

DELIVERABLE 6.3
SUMMARY OF THE
OUTCOMES OF BATTERY
2030+
BATTERY 2030+ CSA3

BATTERY
2030+

At the heart of a connected green society

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1 INTRODUCTION

The Battery 2030+ CSA3, a large-scale research Horizon Europe initiative, builds on two earlier CSA's, orchestrated by Uppsala University. The wider purpose is to facilitate collaboration and the exchange of knowledge, in several aspects, between a number of different R&I projects where the overarching goal is to monitor the research towards the goals as outlined in the Battery 2030+ roadmap. As described in D 1.4 "Collaboration results within Battery 2030+ initiative", the aim is furthermore to reach out and enhance collaboration also with the wider European battery research landscape. By a successful collaboration research results will reach a broader audience, and research results can hence be accelerated toward innovation.

Equally important has been the educational activities and work around standardization, ontology and data management as well as IPR and innovation uptake. Communication is yet another important area, where sharing is a prerequisite for reaching out successfully.

The outcomes in this deliverable will focus on short presentations of the research results and the work with data management and education. It is however rather short since both this and the collaboration already has been covered more in detail in different delivered reports (deliverables), such as the one mentioned above, and the upcoming final report will discuss and cover the work and outcomes of the entire CSA3.

The network Battery 2030+ has built among European battery researchers, educators, data specialists etc will most likely be a good starting point and something to build upon in the Batt-Bridge project just as it was for Batteries Europe and the European Battery Partnership.

2 METHODOLOGY AND OUTLINE

This deliverable consolidates information from the 18 public project deliverables produced within the initiative. To complement this material, all R&I projects were invited to provide a concise summary of their main scientific achievements and results.

Given the breadth of activities and outputs generated within Battery 2030+, this report focuses on the deliverables and outcomes considered most relevant and impactful for the reader. In particular, it highlights key findings related to the Battery 2030+ Roadmap, ontology and data-related developments, educational activities, and communication and dissemination efforts. Readers interested in exploring the full range of deliverables are referred to the Battery 2030+ website and the [CORDIS](#) portal, where additional project information and publicly available deliverables can be accessed.

The report is structured as follows. Chapter 3 provides an overview of the public and sensitive deliverables, while chapter 4 summarises the main scientific outcomes generated by the projects. Chapter 5 presents key outcomes related to the Battery 2030+ Roadmap, and chapter 6 addresses achievements in ontology development, data management, and standardisation. Chapter 7 highlights educational activities and outcomes, and chapter 8 summarises communication and dissemination achievements. Finally, chapter 0 presents the overall conclusions and key takeaways from the initiative.

3 DELIVERABLES

A total of 26 deliverables have been produced within the CSA 3 initiative, comprising 18 public deliverables and 8 sensitive deliverables. As the present deliverable (D6.3) is classified as public, only information and examples from the public deliverables can be presented in this report. However, several of the sensitive deliverables contain highly valuable information, including D2.1: National and International R&I Programmes and Needs and D2.3 and D2.4: Propositions for Future R&I Actions in Europe.

Subject to the availability of resources and budget, Battery 2030+ intends to prepare a number of publications based on selected deliverables. Where appropriate, these publications may also incorporate non-confidential findings and insights originating from the sensitive deliverables, thereby making a broader range of project outcomes accessible to the scientific community and other stakeholders.

The public deliverables cover a wide range of topics, including collaboration within the initiative, strategic roadmap development, ontology and data management, standardisation, education and training, communication and dissemination activities, and the overall outcomes of Battery 2030+.

Equally important has been the work on IPR and innovation uptake. However, the deliverable describing the Battery 2030+ approach to IPR and innovation uptake (D1.3) is sensitive and is therefore not publicly available. As a result, it has not been appropriate to include a summary of D1.3 in this public deliverable (D6.3).

For readers who have access to restricted deliverables, D1.3 provides a description of the Battery 2030+ approach to IPR and innovation uptake.

The Innovation Uptake Session at BID 2025 serves as a practical example of these efforts, aiming to bring key project results and innovations closer to industrial stakeholders and thereby support their potential uptake and exploitation.

The deliverables most relevant to the thematic chapters of this report are summarised as follows:

Chapter 5 is primarily based on D2.2: Battery 2030+ Roadmap, 4th Edition.

Chapter 6 draws on the results and recommendations presented in D3.1 *Interim report reviewing battery domain ontologies and guidelines for their use*, D3.2 *Interim report on guidelines and best practices for battery data management and sharing*, D3.3 *Interim report on standard protocols for theory and experiment* and D3.4 *Interim report on standard protocols for theory and experiment*.

Chapter 7 is based on D4.1 *Update on education/training needs*, D4.2 *Recommendations for European Curricula*, D4.3 *Next Generation Scientists event and Manifesto* and D4.4 *First courses/MOOC and curricula digitalized*.

Chapter 8 builds on D5.1 *Communication and dissemination vision* as well as D5.2 and D5.3 *Communication and dissemination plans*.

Readers interested in specific deliverables are encouraged to consult the complete list provided below and, where applicable, access the publicly available reports through the CORDIS portal.

A complete number of the deliverables can be found in appendix A.

4 RESEARCH OUTCOMES

The projects described below were designed by the European battery partnership together with Battery 2030+ to fulfil the Battery 2030+ roadmap. The project should have elements of low TRL research and long-term vision not hindering innovation aspects and upscaling. The different projects have had regular meetings hosted by the Battery 2030+ CSA 3 to fertilize each other and help each other. A number of different joint workshops IRL or on line have also been hosted.

The projects are depicted in Fig. 1, under the Battery 2030+ umbrella.



FIGURE 1: THE 22 BATTERY 2030+ PROJECTS GROUPED IN TOPICAL AREAS

4.1 Battery functionality

HEALINGBAT

To date, the HealingBat project, which started 1 June 2023, has successfully **developed and validated an innovative sensor–actuator instrumentation system capable of detecting degradation processes in Li–S batteries**. In addition, the system incorporates an integrated heating element that allows the direct initiation of self-healing mechanisms once degradation is detected.

