Batteries of the Future

A Perspective from Young Scientists in Europe

B2030+ CSA

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PREMISE

BATTERY 2030+ is a Coordinated Supporting Action assisting research projects funded by the EC and creating a community by connecting Europe's leading research institutions and universities within battery R&I, with the ambition of reimagining the design of future batteries. Within this dynamic ecosystem, education, training, and the engagement of young scientists play a central role in shaping a forward-looking and inclusive research community.

Following the success of the first edition in 2022, a second **Young Scientist Event** was organized in 2025, gathering over 160 early career researchers across six universities: UPJV Amiens, Vrije Universiteit Brussel, Fraunhofer ICS Würzburg, Politecnico di Torino, Uppsala University, and Warsaw University of Technology. The event was designed to foster cooperation and creativity among young talents, encouraging them to contribute to the transformation of the European battery research landscape.

Participants, seated at mixed-expertise tables, took part in discussions around key challenges and opportunities in battery R&I, ranging from **next generation battery chemistries and technologies** and **circular economy strategies**, to **sustainable production**, **commercialization pathways**, and **regulatory frameworks**. Each table was guided by a dedicated table leader who coordinated the discussion, took notes, and helped draft the **Manifesto of Young Scientists in Europe – Redesigning the Battery of our Future**.

The Manifesto reflects the collective voice of a new generation of scientists that will lead Europe toward a more sustainable, resilient, and innovative battery ecosystem. Their ideas are fresh, bold, and grounded in a strong sense of responsibility toward society and the planet.

The outcome of this collaborative effort will be presented at the **NanoInnovation 2025 Conference in Rome** and will serve as valuable input for the European Commission and stakeholders involved in shaping future battery research roadmaps.

This second edition of the Manifesto confirms the importance of creating space for young scientists to express their vision and drive change. Their enthusiasm and dedication remind us that it is from young minds that new paradigms emerge. We hope this initiative will continue in the years to come, evolving as a recurring platform for creativity, dialogue, and strategic foresight.

We warmly thank all participants, speakers, university hosts, European Commission and supporters for their invaluable contributions. Together, we are building the batteries of the future – and the future of batteries in Europe

Silvia Bodoardo (Politecnico di Torino – Battery2030+ WP4 leader) and
Patrik Johansson Uppsala University Battery2030+ initiative coordinator

The Young Scientists Event agenda

9.00	Welcome	Silvia Bodoardo POLITO
	European Commission	Johan Blondelle European Commission
	Battery2030	Patrik Johansson/ Kristina Edstrom Uppsala
09.30	round table of hosting universities	POLITO, Uppsala, VUB, WUT, CNRS, FHG ISC
09.45	15 min presentation of participants around tables	
10.00	Novelties in battery area: next generation batteries	Mathieu Morcrette (CNRS Amiens)
10.10	Table free discussions	
11.00	Sustainable systems, recycling and second life, circular economy	Witold Uhrynowski (Warsaw)
11.10	Table free discussions	
12.00	Sustainable production processes. How to learn from mistakes	Ilka Von Dalwigk (Recharge)
12.10	Table free discussions	
13.00	LUNCH	
14.30	Industry and EU regulations	Stefan Wolf (VDI-VDE)
14.40	how to commercialize a product	Elena Bonvecchio (BEPA)
14.50	Table free discussions	
15.30	Societal impacts of electrification and bureaucracy	Stefano Corgnati (Politecnico di Torino)
15.40	Table free discussions	
16.20	Each table prepares a summary	
16.50	Table leaders combine summaries	
17.10	Each university presents the results on line	
18.10	Conclusions	Silvia Bodoardo

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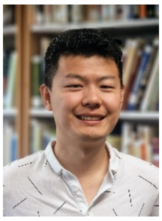

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GRAPHICAL ABSTRACT

Chapter 1: New Battery technologies

Research funding and its allocation priorities, particularly in regard to new technologies, must be addressed. While the importance of fundamental research cannot be overstated and must continue to be supported, we propose that some adjustments in funding distribution may be warranted. The focus here is on the budget for 'applied science,' particularly in the context of collaborative projects with industry.

Funding requirements

To close the gap and strengthen Europe's position in the global battery sector, we must rethink how research is conducted. A more open and collaborative approach is essential, one that values not only successful outcomes but also failed experiments. Systematically sharing all results, including negative and inconclusive data, through accessible open databases will accelerate learning, reduce redundancy, and foster faster, more efficient innovation across the European battery ecosystem. At the same time, funding should go to projects that have a real shot at working in the next 5–10 years. That means tighter teamwork between researchers, companies, and policymakers from the start. With clear goals, Europe can lead the way in battery technology, cut down on imports, create good jobs, and move towards a cleaner future.

