European
Commission

JRC EXTERNAL STUDY REPORT

Analysis of novel EV battery technologies, with a focus on tech transfer and commercialisation

Findings from a qualitative interview-based study

Author: Vilkman, M.
Editor: Battiston, A.

2024

*Joint
Research
Centre*

This publication is an External Study report prepared for the Joint Research Centre (JRC), the European Commission's science and knowledge service. It aims to provide evidence-based scientific support to the European policymaking process. The contents of this publication do not necessarily reflect the position or opinion of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use that might be made of this publication. For information on the methodology and quality underlying the data used in this publication for which the source is neither Eurostat nor other Commission services, users should contact the referenced source. The designations employed and the presentation of material on the maps do not imply the expression of any opinion whatsoever on the part of the European Union concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Contact information
Competence Centre on Technology Transfer
European Commission, Joint Research Centre, Brussels Belgium
Email: EC-CC-TT@ec.europa.eu

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC139632

PDF 978-92-68-21338-4 doi:10.2760/1188315 KJ-01-24-102-EN-N

Luxembourg: Publications Office of the European Union, 2024

© European Union, 2024

The reuse policy of the European Commission documents is implemented by the Commission Decision 2011/833/EU of 12 December 2011 on the reuse of Commission documents (OJ L 330, 14.12.2011, p. 39). Unless otherwise noted, the reuse of this document is authorised under the Creative Commons Attribution 4.0 International (CC BY 4.0) licence (https://creativecommons.org/licenses/by/4.0/). This means that reuse is allowed provided appropriate credit is given and any changes are indicated.

For any use or reproduction of photos or other material that is not owned by the European Union permission must be sought directly from the copyright holders. The European Union does not own the copyright in relation to the following elements:

- Cover page illustration, © AdobeStock/deepagopi2011
- page 9, figure 2, source: BATT4EU, Strategic Research and Innovation Agenda, 2024; original source: EBA250, 2021.
- page 14, figure 3, source: Gerrit Bockey & Heiner Heimes, PEM RWTH Aachen University, 2023. Available at Battery News.
- page 18, figure 4, source: BATT4EU, Strategic Research and Innovation Agenda, 2024; original source: EBA250, 2024.

How to cite this report: European Commission, Joint Research Centre, Vilkman, M., *Analysis of novel EV battery technologies, with a focus on tech transfer and commercialisation*, Battiston, A. editor(s), Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/1188315, JRC139632.

Analysis of novel EV battery technologies, with a focus on tech transfer and commercialisation

Findings from a qualitative interview-based study

This report has been produced by an independent expert under the coordination and the direction of the Joint Research Centre (JRC).

Author

*Marja **Vilkman**, Independent Expert – Principal scientist, VTT Finland*

Coordination and editing

*Anna **Battiston** – Policy and project officer, JRC*

TABLE OF CONTENTS

ABSTRACT 1

ACKNOWLEDGEMENTS 2

EXECUTIVE SUMMARY 3

1 INTRODUCTION 4

2 METHODOLOGY 7

3 EV BATTERY TECHNOLOGY LANDSCAPE: CURRENT STATE AND FUTURE TRENDS 9

- 3.1 Current EV batteries 9
  - *3.1.1 Battery chemistries 9*
  - *3.1.2 Battery manufacturing 9*
  - *3.1.3 Battery producers 10*
- 3.2 Next-generation batteries, approaching market maturity 11
  - *3.2.1 Next-generation battery chemistries 11*
  - *3.2.2 Manufacturing of next-generation batteries 13*
  - *3.2.3 Producers of next-generation batteries 14*
- 3.3 Targeted properties for EV batteries 15
- 3.4 Manufacturing aspects 18
- 3.5 Recycling aspects 20

4 FROM LAB TO MARKET: CHALLENGES IN EV BATTERY TECHNOLOGY TRANSFER, COMMERCIALISATION, AND DIFFUSION 23

4.1 Pilot lines 23
4.2 Trained workforce and skills 25
4.3 Technical barriers and opportunities 26
4.4 Funding, financing, and regulatory aspects 27
4.5 Collaboration amongst relevant stakeholders in the value chain 29
4.6 Support throughout the value chain 31
4.7 Additional observations 32

5 CONCLUSIONS AND RECOMMENDATIONS 34

5.1 Battery chemistries for EVs 34
5.2 Main barriers and proposed recommendations 34
  5.2.1 Technical barriers 34
  5.2.2 Collaboration in RD&I 34
  5.2.3 Funding and financing 35
  5.2.4 Need for pilot lines 35
  5.2.5 Regulatory framework 35
  5.2.6 Citizen acceptance 36

REFERENCES 38

LIST OF ABBREVIATIONS AND DEFINITIONS 44

ABSTRACT

This report summarises the recent advancements in battery technologies for mobility applications, focusing on electric vehicles, and looks at the main barriers encountered in their journey from lab to market. Both Li-ion batteries and next-generation batteries are discussed.

The report includes information about identified barriers for scaling-up the battery manufacturing industry in Europe and proposes solutions to overcome them. It identifies technical challenges, such as manufacturing of Li-ion and next-generation batteries at industrial scale, while maintaining high yield and quality without excessive cost.

It also reveals that scaling up is hindered by financial issues and lack of funding, especially given how expensive and risky setting up raw material, recycling or cell manufacturing factories is. The findings also highlight how unpredictable permitting can be a significant barrier, as well as the limited citizen acceptance of either new factories or electric vehicles in general.

As solutions, we propose setting up pilot facilities to validate new processes and materials, increased financial support and an improved financial framework to create a level playing field when compared to USA and Asia, and clear rules for permitting. Also, activities to train workforce for the factories is needed, as well as sharing clear and reliable information about batteries for citizens and policymakers.

The findings are based on interviews with a sample of 17 research centres, companies and umbrella organisations in Europe along the battery value chain, as well as literature information and the author’s participation in European projects, events, and networks. Relevant policies, such as the Net-Zero Industry Act, the Critical Raw Materials Act and the Batteries Regulation, are taken into consideration in the analysis.

ACKNOWLEDGEMENTS

This project would not have been possible without the valuable contributions of all the stakeholders who agreed to participate in the interviews or who provided information or feedback. A big thank you goes also to all the colleagues across the European Commission who in any way supported this work from its inception to its finalisation, such as by participating in the validation of the preliminary findings, contributing to the report revision, or more generally offering comments and input, in particular: BIELEWSKI Marek (JRC), BLONDELLE Johan (RTD), BOBBA Silvia (JRC), DE GRANDIS Carlo (CLIMA), GARCIA GALAN Ines Pina (GROW), GEORGAKAKI Aliki (JRC), HERMELINK Cornelius (JRC), LATUNUSSA Cynthia (JRC), LOPEZ CALVO Patricia (GROW), MATHIEUX Fabrice (JRC).

EXECUTIVE SUMMARY

This report summarises the recent advancements in battery technologies for mobility applications, focusing on electric vehicles. Both Li-ion batteries and next-generation batteries are discussed. It also identifies the main barriers in their lab to market journey, including for scaling up the European battery manufacturing industry and achieving EV market adoption in the EU, and proposes solutions to overcome them.

The findings are based on interviews conducted with a total of 17 organizations and companies in Europe operating along the battery value chain, as well as on literature information and the author's experience gained through European projects, events, and networks. The report accounts for relevant EU policy developments, such as the Net-Zero Industry Act, the Critical Raw Materials Act and the provisions introduced by the Batteries Regulation.

The report indicates that lithium-ion (Li-ion) is anticipated to remain the predominant battery chemistry employed in mobility applications in the near future. Some improvements are nevertheless foreseen, such as increased energy density, lower cost, and higher sustainability. The findings show a clear consensus across sampled organisations on the most relevant Li-ion battery chemistries and the directions for next-generation batteries. For Li-ion batteries, lithium nickel manganese cobalt oxide (NMC) and lithium iron phosphate (LFP) chemistries are the preeminent ones, while lithium manganese iron phosphate (LMFP) chemistries are clearly emerging to the field as well. Both solid-state batteries (SSBs) and Na-ion batteries were identified as the most promising options for future chemistries, targeting high energy density and sustainable and locally available low-cost materials, respectively.

The report identifies technical challenges, such as manufacturing of Li-ion and next-generation batteries at industrial scale, while maintaining high yield and quality at a competitive cost. Li-ion battery manufacturing presents challenges in reaching gigafactory scale, with cheaper and high-quality batteries being imported from China. The main challenge is to reduce the scrap rate while achieving high-speed production at low cost. This requires automation and state of the art quality control tools. For next-generation batteries, especially all-solid-state, battery production needs considerable efforts to be scaled up. For polymer or gel electrolyte batteries, scalability is less of a challenge and some companies are already delivering such batteries to mobility applications. Na-ion battery production is acknowledged to be more like a “drop in” technology and allows for the use of the same equipment and processes employed for Li-ion batteries.

The report identifies as another clear barrier for scaling up financial issues and lack of funding. Setting up raw material, recycling or cell manufacturing factories is expensive and risky. Unpredictable permitting also emerged as a clear obstacle, and the need to clarify and simplify the routes to apply for funding was also expressed. A “one stop shop” providing information and advice on available funding opportunities for SMEs, larger companies and research organizations was advocated for. Limited citizen acceptance of new factories or EVs in general was also considered to be a barrier.

As a solution to enable the development from laboratory scale to industrial level, we propose setting up pilot lines and plants to validate new processes and materials. Both open access infrastructures hosted by research institutes, where companies can validate their materials, processes, or inspection tools, and company-owned pilot facilities for development activities closer to industrialisation are considered essential. Increased financial support and an enabling financial framework are also key to create a level playing field when compared to USA and Asia, as well as clear rules for permitting. Additionally, activities to train workforce for the factories is needed, with pilot lines playing a significant role also in this respect. Finally, sharing clear and reliable information about batteries with citizens and policymakers will help gain their approval and support towards the new technologies and the measures required for their rollout.

1 INTRODUCTION

Batteries have long been recognised as an enabling technology of strategic relevance in EU policy.[1]

In particular, with regard to EV applications and considering the most recent policy and regulatory context, the **strategic importance of a well-functioning European battery value chain** is threefold.

Firstly, the decarbonisation of road transport has been identified as one of the key means to achieve **climate neutrality**, as almost one fourth of total EU greenhouse gas (GHG) emissions come from transport, of which more than 70% produced by road vehicles.[2] Widespread adoption of electric vehicles is one of the avenues to deliver on such objective, which was set out in the European Green Deal, enshrined in the European Climate Law, and pursued through the adoption of the Fit for 55 legislative package[3].

> In particular, the amendment to the CO2 Emissions Standards Regulation[4] provides for new cars and vans registered in Europe to be zero-emission by 2035, while the mandatory targets set by the Regulation for the deployment of alternative fuels infrastructure (AFIR)[5], including recharging stations for EVs, should enable their take up.
>
> Ensuring that electrification of power trains constitutes a truly sustainable alternative to internal combustion engines (ICE) in a lifecycle perspective, the 2023 Batteries Regulation has set, amongst others, targets in terms of material recovery and recycled content. It also establishes requirements for increased transparency, including the obligation for manufacturers to adopt a carbon footprint declaration by 2025 for each EV battery put on the market, to be embedded in a QR code together with the other mandatory battery passport information starting from 2027.[6]

Secondly, the shift from internal combustion engine to electric mobility represents a challenge for the **competitiveness of the European automotive sector**, traditionally a stronghold of EU economy. EU automotive firms boast a turnover equal to 7% of the GDP[7], employ almost 13 million people (considering both direct and indirect jobs)[8], and constitute the largest EU sector in terms of corporate R&D investments[9][10].

EU performance in battery innovation, production, and recycling is closely related to the ability of European car manufacturers to have sufficient technology leadership and remain competitive in the global EV market, and thus to keep contributing to European prosperity.[11]

---

[1] While already in 2007, the first Strategic Energy and Technology (SET) Plan identified advancements in energy storage technologies as a priority, a turning point in EU battery policy was the launch of the European Battery Alliance in 2017 and the adoption of the Strategic Action Plan on batteries in 2018. The latest revision of the SET Plan dates back to 2023. European Commission (2018). *Europe on the move. Sustainable Mobility for Europe: safe, connected and clean.* COM(2018) 293 final. European Commission (2023). Communication on the revision of the Strategic Energy Technology (SET) Plan. COM(2023) 634 final.

[2] 76% in 2021. EEA (2023, October 24). *Greenhouse gas emissions from transport in Europe.* Retrieved Augst 20, 2024, from: https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-transport?activeAccordion=309c5ef9-de09-4759-bc02-802370dfa366.

[3] European Commission. *Fit for 55: Delivering on the proposals.* Retrieved August 20, 2024, from: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal/fit-55-delivering-proposals_en.

[4] Regulation (EU) 2023/851 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2019/631 as regards strengthening the CO2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition. http://data.europa.eu/eli/reg/2023/851/oj.

[5] Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU. http://data.europa.eu/eli/reg/2023/1804/oj.

[6] Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC. http://data.europa.eu/eli/reg/2023/1542/oj.

[7] ACEA (2023, June 1). *Facts about the automobile industry.* Retrieved August 20, 2024, from: https://www.acea.auto/fact/facts-about-the-automobile-industry/#:~:text=The%20turnover%20generated%20by%20the%20automotive%20sector%20represents,chain%20and%20generating%20an%20array%20of%20business%20services.

[8] Automotive sector: direct and indirect employment in the EU - ACEA - European Automobile Manufacturers' Association

[9] European Commission. Joint Research Centre, Nindl, E., Confraria, H., Rentocchini, F. et al. (2023). The 2023 EU industrial R&D investment scoreboard. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/506189.

[10] For an overview on the Automotive sector, cfr. ACEA (2023, September 28). *The Automobile Industry Pocket Guide 2023/2024.* Retrieved Augst 20, 2024, from: https://www.acea.auto/publication/the-automobile-industry-pocket-guide-2023-2024/.

[11] On the need for the EU automotive domestic supply chains to adapt and innovate to maintain global competitiveness, see *inter alia* European Commission. Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Connell Garcia, W., Garrone, M. (2024). *Reshaping the road ahead – Exploring supply chain transformations in the EU automobile industry.* Publications Office of the European Union. https://data.europa.eu/doi/10.2873/523479.

Thirdly, in times of geopolitical volatility, a strong battery value chain and manufacturing industry in Europe will increase the **resilience and security of supply** within EU and associated countries, reducing vulnerabilities of EU firms from global supply chain disruptions and technology dependencies, most notably related to (raw and processed) materials as well as EV battery components imported from Asia.[12]

> Specifically addressing these bottlenecks and aiming at increasing the EU's strategic autonomy, the Green Deal Industrial Plan[13] set off the process that brought to the adoption of the Critical Raw Materials Act[14] – setting objectives for EU extraction, processing, and recycling of strategic materials and diversification of supply from third countries, while supporting the development of EU capacities in this sector through accelerated permitting.
>
> Similarly, the Net Zero Industry Act[15] is expected to boost EU domestic production of strategic net-zero technologies, including batteries, by setting manufacturing capacity benchmarks, encouraging innovation through regulatory sandboxes and procurement, supporting the launch of net-zero academies to enhance skills, and, once again, fast tracking permitting processes for manufacturing projects.

These three pillars – green transition, strategic autonomy, and competitiveness of EU industry – need **solid research, development and innovation (R&D&I) foundations** in order to be able to stand.

Incremental and disruptive R&I across the battery value chain, in a market-oriented perspective and with **strong technology transfer and commercialisation pipelines** is thus key, and, under the broader strategic framework of the SET Plan, has been pursued through an increasing number of initiatives since the launch of the European Battery Alliance in 2017 and the adoption of the Strategic Action Plan on batteries in 2018.

In part thanks to increasingly closer cooperation, these initiatives led to the creation of a rich and overall well-functioning ecosystem, which, while still having to face considerable challenges, does not present the typical lack of coordination between academia and industry afflicting other sectors, as pointed out in a previous JRC case study on technology transfer and batteries.[16]

The present report aims at summarising the status and anticipated future directions of battery technologies and chemistries, which are currently (or expected to be) used in mobility applications. The main focus is on electric vehicle (EV) batteries, but other mobility applications are included when relevant. The goal is also to identify potential technical or other barriers in the lab to market journey, including for market adoption of EVs and battery production, in Europe, and to provide recommendations on how to overcome these barriers.

The battery and EV manufacturing value chain is broad, and many factors can influence the success in building a strong battery industry in Europe. In this report, the focus is on aspects at the battery cell level. Other aspects are considered at a general level only. The above mentioned JRC case study focused mostly on research conducted at universities and public research institutes and adopted an application-agnostic approach.

With the aim to complement these findings, the present work is slightly shifting the focus towards research and innovation at higher technology readiness level (TRL), while diving deep into the application of battery technologies to EVs. In fact, much of the R&I in the battery sector is done by industry, especially with regard to battery applications and optimisation of manufacturing and

---

[12] In particular, the whole downstream EV battery supply chain (i.e., material processing, cell components, battery cells) is concentrated in China, which is also by large the greatest global producer of non-processed graphite. Upstream, the other strategic raw material source of concern is Cobalt, mostly produced in the Democratic Republic of Congo. IEA (2022). *Global Supply Chains of EV Batteries.* IEA, Paris. Retrieved August 20, 2024, from: https://www.iea.org/reports/global-supply-chains-of-ev-batteries and European Commission. Joint Research Centre, Carrara, S., Bobba, S., Blagoeva, D. et al. (2023). *Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study*. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/386650.

[13] European Commission (2023). *A Green Deal Industrial Plan for the Net-Zero Age.* COM(2023) 62 final.

[14] Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020. http://data.europa.eu/eli/reg/2024/1252/oj.

[15] Regulation (EU) 2024/1735 of the European Parliament and of the Council of 13 June 2024 on establishing a framework of measures for strengthening Europe's net-zero technology manufacturing ecosystem and amending Regulation (EU) 2018/1724. http://data.europa.eu/eli/reg/2024/1735/oj.

[16] European Commission. Joint Research Centre. Vysoká, L., Dörr, R., Sarris, S. et al. (2021). *Technology transfer and commercialisation for the European Green Deal*. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/918801.

production[17], and is mostly driven by electromobility.[18] This shift in scope is reflected in the sample of interviewees, which are for the most part representatives of the industry or research and technology organisations, as explained in the next chapter.

---

[17] See chapter 5.2 Case study: Batteries, in European Commission (2021). *Technology transfer and commercialisation for the European Green Deal*, citing IEA (2020). *Innovation in Batteries and Electricity Storage.* IEA, Paris. Retrieved August 20, 2024, from: https://www.iea.org/reports/innovation-in-batteries-and-electricity-storage.

[18] European Commission. Joint Research Centre. Bielewski, M., Pfrang, A., Quintero-Pulido, et al. (2023*). Clean Energy Technology Observatory: Battery Technology in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets.* Publications Office of the European Union. https://data.europa.eu/doi/10.2760/52259, p.8.

2 METHODOLOGY

This report is based on a qualitative research approach. Semi-structured interviews were conducted with 17 out of the 25 organisations contacted, including representatives from industry, research organizations, academia, and European battery networks and organizations (**Table 1**).

The interviewees were identified so as to have sufficient variation per type of stakeholder, battery technology targeted, and positioning in the value chain, as shown in the table below.

In this context, network organisations were selected to compensate for possible bias due to the limited sampling of companies and research and technology organisations (RTOs), by obtaining aggregated insights on their industry members, research community, or portfolio of projects.

The interviews, carried out through video calls, took place between April and June 2024.

In addition, literature, webinars, and existing reports have been utilised, as well as the knowledge of the author based on her work performed in several battery research projects and discussions within the Battery 2030+, Batteries European Partnership Association (BEPA) and Batteries Europe networks.

The questions covered during the interviews focused on three macro areas, namely: EV battery technological trends and challenges; technology transfer and commercialisation practices and barriers; EU policy considerations. Regulatory aspects were touched upon transversally

Table 1. List of interviewed organizations.

Type of stakeholder	Requests for input	Input collected	Interviewed organisations[19]
Companies and startups/spinoffs			
Automotive manufacturers (OEMs)	4	2	• BMW Group • Renault Group/Ampere
Li-ion batteries	2	2	• Verkor • (Energy storage solutions provider)
Na-ion batteries	1	1	• Altris
Solid-state batteries	2	1	• BasqueVolt
Raw materials and recycling	2	1	• Fortum
Other	2	2	• Comau • Pulsedeon
Research and technology organisations			
	3	2	• Cidetec • Fraunhofer FFB
Network Organisations			
	9	6	• Batteries 2030+ • BEPA • CLEPA • EIT InnoEnergy • EuroBat • EUCAR
total	*25*	***17***	

---

[19] In case of contributions provided under request of anonymity, a generic description of the organisation is offered.

