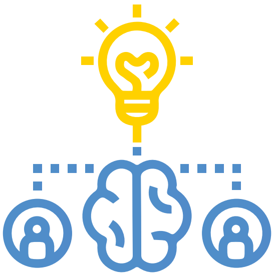
**Establishment of an Integrated Information Platform:** Creating a comprehensive European research and innovation community platform for sharing the latest developments in research and innovation. This platform will facilitate informed decision-making across research programmes, educational programmes, and the development of a future generation of experts in fields like battery technology and system integration.

**Seamless Information Flow Across Funding Instruments:** Ensure that information flows effectively across various funding levels - European, national, and regional. This will enable stakeholders to access and utilize suitable funding opportunities, fostering a well-connected ecosystem for research and innovation.

**Rapid Market Uptake and Global Leadership in Battery Technology:** Aim to make Europe a world leader in battery technology and system integration by 2030. The vision includes setting up future-proof information platforms that will expedite the dissemination of research findings and innovative ideas, leading to their swift integration into the market and attracting top talent globally.

## 2.9.2
# Specific challenges and objectives

**For a well-functioning European battery R&I ecosystem, the following tasks will need to be addressed.**



### AN INFORMATION OBSERVATORY

As pointed out by the Court of Auditors, the European battery value chain, and the public policy around it, would benefit enormously from a better access to accurate and up-date information on key metric and the state-of-art concerning various key technologies. The aim is to create future-proof information platforms that are set up to exist beyond the lifespan of any given project and even the Partnership.

**Concretely, the following actions are necessary:**

- Providing a rolling assessment of the current state of art of battery technology, both globally and in Europe.

- Monitoring the technical progress of the BATT4EU projects and other European-funded battery projects to assess
    - Progress towards the objectives of the BATT4EU Partnership.
    - Progress towards the objectives that are part of the updated SET-plan.
    - Progression of the current state of art.
- Providing a rolling overview of funding opportunities for battery R&I in Europe (i.e. a funding map).
- A rolling overview of ongoing research and innovation projects on batteries in Europe. Not only from the BATT4EU Partnership, but also projects funded by other European funding mechanisms and national and regional funding (in collaboration with the NRCG).
- Support any monitoring efforts undertaken by the European Commission, the EBA or other European initiatives regarding concrete indicators of industrial progress in Europe, such as European pCAM, CAM and cell production capacity and battery recycling capacities, BEVs produced in Europe and installed capacity of stationary battery storage in the grid.

## STRATEGIC ROADMAPPING

The above-mentioned collection of accurate and up-to-date information would already lead to better decision-making. It will remain necessary to build on that information a strategic roadmap on how technological progress can contribute best to the European policy goals and which specific research questions are deserving of (European) funding.

**A balanced strategic roadmapping exercise for the European battery value chain will need to encompass the following actions:**

- Foster exchanges between the experts of the different parts value chain to understand causal relationships between the different research needs in the different sectors, including on cross-cutting activities such as safety, digitisation and sustainability
- Gather experts from different parts of the value chain to identify the short-, medium- and long-term research needs that will need to be addressed to reach the European policy goals and publish them in a publicly accessible roadmap. Key is to entice a broad spectrum of industrial stakeholders, research providers and policy/regulatory bodies in taking part.
- A long-term forecast (possibly as part of the roadmap above) on battery technology and an analysis of how battery research itself can be improved upon.

## BROADENING AND DEEPENING EUROPE'S EXCELLENT R&I COMMUNITY

To ensure that the EU-funded projects contribute to the BATT4EU objective of creating the best battery innovation ecosystem in the world in Europe, several actions need to be employed to get the best out of the projects and the community:

- Organise and support clustering events to ensure that projects working on similar topics can learn from each other's results.
  Organise and support workshops for the community that will improve the overall knowledge level of the sector.
- Share best practices with the community and push for adoption of common data standards and reporting methodologies
- Organise high-level events where researchers, industrial developers and policy makers meet to discuss the most pressing research needs.
- Execute benchmarks of the European battery innovation ecosystem with ecosystems elsewhere in the world and draft recommendations for improvement.

## PROMOTING INNOVATION UPTAKE

The battery sector has shown that rapid adoption of research breakthroughs is key to keep a competitive edge over the competition. Support is therefore needed to ensure that results of the projects under the BATT4EU Partnership project find their way to the market or to the right funding mechanism to take the next step.

- Informing Partnership projects on the possibilities on funding mechanisms to take their developed technologies to the next level.
- Together with funding agencies, make sure that research projects in an early stage get training and mentoring on how to best exploit the ideas coming out of their projects, especially on areas like intellectual property (IP) management and the development of viable business cases.
- Support the EBA, the IPCEIs and the EITs InnoEnergy, Raw Materials and Manufacturing to create research-to-business matchmaking events between projects looking to upscale innovations and possible upscaling partners and investors.

## EDUCATION AND SKILLS BUILDING

Education and training are fundamental both for expanding the relatively new European battery cell production sector and achieving competitive functionality of the whole value chain.

**Specific areas where better cooperation can lead to a faster closing skills gap are:**

- Promotion of the development of, and information sharing between, projects that address the skills gap, with special consideration to factors like gaps in perceived attractivity of the sector, geographical gaps in supply and demand of skilled labour and the timing gap between the rising need and the time it takes to educate the workforce.
- Support the acceleration of programmes that the next generation of excellent scientists that can push the boundaries of battery research in Europe and provide a strong academic network for them which will entice them to stay in Europe. Concrete actions include the development of European-wide curricula and standards for providing access to research infrastructures.
- Support programmes that provide geographical mobility across the European battery value chain for researchers and industrial professionals.

## ENGAGEMENT WITH NGOs AND CIVIL SOCIETY MORE BROADLY

Engagement with NGOs and civil society more broadly is necessary to ensure that correct information about battery technology reaches the wider public. Public acceptance of more widespread use of batteries is crucial for the success of the green transition. This extends to acceptance of mining and processing activities on the European continent.

- Establishing close relationships with NGOs that operate in the European policy space of batteries and provide them with access to the information observatory above to ensure that accurate and up-to-date information will inform the public discourse.
- Development of an educational toolkit of the wider public on the benefits of an electrified society and the key roles that batteries play in it. Efforts should target existing myths around battery performance, sustainability and safety. This educational angle should also consider the potential benefits of educating teachers (train-the-trainers) to bring the battery sector the attention of future students as an attractive profession.

# CONCLUSIONS AND FUTURE OUTLOOK

Europe is at a crossroads to make good on its goal to establish a competitive European value chain for batteries. Big strides have been made to encourage battery manufacturing plants to be established in Europe. The first gigafactory has been brought online by Northvolt in Sweden, with many more initiatives coming down the pipeline. Market demand for batteries is also on the rise, not only from the EV market, but also for other mobility applications and for stationary storage. Recent developments, both on this continent and overseas, however, mean that Europe needs to realign its industrial strategy to meet rising demand achieve its objectives for the battery value chain.

**While building on the general direction as laid out in the previous documents, this new SRIA points to the following six imperatives which are necessary to help the competitive battery value chain in Europe take root and deliver on its promise:**

- **Ensure that (BATT4EU) research results reach gigafactories and the markets,** through pilots, demonstrators and improved decision making aided by digital tools.
- **Increase the strategic autonomy of Europe by reducing the reliance on foreign critical raw materials** by supporting local and circular supply chains and support research into different battery chemistries, including sodium-ion technologies.
- **Improve battery affordability to accelerate the green transition and the keep the European industry competitive** by improving batteries based on materials that are more abundant and push for better integration into end-use applications.
- **Improve the flexibility of battery manufacturing and recycling systems** to reduce lock-in effects and respond quickly to changes in a rapidly developing industry.
- **Implement a safe and sustainable by design framework for batteries,** which plays to European strengths, and which will help reduce emissions and use of substances of concern, improve safety and allow for the integration of smart functionalities.
- **Support the continuity of excellent European battery research and academic-industrial cooperation** by improving access to research facilities and pilot lines, use research projects to build up a skilled workface, and by avoiding gaps in research through continued funding, which will bind talented researchers to Europe.