HealingBat’s approach enables a seamless embedding of sensors and actuators directly into the battery cell without interfering with battery assembly or operation. To achieve this a polyimide substrate, providing mechanical flexibility, chemical stability, and minimal weight contribution was utilized. The total thickness is less than 30 µm, and hence ensures compatibility with standard cells, like the pouch cell.

All functionalities for multiple sensing are connected via a common interface, enabling simplified integration and reducing structural complexity. To ensure long-term stability the system is passivated by encapsulation.

INERRANT

INERRANT, started 1 May 2024, works on direct recycling of anodes and the synthesis of different cathode materials for lithium-ion batteries.

Anode results

INERRANT has developed laser-assisted routes for restructuring conventional slurry-cast graphite/graphene electrodes. The treatment creates more accessible ion-transport pathways, improving electrolyte infiltration and high-rate performance. SEM-based porosity/tortuosity analysis and electrochemical modelling support the optimization of scalable fast-charge-oriented anode architectures.

Cathode results

Standardized synthesis routes have been established for polycrystalline and single-crystal Ni-rich layered oxides and LFMP cathodes. Dual-doping, surface functionalization and solvent-free processing strategies have delivered high capacities and encouraging improvements in cycling stability and capacity retention.

PHOENIX

Phoenix which started 1 May 2024, has the overarching goal to develop self-healing materials and sensors using silicon anodes as model system due to its challenging alloying chemistry with lithium. The KPIs for this goal is the following.

Self-healing materials eliminating/avoiding failure mechanisms, enabling Gen 3b single layer pouch, with Si anode of capacity >1200 mAh/g at 0.5 C-rate, and 80% capacity retention after more than 500 cycles at 1 C-rate.

A novel self-healing polymer with magnetic nanoparticles was implemented in silicon-based anodes, achieving a specific capacity exceeding 1200 mAh/g. While stable operation was confirmed for over 500 cycles, the 80% capacity retention target was not met due to the inactivated magnetic triggering mechanism.

SAFELOOP

Safeloop, started 1 June 2024, and deals among other things with recycled and regenerated graphite cycled vs. NMC811, and an optimized electrolyte. The following were achieved:

Recycled and regenerated graphite reached an exceptionally high purity of >99.99 wt., demonstrating the effectiveness of the recovery process and its suitability for high-performance lithium-ion battery applications.

Graphite was successfully recovered and recycled from spent 18650 lithium-ion battery cells and subsequently reutilized in the production of new anode active materials at a current processing capacity exceeding 100 kg.

NMC811 was selected as the reference cathode material for the technical development line. **The alumina-coated NMC811 cathode achieved a specific discharge capacity of $\geq 200 \text{ Ah kg}^{-1}$ at 1C and a capacity retention of 95% at 2C,** indicating excellent rate capability and electrochemical stability. Furthermore, the surface coating enhanced long-term cyclability.

The optimized electrolyte delivered more than a 15% improvement in long-term galvanostatic cycling stability compared with the reference cell chemistry, demonstrating significant progress towards safer and longer-lasting lithium-ion batteries.

SAGELI

It may be worth noting that SAGELi belongs to the group of projects of Battery 2030+ that started later, 1 January 2025, and is not close to the end of the projects, which is reflected in the current

scope of results. So far, the most relevant outcomes mainly relate to the **development of cathode active materials** (CAMs). At this stage, there are no results yet concerning binders, and only very limited progress has been made in electrolyte modelling.

A key distinguishing feature of SAGELi is its strong safe-by-design approach. While other projects typically integrate safety measures at later stages, SAGELi adopts a bottom-up strategy where safety considerations are embedded from the very beginning of material development.

SAGELi focuses on two types of cobalt-free cathode active materials: High-Lithium Manganese oxides (HLM) and Disorder Rocksalt (DRS) materials, the latter being both cobalt- and nickel-free. The partial results obtained so far are based on electrochemical characterisation and indicate oxygen gas release from the CAMs. **To mitigate this effect and enhance safety, atomic layer deposition (ALD) coatings will be applied. These coatings have been shown to form uniform and conformal layers on the materials without causing structural degradation, thereby reducing gas release and improving overall safety.**

SALAMANDER

One key development from SALAMANDER, started in 1 May 2023, is its computational modelling work building **a new modelling platform capable of simulating self-healing polymer chains with different combinations of functional groups** with approximations for non-equilibrium molecular dynamics up to 60x faster. Another major result is applying ReaxFF to model the evolution of a 23 Å Si nanoparticle and its morphological disintegration during lithiation, especially in the presence of different polymer and electrolyte solvents.

Salamander **successfully developed and implemented two sensor technologies for batteries: temperature and dissolved transition-metal ion sensing**. Key achievements include improving sensor stability in electrolyte environments, integrating multiple sensors into a single platform, and optimizing pouch-cell sealing. Pouch cells with integrated sensors demonstrated cycle life close to the baseline, while the BMS interface was successfully upgraded to manage the additional sensor inputs.

4.2 Battery Interface

ANGELIC

Bio-based gel polymer electrolyte

ANGeLiC, started in 2 May 2025, partners **developed a bio-based gel polymer electrolyte** using a crosslinked isosorbide framework, achieving high ionic conductivity (1.5×10^{-4} S/cm at 30°C) and stable lithium plating/stripping over 2000 hours. This result is published in Materials Today Energy (Del Olmo et al., 2025, DOI: 10.1016/j.mtener.2025.102043) and is now being evaluated for compatibility with Li-S battery chemistry within the project.

Operando XRD insight into sulphur regeneration mechanism

ANGeLiC partners developed a custom operando X-ray diffraction cell to track structural changes in Li-sulphur cathodes during cycling. Contrary to initial expectations, the measurements showed that sulphur regenerates in an amorphous rather than crystalline form during charging — a mechanistic insight relevant to designing next-generation Li-S cathodes.