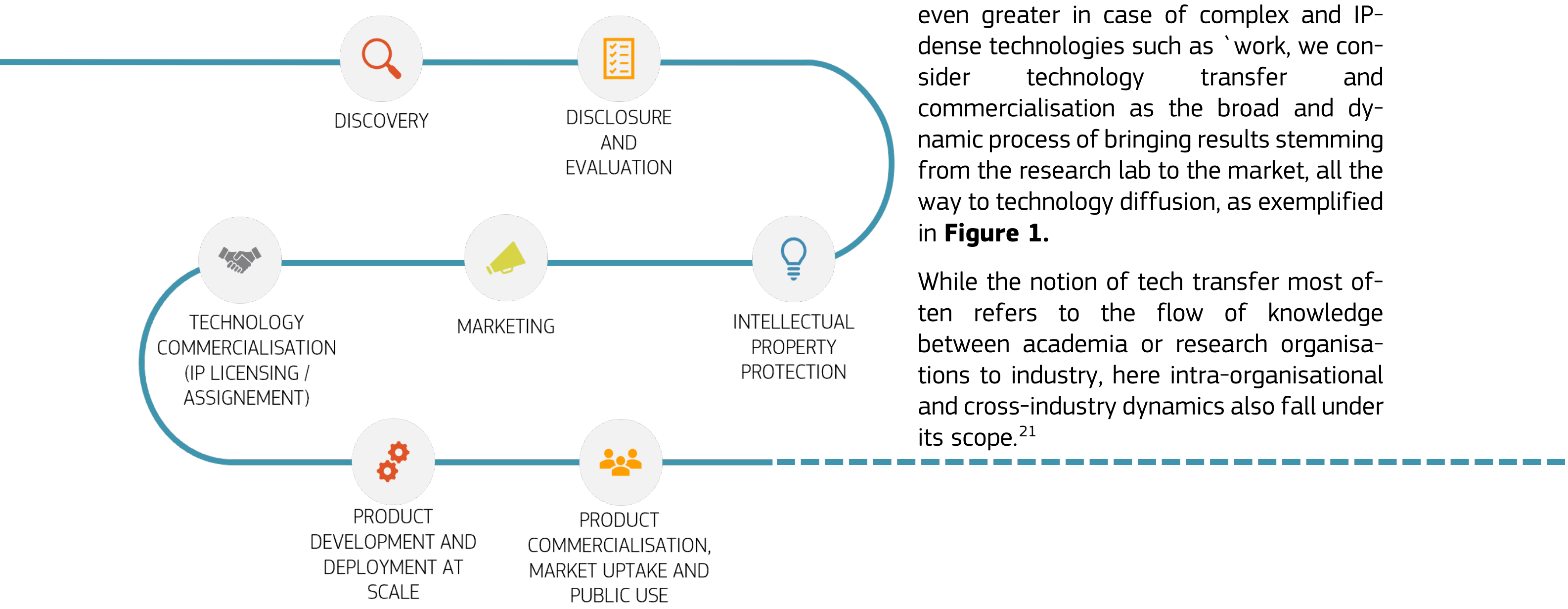
Interview guide: core questions

- What are, in your opinion, the most promising battery chemistries for EVs?
- What are the most important properties of EV batteries, also according to the preference of OEMs (e.g., price, safety, energy density, etc)?
- What are the encountered/anticipated technical barriers (per type of battery)? (e.g., raw materials availability, manufacturability, recycling, etc)
- What is your take on battery second life vs recycling?
- In your opinion, is the EU funding for R&D well allocated throughout the value chain (e.g., battery cell, recycling, manufacturing equipment)? and per stage of technology maturity (e.g., lower TRL vs industrialisation and production as scale)?
- Regarding tech transfer and commercialisation, what are the main challenges you can observe in the R&D battery ecosystem (automotive), in the journey from lab to market (e.g., IP issues, funding and financing, access to technology infrastructures, lack of skills)? What are the challenges specifically encountered in: academia-industry collaborations, cross-industry collaborations, or EU funded consortia?
- What are the main barriers encountered by spinoffs/startups in this sector?
- Is there an issue of battery/cell manufacturers not disclosing the technology/materials, that could impact on optimal recycling, also in view of battery passport requirements?
- Do you think current policy instruments are sufficiently targeting both supply and demand side?
- Do you have any advice on how the EC can further support the battery industry to survive the global competition?
- Anything else you would like to add, on how the EC can support tech transfer and commercialisation of EV battery technologies?

As a multifaceted and complex process, technology transfer presents a plurality of definitions in literature.[20] This intricacy is even greater in case of complex and IP-dense technologies such as `work, we consider technology transfer and commercialisation as the broad and dynamic process of bringing results stemming from the research lab to the market, all the way to technology diffusion, as exemplified in **Figure 1.**

While the notion of tech transfer most often refers to the flow of knowledge between academia or research organisations to industry, here intra-organisational and cross-industry dynamics also fall under its scope.[21]

Figure 1 From lab to market



Source: *own elaboration based on JRC, Technology transfer and commercialisation for the European Green Deal, 2021.*

---

[20] Lavoie, J.R., & Daim, T. (2019). 'Technology Transfer: A Literature Review.' In: Daim, T., Dabić, M., Başoğlu, N., et al. (eds) 'R&D Management in the Knowledge Era.' *Innovation, Technology, and Knowledge Management.* Springer, Cham. https://doi.org/10.1007/978-3-030-15409-7_17.

[21] See as examples: Hofer, F. (2009). *The improvement of technology transfer: An analysis of practices between Graz University of Technology and Styrian companies.* Springer Science & Business Media. Festel, G. (2013). 'Academic spin-offs, corporate spin-outs and company internal start-ups as technology transfer approach.' *The Journal of Technology Transfer*, 38, 454-470. https://doi.org/10.1007/s10961-012-9256-9. Borge, L., & Bröring, S. (2020). 'What affects technology transfer in emerging knowledge areas? A multi-stakeholder concept mapping study in the bioeconomy.' *The Journal of Technology Transfer*, 45(2), 430-460. https://doi.org/10.1007/s10961-018-9702-4. Cross-country technology transfer, as intended in international trade and development cooperation, is not considered in this study.

3 EV BATTERY TECHNOLOGY LANDSCAPE: CURRENT STATE AND FUTURE TRENDS

The following chapters cover the current state and future trends of EV battery technology. However, it should not be intended as an exhaustive overview, as its scope was guided by the insights emerged from the interviews, which are reported below and complemented with literature when needed. Selected passages from the interviews are included, to provide a more detailed account of the discussions.

3.1 Current EV batteries

3.1.1 Battery chemistries

The EV batteries currently on the market are based on Li-ion chemistries. The majority of EV batteries being produced today are using either a lithium nickel manganese cobalt oxide (NMC) or lithium iron phosphate (LFP) **cathode**[22]. NMC batteries provide a higher energy density than LFP batteries, but they are more expensive, mostly due to higher prices of cobalt and nickel compared to that of iron and phosphorous[23]. The trend in the NMC chemistry has been to increase the nickel content while decreasing the cobalt content. This is due to the high price of cobalt and the ethical concerns in cobalt mining, but also enabling slightly higher energy densities, as the voltage of high-nickel content batteries is higher. However, increasing the nickel content to ultra-high levels brings challenges in terms of stability. Thus, additional protective layers on the NMC particles or other stabilising methods will be needed. Lithium manganese iron phosphate (LMFP) batteries are also starting to gain attention[24]. This is due to the higher energy density when compared to LFP, and to the cobalt-free chemistry.

The **anode** in Li-ion batteries is usually made from graphite, but some batteries are also using small amounts of silicon (5-10%) in the anode to increase the energy density[25]. Silicon anodes without or with less graphite would enable increasing the energy density further, but they suffer from severe volume changes during charging and discharging, which is still preventing their use in commercial batteries. However, active research is ongoing to overcome this challenge.

In addition to the cathode and anode active materials, batteries contain also other elements. The electrode layers consist of the active materials mixed with binders and conducting additives. There is also a separator between the electrodes, which is usually a porous polypropylene or polyethylene membrane. The separator will allow ions to flow through and prevents an electric short circuit between the anode and cathode. In Li-ion batteries, all parts are soaked with a liquid electrolyte, which contains a Li-salt and an organic solvent. Finally, the battery cell is covered with a casing, which prevents both the electrolyte from leaking out and moisture and oxygen to penetrate the cell.

3.1.2 Battery manufacturing

Once the raw materials are ready, the Li-ion cell production starts by coating the electrode materials (slurries of the active material, binders/additives, and the solvent) on metallic current collectors. For the cathode, the most common binder is polyvinylidene fluoride (PVDF)[26], which is stable enough for the harsh electrochemical conditions. PVDF requires the use of N-methylpyrrolidone (NMP) as the solvent. For the anode, it is more common to use water-soluble binders as the electrochemical stability requirements are milder. Thus, water can be used as the solvent in the slurry coating of the anode. The slurries are deposited on the current collector by slot die coating in a roll-to-roll process, followed by drying and calendering of the electrode. Drying of especially NMP is very energy intensive[27], as it has a high boiling point. It is also a toxic solvent, and special protective methods are needed to

---

[22] IEA (2024), *Batteries and Secure Energy Transitions,* IEA, Paris. Retrieved August 20, 2024, from: https://www.iea.org/reports/batteries-and-secure-energy-transitions.

[23] IEA (2022*). Global EV Outlook 2022.* IEA, Paris https://www.iea.org/reports/global-ev-outlook-2022.

[24] Jephcott, B. (2024). 'Why LMFP cathode is important to the energy transition.' *Golden Dragon Capital.* Retrieved August 20, 2024, from: https://www.goldendragoncapital.com/lmfp-market-research-report.

[25] Frith, J. T., Lacey, M. J., & Ulissi, U. (2023). 'A non-academic perspective on the future of lithium-based batteries.' *Nature Communications*, 14(1), 420. https://doi.org/10.1038/s41467-023-35933-2.

[26] Dou, W., Zheng, M., Zhang, W., et al. (2023). 'Review on the binders for sustainable high-energy-density lithium ion batteries: status, solutions, and prospects.' *Advanced Functional Materials*, 33(45). https://doi.org/10.1002/adfm.202305161.

[27] The energy consumption for drying and solvent recovery accounts for approximately 40% of the total energy required in battery manufacturing. Cfr. e.g. Sliz, R., Valikangas, J., Silva Santos, H., et al. (2022). 'Suitable cathode NMP replacement for efficient sustainable printed Li-ion batteries'. *ACS applied energy materials*, 5(4), 4047-4058. https://pubs.acs.org/doi/10.1021/acsaem.1c02923.

allow safe working conditions and to avoid leakage to surroundings.

Once the electrodes are coated, they will be cut to a desired shape, and stacked on top of each other and the separator. The stack is placed in the container, e.g., a pouch, filled with the electrolyte and vacuum sealed. The electrolyte-filling step needs to be done in a dry room, as the electrolyte materials are sensitive to moisture and will form toxic gases in humid environments. After sealing, the cells will go through a formation step (soaking at high temperature, followed by slow charging and discharging to create a stable electrode to electrolyte interphase), degassing, and testing.

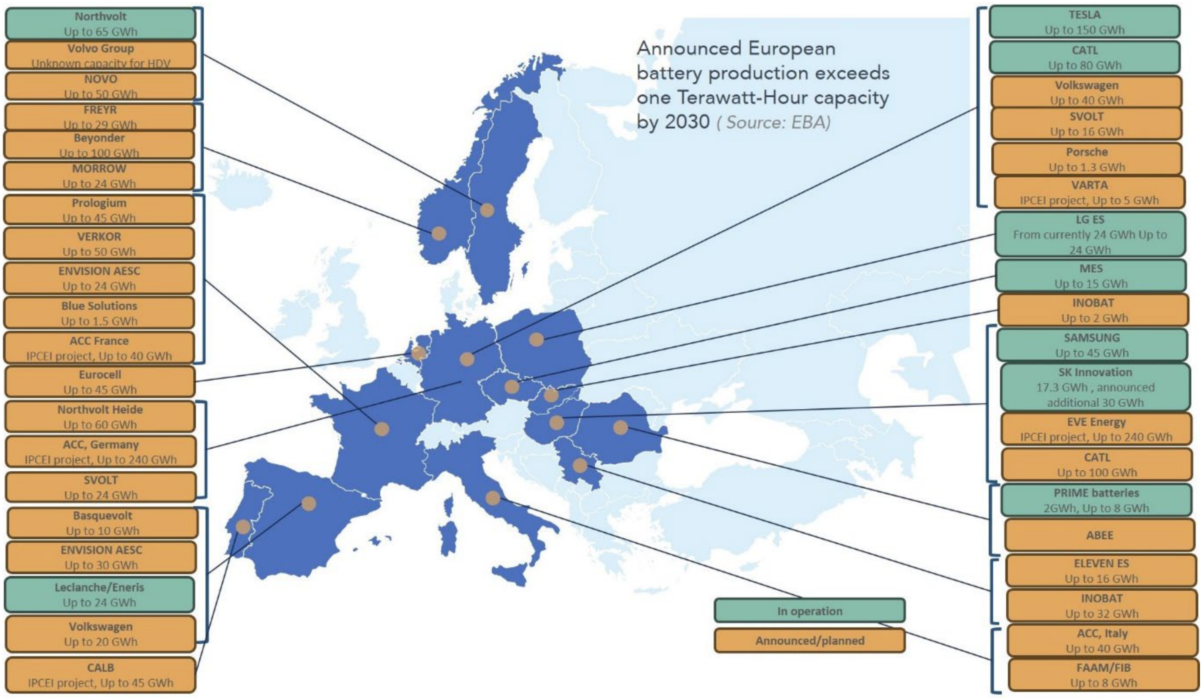
3.1.3 Battery producers

While cell production is heavily dominated by China[28], European companies (see **Figure 2**[29]) have been ramping up their production, with some cell factories having already started constructions or operations, and several others having been announced.[30]

However, despite public support granted, e.g., under the IPCEI framework, scaling up battery production while maintaining high quality and competitive prices remains a challenging task, and there is a clear risk that the announced factories may not reach their targets according to the planned schedules. This concern was highlighted also during the Batteries Europe plenary session[31] in Brussels on June 11th, 2024.

In addition, actual European battery production is much lower than the installed battery production capacity (for instance, in 2021, they were 16 GWh vs. 44 GWh, respectively)[32]. It is also notable that Asian players are setting up cell factories in Europe,

Figure 2 Announced (to be installed by 2030) and existing battery production capacity in Europe



Source: *EBA, 2021; in BATT4EU, SRIA, 2024*

---

[28] IEA (2023). *Lithium-ion battery manufacturing capacity, 2022-2030.* IEA, Paris. Retrieved August 20, 2024, from: https://www.iea.org/data-and-statistics/charts/lithium-ion-battery-manufacturing-capacity-2022-2030.

[29] It should be noted that more recent data (source: EBA250, July 2024) provided to JRC by DG GROW shows some variations in the announced and installed capacity, due to new or modified announcements, or some manufacturing projects being cancelled or put on hold. The data covers Li-ion battery cell manufacturing in EU27+ countries, and shows current installed capacity of 161 GWh and announced capacity for 2030 of 1338 GWh.

[30] BATT4EU (2024, February). *Strategic Research and Innovation Agenda*. Retrieved August 20, 2024, from: https://bepassociation.eu/our-work/sria/.

[31] Batteries Europe (2024). *European R&I Ecosystem Showcased at Batteries Europe plenary session.* Retrieved August 20, 2024, from: https://batterieseurope.eu/news/batteries-europe-plenary-session/.

[32] European Commission. Joint Research Centre. Bielewski, M., Pfrang, A., Bobba, S. et al. (2022). *Clean Energy Technology Observatory, Batteries for energy storage in the European Union – Status report on technology development, trends, value chains and markets – 2022*. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/808352, pp. 39-40.

with Chinese companies believed to account for one third of Europe's domestic battery production by 2030.[33]

3.2 Next-generation batteries, approaching market maturity

3.2.1 Next-generation battery chemistries

Li-ion batteries are considered to remain as the main battery type in the near future. However, some incremental improvements are foreseen, with current R&I efforts concentrating mainly on cost, energy density, lifetime, and sustainability aspects. Considering the materials only, sustainability can be improved e.g., by replacing the natural or synthetic fossil-based graphite with biobased options[34], and by replacing the plastic separator with a cellulose-based one[35]. Active research is ongoing to bring such materials from test cells to EV applications. In addition, energy density of Li-ion batteries can be optimised with high-voltage cathodes and high-capacity anodes.

The interviewees highlighted the importance of considering the up-scaling scenarios even for low technology readiness level (TRL) work with next-generation batteries. For example, it would be beneficial if existing equipment, either from the battery or other industry, could be used for their processing. Exchanges with cell makers are useful to reach this goal. The same applies for recyclability and sustainability. This approach should be integrated, for instance, in EU funding calls.

3.2.1.1 Solid-state batteries

The common feature of solid-state batteries is that they are all using a solid electrolyte. This enables the use of a metallic lithium anode, or even a so-called anode-free structure, which leads to a higher energy density compared to Li-ion batteries. Thus, SSBs are suitable especially for applications requiring high energy density.

There are different types of SSBs, and they have different advantages and disadvantages, as well as different maturity levels. The main differences of SSBs at the material level are related to the electrolyte, which can be ceramic (sulphide or oxide) or polymeric, or a combination of the two. All-solid-state ceramic batteries are still not used in commercially available mobility applications, even though there are already some announcements by industry players of their batteries being currently tested by car manufacturers[36]. On the other hand, the first examples of buses using semi-solid-state batteries with a gel/polymer electrolyte are already in operation[37].

Based on the interviews, customer need for SSBs exists, but some obstacles remain. One interviewee pointed out how the potential shown by SSBs at cell level is yet to be fully realised at the pack level or in real world applications. The biggest obstacle for larger market entry of SSBs is scaling up their manufacturing, while maintaining high quality with competitive cost. In this respect, transferring promising discoveries and processes from lab to pilot scale, and eventually to industrial scale, was identified as a challenge. However, as pointed out by some interviewees, this can also constitute an opportunity for Europe as, while Asian manufacturers dominate in the Li-ion manufacturing field, there is still room for the European SSB industry to grow.

> *"At the moment, nobody is able to make commercially li-metal anode-based solutions with solid state electrolytes. […] They are not real industrial solutions. […] And that is of course one of the benefits for the European and US industry, because in conventional batteries like gen 2 and 3, Asians are superior in cost, volume, market position, and technology, including also manufacturing technology […]. In solid state, like gen 4b and c, the big strategic difference is that [they] do not have a superior position technically".*

It should be however noted that also Asian players are putting considerable efforts in scaling up SSB production[38], and the competition can be expected to be fierce.

> *"China and Korea are trying to occupy this field now – e.g. the Chinese CASIP and the*

---

[33] Benchmark Minerals (2024, February 8). *Chinese companies to account for one third of Europe's domestic battery production by 2030.* Retrieved August 20, 2024, from: https://source.benchmarkminerals.com/article/chinese-owned-companies-to-produce-one-third-of-european-battery-cells-by-2030

[34] Stora Enso. Lignode. https://www.storaenso.com/en/products/lignin/lignode (last access: August 20, 2024).

[35] Delfort. Battery Separator Papers. https://delfortgroup.com/specialty-paper-products/battery/p/battery-separator-papers/ (last access: August 20, 2024).

[36] See an example: ProLogium. https://prologium.com/about (last access: August 20, 2024).

[37] See an example: Blue Solutions. https://www.blue-solutions.com/en/ (last access: August 20, 2024).

[38] Tabeta, S. (2024, February 12). 'CATL, BYD, others unite in China for solid-state battery breakthrough.' *Nikkei Asia.* Retrieved August 20, 2024, from: https://asia.nikkei.com/Business/Technology/CATL-BYD-others-unite-in-China-for-solid-state-battery-breakthrough.

> *Korean initiative. They invest tremendous money and resources to overcome the obstacles. We in EU need to be fast and precise to keep this way forward."*

In addition to the high energy density, SSBs seem to offer increased safety due to the absence of a flammable liquid electrolyte. However, SSB safety is not a completely straightforward matter, as mentioned in recent reports[39], and still requires research to be conducted to address remaining challenges. Safety of SSBs is also linked to the electrolyte in the cell. Semi-solid electrolyte composition still contains a small amount of liquid electrolyte, which might influence safety[40]. On the other hand, sulphide electrolytes in all-solid-state-batteries have been shown to generate 900% more heat than liquid electrolytes, and at the same time, release toxic SO_2 gases[41].