Funding criteria

A strong instrument to steer the direction of development of technologies is the scope of funding programs for research. The following points should be considered when planning the funding of research projects in the future:

- Focus on technologies with supply chains from Europe (for example Na-Ion, Si-Anode, Mg, Sulphur...).
- Another opportunity is to focus on technologies that are still underdeveloped, where Europe can be among the first to bring technologies to scale.
- Improvements compared to state-of-the-art technology should be measurable through KPIs linked to models, enabling clear, quantifiable comparisons.
- Europe should set standards regarding recyclability, non-toxic, fluorine-free components and battery safety.
- A crucial point for funding is that programs are plannable and available over long periods. Additionally, the time between proposal submittal and the start of a project should be less than a year, to keep pace with technological developments.

Smart sensing / self-healing

The integration of intelligent functionalities into battery systems is imperative. Real-time sensing capabilities in smart batteries enable the continuous monitoring of the state of charge (SoC), state of health (SoH), and early indicators of thermal, mechanical, or chemical instability. This facilitates predictive diagnostics, adaptive performance management, and enhanced operational safety. [1] The integration of sensors at the cell level, encompassing parameters such as pressure, strain, temperature, and gas evolution, constitutes the fundamental framework of these intelligent systems. When combined with embedded electronics and machine learning, such platforms enable batteries to self-diagnose and interact dynamically with broader energy infrastructures. [2] At the same time, the incorporation of self-healing materials represents a promising strategy to enhance battery durability and extend operational lifetime. The restoration of component functionality under stress can be achieved through the utilisation of polymeric binders that repair microcracks, electrolyte additives that form regenerative interphases, and nanostructured coatings that prevent dendrite growth. [3]

AI usage in battery charging systems

Artificial Intelligence (AI) could help predict a battery's state of life quickly and efficiently. Traditional charging uses fixed parameters, but AI can adapt by analysing real-time data monitoring temperature, voltage, and current changes. Machine learning can adjust charging to reduce time and protect battery health. It can also detect issues such as overheating or overcharging. This can improve safety, extend battery life, and increase efficiency. In large systems like electric vehicles or energy storage, AI can help manage loads, forecast demand, and support renewable energy integration. [4,5] From a research standpoint, advancing the development of robust and generalisable predictive models, rigorously validated in real-world operational settings, is essential. Equally crucial is the promotion of interdisciplinary synergy among data science, electrical engineering, and energy system domains. Future research must prioritise the design of AI-driven solutions that are not only scalable and transparent, but also reliable and ethically aligned, in order to support the transition toward resilient, intelligent, and sustainable energy infrastructures.

Decentralised stationary storage

The global transition to sustainable energy requires a shift in how energy is produced, stored, and managed. Decentralised energy storage systems play a crucial role in enabling resilience and efficiency at the community level. [6] By integrating storage units behind buildings or within neighbourhoods, excess energy from smart solar systems can be stored and redistributed during low-generation or high-demand periods, reducing dependence on centralised grids and consequently unburden electrical distribution network. In smart urban developments, these storage systems can be linked to intelligent energy management platforms that optimise real-time energy flows. [7] Advancements in storage technologies (solid-state batteries, thermal storage, green hydrogen), their integration with renewable energy conversion systems and system interoperability can support this vision. An integrated approach, combining research, innovation, and community engagement, is key to creating a resilient, decentralised energy ecosystem.

Hybrid configurations of storage systems

Integrating energy storage systems, such as batteries with supercapacitors or fuel cells, offers a promising pathway to enhancing energy efficiency, flexibility, and resilience. Current research shows that hybrid configurations can combine the high energy density of batteries, the rapid response of supercapacitors, and the continuous power supply of fuel cells. However, challenges remain in system integration, including power management, interface compatibility, and long-term stability. [8] Future research should prioritise the development of smart control systems, efficient power electronics, and modular, scalable architectures. Advancing these hybrid systems requires a coordinated European effort to establish standards, ensure cross-technology interoperability, and accelerate their deployment across sectors, from electric mobility to grid-scale storage, supporting the transition to a sustainable energy future.