In development of the SRIA, these imperatives have been kept in mind by identification of the R&I needs across the value chain that would benefit from collective European action. Furthermore, future actions on sustainability and education are also needed in the short and the medium term. While updating this SRIA with the help of, and for the benefit of, European battery community, it has become clear that many research questions will outlast the scope of Horizon Europe and the BATT4EU Partnership within it. Public European funding for the development of batteries after 2030 will remain crucial for several compelling reasons. Firstly, sustainability will remain at the forefront of the global agenda, and investing in advanced battery technologies is one of the main enablers of achieving Europe's commitment to reducing carbon emissions and transitioning towards a greener future. As traditional energy sources face increasing scrutiny, batteries play a pivotal role in facilitating the integration of renewable energy into the grid, promoting cleaner and more efficient energy systems. This upward trend in the demand for stationary storage has been observed in the time which as passed since the publication of the BATT4EU SRIA in 2021 and will continue to make great strides. Additionally, with the growing awareness of resource scarcity, strategic investments in battery development can help Europe secure a stable supply chain for essential raw materials, reducing dependence on external sources. Breakthroughs in sodium-ion technology are happening now, but other chemistries with potentially European supply chains are still being researched at low TRL levels and will need continued support to come to market. Moreover, fostering innovation in battery technology enhances Europe's global competitiveness, positioning the continent as a leader in the rapidly evolving clean energy market. The drive of the last 5 years to establish gigafactories in Europe is only the start of this trajectory, with the future focus shifting on onshoring many of the supporting supply chains and making the battery value chain more sustainable. This task can only be achieved through broad support of research and innovation across the value chain, through a mix of private and public funding. Only that way will we able to promote environmental sustainability and ensure economic growth and technological leadership, reinforcing Europe's position on the world stage.


ENERGY
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ENERGY
STORAGE

# ANNEX

## 4.1 KEY PERFORMANCE INDICATORS

This link provides a set of battery-related KPIs that have been defined jointly by BE and BEPA members. The document is structured by domain, according to the six WGs, to improve the readability and to reflect the working process, even there are some KPIs that are relevant for several domains. The excel gathers the KPI values per working group, indicating a disclaimer to facilitate its understanding by pointing the approach and the boundaries of the work done. These include referenced baseline values from 2023 (carefully evaluated according to reliably published data) and future expected values, framed in 2027, 2030, 2035 or 2050, depending on the type of KPI.

**PLEASE SCAN THE QR CODE TO ACCESS KPIs**

# 4.2 BATT4EU VISION, OBJECTIVES AND EXPECTED IMPACT

This annex expands on the vision, objectives and expected impacts of the BATT4EU Partnership, as listed in paragraph 1.5 of the SRIA

## 4.2.1

## Common vision and ambition of the Partnership

**The vision and ambition of BATT4EU are as follows:**

**BATT4EU Partnership 2030 vision is to have the best innovation ecosystem in the world in Europe.** Thus boosting a competitive, sustainable and circular European battery value chain and driving the transformation towards a carbon-neutral society.

**The partnership's ambition is to prepare and equip Europe to commercialise the next-generation battery technologies by 2030,** which will enable the rollout of zero-emission mobility and renewable energy storage.

### MAIN CHALLENGES

Europe has to move fast. In order to achieve the ambition in the overall context as described in the first chapter of the SRIA, the European battery sector has to face four major, interdependent challenges:

- **Competitiveness:** It must be possible to produce competitive battery solutions in Europe; otherwise, the established players in Asia will further expand their market domination and capture the growing market potential in Europe and elsewhere. Competitivity embraces technical performance, such as energy and power density or lifetime, and affordable costs. R&I is crucial to reach ambitious performance targets; introduce abundantly available, low carbon-intense and low-cost materials; enhance efficiency and lifetime; and, develop cost-effective material processing, cell manufacturing and recycling processes and machinery. Only the combined effects of economies of scale (high volume manufacturing) and technology innovation along the battery value chain will enable Europe to catch up with Asia.

- **Sustainability:** Whilst batteries will indirectly enable massive reductions in GHG emissions, it is crucially important that battery manufacturing itself is done at the lowest possible environmental footprint and in respect of UN Sustainable Development Goals, embracing transparency and respect of international good practices along the entire value chain, including raw materials. Furthermore, the carbon and environmental footprint during the operational life of batteries and at their end-of-life need to be minimised. The industry needs to shift towards a circular value chain. Besides the fundamental work in material research, R&I is necessary to reduce the carbon intensity of industrial processes like refining and manufacturing, to enhance the depth and efficiency of recycling and contribute to implementing a circular economy for batteries..

- **Industrial upscaling:** To satisfy future market demand in Europe, construction of high-volume giga-factories with manufacturing capacities of several 10's of GWh of battery cells is needed. Upstream industries like mining and refining, and components production, as well as downstream industries for battery system manufacturing and integration, will need to multiply their current capacities. Such industries need to be highly automated, energy and material-efficient with the lowest possible environmental footprint, and able to manufacture future battery technologies. Investments will only be executed if the industry can demonstrate its ability to achieve future-proof, cost-effective and sustainable industrial processes exceeding the current state-of-the-art of Asian manufacturers. R&I for advanced refining, manufacturing and recycling methods and machinery, strongly interconnected with material research, will allow these ambitions to be achieved.

- **Market uptake :**Successful and fast market uptake will depend on a number of technical and non-technical aspects. First of all, the integration of batteries into the various functional systems they power is key for customer and market acceptance and can represent up to 50% of the entire system value. Integration needs to be user-specific and user-friendly and faces significantly different challenges between sectors such as automotive, rail, air or waterborne transport, industrial or stationary usages. Integration also needs to take into account the necessary infrastructure (charging, grid connection) as well as end-of-life measures like re-use and dismantling. Furthermore, market uptake depends on policy and regulation concerning materials, logistics, end-of-life as well as application or segment-specific frameworks ruling the usage of the functional system as such. R&I is needed in all these fields, some of which will be very application-specific (e.g., battery modules for EVs), whilst others are transversal across several or all applications (e.g., safety, digital passport and information systems). Finally, strong upstream interaction with policymakers is needed in order to ensure policies and regulation sufficiently anticipate the innovations to come.

The ambitious objectives of mobility, energy storage and industrial strategy can be reached by mobilising financial investments in establishing the manufacturing bases in Europe. However, the goal is not only to catch up but also to become world leaders in battery energy storage technology and its manufacturing. **Only through R&I can we deliver breakthrough innovation and disruptive inventions to push the boundaries of the technological performance** of materials and chemistries, to increase the effectiveness of manufacturing processes, to ensure smart integration in applications and to guarantee reuse or recycling and sustainability of the whole battery value chain in an affordable way.

Results of R&I developed in the partnership are expected to be rapidly taken up by the emerging industry. Notably, most of the industrial players are taking part in the partnership, thus also considerably shortening the time from lab to market.

## 4.2.2

# Strategic objectives

### 4.2.2.1 GENERAL OBJECTIVES OF THE PARTNERSHIP

Mobility and energy sectors face drastic environmental, societal and political pressure to shift towards clean technologies and at the same time maintain jobs and growth. The partnership's general objectives, therefore, encompass (GO1) contributing to climate neutrality through the widespread adoption of e-mobility and stationary electrical energy storage; (GO2) ensuring sustainable growth and industrial leadership by supporting the development of an innovative, competitive and sustainable battery manufacturing industry; and, (GO3) contributing to improving air quality and environmental conditions by providing safer and more sustainable batteries and processes.

**GENERAL OBJECTIVE #1:**
**Contribute to making Europe the first climate-neutral continent by 2050 through widespread adoption of e-mobility and stationary electrical energy storage.**

**Batteries are a key technology required to decarbonise the European energy system, both:**

- in the transport sector (electrification of transport, enabling a shift to **sustainable mobility**); and,
- in the power sector (stationary energy storage of intermittent renewable energy sources, enabling a **clean and secure energy supply**).

Supporting the power sector will also have a positive impact on **decarbonising industry** (via electrification of industrial processes). **To make this happen, affordable, sustainable batteries must be quickly available and broadly adopted as key enablers:**

- for e-mobility, **substituting combustion engines** across all transport sectors (road, off-road, rail, air, water); and,
- for an **energy system based on renewables,** providing the necessary flexibilities, system capacity and grid stability needed under high penetration of variable renewable generation.