The interviewees highlighted also that SSBs can bring benefits to the battery design: optimised cooling and heating, cell-to-pack approach, and bipolar design can bring the overall battery pack costs down, even if the actual SSB cell would be more expensive than a Li-ion cell. However, SSBs (depending on the chemistry) might require also high stack pressure, which again increases the pack costs[42]. One interviewee mentioned how reducing the pressure requirement is one of the hurdles to overcome in SSBs, as it would allow a considerable increase in energy density.

In any case, the SSB cell will most likely, and especially in the early stage, be more expensive than current batteries. Thus, applications of SSBs are believed to be at first in premium cars, but also in industrial vehicles, satellites, and drones. However, semi-solid-state batteries can be also produced at lower cost, and those could be installed in more affordable, entry-level cars. One of the interviewees also noted that the SSB industry might not have as big a challenge with skilled workforce as the Li-ion battery industry, considering that the SSB production presents many similarities with processes in the semiconductor industry, which is already established in the EU and boasts qualified workforce with potentially transferrable skills.

3.2.1.2 Na-ion batteries

Na-ion batteries are a sustainable and potentially low-cost option for battery applications that do not require extremely high energy density. Their main application area is considered to be stationary storage. However, some mobility applications, such as standard-range cars, are also expected to run on Na-ion batteries in the future[43,44]. Faster charging of Na-ion batteries, compared to Li-ion batteries, will also make them an attractive alternative.[45] One of the interviewees noted the importance for Na-ion batteries to achieve similar energy density to LFP batteries, to be competitive in mobility applications. Based on the interviews, they could be also used to replace lead-acid batteries in cars. It is notable that the first Na-ion battery-powered EVs have already gone into serial production in China[46].

The Na-ion battery industry is still relatively young, but some companies are actively developing these batteries in Europe[47]. The majority of Na-ion battery companies are however based and incorporated in China, which has global leadership in this technology and is fast advancing on its commercialisation, and some are present in USA.[48] There are several types of Na-ion batteries, and they can be classified based on the cathode material: Prussian blue analogs, layered oxides, or

---

[39] Edmondson, J. (2023, May 12). 'Will Solid-State Batteries Eliminate the Need for EV Fire Protection?' *IDTechEx.* May 12, 2023. Retrieved August 20, 2024, from: https://www.idtechex.com/en/research-article/will-solid-state-batteries-eliminate-the-need-for-ev-fire-protection/29300.

[40] Janek, J., & Zeier, W. G. (2023). 'Challenges in speeding up solid-state battery development.' *Nature Energy*, 8(3), 230-240. https://doi.org/10.1038/s41560-023-01208-9.

[41] Rui, X., Ren, D., Liu, X., et al. (2023). 'Distinct thermal runaway mechanisms of sulfide-based all-solid-state batteries.' *Energy & Environmental Science*, 16(8), 3552-3563. https://doi.org/10.1039/D3EE00084B.

[42] IEA (2024), *Batteries and Secure Energy Transitions.*

[43] Siddiqi, S., Holland, A. 'Sodium-ion Batteries 2024-2034: Technology, Players, Markets, and Forecasts.' *IDTechEx.* Retrieved August 20, 2024, from: https://www.idtechex.com/en/research-report/sodium-ion-batteries-2024-2034-technology-players-markets-and-forecasts/978.

[44] Rudola, A., Sayers, R., Wright, C. J., et al. (2023). 'Opportunities for moderate-range electric vehicles using sustainable sodium-ion batteries.' *Nature Energy*, 8(3), 215-218. https://doi.org/10.1038/s41560-023-01215-w.

[45] Wang, Q., Zhou, D., Zhao, C. et al. (2024). 'Fast-charge high-voltage layered cathodes for sodium-ion batteries.' *Nat Sustain,* 7, 338–347. https://doi.org/10.1038/s41893-024-01266-1. Li, Y., Vasileiadis, A., Zhou, Q. et al. (2024). 'Origin of fast charging in hard carbon anodes.' *Nat Energy,* 9, 134–142. https://doi.org/10.1038/s41560-023-01414-5.

[46] Randall, C. (2024, January 02). 'First sodium-ion battery EVs go into serial production in China.' *Electrive*. Retrieved August 20, 2024, from: https://www.electrive.com/2024/01/02/first-sodium-ion-battery-evs-go-into-serial-production-in-china/.

[47] European players are Altris and Tiamat. Altris. https://www.altris.se/ (last access: August 20, 2024). Tiamat. https://www.tiamat-energy.com/. (last access: August 20, 2024). In the UK, the Na-ion startup Faradion was acquired by Indian company Reliance. Faradion. https://faradion.co.uk/ (last access: August 20, 2024).

[48] For a list of global leaders in Na-ion technology, see European Commission (2023). *Clean Energy Technology Observatory: Battery Technology in the European Union,* p.46.

polyanions.[49] On the anode side, it is not possible to use graphite as the Na-ion does not intercalate inside the narrow graphene layers in the graphite structure. Instead, hard carbon type anodes are used. Biobased hard carbon is also a good match for Na-ion batteries and, recently, a collaboration with a biocarbon and Na-ion battery company was announced.[50]

The interviewees noted that the raw material value chain for Na-ion batteries exists in Europe, but there is a need to ramp up the raw material production when the Na-ion cell production will increase.

> *"If we can compare it with li-ion, which is already well established [...] it seems that Na-ion is still at its infancy in that sense. We know what are the potential materials, but we do not know which ones are going to work [or] that all will reach the market. I think this is the major technical barrier. [...] And then related to this is the production of these materials, which is today in Europe very low".*

They also highlighted that recycling Na-ion batteries can be simpler than recycling Li-ion ones, due to the possibility to use water-based binders for both electrodes, and to employ aluminium as a current collector both for the anode and cathode. As the value of raw materials is lower than for Li-ion battery materials, cost-efficiency in recycling is, however, a must.

3.2.1.3 Dual chemistry batteries

The possibility for dual chemistry batteries, i.e., mixing two different chemistries into one battery pack, was not highlighted clearly in the interviews. This probably reflects the understanding that mixing two different chemistries will make the battery pack more complicated, and thus expensive. There are nonetheless already examples from China, e.g., a battery pack with both NMC and LFP cells[51], or of an EV containing both a Li-ion and Na-ion battery[52]. In the latter case, it is possible to combine the best properties of both: the Na-ion part is used for short range and frequent driving, as it has lower energy density but better durability; whereas the Li-ion part will be put into use only if the Na-ion battery capacity has been used. Another example of a dual chemistry battery comes from the US[53], using a combination of a LFP battery with an anode-free one.

One possibility is also to use a modular structure, where a smaller, and thus cheaper and lighter, battery is dedicated to daily use, and another one can be added for occasional, longer-range drives. Optimally, the user could even rent it, instead of owning it. This would help to use the battery raw materials in an optimised way. However, such cars are not yet on the market. In this regard, one interviewee suggested that commercial vehicles could be a more suitable application than passenger cars.

3.2.2 Manufacturing of next-generation batteries

Manufacturing of next-generation batteries differs from chemistry to chemistry. For **SSBs**, manufacturing at higher scale is the main barrier. Currently, quality and cost-efficiency in high volumes is not yet met, especially for all-solid-state batteries with ceramic solid electrolytes. Interfaces are critical, and materials are sensitive to the environment: e.g., metallic Li is sensitive to air and humidity, and some solid electrolytes can even form toxic gases when in normal atmosphere. R&I on SSB manufacturing is ongoing, *inter alia* under support from Horizon Europe.[54]

One of the interviewees estimated that 60 % of the manufacturing equipment will be different for SSBs compared to Li-ion batteries. This can slow down some decisions to set up SSB manufacturing facilities. However, when using a polymer or gel electrolyte, it is possible to better utilise existing Li-ion battery manufacturing equipment, even for the electrolyte injection. Due to the uncertainties in scaling up the SSB production, the interviewees pointed out the need for pilot lines.

> *"[Pilot plants] is something we should have, so that we can manage this manufacturing technology gap. We can learn how to handle, manufacture SSBs using both existing but also new, novel technology required for SSBs or [other] next-generation batteries. There is no such system at the moment nowhere in Europe."*

---

[49] European Commission (2023). *Clean Energy Technology Observatory: Battery Technology in the European Union,* p.10.

[50] Altris. https://www.altris.se/ (last access: August 20, 2024).

[51] Nio. https://www.nio.com/news/nio-launches-standard-range-hybrid-cell-battery (last access: September 14, 2024).

[52] Zhang, P. (2023, April 20). 'CATL, BYD's sodium-ion batteries both to be in mass production within this year, report says. *CnEVPost.* Retrieved August 20, 2024, from: https://cnevpost.com/2023/04/20/catl-byd-sodium-ion-batteries-mass-production-this-year-report/.

[53] ONE. Gemini. https://one.ai/products/gemini (last access: August 20, 2024).

[54] European Commission. *Manufacturing technology development for solid-state batteries (SSB, Generations 4a - 4b batteries) (Batteries Partnership).* Retrieved August 20, 2024, from: https://cordis.europa.eu/programme/id/HORIZON_HORIZON-CL5-2021-D2-01-05/en.

The SSB field would benefit from pilot scale facilities where new materials and processes could be tested. It is not yet sure which one will be the winning SSB technology, and investing in new equipment is expensive. Thus, it is very risky to invest until scalability is demonstrated at pilot level.

The situation is different for **Na-ion batteries**, as they can be described as a “drop-in” type of technology, especially if the cathode active material can be handled and coated without a dry room. While some cathode active materials can be coated in normal atmosphere, others may not be stable enough without a dry room during coating. Apart from that, the processing is very similar to Li-ion battery cells and no new equipment is needed.

The interviewees mentioned that investing in SSBs and other new battery technologies can be considered part of a “risk management” strategy for the EU. If SSBs are successful and upscaling issues are solved, they might get a significant market share, according to some of the interviewees. However, it is not foreseen that SSBs will fully replace Li-ion batteries. Most of the interviewees agreed that the capital investments for current Li-ion battery manufacturing are not squandered, as it is more likely that the production of SSB and Na-ion batteries will be an add-on, and that there will be a need for different battery factories in the future.

3.2.3 Producers of next-generation batteries

The field of next-generation battery manufacturing is evolving rapidly, and having reliable up-to-date information about existing and planned cell manufacturing factories in Europe is challenging. Given that some of the information is based only on announced plans, and that scaling up is a huge task, some of these endeavours might end up not being realised, or investments might be redirected towards non-EU countries offering a more attractive business environment.

Some sources identifying main players in Europe active on solid-state batteries[55] are Battery News, which lists SSB and next-generation battery activities in Europe as shown in **Figure 3**; and Fraunhofer ISI, mentioning the plans of LeydenJar to produce SSBs in the future[56]. As examples, two next-generation battery companies are presented here in more detail. They were selected as case studies to represent the two most advanced next-generation battery chemistries: SSBs and Na-ion batteries. Note that there are also other companies working in this field and these two were selected purely since they were the first next-generation battery companies with whom we were able to arrange an interview.

Case study: Basquevolt, Spain

Solid-state battery industry

- Established based on an electrolyte invention from CIC energiGUNE.
- Founded in 2022, after 10 years of research.
- Funding e.g., from InnoEnergy, industrial players in the energy and automotive sector and the Basque government.
- Strategy for industrialisation: Starting by processes and materials which are easy to scale up, have low cost, and can use existing tools as much as possible, e.g., infiltration of the gel electrolyte. Make this work first and then continue further.
- Cells scaled up to 20 Ah in 2024, next targeting a larger dry room and 80 Ah cells.
- Examples of benefits of the Basquevolt technology: High energy density (450 Wh/kg, 1000 Wh/l) while maintaining low cost, great safety, cathode agnostic electrolyte, fast formation.

Case study: Altris, Sweden

Na-ion battery industry

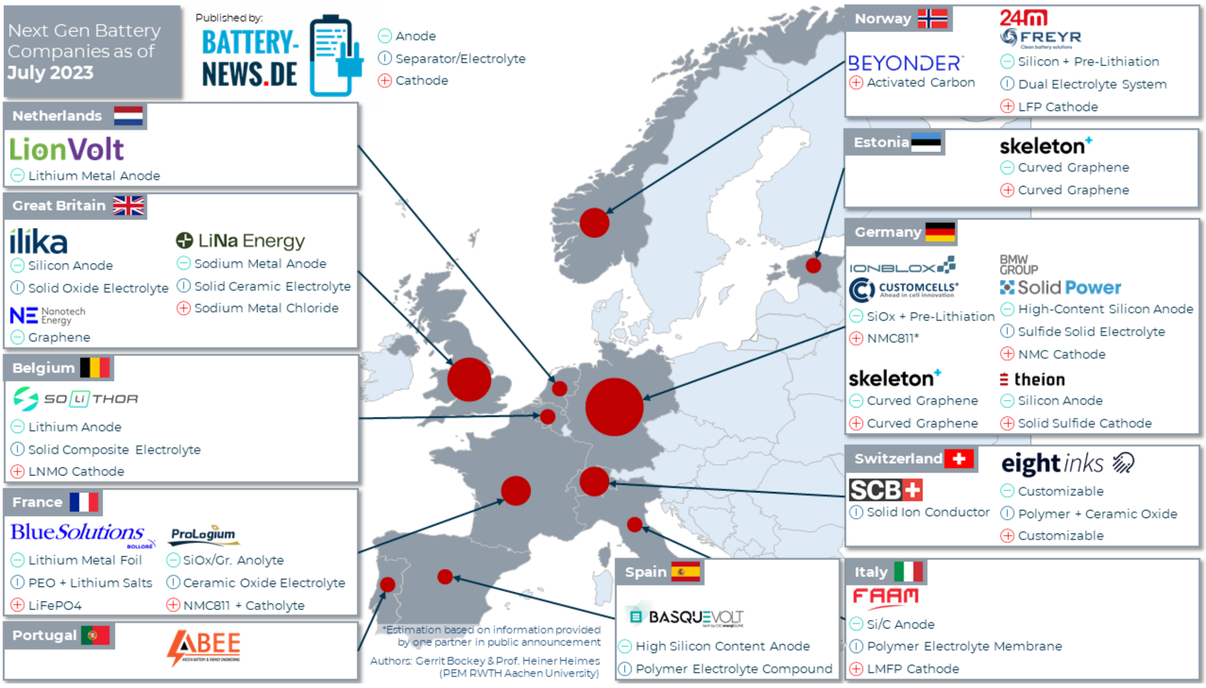
- Established based on an invention from the Ångström lab of Uppsala University in 2015.
- Idea patented in 2017 and Altris founded.
- Funding e.g., from InnoEnergy, Northvolt, Molindo and the Swedish Energy Agency.
- Strategy for industrialisation: Focus first on the cathode active material production to prove scalability at pilot level and then at full industrial level in synchronization with customer and market needs.
- New cell pilot line being built in 2024 as the customers also need cells for a proof of concept.
- Examples of benefits of the Altris technology: Low carbon footprint, low ESG risk, fluorine-free materials in the whole cell design, sustainable and localised supply chains, water-based slurries for electrodes, coating and cell assembly without a dry room, easy recycling.

---

[55] A tool to identify some players active in the field of next-gen batteries based on EPO patent data is the EPO’s Deep tech finder, at https://datavisualisation.apps.epo.org/datav/public/dashboard-frontend/host_epoorg.html#/explore?dataSet=1 (last access: August 20, 2024).

[56] Rosellón Inclán, I. (2024, April 30). ‘Solid-state batteries for electric vehicles: Still in R&D or on the verge of commercialization?.’ *Fraunhofer ISI*. Retrieved August 20, 2024, from: https://www.isi.fraunhofer.de/en/blog/themen/batterie-update/feststoffbatterien-elektro-autos-kommerzialisierung-stand-forschung-entwicklung.html

Figure 3 Next-generation battery companies in Europe



Source: *Battery News, 2023. Authors: Gerrit Bockey & Heiner Heimes, PEM RWTH Aachen University. Available at: https://battery-news.de/next-gen-batterien-europa/). (data from July 2023). Note that the Na-ion battery companies are missing from this image, as the authors focused on chemistries that represent an increase in cell capacity and alternative cell structures. European Na-ion companies include e.g. Altris (Sweden), Tiamat (France), and Faradion (UK, acquired by Indian company)*

3.3 Targeted properties for EV batteries

The desired properties for EV batteries vary quite a lot in different countries in Europe, from the consumer's perspective. Some highlight the need for low cost, some want sustainability, some aim for longer range. For the EV and battery producers, safety seems to be the number one priority. Cost is another priority, but not for all. Some of the interviewees stated that they have chosen to invest in superior battery performance and focus not as much on affordability. Such batteries could serve markets with special requirements, e.g., e-aviation.

> *"It is true that we are seeing two trends simultaneously: the first one is to improve performance and energy density, with silicon etc; but the other trend is lowering the cost, and in this regard, we are seeing more and more requests to work on Na-ion batteries, for example, and also a few with LFP. I think both trends are developing rather strongly - as complementary, maybe not addressing exactly the same product range - from the side of the industry."*

The EU's focus on sustainability aspects, specifically in EU-funded research projects as well as at regulatory level, was mentioned positively by multiple interviewees. However, it was also noted by a couple of interviewees how sustainability aspects are not always the first priority for some companies, especially those still in the development phase, which might focus first on [cost] competitiveness and viability of their business model, and address sustainability or traceability concerns once securely established in the market.

In this regard, it has to be pointed out that there are many exceptions of European companies investing a lot in sustainability, with some of the interviewed companies explicitly putting sustainability and low carbon footprint at the forefront. Beyond the characteristics of the battery and the sustainability of the value chain, one interviewee further stressed the importance of achieving cost competitiveness to make these sustainable mobility solutions accessible to everyone in Europe, to effectively drive down road transport emissions. In terms of carbon footprint, the most ambitious targets for the Li-ion battery are below 30 kgCO2e/kWh, and even lower for Na-ion batteries. Current levels are around 70-

170 kgCO2e/kWh[57]. In addition, cell design also takes into account recyclability.

Regarding battery properties, the interviewees provided several recommendations for the European battery industry and research field.

Firstly, when competing against global battery production, a key target for Europe should be to achieve both competitiveness and decarbonisation at the same time. Furthermore, it is crucial to ensure that there are clear and transparent methods to compare different batteries, especially regarding carbon footprint calculations. It is essential to understand the real impact and have a fair comparison of different chemistries and applications. As part of an effort to harmonise the regulatory framework for dealing with the entire life cycle of batteries, the carbon footprint calculation methodology, recently published for consultation by the European Commission[58], is expected to help achieve this target.

Another concern raised by some interviewees is the need to focus more on cheaper technologies. As of now, the focus in Europe has been on high battery performance[59], which has (for one) led into high cost for the produced batteries.

> *"In EU [...] we need to focus more on Na-ion, LFP, and LMFP: on the low-cost area. If we lose the market entry in electrification, we will also lose jobs too. So the focus needs to be on new chemistries, and Solid State; but with a strong focus on R&D and implementation of Na-ion and LFP, for the low cost segment."*

However, some companies have decided to adopt an opposite approach and focus only on high performance, to the detriment of affordability. An approach where both low-cost and high-performance battery types are produced in Europe seems to be the most optimal one, as we need to target different market segments with the most appropriate battery technologies. A certain degree of diversification in battery technology can also be important to increase the EU resilience to supply chain disruptions, as well as to maximise the chances of success.[60]

> *"To be competitive today, you need to invest early, and a lot of money. The growth of cost form low TRL to high TRL is exponential. So it's a must to invest in low TRL, to get a feeling of what's next, in the technology race; but you need to carefully choose what technologies to transfer to next level. You can burn a lot of money pushing forward something that is not applicable in the market. Diversifying is important also for that; doing research on a lot of different technologies."*

> *" [with regard to SSBs] We have a mission, which is towards Europe, and make sure we have technological sovereignty [...] to secure the EU competitiveness".*

> *"It is crucial for Europe to invest in innovation to diversify the supply chain for raw materials across all mainstream battery technologies used in various applications, which would also benefit the BEV market."*

It was noted that range anxiety seems to affect customer choice less than it used to, now that EVs use has become more frequent and there are more [positive] experiences. However, for example in cold countries, low range is still a challenge in wintertime. Charging speed is also approaching good levels, and further improvements are foreseen. In this respect, one of the interviewees mentioned that, in Li-ion batteries, high energy density (and thus long range) and high charging speed are alternative properties, as it is challenging, if not unnecessary, to optimise both for a single cell type.