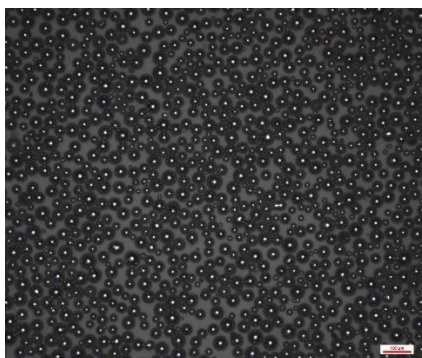
HIGHMAG

Highmag started in 1 May 2025 and comprises studies of Mg-batteries.

Anode materials:

Production of spherical Mg metal powder. **High-purity spherical Mg powder was successfully produced by ultrasonic atomization of induction-melted magnesium under an inert atmosphere.** The

molten metal was atomized into fine droplets, which subsequently solidified into highly spherical particles. The process yielded oxide-free Mg powder that could be handled and transferred under inert conditions to subsequent processing steps without surface oxidation. The resulting powder exhibited a purity above 99%, an average particle size of approximately 55 μm , and a high degree of sphericity.



Protective coatings on Mg metal powder. Using Atomic Layer Deposition (ALD), Mg metal powder was coated with ultrathin metal-oxide and Mg-containing metal-oxide films, including ZnO, Al_2O_3 , MgZnO , and MgAlO . These conformal coatings serve as protective interfacial layers, mitigating electrolyte decomposition while promoting more uniform and reversible Mg plating/stripping. Among the investigated coatings, ZnO-coated Mg powder demonstrated the best overall performance. The ZnO coating enhanced the thermal stability of the Mg powder by increasing the onset temperature of Mg combustion and significantly improved its electrochemical performance. The Mg powders (coated and uncoated) resulted to be processable under standard conditions, i.e. in air atmosphere, and electrodes could be easily produced at a lab scale. In symmetric cells, the coated Mg exhibited stable Mg plating/stripping for up to 500 h, demonstrating the effectiveness of ALD surface engineering for improving the stability and safety of Mg metal powder.

OPERA

OPERA, which started in 1 June 2023, developed **novel high-resolution operando characterization methodologies for anode-free solid-state batteries**, including Virtual-Electrode Low-Energy Electron Microscopy (VE-LEEM) and Cross-Sectional X-ray Nanodiffraction (CSnanoXRD). These techniques enable direct nanoscale observation of lithium and sodium plating/stripping, interfacial stress evolution, and dendrite growth. Together with multiscale simulations, they provide key insights into degradation mechanisms in next-generation solid-state batteries.

OPINCHARGE

The OPINCHARGE project, started in 1 June 2023, achieved several successful outcomes. Fast Raman sampling with boosted sensitivity (SHINERS) & controlled beam damage enabled extraction of interfacial composition dynamics (Solid Electrolyte Interphase, SEI) on silicon and anode-less systems (coin-cells). Alternative scan patterns were explored as damage mitigation technique for electron and ion beam microscopy observations of beam sensitive battery materials in systematic tests. Operando correlative Secondary Electron-Secondary Ion Mass Spectrometry imaging workflow was developed for investigating nanoscale Li^+ transport and related bottlenecks in solid-state batteries. Other achievements include operando NMR, operando neutron capture imaging, a method to assess LiF -SEI passivation using ferrocene (Fc) redox-probe, an operando high-throughput X Ray Reflectometry methodology to capture both fast and slow processes at the surfaces and interfaces, a locally resolved EIS method using segmented current collectors, and the development of multiscale models to capture the dynamics of SEI.

Form factor < 10% compared to battery cells w/o sensing; energy consumption of sensors < 50 Wh/kg. Integrated sensors achieved a thickness contribution below 10% of the multilayer pouch cell, using thin (0.1 mm) flexible substrates or fibers under 0.25 mm diameter, placed only at selected

locations. Dielectric and ultrasound sensors for expansion/mechanical monitoring were thicker (2–5 mm, >10%), but each can monitor multiple parallel-clamped cells simultaneously. Low-power electronic hardware with optimized microcontrollers was developed for signal acquisition and BMS transmission.

ULTRABAT

Ultrabat started in 1 September 2023 and is studying battery materials with, among other things, the FEL ultrafast technique.

In lithium lanthanum zirconium oxide ($\text{Li}_7\text{La}_3\text{Zr}_2\text{O}_{12}$), lithium motion is now seen to be strongly coupled to specific lattice vibrations rather than occurring in a static structure. THz pump–X-ray probe measurements show that driving low-frequency modes launches coherent lattice motion that persists beyond the excitation, indicating lattice memory on transport-relevant timescales. There are also indications of coupling to other modes, though these require further confirmation. Nonlinear infrared measurements reveal strong non-equilibrium behavior, including spectral transparency, saturation, and AC Stark-like shifts, showing that the lattice potential can be dynamically modified. 2D Raman measurements directly show coupling between lithium and host-lattice motions, supporting the idea that specific distortions gate ion hopping.

Ultrafast optical measurements on $\text{Li}_x\text{Mn}_2\text{O}_4$ probe battery-relevant electron injection and reveal intrinsic polaron formation and transport far faster than electrochemical timescales. The dynamics depend strongly on lithium content and are governed largely by lattice-driven Arrhenius prefactors. By combining AIMD, NEB, MLMD, and XFEL experiments, we link Jahn–Teller lattice distortions to $\text{Mn}^{3+}/\text{Mn}^{4+}$ polaron migration. The simulations quantify migration barriers and identify pseudorotational lattice motions that drive structural cooperativity and phase transformation. Together, the work shows that key lattice motions control both ionic and electronic transport, offering a route to tune battery performance through lattice dynamics.

4.3 Accelerated Material Discovery

FULL-MAP

FULL-MAP is the follow up of the earlier project BIG-MAP and started in 1 February 2025. It is one of the largest projects and there are high expectations that the project should manage all the tools developed by BIG-MAP and build the next versions to reach an Accelerated Material Discovery Platform.

Digital Architecture

The FULL-MAP project successfully transitioned from theoretical design to the initial deployment of its “Mini-MAP” prototype. By implementing a modular software architecture on the Flemish Supercomputer Centre (VSC), we established a core digital framework specifically designed to enable scalable interoperability across diverse partner tools. With this secured, integrated infrastructure can set the foundation for future autonomous, AI-driven battery materials discovery.