In order to provide an overview of the outcomes that could reasonably be expected from the BATT4EU Partnership and in order to be able to monitor and report on the progress of the partnership towards its objectives, a list of **Key Performance Indicators (KPIs)** was elaborated within the **BATT4EU Monitoring Framework (Annex 1).** Being successful in achieving the targets suggested in this Monitoring Framework will not entirely rely on the BATT4EU Partnership actions. While the partnership will carry out additional activities to tackle some of the above-mentioned challenges related to market, societal and regulatory uptake, many of them are not under the control of the partnership and will also need to be carried out in parallel. **The BATT4EU Partnership** will also bring a major contribution to broader additional outcomes not listed (for example the transformation of the energy production system, zero-emission urban areas, market accessibility, leadership position in exports…).

**The KPIs identified for the General Objective 1 are the following:**

- EU sales of EVs for different transport modes using batteries manufactured in Europe.
- EU installed capacity of EU manufactured battery energy storage systems connected to the grid.

**GENERAL OBJECTIVE #2:**
**Enable European leadership in the battery industry across the value chain and create economic growth and quality jobs in a circular economy, by supporting the development of an innovative, competitive and sustainable battery manufacturing industry and a skilled workforce in Europe.**

Batteries represent a **new and fast-growing market for Europe across the full value chain**. Europe can pave the way towards a circular battery value chain to reduce the raw material and carbon footprint of the European economy, **leveraging the European assets in terms of industrial know-how (recycling industry**) and regulatory framework (updated batteries directive). The partnership will have to pay particular attention to initial and lifelong education, as skills will be a condition for Europe to catch up in the field of batteries. **To make this happen, massive industrial upscaling in Europe needs to occur and be based on:**

- available advanced battery materials;
- competitive cell and battery technologies; and,
- BAT (Best Available Technologies) in manufacturing and recycling.

**The KPIs identified for General Objective 2 are the following:**

- EU battery manufacturing's capacity to be competitive with respect to the rest of the world.
- Creation of new jobs and skills.

**General Objective #3:**
**Contribute to achieving zero pollution for a toxic-free environment, by providing safer and more sustainable batteries and processes in the context of the circular economy (along the whole value chain, including recycling).**

Batteries will enable the deployment of fully electric vehicles with **zero local emissions** of air pollutants (such as NOx), in particular in urban areas. Likewise, **batteries will enable other mobility and transportation segment**s (trucks, buses, rail, off-road, waterborne and aviation) as well as fossil-based power generation to significantly reduce or eliminate emissions. In addition, **the entire value chain of battery production and dismantling will be optimised** to achieve a fully sustainable process over the whole battery life cycle – from battery-grade raw materials to recycling processes – with minimal carbon emissions and environmental impacts. This will lead to an improved environment and quality of life for European citizens. To make this happen, batteries made in Europe must have **the world's lowest carbon and environmental footprint** throughout their life cycle, which embraces materials, manufacturing, usage and recycling.

**The KPIs identified for the General Objective 3 are the following:**

- % of improvement of environmental impact in terms of $CO_2$ and toxic material.
- % of recycled materials.

### 4.2.2.2 SPECIFIC OBJECTIVES

The BATT4EU Partnership will, in a coordinated manner, generate knowledge and innovations to accelerate the learning curve and fill in the current gaps in the European battery value chain. Innovations fit to be industrialised will be rapidly implemented while more ambitious concepts will be nurtured with a view of developing and sustaining a long-term competitive edge.
The dimension of the global battery ecosystem also has to be taken into account. Due to the current lack of development and a very limited market share of cell manufacturing in Europe, **there is also a lack of development of the related supply chain: from the specific chemicals, mechanical and electronic components, to the specialised manufacturing equipment,** as a large number of the more competitive companies in the supply chain are based outside Europe. This has a significant impact on the ability of the battery industry to become competitive with a European manufacturing base.

The need to import competences has been identified by the first companies developing industrial capacities in Europe (e.g., Northvolt), but the target for the longer term is to make Europe globally competitive and independent from foreign technologies.

**The partnership will coordinate R&I efforts to identify and develop the key technologies required for an innovative, competitive and sustainable supply chain in Europe, developing at the same time the much-needed skills and trained workforces.**

**In line with the general objectives, the specific objectives of the partnership are as follows:**

### SPECIFIC OBJECTIVE #1:
**Support the development of differentiating technologies in battery materials, cell design and manufacturing and battery recycling, leading to demonstrations of new chemistries, cells, production lines and proof of concept of recycling logistics and methods.**

The European share of global cell manufacturing is projected to increase from 3% in 2018 to a significant share by 2030 (more than 15% by 2028 according to the JRC estimates[31]). This will lead to more than 200,000 direct and indirect jobs in cell manufacturing by 2028.

One of the most crucial aspects of battery development – in which Europe needs to build competencies and a world-leading knowledge base – is battery components and cell manufacturing. Environmentally sustainable and cost-effective manufacturing will be essential to give Europe a competitive edge. Currently, the level of processing of battery's raw materials and the production of advanced materials in Europe is marginal. Improving yields and material performance in minerals and metals processing as well as in advanced materials production whilst reducing energy consumption and $CO_2$ footprint of battery materials will be essential to achieve sustainable battery material production in Europe. Furthermore, given the rapid growth of the e-mobility and energy storage industries, Europe will face a serious challenge to effectively handle a large number of used Li-ion batteries. The stream/flow throughout the value chain of Li-ion batteries across Europe is very diverse. The large variety of battery types, sizes, shapes, connections and chemical compositions make it very difficult to dispose of them effectively. One way this could be achieved is by re-directing some used batteries to second life applications after expert diagnosis and assessment of state-of-health. Sorting technologies are therefore another area to be further developed.

The BATT4EU Partnership will strongly contribute to creating and maintaining a cell manufacturing base in Europe, by providing the European industry with **differentiating technologies in the fields of raw materials** (battery-grade); **advanced materials** (for example, in the case of the state-of-the-art lithium-ion battery cells, advanced materials represent between 50% and 70% of the cost structure); **cell design and manufacturing processes; and, battery recycling processes.** The upstream materials industry also projects huge investments, with associated job creation. The entire life cycle, from raw materials across cell/battery manufacturing to recycling, will be designed with sustainability and minimal environmental impact in mind.

**The KPIs identified for the Specific Objective 1 are the following:**

- The number of EU-funded projects on novel chemistries at TRL 4 or higher.
- The number of EU-funded projects on cell architectures at TRL 4 or higher.
- The number of demonstrations of production lines.
- EU recycling capacity (tonnes/year).

### SPECIFIC OBJECTIVE #2:
**Accelerate the development and deployment of sustainable and affordable battery solutions for clean mobility, by building a strong innovation ecosystem with downstream partnerships leading to joint demonstrations in different transport modes.**

Transport in general, and the personal vehicle sector in particular, will dominate growth in demand for battery cells in the mid-term, as is already the case today. This will play a key role in driving down costs thanks to significant economies of scale. However, large scale and specialised batteries will also be developed for the waterborne and aviation sectors.

31 https://ec.europa.eu/commission/sites/beta-political/files/report-building-strategic-battery-value-chain-april2019_en.pdf

Solutions developed within the partnership will contribute to offering the same or greater usability and safety than conventional means of transport at similar or reduced cost level (total cost of ownership), while achieving decarbonisation targets. The innovative technologies developed by the partnership on batteries will target mobility applications, in particular, road transport (which will remain the largest battery market by far in the foreseeable future), but also other modes such as waterborne or airborne transport. **The sustainability of batteries should become a competitive and differentiating advantage for the EU, in line with the European Green Deal objectives.**

**The KPI identified for Specific Objective 2 is the following:**

- The number of joint demonstration projects addressing different transport modes.

### SPECIFIC OBJECTIVE #3:
### Enable a cost-effective integration of renewable energy sources in the power grid, by developing affordable batteries for stationary energy storage applications, leading to demonstrations of different scales of storage systems.