However, there are efforts to manufacture batteries with a chemistry that can "eliminate the barrier between lower segment and premium", i.e., that have a cobalt-free high-voltage cathode, combined with a high-capacity anode. These batteries would enable reasonably high energy density (but not as high as the best SSBs), combined with low-cost materials. One of the interviewees stressed how such development requires, even more so than usual, good collaboration and an ecosystem of start-ups and cell makers that can work together to create a superior solution.

Durability and lifetime of the battery is also important. In general, the lifetime of Li-ion batteries is considered to have reached a good level, to the point of posing a challenge to meeting the recycling

---

[57] Casas Ocampo, A. (2024, April 23). 'Carbon footprint as key element to comply with battery regulation.' *CIC energyGUNE*. Retrieved August 20, 2024, from: https://cicenergigune.com/en/blog/carbon-footprint-comply-battery-regulation.

[58] European Commission. *Batteries for electric vehicles – carbon footprint methodology*. Public Consultation. https://ec.europa.eu/ info/law/better-regulation/have-your-say/initiatives/13877-Batteries-for-electric-vehicles-carbon-footprint-methodology_en.

[59] European Commission (2022). *Clean Energy Technology Observatory, Batteries for energy storage in the European Union*, p. 48.

[60] On this cfr. e.g. EUROBAT (2024, June), *Battery Innovation Roadmap 2035*. Retrieved September 09, 2024, from: https://www.eurobat.org/campaigns-and-initiatives/battery-innovation-roadmap-2035/.

targets set in EU legislation, as batteries will reach their end of life later than originally anticipated.

The main challenges related to lifetime appear in novel chemistries, such as the silicon anode with high volume changes during cycling, or solid-state batteries using a metallic lithium anode.

The interviews, as well as this report, focused mainly on EV batteries. However, it is worth to mention that other mobility applications, such as heavy-duty machines for mining and agriculture, will have a different set of requirements[61]. For such applications, the batteries may need properties that allow, e.g., fast charging (at least 3C, i.e., reaching a full charge in 20 min) to keep the downtime of the machines low, and strict cycle life requirements (12 000 cycles/lifetime). Thus, e.g., lithium titanium oxide (LTO) batteries might find use in these applications, as they allow fast charging without damaging the cell, even though they do not reach very high energy density. Potential emerging EV batteries

Battery chemistries beyond Li-ion, Na-ion and SSBs were not highlighted much in the interviews. This might be explained by the lack of many academic partners (traditionally focusing more on basic research than RTOs and industry) amongst the interviewees composing our sample, in line with the focus of the report on higher TRL R&D&I, as mentioned in the introduction.

However, there are some noteworthy potential emerging battery chemistries that can be suitable for mobility applications due to their high energy density (Wh/l) or high specific energy (Wh/kg), or due to their sustainability and locally available raw materials.

Two main emerging chemistries identified in literature[62] include batteries that use metallic lithium as the anode, with a different cathode than that used in conventional SSB chemistries – notably, a cathode containing sulphuric materials (Li-sulphur batteries) or an air cathode (Li-air batteries).

Several other battery types, such as monovalent or dual ion batteries like potassium-[63], zinc-[64], magnesium-[65] or calcium-[66] based chemistries and even organic batteries[67] are also under development, but they are still at a very early stage. If the challenges met in scaling up the Li-ion battery industry are anything to go by, these new chemistries still face a very long path towards commercialization. It is however notable that some companies, such as Theion[68] in Germany and LG Energy Solution[69] in South Korea are planning to commercialize Li-sulphur batteries soon.

Yet another battery category includes redox flow batteries. They are mainly targeted for stationary applications, even though cases of testing flow batteries in EVs have been reported[70]

In conclusion, no major role is foreseen for the emerging battery chemistries in the EV industry in the near future.

Nevertheless, it is important to continue working on their development as they could provide, for instance, very sustainable, cheap, and readily available material options for batteries, or improved energy density.

Alternative energy storage solutions

Batteries are the main energy storage method for mobility applications. However, some alternative

---

[61] Jeffs, J., Jaswani, P., & Holland, A. (2024) 'Battery Markets in Construction, Agriculture & Mining Machines 2024-2034.' *IDTechEx.* Retrieved August 20, 2024, from: https://www.idtechex.com/en/research-report/battery-markets-in-construction-agriculture-and-mining-machines-2024-2034/1008.

[62] Liu, W., Placke, T., & Chau, K. T. (2022). 'Overview of batteries and battery management for electric vehicles.' *Energy Reports*, 8, 4058-4084. https://doi.org/10.1016/j.egyr.2022.03.016.

[63] Zarrabeitia, M., Carretero-González, J., Leskes, M., et al. (2023). 'Could potassium-ion batteries become a competitive technology?' *Energy Materials*, 3(6). https://doi.org/10.20517/energymater.2023.41.

[64] Mageto, T., Bhoyate, S. D., Mensah-Darkwa, K., et al. (2023). 'Development of high-performance zinc-ion batteries: issues, mitigation strategies, and perspectives.' *Journal of Energy Storage*, 70, 108081. https://doi.org/10.1016/j.est.2023.108081.

[65] Leong, K. W., Pan, W., Yi, X., et al. (2023). 'Next-generation magnesium-ion batteries: The quasi-solid-state approach to multivalent metal ion storage.' *Science advances*, 9(32). https://doi.org/10.1126/sciadv.adh1181.

[66] Ye, L., Liao, M., Zhang, K., et al. (2024). 'A rechargeable calcium–oxygen battery that operates at room temperature.' *Nature*, 626(7998), 313-318. https://doi.org/10.1038/s41586-023-06949-x.

[67] Kim, J., Kim, Y., Yoo, J., et al. (2023). 'Organic batteries for a greener rechargeable world.' *Nature Reviews Materials*, 8(1), 54-70. https://doi.org/10.1038/s41578-022-00478-1.

[68] theion. https://www.theion.de/ (last access: August 20, 2024).

[69] Yun, G., & Kim, J. (2021, April 29). 'LG Energy Solution Looking to Commercialize Lithium-Sulfur Batteries and All-Solid-State Batteries Starting from 2025 at the Earliest.' *ETNews.* Retrieved August 20, 2024, from: https://english.etnews.com/20210429200001?mkt_tok=MjExLU5KWS0xNjUAAAGKVstCxY9GH0H3s8Ndg-V2NNS_kXvxJfVl22o7zs9JnvHcr8lWCUo_k0u7Fveph04o85P16_gug30KPPZI-gk.

[70] Casey, T. (2023). 'New Flow Battery Electric Car To Be Made In The USA.' *CleanTechnica.* Retrieved August 20, 2024, from: https://cleantechnica.com/2023/12/31/new-flow-battery-electric-car-usa-ira/.

solutions do exist, such as supercapacitors and hydrogen fuel cells. Their properties are shortly explained below.

Supercapacitors are energy storage devices, which can provide high power density, but are not capable of reaching the same high energy density as batteries. They are already used as ancillary devices in EVs to store energy captured during braking and to boost acceleration, both of which require higher power capacity. The main benefit of utilising supercapacitors is indeed that they can be charged and discharged at very high current values, which may be over 100 times that of batteries, without any damage to the device.[71] However, due to the low energy density, in EVs they will be most likely used only in combination with batteries.

Hydrogen is another energy storage medium alternative to batteries. Hydrogen fuel cell vehicles (HFCVs) are one option to replace ICE cars and other mobility applications relying on gasoline or diesel. As a share of total hydrogen demand, however, transport represents only 0.03%, and as a share of total transport energy, hydrogen represents only 0.003% (in 2022).[72] When comparing the benefits of HFCVs and battery EVs, battery EVs provide higher energy efficiency, and they have also much more advanced charging infrastructure. On the other hand, HFCVs can provide longer range, as transporting a larger amount of fuel in the vehicle is easier than increasing the battery size significantly[73,74]. In general, HFCVs are considered to find applications especially in fields where direct electrification is not possible, such as long-distance transport without access to charging infrastructure. The challenges in HFCV uptake include, for instance, high cost of the platinum catalyst, resulting in high cost of the fuel cells. In addition, issues with the cold start and safety in storing the hydrogen are topics that need to be solved before wider HFCV adoption.

3.4 Manufacturing aspects

The battery **manufacturing equipment** industry is heavily dominated by China. This was clearly stated during the interviews and is confirmed by recent reports[75]. European players are entering the market later than their Asian competitors, and this is currently resulting in a shortage of European battery equipment suppliers. To be able to accelerate the development of this component of the battery value chain and close this gap, the European industry would require huge investments, as Asian suppliers are already ready to deliver.

Some interviewees mentioned a **skill gap** as one of the other barriers to speeding up industrial battery manufacturing. Specifically, lack of experienced staff to work with automation and quality control was identified as a challenge, and training for technicians was deemed necessary to ensure that there is enough work force for the battery industry.

Some key areas for improvement in **battery manufacturing** were mentioned in the interviews. Firstly, the European community should improve processing speed, while maintaining high quality. Decreasing the scrap rates is essential to be profitable, and digital quality control methods are a key to enable this. This includes automation, process control, sensors with algorithms to analyse their data, and inline inspection tools. However, even if a battery production line had the quality control tools in use, there would still be uncertainties related to the boundary conditions. European players need to learn better which defects are detrimental and will have a negative effect on battery performance, either directly or with a delay. The latter case is more challenging to identify.

In addition, sustainability also warrants more attention. The use of dry rooms should be minimized by using stable materials or by using the dry conditions only locally, e.g., through a dry tunnel for the coating line. This would improve the energy efficiency of processing and help minimize the carbon footprint of battery manufacturing.

Dry processing, i.e., coating the electrode layers without a solvent, is also seen as a very promising solution to further reduce energy consumption. It may cut down energy consumption by as much as 40 % in the cell manufacturing stage[76], and would avoid the use of toxic solvents, such as NMP. This would thus also improve the safety of workers.

---

[71] Horn, M., MacLeod, J., Liu, M., et al. (2019). ‘Supercapacitors: A new source of power for electric cars?’ *Economic Analysis and Policy*, 61, 93-103. https://doi.org/10.1016/j.eap.2018.08.003.

[72] IEA (2022). *Global Hydrogen Review 2022.* IEA, Paris. Retrieved August 20, 2024, from: https://www.iea.org/reports/global-hydrogen-review-2022.

[73] Shao, P., & Zheng, H. (2023). ‘Comparison of Electric Vehicles and Hydrogen Fuel Cell Vehicles.’ *Highlights in Science, Engineering and Technology,* 32, 259-270. https://doi.org/10.54097/hset.v32i.5176.

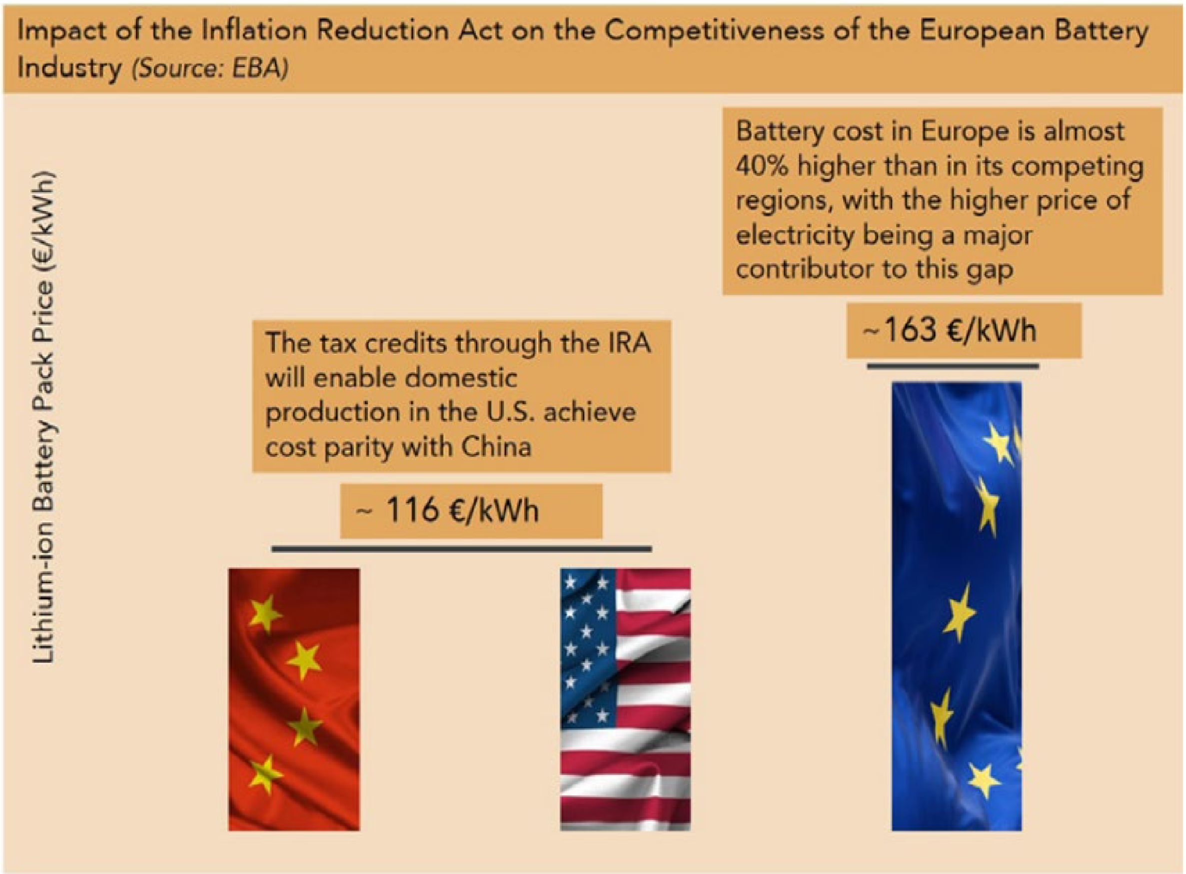
[74] Aminudin, M. A., Kamarudin, S. K., Lim, B. H., et al. (2023). ‘An overview: Current progress on hydrogen fuel cell vehicles.’ *International Journal of Hydrogen Energy*, 48(11), 4371-4388. https://doi.org/10.1016/j.ijhydene.2022.10.156.

[75] IEA (2023). *Lithium-ion battery manufacturing capacity, 2022-2030.*

[76] Lu, Y., Zhao, C. Z., Yuan, H., et al. (2022). ‘Dry electrode technology, the rising star in solid-state battery industrialization.’ *Matter*, 5(3), 876-898. https://doi.org/10.1016/j.matt.2022.01.011.

Some suggestions from the interviewees to support the battery manufacturing ecosystem in Europe included making use as much as possible of existing infrastructure, either from the battery or other industry, to speed up the development; and strengthening financial support, along the lines of the US Inflation Reduction Act was considered crucial for the European battery industry. It was also mentioned as being of great importance to work in collaboration with equipment producers, material scientists, and manufacturing experts already at early stages of the R&D&I process, to help tune the materials and processes and eventually facilitate scaling up; product and process development should go hand in hand. Finally, it was noted that, in order to speed up market entry, Europe should focus more on industrialisation, manufacturing, and recycling of batteries, instead of only optimizing their performance at small scale.

Figure 4 Cost of Li-ion batteries, produced in China, USA and in Europe



***Source:** EBA, in BATT4EU, SRIA, 2024*

> *"What really is an issue, I think, is manufacturability, for everything; because it's such a mass market [EV batteries], production on such a big scale...you need to think at an early stage [...] how to ensure production at the scale that we need, what kind of hurdles are there, that we might not encounter in the lab but the moment we do it on a larger scale we will definitely encounter".*

> *"It is useful to work together already at the beginning of the development phases; there were cases where the technology was working very well at lab level, but it was very difficult to be upscaled. [...] The collaboration between developers and equipment providers could be also in the process development: finding together good solutions form the process point of view that provide the needed performance but can be upscaled."*

> *"In terms of R&D&I, European partnerships should be set up along value chains to support [each] value chain's needs, as it is executed in BEPA"*

Finally, as of 2023, Li-ion batteries have seen their price decrease by 90% when compared to 2010 levels[77]. However, the cost of batteries depends

---

[77] IEA (2024), *Batteries and Secure Energy Transitions.*

heavily on the location where they are produced. According to EBA, the costs in Europe are 40 % higher than in China and USA, due to the high electricity prices and as an effect of the IRA and subsidies in China, as shown in **Figure 4**. The difference in price levels is a major challenge for the European battery industry, also considering that Europe has been focussing mostly on R&D and production of more expensive, higher-end batteries like NMC, as opposed to Chinese competitors who are particularly strong in cheaper batteries such as LFP.[78]

3.5 Recycling aspects

Recycling methods for batteries can be roughly divided in three categories: hydrometallurgy, pyrometallurgy and direct recycling[79]. Before undergoing any of these processes, batteries must go through several pre-treatment steps, such as discharging, disassembly, and separation. Hydrometallurgical processes use aqueous solutions to extract the metals from the black mass, which is formed after the pre-treatment steps. In pyrometallurgy, heat is used to convert the metal oxides into metals or metal compounds. Often, a combination of these processes is also used. On the other hand, direct recycling is a method where the materials are not recovered as elements. Instead, e.g., only the binder is removed, and the active material will be reconditioned and reused as such.

Based on the interviews, we have identified some potential challenges faced by the European recycling industry. A clear challenge consists in the **funding** of new recycling plants, which require significant investments to scale up from small-scale (already estimated to be a half-billion-euros investment) to large industrial scale. A funding gap was identified for bringing the recycling technology from TRL 8 to TRL 9.

A **technical challenge** mentioned was the lack of a universal recycling solution that could work for all battery chemistries. Different chemistries require a different recycling line, which will bring extra costs. In addition, some of the new chemistries may be more difficult to recycle (e.g., solid-state batteries). Provisions of various articles of the 2023/1542 battery regulation and related implementing legislation should in principle harmonise the minimum levels of performances the recycling chains are expected to reach in the EU across battery technologies and recycling routes[80], including the collection stage[81]. On the other hand, as a positive note, some can be easier to recycle. For instance, Na-ion batteries with water-based binders both at the anode and cathode side and only aluminium as current collector may have simpler recycling processes than Li-ion batteries. One of the interviewees also mentioned that recycling represents a great opportunity in terms of reducing the environmental impact of batteries, since the **carbon footprint** of secondary materials can be considerably lower (as low as one tenth) than that of primary materials. The emission reduction is however dependent on many factors, such as the recycling method and the origin of the primary raw materials. Based on calculations by Aalto University, the carbon footprint of the raw material obtained by the recycling process is 38% lower than that of the virgin raw material. The difference is even greater if copper and aluminium recovered during mechanical pre-treatment are included.[82] Article 7 of the 2023/1542 battery regulation related to the carbon footprint declaration and related implementing legislation defines clear guidelines on how to consider the contributions of circularity.

As for manufacturing aspects, the interviewees also provided some suggestions on how to support the recycling industry. These include the need to design batteries, and especially the battery packs, for better recyclability – e.g., avoiding excessively big modules, and enabling easier disassembly of the cells from the pack allow higher recycling efficiencies[83]. However, as easy disassembly can compromise safety unless carefully planned, it is important to ensure safety in case of changes in

---

[78] Trends in electric vehicle batteries – Global EV Outlook 2024 – Analysis - IEA and European Commission. Joint Research Centre. Bielewski, M., Pfrang, A., Bobba, S. et al. (2022). *Clean Energy Technology Observatory, Batteries for energy storage in the European Union – Status report on technology development, trends, value chains and markets – 2022*. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/808352.

[79] See e.g., Baum, Z. J., Bird, R. E., Yu, X., et al. (2022). 'Lithium-Ion Battery Recycling – Overview of Techniques and Trends.' *ACS Energy Letters.* 7 (2), 712-719. https://doi.org/10.1021/acsenergylett.1c02602.

[80] Orefice, M., Manni, F.M., Pierri, E., Bobba, S., Gaudillat, P., Vaccari, M., Mathieux, F.. *Technical suggestions for the rules for calculation and verification of rates for recycling efficiency and recovery of materials of waste batteries*,.JRC137139. (to be published in October 2024)

[81] Bobba, S., Manni, F.M., Orefice, M., Mathieux, F. *Technical specifications for a harmonised methodology to calculate collection rates for waste portable and Light Means of Transport (LMT) batteries.* JRC137863. (to be published in October 2024)

[82] Jurva, K. (2021, March 21). 'Is battery recycling environmentally friendly?' *Aalto University.* Retrieved August 20, 2024, from: https://www.aalto.fi/en/news/is-battery-recycling-environmentally-friendly.