Battery technologies in development

The European Green Deal prioritises sustainable energy transition [9]. Innovation in battery technologies is key to electrifying transport, stabilising grids, and integrating renewables. To ensure Europe's competitiveness and sovereignty, accelerating next-generation energy storage development through a coordinated, strategic approach is essential in a globalised technological context.

Short term

In the short term, lithium-ion batteries are expected to retain market leadership, with continued progress largely enabled by advancements in material science. High-voltage cathodes like $LiNi_{0.5}Mn_{1.5}O_4$ (LNMO) increase energy density and thermal stability, while silicon-based anodes offer greater capacity despite challenges like volume expansion. [10,11] Electrolyte improvements focus on safety and thermal tolerance. Sodium-ion batteries are emerging as a compelling alternative to lithium-based systems, particularly for stationary energy storage and cost-sensitive mobility applications. Beyond their economic viability, Na-ion technologies present a fundamentally more sustainable profile: sodium is earth-abundant, widely distributed, and free from the geopolitical and ethical concerns associated with critical raw materials like lithium, cobalt, and nickel. Moreover, the overall environmental impact of Na-ion battery production is significantly lower, offering a reduced carbon footprint and fewer end-of-life management challenges. These attributes position sodium-ion batteries not merely as a substitute, but as a strategically vital solution for building a resilient, low-impact energy storage infrastructure. [12,13] Although sodium-ion batteries currently offer lower energy densities compared to lithium-ion systems, their environmental advantages and compatibility with existing Li-ion manufacturing infrastructure make them an increasingly attractive alternative. While China leads in industrial-scale sodium-ion deployment, Europe should actively invest in pilot projects and cross-sector research initiatives to bridge the innovation gap and accelerate the deployment of advanced energy solutions.

[14] Moving forward, short-term research efforts in Europe should focus on scaling up cell performance, developing standardised testing protocols, and fostering industry–academia collaboration to accelerate commercialisation. This dual-track strategy, refining lithium-ion technologies while advancing sodium-based alternatives, will be essential to ensure a resilient, sustainable, and competitive European battery ecosystem.

Medium term

In the medium term, solid-state batteries can be a transformative advancement due to their improved safety, energy density, and thermal stability. Key enabling technologies encompass gel-polymer electrolytes, which optimise the trade-off between ionic conductivity and mechanical flexibility; solid-state batteries, offering superior safety but often requiring harsh conditions, such as elevated temperatures and/or pressures, for optimal performance; and composite ceramic electrolytes, including garnet and perovskite, which deliver exceptional performance yet confront significant challenges related to interface stability and scalability. [15] Redox-flow batteries also hold strong potential for grid-scale storage, thanks to their long cycle life, modularity, and independent scaling of energy and power. [16] Future research should focus on addressing key challenges in solid-state, particularly at the electrode-electrolyte interface, and redox-flow batteries to enhance stability and scalability. [17] Investigating advanced materials for solid-state electrolytes, such as tailored ceramics or hybrid systems, could improve ionic conductivity and reduce the need for harsh operating conditions. Moreover, optimising the performance of metal-organic frameworks (MOFs) for battery applications, including as high-capacity electrodes or selective separators, could offer breakthroughs in energy storage density and safety. Additionally, exploring hybrid architectures that combine the advantages of multiple technologies may provide synergistic solutions for next-generation, scalable, and efficient energy storage systems.

Long term

Addressing the long-term challenges of energy storage and decarbonization requires a forward-looking research agenda focused on next-generation battery technologies. This means moving beyond lithium-ion systems to explore novel chemistries and abundant materials that offer scalable, sustainable, and high-performance alternatives. Early-stage research is essential to overcome current limitations and lay the foundation for future energy systems. Multivalent batteries, using metals like magnesium and potassium, offer promising pathways. Magnesium provides higher theoretical capacity and greater safety due to its dendrite-resistant nature, while potassium combines fast ionic transport with wide availability. Despite challenges in electrolyte and electrode compatibility, these systems present strong potential for low-cost, efficient storage. [18] Metal-air batteries (MABs), such as zinc-air, aluminium-air, and lithium-air, use atmospheric oxygen as a cathode, achieving ultra-high theoretical energy densities and minimal weight. Ideal for electric vehicles and aerospace applications, MABs still face barriers like oxygen flow control, cathode stability, and byproduct accumulation. [19] Lithium-sulphur (Li-S) batteries also stand out, with theoretical energy densities up to five times greater than lithium-ion cells. [20] Sulphur's abundance, low cost, and environmental benefits make Li-S both sustainable and economically attractive. However, performance issues, such as low conductivity and polysulfide dissolution, must be addressed through advanced cathode designs, optimized electrolytes, and scalable manufacturing methods. [21] To unlock the full potential of these emerging battery technologies, research efforts must be coordinated, interdisciplinary, and strategically targeted. Priority actions include the design of novel materials tailored to the unique chemistries of each system, the development of stable and efficient electrolytes, and the engineering of interfaces that enhance performance and longevity. Equally important is the advancement of scalable, cost-effective manufacturing processes that can bridge the gap between laboratory innovation and real-world deployment.

