CHARACTERIZATION OF THE CIRCULAR BATTERY VALUE CHAIN

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CEA	Beneficiary	RTO	FR
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ABEE – Avesta Battery & Energy Engineering	Beneficiary	Enterprise	BE
ITE – Instituto Tecnológico de la Energía	Beneficiary	RTO	ES
TECNALIA	Beneficiary	RTO	ES
NUTAI	Beneficiary	Enterprise	ES
COMAU	Beneficiary	Enterprise	IT
LUT University	Beneficiary	University	FI
THI - Technische Hochschule Ingolstadt	Beneficiary	University	DE
VDL Staalservice BV	Beneficiary	Enterprise	NL
VDL Parts BV	Affiliated Entity	Enterprise	NL
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Executive summary

This report is conducted under the EU Horizon REINFORCE project, which aims to strengthen the European batteries industry, mitigate supply risk, reduce dependence on battery imports, and address environmental concerns related to battery lifecycle. Key goals include developing a circular economy for batteries, promoting battery lifecycle extension through repurposing them for second and third life applications, and improving the recycling of critical raw materials from end-of-life batteries. The REINFORCE project envisions a paradigm shift towards holistic circular economy strategies, covering the entire battery value chain from design and manufacturing to recycling.

This report maps the circular battery value chain and creates ground for circular business model design. The overview of the battery value chain presented in this report is a synthesis of information gathered from primary and secondary sources. Primary data, collected through 53 interviews with 66 circular battery value chain representatives between 2021-2024, was complemented by scientific literature, current market data and policy documents.

Chapter 1 provides background on the need for battery value chain development, driven by increased demand and the presence of critical raw materials in batteries, and introduces circular economy strategies as a potential solution to the battery challenge.

Chapter 2 describes the different stages of the circular battery value chain and presents the most significant industrial actors. This section shows that raw materials originate outside of Europe, and cell manufacturing is a bottleneck, from the perspective of European sufficiency. Major players include automotive OEMs, battery manufacturers, and recycling companies, and a key trend, among actors, is vertical integration to get greater control over the value chain and secure a stable supply of primary and secondary raw materials.

Chapter 3 maps the regulations, policies, and incentives related to developing the circular battery value chain and promoting battery repurposing in Europe. The current regulatory environment is heavily focused on reducing resource dependencies on critical raw materials from countries such as China. Consequently, as batteries contain high concentrations of critical raw materials legislation is focused on incentivizing recycling of used batteries, rather than repurposing. Current regulation in the EU provides little to no incentives for battery lifecycle extension through repurposing.

Chapter 4 details the used battery value chain, highlighting various lifecycle extension strategies with a particular emphasis on repurposing batteries for second life applications. Chapter 4 introduces six organizational models for second life business for used batteries: 1) Automotive OEMs entering the energy storage business; 2) Recycling companies piloting their second life solutions; 3) Energy companies offering second life solutions for batteries, 4) Battery manufacturing companies closing the resource loop; 5) New businesses and startups; and 6) Marketplace platforms. These organizational models represent the summary of the emerging batteries' second life business.

Chapter 5 outlines the key challenges in the circular battery value chain and uncertainties in the development of a market for repurposing used batteries. Key challenges are lack of used batteries, lack of control over batteries through their lifecycle, legislation favoring recycling routes over repurpose, lack of standardization, and economic unprofitability.

Chapter 6 concludes the report by considering the future of the European circular battery value chain from various perspectives. It discusses the geopolitical landscape, technological advancements, and market dynamics affecting the value chain and summarizes the most significant uncertainties regarding the development and scaling of a battery repurposing business. Alongside battery availability, the competition between various circular economy strategies is considered a challenge. The evaluation of different circular economy strategies is heavily influenced by the level at which they are studied. From a perspective of the level of circularity and overall sustainability and performance, various aspects should be considered, such as a holistic examination of battery performance, durability, and sustainability throughout its lifecycle, the development of supply and demand in terms of vehicle and battery sizes, and the impact of carbon emission targets.

This report provides an overview of the European battery value chain as it existed in 2024. However, the dynamic nature of the battery industry necessitates acknowledging ongoing market shifts. For instance, lithium iron phosphate (LFP) batteries have gained prominence while the new Battery Regulation 2023/1542, largely designed for lithium nickel manganese cobalt oxides (NMC) chemistry, has entered into force. Furthermore, fluctuating demand has disrupted forecasts, leading to battery project delays and cancellations. Despite these current market uncertainties, batteries remain crucial for the energy transition and electrification and the sustainable circular battery value chain plays a significant role in Europe’s security.

1. INTRODUCTION

Lithium-ion batteries (LIBs) play a significant role in enabling the transition to clean energy, particularly in electrification. While highly efficient for storing electricity, the increasing demand for LIBs in electric vehicles (EVs) and energy storage systems (ESSs) has led to increased demand for critical raw materials (CRMs), particularly lithium, but also cobalt, and nickel (IEA, 2024a; 2024b) (Figure 1). These materials are not only strategically and economically important but also face risks of supply shortages and price volatility (European Council, 2024).

In 2023, battery demand for lithium reached approximately 140 kilotons, constituting 85% of total lithium demand and representing a 30% increase from the previous year. Similarly, battery demand for cobalt increased by 15% to 150 kilotons, accounting for 70% of total cobalt demand. While less pronounced, battery demand also contributes to the rising demand for nickel, comprising over 10% of total nickel demand. In 2023, battery demand for nickel reached nearly 370 kilotons, a 30% increase compared to the previous year. (IEA, 2024b)

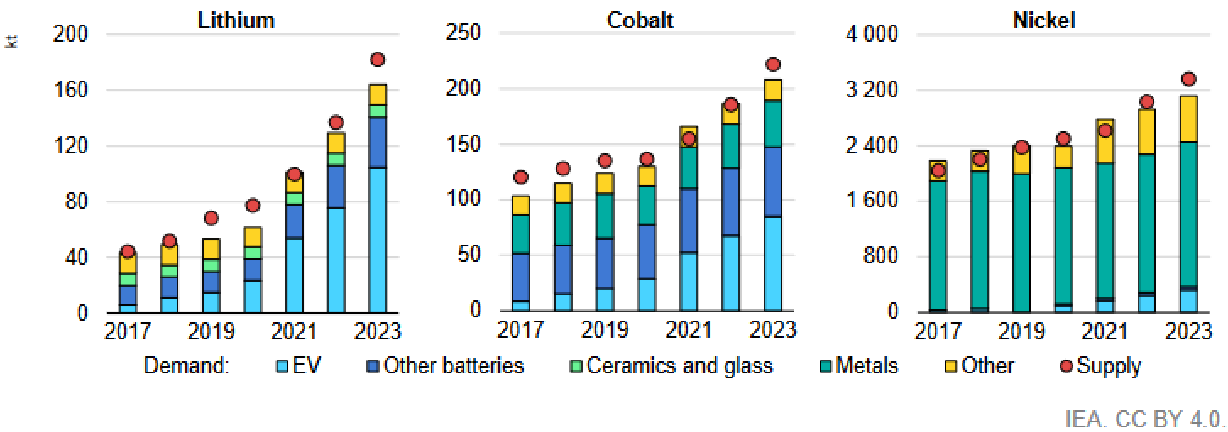


Figure 1. Supply and demand of battery metals by sector 2017-2023 (IEA, 2024b)

Global demand for EV batteries is projected to increase substantially, fueled by rising EV sales in established and emerging markets (Figure 2). While China, Europe, and the Unites States (US) remain major players, countries like India, Southeast Asia, South America, Mexico, and Japan are emerging as key contributors to future battery demand. The International Energy Agency (IEA) has presented various growth scenarios, each indicating significant growth. In the Stated Policies Scenario (STEPS), EV battery demand is projected to grow four-and-a-half times by 2030 and nearly seven times by 2035 compared to 2023. The Announced Pledges Scenario (APS) and The Net Zero Emissions by 2050 Scenario (NZE) project even more significant growth, with demand multiplying by five and seven times in 2030, and nine and twelve times in 2035, respectively. Additionally, the emerging stationary energy storage market will further boost battery demand, contributing approximately 400 GWh and 500 GWh in the STEPS and APS scenarios, respectively, by 2030. (IEA, 2024b)

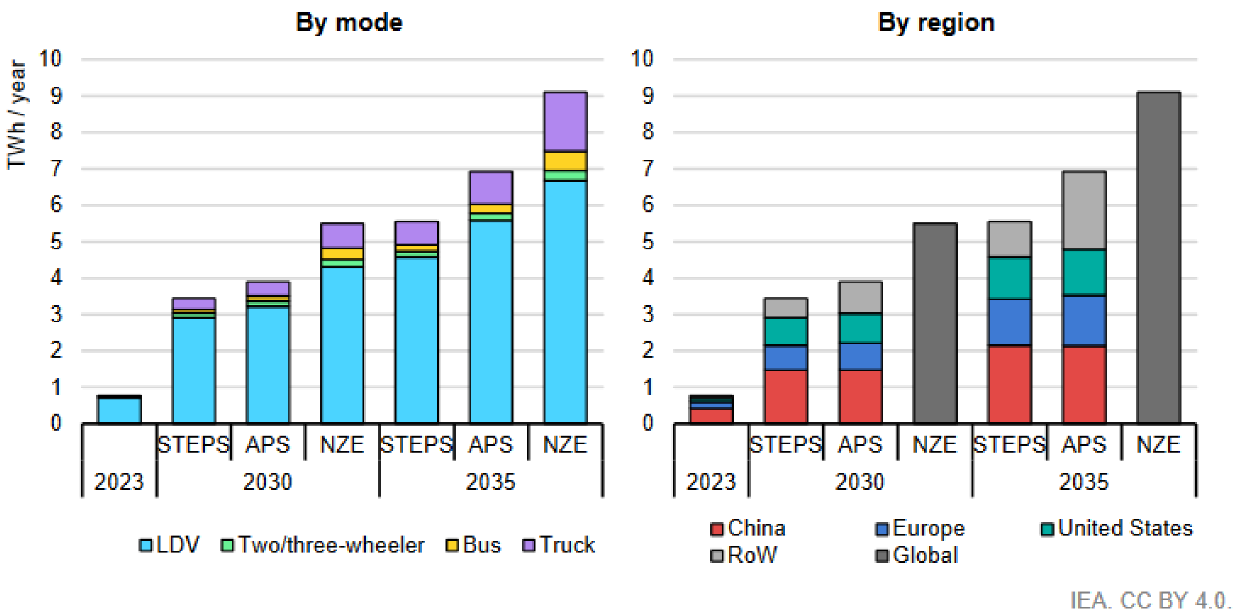


Figure 2. Battery demand for EVs by mode and region 2023-2035, Notes: LDV = light-duty vehicle, including cars and vans; RoW = Rest of the world (IEA, 2024b)

LIB producers rely on a few countries for most of their key raw materials, but the geographical concentration does not only apply to raw material sources but also to production. The LIB supply chain is global, and the majority of LIBs are manufactured in China, increasing the supply risk. Growing demand for LIBs increases the importance of anticipating the occurrence of supply chain disruptions and proactively preparing for supply risks. However, many traditional supply risk management practices, such as avoidance of risky geographical areas or certain suppliers cannot be used in LIB supply chains because of the high geographical concentration. Strategies aiming for circularity as well as technologies, governmental and regulatory support, and cooperation between stakeholders are proposed to mitigate supply risks in the batteries supply chain (Baars et al., 2021).

1.1. Circular economy strategies as solutions to Battery Challenge

According to Geissdoerfer et al. (2020, p. 3), a circular economy (CE) is "*An economic system in which resource input and waste, emission, and energy leakages are minimized by cycling, extending, intensifying, and dematerializing material and energy loops. This can be achieved through digitalization, servitization, sharing solutions, long-lasting product design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling*." The number of CE strategies, often referred to as so-called R-strategies, has evolved from the 3R concept of 'reduce, reuse and recycling' to 10 Rs (Reike et al., 2018) covering the entire lifecycle of a product (Figure 3).

Figure 3. Circular economy strategies (Kirchherr and Piscicelli, 2019)

While this study examines the entire battery value chain and the promotion of circularity, the focus is on extending the battery lifecycle through repurposing before recycling. Repurpose, should not be considered a standalone practice; to understand the viability and sustainability of the strategy, it must be considered within the broader context of the CE. As many of the used EV batteries maintain significant energy capacity, the decision to repurpose or recycle them for raw materials is a pressing one. We start by defining **battery repurposing** as the usage of the battery in another application than its original purpose, such as stationary energy storage, providing a second or even third life to the used battery (Quinteros-Condoretty et al., 2025).

The second life EV battery market is of great importance for many reasons. These include adding value to future energy infrastructure, creating a CE for EV batteries, and mitigating battery supply risk. IDTechEx (2023) forecasts that the second life EV battery market will be worth US$7 billion by 2033.

To secure a sustainable supply of CRMs, the European Union (EU) aims to enhance battery lifecycle extension and promote recycling, which is also the main focus of the REINFORCE project and this report. However, the significantly growing demand cannot be solely met through increased circularity; increasing domestic mining activities and securing CRM imports from outside the EU are needed as well. To accurately model battery material demand, it is essential to consider three key factors:

1) **the potential to extend battery lifecycles and the demand met via repurposing**,
2) **the availability of recycled materials**, and
3) **the continued need for primary raw materials**.

1.2. The focus of this study and the aim of the report

This report is conducted under the EU Horizon REINFORCE project, which aims to strengthen the European batteries industry, reduce dependence on battery imports, and address environmental concerns related to battery lifecycle. Key goals include developing a CE for batteries, promoting reuse and repurposing used batteries in second and third life applications, and improving the recycling of CRMs from end-of-life batteries. The REINFORCE project envisions a paradigm shift towards holistic CE strategies, covering the entire battery value chain from design and manufacturing to recycling.