The innovative technologies developed by the BATT4EU Partnership will also target stationary energy storage applications, which are key to providing a **sufficient level of flexibility to the power grid** when increasing the share of variable renewables in the energy mix, supporting the utilisation of industry 4.0 and boosting the development of small, robotised devices dedicated to the industry or private households. This will also guarantee the energy sector's decentralisation and empower individuals through flexible energy solutions.

**The KPI identified for Specific Objective 3 is the following:**

- The number of demonstration projects for stationary electricity energy storage.

**Figure 11** below summarises the intervention logic for the partnership, highlighting (the green sections of the arrows) the key challenges to be tackled for each specific objective.

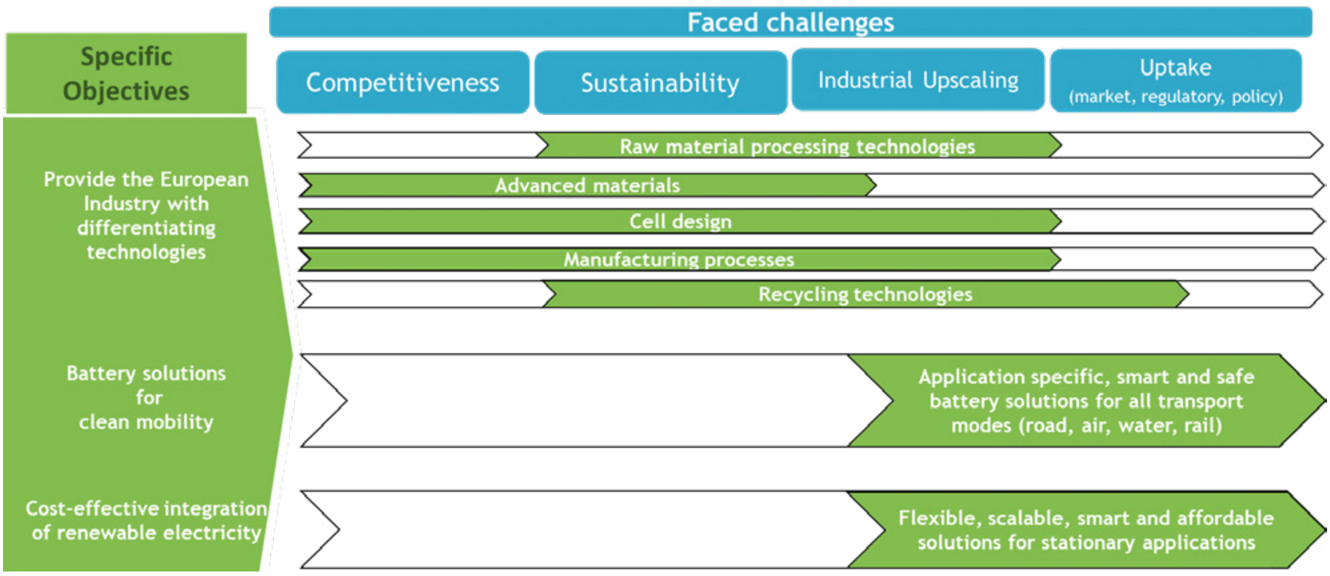


***Figure 11.*** *Scheme of the intervention logic for the BATT4EU Partnership.*

With progressing deployment, the specific objectives of the partnership will trigger positive trends and contribute to the general objectives that will yield the expected impacts.

### 4.2.2.3 TECHNOLOGICAL SCOPE AND OPERATIONAL OBJECTIVES OF THE PARTNERSHIP

The BATT4EU Partnership will mainly cover R&I activities dealing with the upstream segments of the battery value chain, from raw materials to battery cells manufacturing, **regardless of the chemistry/technology** (as long as it matches the objectives of the partnership). It will also cover circular economy actions. While R&I will be performed on all parts of the value chain, **advanced materials and battery cell design and manufacturing** are seen as the key activities of the partnership, for which well-structured coordination will allow Europe to develop the most differentiating technologies. These parts of the value chain have been identified in a recent JRC report as the ones requiring key R&I activities in order to achieve the goal of a competitive EU battery industry[32]. In addition, **battery recycling and secondary raw materials** are also a key priority of the partnership.


***Figure 12.*** *Technological scope of the partnership (focus areas in green)..*

**The partnership will, therefore, allocate a substantial part of its resources to the advanced materials and battery cell manufacturing and design segments, along with circular economy activities:**

- innovative active materials and related components (battery-grade raw materials, cathodes, anodes, current collectors, binders, electrolytes and in particular solid-state future electrolytes), new processes and equipment to manufacture them and novel methods for accelerated discovery and engineering of materials and interfaces;
- other materials (separators, casing, mechanical components, etc.);
- cell assembly technologies (the transition to solid-state batteries will create the opportunity to invest in new manufacturing technologies to compete worldwide);
- battery recycling processes and secondary raw materials.

In terms of TRLs, both the enhancement of close-to-market Li-ion technologies (TRL 5-8), as well as new promising and longer-term breakthrough technological solutions (TRL 2-4) are included, **provided they significantly contribute to achieving the defined specific objectives and to the long-term directionality of the proposed partnership** within a reasonable timeframe. The partnership aims at creating industrial impact as soon as possible, while, at the same time, nurturing the European knowledge base in the field of batteries. By securing the development of future disruptive technologies within Europe, the European battery value chain will get ahead in the global race for the future generation of sustainable batteries. The partnership has taken the utmost care to ensure an appropriate balance between the short-to-medium term and the long-term R&I activities.

**In order to achieve the specific objectives and respective outcomes, the partnership identified the following operational objectives which will benefit all markets segments (in line with the ambitious targets of the SET-Plan Action 7):**

| | |
|---|---|
| **Operational Objective #1** | Increase battery energy density (+60% compared to 2019 values). |
| **Operational Objective #2** | Increase battery power density and charging rate. |
| **Operational Objective #3** | Improve cycle lifetime (at least by a factor of 2 compared to 2019 state-of-the-art values). |

32 *Steen M., Lebedeva N., Di Persio F., Boon-Brett L., EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions, European Commission, Petten, 2017, JRC108043*

| | |
|---|---|
| **Operational Objective #4** | Reduce battery cost (-60% compared to 2019 values). |
| **Operational Objective #5** | Ensure battery safety in the different targeted application sectors. |
| **Operational Objective #6** | Implement worldwide best available technologies (BATs) in manufacturing and recycling operations (plants generation 4.0 or 5.0). |
| **Operational Objective #7** | Enhance the sustainability of the main supply chains of battery's raw materials and achieve the lowest possible carbon footprint of the supply chain from raw material extraction through battery manufacturing, use and recycling. |

**While some of these operational objectives may, at first sight, appear less directly relevant for some specific applications than others, they are consistent with the main application sectors identified by the partnership (electrified transport and stationary storage applications):**

- **Increasing energy density** is a key requirement for road transport applications, as well as for other transport modes (such airborne transport); in addition, increasing the energy density (in kWh/l or kWh/kg) will usually lead to cost reduction (in EUR/kWh), which is crucial for stationary and waterborne applications (requiring a low cost in terms of EUR/kWh/cycle).

- **Increasing the power density** is mandatory both for transport applications (e.g., for fast charging) and stationary applications (for grid services with a short time scale, such as frequency regulation).

- **Improving cycle lifetime** is required for several stationary applications (in particular to reach a very low cost in terms of EUR/kWh/cycle) and is also needed for some transport applications (such as Plug-in Hybrid Electric Vehicles (PHEVs)).

- **Reducing battery cost** is essential for all applications.

- **Ensuring battery safety** is also a key requirement for all applications, although the required level of safety can change depending on the application sector; the development of battery technologies with higher levels of safety (urgently required for waterborne and airborne transport) can only have a positive impact on other applications such as road transport and stationary energy storage.

- **Recyclability and sustainability** are essential requirements in the framework of the European Green Deal in order to decarbonise and ensure materials supply in the value chain; to decrease European dependence on Critical Raw Materials (CRMs) and, to establish EU industry standards as worldwide leading references for sustainability.