[83] See e.g., Thompson, D. L., Hartley, J. M., Lambert, S. M., et al. (2020). 'The importance of design in lithium ion battery recycling–a critical review.' *Green Chemistry*, 22(22), 7585-7603. https://doi.org/10.1039/D0GC02745F.

battery pack design. Another comment was related to the importance of starting to build up the European recycling capacity and skills in advance, eventually adapting [the recycling process and infrastructures] to new chemistries when needed. With regard to the challenge of dealing with the variety of battery chemistries that will eventually enter the feedstock, the battery passport was also regarded as a crucial tool.

As already mentioned, financing the recycling infrastructure is quite challenging. One suggestion was that the EU Member States or the European Commission could create a stockpile of battery raw materials (primary and secondary), to be purchased from the European recycling industry at a pre-agreed price [a form of offtake agreement]. This might help the recycling industry finance the infrastructure, while increasing the security of supply in Europe.

Closely related to recycling, **2nd life use**, i.e., using the end-of-life batteries from EVs in some other application, such as stationary storage, is a topic that has increasingly gained attention. Usually, the battery is considered to reach its end of life in EV applications once its state of health drops to around 80 %, compared to original capacity.[84] It is, however, not so straightforward to identify optimal use for old EV batteries – i.e. recycling them as soon as possible, or extending their lifetime in other applications[85] first.

Many of the interviewees seemed to propend more towards the option of recycling the battery chemicals after first use, instead of employing the batteries in a 2nd life application, especially considering the benefits in terms of valuable critical materials recovery. In addition, it was noted that the properties of a battery designed for EVs might not be a good fit for other applications; for instance, batteries especially designed for stationary storage are expected to work better than 2nd life ones. Cost might also play a role: with 1st life LFP batteries becoming cheaper and overcapacity building up in China, it might not be economically viable to modify and test used EV batteries to build stationary storage systems. In some cases, like for reasonably fresh batteries, a 2nd life approach could be a good solution. There are also companies offering new tools and services to identify the optimal 2nd life use for batteries[86], which might lead to an increase in 2nd life battery applications. It should be noted that extension of lifetime of batteries by repurposing may conflict with the policy objective of integrating more recycled materials in new batteries.[87] Eventually, it will be a market-driven, case-by-case decision to estimate the best use for batteries and their materials after they are not used in EVs anymore.

Finally, current **availability and quality of recycled battery materials** constitute a challenge according to cell manufacturers, who would have an interest and a need to start using and testing secondary materials in their processes. In this regard, it has been noted that batteries have a longer lifetime than originally anticipated; while this can be positive from a consumer and circular economy perspective, it inevitably delays the availability of feedstock and thus recycled raw materials, posing a challenge to cell makers having to soon comply with recycled content requirements set in the Batteries Regulation[88]. In this respect, the main barrier is not the recycling technology itself, but rather the lack of feedstock from end-of-life batteries. This shortage is mainly due to the still limited uptake of EVs and long battery lifetime and could be made worse by indiscriminate 2nd life use. It is also estimated that manufacturing scrap will serve as the primary source for recycling in this decade[89]; to use the phrasing of the Batteries Regulation, only manufacturing waste will be counted as part of the recycled content targets, and not by-products of battery manufacturing that are re-used in the production process.[90] Post-consumer battery waste are expected to grow significantly in recycled content in the next years. One of the interviewees

---

[84] For an overview of EoL thresholds in literature, see Etxandi-Santolaya, M., Casals, L. C., & Corchero, C. (2024). 'Extending the electric vehicle battery first life: Performance beyond the current end of life threshold.' *Heliyon*, 10(4). https://doi.org/10.1016/j.heliyon.2024.e26066.

[85] This can be e.g., as a pack, or after being dismantled and repurposed, both options presenting their own challenges.

[86] CeLLife. https://www.cellife.fi/ (last access: August 20, 2024).

[87] Bobba, S., Mathieux, F., & Blengini, G. A. (2019). 'How will second-use of batteries affect stocks and flows in the EU? A model for traction Li-ion batteries'. *Resources, Conservation and Recycling*, 145, 279-291. https://doi.org/10.1016/j.resconrec.2019.02.022.

[88] Regulation (EU) 2023/1542.

[89] Yu, L., Bai, Y., Polzin, B., et al. (2024). 'Unlocking the value of recycling scrap from Li-ion battery manufacturing: Challenges and outlook.' *Journal of Power Sources*, 593, 233955. https://doi.org/10.1016/j.jpowsour.2023.233955.

[90] "Battery manufacturing waste is likely to be the main source of secondary raw materials for battery manufacturing due to the increase in the production of batteries and should be subject to the same recycling processes as post-consumer waste. Therefore, battery manufacturing waste should be counted as part of the recycled content targets with the objective of accelerating the development of the necessary recycling infrastructure. However, by-products of battery manufacturing that are re-used in the production process, such as manufacturing scrap, do not constitute waste and should therefore not be counted as part of the recycled content targets. [...] 'battery manufacturing waste' means the materials or objects rejected during the battery manufacturing process, which cannot be re-used as an integral part in the same process and need to be recycled". Respectively Rec. 30 and Art.1, par.1(53) of Regulation (EU) 2023/1542.

pointed out that in case the lack of recycled materials were to pose a serious risk to the European battery production, the regulatory framework should be amended accordingly.[91]

> *“Access to raw materials is also a great challenge in Europe: there is need for more incentives and support there, with a database to have a view of those European regions where it is possible to gain access to raw materials, to make batteries and recycle them; as well as to access renewable energy.”*

Once overcome the feedstock hurdle, the challenge will be for the recycling industry to be able to operate at sufficiently high throughput rate and maintain competitive costs, compared to those of virgin materials, while ensuring a high recycling rate, low energy consumption and reduced environmental impact. In this respect, economic viability of recycling can prove particularly challenging for lower value batteries, such as LFP.

---

[91] This possibility to revise the targets set in the Batteries Regulation is envisioned under art. 8(5) of the Regulation, which allows the Commission to amend the provisions in question via delegated act.

4 FROM LAB TO MARKET: CHALLENGES IN EV BATTERY TECHNOLOGY TRANSFER, COMMERCIALISATION, AND DIFFUSION

The following chapters include observations from the interviews focusing on technology transfer and commercialization aspects. Some topics emerged more clearly than others, as they were identified by several different stakeholders; those are given a dedicated section. Additional observations are listed under section 4.7. Selected passages from the interviews are included, to provide a more detailed account of the discussions.

4.1 Pilot lines

The path from an invention to up-scaled production is notoriously difficult, risky, and requiring significant CAPEX. Thus, **pilot lines are important to scale-up** and cross the second valley of death, as they can help with performance and cost validation before investing in larger infrastructure. This answer emerged clearly from almost all the interviews, and the need to have more of these technology infrastructures was the most common recommendation. This is true both for Li-ion batteries and for new chemistries, such as SSBs, which may require high-quality dry rooms. Companies are working on enabling Li-ion battery manufacturing at large scale, and investing in new technologies at the same time is a challenge.

> *"There is a lack of these facilities, [and as a result] lots of startups go to China and Corea to do this now. […] For scaling up fundamental research into prototype and into commercialisation, something is missing in the EU."*

> *"Most of these innovations work perfectly well at lab size […] but then we go at TRL 5-6 and they all fail. […] We need that organisation to test not at lab scale size, but at interim pilot scale, before we go to the next step"*

> *We should support credible technical solutions at pilot plant level […] we need to go beyond all of these different R&D programmes, which are sort of creating separate knowledge and competences; we need to go for manufacturing issues: if you don't create manufacturing capabilities and technologies, then you don't create the jobs and factories".*

It was also clear that **different pilot line concepts** are needed: both open and accessible pilot lines hosted by research institutes or universities for testing new materials and processing methods, and industry-owned pilot lines for intellectual property (IP)-sensitive development. Both are equally important and helping to scale-up at different TRLs[92].

> *"Open access pilot lines would help in the up-scaling work. They could be used even to module/system level. Industry IP can't be shared with the research centres. This would be a problem. However, even without officially sharing the IP, the industry is worried that some secret knowhow might leak out. Collaboration requires high trust. Thus, local pilot lines are needed as trust is built easier in this case. Companies might prefer also using their own pilot lines for very sensitive work."*

Pilot lines can be also used for testing quality control tools and sensors, which would be tricky to do on industrial production lines that do not allow breaks in the production. In addition, they could be also used to train technicians and researchers, as highlighted also in the BATT4EU SRIA (strategic action "Development of education-specific pilot lines"). This kind of facilities are lacking in Europe.

---

[92] According to EARTO, pre-production environments such as pilot lines could be positioned at TRL 7-8 (low scale pilot production demonstrated – manufacturing fully tested, validated and qualified), whereas other technology infrastructures are at TRL 5-6 (testing prototype in user environment – pre-production product). However, it needs to be noted that different interpretations of the TRL scale, as well as the various level of maturity of (especially complex) technologies being piloted in a specific environment make it challenging to identify with precision a TRL. This particular TRL scale integrates manufacturability, thus going from invention (TRL 1-2) all the way to market expansion, where the product and production are fully operational (TRL 9). However, it must be noted that sometimes the use of the term pilot line can be used to refer to prototyping environments, as was mentioned during the interviews conducted for this study. On the complexity of pilot environments and other technology infrastructures, see e.g. EARTO (2014). *The TRL Scale as a Research & Innovation Policy Tool*. Retrieved August 20, 2024, from: https://www.earto.eu/wp-content/uploads/The_TRL_Scale_as_a_R_I_Policy_Tool_-_EARTO%5FRecommendations_-_Final.pdf.

> *"It is also needed to have some training of specialised technicians, on the use of this equipment. Other than having pilot lines for development of the technology, it would be useful to have pilot lines open to training of specialised technicians, that will then have to operate at industrial scale. […] This is something that in this moment is almost lacking; […] several discussions are ongoing, and something is moving, but maybe not yet enough".*

Some pilot lines for Li-ion batteries do already exist in Europe[93]. It was however noted that new pilot lines in Europe should be built ensuring a certain geographical distribution, to enable training of people in several countries, and, thanks to proximity, facilitate collaboration between industry and local organizations. **Geographic proximity** was indeed identified as an important factor, as it helps to build trust, which is essential for any collaboration.

In the interviews, multiple challenges were identified in relation to pilot lines.

For companies, especially for SMEs, access to pilot lines can be a hurdle, as **access fees** can be too onerous. In this respect, one interviewee suggested that the European Commission could establish innovation voucher schemes for SMEs to buy testing time from pilot lines. This kind of Open Innovation test beds and ecosystems do exist in other research fields, e.g., for nano-enabled biobased materials[94], and at least one example exists in the electrochemical storage field too[95]. Such projects offer piloting services for SMEs, and the funding is covered by the projects. In these ecosystems, IP is jointly owned by the SME and the partners involved in the research work. Similar Open Innovation test beds could be useful also in the battery field.

> *"The most expensive part is the [validation] and then TRL 7-8, so basically the stage before going into industrial production. If you really want to show your technology is superior to others, you cannot produce 100 cells, you really need to produce a large amount of cells; that's quite expensive. […] There will be cases where some companies [wanting to use pilot lines] are just not capable to pay for so many cells that have to be produced. […] It would really help European companies to get some funding there."*

> *"Development cycles need to be fast, so startups/spinoffs are the way to go. But access to such infrastructures is a challenge for them, and the access to capital today is very challenging for startups."*

Confidentiality and IP was also mentioned several times as a challenge. As mentioned above, the need for diversified pilot environments was also noted, and in particular to have pilot lines available for use where the IP stays with the company, and ownership does not have to be shared with the pilot line owner. Confidentiality was also presented as an issue. Despite the adoption of non-disclosure agreements (NDA), the risk of information leaking out remains – e.g. in case an individual previously employed at a technology infrastructure is hired by a competitor of a company who has used the pilot line for their development work. Thus, in case of highly IP-sensitive topics, the industry often favours constructing their own pilot lines.

Finally, **insufficient funding** was identified as a barrier to establishing pilot lines, and thus to scaling up. It was noted how national funding has been available only in very few countries, with other member states, especially the smaller and the so-called EU13 countries, lacking the same resources as the others. Some of the interviewees pointed out how they were unable to identify suitable funding, especially for the construction of open-access pilot lines for battery manufacturing at EU level. However, it must be noted that the Innovation Fund[96]

---

[93] See e.g., Fraunhofer Research Institution for Battery Cell Production (FFB), https://www.ffb.fraunhofer.de/en.html (last access: August 20, 2024); and Cidetec Battery Cell Manufacturing Pilot Line, https://energystorage.cidetec.es/en/equipment-and-facilities/battery-cell (last access: August 20, 2024).

[94] European Commission. *Open Innovation Test Beds for nano-enabled bio-based materials (IA).* Retrieved August 20, 2024, from: https://cordis.europa.eu/programme/id/H2020_DT-NMBP-04-2020/en.

[95] TEESMAT. https://www.teesmat.eu/our_services/ (last access: August 20, 2024).

[96] European Commission. CINEA. *Innovation Fund. Deploying innovative net-zero technologies for climate neutrality.* Retrieved August 20, 2024, from: https://cinea.ec.europa.eu/programmes/innovation-fund_en. For instance, under the 2023 call, the IF provides grants to commercialisation projects that consist in (with regard to batteries) "activities helping the construction and operation of innovative renewable energy and energy storage technologies" (small, mid, and large scale general topics), and "construction and operation of manufacturing facilities to produce specific components" for batteries (clean-manufacturing topic). Pilot projects could also apply for grant funding under a dedicated topic; they are expected to "prove an innovative, deep decarbonisation or net carbon removal technology or solution in an operational environment, but are not expected yet to reach large scale demonstration or commercial production. Nevertheless, the project can entail limited production/operation for testing purposes, including delivery to/from potential customers for validation. Typically, these projects would have a limited life-time (3 to 5 years). If the project is successful, the proposed technology should move to the

offers funding for industry-led cell and battery component lines, and potentially also to pilot lines; furthermore, up to €3 billion are earmarked for the battery sector in the upcoming calls to boost the EU's battery manufacturing industry[97]. In addition, funding and financing for pilot lines was, and can be, granted through European Regional Development Fund and EIB loans[98], but also that funding is not accessible to all regions and organizations at the same conditions.

4.2 Trained workforce and skills

Most of the interviewees stated that while in Europe there are numerous skilled researchers, chemists, and electrochemists, there is a **lack of skilled workforce** for factories. This means e.g., operators and technicians, with knowledge on battery manufacturing and quality control tools. In addition, it emerged from the interviews that Europe has limited knowledge on how to set up a cell manufacturing factory. Scaling up battery manufacturing is far from trivial, especially while maintaining high quality with minimized scrap rate and competitive cost. Efficient quality control is essential for the gigafactories. Also, safe working conditions need to be ensured, as well as environmental safety.

> *"We need proper experts in the region, when it comes to new technologies, so that the business can survive"*

> *“"the industry […] are screaming for competence in production, and they also need process. […] we need more education and effort in this sector.”*

The importance of **training opportunities** and the training environment was highlighted by multiple interviewees. It was mentioned that targeted training courses could be complementary to standard education programs better tailored to the battery industry needs, as implementation can be faster than in universities or other schools. It was suggested this could be achieved by short courses of around 6-month duration, on e.g., operations, processing, quality control, and automation. One example of an existing platform providing such courses is the InnoEnergy Skills Institute[99]. A couple of interviewees also mentioned **strategic partnerships** with third countries as a venue to develop skills in EU, including by attracting talent.

> *“We need to attract skills, but with the entire value chain ready to deploy; so we have to look at its weak parts and put efforts in there, for a fully European-based industry”.*

The Batteries Europe position paper on Education and Skills also highlights the importance of training new people and of reskilling activities.[100] The launch of Net-Zero Industry Academies under the eponymous act also aims to address the skills shortage in these sectors, e.g., by developing learning programmes and training materials that can be adopted by Member States and education and training providers.[101] Hands-on training is essential especially for battery manufacturing, for which open-access pilot lines would constitute an important asset. We also need to train the trainers.

Transferrable skills are considered valuable, in order to ramp up the whole battery value chain in a short time. This is an opportunity especially for the SSB industry, which can benefit from the semiconductor or glass industry knowhow, since the processing methods, such as thin film deposition, are partly similar. Education of battery users, wider public and policy makers is also of great importance, as user acceptance, promoted through appropriate policy instruments, is needed to enable wider adoption of EVs, battery technology diffusion and industry scaleup.

Finally, with regard to **tech transfer and commercialisation** skills, a few interviewees highlighted the lack of entrepreneurial, “start-up”, California-like mindset in Europe. This gap was reported both in academia and the research

---

next stage of large-scale demonstration or first-of-a-kind commercial production”. IF grants cover up to 60% of relevant costs and can be cumulated with state aid or other EU funding instruments. European Commission. CINEA. (2024, March 27). *Innovation Fund call 2023 Net Zero Technologies (INNOVFUND-2023-NZT). Version 1.3.* Retrieved August 20, 2024, from: https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/innovfund/wp-call/2023/call-fiche_innovfund-2023-nzt_en.pdf.

[97] BATT4EU (2023, December 18). *The Commission announces €3 billion to boost the EU's battery manufacturing industry.* Retrieved August 20, 2024, from: https://bepassociation.eu/the-commission-announced-e3-billion-to-boost-the-eus-battery-manufacturing-industry/.

[98] Court of Auditors (2023). *Special report 15/2023. The EU's industrial policy on batteries. New strategic impetus needed.* Retrieved August 20, 2024, from: https://www.eca.europa.eu/ECAPublications/SR-2023-15/SR-2023-15_EN.pdf.

[99] EIT InnoEnergy Skills Institute, Battery/Storage, https://www.innoenergy.com/skillsinstitute/solutions/battery/ (last access: August 20, 2024).

[100] Batteries Europe (2024, April). *D1.4 - Position Paper on cross-cutting topics. Education & Skills Task Force.* Retrieved August 20, 2024, from: https://batterieseurope.eu/wp-content/uploads/2024/05/Task-Force-Education-Skills_.pdf.

[101] Regulation (EU) 2024/1735.

community, and in startups attempting to scaleup their technology. In this respect, it was mentioned how Europe should take example from the US attitude towards entrepreneurship, and that PhD and other students should be trained to think beyond the lab, with education supporting tech transfer. Courses for PhD students, providing training for pitching is one tool for this. Having a solid business plan, assessing the commercialisation (licensing) potential of the technology, and adopting a market- and application-oriented approach are some of the features mentioned as important to attract investments and succeed. In addition, Asian companies operating in the EU could be encouraged to participate in the offer of training activities.

4.3 Technical barriers and opportunities

To be competitive at the global level, Europe needs to ramp up production of Li-ion batteries and simultaneously develop new battery technologies, while following through on localisation efforts across the value chain. However, there are several technical challenges that remain to be addressed in order to achieve this goal.

First, there is an urgent need to succeed in getting **Li-ion battery gigafactories** in Europe up and running. This will benefit all stakeholders within the value chain, including smaller companies and researchers. While most of the technical barriers can be overcome, the optimisation of numerous processing steps requires time and effort. According to McKinsey[102], gigafactories in Europe have experienced an average delay of more than 10 months in their start of production, and recent news report about delays e.g., in the Northvolt cell production schedule.[103]

This challenge was a topic of discussion during the interviews. One interviewee noted the **lack of system-level thinking** in Europe, such as an understanding on how to set up battery factories, despite the existing knowledge and expertise in manufacturing. In order to build this type of competence in Europe, pilot lines could play an important role, combined with projects adopting a "helicopter view", e.g. addressing manufacturability aspects early on in the R&D&I process.

The use of digital twins was also mentioned as important to ensure high quality and low scrap rates in cell production. The fierce international competition – both cost and technology wise – was also highlighted as a risk for the long-term sustainability of EU gigafactories.

> *"It would be good to focus on commercialisation challenges, i.e. industrialisation, manufacturing, recycling, more than trying to enhance chemistry properties more and more at lab scale. It doesn't matter how good a chemistry is at lab scale, as long as you cannot scale it and put it in a real application."*

> *"[li-ion]factories in Europe (and the rest of the world, in fact) that are going to be manufacturing more or less the same technology that China has been doing for 10 years and has the economies of scale, raw materials supply, and technological advantage [...]; with the cost structure of Europe we [will struggle] to be competitive versus China unless we are doing something like the US is doing [...]; the business model of these gigafactories is going to be quite complicated".*

Second, bridging the gap between Li-ion and **next-gen batteries** is another main challenge to tackle. Next-generation batteries (at least most of them) still present challenges in terms of lifetime and stability, and especially manufacturing at scale. The interviewees estimated that all-solid-state batteries with a ceramic electrolyte might still take 5 to 10 years to reach sufficient maturity for EV applications; up-scaling their production has revealed to be more challenging than originally expected. However, Na-ion batteries and SSBs with a gel or polymer electrolyte are approaching maturity, and they have been already used in some mobility applications.