FULL-MAP ENDS January 31 2029, so there is more than half of the project left. More results are to come!

4.4 Manufacturability

BATCAT

BATCAT started in 1 January 2024 and the overall goal is to predict solid-electrolyte-interphase growth by developing modelling tools.

Surrogate modelling for battery formation

A cross-protocol machine-learning framework was developed to predict solid–electrolyte–interphase growth and cell temperature during lithium-ion battery formation. The approach reduces the computational effort required for evaluating formation protocols and supports faster, data-driven optimization of battery manufacturing processes.

Optimal experimental design for transport-property models

A model-based optimal experimental design method was developed for parameterizing entropy-scaling models of viscosity, thermal conductivity, and self-diffusion. The method identifies the most informative thermodynamic conditions for measurements, reducing experimental effort while maintaining accurate transport-property models.

BATTWIN

The BATTwin platform, started in 1 December 2023, enables **zero-defect battery manufacturing through a layered, digitally integrated digital-twin architecture**. It combines secure, standardized multi-source data acquisition with process- and system-level digital twins to model, analyze, and optimize production performance, quality, and energy efficiency. Goal-driven, user-centric workflows support monitoring, decision-making, and control, enabling systematic defect detection, root-cause analysis, and corrective strategies across the entire battery production line.

STELLAR

August 2026 marks Month 15 (M15) of the STELLAR project, started in 1 June 2025 indicating a key midpoint in its progression. By M12 (May 2026), two major milestones were achieved, namely “**the definition of lithium production specifications with coating and inspection methods**” and “**the first screening of lithium-metal coating candidates**” related to artificial SEI (ASEI). Building on this progress, STELLAR has completed materials specifications and testing protocols for both Li-metal anodes and ASEI candidates. In addition, machine design and safety requirements have been finalised, alongside successful laser cutting trials for the Li-metal anode on copper and the initial setup of the recycling process, both for the direct recycling approach for the production scrap and the end of life (EoL) battery. Furthermore, through Battery 2030+, the project strengthens collaboration with cross-project partners and reinforces its impact within the Solid4B Cluster. Finally, the STELLAR project is ready to collaborate further with the Battery 2030+ initiative partners in the future movement, BATT-BRIDGE.

4.5 Raw materials & Recycling

CICERO

The CICERO project which started in 1 November 2023, focused on the development of an **innovative methanesulphonic acid (MSA)-based circular hydrometallurgical route for the production of NMC cathode materials**, has demonstrated substantial progress toward its scientific and technological key performance indicators (KPIs).

Achievement lies in the bioleaching of sulphidic tailings. The targeted KPI of dissolution yields exceeding 80% within a residence time of less than 10 days has been met for selected feedstocks. Recovery of manganese and cobalt remains within the targeted performance range, confirming the partial applicability of the process.

Downstream processing via ion exchange has also yielded promising results. Metal recovery efficiencies exceeding 90% have been achieved under controlled conditions, and similarly high recoveries have been demonstrated using real bioleachates, with manganese, nickel and cobalt recoveries. The successful scale-up to 10 L demonstrates technological maturity and confirms the viability of the approach for industrial implementation.

CIRCUBATT

CIRCUBATT, started in 1 January 2025, is focused material recovery and recycling as well as environmental analysis,

Advanced Recycling Technologies Achieving High Material Recovery

The project promotes innovations in closed-loop recycling, including improved recovery of electrodes, electrolytes, and solvents, supported by sustainable chemistry methods. These are aligned with KPIs focused on reducing reliance on critical raw materials, increasing material recovery rates, and lowering environmental impact per kWh produced.

Integration of S-LCA for Comprehensive Lifecycle Sustainability Assessment

The project highlights a holistic approach to sustainability, combining environmental, economic, and social dimensions across the battery lifecycle. The inclusion of social life cycle assessment (S-LCA) and related sustainability tools enhances the project's capacity to measure social impacts along the value chain, contributing to KPIs related to responsible innovation, stakeholder well-being, and societal sustainability performance.

LI4LIFE

LI4LIFE started 1 March 2024 and has the goal to work on environmental issues and the lithium processing value chain.

Integrated, resource-efficient lithium processing value chain validated at pilot scale

The project has demonstrated a fully integrated lithium processing chain, from ore characterisation to Li_2CO_3 production, validated under pilot-scale conditions. Key unit operations, including smart sorting, mineral processing, and hydrometallurgical extraction, were successfully combined and optimised. The approach enables efficient handling of diverse European lithium ores while ensuring process robustness. This represents a significant step towards industrial deployment of a European lithium value chain.

Breakthrough reductions in environmental footprint and resource consumption

The developed process achieved substantial sustainability improvements, including ~30% reduction in energy consumption and carbon footprint, and up to 90% water reuse. These gains are enabled by early-stage waste rejection, selective comminution, and low-impact extraction technologies. The integration of green chemistry and bioleaching further reduces reliance on energy-intensive and hazardous processes. This directly supports EU objectives for sustainable and climate-neutral battery materials.

RENOVATE

RENOVATE started 1 January 2024 and targets efficient recycling processes.

To improve battery recycling efficiency and value creation Renovate has developed advanced, circular, and digitalized processes. Selective separation enables recovery of >95% of reusable components (Cu, Al foils and separators) and the production of high-purity black mass with Cu/Al impurities below 10 ppm. Overall profitability is enhanced by recovering non-CAM materials,

including >90% PVDF, >85% graphite, >80% electrolyte, and high-quality Li salts and solvents, all meeting strict electrochemical performance targets.

Two novel technologies for direct reuse of LFP materials from end-of-life batteries and manufacturing scrap are developed and validated at TRL4, achieving >95% of pristine capacity and >90% scrap reduction. Green, closed-loop chemical routes are implemented to recover >95% Ni, Co, and Mn and >90% Li from black mass using adaptable leaching systems. Side streams are fully valorised through CO₂ reuse, regeneration of leaching agents, and wastewater reuse.