**The KPIs identified for the corresponding operational objectives are the following:**

- % of battery energy density increase (target +60% compared to 2019 baseline).
- % of battery power density and charging rate increase (target at least +30% compared to 2019 baseline).
- % of cyclability and lifetime increase (target factor >2 increase compared to 2019 baseline).
- % of cost reduction (-60% compared to 2019 baseline).
- Development and adoption of safety assessment methodologies (target EUCAR safety level 4 for automotive, level 2 for aviation and waterborne).
- The number of innovative manufacturing and recycling processes demonstrated.
- Recycling efficiency in % and $CO_2$ footprint of batteries over their full life cycle.

**The partnership has a very high ambition in terms of technology development.** In particular, increasing the energy density by +60% will require the development of radically new cell chemistries and technologies such as solid-state batteries incorporating lithium metal anodes. Furthermore, reaching the ambitious SET-Plan targets will also require the development of new methods and tools to accelerate the discovery and engineering of battery materials and interfaces, such as the Materials Acceleration Platforms proposed in the "Battery 2030+" research agenda, which are based on a combination of artificial intelligence, multi-scale modelling and high-throughput material synthesis and characterisation.

For Europe to be able to grow its market share in the future, it has to accelerate the development of the know-how in electro chemistries, materials, manufacturing processes and integration, notably by the digitalisation of the R&I pipeline. The BATT4EU Partnership will greatly contribute to closing this gap and bringing closer **industry-research collaborations to develop the knowledge and skills and accelerate the implementation of innovations in the battery industry in Europe[33].**

## FULL TABLE OF THE BATT4EU PARTNERSHIP KPIs

<table>
<tr><th>General Objectives (linked to impact indicators)</th><th>What is a measure of success by 2030?</th><th>Description of what will be measured</th><th>Baseline 2020</th><th>Mid-term target</th><th>Target 2030</th></tr>
<tr><td rowspan="3">GO1: Contribute to making Europe the first climate-neutral continent by 2050 by widespread adoption of e-mobility and stationary electrical energy storage</td><td rowspan="2">KPI 1: EU Sales of EV's for different transport modes using batteries manufactured in Europe [1]</td><td rowspan="2">Numbers of registrations in EU of personal vehicles (PV) and commercial vehicles (CV), both electrically chargeable vehicles (ECV).<br><br>CV-types:<br>- Vans (up to 3,5 tons)<br>- Trucks (over 3,5 tons)<br>- Buses (over 3,5 tons)<br><br>ECV deployment will depend on availability of charging infrastructure. The total number of public charging points will therefore also be monitored to serve as a reference for the ECV registrations above [2].</td><td>Baseline 2019 figures<br>- PC 3,0% ecv share<br>- CV 1,2 % ecv share (in total)<br>- Vans. 1,3% ecv share<br>- Trucks: 0,2% ecv share<br>- Buses: 4,3% ecv share</td><td>2025:<br>- PC 20% ecv share<br>- CV 2% ecv share (in total)<br>- Vans 5% ecv share<br>- Trucks 1% ecv share<br>- Buses 10% ecv share</td><td>PC: 50% ecv share<br>CV: 20% ecv share<br>(commitment within April)</td></tr>
<tr><td colspan="3">[1] As mentioned in the Overall Context section of the main document, new and additional European targets have been set since the first the publication of the SRIA, and the adoption of this KPI in the Monitoring Framework, which will affect the overall sales for EVs in Europe. However, given that this KPI and the associated values were chosen as an indirect indicator for EU-produced battery systems, the decision was made to keep the current KPI and targets unchanged. Efforts are being made to find a good source to track EU-battery systems, but none was found at the time this SRIA was finalised. Finding a direct measurement of battery system production in Europe will remain a point of continued attention until the next iteration of the SRIA<br><br>[2] The following infrastructure requirements will be necessary to ensure the target number of new vehicle registration included in the table<br>- HDV will require around 50,000 charging points and around 1,000 hydrogen re fuelling stations suitable.<br>- At least one high-power charging station with a minimum of 4 charging points every 100 km by 2025 and at least one site every 50 km by 2030 on the TEN-T Core Network.<br>- At least one truck-suitable hydrogen re-fuelling site every 200 km on the TEN-T Core network in 2030 with a daily capacity of at least 6 tonnes of H2.</td></tr>
<tr><td>KPI 2: EU installed capacity of EU manufactured battery energy storage systems connected to the grid</td><td>Capacity Installed in Europe by different categories: large scale for Grid services (both integrated in power plants and standalone) C&I, residential, Off grid</td><td>4GW / 7GWh</td><td>15 GW / 30 GWh</td><td>40 GW / 100 GWh</td></tr>
</table>

33 *Along with 2Zero and other applications partnerships for system integration aspects.*

| General Objectives (linked to impact indicators) | What is a measure of success by 2030? | Description of what will be measured | Baseline 2020 | Mid-term target | Target 2030 | Notes on 2023 update |
|---|---|---|---|---|---|---|
| GO2: Enable European leadership in the battery industry across the value chain, creating economic growth and jobs in a circular economy, by supporting the development of an innovative, competitive and sustainable battery manufacturing industry in Europe; | **KPI 3**: EU Battery manufacturing capacity competitive with respect to the rest of the world | New battery cell manufacturing plants. | 26 GWh (reference coming from several reports.) | EBA target of 200 GWh/yr manufacturing capacity by 2025. Based on current announcement, by 2025 at least 231 GWh/yr manufacturing capability should be installed | 400GWh by 2028 (EU Implementation of the strategic plan on batteries). Min scenario approx. 300 GWh/yr, max scenario 700 GWh/yr based on 2021 announcement and potential expansion | |
| | **KPI 4**: Creation of new jobs and skills | Jobs: Number of newly employed in Battery industry<br><br>Education: Number of newly educated in Battery technology Across the whole value-chain. | Jobs: 200 000 jobs along the full battery value chain. (Source: BE TF Education). | Jobs: 800 000 wide jobs along the full battery value chain in 2025. (Source: BE TF Education) | Jobs: Between 900 000 and 1.3 m of jobs along the full battery value chain. (Source: BE TF Education)<br>At least 100 to 300 indirect jobs per GWh (EIT RawMaterials-Fraunhofer-Report) | |

| General Objectives (linked to impact indicators) | What is a measure of success by 2030? | Description of what will be measured | Baseline 2020 | Mid-term target | Target 2030 | Notes on 2023 update |
|---|---|---|---|---|---|---|
| GO3: Contribute to achieving a zero-pollution ambition for a toxic-free environment, by providing safer and more sustainable batteries and processes (along the whole value chain, including recycling). | **KPI 5**: % of improvement of environmental impact in terms of $CO_2$ and toxic material | Reduction of $CO_2$ per kWh<br><br>$CO_2$ = amount of $CO_2$-equivalents emitted during battery production "cradle to gate" (cell manufacturing only)<br><br>"per kWh" will be initially defined as the nominal battery capacity. As LCA methodologies improve and become codified in EU Regulations, this minimal definition will be complemented with a $CO_2$ value per kWh delivered over the life of the battery. In all cases, measurements for this KPI will be in line with methodologies used in future EU Regulations. | 13 kg$CO_2$ per kWh For cell manufacturing only<br><br>-50 kgCO2 per kWh for cradle-to-gate<br><br>(Batteries Europe KPIs Benchmarking II, October 2023) | | -75% reduction to 3 kg$CO_2$ per kWh for cell manufacturing<br>-50% reduction to 12-24 kg $CO_2$ per kWh in cradle-to-gate scenario<br><br>(Batteries Europe KPIs Benchmarking II, October 2023) | Agreement on $CO_2$ targets reached in Batteries Europe KPI exercise |
| | **KPI 6**: % of recycled materials | % of recycled materials (focus on metals/materials as per Battery Regulation) used in new batteries.<br><br>% of batteries where traceability of raw materials is integrated. | | Battery Regulation foresees reporting duty as 2027 only | 2030 target: 70% for lithium-based batteries<br>2031 targets: 95% for Cobalt, Copper, Nickel<br>80% for Lithium | Taken from Regulation (EU) 2023/1542 concerning batteries and waste batteries |