In this context, an opportunity to be better leveraged is the **quality of EU research outputs**. Multiple interviewees agreed on the overall good EU performance in basic research and inventive potential. However, many stressed how bringing research results to market presents significant hurdles, going from fundamental research to prototype [first valley of death] and even more so to demonstration at industrial scale and commercial deployment [second valley of death]. As previously mentioned, while at early stages the entrepreneurial mindset is still a challenge, a key obstacle identified in going from "lab to fab" was the lack of funding and technology infrastructures necessary to validate ideas at pilot and eventually at industrial scale. Moreover, while start-ups offer innovative solutions, they

---

[102] A radical approach to cost reduction at climate tech companies | McKinsey

[103] Northvolt likely losing billion-euro order from BMW - electrive.com

might not fully understand all knock-on effects across the value chain. In order to withstand the fierce competition, when developing new battery technologies, it is crucial to account for customer needs, even if this means prolonging the development timeline by 1-2 years.

> *"Something to keep in mind looking at new technologies and chemistries is: capacity of manufacturing, availability of materials, and scale up of production. These are often overlooked in research but should be looked at in the early stages, by having early interactions with OEMs."*

In particular, batteries and battery materials need to be developed to address specific problems and align with application requirements. For instance, BEPA provides support in the form of start-up training, aiming at helping start-ups polish their ideas and be ready for industrialisation.

Finally, one interviewee pointed out that, on top of addressing industrialisation issues early on in the R&D process, more effort should be put into the very last link of the chain – i.e. attracting and securing the massive investments required to set up operations at industrial scale – so that funding dedicated to research grants, piloting, and scaling up is not squandered.

> *"[while] we are throwing in hundreds of millions in pilots and scaleups [TRL 8, relevant industrial environment] […], we do not have a path to put this on the market".*

4.4 Funding, financing, and regulatory aspects

In addition to the technical barriers, most of the interviewed organizations mentioned the clear adverse impact of the US Inflation Reduction Act (IRA) and Chinese subsidies on the European battery industry.

While competition is welcome, the need for this to occur under fair conditions and on a **level-playing field** was stressed multiple times. This is where the EU can play a role in helping the local industry.

> *"We tend to give subsidies to consumers, but we do not give [enough] subsidies to the producers […] I think it is important the EC provides sufficient support in grants and subsidies to industrial [battery] players, so we do not lose too many jobs, competence, and traction."*

In this context, continued R&D&I efforts are essential to ensure Europe remains competitive in this global race for fast advancing battery technologies. However, while the EU R&D ecosystem works well, more funding is deemed necessary for the next step, as scaling-up is very expensive and challenging. One of the examples provided was the considerable differences in material synthesis happening in a 1 litre reactor versus a 20+ litres one; the same applies for all steps in battery manufacturing. EU funded projects are helping to bridge this gap, but according to the interviewees, they are not enough.

> *"I would say this is the main challenge right now in industry: so many initiatives stand right at the starting line, about to kick off, to start building a pilot line or factory. All of this is very CAPEX intensive, it requires a lot of money; the challenge is putting enough time, competence, and money into this."*

> *"Scale-up is a challenge. The industry needs more money to take the next step, but there is not yet much revenue. Thus, they need financial support and in many cases that support requires that you can prove scalability, so it is somewhat a catch 22 situation."*

> *"Between high scale and the lab, there should be an organisation in the middle [bridging this gap], to validate the A sample. […] Especially in the EU ecosystem, people are very innovative on the material science. But there is not enough money, and there is not that middle organisation that helps prove the technology works at reasonable scale, to accelerate development."*

> *"Universities and startups have business angels to get from TRL 3 to 5-6-7; but when the big money is needed, this is a big challenge to overcome. And the bureaucracy is too much burden. So we need programmed support for deployment. We hope the Innovation Fund will help, but we need to start improving it to help deployment in Europe".*

In this regard, there are already funding opportunities for the European battery industry to prepare for and facilitate scaling-up. Some interviewees mentioned the European Innovation Council (EIC) Accelerator programme and the Innovation Fund, both of which received positive feedback and were valued for their support. However, what emerged from the interviews is that industry and research organizations at times encounter **challenges in**

identifying funding sources, and that the applicable rules were not very clear to all. The application process for funding was also perceived as complex, particularly when compared to the situation in the USA. While Horizon funding opportunities for battery-related activities are very well known, other funding instruments were less familiar. To facilitate access to funding, one of the interviewees suggested a single address providing an overview of funding opportunities[104] and targeted advice. A service along these lines is being provided by the European Battery Alliance (EBA)[105], but a tool with wider scope would be valuable, as the EBA's one-stop-shop is meant only to support start-ups and scaleups in getting investor ready for selected EU funding and financing opportunities (EIC Accelerator, Innovation Fund, European Investment Bank (Advisory and Venture Debt), European Bank for Reconstruction and Development). [106]

State aid granted under the **IPCEI** framework was also mentioned more than once as important for funding activities closer to industrialisation, especially in view of making the EU industry more competitive.

> *"EU R&D funding is generally appropriate, but more funding is needed for later stages, such as through IPCEI. Scaling up is expensive and requires many investors."*

However, some barriers were identified, such as disparity of access conditions to IPCEIs across countries[107], administrative burden, and potential challenges for newcomers to the market in entering such projects.

> *"IPCEIs for instance are very good, but [...] from TRL 7 to 10 - the valley of death, first industrial deployment [...], for net zero industries, like batteries, technology development is very fast and very competitive, and there is a race to subsidies too. In this, you cannot have a state aid tool like IPCEI. One way forward is the Innovation Fund, which can help to go forward, to not loose speed towards deployment".*

It was also observed that securing funding can be a time-consuming process, with **Horizon proposals** being particularly challenging to write. In order to make the proposal writing more efficient across Europe, a two-stage process was suggested by one interviewee. In addition, some stakeholders emphasized the importance of increased project flexibility, to accommodate fast-changing market needs. As the planning happens several months before the start of the project, and implementation lasts several years, it is very likely that the global situation will change significantly, and the initial plans might not align with the real market needs anymore.

> *"EU [-funded] projects need more flexibility to quickly follow market trends. It's frustrating to wait before scaling up materials, which may not work once production starts."*

Finally, the Critical Raw Materials Act, Net-Zero Industry Act and the new Batteries Regulation were considered as positive and very welcome steps towards a sustainable and competitive battery value chain in Europe. However, some challenges, uncertainties, and further needs were identified. **Traceability** needs to be implemented carefully and it is not yet clear to industry and researchers how this will be done reliably. There is also a need for certificates for sustainably produced raw materials, taking social and environmental aspects into account.

> *"What was already done in the Batteries Regulation is great, as it puts sustainability at the core of the battery [...] It is also important that sustainability at the core can be implemented in other regulations, like in CRM Act, that sets targets in terms of production capacity and recycling, refining capacity, but there is actually no obligation on traceability. Even if we re-localise [in the EU] part of the supply chain of the battery [...], we already know there are resources we will not be able to re-localise. It's there where traceability is complementary, and needs to be implemented."*

---

[104] With regard to the need to ensure adequate coordination of EU funding and appropriate targeting of support measures, the need for a better overview of EU and national financial support to the battery value chain was also acknowledged in Court of Auditors (2023). *Special report 15/2023. The EU's industrial policy on batteries.*

[105] The service will focus on investor readiness for the EIC Accelerator, the Innovation Fund, selected offerings from the European Investment Bank (Advisory and Venture Debt) and the European Bank for Reconstruction and Development. European Battery Alliance. One-Stop-Shop to EU Finance. https://www.eba250.com/one-stop-shop/. (last access: August 20, 2024). To apply see: https://www.eba250.com/one-stop-shop-form/.

[106] While not exclusively targeting battery technologies, the Strategic Technologies for Europe Platform (STEP) also offers a form of one-stop-shop, providing an overview of funding opportunities supported by the EU budget in the fields of digital and deeptech, cleantech, and biotechnologies. (last access: August 20, 2024). https://strategic-technologies.europa.eu/get-funding_en

[107] This was also highlighted in Court of Auditors (2023). *Special report 15/2023. The EU's industrial policy on batteries.*

Concern regarding future phasing-out of per- and polyfluoroalkyl substances (PFAS)[108] from batteries was also voiced during one interview: in case of a ban of PFAS materials in new batteries, the overall recycling targets are expected to be more challenging to achieve, as it might not be possible to recycle batteries containing these substances into new ones as effectively as required. There is thus a slight conflict in the different regulations: one expects to recycle and reuse most of the battery materials in new batteries, but the other might ban the use of part of the materials (i.e., PFAS) in them.

Slow, and especially unpredictable, **permitting** was also identified as an issue. Despite the new regulatory framework specifically addressing this, some concerns remain in industry. Even though the standard permitting process is expected to become more predictable, the handling of complaints might still cause delays. Concerns over legal certainty seem to be motivated by cases of inconsistent interpretation of the rules (such as court decisions conflicting with the advice the industry had received from the regional authorities) significantly delaying the permitting process.[109] Current lack of clear permitting procedures for new chemistries, such as Na-ion, was also mentioned as a challenge by one of the interviewees; in this respect, the EU regulatory framework was perceived to be Li-ion-chemistry-oriented, raising concerns on its ability to fit with all chemistries.

Finally, it emerged from more than one interview how having an **enabling legislative and policy framework** supporting the battery industry on its path towards increased sustainability and circularity is paramount.

> *"In EU, we need consistent approaches to the transformation, as investments for CAPEX need to have a long-term horizon. […] Transitions and transformations are ok, but we need a profitable industry in order to invest in the transition."*

In particular, the need for a unified and coherent approach was expressed, as opposed to fragmented legislation addressing different aspects and chemistries separately; the Batteries Regulation was mentioned as a positive step in this direction, with the JRC providing the scientific basis for calculations.

> *"EU policy should ensure that the new Battery Regulation treats all mainstream and future battery technologies equally. […] standards play a critical role in providing a cohesive framework to enforce regulatory measures (such as CEN/CENELEC Mandate M/579), while striving for autonomy and engaging in collaboration with international standardization partners."*

4.5 Collaboration amongst relevant stakeholders in the value chain

Establishing and maintaining a competitive and sustainable battery value chain in Europe requires collaboration between academia, research organizations, and industry. All stakeholders are equally important in maintaining a well-functioning ecosystem, each with a specific role and operating at different TRLs.

> *"If you rely on university lab for higher TRL, it's not working well, as it's not their speciality. So the idea is to find an appropriate partner – depending on where you are in your development: at early development it can be a [university] lab; if you want to develop a machine or a system that you want to have in production in two years it needs to be a company."*

> *"Li-ion tech is going to be a slow adoption technology, not a market disruption one. So creating a good ecosystem for li-ion goes in the right direction. But we need to have many companies to work together to build value chains segments that are not yet developed in the EU."*

While the European battery ecosystem is overall well structured, also thanks to the alliances, platforms and initiatives that have flourished at EU level, there is still some room for improvement.

In the context of **academia-industry collaboration**, low-TRL projects were characterised by the interviewees as less challenging. The perceived benefits include the opportunity for industry to acquire new contacts and workforce; an easier collaborative process, as the development is not yet close to commercialization and less IP-sensitive; the chance to train new human resources in the

---

[108] ECHA. Registry of restriction intentions until outcome. https://echa.europa.eu/fi/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b. (last access: August 20, 2024).

[109] An example is that of the German company BASF, having faced permitting issues in setting up a new plant in Harjavalta, Finland, as reported in Weiss, P., Murray M., More, R., et al. (2024, April 11). 'BASF starts layoff process at Finland site after permit problems.' *Reuters.* Retrieved August 20, 2024, from: https://www.reuters.com/markets/commodities/basf-starts-layoff-process-finland-site-after-permit-problems-2024-04-11/.

field, while taking industry needs into account. Once the development approaches higher TRLs, collaboration might encounter difficulties, as the focus shifts towards activities closer to the core business interests of industry partners. One noted challenge in high-TRL collaboration was the tendency of academia, as well as startups and inventors more generally, to prioritise novelty, material innovation, and increased performance above scalability and processability, which are often considered not "good enough" results to be publication-worthy. This approach can potentially result in, e.g., RD&I on an averagely performing material offering ease of processing and energy-efficiency to be dropped due to its below-state of-the-art performance, despite such materials being of value for industry.[110]

> *"Collaboration between academia and industry in Europe is, generally speaking, quite good; in the field of batteries, we have a lot of relationships with labs and so on, also supported by EU funding. […] The main concern in Europe is: how can we go from the science to industrial applications? In Europe we are quite strong in upstream studies and collaborations, but when it comes to real applications, in scaling up into industrial application, things are more difficult. "*

> *"We collaborate with academia as part of the value chain. But sometimes academia announces too soon the potential of some chemistries, and then we face issues in availability of materials, vehicle integration, etc. "*

> *"It's not only about chemistries, it's also about technologies, how do we scale that up. That's something that startups, inventors tend to forget: that in most cases the second best choice is the one that works in industrial scale, not the best case. "*

Collaboration often requires **IP-sensitive data and/or material sharing**, which might pose challenges. Some interviewees mentioned that despite the collaboration usually working well, there have been some issues with sharing information in jointly funded projects. Working with certain partners or research organizations might also be a challenge in case of pre-existing collaboration with competitors. While according to the interviewees severe IP-related conflicts have not been a problem in EU-funded projects, some mentioned how IP can at times still constitute a barrier to accessing materials in jointly funded projects. Overall, cross-industry collaboration entailing information disclosure and materials exchange seems to be perceived as more straightforward and effective, although many companies reported productive collaboration with academia and research centres.

> *"The issue with collaborative IP is of course who owns it in the end and who can take the next step. […] The issue of IP release, […] that's something that we need to tackle within Horizon Europe, and maybe the next Framework Programme […] so that the consortia think about that more clearly from the beginning."*

> *"IP is not an obstacle, it's just a hot point to cover at the beginning of the collaboration, to make sure everyone will be happy in the end."*

Data sharing was mentioned as particularly challenging in relation to the **Battery passport**.[111] The interviewees highlighted the urgency of regulating which information will be mandatory to share and who has access to it. European companies were considered by one interviewee to be more open and some even want to brainstorm with other stakeholders and new technology providers, whereas Chinese and South-Korean companies usually do not disclose much. It also takes time to discuss and explain why the European industry needs the information. It is however believed that the openness will increase once the industry starts to see the value of the Battery passport. It is foreseen that industry might be even willing to share information that is not mandatory to share – if this helps, e.g., with their sales. It is also essential to ensure that

---

[110] According to recent literature, similar difficulties in getting research results to industrialisation scale exist for electrolysers, necessary for green hydrogen production: "In addition to the drive of the academic community in performance improvement by developing novel materials or methods, it would be more practical to identify fundamental structure–function relationships to instruct the development of commercial electrolysers. Instead of one-way scale-up, scale-down may be an important complement to accelerate the deployment of a new technology in industry." Tao, H. B., Liu, H., Lao, K., et al. (2024). 'The gap between academic research on proton exchange membrane water electrolysers and industrial demands.' *Nature Nanotechnology*, 1-3. https://doi.org/10.1038/s41565-024-01699-x.

[111] For an account of recent developments and main challenges, see Rizos, V., & Urban, P. (2024), 'Implementing the EU Digital Battery Passport. Opportunities and challenges for battery circularity.' *CEPS.* Retrieved August 20, 2024, from: 1qp5rxiZ-CEPS-InDepthAnalysis-2024-05_Implementing-the-EU-digital-battery-passport.pdf (europa.eu)

the shared information is reliable, and that confidential information is safely stored. Audits will be needed to make sure that the Battery passport contains information that can be trusted. Finally, the interviewees highlighted the importance to design the Battery passport together with original equipment manufacturers (OEMs), as those mostly affected by it, to get the most out of this tool.

> *"The [Battery Passport's] spirit is good. However, it might be a bit premature. There are challenges in sharing data and assuring that the data is transferred from battery to battery. "*

> *"[The Battery Passport] is very important for the industry, especially for OEMs. It will be a very important tool for circularity - either as proper recycling, or secondary storage systems in industrial areas. But it is very important that sensitive data of companies regarding competition and the battery are well protected."*

> *"How that [the battery passport] is going to work, and how to get data authentication across the whole value chain, down to the mine, is going to be a challenge; an option could be blockchain technology. And also, who should have access to this data? It needs to be only for justified reasons, and not giving access to all those that claim to have an interest. Also because battery manufacturers do not want to disclose the secret recipe of their battery materials to all, unless there is a justified reason, such as for recycling."*

Finally, **trust** amongst partners was mentioned multiple times as crucial for the success of any collaboration, regardless of the project, infrastructure, or existence of non-disclosure agreements. As facilitators of this process, the European networks, such as BEPA, Batteries Europe, EBA and Battery 2030+ are deemed to be of help.

> *"Battery technology uptake goes still quite fast, especially given other things in automotive I think, but still the tech won't get from the lab to the product in one or two years; […] If you have more established networks within Europe where the people know each other, […] and see each other's progress, I think that will help, and is already helping a lot, in making this tech transfer possible, to scaleup and bring different people together from different parts of the value chain."*

The Upcell Alliance, a relatively new initiative bringing together the equipment and machinery for battery manufacturing industry, academia, and research centres, also received positive feedback. Finally, while the EU landscape is populated by a variety of networks and initiatives at times overlapping, this is not seen as necessarily detrimental, as long as these pursue different goals. Furthermore, simplifications and increased coordination amongst the networks have already been undertaken and, with the battery field growing fast, continuous evolution and improvement along the way are expected.

4.6 Support throughout the value chain

With regard to the appropriateness of public funding (either for industry, or via collaborative research projects) supporting different parts of the European battery value chain, the interviewees provided various, at times contrasting feedback.

Some stated that **battery manufacturing** has not been supported as much as **material development**, and this imbalance should be corrected. Some stated the opposite, i.e., that the funding should not focus only on cell manufacturing. Others that there is an overall good balance in EU projects funding throughout the value chain.

> *"Historically, Europe has been too research-focused, with the idea that someone is going to solve the manufacturing. We finally understood this is not the case, and that this someone else might not be Europe. So, it's very important that we follow this all the way from research to the final product, and to be as supportive at the end of this journey as in the beginning."*

While many agreed that support to the production of **equipment for battery manufacturing** is insufficient, one interviewee believed that Europe is lagging too far behind in this field for any increase of funding to be effective, as China is an undiscussed leader in supplying equipment for Li-ion battery production and can boast the best tooling engineers.

Many stated that the **upstream production** (extraction and refining) needs more support. This was believed to bring multiple benefits, including reduced CO_2 footprint of batteries, by striving to make European mining and refining more energy efficient, and increased strategic autonomy of Europe.

> *"[…] we also need to consider the fact that even if cells are manufactured in EU, on the*

> *upstream part of manufacturing – like mining and refining of raw materials – most of the times we are dependent from extra-EU countries, especially China; this is something we need to consider at the highest EU level, as the battery field is of strategic importance. We need to consider what type of technology we want to promote, and how to ensure independence from not only extraction but also refining of raw materials."*

It was also mentioned how public support for the industry can consist not only in grants or subsidies, but also support to reskilling of the workforce, covering education costs, as well as land and access to utilities; in this sense, public-private partnerships with government involvement can be of great help.

Finally, one conclusion was that, in providing support to RD&I solutions across the value chain, the potential for clear positive **societal impact** should serve as a compass. This also means involving early on industry partners to address scalability and industrialisation aspects, ensuring that research results reach the market and benefit wider society.

4.7 Additional observations

One of the indispensable conditions for wider adoption of EVs, and thus to reach carbon neutrality targets, is social acceptance. In this respect, one interviewee stressed that challenges might vary across Europe and across regions, based on factors such as climate and level of urbanisation. Consumer needs mentioned by the interviewees include better charging infrastructure, less expensive EVs, increased sustainability of batteries, as well as reliable and transparent methods to evaluate it.[112]

In order to address the misconceptions around EVs that might further hinder their adoption[113,114], sharing reliable information on how EVs generate and avoid CO_2 emissions compared to ICE vehicles can be important. While it is not straightforward to understand and calculate the impact, some tools are already available for this purpose.[115]

In addition, mining and refining in Europe is a controversial topic. Europe strong dependency on raw materials imported from third countries is a risk for its security of supply and limits the possibility to control mining and refining conditions. New mines are thus needed also in Europe. There is, understandably, a lot of resistance towards these in local communities.