Chapter 2: Sustainability and circular economy

Batteries are a significant resource on the way to a sustainable economy. During their use-phase they enable the reduction of emissions in a wide array of industries e.g. through more sustainable mobility. The benefit in sustainability can be increased by looking at the whole battery ecosystem. A truly circular economy should be the goal by improving sustainability in every aspect of the battery life cycle as shown in Figure 1. For example, after their use-phase, lithium-ion batteries are still primarily regarded as waste to be managed rather than as valuable resources, both in public perception and at the industrial level. This mindset must shift. Every stage beyond the battery's use phase (collection, second-life applications, and finally recycling) must be properly regulated, optimised, and standardised. Increased sustainability should also be true for production and mining, and even machinery suppliers. The scarcity of raw materials within Europe makes the accelerated adoption of circular economy practices, particularly in the recycling and recovery of critical materials from lithium-ion batteries even more critical. By reintegrating these materials into the supply chain, Europe could mitigate the impact of limited domestic resources and reduce reliance on extractive operations in other parts of the world. Moreover, ensuring a steady supply of such materials within the EU would significantly strengthen the region's economic independence from global powers such as China.

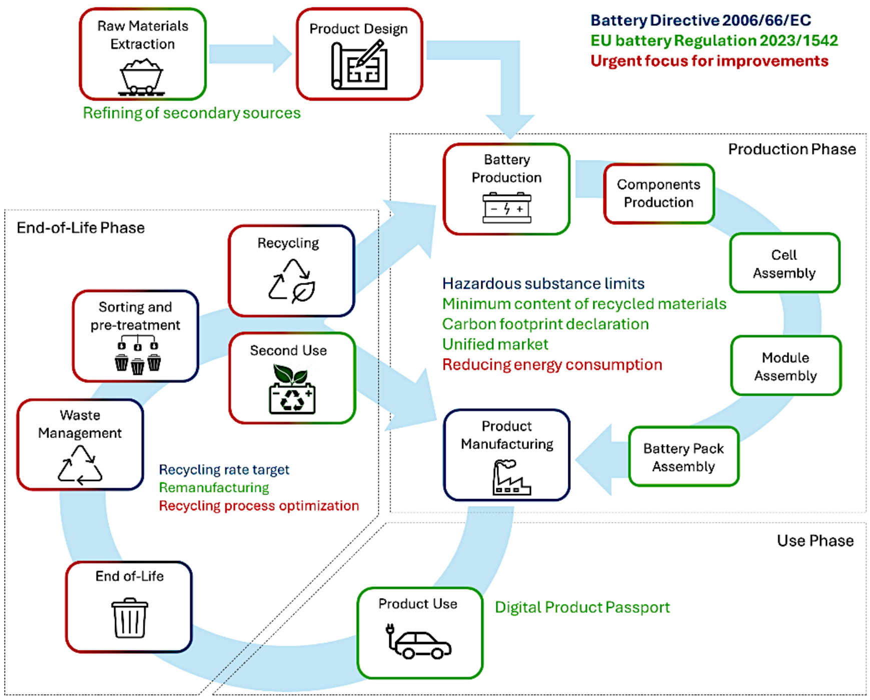

Figure 1 - Improvements and EU regulations along the battery life cycle

Sustainable mining
The mining and refining of elements needed for battery manufacturing is a part of the battery value chain that European countries have largely outsourced to other countries. For example, currently around 70% of all the Cobalt mined in the world currently comes from the Democratic Republic of the Congo (DRC) while China controls the refining of cobalt products. [22] To ensure a secure supply chain, as well as to increase the sustainability of the mined elements, mining in Europe should be expanded. While the largest mineral reserves lie outside Europe, there are relevant deposits in Europe, especially in the Balkans and Scandinavia. [23] These deposits should be evaluated, and those with potential exploited. When such relevant deposits are found, the local officials should be given the tools to work efficiently with e.g. the environmental authorities to both ensure the environmental friendliness of the mine but also to not prolong the evaluation process extensively.