| Specific Objectives Objectives (linked to impact indicators) | What is a measure of success by 2030? | Description of what will be measured | Baseline 2020 | Mid-term target | Target 2030 | Notes on 2023 update |
|---|---|---|---|---|---|---|
| SO1: Support the development of differentiating technologies in battery materials, cell design and manufacturing and battery recycling, leading to demonstrations of new chemistries, cells, production lines and proof of concept of recycling logistics and methods. | **KPI 7**: Number of EU-funded projects on novel chemistries at TRL 4 or higher | Measurement of the TRLs achieved at the end of EU-funded projects [3], level of technologies' market uptake, qualitative analysis of the work done. | Not before 2025 | 12 projects | 15 projects<br><br>[3] EU-funded projects for KPIs 7-9 = projects funded by HE calls within the Batt4EU Partnership | Focus of the Partnership after mid-term shifts on upscaling of technologies |
| | **KPI 8**: Number of EU-funded projects on cell architectures at TRL 4 or higher | Measurement of the TRLs achieved at the end of EU-funded projects , level of technologies' market uptake, qualitative analysis of the work done. | | 12 projects | 15 projects<br><br>EU-funded projects for KPIs 7-9 = projects funded by HE calls within the Batt4EU Partnership | Focus of the Partnership after mid-term shifts on upscaling of technologies |
| | **KPI 9**: Number of demonstrations of production lines | Measurement of the TRLs achieved at the end of EU-funded projects, level of technologies' market uptake, qualitative analysis of the work done. | - | By 2025, 4 projects (Innovation Actions WP21-22) on topics such as dry coating, solid state manufacturing, digitaliztion | By 2030, 10 projects in total<br><br>[3] EU-funded projects for KPIs 7-9 = projects funded by HE calls within the Batt4EU Partnership.<br><br>[4] New technological processes demonstrated for use production lines, not entire production lines. | |
| | **KPI 10**: EU Recycling capacity (tonnes/year) | Cells recycling capacity (tonnes)<br><br>In line with revision of battery regulation. | | Min 3 facilities with >15kmt/yr each | Min 5 facilities with >25kmt/yr each | |

| Specific Objectives (linked to impact indicators) | What is a measure of success by 2030? | Description of what will be measured | Baseline 2020 | Mid-term target | Target 2030 |
|---|---|---|---|---|---|
| SO2: Accelerate the development and deployment of sustainable and affordable battery solutions for clean mobility, by building a strong innovation ecosystem with downstream partnerships leading to joint demonstrations in different transport modes. | **KPI 11:** Number of joint demonstration projects addressing different transport modes | Specific cells for different applications<br>- design to cost (dtc)<br>- design to energy (dte)<br>- design to power (dtp) | Zero projects | - 2 projects to dtc<br>- 2 projects to dte<br>- 1 projects to dtp | - 5 projects to dtc<br>- 5 projects to dte<br>- 3 projects to dtp |
| SO3: Enable a cost-effective integration of renewable energy sources in the power grid, by developing affordable batteries for stationary energy storage applications, leading to demonstrations of different scales of storage systems. | **KPI 12:** Number of demonstration projects for stationary electricity energy storage | Measurement of the TRLs achieved at the end of EU-funded demonstration projects [3], qualitative analysis of the work done. | Zero projects | By 2025, 3 projects for BtM-applications (residential and commercial and/or industrial) and/or FtM-applications (large scale stand-alone or integrated in power plants) | By 2030, 8 projects for BtM-applications (Residential and commercial, and/or industrial) and/or FtM - applications (large scale stand-alone or integrated in power plants) |

| Operational objectives (linked to impact indicators) | What is a measure of success by 2030? | Description of what will be measured | Baseline 2020 | Mid-term target | Target 2030 |
|---|---|---|---|---|---|
| OO1: increase battery energy density (+60% compared to 2019 values) | **KPI 13:** % of battery energy density increase (target +60% compared to 2019 baseline) | Gravimetric & volumetric energy densities at cell level | Baseline depends on application sector. For BEV in 2019: 250 Wh/kg, 500 Wh/L (source: EUCAR) | | +60% compared to 2019 baseline |
| OO2. increase battery power density and charging rate | **KPI 14:** % of battery power density and charging rate increase (target at least +30% compared to 2019 baseline) | Gravimetric & volumetric power densities at cell level | Baseline depends on application sector. For BEV in 2019: 750 W/kg, 1500 W/L (source: EUCAR) | | At least +30% compared to 2019 baseline |
| OO3. improve cycle lifetime (at least by a factor of 2 compared to 2019 state-of-the-art values) | **KPI 15:** % of cyclability and lifetime increase (target factor >2 increase compared to 2019 baseline) | Cycle life at cell level | Baseline depends on application sector. For BEV in 2019: 1000 cycles at 80% DoD (source: EUCAR) | | At least x2 compared to 2019 baseline |
| OO4. reduce battery cost (-60% compared to 2019 values) | **KPI 16:** % of cost reduction (-60% compared to 2019 baseline) | Cost at cell level (€/kWh) | Baseline depends on application sectors. For BEV: 125 €/kWh (source: AABC 2019 EV-volumes.com) | | -60% compared to 2019 baseline |
| OO5. ensure battery safety in the different targeted application sectors | **KPI 17:** Development and adoption of safety assessment methodologies (target EUCAR safety level 4 for automotive, level 2 for aviation and waterborne) | *Availability of updated and new standard methodologies (ISO, IEC, UL or others) to design and operate batteries in the new applications, and integrating the potential new hazards attached to new technologies (lithium solid state, lithium metal, lithium sulfur, and other non-lithium).<br><br>*Availability of testing standards and methodologies for batteries hazards characterisation, including new technologies of characterisation when available (i.e. gas compositions). | Final baseline values will be defined more precisely in the ETIP 2020 SRA. | | Nb of updated/new battery standards in new applications. TBD. |
| OO6. implement worldwide Best Available Technologies in manufacturing and recycling operations | **KPI 18:** Number of innovative manufacturing and recycling processes demonstrated | Assessing number of projects developing and demonstrating innovative process technologies. Qualitative and quantitative results, and TRL / market readiness levels | Final baseline values will be defined more precisely in the ETIP 2020 SRA. | By 2025,<br>- 3 projects in raw materials processing<br>- 3 projects in recycling materials processing | By 2030,<br>- 6 projects in raw materials processing<br>- 6 projects in recycling materials processing |
| OO7. enhance the sustainability of the main supply chains of battery raw materials and achieve the lowest possible carbon footprint of the supply chain from raw materials extraction through battery manufacturing, use and recycling. | **KPI 19:** *Recycling efficiency in %<br><br>*CO2 footprint of batteries over their full life cycle<br><br>(reduced carbon footprint of battery raw material supply chain, and enhanced recycling efficiency) | CO2 equivalent of battery materials, per manufactured kWh of battery<br><br>Recycling efficiency of Li-ion batteries | | As per the battery regulation:<br>(a) recycling of 75 % by average weight of lead-acid batteries;<br>(b) recycling of 65 % by average weight of lithium-based batteries;<br>(c) recycling of 80 % by average weight of nickel-cadmium batteries;<br>(d) recycling of 50 % by average weight of other waste batteries. | As per the battery regulation:<br>(a) recycling of 80 % by average weight of lead-acid batteries;<br>(b) recycling of 70 % by average weight of lithium-based batteries. |

### 4.2.3

# Expected impact and needed investments in R&I

## 4.2.3.1 R&I INVESTMENTS NEEDED TO ACHIEVE THE OBJECTIVES OF THE PARTNERSHIP

The typical level of investment in R&I in the battery value chain industry, required to maintain the battery technology at a competitive level, is expected to be more than 5% of the battery market turnover. In addition, battery cell manufacturing is an investment intensive industry, requiring high volume and highly automated manufacturing processes. Capital costs per unit of battery manufacturing capacity trends converge at about 90-100 million EUR/GWh in 2019.
The industry investment in the final phases of the new technologies (moving from TRL 7 to TRL 9) is important, as significant pre-industrial validation is needed: pilot equipment, product design for manufacturability updates, etc. The partners' assessment is that **the achievement of the partnership's objectives is estimated to require an overall mobilisation of R&I resources of at least one billion Euros per year over the next decade.**

Depending on the projects and programs, it is expected that a part of the pre-industrial investment will be supported by/pooled from cohesion policy funds, IPCEIs and other public investors – like EIB – having financial products for pilot lines and demonstrators.