This report presents a summary of findings from task 7.1 **Circular battery value chain characterization** of work package 7 Sustainability and circular business modeling. This report maps the circular battery value chain and creates ground for circular business model design.

The report is structured as follows: Chapter 2 maps the European circular LIB value chain from raw material sourcing to recycling. Chapter 3 explores relevant regulations, policies, and incentives for LIBs and the development of a circular LIB value chain. Chapter 4 focuses on the value chain for used LIBs, while Chapter 5 delves into the challenges associated with extending the LIB lifecycle. Finally, Chapter 6 concludes with future considerations. Next, prior to Chapter 2, the key concepts used in this report are defined.

1.3. Key concepts

To fully understand the findings and implications of this report, it is essential to grasp the key concepts that underpin the research. Given the diversity of terminology surrounding the circular battery value chain, where terms are often used inconsistently, this section summarizes the key terms used in this report and their corresponding definitions.

Critical raw materials (CRMs) are raw materials of high economic importance for the EU, with a high risk of supply disruption due to their concentration of sources and lack of good, affordable substitutes. In 2023, a fifth list of 34 CRMs was published. Out of the 34 CRMs listed, specific **strategic raw materials (SRMs)** are identified. These are materials that are needed for the green transition, digitalization, or defense technologies and are expected to grow exponentially in terms of supply, which have complex production requirements and thus face a higher risk of supply issues. Battery-grade metals lithium, nickel, manganese, and natural graphite are considered both critical and strategic raw materials. (European Council, 2024)

Circular economy (CE) is: "An economic system in which resource input and waste, emission, and energy leakages are minimized by cycling, extending, intensifying, and dematerializing material and energy loops. This can be achieved through digitalization, servitization, sharing solutions, long-lasting product design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling." (Geissdoerfer et al., 2020, p. 3)

Circular economy (CE) strategies form a framework designed to shift away from the traditional "take-make-dispose" linear economic model towards a circular model where 1) resource use is minimized through smarter design, manufacture, and use, 2) resources are kept in use for as long as possible, extracting the maximum value from them as product, and 3) finally recovering materials for further use. The prioritized CE strategies are refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover (Reike et al., 2018).

End-of-life management of batteries begins when a battery can no longer be used in the application it was initially designed for (e.g. EV batteries). This report refers end-of-life management to the CE strategies: reuse, repair, refurbish, remanufacture, repurpose, and recycle. Batteries can be reused, repaired, refurbished, remanufactured, and repurposed through a process that includes battery assessment, disassembly, and reintegration. As a final step, end-of-life management includes recycling.

Battery repurposing, often confused with reuse, means that a battery is completely or partially used in another application than its original purpose, such as stationary energy storage, providing a **second life** to the used EV battery (energy capacity below 80%). After a second life, used batteries (where energy capacity is between 40-60%; if less, the battery goes for recycling) can even have a **third life** in another application, such as backup power. (Quinteros-Condoretty et al., 2025) This report uses the term "**used battery**" instead of "end-of-life battery" to emphasize that the battery is not at the end of its lifecycle as a product but holds value and has significant remaining capacity. The term "**end-of-life battery**" refers to a battery that no longer functions as a usable product and is directed to recycling.

2. EUROPEAN CIRCULAR BATTERY VALUE CHAIN

In this Chapter, the European circular LIB value chain is mapped from primary raw material sources to recycling (Figure 4).

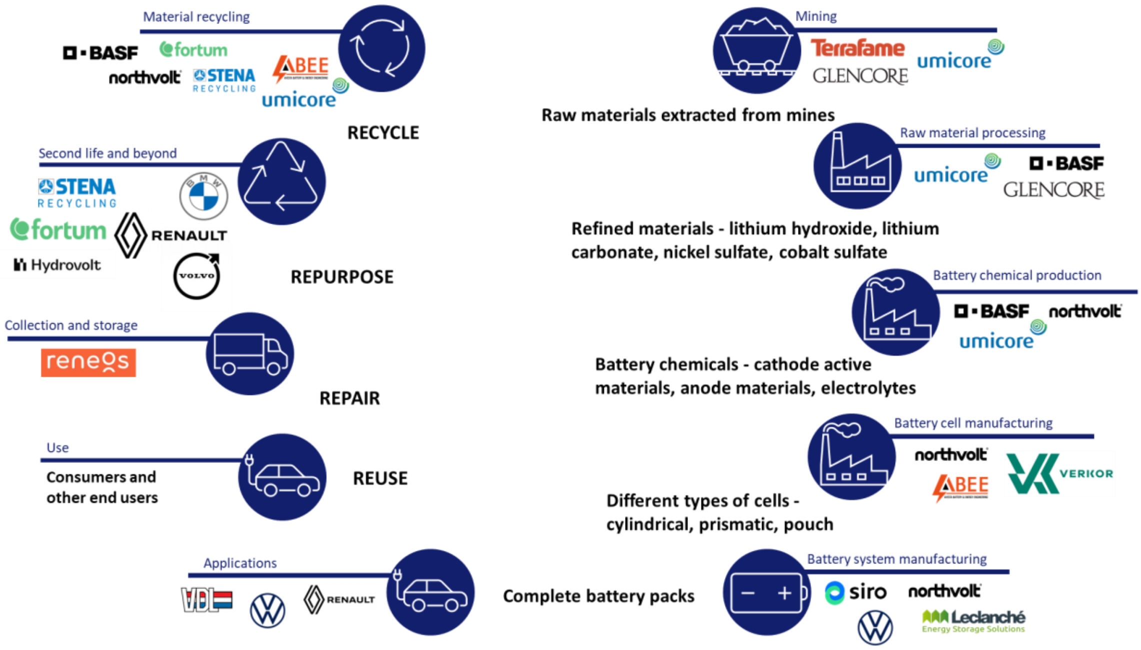


Figure 4. Circular battery value chain with some company examples

2.1. Mining

Mining plays a crucial role in the early stages of the LIB value chain. It involves the extraction of **CRMs** like lithium, cobalt, nickel, manganese, and graphite, which are essential components for manufacturing battery cells.

LIB producers rely on a few countries for most of their key raw materials (Table 1) and the EU is heavily dependent on imports of CRMs from third countries. For example, around 70% of cobalt originated in the Democratic Republic of Congo (DRC) (IEA, 2023) (Figure 5), a country where women and children work in or around unsafe mines for non-existent pay (Sovacool et al., 2020).

Table 1. Share of top-five countries of critical battery raw materials reserves (IEEP, 2024)

CRM	Country	Reserves (tons)
Cobalt	DRC	4.000.000
	Australia	1.500.000
	Indonesia	600.000
	Cuba	500.000
	Philippines	260.000
Lithium	Chile	9.300.000
	Australia	6.200.000
	Argentina	2.700.000
	China	2.000.000
	USA	1.000.000
Manganese	South Africa	640.000
	China	280.000
	Australia	270.000
	Brazil	270.000
	Ukraine	140.000
Nickel	Australia	21.000.000
	Indonesia	21.000.000
	Brazil	16.000.000
	Russia	7.500.000
	Philippines	4.800.000

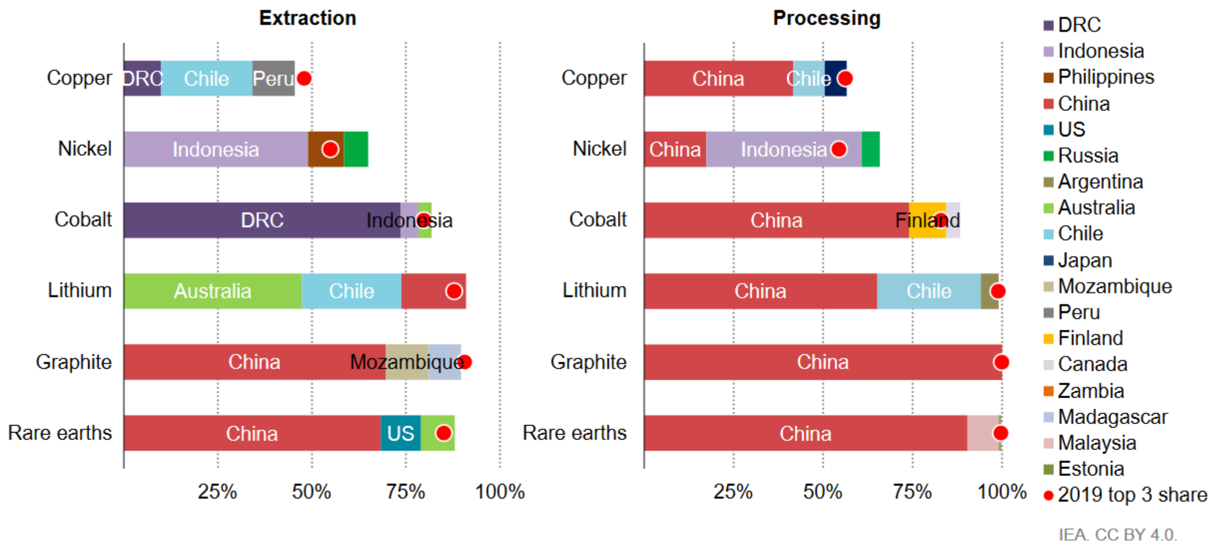


Figure 5. Share of top three producing countries in total production for selected resources and minerals, 2022 (IEA, 2023)

While Europe has made significant progress in developing a circular and sustainable LIB value chain, there are still gaps, particularly regarding raw materials. The dependence on foreign sources can create geopolitical risks and supply chain vulnerabilities. Historically, Europe has exploited colonies for raw materials (Hobson, 2018), but today's supply of raw materials has become even more complex and faces numerous challenges. China's dominance in securing LIB raw materials from Africa highlights the competitive landscape and the need for Europe to develop alternative sourcing strategies. Moreover, environmental issues can pose supply risks to LIB raw materials. The extraction and processing of these materials can have severe environmental consequences, such as water scarcity, acid mine drainage, and wastewater pollution.

Investments in raw material extraction and processing and developing new sourcing strategies are crucial to mitigate supply risk. Both automotive and battery original equipment manufacturers (OEMs) are becoming serious about CRM supplies as there has been a notable pick-up in strategic investment into the raw material sector since 2021 (IEA, 2023). For example, in 2023, **Volkswagen** announced to build an EV battery ecosystem in Indonesia and partner with miner Vale, Ford Motor Company, and China's battery minerals producer Zhejiang Huayou Cobalt to reduce costs and ensure a stable supply of nickel for Volkswagen's EV production (Reuters, 2023).

Reopening mines in Europe could potentially provide a more secure and sustainable source of raw materials for the battery industry. However, the feasibility of this approach depends on various factors, including the availability of suitable mining sites, environmental regulations, and economic considerations. Europe does not have significant primary cobalt and lithium mining operations, but cobalt resources are spread across Europe in various deposit types, with the greatest potential in Balkan and Turkish laterites and Fennoscandian magmatic and black shale deposits (Horn et al., 2021). Europe also has significant lithium deposits as 27 potential hard-rock lithium deposits have been identified across Europe, totaling an estimated 8.8 million tons of lithium oxide (Gourcelor et al., 2019).

European legislation is viewed as a hindrance to development. New mining projects also must get social licenses to operate as there is a reluctance to reopen mines within Europe, which at least slows down the projects.

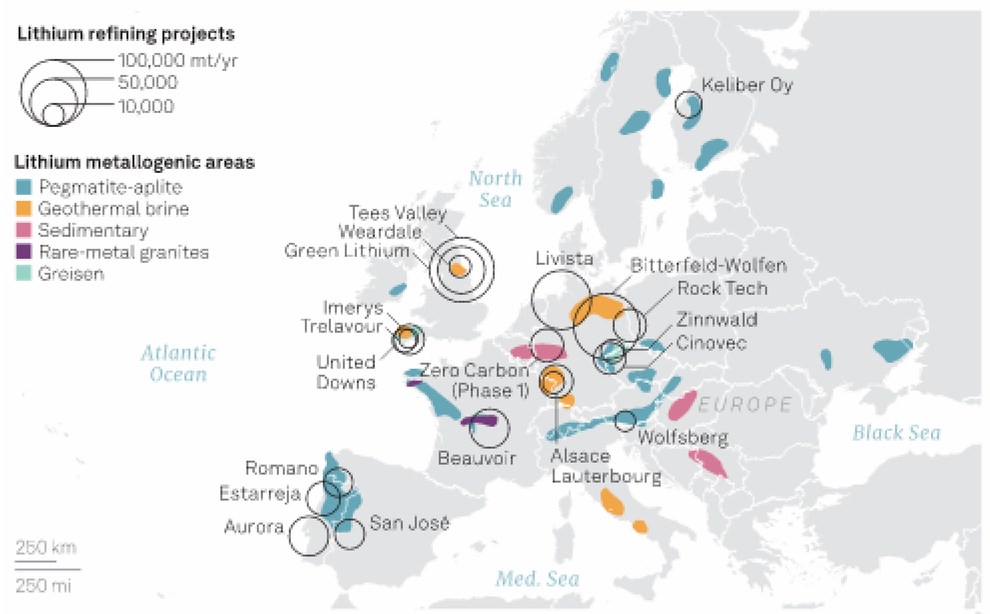
2.2. Raw material processing

Refining is a crucial stage in LIB value chain, transforming raw materials extracted from mines into battery-grade chemicals suitable for battery production. High-quality refined materials are crucial for producing efficient, long-lasting, and safe LIBs, while efficient refining processes minimize environmental impact and add significant economic value to raw materials. The refining process involves steps of purification, in which impurities and contaminants from the raw materials are removed, the concentration of valuable materials, like lithium, cobalt, nickel, and manganese, and conversion to battery chemicals, for example, lithium is chemically transformed into lithium hydroxide. As outputs, a refining process provides refined materials like lithium hydroxide, lithium carbonate, nickel sulfate, and cobalt sulfate. While lithium carbonate has been the traditional choice for battery materials, the increasing demand for higher-performance batteries has led to a growing preference for lithium hydroxide. The choice between the two depends on the specific requirements of the battery application, such as energy density, cost, and performance.