Circular design
Circular design poses a systems challenge. The integration of engineering, industrial design, data science, and policy studies is a prerequisite to mitigate that challenge. The establishment of harmonised metrics, regulatory guidance, and open design principles should be an integral component of the scientific discourse. It is therefore necessary to propose a coordinated European research initiative to elevate circular design from marginal consideration to central strategy. [24] This would help ensure the safety of raw materials, reduce emissions, and facilitate a regenerative battery economy. Furthermore, an increased comprehension of the interplay between design and closed-loop recycling technologies is essential. [25] It is imperative that research is conducted to assess the impact of design variables on recovery rates, the purity of secondary materials, and the energy intensity of recycling processes. In this context, the development of digital product passports, integrated into the design process, is also of importance. These systems should be scalable, secure, and interoperable across supply chains in order to track material provenance, usage history, and recyclability. [26] Research needs to be conducted regarding the potential for data systems to inform and co-evolve with design standards, and material selection should be re-evaluated through the lens of circularity. The necessity for innovation in eco-design frameworks is evident, with the imperative for such frameworks to prioritise non-toxic, easily recoverable, and abundant materials, without compromising performance. Life cycle-based design criteria and predictive modelling tools should guide early-stage decisions.

Sustainable production
Whilst the production and implementation of batteries already contributes significantly to the reduction of carbon emissions in a wide array of industry sectors, the battery production itself still has a lot of potential for reducing its carbon footprint and increasing its sustainability. There are several aspects of production that should be considered and the focus of research activities on this topic. The carbon emissions associated with input materials should be

reduced by, as mentioned previously, mining in a more sustainable fashion as well as by increasing the share of recycled content. Whilst it is imperative that energy consumption is reduced in each process stage, particular emphasis should be placed on the coating and drying stages, which represent the process steps in battery cell production with the highest energy consumption. [27] Using less and different solvents such as water, also relevant from a toxicological perspective, utilising new drying methods and even wholly new production methods such as dry coating should be investigated. Another significant factor regarding to carbon emissions are the process atmospheres with the use of dry rooms contributing to a high energy demand. [27] As such advantageous atmospheric conditions should be researched e.g. ways to reduce the necessary dew point or the implementation of mini environments, which will also be of interest when looking at production processes for new cell chemistries. From a holistic standpoint, digitalisation is, as in other industries, of importance for increasing efficiency and for making improvements regarding e.g. traceability, resource consumption, energy efficiency and scrap reduction. Relevant research topics for realising those improvements are, amongst others, digital twins and process simulations, which may also help in considering the best production conditions to anticipate a proper following step of reuse and recycling..

Waste management

In the context of end-of-life management, collected waste volumes are low across all battery categories. This is due to a widespread lack of knowledge on proper disposal that should be faced by comprehensive communication activities and behavioural analyses. The goal is to identify easily accessible and recognisable collection points for citizens. Alongside this, mapping campaigns should be conducted to monitor and gather data on collected waste batteries (e.g., category, chemistry, safety condition, and collection channel). This would help develop an efficient and safe collection system that considers the updated collection targets and new battery categories of Regulation 2023/1542.

Reuse and refurbishment

A fundamental principle of this regulation is the recognition of the *second life* potential of industrial and electric vehicle (EV) batteries, thereby establishing them as pivotal assets for the promotion of a sustainable circular economy. [28] Research must lead the transition toward systematic reuse and large-scale refurbishment of batteries, establishing these practices as core enablers of a circular energy economy. Priority should be given to developing intelligent diagnostic tools—integrating AI, embedded sensors, and real-time data—to assess battery health and guide second-life decisions. Modular design and design-for-disassembly approaches must be advanced to facilitate repair, reconfiguration, and end-of-life handling. The scientific community is also called to define robust protocols and standards ensuring safety, quality, and traceability across reuse pathways. Crucially, interdisciplinary studies on environmental, economic, and social impacts must inform scalable and evidence-based policy frameworks. Reuse and refurbishment are not just technical challenges; they mark the beginning of a new scientific frontier in sustainable value creation.