It is thus paramount to have an open dialogue with the citizens and ensure that the mines and raw material factories do not cause any significant harm to the environment. Sharing clear and reliable information about the negative and positive effects of setting up mines in Europe could help to gain citizen acceptance. In particular, potential local negative externalities are expected to be overall offset by the broader positive impact in terms of achieving net-zero and slowing down climate change.

Failing to set up European mines (in a sustainable, ethical, and reliable way) might entail much more negative effects on nature and people living in Europe (and globally) than succeeding in doing so. The need for minerals and methods to ensure their availability in a sustainable way are summarized in the ERA-MIN Strategic Research & Innovation Agenda[116], which states that "Climate change and environmental degradation are an existential threat to Europe and the world". The minerals are needed to prevent this threat. In addition, it has been calculated that the energy transition will require substantially less mining than the current fossil

---

[112] This is in part confirmed by the results of a recent survey conducted across 12 EU member states, which identifies as main barriers for EV adoption amongst non-BEV drivers: price of BEVs, limited recharging options (either private or public), and BEVs' range. European Commission. Directorate-General for Mobility and Transport (2023). *Consumer Monitor 2023. European Alternative Fuels Observatory. European. Aggregated Report.* https://alternative-fuels-observatory.ec.europa.eu/consumer-portal/consumer-monitor. On sustainability aspects, see footnote 95.

[113] According to the above-mentioned survey, the most valuable information for the EU drivers to have on EVs would be: cost comparison with fossil fuel cars, more information about batteries and/or driving range, and a test drive. European Commission (2023). *Consumer Monitor 2023. European Alternative Fuels Observatory. Aggregated Report.*

[114] Environmental factors are shown to influence EV adoption. For instance, according to one literary review on consumers' intention, the reduction in air pollution (e.g., greenhouse gases (GHG), CO2, etc.) is the most cited environmental factor with positive impact on EV adoption, while pollution from battery production is an evident barrier. Pamidimukkala, A., Kermanshachi, S., Rosenberger, J. M., et al. (2024). 'Barriers and motivators to the adoption of electric vehicles: a global review.' *Green Energy and Intelligent Transportation*, 100153. https://doi.org/10.1016/j.geits.2024.100153.

[115] IEA (2024). *EV Life Cycle Assessment Calculator.* Retrieved August 20, 2024, from: https://www.iea.org/data-and-statistics/data-tools/ev-life-cycle-assessment-calculator.

[116] ERA-MIN3 (2024, May). *Strategic Research and Innovation Agenda.* Retrieved Augst 20, 2024, from: https://www.era-min.eu/sites/default/files/publications/eramin_sria_def.pdf.

system[117]. These messages should be shared with the citizens in a clear, visual way.

Reliability of reported battery innovations is also important. Data standardization is one tool mentioned by the interviewees as instrumental to achieving this goal. For example, Batteries Europe has created guidelines for reporting of results[118], currently being updated. Announcements about new RD&I results, performed either at lab scale, with modelling, or any other way, should be realistic. Creating excessive expectations that risk going unmet is detrimental, both for the industry and the research community.

> *"In the past 6/8 years, we have been very optimistic about new technologies and chemistries, and raising the bar on what we expect from new chemistries. This led to expectations and reality to drift apart."*

Researchers should also put more effort into science communication, i.e., disseminating research results in a way that is accessible and understandable to the general public. While scientific publications clearly remain the main outlet for research findings, discussing results in social or other media can be equally important.

---

[117] Nijnens, J., Behrens, P., Kraan, O., et al. (2023). 'Energy transition will require substantially less mining than the current fossil system.' *Joule*, 7(11), 2408-2413. https://doi.org/10.1016/j.joule.2023.10.005.

[118] Batteries Europe (2021). *D3.3.1: Status Report: Continuous benchmarking of cell chemistries: Stage 1 Development of reporting methodologies.* Retrieved August 20, 2024, from: https://batterieseurope.eu/results/reporting-methodologies/.

5 CONCLUSIONS AND RECOMMENDATIONS

While some stakeholders mentioned academic research outputs at times not being sufficiently market-oriented, and some remaining obstacles related to IP, the more pressing lab-to-market challenges for EV batteries were identified downstream in the tech transfer and commercialisation path, where dedicated funding is needed to make it through the second valley of death, e.g. by financing pilot lines and plants, or at the stage of ramping up large scale industrial production. Similarly, the regulatory aspects mentioned as most challenging do not pertain as much to the enabling innovation framework or inventiveness potential in the EU, as to the rollout of the technologies at scale and their diffusion through mass EV adoption in the current sustainable competitiveness paradigm.

The following chapter summarizes the main findings as reported in the chapters above, listing the barriers encountered by the European battery industry in the journey from lab to market and identifying main lines of action and recommendations required to overcome them.

5.1 Battery chemistries for EVs

A clear consensus emerged from the interviews on the future directions for EV battery chemistries: **Li-ion batteries are considered to continue being the predominant chemistry.** On the cathode side, while NMC and LFP are expected to remain the most common, LMFP is gaining more and more attention. Concerning the optimisation of Li-ion batteries, improvements foreseen are silicon-containing anodes, as well as a further increase of the nickel-content in NMC batteries.

Na-ion and solid-state batteries are considered as the next potential candidates for EV applications. While they are not expected to completely replace Li-ion batteries, **Na-ion and solid-state batteries are seen as complementary options for different segments or applications**. Na-ion batteries are suitable especially for entry-level cars, affordable and with shorter-range. Solid-state batteries are expected to power vehicles positioned more towards the premium segment, with more autonomy but higher price, as well as other mobility applications with special requirements, such as e-aviation or drones.

Very few interviewees mentioned chemistries beyond these, in particular emerging technologies at lower level of maturity; this is probably due to the nature of our sample, which did not include many academic partners. Additionally, industry interest in these alternatives has become more limited, also due to excessive expectations created by announcements during the early stages of development. However, there is potential for some emerging chemistries to eventually be suitable for EV applications, such as Li-S or metal air batteries. While it is anticipated that they will not reach the market in the near future, **ongoing and future research on emerging chemistries is highly valuable to uncover new properties that could be applied to EV battery technologies currently in use**, for increased sustainability, energy density or other enhancement of important features. In conclusion, there won't be a one-size-fits-all battery, but chemistry and properties will be tuned to specific application requirements.

5.2 Main barriers and proposed recommendations

5.2.1 Technical barriers

For Li-ion batteries, the main technical barrier is to rapidly scale up production, while having high yield and competitive cost. High quality is not easy to achieve, and digital tools and processing knowhow, amongst others, are needed to minimize the scrap rate.

Regarding next-generation batteries, **Na-ion batteries are expected to benefit from the Li-ion battery processing knowhow**, as the process steps are very similar.

On the other hand, **SSBs still need considerable investments in research for scaling up their processing, and the optimization of their manufacturing is particularly challenging,** compared to Li-ion battery production. However, it is suggested that some skills and knowledge can be adopted from other industries, such as that of semiconductors.

5.2.2 Collaboration in RD&I

The experiences recounted by the interviewed stakeholders in working in collaboration with industry and academia or research centres were quite heterogeneous.

While many spoke of an overall well-functioning ecosystem, some reported hurdles pertaining to sharing of information or to IP, especially in EU-funded projects. Academia-industry collaboration, especially at low-TRL, was considered important in creating connections and training new people working in the battery field. However, in collaborating with academia, it was noted how it is often easier for industry to work on topics that are not yet very close to commercialization.

A recurring message conveyed by multiple interviewees was that **it is essential for academic partners to work together with industry early on in the development process, also to ensure that the developed materials and processes are eventually suitable for production.**

Finally, it was clear from the interviews conducted that while R&D is considered to work well, the biggest challenge in the EU consists in bringing developed inventions to industrial level, with **the gap from TRL7 to TRL9 being a real barrier.**

5.2.3 Funding and financing

There is a clear need for additional financial support for the European battery industry throughout the value chain. This is especially important to **ensuring a level playing field vis-à-vis the IRA in the United States and other subsidy policies in Asian countries**, with newcomers in particular requiring more capital injection for creating new gigafactories in Europe, compared to their more established competitors. These investments are deemed to eventually benefit the whole industry. In this respect, at the EU level, the IPCEI framework was considered to be an important tool, allowing Member States to provide state aid support capable of leveraging significant private investments. However, as there is no centralised EU fund, resources for IPCEI-approved projects need to be secured by beneficiaries in the form of EU and/or national funding. This was mentioned by the interviewees as an overall lengthy process, insufficiently agile for the fast pace of technology development and fierce competition characterising the battery industry, and presenting different degrees of hurdles depending on the Member State granting the aid – a conclusion also reached by the Court of Auditors in their 2023 special report.

In addition, maintaining a diversified approach to R&D on battery chemistries and technologies was recognised as important. In particular, as a domain in which the EU can still have a technological advantage, **next-generation batteries such as SSBs need not only continued research efforts, but also dedicated financial support to transfer the processes from laboratory to a higher scale** and accelerate their deployment. Furthermore, the creation of a domestic EU recycling industry, both for Li-ion batteries and future chemistries, is needed to ensure resilience and to secure availability of secondary raw materials in Europe, in line with the CRMA. This also requires financial support for industry to invest in recycling plants, as well as investments in research activities in the recycling field. Upcoming clarifications on the calculation rules for the implementation of several circularity articles of the 2023/1542 (e.g. article 71 on recycling efficiency) are expected to give more certainty to allow investments in the sector.

Flexibility in the framework programme for research and innovation was also mentioned as an aspect to be improved, allowing for adjustments required by the fast pace of technology development and shifting market needs, together with the need to address IP ownership issues in consortia.

Finally, **a "one stop shop" providing stakeholders with information about different funding opportunities** was also called for, as the funding schemes and instruments outside of Horizon were often considered unclear or were not well known. A more comprehensive mapping of funding sources would also allow for a more synergetic approach to the funding of the battery value chain, both at EU and national level.[119]

5.2.4 Need for pilot lines

As the most common recommendation emerged from the interviews, the need to **potentiate funding for both industrial and openly accessible pilot lines and plants** warrants special attention. Some countries have supported this kind of pilot activities, but the examples are still rare. Having pilot facilities geographically **distributed across Europe** would also help the widening and smaller countries to increase their activities in the battery field and would enable training of workforce locally. In addition, company-owned pilot lines remain necessary for IP-sensitive work.

At EU level, any efforts in this direction should ideally take stock of current funding streams and instruments admitting the funding of such technology infrastructures, such as the Innovation Fund, ERDF, and EIB. The creation of a €3 billion dedicated EU instrument to boost the battery manufacturing industry announced in 2023 could also represent an opportunity in this context.

5.2.5 Regulatory framework

The new Batteries Regulation, as well as the Critical Raw Materials Act and the Net-zero Industry Act were positively welcomed by the interviewed organizations. Setting targets and rules, especially for the sustainable production of batteries, was

---

[119] Court of Auditors (2023). *Special report 15/2023. The EU's industrial policy on batteries.*

acknowledged as important in promoting a sustainable and competitive value chain in Europe.

However, while the two acts specifically aim to streamline and accelerate permitting procedures, **some concerns remain amongst stakeholders on the clarity of the rules laid out and the overall unpredictability of permitting;** in particular, the dilatory effect of prospective complaints on permitting times and conflicting interpretation by competent authorities can constitute a source of uncertainty. Aside from the time limits set for permitting procedures, such issues should be in principle addressed by the "single point of contact" approach adopted in the CRMA and NZIA, the obligation for Member States to ensure that a coordinated or joint procedure is adopted when multiple environmental assessments are required for one project, as well as the possibility for the Net-Zero Industry Academies to target competences for public administrators working in the field of permitting. At this stage, the challenge will be to **ensure that the EU-level provisions are effectively implemented in the Member States at the appropriate level and to facilitate the process through the successful collection and dissemination of best practices on permitting,** e.g., via the Net-Zero Europe Platform and the European Critical Raw Materials Board, as envisioned by the two respective regulations.

Careful implementation of sustainability aspects in the CRMA, e.g., ensuring reliable certification schemes and binding requirements on environmental footprint of the minerals, was also mentioned as paramount to effectively complement relocalisation efforts. Furthermore, while the **ambitious targets on recycled content were deemed to constitute a challenge given the current shortage of feedstock for recycling in the EU**, the option envisioned by the Batteries Regulation to revise them if needed was noted positively.

Finally, the need for an overall enabling legal framework with a unified and coherent approach was also expressed, as opposed to fragmented legislation addressing different aspects and chemistries separately.

5.2.6 Citizen acceptance

Finally, Europe will not be able to succeed in its efforts to scale up the battery industry, reach mass EV deployment while maintaining strategic autonomy, and reduce the emissions from road transport without citizen acceptance. This applies both to new powertrain technologies as well as measures aimed at ensuring their successful rollout, e.g., ensuring sufficient supply of raw materials through relocalisation. While cost of EVs and access to charging infrastructures continue to drive user preference, **clear and accessible communication, such as through a visual approach, of the positive and negative impact of EVs, a battery manufacturing factory, a mine, or a raw material plant could significantly contribute to steer consumers' choice and increase acceptance.** In addition, it is just as important to effectively get across the consequences of failing to set up these factories in Europe, and in particular of the ensuing stronger dependency on other continents, unsecure supply chains and most of all, increasing emissions.

An overview of the above barriers and recommendations is provided below in **Table 1**.

Table 1. Main identified barriers to scaling up EV battery technologies in Europe, and key recommendations

Topic	Barrier/challenge	Recommendation
Li-ion batteries	Setting up gigafactories that can operate with low scrap rate and at competitive cost	More pilot facilities to help with scaling up: both open access and industry owned, geographically distributed across Europe More trained workforce for factories Digital tools to minimize scrap
Next-generation batteries	Upscaling processes to industrial level, especially for SSBs	Piloting activities, e.g., to test new materials and manufacturing technologies Learning and adapting equipment from other industries, such as semiconductor industry
Collaboration in RD&I	Academic research outputs not always in line with industry and manufacturing needs	Ensure academic partners work together with industry early in the development process, also to ensure that the developed materials and processes are eventually suitable for production
Funding and financing	Competing with global players benefitting from subsidy policies in non-EU countries, and lack of funding to reach TRL9 Limited knowledge of funding opportunities beyond Horizon and difficulty in accessing information Challenges in the Framework Programme for research and innovation pertaining to flexibility and IP	Financial support for scaling up, and an enabling financial framework, to create a level playing field within European countries and *vis-à-vis* global competitors Mapping of funding sources and opportunities across the EU at different levels of governance, with potentiated one-stop-shop at EU level to support prospective beneficiaries Consider addressing in the FP the need for a more flexible, market-attuned, industry-oriented approach, and IP-related issues hindering valorisation
Regulatory framework	Slow and unpredictable permitting Ambitious targets set by the Batteries Regulation on recycled content Fairness and sustainability of the critical raw materials value chain heavily dependent on adoption of secondary legislation	Increase legal certainty: ensure the effective implementation of NZIA and CRMA provisions on permitting in the MS and facilitate the process by successfully collecting and disseminating best practices Apply Batteries Regulation provisions on targets revision in case of need Careful implementation of sustainability aspects in the CRMA
User acceptance and uptake	Insufficient citizen acceptance, mostly due to high EV cost and lack of infrastructures Misperception of positive/negative impact of EV batteries and other supporting measures	Accelerate on the deployment of charging infrastructures, lower cost of EVs Share clear and visual information about the benefits/impact of EU-made batteries, locally sourced minerals, etc., *vs* alternative scenarios

REFERENCES

Literature

ACEA (2023, October 7). *Automotive sector: direct and indirect employment in the EU*. Retrieved August 20, 2024, from: https://www.acea.auto/figure/automotive-sector-direct-and-indirect-employment-in-the-eu/.

ACEA (2023, September 28). *The Automobile Industry Pocket Guide 2023/2024*. Retrieved Augst 20, 2024, from: https://www.acea.auto/publication/the-automobile-industry-pocket-guide-2023-2024/.

ACEA (2023, June 1). *Facts about the automobile industry.* Retrieved August 20, 2024, from: https://www.acea.auto/fact/facts-about-the-automobile-industry/#:~:text=The%20turnover%20generated%20by%20the%20automotive%20sector%20represents,chain%20and%20generating%20an%20array%20of%20business%20services.

Altris (2024, June 5). *Altris and Stora Enso in partnership to develop hard carbon anode material for sodium-ion batteries*. Retrieved August 20, 2024, from: https://www.altris.se/news/altris-and-stora-enso-in-partnership-to-develop-hard-carbon-anode-material-for-sodium-ion-batteries.

Aminudin, M. A., Kamarudin, S. K., Lim, B. H., et al. (2023). 'An overview: Current progress on hydrogen fuel cell vehicles.' *International Journal of Hydrogen Energy*, 48(11), 4371-4388. https://doi.org/10.1016/j.ijhydene.2022.10.156.

BATT4EU (2024, February). *Strategic Research and Innovation Agenda*. Retrieved August 20, 2024, from: https://bepassociation.eu/our-work/sria/.

BATT4EU (2023, December 18). *The Commission announces €3 billion to boost the EU's battery manufacturing industry.* Retrieved August 20, 2024, from: https://bepassociation.eu/the-commission-announced-e3-billion-to-boost-the-eus-battery-manufacturing-industry/.

Batteries Europe (2024, April). *D1.4 - Position Paper on cross-cutting topics. Education & Skills Task Force.* Retrieved August 20, 2024, from: https://batterieseurope.eu/wp-content/uploads/2024/05/Task-Force-Education-Skills_.pdf.

Batteries Europe (2024). *European R&I Ecosystem Showcased at Batteries Europe plenary session.* Retrieved August 20, 2024, from: https://batterieseurope.eu/news/batteries-europe-plenary-session/.

Batteries Europe (2021). *D3.3.1: Status Report: Continuous benchmarking of cell chemistries: Stage 1 Development of reporting methodologies.* Retrieved August 20, 2024, from: https://batterieseurope.eu/results/reporting-methodologies/.

Battery News (2023, April 12). *Next-Gen-Batterietechnologien.* Retrieved August 20, 2024, from: https://battery-news.de/next-gen-batterien-europa/.

Baum, Z. J., Bird, R. E., Yu, X., et al. (2022). 'Lithium-Ion Battery Recycling – Overview of Techniques and Trends.' *ACS Energy Letters.* 7 (2), 712-719. https://doi.org/10.1021/acsenergylett.1c02602.

Benchmark Minerals (2024, February 8). *Chinese companies to account for one third of Europe's domestic battery production by 2030.* Retrieved August 20, 2024, from: https://source.benchmarkminerals.com/article/chinese-owned-companies-to-produce-one-third-of-european-battery-cells-by-2030.

Bobba, S., Manni, F.M., Orefice, M., Mathieux, F. (2024) *Technical specifications for a harmonised methodology to calculate collection rates for waste portable and Light Means of Transport (LMT) batteries*. JRC137863. (To be published in October 2024)

Bobba, S., Mathieux, F., & Blengini, G. A. (2019). 'How will second-use of batteries affect stocks and flows in the EU? A model for traction Li-ion batteries'. *Resources, Conservation and Recycling*, 145, 279-291. https://doi.org/10.1016/j.resconrec.2019.02.022.

Borge, L., & Bröring, S. (2020). 'What affects technology transfer in emerging knowledge areas? A multi-stakeholder concept mapping study in the bioeconomy.' *The Journal of Technology Transfer*, 45(2), 430-460. https://doi.org/10.1007/s10961-018-9702-4.

Casas Ocampo, A. (2024, April 23). 'Carbon footprint as key element to comply with battery regulation.' *CIC energyGUNE.* Retrieved August 20, 2024, from: https://cicenergigune.com/en/blog/carbon-footprint-comply-battery-regulation.

Casey, T. (2023). 'New Flow Battery Electric Car To Be Made In The USA.' *CleanTechnica.* Retrieved August 20, 2024, from: https://cleantechnica.com/2023/12/31/new-flow-battery-electric-car-usa-ira/.

Court of Auditors (2023). *Special report 15/2023. The EU's industrial policy on batteries. New strategic impetus needed.* Retrieved August 20, 2024, from: https://www.eca.europa.eu/ECAPublications/SR-2023-15/SR-2023-15_EN.pdf.

Dou, W., Zheng, M., Zhang, W., et al. (2023). 'Review on the binders for sustainable high-energy-density lithium ion batteries: status, solutions, and prospects.' *Advanced Functional Materials*, 33(45). https://doi.org/10.1002/adfm.202305161.

EARTO (2014). *The TRL Scale as a Research & Innovation Policy Tool.* Retrieved August 20, 2024, from: https://www.earto.eu/wp-content/uploads/The_TRL_Scale_as_a_R_I_Policy_Tool_-_EARTO%5FRecommendations_-_Final.pdf.