Refining and battery recycling are closely intertwined. Refining processes, originally designed for extracting metals from raw materials, are now adapted to recover valuable metals from used batteries. By applying similar techniques, recycling facilities can extract and purify lithium, cobalt, nickel, and other critical materials, making them suitable for reuse in new battery production.

China dominates battery raw material processing (Figure 5), but both new mining and refining projects are set to strengthen Europe's battery value chain. Several European lithium mining and refining projects are set to begin commercial operations in the next years (Figure 6), driven by OEMs' efforts to localize battery value chains and reduce reliance on imports. For example, developed by **European Lithium**, the Wolfsberg project in Austria aims to produce lithium hydroxide for EV batteries, and **Keliber** is developing a lithium hydroxide production plant in Finland. Further, even though, most of the world's cobalt production comes from the DRC and Europe does not have large-scale cobalt mining, it plays a significant role in the cobalt refining. For example, a Finnish mining company **Terrafame** produces nickel and cobalt sulphates, which are used as battery chemicals.

Sustainability has become a competitive advantage in the mining industry, especially for companies that have already integrated sustainability as a core value in their operations. The increasing demand in the automotive industry for sustainably produced materials highlights this trend. European companies such as Boliden and Terrafame have focused on minimizing their carbon footprints, thus making them more potent for suppliers for automotive companies.



Extraction   Processing   ■ Lithium Hydroxide   ● Lithium Carbonate

Project name	Owner	Start	Category	Capacity ('000 mt/yr)	Product
Bitterfeld-Wolfen	AMG Lithium	2024	Processing	100.0	■
Cinovec	European Metals-CEZ	2024	Extraction, Processing	22.5	●
United Downs	Geothermal Engineering	2024	Extraction, Processing	12.0	●
Tees Valley Lithium	Tees Valley Lithium	2025	Processing	96.0	■
Lauterbourg (First Phase)	Viridian Lithium	2025	Extraction, Processing	25.0	■
Keliber Oy	Sibanye-Stillwater-FMG	2025	Extraction, Processing	15.0	■
Wolfsberg	European Lithium	2025	Extraction, Processing	8.8	■
Livista	Livista Energy	2026	Processing	80.0	■ ●
Aurora	Galp-Northvolt	2026	Processing	35.0	■
Rock Tech Lithium	Rock Tech Lithium	2026	Processing	24.0	■
Zero Carbon Lithium (Phase 1)	Vulcan Energy Resources	2026	Extraction, Processing	24.0	■
Imerys British Lithium	British Lithium-Imerys	2026	Extraction, Processing	20.0	●
San José Lithium Project	Infinity Lithium-Valoriza Minera	2026	Extraction, Processing	19.5	■
Zinnwald Lithium Project	Zinnwald Lithium	2026	Extraction, Processing	12.0	■
Trelavour	Cornish Lithium	2026	Extraction, Processing	7.8	■
Green Lithium	Green Lithium	2027	Processing	50.0	■
Estarreja Lithium Refinery	Bondalti-Neometals	2027	Processing	25.0	■
Romano Mine	Lusorecursos Portugal Lithium	2027	Extraction, Processing	18.0	■
Beauvoir	Imerys	2028	Extraction, Processing	34.0	■
Weardale Lithium	Weardale Lithium	NA	Extraction, Processing	10.0	●
Alsace	Eramet-Electricite de Strasbourg (ES)	NA	Extraction, Processing	10.0	●

Figure 6. New lithium refining capacity set to reduce Europe's import dependence (S&P Global, 2023)

2.3. Battery chemical production

Battery chemical (or battery component) production companies use the refined materials as process inputs to create the final battery chemicals like cathode active materials, anode materials, and electrolytes, used in LIB production. The battery industry has shifted towards developing chemistries that minimize reliance on CRMs. For example, the focus is currently on creating precursors without cobalt and litium-rich compositions. Furthermore, there is a parallel effort in developing sodium-ion battery technologies.

Traditional companies like US-based multinational company **3M** and German multinational company **BASF** have been involved in materials production for decades and have diversified into battery components. Newer companies like South Korean **SK Innovation** and Belgian **Umicore** have expanded their operations to focus on battery materials and components in response to the growing demand for EVs and ESSs. While some companies may be vertically integrated, handling both refining and chemical production and/or cell manufacturing, it is also common to see specialized companies focusing on either refining, chemical production or cell production. There are many planned and already implemented projects in the field of active material production for LIBs in Europe (Figure 7). For example, the Norwegian company **Vianode** specializes in the production of sustainable anode graphite materials for LIBs (Figure 8).

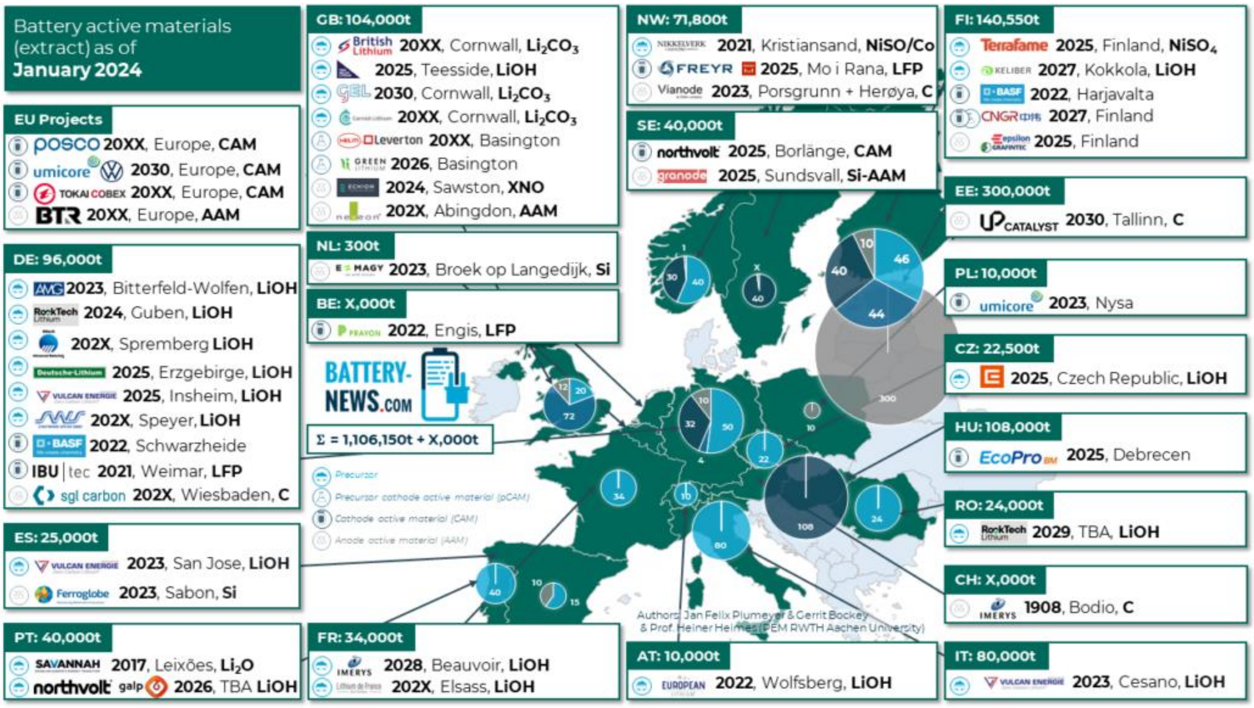


Figure 7. Planned and implemented LIB active material projects in Europe (Battery-News, 2024a)

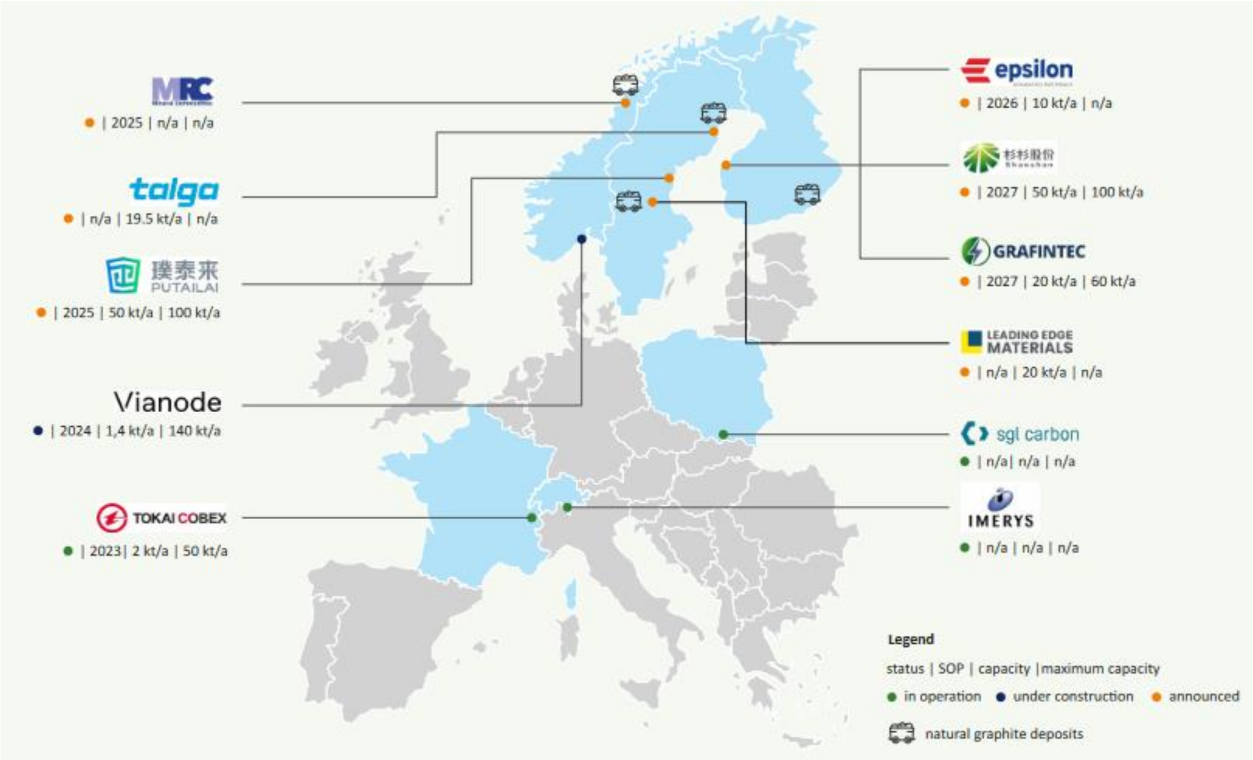


Figure 8. Anode active material production in Europe (IPCEI, 2024)

2.4. Battery cell manufacturing

Battery cell manufacturers use the materials provided by chemical production companies to create the fundamental units of batteries, i.e. cells, that are further combined to form battery modules and packs. At the core of battery technology lies in the cell and the **design** plays a crucial role. The performance of a LIB depends on several factors, including its chemistry and cell format, which are determined before the actual cell manufacturing process begins. The decision is based on factors like the desired energy density, power output, lifespan, and safety requirements.

Different chemistries, such as Lithium Iron Phosphate (LFP), Lithium Nickel Manganese Cobalt Oxide (NMC), and Lithium Nickel Cobalt Aluminum Oxide (NCA), offer varying levels of energy density, power density, and safety. All these chemistries are used in EV batteries. The current market is increasingly shifting from NCA and NMC towards LFP batteries, which contain fewer CRMs than NCA and NMC batteries. Battery chemistry significantly impacts batteries' end-of-life management. NMC batteries, rich in valuable CRMs, are relatively easy to recycle economically. In contrast, recycling LFP batteries is often considered less economically viable due to their simpler composition. However, LFP batteries, known for their better safety, could potentially find a second life in stationary energy storage applications, extending their overall lifecycle.

There are three primary types of LIB cell formats: cylindrical, prismatic, and pouch, with different shapes and offer also varying levels of energy density, cycle life, mechanical robustness, and safety, and being suitable for different applications. All these cell types are used in EV batteries. For example, cylindrical cells (Figure 9) are used in Tesla Model 3 and Model Y. BMW and Volkswagen group primarily utilize prismatic cells (Figure 10) in their EVs while Ford, for example, primarily uses pouch cells (Figure 11).

For second life applications, prismatic cells are often considered the most suitable. The prismatic cells are assembled in hard shells and are typically designed as modules, which makes them easier to disassemble and reassemble into new applications and scale to different sizes and capacities.

Figure 9. Cylindrical cells in Tesla model S module

Figure 10. Prismatic cells in BMW module

Figure 11. Pouch cell

China dominates raw material processing, battery chemical production, battery cell manufacturing, and further EV production (Figure 12). Major investments are being made in building large-scale battery cell factories to strengthen the resilience of Europe's LIB value chain. Several companies are investing heavily in building battery gigafactories and completely new projects are under development, such as Belgian **Avesta Battery & Energy Engineering (ABEE)** and French **Verkor** (Figures 13 and 14). In Europe, seven companies—ACC, AESC, CATL, LG Energy Solution, Northvolt, Samsung SDI, and SK On—are operating in LIB cell manufacturing. These facilities have a combined nominal annual production capacity of approximately 190 gigawatt-hours. In addition, several sites are currently in the construction phase and numerous others are planned.