Considering the automotive industry, the role of car manufacturers should evolve to include the reuse value chain. Indeed, car makers should directly manage their end-of-life batteries to assess their state and suitability for second life. In aid of this brand-specific waste collection should be implemented. Currently, Producer Responsibility Organizations (PROs) manage all types of waste batteries on behalf of car manufacturers, sending them directly to treatment. Sorting is not feasible because of the lack of information, and testing is not necessary since waste is sent directly to recycling. In the future, PROs should collaborate closer with producers, managing only those batteries that have been tested at the car manufacturer facility and declared unsuitable for second life.

Recycling

Alongside refurbishment, recycling aims to improve material retention, responding to the increasing demand for raw materials, and by doing so alleviate the environmental impact of the battery industry. Although there is significant economic potential in the recycling market, the rapidly growing battery industry, as well as different next generation chemistries pose important challenges that need to be tackled. Especially the recycling of different chemistries and whether they should be processed separately or together will have to be discussed. Similarly solid-state electrolytes are expected to significantly affect recycling practices compared with traditional liquid electrolytes due to different decomposition products and differing separation behaviour. Several recycling techniques such as pyrometallurgy, hydrometallurgy, biometallurgy, solvometallurgy and direct recycling are described in literature. [29,30] These recycling processes and their value chains must be well understood in order to increase their economic feasibility and concurrently boost their implementation. However, life cycle assessments and process comparisons often achieve differing results depending on the considered constraints. Therefore, a more holistic approach should be taken into account when evaluating different processes in the future. Nevertheless, continuing research on better and more efficient recycling techniques remains fundamental to increase profitability and sustainability.

Finally, battery design, component selection, and electrode material modifications affect recycling considerably. [31] As mentioned previously, end-of-life processes should therefore be anticipated during the design phase. This approach is pivotal for next generation batteries, establishing circular and sustainable business models while scaling the European battery market.

Chapter 3: Industry and EU perspective

To realize the ambitious goals of Battery 2030+, we must go beyond materials and technologies. A successful transition to next-generation battery systems depends equally on how we educate future experts, shape regulatory frameworks, and align with the broader European vision. This section outlines the foundational role of education in building interdisciplinary capacity, the need for forward-thinking regulation that enables innovation while protecting society, and the importance of integrating with EU strategies for research, sustainability, and competitiveness.

Bridging the Gap Between Research and Industry

Industrial realities must be considered when shaping the future of battery technologies. Even well-known initiatives in Europe, such as Northvolt, have faced a critical 'valley of death' during industrial scale-up, experiencing significant production challenges. From an academic standpoint, we aim to contribute by addressing upstream issues that can accelerate the deployment of both current and emerging battery technologies. Our focus is not on solving large-scale industrial problems directly, but on identifying early-stage actions that can ease the transition from research to production.

Building a battery pack involves far more than understanding individual cells. Cell format, pack architecture, integration methods, battery management, and thermal regulation all influence system performance, and each comes with its own manufacturing constraints. A better understanding of these constraints and the processes involved can help avoid inefficient iterations between research and industrial readiness. This underlines the importance of strengthening the connection between academia and industry.

There are several possibilities to build common knowledge between academia and industry, each with different levels of investment:

- At a foundational level, supporting initiatives such as congresses, summer schools, and roundtables can promote dialogue, exchange of ideas, and informal collaboration.
- On a larger scale, the creation of industrial research centres and shared pilot facilities can significantly enhance progress across successive Technology Readiness Levels (TRLs). These centres would reduce costs through shared infrastructure and enable collaborative work on key challenges, including battery production, recycling, digitalization, and standardization. Such facilities could also serve as hubs for consulting, joint research, and educational activities. However, when public institutions engage in partnerships with industry, it is essential to ensure fair returns, such as intellectual property rights and performance guarantees, to protect public investment and maintain trust.

A strong example of bridging the gap between research and industrial production is the Fraunhofer Research Institution for Battery Cell Production (FFB) in Münster. Its mission is to transfer new battery concepts and production technologies from mid-level maturity (TRL 5–6) to full industrial scale (TRL 8–9). Similar initiatives across Europe could play a critical role in accelerating battery innovation and strengthening the entire battery ecosystem.

Education

A robust and forward-looking education system is essential to the long-term success of the European battery industry. Education should be seen not only as a pipeline for skilled talent, from technical training to advanced research, but also as a foundation for innovation, mobility, and global competitiveness. Strengthening collaboration between universities, research institutions, and industry is critical across all sectors. In this context, exchange and mobility programs are particularly valuable, as they support skills development, knowledge transfer, and a closer alignment between education and the needs of the market.