Edmondson, J. (2023, May 12). 'Will Solid-State Batteries Eliminate the Need for EV Fire Protection?' *IDTechEx.* May 12, 2023. Retrieved August 20, 2024, from: https://www.idtechex.com/en/research-article/will-solid-state-batteries-eliminate-the-need-for-ev-fire-protection/29300.

EEA (2023, October 24). *Greenhouse gas emissions from transport in Europe.* Retrieved Augst 20, 2024, from: https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-transport?activeAccordion=309c5ef9-de09-4759-bc02-802370dfa366.

ERA-MIN3 (2024, May). *Strategic Research and Innovation Agenda.* Retrieved Augst 20, 2024, from: https://www.era-min.eu/sites/default/files/publications/eramin_sria_def.pdf.

Etxandi-Santolaya, M., Casals, L. C., & Corchero, C. (2024). 'Extending the electric vehicle battery first life: Performance beyond the current end of life threshold.' *Heliyon*, 10(4). https://doi.org/10.1016/j.heliyon.2024.e26066.

EUROBAT (2024, June). *Battery Innovation Roadmap 2035*. Retrieved September 09, 2024, from: https://www.eurobat.org/campaigns-and-initiatives/battery-innovation-roadmap-2035/.

EUROBAT (2024, June). *Battery Innovation Roadmap 2035*. *Technical Annex*. Retrieved September 20, 2024, from: https://www.eurobat.org/campaigns-and-initiatives/battery-innovation-roadmap-2035/.

European Commission (2023). *A Green Deal Industrial Plan for the Net-Zero Age*. COM(2023) 62 final.

European Commission (2023). *Communication on the revision of the Strategic Energy Technology (SET) Plan.* COM(2023) 634 final

European Commission (2018). *Europe on the move. Sustainable Mobility for Europe: safe, connected and clean.* COM(2018) 293 final.

European Commission. *Batteries for electric vehicles – carbon footprint methodology.* Public Consultation. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13877-Batteries-for-electric-vehicles-carbon-footprint-methodology_en

European Commission. *Fit for 55: Delivering on the proposals.* Retrieved August 20, 2024, from: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal/fit-55-delivering-proposals_en.

European Commission. *Manufacturing technology development for solid-state batteries (SSB, Generations 4a - 4b batteries) (Batteries Partnership).* Retrieved August 20, 2024, from: https://cordis.europa.eu/programme/id/HORIZON_HORIZON-CL5-2021-D2-01-05/en.

European Commission. *Open Innovation Test Beds for nano-enabled bio-based materials (IA).* Retrieved August 20, 2024, from: https://cordis.europa.eu/programme/id/H2020_DT-NMBP-04-2020/en.

European Commission. CINEA. (2024, March 27). *Innovation Fund call 2023 Net Zero Technologies (INNOVFUND-2023-NZT). Version 1.3.* Retrieved August 20, 2024, from: https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/innovfund/wp-call/2023/call-fiche_innovfund-2023-nzt_en.pdf.

European Commission. CINEA. *Innovation Fund. Deploying innovative net-zero technologies for climate neutrality.* Retrieved August 20, 2024, from: https://cinea.ec.europa.eu/programmes/innovation-fund_en.

European Commission. Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Connell Garcia, W., Garrone, M. (2024). *Reshaping the road ahead – Exploring supply chain transformations in the EU automobile industry*. Publications Office of the European Union. https://data.europa.eu/doi/10.2873/523479.

European Commission (2023). Directorate-General for Mobility and Transport. *Consumer Monitor 2023. European Alternative Fuels Observatory. European Aggregated Report.* https://alternative-fuels-observatory.ec.europa.eu/consumer-portal/consumer-monitor.

European Commission. Joint Research Centre. Carrara, S., Bobba, S., Blagoeva, D. et al. (2023). *Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study*. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/386650.

European Commission. Joint Research Centre. Nindl, E., Confraria, H., Rentocchini, F. et al. (2023). *The 2023 EU industrial R&D investment scoreboard*. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/506189.

European Commission. Joint Research Centre. Bielewski, M., Pfrang, A., Quintero-Pulido, et al. (2023*). Clean Energy Technology Observatory: Battery Technology in the European Union - 2023 Status Report on Technology Development Trends, Value Chains and Markets.* Publications Office of the European Union. https://data.europa.eu/doi/10.2760/52259.

European Commission. Joint Research Centre. Bielewski, M., Pfrang, A., Bobba, S. et al. (2022). *Clean Energy Technology Observatory, Batteries for energy storage in the European Union – Status report on technology development, trends, value chains and markets – 2022*. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/808352.

European Commission. Joint Research Centre. Vysoká, L., Dörr, R., Sarris, S. et al. (2021). *Technology transfer and commercialisation for the European Green Deal*. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/918801.

Festel, G. (2013). 'Academic spin-offs, corporate spin-outs and company internal start-ups as technology transfer approach.' *The Journal of Technology Transfer*, 38, 454-470. https://doi.org/10.1007/s10961-012-9256-9.

Frith, J. T., Lacey, M. J., & Ulissi, U. (2023). 'A non-academic perspective on the future of lithium-based batteries.' *Nature Communications*, 14(1), 420. https://doi.org/10.1038/s41467-023-35933-2

Granskog, A., Bolin, G., Bowcott, H., et al. (2024, June 18). 'A radical approach to cost reduction at climate tech companies.' *McKinsey*. Retrieved August 20, 2024, from: https://www.mckinsey.com/capabilities/sustainability/our-insights/a-radical-approach-to-cost-reduction-at-climate-tech-companies.

Hofer, F. (2009). *The improvement of technology transfer: An analysis of practices between Graz University of Technology and Styrian companies.* Springer Science & Business Media.

Horn, M., MacLeod, J., Liu, M., et al. (2019). 'Supercapacitors: A new source of power for electric cars?' *Economic Analysis and Policy*, 61, 93-103. https://doi.org/10.1016/j.eap.2018.08.003.

IEA (2024), *Batteries and Secure Energy Transitions,* IEA, Paris. Retrieved August 20, 2024, from: https://www.iea.org/reports/batteries-and-secure-energy-transitions.

IEA (2024). *EV Life Cycle Assessment Calculator.* Retrieved August 20, 2024, from: https://www.iea.org/data-and-statistics/data-tools/ev-life-cycle-assessment-calculator.

IEA (2024). *Global EV Outlook 2024*. IEA, Paris. Retrieved August 20, 2024, from: https://www.iea.org/reports/global-ev-outlook-2024.

IEA (2023). *Lithium-ion battery manufacturing capacity, 2022-2030.* IEA, Paris. Retrieved August 20, 2024, from: https://www.iea.org/data-and-statistics/charts/lithium-ion-battery-manufacturing-capacity-2022-2030.

IEA (2022*). Global EV Outlook 2022.* IEA, Paris. Retrieved August 20, 2024, from: https://www.iea.org/reports/global-ev-outlook-2022.

IEA (2022). *Global Hydrogen Review 2022.* IEA, Paris. Retrieved August 20, 2024, from: https://www.iea.org/reports/global-hydrogen-review-2022.

IEA (2022). *Global Supply Chains of EV Batteries.* IEA, Paris. Retrieved August 20, 2024, from: https://www.iea.org/reports/global-supply-chains-of-ev-batteries.

IEA (2020). *Innovation in Batteries and Electricity Storage.* IEA, Paris. Retrieved August 20, 2024, from: https://www.iea.org/reports/innovation-in-batteries-and-electricity-storage.

Janek, J., & Zeier, W. G. (2023). 'Challenges in speeding up solid-state battery development.' *Nature Energy*, 8(3), 230-240. https://doi.org/10.1038/s41560-023-01208-9.

Jeffs, J., Jaswani, P., & Holland, A. (2024) 'Battery Markets in Construction, Agriculture & Mining Machines 2024-2034.' *IDTechEx*. Retrieved August 20, 2024, from: https://www.idtechex.com/en/research-report/battery-markets-in-construction-agriculture-and-mining-machines-2024-2034/1008.

Jephcott, B. (2024). 'Why LMFP cathode is important to the energy transition.' *Golden Dragon Capital.* Retrieved August 20, 2024, from: https://www.goldendragoncapital.com/lmfp-market-research-report.

Jurva, K. (2021, March 21). 'Is battery recycling environmentally friendly?' *Aalto University.* Retrieved August 20, 2024, from: https://www.aalto.fi/en/news/is-battery-recycling-environmentally-friendly.

Kim, J., Kim, Y., Yoo, J., et al. (2023). 'Organic batteries for a greener rechargeable world.' *Nature Reviews Materials*, 8(1), 54-70. https://doi.org/10.1038/s41578-022-00478-1.

Lavoie, J.R., & Daim, T. (2019). 'Technology Transfer: A Literature Review.' In: Daim, T., Dabić, M., Başoğlu, N., et al. (eds) 'R&D Management in the Knowledge Era.' *Innovation, Technology, and Knowledge Management.* Springer, Cham. https://doi.org/10.1007/978-3-030-15409-7_17

Leong, K. W., Pan, W., Yi, X., et al. (2023). 'Next-generation magnesium-ion batteries: The quasi-solid-state approach to multivalent metal ion storage.' *Science advances*, 9(32). https://doi.org/10.1126/sciadv.adh1181.

Li, Y., Vasileiadis, A., Zhou, Q. et al. (2024). 'Origin of fast charging in hard carbon anodes.' *Nat Energy,* 9, 134–142. https://doi.org/10.1038/s41560-023-01414-5.

Liu, W., Placke, T., & Chau, K. T. (2022). 'Overview of batteries and battery management for electric vehicles.' *Energy Reports*, 8, 4058-4084. https://doi.org/10.1016/j.egyr.2022.03.016.

Lu, Y., Zhao, C. Z., Yuan, H., et al. (2022). 'Dry electrode technology, the rising star in solid-state battery industrialization.' *Matter*, 5(3), 876-898. https://doi.org/10.1016/j.matt.2022.01.011.

Mageto, T., Bhoyate, S. D., Mensah-Darkwa, K., et al. (2023). 'Development of high-performance zinc-ion batteries: issues, mitigation strategies, and perspectives.' *Journal of Energy Storage*, 70, 108081. https://doi.org/10.1016/j.est.2023.108081.

Nijnens, J., Behrens, P., Kraan, O., et al. (2023). 'Energy transition will require substantially less mining than the current fossil system.' *Joule*, 7(11), 2408-2413. https://doi.org/10.1016/j.joule.2023.10.005.

Orefice, M., Manni, F.M., Pierri, E., Bobba, S., Gaudillat, P., Vaccari, M., Mathieux, F. *Technical suggestions for the rules for calculation and verification of rates for recycling efficiency and recovery of materials of waste batteries.* JRC137139. (To be published in October 2024)

Pamidimukkala, A., Kermanshachi, S., Rosenberger, J. M., et al. (2024). 'Barriers and motivators to the adoption of electric vehicles: a global review.' *Green Energy and Intelligent Transportation*, 100153. https://doi.org/10.1016/j.geits.2024.100153.

Randall, C. (2024, January 02). 'First sodium-ion battery EVs go into serial production in China.' *Electrive*. Retrieved August 20, 2024, from: https://www.electrive.com/2024/01/02/first-sodium-ion-battery-evs-go-into-serial-production-in-china/.

Randall, C. (2024, June 20). 'Northvolt likely losing billion-euro order from BMW.' *Electrive*. Retrieved August 20, 2024, from: https://www.electrive.com/2024/06/20/northvolt-likely-losing-billion-euro-order-from-bmw/.

Rizos, V., & Urban, P. (2024), Implementing the EU Digital Battery Passport. Opportunities and challenges for battery circularity.' *CEPS.* Retrieved August 20, 2024, from: 1qp5rxiZ-CEPS-InDepthAnalysis-2024-05_Implementing-the-EU-digital-battery-passport.pdf (europa.eu)

Rosellón Inclán, I. (2024, April 30). 'Solid-state batteries for electric vehicles: Still in R&D or on the verge of commercialization?.' *Fraunhofer ISI.* Retrieved August 20, 2024, from: https://www.isi.fraunhofer.de/en/blog/themen/batterie-update/feststoffbatterien-elektro-autos-kommerzialisierung-stand-forschung-entwicklung.html

Rudola, A., Sayers, R., Wright, C. J., et al. (2023). 'Opportunities for moderate-range electric vehicles using sustainable sodium-ion batteries.' *Nature Energy*, 8(3), 215-218. https://doi.org/10.1038/s41560-023-01215-w.

Rui, X., Ren, D., Liu, X., et al. (2023). 'Distinct thermal runaway mechanisms of sulfide-based all-solid-state batteries.' *Energy & Environmental Science*, 16(8), 3552-3563. https://doi.org/10.1039/D3EE00084B.

Shao, P., & Zheng, H. (2023). 'Comparison of Electric Vehicles and Hydrogen Fuel Cell Vehicles.' *Highlights in Science, Engineering and Technology,* 32, 259-270. https://doi.org/10.54097/hset.v32i.5176.

Siddiqi, S., Holland, A. 'Sodium-ion Batteries 2024-2034: Technology, Players, Markets, and Forecasts.' *IDTechEx.* Retrieved August 20, 2024, from: https://www.idtechex.com/en/research-report/sodium-ion-batteries-2024-2034-technology-players-markets-and-forecasts/978.

Sliz, R., Valikangas, J., Silva Santos, H., et al. (2022). Suitable cathode NMP replacement for efficient sustainable printed Li-ion batteries. *ACS applied energy materials*, 5(4), 4047-4058. https://pubs.acs.org/doi/10.1021/acsaem.1c02923.

Tabeta, S. (2024, February 12). 'CATL, BYD, others unite in China for solid-state battery breakthrough.' *Nikkei Asia.* Retrieved August 20, 2024, from: https://asia.nikkei.com/Business/Technology/CATL-BYD-others-unite-in-China-for-solid-state-battery-breakthrough.

Tao, H. B., Liu, H., Lao, K., et al. (2024). 'The gap between academic research on proton exchange membrane water electrolysers and industrial demands.' *Nature Nanotechnology*, 1-3. https://doi.org/10.1038/s41565-024-01699-x.

Thompson, D. L., Hartley, J. M., Lambert, S. M., et al. (2020). 'The importance of design in lithium ion battery recycling–a critical review.' *Green Chemistry*, 22(22), 7585-7603. https://doi.org/10.1039/D0GC02745F.

Wang, Q., Zhou, D., Zhao, C. et al. (2024). 'Fast-charge high-voltage layered cathodes for sodium-ion batteries.' *Nat Sustain*, 7, 338–347. https://doi.org/10.1038/s41893-024-01266-1.

Waseem, M., Amir, M., Lakshmi, G. S., et al. (2023). 'Fuel cell-based hybrid electric vehicles: An integrated review of current status, key challenges, recommended policies, and future prospects.' *Green Energy and Intelligent Transportation*, 100121. https://doi.org/10.1016/j.geits.2023.100121.

Weiss, P., Murray M., More, R., et al. (2024, April 11). 'BASF starts layoff process at Finland site after permit problems.' *Reuters*. Retrieved August 20, 2024, from: https://www.reuters.com/markets/commodities/basf-starts-layoff-process-finland-site-after-permit-problems-2024-04-11/.

Ye, L., Liao, M., Zhang, K., et al. (2024). 'A rechargeable calcium–oxygen battery that operates at room temperature.' *Nature*, 626(7998), 313-318. https://doi.org/10.1038/s41586-023-06949-x.

Yu, L., Bai, Y., Polzin, B., et al. (2024). 'Unlocking the value of recycling scrap from Li-ion battery manufacturing: Challenges and outlook.' *Journal of Power Sources*, 593, 233955. https://doi.org/10.1016/j.jpowsour.2023.233955.

Yun, G., & Kim, J. (2021, April 29). 'LG Energy Solution Looking to Commercialize Lithium-Sulfur Batteries and All-Solid-State Batteries Starting from 2025 at the Earliest.' *ETNews*. Retrieved August 20, 2024, from: https://english.etnews.com/20210429200001?mkt_tok=MjExLU5KWS0xNjUAAAGKVstCxY9GH0H3s8Ndg-V2NNS_kXvxJfVl22o7zs9JnvHcr8lWCUo_k0u7Fveph04o85P16_gug30KPPZI-gk.

Zarrabeitia, M., Carretero-González, J., Leskes, M., et al. (2023). 'Could potassium-ion batteries become a competitive technology?' *Energy Materials*, 3(6). https://doi.org/10.20517/energymater.2023.41.

Zhang, P. (2023, April 20). 'CATL, BYD's sodium-ion batteries both to be in mass production within this year, report says. *CnEVPost*. Retrieved August 20, 2024, from: https://cnevpost.com/2023/04/20/catl-byd-sodium-ion-batteries-mass-production-this-year-report/.

Legislation

Regulation (EU) 2024/1735 of the European Parliament and of the Council of 13 June 2024 on establishing a framework of measures for strengthening Europe's net-zero technology manufacturing ecosystem and amending Regulation (EU) 2018/1724. http://data.europa.eu/eli/reg/2024/1735/oj.

Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020. http://data.europa.eu/eli/reg/2024/1252/oj.

Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020. http://data.europa.eu/eli/reg/2024/1252/oj.

Regulation (EU) 2023/851 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2019/631 as regards strengthening the CO2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition. http://data.europa.eu/eli/reg/2023/851/oj.

Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU. http://data.europa.eu/eli/reg/2023/1804/oj.

Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC. http://data.europa.eu/eli/reg/2023/1542/oj

Other websites

Altris. https://www.altris.se/ (last access: August 20, 2024)

Blue Solutions. https://www.blue-solutions.com/en/ (last access: August 20, 2024)

CeLLife. https://www.cellife.fi/ (last access: August 20, 2024)

Cidetec. https://energystorage.cidetec.es/en/equipment-and-facilities/battery-cell (last access: August 20, 2024)

Delfort. Battery Separator Papers. https://delfort-group.com/specialty-paper-products/battery/p/battery-separator-papers/ (last access: August 20, 2024)

ECHA. Registry of restriction intentions until outcome. https://echa.europa.eu/fi/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b. (last access: August 20, 2024)

EIT InnoEnergy Skills Institute, Battery/Storage, https://www.innoenergy.com/skillsinstitute/solutions/battery/ (last access: August 20, 2024)

EPO. Deep tech finder. https://datavisualisation.apps.epo.org/datav/public/dashboard-frontend/host_epoorg.html#/explore?dataSet=1 (last access: August 20, 2024)

European Battery Alliance. One-Stop-Shop to EU Finance. https://www.eba250.com/one-stop-shop/. (last access: August 20, 2024)

Faradion. https://faradion.co.uk/ (last access: August 20, 2024)

Fraunhofer FFB. https://www.ffb.fraunhofer.de/en.html (last access: August 20, 2024)

Nio. https://www.nio.com/news/nio-launches-standard-range-hybrid-cell-battery (last access: September 14, 2024).

ONE. Gemini. https://one.ai/products/gemini (last access: August 20, 2024)

ProLogium. https://prologium.com/about (last access: August 20, 2024)

STEP. https://strategic-technologies.europa.eu/get-funding_en (last access: September 25, 2024)

Stora Enso. Lignode. https://www.storaenso.com/en/products/lignin/lignode (last access: August 20, 2024)

TEESMAT, https://www.teesmat.eu/our_services/ (last access: August 20, 2024)

theion. https://www.theion.de/ (last access: August 20, 2024)

Tiamat. https://www.tiamat-energy.com/. (last access: August 20, 2024)

LIST OF ABBREVIATIONS AND DEFINITIONS

AFIR	Alternative fuels infrastructure
B2B	Business to business
CRM	Critical raw materials
CRMA	Critical Raw Materials Act
BEPA	Batteries European Partnership Association
EBA	European Battery Alliance
EIC	European Innovation Council
EV	Electric vehicle
GHG	Greenhouse gas
HFCV	Hydrogen fuel cell vehicle
ICE	Internal combustion engine
IP	Intellectual property
IPCEI	Important Project of Common European Interest
IRA	Inflation reduction act
LFP	Lithium iron phosphate
LMFP	Lithium manganese iron phosphate
LTO	Lithium titanium oxide
NDA	Non-disclosure agreement
NMC	Lithium nickel manganese cobalt oxide
NMP	N-methylpyrrolidone
NZIA	Net-Zero Industry Act
PVDF	Polyvinylidene fluoride
RDI	Research, development, and Innovation
RTO	Research and technology organisation
SME	Small and medium-sized enterprise
SSB	Solid-state battery
TRL	Technology readiness level

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

— by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

— at the following standard number: +32 22999696,

— via the following form: european-union.europa.eu/contact-eu/write-us_en.

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

Open data from the EU

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.