Recovered materials are validated in new battery cells within a closed-loop approach. Full LCA and LCC assess environmental and economic impacts. A FAIR and SSbD-compliant data infrastructure supports digital battery passports, while real-life exploitation is enabled through predictive OPEX and CAPEX models.

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REUSE

The ReUse project, started 1 January 2024, has demonstrated two key advances in direct recycling of LFP batteries. **A sensor-based sorting system achieves >96% accuracy in differentiating LFP from non-LFP chemistries** at a throughput of 2 tones/hour of cylindrical battery cells, providing a critical foundation for targeted, chemistry-specific recycling routes.

A water-based delamination process achieves 100% cathode and >95% anode detachment efficiency across production scrap and end-of-life batteries under varying operational conditions. The recovered materials are structurally intact and largely free of metallic contamination, making them directly suitable for regeneration and reintroduction into battery production. Together, these results establish a robust and scalable foundation for efficient, high-purity direct recycling of LFP batteries.

REVITALISE

REVITALISE started 1 November 2023 and has as a goal to develop direct recycling processes for both lithium- and sodium batteries.

Pre-treatment and direct recycling

A simplified pre-treatment flowsheet combining shredding, electrostatic and magnetic separation has been developed, recovering the majority of separators and effectively separating anode from cathode. A complementary ice stripping process produces pure cathode and anode fractions from battery scrap, which are fed to relithiation/resodiation for cathode active material regeneration.

Hydrometallurgy and effluent remediation

Low-grade material unsuitable for direct recycling is treated hydrometallurgically, with dedicated flowsheets devised for NMC, LFP and Na-ion chemistries to produce salts for cathode active material reproduction. An AI-driven model predicts optimum leaching conditions and yields across chemistries and acids, while new membrane technology recovers residual Li, fluoride and phosphate from process wastewater.

STREAMS

STREAMS, started 1 January 2024, aims to strengthen the European battery materials supply chain, reduce Europe's dependency on imported raw materials supplies and increase its resilience, competitiveness and strategic autonomy in the global battery manufacturing industry.

In STREAMS, nickel, cobalt and manganese were separated and purified from leachates obtained from pyrite ash mining residues. Structural, compositional and morphological investigations showed

that the recovered sulphate salts are comparable to their commercial analogues. The precursors were used to produce new NMC 811 cathode active materials meeting the minimum recycled content thresholds for Co and Ni in new battery materials, as defined in the EU Battery regulation (EU) 2023/1542.

STREAMS developed a direct recycling process to recover cathode and anode active materials from cylindrical end-of-life cells. Regarding the anode material, successive thermal purification, re-spheroidization, and surface-coating steps were applied to recondition the material. At a C/5 rate, the purified recycled anode material achieved an average discharge capacity of 350 mAh/g, whereas the coated material achieves 345 mAh/g. Both values are in line with state-of-the-art commercial graphite.

5 ROADMAP

Introduction

The Battery 2030+ Roadmap ([4th Edition](#)) presents a long-term strategic vision for how Europe can strengthen its leadership in battery research, innovation, manufacturing, and sustainability. The roadmap identifies the scientific priorities, technological challenges, and innovation pathways required to develop the next generation of sustainable, intelligent, and competitive battery technologies. It serves as a common framework for research organizations, industry, policymakers, and funding bodies, guiding future investments and collaborative efforts across the European battery ecosystem.

A central ambition of Battery 2030+ is to transform today's fragmented battery value chain into a fully connected and circular innovation ecosystem. In this vision, materials discovery, battery design, manufacturing, operation, data management, and recycling are linked through digital technologies, artificial intelligence (AI), advanced sensing, and standardized data infrastructures. The overall objective is to accelerate innovation while simultaneously improving sustainability, competitiveness, resilience, and strategic European autonomy.

The roadmap is structured around seven interconnected research areas that together define the future direction of European battery research and innovation.

Accelerated Materials Discovery

One of the central pillars of the roadmap is Accelerated Materials Discovery. Traditional battery development remains slow and largely based on trial-and-error approaches. Battery 2030+ proposes replacing this methodology with AI-supported, data-driven and highly automated workflows capable of discovering and optimizing battery materials much faster than today.

The concept is built around Materials Acceleration Platforms (MAPs), which combine high-throughput experimentation, automation, robotics, advanced modelling, machine learning, and autonomous laboratories. These platforms are designed to create closed-loop discovery systems where experimental results continuously improve computational models and vice versa.

Battery Interface Genome (BIG)

Battery performance, safety, and lifetime are often determined by processes occurring at battery interfaces and interphases. The Battery Interface Genome (BIG) initiative seeks to establish a scientific framework for understanding, predicting, and eventually designing these interfaces through integration of advanced characterization methods, modelling, AI, and large-scale data analysis.

The roadmap highlights that many of the critical degradation mechanisms in batteries originate at interfaces between electrodes and electrolytes. By combining operando characterization techniques with multiscale simulations and machine learning, Battery 2030+ aims to move from observing interface degradation to actively designing stable and durable interfaces.

In the long term, this knowledge will enable inverse design strategies where desired battery performance determines the optimal interfacial structure and chemistry, rather than relying on conventional empirical development.

Smart Batteries: Sensing, Management and Self-Healing

Another key theme is the development of smart batteries that can monitor themselves, identify degradation, and respond autonomously. This vision combines advanced sensors, battery management systems (BMS), digital twins, and self-healing functionalities.

Future batteries are expected to contain embedded sensors capable of monitoring parameters such as temperature, pressure, strain, gas evolution, state-of-charge, and state-of-health in real time. Sensor data will be integrated into advanced BMS platforms and digital twins that predict degradation and optimize operation.

The roadmap also introduces self-healing batteries as a long-term objective. Self-healing components may repair damage such as microcracks, degradation products, loss of conductivity, or lithium loss during battery operation. Ultimately, sensing technologies and self-healing mechanisms are envisioned to operate together in closed-loop systems where degradation is detected, diagnosed, and corrected autonomously.

New Chemistries and Technologies

While lithium-ion batteries will continue to dominate in the near future, the roadmap emphasizes the importance of exploring alternative chemistries to enhance sustainability, reduce dependence on critical raw materials, and address applications not well served by current battery technologies.