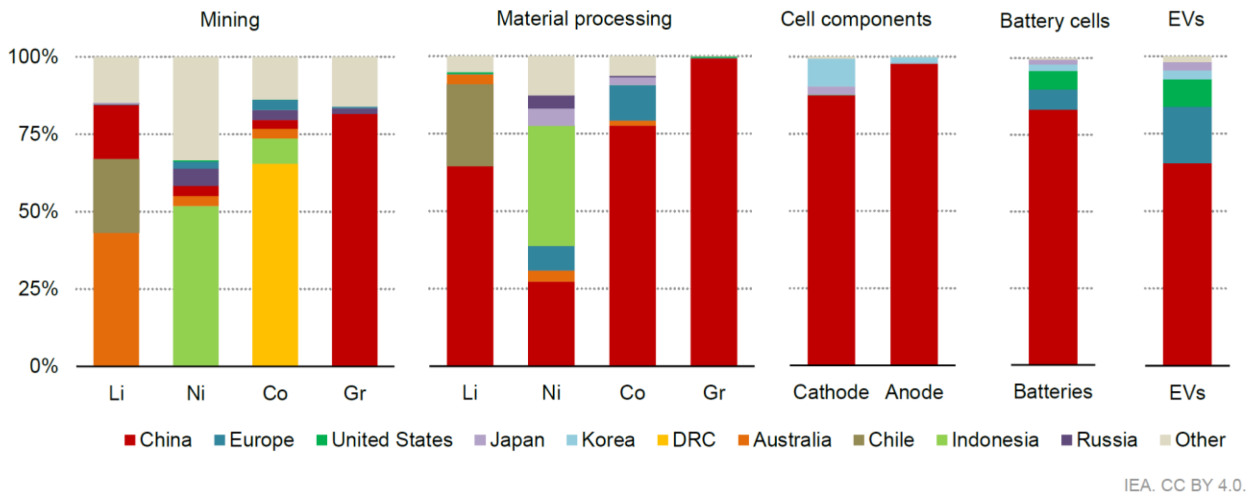


Figure 12. Geographical distribution of the global EV battery supply chain 2023, Notes: Li = lithium; Ni = nickel; Co = cobalt; Gr = graphite (IEA, 2024b)

ACC (Automotive Cells Company), a joint venture between Saft, Stellantis, TotalEnergies, and Mercedes-Benz, has cell production in France and is developing other facilities in Germany and Italy. **AESC**, founded in Japan in 2007 and has been a producer of Nissan LEAF's battery cells since 2010, expanded EV battery production to the U.K. in 2012. In 2021, Renault announced a strategic partnership with AESC and one year later BMW did the same (AESC, 2024). Also, Chinese company **CATL** has expanded its operations to Europe and has an operating manufacturing facility in

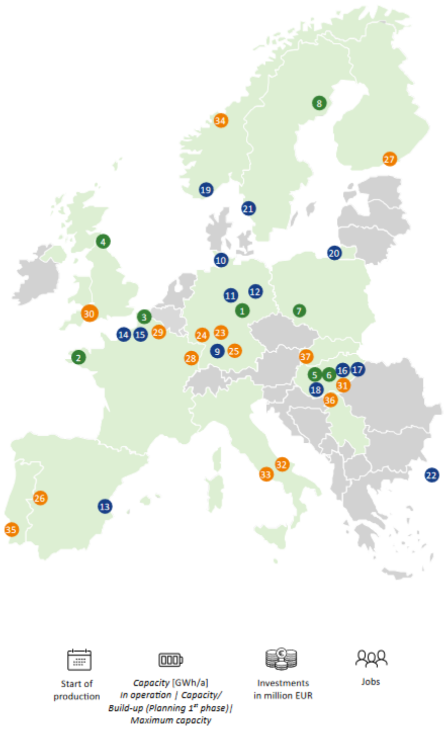
Germany. South Korean company **LG Energy Solution (LGES)** has a significant presence in Poland, where they have established a large-scale battery cell production facility providing battery cells to various European automotive OEMs, including Audi, BMW, and Volkswagen. Both South Korean companies **Samsung SDI** and **SK On** have their European presence in Hungary, where they have built large-scale battery cell production facilities to expand their battery production capacity and meet the growing demand for EVs. In Europe, Poland is the leading producer of battery cells for EVs, accounting for approximately 60% of the region's total production in 2023, and Hungary follows closely, contributing nearly 30% (IEA, 2024b). Approximately 75% of existing European battery cell manufacturing capacity is owned by Korean companies, with LG's Polish plant contributing roughly 50% (IEA, 2024b).

In operation

#	company							
1	CATL	DE	2022	14	24	24	2.000	1.800
2	BlueSolutions	FR	2013	1	1	1		
3	acc	FR	2013	13	26	40	2.000	
4	AESC	GB	2012	2	14	35	1.470	
5	SK on	HU	2020	18	18	18		
6	Samsung SDI	HU	2018	40	50	50		
7	LG Energy Solution	PL	2018	86	90	115		
8	northvolt	SE	2021	16	60	60		

Under construction

#	company							
9	CELLFORCE	DE	2024		0,1	1		
10	northvolt	DE	2026			60	3,000	4,500
11	PowerCo	DE	2025		20	40		2,000
12	Tesla	DE				100		
13	PowerCo	ES	2026		40	60		
14	AESC	FR	2025		9	30		1,300
15	Verkor	FR	2025		16	50	1,200	1,941
16	CATL	HU	2025			100		7,340
17	EVE 亿纬锂能	HU	2026		28	28	1,000	1,000
18	SK on	HU	2024		30	30		2,483
19	MORROW	NO	2024		1	43		
20	Rosatom	RU	2026		4	12		
21	NOVO	SE	2026		18	50		2,965
22	Farasis	TR	2026		20	50		



Announced (Potential)

#	company							
23	acc	DE	2026		13	40		
24	SVOLT	DE			6	24		
25	VARTA	DE				2		
26	AESC	ES	2025			50		
27	Finnish Minerals Group	FI				60		
28	BlueSolutions	FR	2030			25		2,000
29	ProLogium	FR	2026			48		
30	AGRATAS	GB	2026			40		
31	Sunwoda	HU						
32	acc	IT	2026		26	40	2,000	2,000
33	FAAM	IT	2022		8	8		500
34	elinor.	NO	2026			40		
35	CALB	PT	2025		15	45		
36	ElevenEs	RS	2026		8	48		
37	InoBat	SK	2026		20	40		

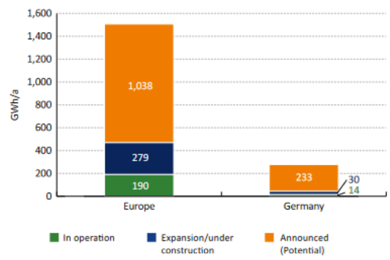


Figure 13. Manufacturing of LIB cells for traction batteries in Europe (IPCEI, 2024)

Funded by the European Union

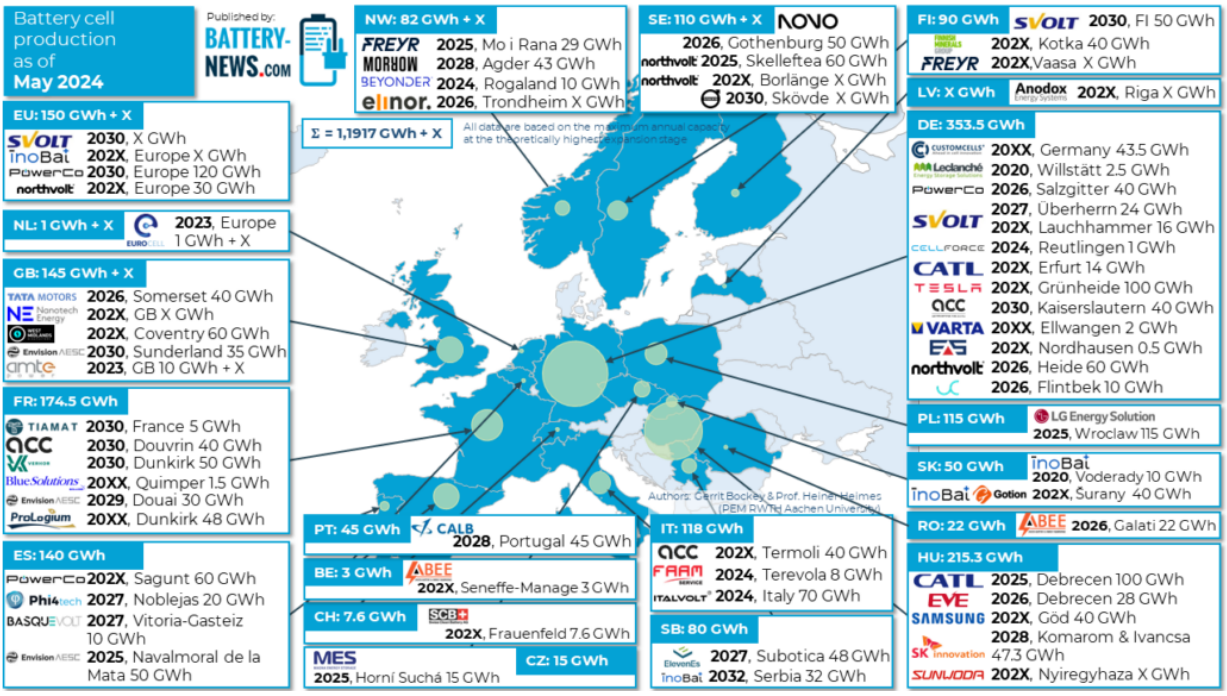


Figure 14. Battery cell production in Europe as of May 2024 (Battery-News, 2024b)

While Europe is actively pursuing innovation, it struggles to match the scale and speed of innovation seen in Asia and major difficulties are encountered recently. Europe has become a major buyer of Chinese cells (Figure 15), putting pressure on local manufacturers like **Northvolt**. In October 2024, Northvolt announced the bankruptcy of one of its subsidiaries, halting a planned expansion. Similarly, Norway's **Freyer** was forced to lay off workers and delay production at its Mo i Rana facility in August 2024. Chinese companies are also struggling in the European market. For example, in October 2024, Chinese battery manufacturer **SVOLT** confirmed that it would end its European operations. SVOLT had previously made significant investments in the European market, including plans to build production facilities in Germany.

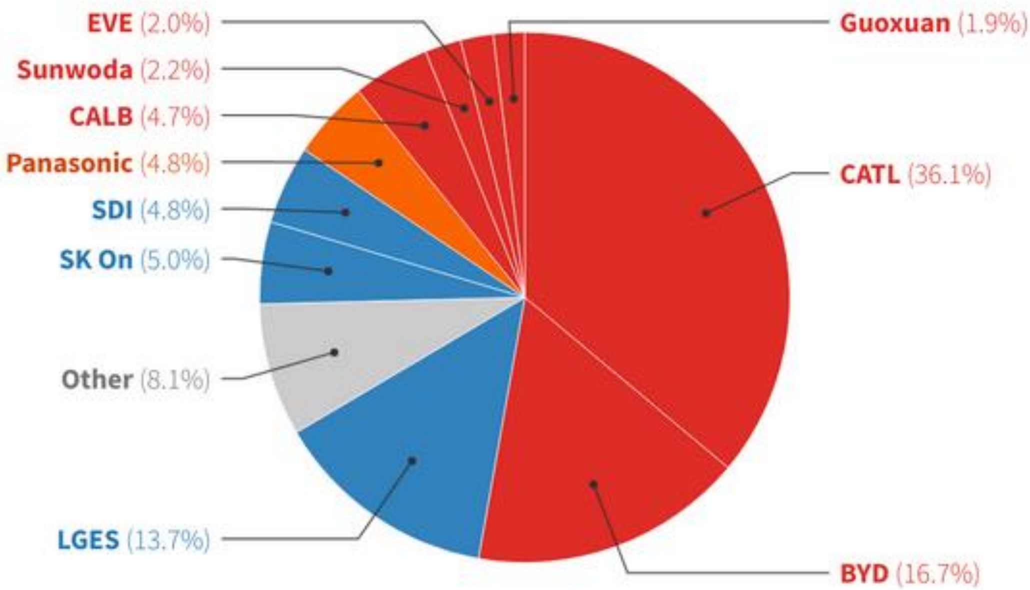


Figure 15. Chinese companies dominate global battery sales, Notes: Chinese companies are marked in red and South Korean companies in blue (Reuters, 2024a)

2.5. Battery system manufacturing

Battery system manufacturers assemble individual battery cells, typically cylindrical, prismatic, or pouch-shaped, to form modules and battery packs. Battery system manufacturers may also design and manufacture battery management systems (BMS) because the battery system manufacturing process involves mechanical and electrical engineering to connect cells, add cooling systems, and integration of BMS. The process outputs are complete battery packs, ready to be integrated into EVs or energy storage systems (Figure 16).

The collaboration between previous (battery cell manufacturing) and further (battery integration into applications) stages is crucial for the production of high-performance, reliable batteries for various applications. To ensure optimal performance and cost-effectiveness, cell manufacturing companies (e.g. **CATL**), EV manufacturers (e.g. **Tesla, Volkswagen**), or energy storage system providers (e.g. **Leclanche**, **Siro,** and **VARTA**) also manufacture battery systems. Independent battery pack assemblers often focus on niche markets or specific applications. Figure 17 summarizes planned and already implemented projects in the module and pack production of LIBs in Europe.