## 4.2.3.2 THE ADDED-VALUE PROVIDED BY A EUROPEAN BATTERIES PARTNERSHIP

As stated in the diverse objectives of the BATT4EU Partnership, its ambition is to **support the creation of an innovative, competitive and sustainable industrial value chain for batteries in Europe.** It is a highly challenging endeavour, given the narrow time frame left for Europe in the context of extremely strong international competition. **The partnership will focus on differentiating technologies** that are key to supporting the competitiveness of the European battery industry in the short, medium and long term. The usual forms of support to R&I from the EU Framework Programme are not suited given the scale and speed of investment needed to create a world-leading European battery industry. **It is crucial to work in parallel (not in sequence) on the entire value chain, including manufacturing (largely neglected in the past).** This needs close cooperation, in a holistic and integrated manner, between R&D and industry players from different sectors, e.g., raw materials, advanced materials, cell development and manufacturing, industrialisation, recycling and others, as well as cross-sectional sectors, including AI specialists, data sciences and LCA.

**Only a partnership,** i.e., a long-lasting and coordinated effort involving industry, research and the public sector, can live up to the challenge and bring predictability to European battery value chain stakeholders. By pooling Europe's resources and knowledge, partnerships have demonstrated their efficiency for accelerating the development, industrialisation and deployment of strategic technologies that underpin growth and jobs in key sectors of the European economy.

**More specifically, the BATT4EU Partnership will provide the following key advantages:**

- **Long-lasting and continuous industrial support and commitment for a common R&I vision in the field of batteries.** The partnership will ensure that a consistent R&I programme is designed and implemented over a period of 7 years, which will give the necessary timeframe and predictability to develop innovative battery technologies and bring them to higher levels of technological and manufacturing readiness.

- **R&I action portfolio management.** The partnership identified and will implement joint strategic R&I activities, not only by proposing a sound R&I programme but also by monitoring the execution phase of the funded R&I actions and consequently reporting the advancements to the wider battery community, mainly through ETIP Batteries Europe. Following the progress made by the individual funded projects (in particular, checking whether they are able to reach their quantitative targets and contribute to achieving the key performance indicators defined in the strategic R&I agenda and the SET-Plan Action 7), it will provide extremely valuable inputs to design the next phases of the R&I programme.

**Such an R&I action portfolio management, i.e., the establishment of a "feedback loop" between the outputs of the funded R&I projects and the inputs of the R&I programme, together with additional activities supporting market take-up, will maximise the impact of R&I.**

- **Leveraging technical and financial resources from both the public and private sectors** (see section 5 for more details).

- **Aligning R&I policy with industrial, environmental and education and training policies.** The partnership brings together industry, research and the European Commission, which will ensure that the R&I programme is well aligned with the other relevant European policies, including industrial, environmental, education and training policies. A strong alignment between the different policies is mandatory to achieve the ambitious goal of creating a competitive and sustainable battery manufacturing industry in Europe, as clearly explained in the European Commission Strategic action plan on batteries[34]. Collaboration with national and regional initiatives will also be essential (as described in section 5).

- **To strengthen the European batteries value chain,** research across the value chain must be better coordinated. The proposed partnership will bring together actors across the value chain and ensure that: (1) research and innovation is targeted to tackle each industrial segment's needs within the same overarching objective; (2) results are further adopted in consequent links of the value chain; and (3) two-way communication is constant in defining requirements and targets.

### 4.2.3.3 EXPECTED IMPACT AND SUPPORT TO A BROADER R&I ECOSYSTEM

The timing of this initiative is crucial (in coordination with the preparation of the Horizon Europe programme) to maximise the impact of the investments made by Horizon Europe and the batteries industry across the full value chain (from raw materials to advanced materials, battery cells, modules, packs, applications and end-of-life management). The BATT4EU Partnership will deliver on this ambition by supporting the European battery ecosystem. **It will enable the coordination of the targeted strategy covering the entire battery value chain, from cradle to grave, across the full spectrum of technologies used in the "ecosystem of batteries", for the key applications** (electrified transport and stationary energy storage).

The role of a partnership is indeed essential when it comes to the coordination and coherence assessment of the R&I funded programs. A partnership is necessary to fulfil and complete the required support, in the framework of a multi-year and multi-project context, and to successfully achieve the transition to industrial investment and manufacturing. **A practical core objective of the partnership is to accelerate the transfer of R&I knowledge to industrial manufacturing and thereby support the EU battery industry development beyond 2025.** A key example is the transfer of generation 4 of lithium batteries technologies (solid-state batteries, TRL 2-4) to industrial manufacturing: there is an urgent need for coordinated support to efficiently help the public and private research organisations move this highly challenging technology through the TRLs 4 to 7.

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**34** *https://ec.europa.eu/transport/sites/transport/files/3rd-mobility-pack/com20180293-annex2_en.pdf*
**35** *Where applicable, any funding from state resources must be compliant with State Aid rules.*

# 4.3 BATT4EU IMPLEMENTATION

## 4.3.1 Activities and resources

By covering the whole industrial value chain and a wide range of technology readiness levels, the BATT4EU Partnership will efficiently coordinate the selection, implementation and execution of R&I activities and the take-up of results among different key stakeholders along the battery value chain. **The main activity of the partnership will thus be to provide input and advice to the European Commission in order to contribute to the identification of priorities of research and innovation activities and the definition of call topics to be included in the Horizon Europe Work Programmes.**

### 4.3.1.1 SCALE OF RESOURCES

**The achievement of the partnership's objectives is estimated to require an** overall mobilisation of resources of **approximately EUR 925 million for actions within the scope of the partnership.**

**Resources contributed by the private side will include:**

- **Contributions from the members** participating in projects funded by the Union contributions (on the basis of the non-reimbursed eligible costs);
- **In-kind contributions to additional activities** in the scope of the SRIA not covered by Union funding;
- **Investments in operational activities** that is spent beyond the work that is foreseen in the SRIA and aligned with the objectives of the partnership.

### 4.3.1.2 SCOPE OF IN-KIND ADDITIONAL ACTIVITIES

**In-kind additional activities may include:**

- **Activities contributing to strategic and operational alignment,** coordination and synergies with other partnerships and initiatives at EU/national/regional or international level[35];
- **Activities contributing to the development of battery R&I ecosystems** at EU/national/regional or international level;
- **Communication, networking and outreach activities,** including matchmaking and brokerage services on the calls for proposals, and activities ensuring dissemination and exploitation of results of R&I activities in the scope of the SRIA of the European partnership;
- **Activities promoting, facilitating or accelerating innovation** uptake in the market, including via financing opportunities provided by the European Investment Bank or venture capital funds;
- **Scaling-up of technologies at higher TRL** and uptake of results from partnership projects, such as pre-commercial trials, proof of concept, improvement of existing production lines for up-scaling or building new production facilities;
- **Activities supporting regulations and standards activities,** especially on safety and sustainability aspects;
- **Complementary side/upstream projects not funded by the EU, including:**
  - low-TRL research activities, feeding into partnership projects,
  - R&I activities within the scope of the SRIA but not funded by the partnership;
- **Activities addressing training and skills development,** including contributing to the identification of gaps and needs, and the definition of joint training programmes.

### 4.3.1.3 REPORTED IKAA

In 2021-2022, these contributions represented an estimated total of at least €496 million, which is more than half of the EU funding of the Partnership for the whole period 2021-2027 and exceeded the Union contribution in the same period by around €200 million.

**Striving towards a sustainable battery value chain**

The BATT4EU Partners other than the Union invested in developing new technologies and techniques for resource efficient production of advanced materials for batteries, battery cells, and battery packs. **Notable additional activities undertaken from June 2021 to December 2022 are:**

- **Research on solid polymeric electrolytes for safe Li, Na or Zn batteries,** prepared with sustainable and scalable materials and methodologies.
- **Generation of a database for the use and end of life of batteries** that is broad enough to be used by manufacturers in the evaluation of their technologies in order to improve their design.
- **Research and development** of novel chemistries and materials for batteries.
- **Development of doped vanadium oxide/graphene** composite by physical vapour deposition for sustainable and eco-friendly energy storage application.
- **Design, building, and testing** of next generation machines and prototypes for lithium-ion battery assembly based on industrial technical requirements.
- **Development of a proof of concept** to maximize machine performances and parameters for new lithium battery manufacturing processes and technologies (Gen 3b/ Gen 4) : OEE, increasing productivity output rate, and reducing energy consumption.