One of the main obstacles to educational mobility in the European Union is the fragmented and repetitive visa process faced by international students in joint academic programs. The EU hosts a wide range of joint master's degrees, especially through initiatives like Erasmus Mundus, which attract students from around the world. These programs often require study in multiple countries, such as beginning in France, continuing in Poland or Germany, and completing a thesis in another location. Each transition, however, typically involves a new visa and residence permit application. This administrative burden causes stress, increases costs, and disrupts academic continuity. It stands in contradiction to the EU's goal of offering a seamless, integrated academic experience.

To address this challenge, we propose the creation of a specialised, EU-wide Academic Mobility Visa. This unified permit would allow international students enrolled in multi-country degree programs to travel, reside, and study across EU member states without the need to reapply for separate visas or residence permits each semester. The visa would be linked to an academic itinerary validated by participating institutions and would include appropriate checks and reporting procedures to ensure accountability. While implementing such a system would be complex, it is achievable and would demonstrate the European Union's commitment to accessible, integrated education and long-term talent development. By reducing administrative barriers and simplifying student mobility, this initiative would enhance the appeal of EU academic programs on the global stage.

It is evident that the battery sector faces a significant skills gap across all levels, not only among PhDs and engineers but also among technicians, operators, and managers. The complexity of gigafactory operations requires continuous and specialised training throughout a worker's career. To address this, targeted educational programs should be developed, including industry-integrated PhDs, certified MOOCs, and structured training through European or International Battery Schools. These initiatives would help harmonise knowledge across the sector and strengthen collaboration between academia and industry. In this context, an EU-wide Academic Mobility Visa would be a key enabler. By simplifying access to cross-border programs and internships, it would support the development of a skilled and mobile workforce for Europe's battery ecosystem.

Start-up support

To further reduce barriers to entrepreneurship, we propose a regulatory reform that allows EU PhD students to initiate and participate in startups during their studies. In many EU countries, e.g. France, students enrolled in EU-funded doctoral programs face restrictive rules that prevent them from engaging in entrepreneurial activities. Even when a student develops a commercially viable or socially impactful solution, current frameworks often prevent them from launching a startup while still enrolled. PhD students are a critical source of innovation, and limiting their ability to act on market-ready ideas hinders technological progress, economic growth, and individual potential.

We recommend the inclusion of a "Research-to-Market" clause in PhD contracts, with the following conditions:

- Startup activity must be directly related to the student's research topic.
- Oversight from the host institution must ensure continued academic performance.
- While full-time employment or board directorships should remain restricted, students should be permitted to hold equity and limited executive roles.
- Eligibility would depend on academic progress and institutional approval.

This approach would support the EU's broader objectives of promoting innovation, entrepreneurship, and knowledge transfer. It would also enable Europe to better convert its research excellence into economic impact, without forcing young innovators to choose between academic commitment and entrepreneurial ambition.

Accessibility of the Regulatory Framework

The European battery industry is expanding rapidly in pursuit of climate neutrality and strategic autonomy. This transformation is shaped by a complex and evolving set of regulations, such as the Battery Regulation (2023/1542), which govern all stages from material sourcing to recycling. These frameworks are essential for building a sustainable future, yet they remain difficult to navigate. Both industry and academia face fragmented and often inconsistent standards that make it challenging to access basic compliance information. Despite their critical role in determining whether innovations can reach the market, regulatory topics are rarely addressed in scientific education. Most researchers are not trained to interpret legal texts or assess how regulations apply to their work. This disconnect creates uncertainty, slows innovation, and adds unnecessary barriers for academic spin-offs and startups.

To address this gap, we call for better integration of regulatory content into scientific training, clearer and more accessible guidance for researchers, and active involvement of young professionals in policy development. We also propose the development of a pan-European, digital regulatory platform. This platform would serve as a single, user-friendly interface through which innovators, research labs, and small and medium-sized enterprises can access and engage with sector-specific regulations. It would consolidate existing rules, provide real-time updates, and use digital tools such as artificial intelligence and data analytics to offer performance benchmarking and feedback. By embedding sustainability and compliance considerations into early-stage research, and offering tailored regulatory pathways, the platform would support both innovation and accountability. By moving in this direction, the European Union can lead a digital transformation of regulation that strengthens the connection between governance and innovation. This approach would set a global benchmark, positioning Europe as a leader not only in battery technology but also in regulatory excellence.