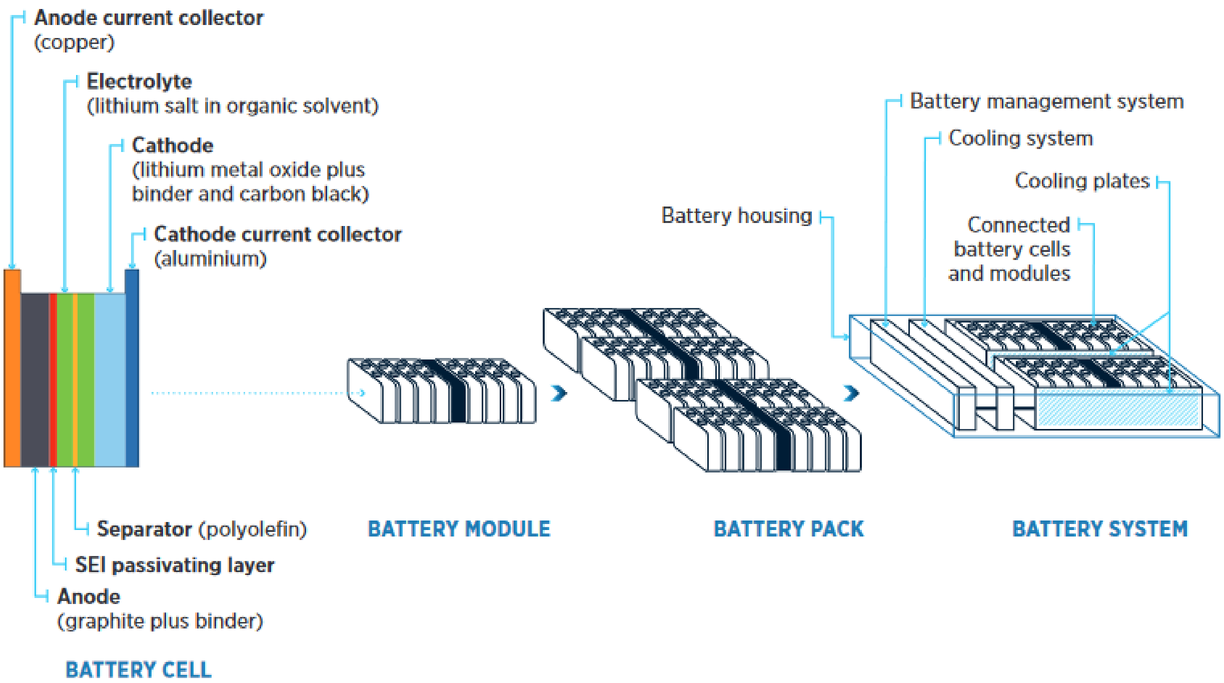


Figure 16. From battery cell to battery system (IRENA, 2024)

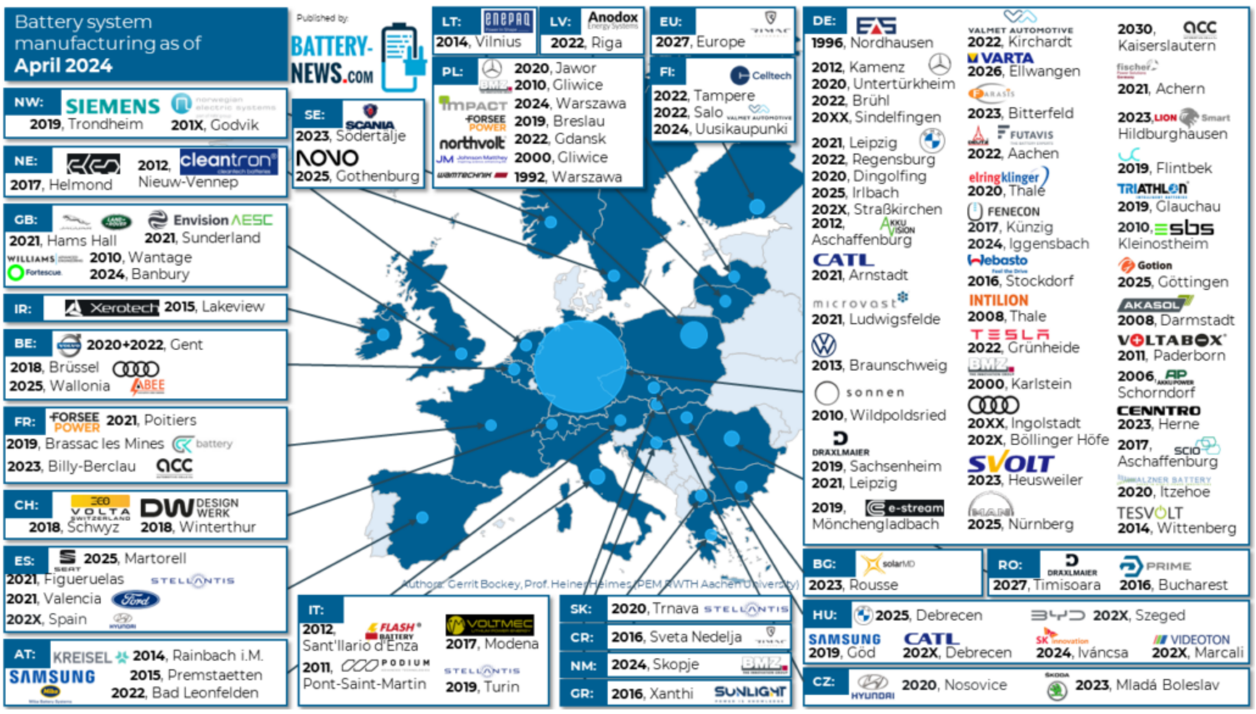


Figure 17. Battery system manufacturing in Europe as of April 2024 (Battery-News, 2024c)

2.6. Applications

After battery system manufacturing, the next step in the LIB value chain is integration into the final product such as EVs or stationary ESSs for residential, commercial, or utility-scale applications. This final integration stage includes thermal management and safety mechanisms to ensure optimal operating temperatures, preventing overheating and thermal runaway; and overall monitoring and control mechanism implementation.

EVs account for the majority of LIBs demand, although energy storage is the fastest-growing source of demand (Figure 18). While Europe has a strong presence in the light-duty EV market, the commercial vehicle segment, especially buses and trucks, is still emerging. The main automotive OEMs in Europe are the German **Volkswagen Group**, **BMW Group**, **Mercedes-Benz Group AG**, the French **Renault Group**, the Swedish **Volvo Group,** and the multinational corporation **Stellantis**. Germany is the leading producer of EVs in Europe, accounting for nearly 50% of the continent's EV production in 2023 (IEA, 2024b). While European OEMs have established themselves in cell manufacturing and system integration, the competition from Chinese EV manufacturers offering competitive pricing is a growing concern.

Besides Volvo Group, the main European EV bus manufacturers are a Dutch **VDL Bus & Coach**, a German **MAN Truck & Bus**, and an Italian **Iveco Bus**. European EV truck manufacturers are Volvo trucks, **Mercedes-Benz Trucks**, Swedish **Scania,** and Dutch **DAF Trucks**.

European stationary ESS providers are Swiss company **Leclanché**, German **VARTA Storage** and **Sonnen**, Italian **Enel X**, Finnish **Wärtsilä,** and Swedish **Northvolt**.

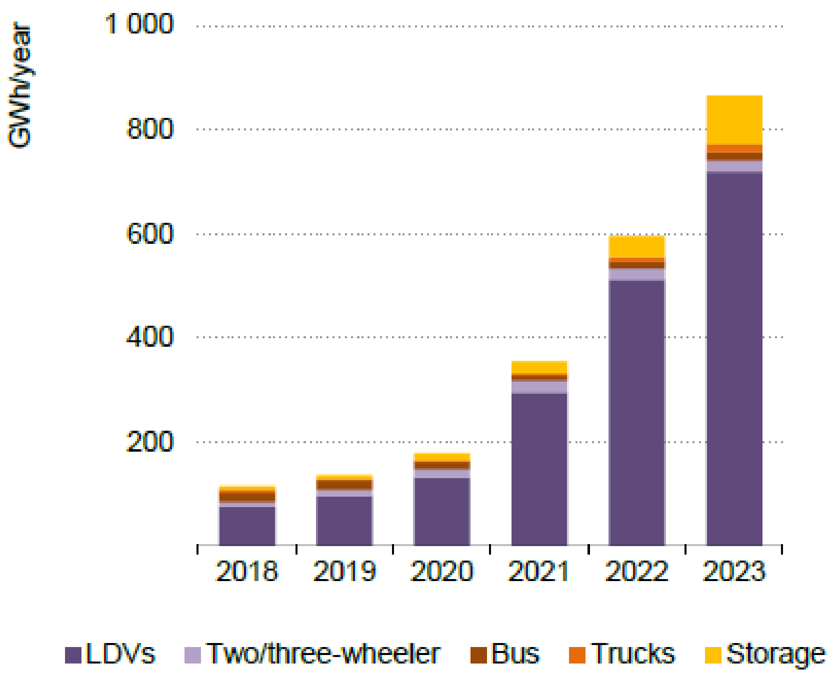


Figure 18. EV and ESS battery demand 2018-2023, Note: LDVs = light-duty vehicles (IEA, 2024b)

2.7. First life use

2.7.1. Electric vehicle market

China, Europe, and the United States (US) remain the leading EV markets (Figure 19) (IEA, 2024b). In 2023, the global EV market continued to grow, with 14.2 million new battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) delivered worldwide. This represents a 35% increase from the previous year, though slower than the 55% growth in 2022. Of the total, 10 million were BEVs, while 4.2 million were PHEVs and range-extended EVs (REVs). The European automotive industry experienced a positive year in 2023, with the European Automobile Manufacturers Association (ACEA) reporting a 14% increase in car sales, reaching over 10.5 million new registrations. This marks the highest level of new car registrations in Europe since the pre-pandemic era. BEVs gained significant traction in 2023, surpassing diesel cars in popularity. BEV sales increased by 37%, capturing a 14.6% market share, up from 12.1% in 2022. With over 1.5 million BEVs sold, the industry is poised for further growth, with BEV sales projected to surpass those of internal combustion engine (ICE) vehicles by 2025. (Statzon, 2024)

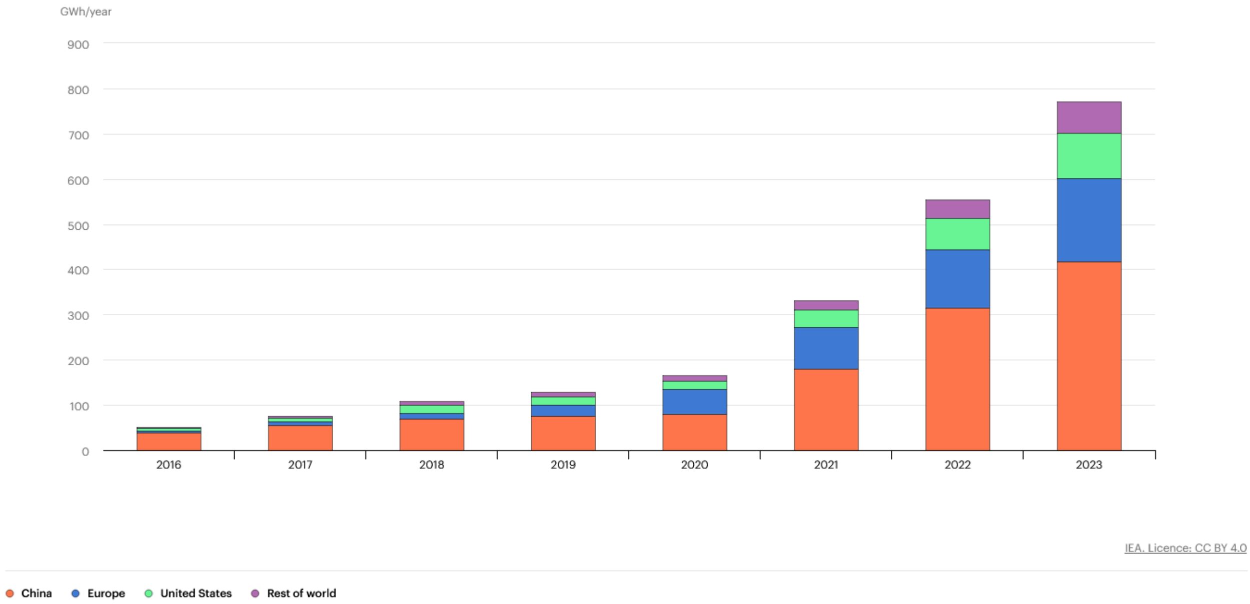


Figure 19. EV battery demand by region 2016-2023 (IEA, 2024b)

Germany, **France**, and the **United Kingdom (UK)** remain Europe's top three EV markets. Despite the discontinuation of government subsidies in Germany, the country saw a 12% increase in BEV sales in 2023, capturing 18.3% of the market share. France experienced a 39% growth in overall EV sales, with BEVs and PHEVs increasing by 46% and 28%, respectively. The UK also witnessed substantial growth, with BEV sales rising 17.8% and PHEV sales increasing to 7.4% market share. **Norway** continues to lead the world in EV adoption, with BEVs accounting for a staggering 82%

of new car registrations in 2023. This dominance is attributed to strong government incentives and a supportive infrastructure. Other European countries like Iceland, Sweden, Denmark, Finland, the Netherlands, Austria, and Belgium also have significant EV adoption rates. (Statzon, 2024) Figure 20 gives an overview of newly registered EVs by EU countries (EEA, 2024). January–June 2024 top 10 selling EVs in Europe were: Tesla Model Y, Tesla Model 3, Volvo EX30, Audi Q4 e-tron, MG 4, Volvo XC60 PHEV, Skoda Enyaq, VW ID.3, VW ID.4, and Volvo EX/XC40 (BEV+PHEV) (European Commission, 2024a).