Examples include sodium-ion batteries, multivalent batteries based on magnesium, calcium, zinc or aluminium, solid-state batteries, metal-sulphur systems, metal-air batteries, organic batteries, and flow batteries. The roadmap stresses that future evaluation should not focus solely on energy density but also consider sustainability, manufacturability, recyclability, safety, and strategic value for Europe.

A key recommendation is the establishment of more flexible and agile funding mechanisms that allow high-risk and potentially disruptive battery concepts to be explored efficiently.

Manufacturing and Digital Twins

The roadmap identifies manufacturing as a critical link between laboratory discoveries and industrial implementation. Europe faces challenges related to production costs, scale-up, process efficiency, and competitiveness. To address these challenges, Battery 2030+ promotes extensive digitalization of battery manufacturing.

Digital twins are highlighted as a transformative technology. These virtual representations of manufacturing processes and battery systems use real-time data to predict performance, optimize processes, improve quality control, and reduce production waste.

The ambition is to create highly flexible and data-driven manufacturing systems capable of accommodating new chemistries, advanced battery functionalities, and circular manufacturing principles. Such developments are expected to reduce development time, improve product quality, and accelerate industrialization of future battery technologies.

Recycling and Circularity

Circularity and resource efficiency are central components of the Battery 2030+ vision. The roadmap recognizes that Europe must reduce its dependence on imported critical raw materials while increasing the recovery and reuse of battery materials.

Particular emphasis is placed on direct recycling approaches that preserve and restore battery materials rather than breaking them down into their elemental constituents. The roadmap foresees highly automated recycling systems supported by battery passports, AI, digital twins, and advanced sorting technologies.

In the long term, battery recycling should be integrated into battery design, manufacturing, and operation from the outset. Concepts such as design-for-recycling, design-for-disassembly, and design-for-circularity are expected to become standard practice throughout the European battery value chain.

Data, Standards and Digital Infrastructure

Data and standardization form the backbone of the entire Battery 2030+ strategy. The roadmap highlights the need for FAIR data principles (Findable, Accessible, Interoperable, Reusable), common ontologies, standardized protocols, and interoperable digital infrastructures.

A major achievement is the development of BattINFO, a battery ontology that provides a common language and structure for battery information. Combined with emerging tools, databases, data spaces, battery passports, and digital twins, these standards will enable seamless exchange of information across projects, disciplines, institutions, and industrial sectors.

The long-term vision is a European battery data ecosystem where data generation, management, sharing, and reuse become largely automated, supporting AI-assisted discovery, industrial competitiveness, and regulatory compliance.

Overall Conclusions

The Battery 2030+ Roadmap outlines a bold and comprehensive strategy for Europe's battery future. Rather than focusing on individual technologies, it presents an integrated ecosystem where materials discovery, interface science, smart functionalities, advanced manufacturing, new chemistries, recycling, and digital infrastructures reinforce one another.

The roadmap's central message is that Europe's future competitiveness will depend not only on scientific excellence but also on its ability to connect research, industrial deployment, sustainability, and digitalization across the entire battery lifecycle. Through coordinated investments, interdisciplinary collaboration, open innovation, and common standards, Battery 2030+ seeks to establish Europe as a global leader in sustainable, intelligent, and circular battery technologies.

6 DATA HANDLING – BEST PRACTISE

The CSA 3 has facilitated battery research in Europe by promoting best-practice recommendations for experimental workflows, data handling, and interoperability. The goal is to ensure that European researchers have access to clear, widely adopted guidelines that enable efficient data sharing, reproducibility, and integration across projects. At the same time, these recommendations are designed with a global perspective, providing a foundation for collaboration and alignment to researchers also outside Europe.

Best practises, to define how to share data and common ontology is fundamental if one wants to support knowledge building. By using common protocols of data, standards and battery ontology the results are able not only to share, but also to be evaluated by others, and build upon. With input from the B 2030+ consortium WP3 created the “BATTERY 2030+ [Knowledge base for standards and protocols in battery research & development](#)”. The first version had a graphical interface to navigate the process chain and a second, interactive Battery Knowledge Base is based on Open Semantic Lab connected to BattINFO Ontology. This gives an open access overview on over 100 Key Performance Indicators (KPIs) and over 110 Process Parameters (PPs) that are involved in the battery research and development process chain. The knowledge base will be further improved in an iterative and ongoing process.

The Technical University of Denmark (DTU) and Sintef in Norway have developed a massive open online course (MOOC) as mentioned above called the [Five Star Battery Data](#). This course provides a practical guideline on how to publish standardized data decorated with complete and machine-readable metadata. More can be read in the paper DTU and Sintef are presently finalizing a paper about the MOOC.

In order to facilitate researchers to collaborate efficiently harmonized procedures and mutual accepted protocols needs to be in place. Else data sharing and data reuse will be severely hampered. There for we have developed the interactive [Battery Knowledge Base](#) for standards and protocols in battery research and development.

The focus areas for the Knowledge base are Electrochemical Testing, Synthesis and Characterization Protocols, Confirmation of Theoretical Data with Experimental Results (and vice versa) and Simulation infrastructure and interfaces.

The deliverables for data handling – best practise are listed below, with main responsible organisation named.

- D3.1 Interim report reviewing battery domain ontologies and guidelines for their use, SINTEF.
- D3.2 Interim report on guidelines and best practices for battery data management and sharing, DTU.
- D3.3 Interim report on standard protocols for theory and experiment, KIT.
- D3.4 Interim report on standard protocols for theory and experiment, EMPA.
- M8 workshop on Interim report on standard protocols for theory and experiment, SINTEF.

7 EDUCATIONAL OUTCOMES

Part of the initiative is to disseminate the research results for the education of the next generation of workers and scientists, as outlined in WP4. One example is the interactive recycling workshop held on March 6th 2025 with the afternoon dedicated to a Young Scientist's hackathon.