Communication

Effective communication between researchers, industry experts, policymakers, and decision-makers is essential to strengthen collaboration and ensure that research translates into real-world applications. Academic work should align more closely with industry needs, while industry stakeholders should share insights and results more openly. Publishing industrial findings in peer-reviewed journals would accelerate scientific progress and improve transparency. Additionally, patent documents should be written in clear, accessible language and include inventor contact details to facilitate engagement from researchers and editors.

Academic training must also evolve. Core industry-relevant skills such as quality assurance, project management, and leadership are often absent from current curricula. Addressing this gap would better prepare graduates to tackle real-world challenges. Successful industry-academic partnerships depend on shared goals, open communication, and tangible mutual benefits. Promoting student involvement in industry-led projects and nurturing a collaborative innovation ecosystem are key to advancing practical and impactful research across Europe.

While these communication and training reforms are essential, they address only part of the challenge. A broader question remains: how can we better leverage education, digital platforms, and regulatory frameworks to make these efforts more coherent, scalable, and effective? A truly integrated approach is needed, one that connects knowledge development, policy design, and technological advancement to support a resilient and future-oriented European battery ecosystem.

With this, we believe the perspectives and solutions outlined in this document can contribute meaningfully to building a more sustainable and forward-looking foundation for energy storage in Europe. By aligning education, regulation, innovation, and collaboration, the European battery ecosystem can evolve into a global benchmark for responsible and high-impact technological development.

CONCLUSIONS

Batteries are a fundamental component for the electrification of a diverse range of industry sectors such as electricity production, consumer products and mobility, and consequently play a key role in the reduction of carbon emissions. As young scientists, we are fully invested in the future of batteries, and we are enthusiastic to contribute to the transition toward a more sustainable society. Such a society would not only overcome climate change, but also sovereignty and supply risks and stay within planetary boundaries. This transition presents many technological, industrial, supply, and societal challenges.

Currently, several technologies exist that can contribute to reducing greenhouse gas emissions. Lithium-ion batteries are commercially available, and sodium-ion and solid-state batteries are nearing commercialisation. In light of Northvolt's failure it seems that the deployment of European gigafactories is limited not by technological readiness, but by industrial bottlenecks. For this reason, we advocate for investments that bridge the gap between industrial and academic research. These investments could be financial, e.g. for the construction of pilot factories, or educational for a better qualification of the workforce at all levels of a company, from technicians to researchers, including operators, engineers and project management staffs. Europe needs to develop a culture around batteries.

In addition, Europe needs to invest in the resource efficiency and circularity of its battery market. The scarcity of raw materials within Europe makes the development of circular economy practices vital, especially those related to the recycling and recovery of critical materials from lithium-ion batteries. If Europe wants to mitigate the impact of limited domestic resources and reduce reliance on extractive operations in other parts of the world, it does not have any other choice. Even if recycling, reuse and circular design are currently not always economically attractive, there is potential for worldwide leadership in end-of-life practices for batteries. Most importantly however they will contribute to European technological sovereignty and the preservation of limited planetary resources. At the same time improvements need to be made regarding the resource efficiency of battery manufacturing and the utilisation of mineral resources within the EU. New chemistries such as sodium-ion batteries can aid in reaching a more diverse and European resource supply chain.

Lastly, considering the long-term future of batteries is crucial. It is important to continue investing in the development of the entire value chain, both at a fundamental and a manufacturing level. Depending on the application, we can imagine a world with various battery technologies that address specific needs, ranging from electronic devices to soft mobilities, electric vehicles, electricity storage and even aeronautical applications. However, it's important to note that while battery-powered technologies help mitigate greenhouse gas emissions when powered by green electricity, they also introduce new challenges related to resource sovereignty, supply chain risks, and planetary boundaries. Indeed, even with technological breakthroughs, the large-scale transition toward widespread battery use, across electric vehicles, energy storage systems, and other applications, is likely to put significant strain on planetary limits. The proposed strategies encompass the adoption of sustainable alternatives, the deployment of technologies characterized by enhanced efficiency and reduced environmental impact, and a critical reassessment of consumption and usage patterns to foster responsible resource management. These solutions, already viable from both technological and social perspectives, must be implemented alongside a systemic transition from internal combustion engines to electric propulsion to achieve meaningful emission reductions. Only through an integrated and multidisciplinary approach can we ensure the advancement of sustainable development and the preservation of planetary health for future generations.

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