**Developing a circular model for batteries in Europe**

Activities performed by the BATT4EU Partnership aim to enhance the reuse, recycling, and comprehensive optimisation of the use of critical raw materials within the European battery value chain. **This has included:**

- **The development of Fortum's battery recycling technologies,** a lot of emphasis is put into managing the carbon footprint of the operations – in addition to considerations linked to material efficiency and profitability.
- **Projects aiming at finding means of adding value** to the battery metals sector by more efficient screening and tilization of the domestic mineral resources, improving the metal refining processes, recycling battery metals, and improving co-operation between the companies and research organisations.
- **Development of pre-treatment technologies** (safe deactivation, regeneration of solvents, electrolyte recovery, graphite recovery) for the recycling of Li-ion batteries.
- **Running of a pilot line for the recovery of critical raw materials** from black mass and for the extraction of Cobalt, Nickel, and Lithium from end-of-life batteries.

**Building a competitive European battery value chain**

Optimising battery costs, developing new businesses; through their additional activities, **BATT4EU partners contribute to a competitive European battery value chain:**

- **Strengthening the competitiveness of new innovative storage providers** by using a user-centric, demand-driven approach to bring products closer to market through tailored testing.
- **Establishing new business partnerships with European cell and battery manufacturers.** Within the scope of these business partnerships, studies for the development of new technologies, technology transfer, and improvement of existing technology are carried out.
- **Investments in and projects with spin-offs/start-ups** on solutions developed within research projects.
- **Analysis and experimentation of residential batteries** aggregation for national program participation in order to validate a business model and assess future market opportunities.

### Ensuring a high safety standard for batteries in Europe

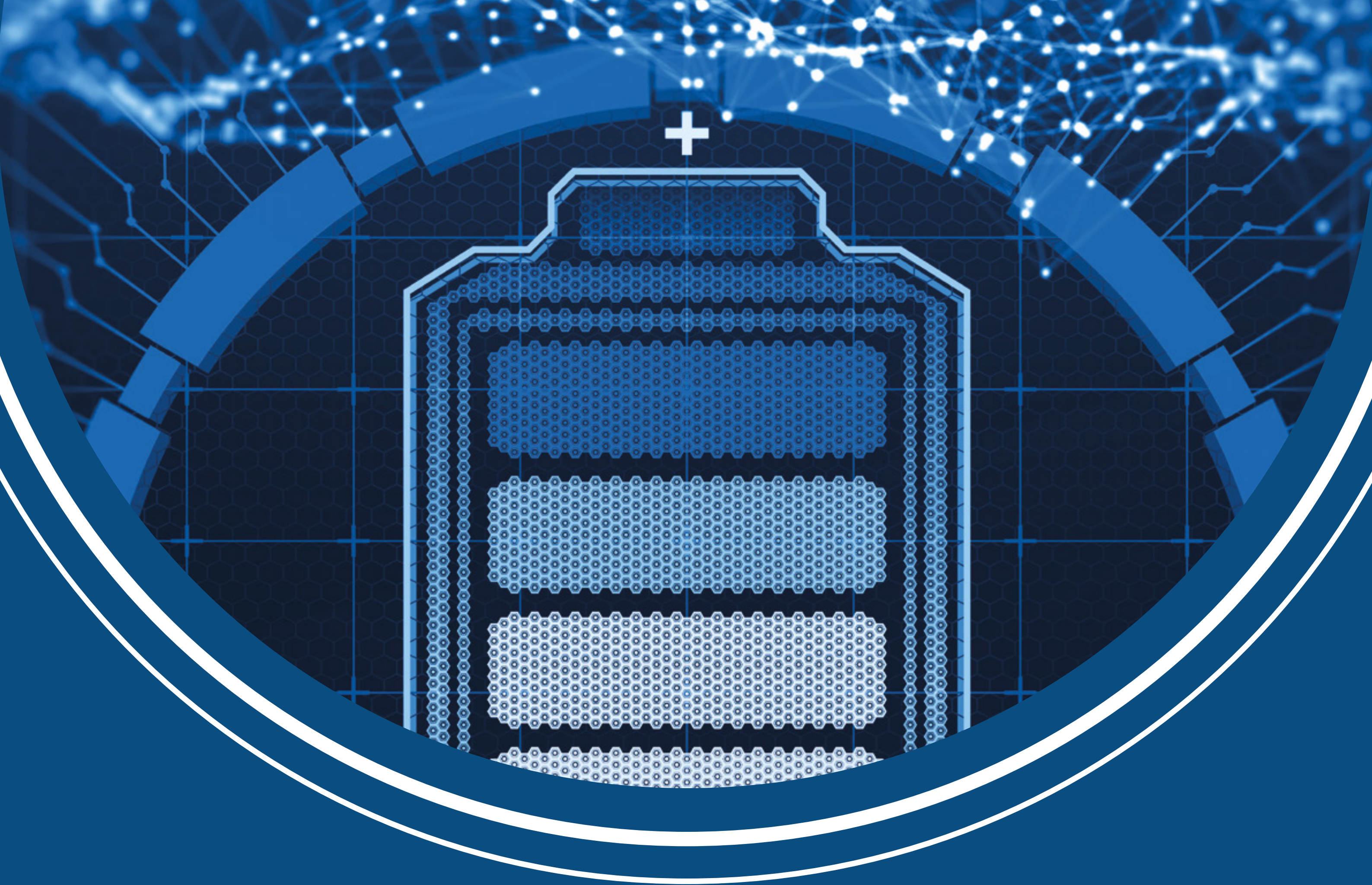
As the use of batteries in society increases, it becomes ever more important for them to be safe. **Take a look at some of the activities BATT4EU Partners undertook in order to make their batteries safer:**

- **Project SOLIDEL (Solid Electrolytes for Lithium-Ion Batteries) explores new, radical, and high-tech methods** to enhance the performance and safety of lithium-ion batteries. More specifically it pertains to the synthesis of solid polymer electrolytes (SPEs) for lithium-ion batteries, by applying the principles of nanostructured macromolecular materials. The project aims to develop single-ion SPEs that will allow the development, design and manufacturing of prototype lithium-ion battery cells with solid electrolytes.
- **Improvement of existing battery testing infrastructure:** Thanks to this project, module and pack level testing systems will be installed to serve domestic or international battery developers.
- **Development of non-flammable and high voltage electrolytes** for next generation Li-ion batteries, including Cobalt-free cathodes.
- **Advanced data analysis, including:** server-side and embedded AI techniques; estimation of state of health, residual life, early detection of anomalies, early application of new technologies.

### Informing, educating, and training European citizens for an inclusive battery value-chain

As the battery market grows, it is important to raise awareness on the benefits of batteries and normalise their usage. Training a relevant work force within Europe for a stronger European battery industry is also critical. Activities from BATT4EU partners striving towards these goals are:

- **Organisation of NEXUS event by ADItech and the Navarra region government.** This event served as a knowledge transfer and networking event among the attendees. As well as the dissemination of R&D&I projects and technologies in the main sectors of the region. One of the sessions presented the BATRAW project.
- **Creation of internal company training programmes and collaboration** between academia and industry on new master programmes on battery technology for joint skilling efforts.
- **Many BATT4EU partners are in regular contact with national and other local authorities** and carry out specific communication and dissemination activities on Partnership results aimed at these decision makers.
- **Regular update of a company blog to ensure effective dissemination** of technical content on electrification that is easy for citizens to understand.
- **Constant creation of contents in cooperation with trade magazines** with a predominantly industrial circulation, together with magazines and newspapers with a more general circulation.
- **Young and established scientists awarded internationally and nationally for battery research**. For example, Guiomar Hernandez received the POLIS award.



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