The Battery 2030+ Young Scientists community also organised a dedicated Young Scientists Event, bringing together young scientists from across Europe simultaneously at six interconnected universities. During the event, participants jointly developed the manifesto Batteries of the Future – A Perspective from Young Scientists in Europe. The manifesto was subsequently presented at Nano Innovation 2025 and was also highlighted by Beatrice Coda from DG RTD in her speech at the Battery 2030+ Annual Conference 2026 in Turin.

The CSA has furthermore developed a MOOC, which has been made publicly available through YouTube and provides participants with a certificate of attendance upon completion. Excellence seminars and other educational resources have also been made available online (see also previous chapter on data handling where for instance the Five Star Battery Data-course is mentioned).

The deliverables for educational matters have provided a comprehensive mapping of ongoing education and training initiatives across Europe. It revealed a highly fragmented landscape marked by limited coordination, weak visibility of existing programs, and major differences in how content is developed, delivered and recognised across countries. There are particular shortcomings in practical, hands-on training, the alignment of curricula with industrial needs, and the harmonisation of certification standards. To address this the CSA proposes the development of a harmonised yet flexible curriculum framework that can support both academic research and the industrial workforce. The recommendations are designed to enhance comparability, quality, and cross-border collaboration, offering guidance to universities, national authorities, and EU stakeholders alike.

A growing number of educational programmes across Europe are beginning to integrate data-driven methods and ontology-based frameworks to support next-generation battery research and innovation. These initiatives promote system-level thinking, predictive performance modelling, and structured approaches to handling battery-related data. Training elements often include digitalisation, diagnostics, and lifecycle analysis, preparing students to work with industrial data environments and apply advanced modelling techniques. By contributing to standardised vocabularies, metadata structures, and interoperable data practices, such programmes align with Battery 2030+ objectives to foster FAIR data principles, accelerate materials discovery, and enable smart functionalities across the battery value chain.

The deliverables for educational initiatives and efforts are listed below, with main responsible named.

- D4.1 Update on education/training needs, WUT
- D4.2 Recommendations for European Curricula, KIT
- D4.3 Next Generation Scientists event and Manifesto, POLITO
- D4.4 First courses/MOOC and curricula digitalized, DTU
- M10 Curricula updated, POLITO, (list suggested to GA)
- M11 Next Generation Scientist Manifesto
- M12 On-line courses realised, POLITO (material on the web).

8 COMMUNICATIONAL AND INNOVATION OUTCOMES

To support these efforts, a communication group was established within the initiative, comprising one or more representatives from each project. The coordinating project provided guidance and support to the individual projects in their communication activities and encouraged collaboration between the projects and the supporting organisations.

The shared objective was to build brand awareness and recognition for the initiative across Europe. Throughout the project, the communication group met at least once a month, creating a platform for sharing information about events organised by both Battery 2030+ and the individual projects. This continuous exchange increased awareness of ongoing activities and facilitated collaboration, leading to the organisation of several joint events involving multiple projects.

Communication activities focused on building awareness, knowledge, and engagement with both the Battery 2030+ initiative and its individual projects. Through these efforts, the initiative established a strong identity, strengthened its recognition, and increased its influence within the European research and innovation landscape. This was achieved by presenting research activities, objectives, and results, connecting audiences with the Battery 2030+ roadmap and long-term vision, and highlighting the key teams and individuals driving the initiative. By increasing awareness and visibility, the initiative enabled a broader audience to benefit from scientific advances and findings. These activities also created opportunities for organisations and individuals across Europe to engage in dialogue, exchange knowledge, and contribute to collaborative efforts within the European Union.

The dissemination of results and project progress was carried out by the individual projects within the Battery 2030+ initiative. Battery 2030+ CSA3, acting as the coordinating CSA, was informed of these activities through the designated communication group and project coordinators. The coordinating CSA subsequently disseminated project results and progress to a broader audience through its established communication channels and network of influential partners. This approach ensured that results and achievements were first communicated by the individual projects and subsequently amplified through the wider Battery 2030+ initiative, thereby increasing their visibility and impact. Project results were disseminated through appropriate channels and formats, including reports, guidelines, presentations, workshops, conferences, and scientific publications.

Throughout the reporting period, Battery 2030+ maintained an active presence on LinkedIn and YouTube, supported by a growing community of stakeholders from academia, industry, and the wider battery ecosystem. The number of followers and subscribers increased steadily, reflecting the growing visibility and recognition of the initiative.

In particular, Battery 2030+ established a strong presence on LinkedIn, reaching more than 15,000 followers (15,361). This audience provided an important channel for the dissemination of project results, news, events, and strategic developments, making LinkedIn one of the initiative's most effective communication platforms.

The communication reach achieved during the project included:

- LinkedIn: 15,361 followers
- YouTube: 871 subscribers
- Newsletter: approximately 2,000 subscribers

To further strengthen knowledge sharing and stakeholder engagement, Battery 2030+ organised and recorded a total of 37 Excellence Seminars featuring internationally recognised researchers and experts from across the global battery research community. These seminars provided a valuable platform for disseminating scientific advances, fostering discussion, and connecting researchers and stakeholders across disciplines and regions.

The deliverable describing the Battery 2030+ approach to IPR and innovation uptake (D1.3) is sensitive and is therefore not publicly available. As a result, it has not been appropriate to include a summary of D1.3 in this public deliverable (D6.3).

For readers who have access to restricted deliverables, D1.3 provides a description of the Battery 2030+ approach to IPR and innovation uptake.

The Innovation Uptake Session at BID 2025 serves as a practical example of these efforts, aiming to bring key project results and innovations closer to industrial stakeholders and thereby support their potential uptake and exploitation.

9 CONTINUATION OF ACHIEVEMENTS

The most significant achievement of Battery 2030+ has been its role in building and nurturing a European battery research and innovation community. The initiative has provided a platform where researchers, industry representatives, policymakers, and other stakeholders have been able to meet, exchange knowledge, and establish long-term collaborations. Through workshops, annual conferences, excellence seminars, roadmap activities, and thematic working groups, Battery 2030+ has facilitated interactions that would otherwise have been difficult to achieve across the fragmented European battery landscape.