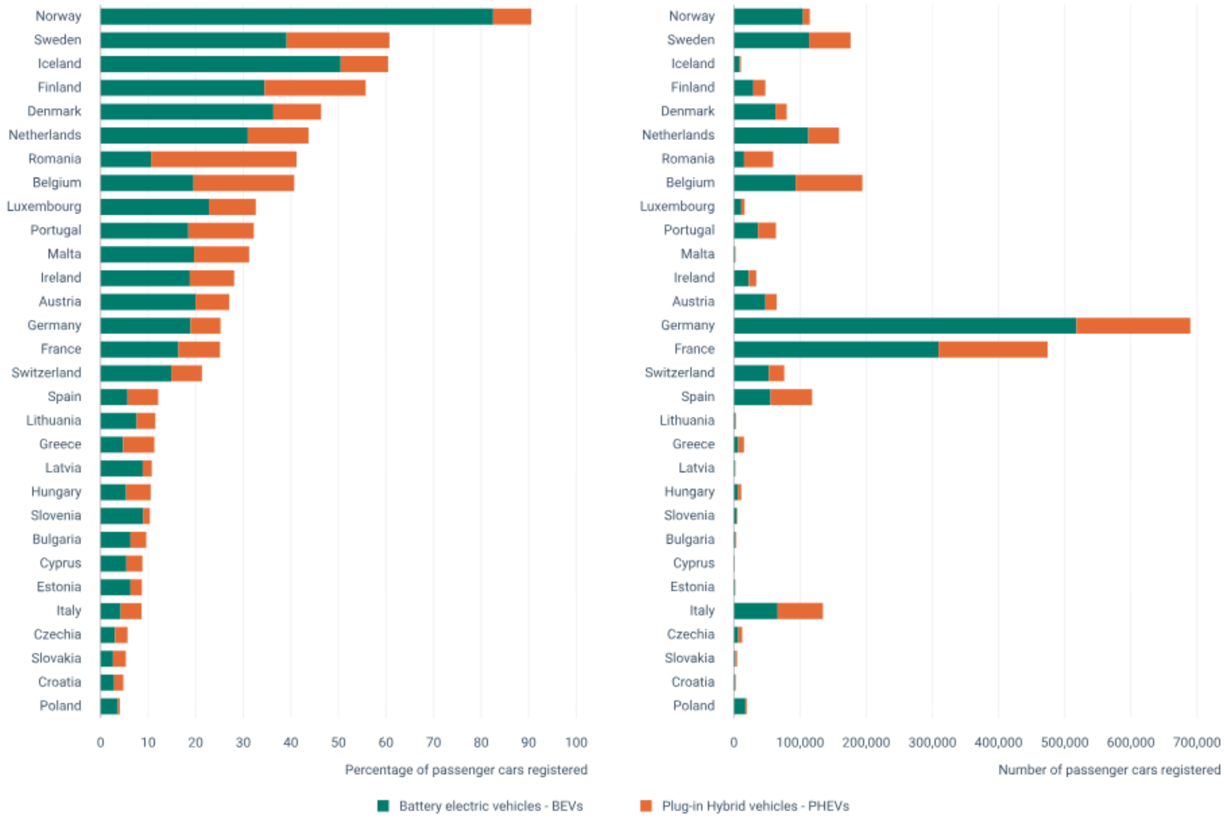


Figure 20. Newly registered electric cars by country (EEA, 2024)

EVs are becoming increasingly affordable as battery prices decline, competition intensifies, and manufacturers achieve economies of scale. However, in most cases, EVs still command a higher price tag compared to their ICE counterparts. In China, where EVs have been popular for years, the average selling price of EVs, even before government subsidies, is now lower than that of traditional ICE vehicles. Since 2018, EV prices have decreased significantly. In Europe, pricing trends for EVs vary across countries and often differ between segments. In Norway, due to the exemption of EVs from sales tax, EVs are already more affordable than their ICE counterparts across all segments. In 2022, EVs were approximately 15% cheaper on average compared to ICE vehicles, with this difference reaching 30% for mid-sized cars. However, the gradual reintroduction of sales taxes on EVs starting in 2023 may impact these price differentials. In addition, in Germany, France, and the UK, EVs are cheaper, but elsewhere in Europe, EVs remain typically much more expensive than ICE equivalents. As battery costs decline, manufacturing efficiency improves, and competition intensifies, EV prices in Europe are projected to decrease. Some analyses suggest that certain EV models, particularly smaller cars in Europe, could reach price parity with ICE vehicles as early as 2025. However, various factors, including fluctuating commodity prices, supply chain disruptions, and necessary profit margins for manufacturers, could delay this milestone. Additionally, the dynamic regulatory landscape, geopolitical tensions, domestic content incentives, and the evolving battery technology landscape, with diverse chemistries and regional specificities, further complicate the cost equation. (IEA, 2024b)

As the EV market matures, the second-hand market is gaining significance. Similar to other technological products, the availability of newer EV models is driving the emergence of a thriving second-hand market. This trend is significant when it comes to mass-market adoption, especially as new EVs may remain relatively expensive. In the EU, for instance, approximately eight out of ten citizens opt for second-hand cars. In 2023, an estimated 800,000 used EVs were sold in China, while the combined total for France, Germany, Italy, Spain, the Netherlands, and the UK exceeded 450,000. (IEA, 2024b) Figure 21 shows the size of the US, EU (EUR-6, see Figure 21 for details), and Chinese secondhand markets for both conventional and EVs.

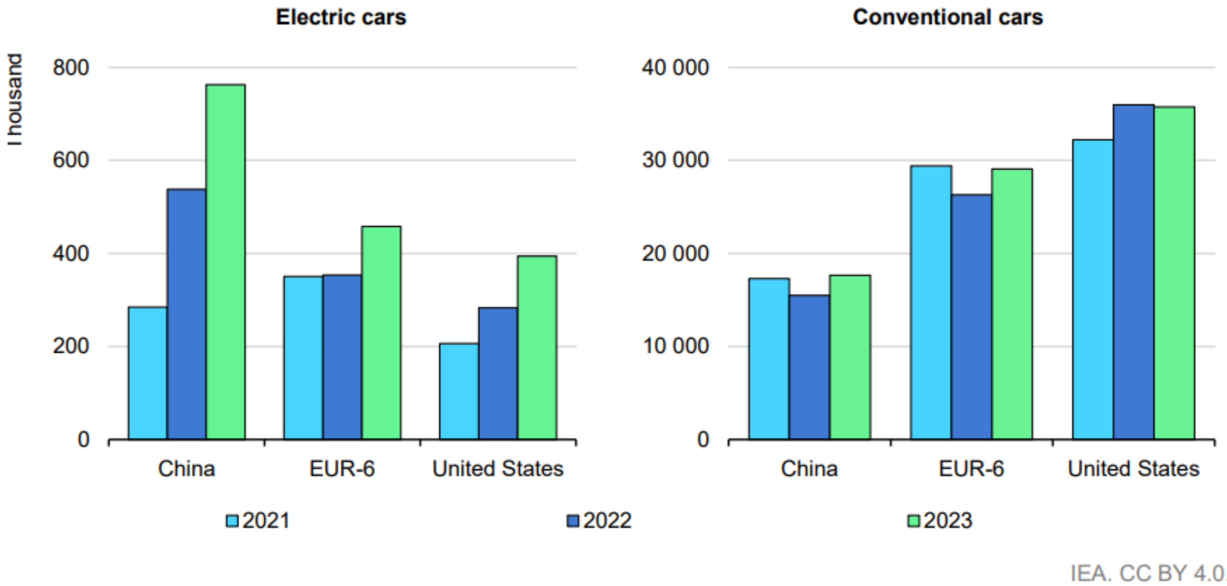


Figure 21. The secondhand market size for conventional and electric vehicles in China, EUR-6 and US between 2021 -2023. Notes: EUR-6 refers to France, Germany, Italy, Spain, the Netherlands and the United Kingdom. (IEA, 2024b)

2.7.2. Batteries use

A significant challenge facing automotive OEMs is aligning the lifecycle of the battery with that of the vehicle. While the goal for vehicles is to last 15 to 20 years, battery technology evolves rapidly, and battery capacity diminishes over time. To address this, manufacturers are exploring strategies such as battery replacement and reuse. One potential solution is to replace or upgrade the battery pack as technology advances. This would allow vehicles to maintain optimal performance and range. However, the cost of replacement or upgrading can be substantial. Another approach is to repurpose batteries for stationary ESSs. Once a battery pack no longer meets the performance requirements of an EV, it can be used to store renewable energy, such as solar or wind power. This extends the battery's lifespan and reduces its environmental impact and the customer gets a refund for the replacement battery.

However, users have different needs; for example, some drivers are perfectly content with a 50% capacity battery and only notice the reduced maximum range. As long as the battery does not fail, there is no reason to decommission it when its capacity drops to 75-80%. The expanding market for secondhand EVs is prolonging the lifecycle of batteries used in these vehicles.

To maximize battery lifespan in vehicles, batteries are maintained and repaired. Often, the issue is found in components other than the battery itself, such as the electronics, which can be repaired. Alternatively, if the problem lies within the battery, it is often isolated to a single cell or module, allowing for repair by replacing that specific component. The use of artificial intelligence (AI) in battery health diagnostics is growing. AI models can be used the visualize the structure of the battery and indicate what specific modules and cells are not functioning properly. AI can also be used to optimize the charge and discharge cycles of batteries to further extend battery lifespan. Thermal management also plays a significant role in battery lifecycle extension. Despite maintenance and repair efforts, batteries will eventually reach the end of their first life when their capacity significantly diminishes.

2.8. Collection and storage

There is not a single centralized point of collection, but in general, the main collection points for used and defective batteries are 1) **repair shops** and 2) **take-back points for end-of-life vehicles**. Certified repair shops serve as the primary collection point for batteries that are removed from their first application during the vehicle's lifecycle. Automotive OEMs are accumulating a growing number of used batteries as EV adoption increases. These manufacturers are faced with the challenge of determining the best course of action for these batteries, including potential second life applications or partnerships with recycling companies.

Take-back points for end-of-life vehicles, in turn, typically accept batteries from recycled electric and hybrid cars at the end of their lifecycle. For example, In Finland, the collection of end-of-life vehicles is operated by **Finnish Car Recycling Ltd**. There are nearly 300 take-back points for end-of-life vehicles across Finland. **Stena Recycling** and **Kuusakoski Recycling** are the official and authorized recycling partners of Finnish Car Recycling Ltd. National battery collection systems in Europe are discussed more broadly in section 3.6.

Reneos acts as a network of Europe's top national battery collection systems. From initial pickup to final recycling or reuse, Reneos offers a comprehensive battery end-of-life management solution. For example, their online platform connects car dealers in Norway, storage partners in Germany, diagnostic centers in Belgium, reuse facilities in Italy, and recyclers in France. This centralized platform provides clear and convenient dashboards for all stakeholders, streamlining the entire battery lifecycle management process.

Specific regulations and collection systems may vary from country to country, but the general trend is toward more efficient and sustainable collection and end-of-life practices for EV batteries. As the volume of used batteries increases, to ensure efficient and cost-effective battery end-of-life management, the organization of **local collection points/regional hubs** should be considered. These hubs would serve as local collection and processing centers, performing the sorting process of batteries into reusable/repurposable and recyclable streams and further handling the disassembly, shredding, and initial separation of battery materials. By processing batteries closer to their source, transportation costs and regulatory hurdles associated with cross-border shipments can be significantly reduced. This localized approach allows for the recycling of materials like aluminum, copper, and stainless steel locally, while the valuable black mass can be transported to specialized hydrometallurgical facilities for further processing. This strategy optimizes the recycling process and minimizes environmental impact.

There are specialized companies that handle the collection and transportation of used batteries. These companies often have the necessary expertise and infrastructure to safely transport batteries, adhering to strict regulations and safety standards. These companies may also partner with automotive OEMs, dealerships, and recycling facilities to establish efficient collection networks. For example, the UK-based company **Cellcycle** offers a solution for battery end-of-life management, including ADR (Agreement concerning the International Carriage of Dangerous Goods by Road) compliant logistics for the collection and batteries reuse and recycling. Also, many logistics and waste management companies as well as automotive companies have expanded their services to include battery collection and transportation. For example, as the hazardous waste expert, Finnish company **Fortum** offers safe solutions for the handling, transportation, storage, and recycling of LIBs. Dutch company **VDL** has designed a specialized container – Bunker – for the safe transportation of LIBs.

2.9. Second and third life

Following CE strategies (Figure 3) and the waste hierarchy (European Commission, 2024a), the first step in battery end-of-life management is to assess the potential for reuse. Before recycling, batteries in good condition can be repurposed for second life applications and even third life (Quinteros-Condoretty et al., 2025), delaying recycling and increasing their residual value. Repurposing offers a sustainable alternative to immediate recycling (Dunn et al., 2023) to extend the battery's lifespan (Bobba et al., 2019). This strategy aligns with the growing demand for both EVs and ESSs, as it reduces the environmental impact of battery production and eases the strain on raw material supply. There are many second life battery applications projects ongoing in Europe (Figure 22) by different actors across the LIB value chain, including automotive OEMs (e.g. **Mercedez-Benz**, **Renault**), recycling companies (e.g. **Stena Recycling**), and energy companies (e.g. **Fortum**, **Enel X**), but also new businesses emerge (e.g. **BeePlanet**, **EcarAccu**).