Many of the professional relationships and networks established through Battery 2030+ have already resulted in joint research activities, collaborative project proposals, scientific publications, educational initiatives, and dissemination events. These personal and institutional connections constitute an important legacy of the initiative and will continue to generate value long after the formal conclusion of the project. The trust, mutual understanding, and shared vision developed among participants create favourable conditions for future collaborations, new funding applications, and innovative research projects.

Nevertheless, sustaining a dynamic battery ecosystem requires more than maintaining existing networks. Without continued efforts to create new connections, engage emerging actors, and stimulate cross-sector collaboration, there is a risk that the ecosystem will gradually stagnate. The rapid development of battery technologies, digitalisation, manufacturing processes, and sustainability requirements demands continuous renewal of the community and the integration of new competences, stakeholders, and perspectives.

In this context, the follow-up Coordination and Support Action, Batt-Bridge, will play a crucial role in ensuring continuity and further development of the European battery ecosystem. Building upon the foundations established by Battery 2030+, Batt-Bridge will continue several of the initiative's most successful activities. Among the most important is the establishment of the Batt-Bridge Community (BBC), which will extend and strengthen the collaborative network developed within Battery 2030+. All Battery 2030+ projects will be invited to become part of this community, ensuring that existing links are maintained while creating opportunities for new partnerships and stakeholder engagement.

In addition, Batt-Bridge will continue highly appreciated activities such as the Battery 2030+ Excellence Seminars and the Annual Conference. These activities have proven particularly effective in disseminating knowledge, fostering scientific excellence, strengthening industry engagement, and creating visibility for emerging research areas. Maintaining such meeting places is essential for preserving momentum within the European battery research and innovation landscape.

Another lasting legacy of Battery 2030+ is its contribution to education and capacity building. Across Europe, an increasing number of educational programmes are integrating data-driven methods, digital tools, FAIR data principles, battery ontologies, and other concepts promoted through the Battery 2030+ roadmap and best-practice activities. This trend reflects a broader transformation of battery education towards a more digital and interdisciplinary approach. While these developments are likely to continue independently of both Battery 2030+ and Batt-Bridge, the initiative has been an important catalyst for this evolution and has contributed to raising awareness of future skills needs within the battery sector.

The sustainability of Battery 2030+ outputs is further strengthened through open-access dissemination and long-term availability of project results. Some key documents, including scientific publications, and roadmap editions are collected and preserved in an openly accessible repository on Zenodo. This ensures that the knowledge generated by the initiative remains available to researchers, industry stakeholders, students, and policymakers beyond the lifetime of the project.

Similarly, the Battery 2030+ YouTube channel will remain accessible after the project's conclusion, serving as a long-term knowledge resource for the battery community. Recordings of excellence seminars, workshops, conference presentations, interviews, and educational activities will continue to provide valuable insights and training opportunities for both existing and future stakeholders. Together with the Zenodo repository, these digital resources ensure that the results and impact of Battery 2030+ will remain visible, accessible, and reusable for years to come.

10 CONCLUSION

In conclusion, while many of the tangible outputs of B 2030+ will remain available through open repositories and educational resources, its most enduring legacy is the strong European battery community it has helped create. The continuation of this community through Batt-Bridge, combined with the preservation of knowledge resources and the growing integration of Battery 2030+ concepts into education and research, provides a solid foundation for the future development of Europe's battery research and innovation ecosystem

The CSA is a vital part of the creation of a strong European battery research community and cross-project collaboration. Innovation and industrial outcome include improved pathways for research exploitation and stronger engagement with industry.

The B2030+ CSA3 has contributed to a scientific and technological impact including accelerated battery research through coordinated efforts and advanced tools such as AI-driven modelling and sensing technologies. Standardised protocols for experimental and theoretical research were developed, improving reproducibility and benchmarking across Europe. A flagship result is the [Battery Knowledge Base](#), a collaborative platform integrating KPIs, measurement techniques, and process chains.

Our strategic impact furthermore includes strengthening EU competitiveness by contributions to Horizon Europe and Batt4EU.

Educational outcomes include addressing skills gaps and strengthening links in a fragmented landscape within and between academia and industry.

APPENDIX A. OVERVIEW OF BATTERY 2030+ DELIVERABLES

Battery 2030+ produced a total of 26 deliverables during the project period, comprising 18 public deliverables and 8 sensitive deliverables.

A.1 Public Deliverables

No.	Deliverable	Title
1	D1.4	Collaboration Results within Battery 2030+
2	D2.2	Battery 2030+ Roadmap, 4th Edition
3	D2.5	National and International R&I Programmes and Needs
4	D3.1	Interim Report Reviewing Battery Domain Ontologies and Guidelines for Their Use
5	D3.2	Interim Report on Guidelines and Best Practices for Battery Data Management and Sharing
6	D3.3	Interim Report on Standard Protocols for Theory and Experiment
7	D3.4	Final Report on Best Practices in Battery Research
8	D4.1	Update on Education and Training Needs
9	D4.2	Recommendations for European Curricula
10	D4.3	Next Generation Scientists Event and Manifesto
11	D4.4	First Courses, MOOCs and Curricula Digitalised
12	D5.1	Communication and Dissemination Vision
13	D5.2	Communication and Dissemination Plan
14	D5.3	Communication and Dissemination Plan Update
15	D5.4	Annual Conferences and Battery Innovation Days Proceedings
16	D5.5	Annual Conferences and Battery Innovation Days Proceedings
17	D5.6	Annual Conferences and Battery Innovation Days Proceedings

18	D6.3	Summary of the Outcomes of Battery 2030+
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A.2 Sensitive Deliverables

No.	Deliverable	Title
19	D1.1	Monitoring Process Including KPIs
20	D1.2	Updated Monitoring Process Including KPIs
21	D1.3	Action Plan on Innovation Uptake, IPR Management and Industrial Exploitation
22	D2.1	National and International R&I Programmes and Needs
23	D2.3	Propositions for Future R&I Actions in Europe
24	D2.4	Propositions for Future R&I Actions in Europe
25	D6.1	Project Handbook
26	D6.2	Data Management Plan