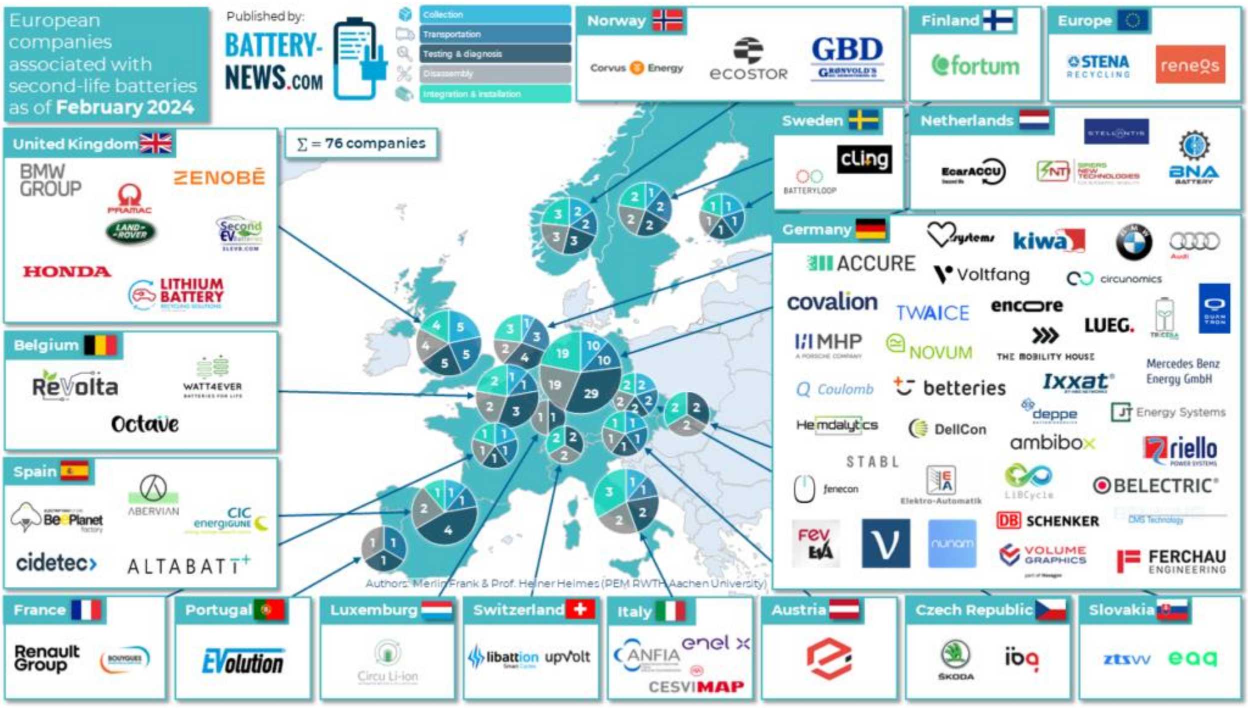


Figure 22. Second life Battery Applications in Europe as of February 2024 (Battery-News, 2024d)

While the batteries repurposing holds significant promise, practical implementation remains a complex challenge, compared to the conceptual model for battery lifecycle extension (Figure 23) (Quinteros-Condoretty et al., 2025). Section 4.5 delves deeper into the six different organizational models for second life businesses for used EV batteries, which is the primary focus of this study. Chapter 5 discusses the obstacles hindering the widespread adoption of battery repurposing. These challenges include technical limitations, economic factors, and regulatory hurdles.

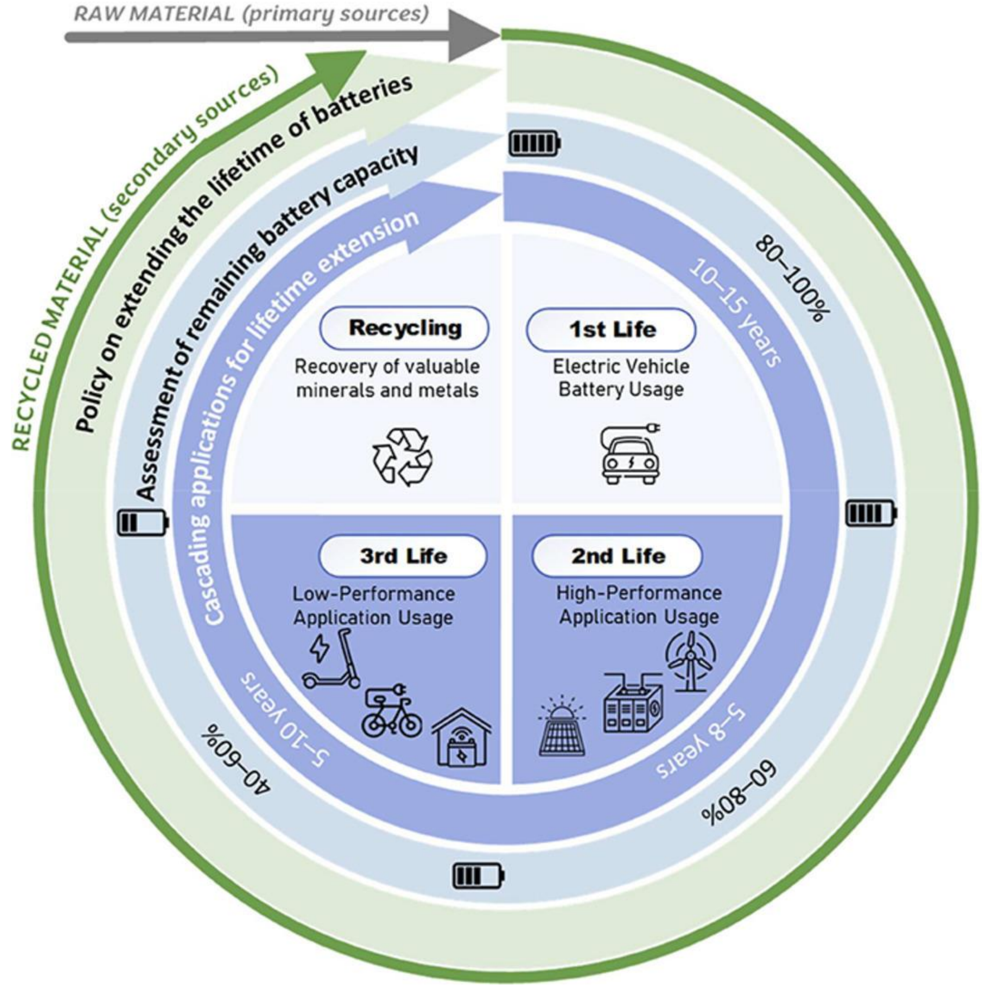


Figure 23. Conceptual model of the extension of EV battery lifecycle (Quinteros-Condoretty et al., 2025)

2.10. Recycling

Finally, recycling completes the loop by recovering valuable materials like lithium, cobalt, and nickel. These recovered materials are then reintroduced into the battery production process as secondary resources, reducing the reliance on primary raw materials extraction. The recycling method (direct recycling, hydrometallurgical recycling, pyrometallurgical recycling) employed significantly impacts the process output and the secondary raw material integration into the LIB value chain (Figure 24).

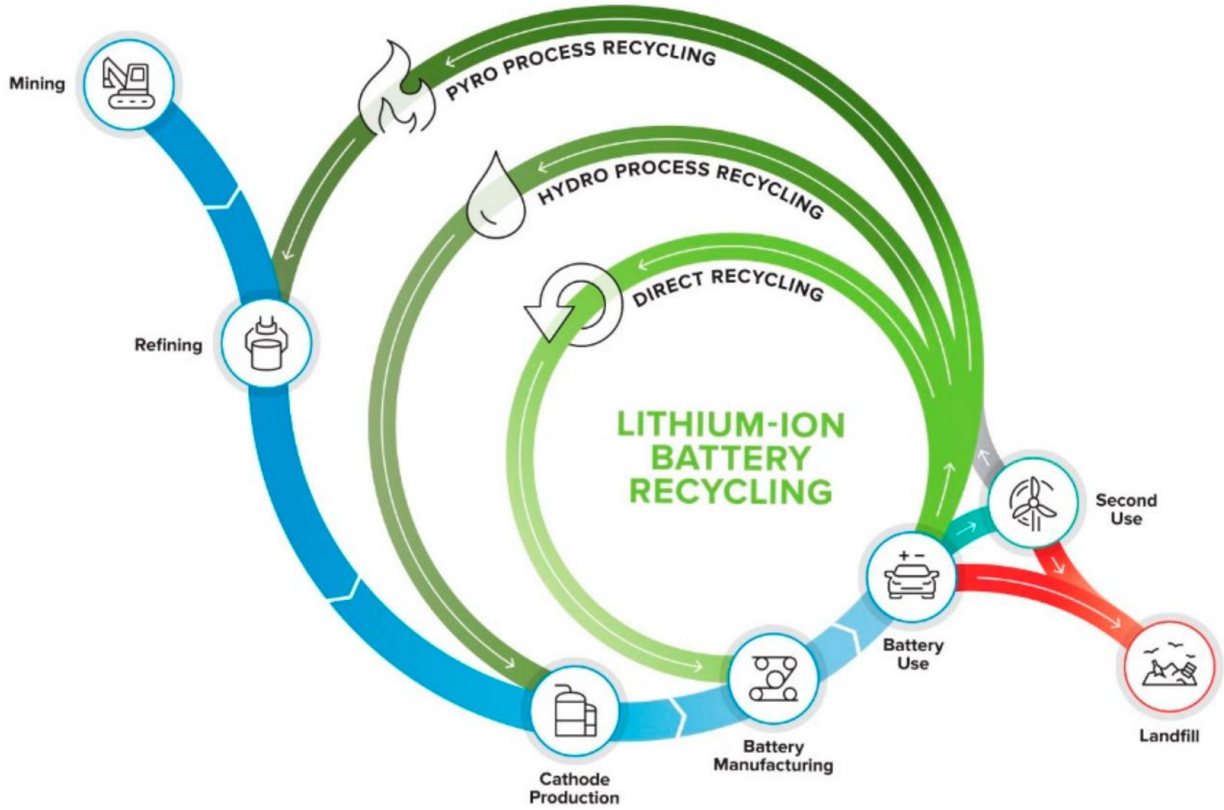


Figure 24. Different recycling processes for LIBs (Gaines et al., 2021)

As the demand for LIBs increases, effective recycling is essential to mitigate the demand for CRMs. The battery recycling sector, still in its early stages, will play a pivotal role in shaping the future of EV value chains and maximizing their environmental benefits. Global battery recycling capacity surpassed 300 GWh/year in 2023, with China dominating the market, accounting for over 80% of the total capacity. Europe and the US lagged significantly, each holding less than 2% of the global capacity. If all planned battery recycling projects are realized, global recycling capacity could exceed 1,500 GWh by 2030. While China is expected to retain a dominant position, with around 70% of the global capacity, Europe and the US are aiming to increase their share to approximately 10% each. (IEA, 2024b)

There are several battery recycling projects underway in Europe (Figure 25). **Stena Recycling** is a Swedish recycling company that is involved in the recycling of LIBs. A Swedish battery manufacturer **Northvolt** is also investing in battery recycling technologies. Belgian materials technology company **Umicore** has also a strong focus on LIB recycling. **Hydrovolt** is Europe's largest battery recycling pilot. It is a joint venture between Hydro and Northvolt located in Norway. **Fortum** Battery Recycling opened Europe’s largest closed-loop hydrometallurgical battery recycling facility in Finland. **Mercedes-Benz** has very recently opened its recycling factory to close the battery loop. This recycling plant in Kuppenheim, Germany, is the first plant to use an integrated mechanical-hydrometallurgical process in Europe. The Canadian recycling company **Li-**

Cycle also has a strong presence in Europe, with ongoing recycling operations in Germany and France. **Veolia**, a French multinational company specializing in water, waste, and energy services, is also operating LIB recycling and has expansion targets in the field. Like many other LIB recyclers, Veolia offers a comprehensive recycling solution for EV batteries, encompassing the LIB collection and preparation for recycling, dismantling, mechanical separation, hydrometallurgical separation process, and refining to reach a high degree of purity, enabling reuse in the production of new batteries.

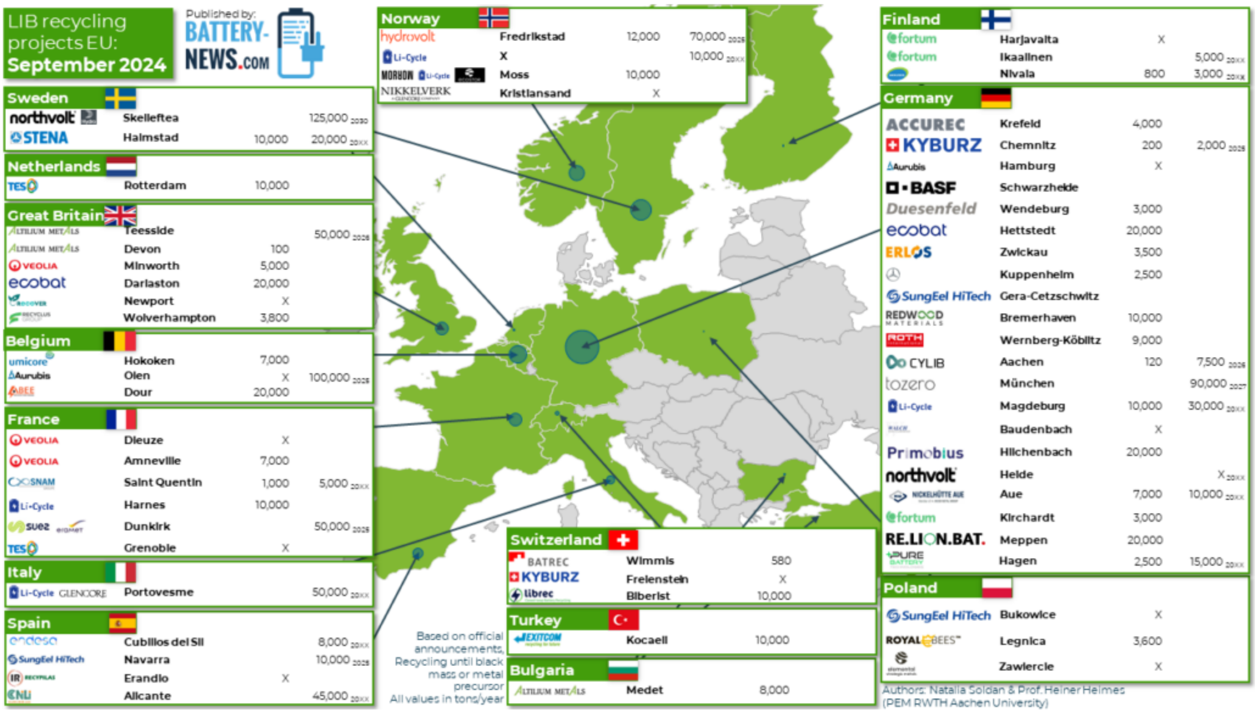


Figure 25. Overview of planned and already implemented LIB recycling projects in Europe (Battery-News, 2024e)

Currently, approximately 50 kilotons of used batteries are recycled annually in Europe (Fraunhofer ISI, 2023). This figure is projected to rise significantly in the coming years, and the origin of these batteries will also change.

According to Fraunhofer ISI (2023), the quantity of batteries to be recycled in Europe is expected to reach 420 kilotons by 2030, with a potential range of 200-800 kilotons. By 2040, this figure could soar to 2 100 kilotons, potentially ranging from 1 100 to 3 300 kilotons. In 2020, the majority of used batteries originated from consumer electronics such as cell phones and laptops. However, today, the largest share of battery material to be recycled comes from production scrap generated during battery manufacturing. This trend is set to continue in the near future, making production scrap the primary source for recycling in the medium term.

In 2030, scrap from battery production (50%) and retired EVs (20%) are expected to be the primary sources of materials for battery recycling plants (Figure 26) (IEA, 2024b). Scrap materials,

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being relatively pristine, are significantly easier and cheaper to recycle. It is only in the longer term, from around 2035, that end-of-life batteries from passenger cars will become the dominant source of battery waste, as a larger number of automotive batteries reach the end of their lifespan (Fraunhofer ISI, 2023).

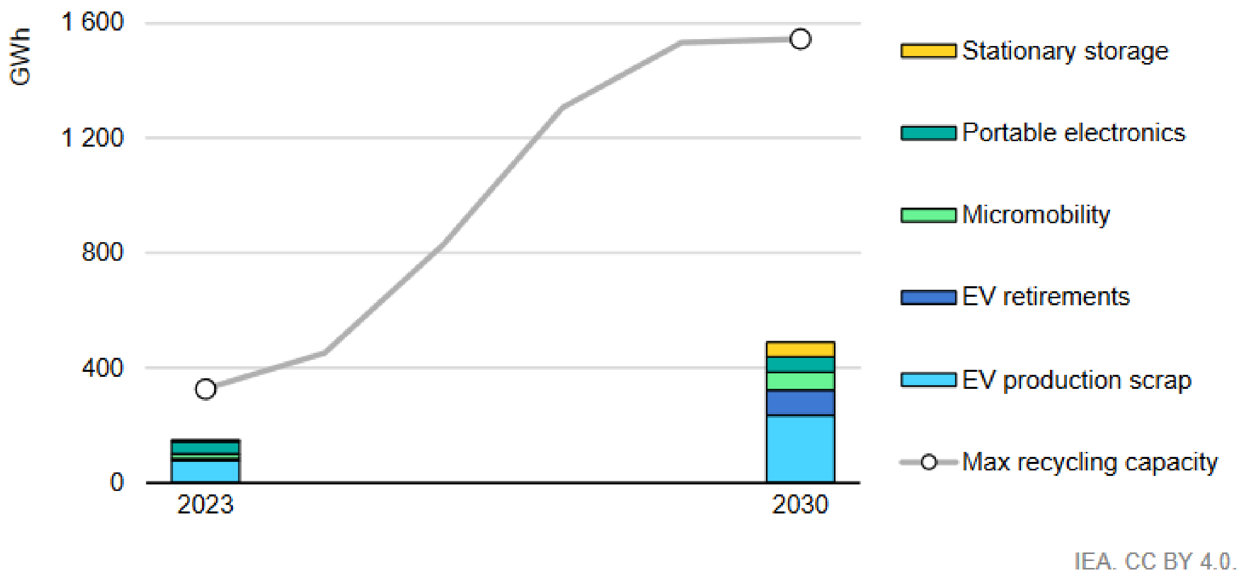

Figure 26. Current and announced global battery recycling capacity and potential supply of end-of-life batteries according to existing and announced policies, 2023-2030 (IEA, 2024b)

While the supply of scrap materials and retired EVs is projected to grow, current expansion plans suggest that battery recycling capacity could exceed demand in 2030 (Figure 26). This overcapacity could lead to financial challenges for recycling companies struggling to secure a stable supply of end-of-life batteries, potentially resulting in market consolidation. However, the situation may evolve as planned projects materialize into actual investments, and as the number of retired EVs increases significantly from the mid-2030s onwards. (IEA, 2024b)

However, making future projections is challenging as the geographical distribution of retired batteries is uncertain and may differ from their initial purchase location due to factors such as the second-hand EV market and potential second life applications (IEA, 2024b). On the other side, the overcapacity of recycling can hinder the adoption of second life applications. This is because the demand for used batteries as raw material for recycling can compete with their potential for repurpose in second life applications.

The evolving landscape of battery chemistries will significantly impact the recycling landscape. While NMC batteries, with their higher content of valuable metals, are well-suited for recycling, LFP batteries present a more complex challenge due to their lower residual value. However, regulatory incentives can play a crucial role in driving LFP recycling, as demonstrated by the successful recycling of lead-acid batteries. With its strong focus on LFP batteries and supportive policies, China is actively building recycling capacity to meet future demand. However, overcapacity in the LFP recycling market could emerge if planned projects are fully realized, potentially impacting the economics of the industry. (IEA, 2024b)

2.11. Other battery value chain actors

The main stages in the circular LIB value chain, from mining to recycling, have been described above. However, the LIB value chain is more complex, involving numerous other actors that play a crucial role, such as robotics and automation, and battery analytics and software (Figure 27).

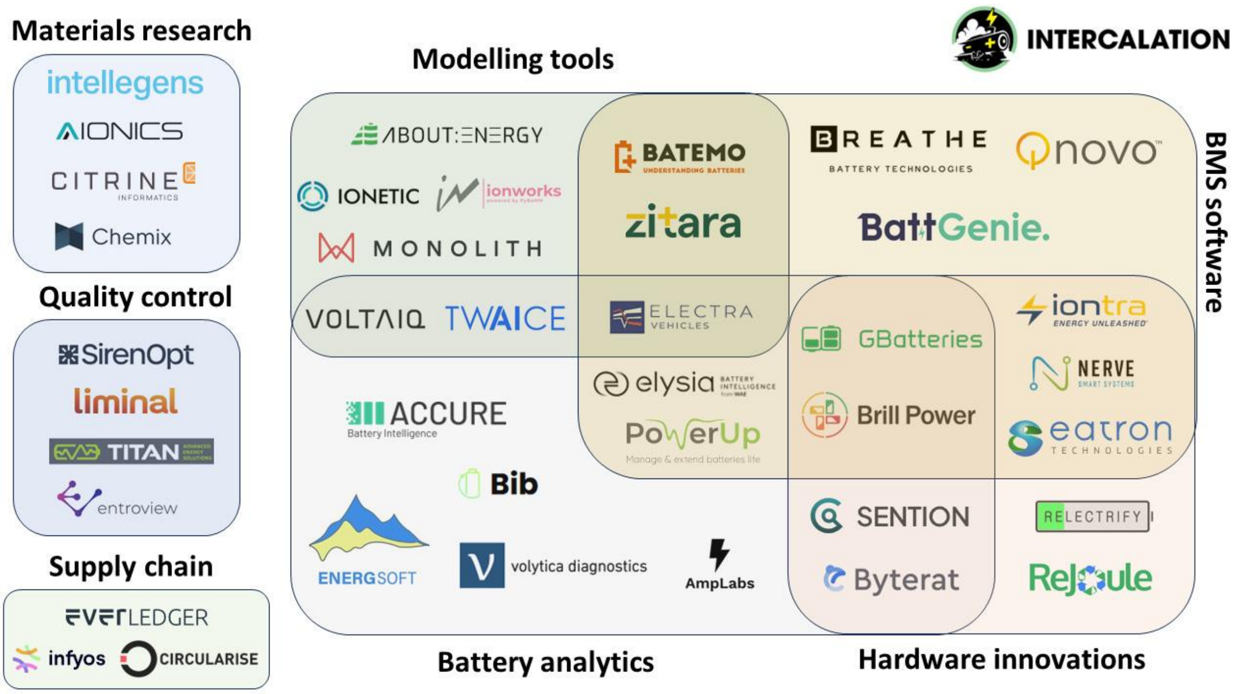

Figure 27. Battery software companies (Intercalation, 2024)

For example, German companies **Accure Battery Intelligence** and **TWAICE** offer platforms that collect data from BMS to provide insights such as warranty compliance, performance optimization, and state-of-health estimations. German company stemming from Fraunhofer Institute **Volytica Diagnostics** provides dashboard-based monitoring for warranty compliance and performance optimization, with potential applications in second life battery management. French company **Bib Batteries** offers AI-powered analytics to extend the lifecycle of batteries. **PowerUp**'s (French company) Battery Insight platform offers state-of-health estimation, remaining useful life predictions, and embedded software solutions. **Circularise** and **Everledger** support the Battery Passport initiative with a blockchain-assisted platform designed to enhance product traceability and transparency. Volvo has invested to **Circulor**, to a company that also provides blockchain-based technology for the battery passport. A French multinational software company **Dassault**

Systèmes offers software solutions that can be used to design, simulate, and optimize battery systems.

Spanish engineering company **NUTAI** and an Italian company **COMAU** both specialize in industrial automation systems. These companies contribute to the LIB value chain by providing battery testing and automation solutions for cell assembly, module and pack assembly, battery dismantling, material separation, and recycling processes.

The focus of AI in battery use optimization will grow in the future, for example, for charge and discharge cycles of LIBs among different users, which can significantly impact prolonging battery life (Liu et al., 2022; Zhao et al., 2024). In addition, there will be a growing focus on thermal management, creating efficient tools for cooling LIBs, to further improve battery life. The aforementioned factors, along with access to BMS data will help extend the lifecycle of batteries during their first life, for repair and further repurposing.

2.12. Summary of the main circular battery value chain actors

The LIB value chain is becoming increasingly complex and interconnected. Key players include automotive OEMs, battery manufacturers, and recycling companies. While these entities have traditionally operated independently, there is a growing trend toward vertical integration and strategic partnerships.

In China, major OEMs are vertically integrating their operations, controlling the entire battery value chain from raw material sourcing to recycling. This approach offers greater control over the value chain but can limit competition. In Europe, the partnerships are becoming more common as well. Volkswagen, for instance, has formed partnerships with both mining and recycling companies as well as cell manufacturers to secure a stable supply of primary and secondary raw materials. Table 2 provides an overview of selected European companies and maps their vertical integration in the circular LIB value chain.

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*Table 2. Selected European companies vertically integrated in the circular LIB value chain (*joint ventures and strategic partnerships, **under planning/development), Note: Data in the table reflects vertical integration of industry actors through publicly available data during November 2024*

	Mining	Raw material processing	Battery chemical production	Battery cell manufacturing	Battery system manufacturing	Applications: EVs	Applications: ESSs	Collection and storage	Second life applications	Recycling
Keliber (FI)	x	x	x							
Terrafame (FI)	x	x	x							
Glencore (UK-CH)	x	x							x*	x
Umicore (BE)	x	x	x					x		x
Basf (DE)		x	x							x**
Northvolt (SE)		x*	x	x	x	x	x	x	(x)	x
Freyr (NO)			x							
ABEE (BE)				x	x					
Verkor (FR)				x						
Leclanché (CH)				x	x		x			
Siro (TR)					x					
VARTA (DE)					x		x			
Volkswagen (DE)	x**			x*, **	x	x	x	x	x	x*
Mercedez-Benz (DE)					x	x	x	x	x	x
BMW (DE)						x	x	x	x	
Volvo (SE)						x	x	x	x	
Renault (FR)						x	x	x	x	x**
VDL Bus & Coach (NL)						x		x		
Enel X (IT)							x		x	
Fortum (FI)							x	x	x	x
Stena Recycling (SE)								x	x	x
Cellcycle (UK)								x	x	x
EcarAccu (NL)							x	x	x	
ECO STOR (NO)							x	x	x	
Connected Energy (UK)							x	x	x	
Veolia (FR)		x						x		x

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3. EU AND NATIONAL LEVEL LEGISLATIVE FRAMEWORK

In this Chapter, the regulations, policies, and incentives related to LIBs and the development of the circular LIB value chain are mapped. The structure of the EU's legislative framework and its potential to foster second life LIBs are also discussed.

3.1. EU level legislation

The EU has introduced a vast amount of legislation and initiatives to develop the EV and stationary LIB industry in Europe. While there is already a significant amount of legislation concerning the LIB industry, there is not much regulation that is binding to member states as is. A lot of legislation related to the LIB industry is in fact on a directive form, which allows flexibility for member states on how it is applied to a country's own legislation. Directives set goals for member states, but the means to achieving these goals is up to the member states themselves. Therefore, the application of different EU directives differs from country to country.

The new Battery Regulation 2023/1542 (European Union, 2023) is a big change for the industry because it is a regulation that is binding to all member states, without any exceptions. The battery regulation will be discussed in further detail in sections 3.2 and 3.3. The legislations that play a key role in the EV and stationary batteries industry (regulation, directives, and other EU initiatives and plans) are illustrated in Figure 28 below and further described in Table 3.

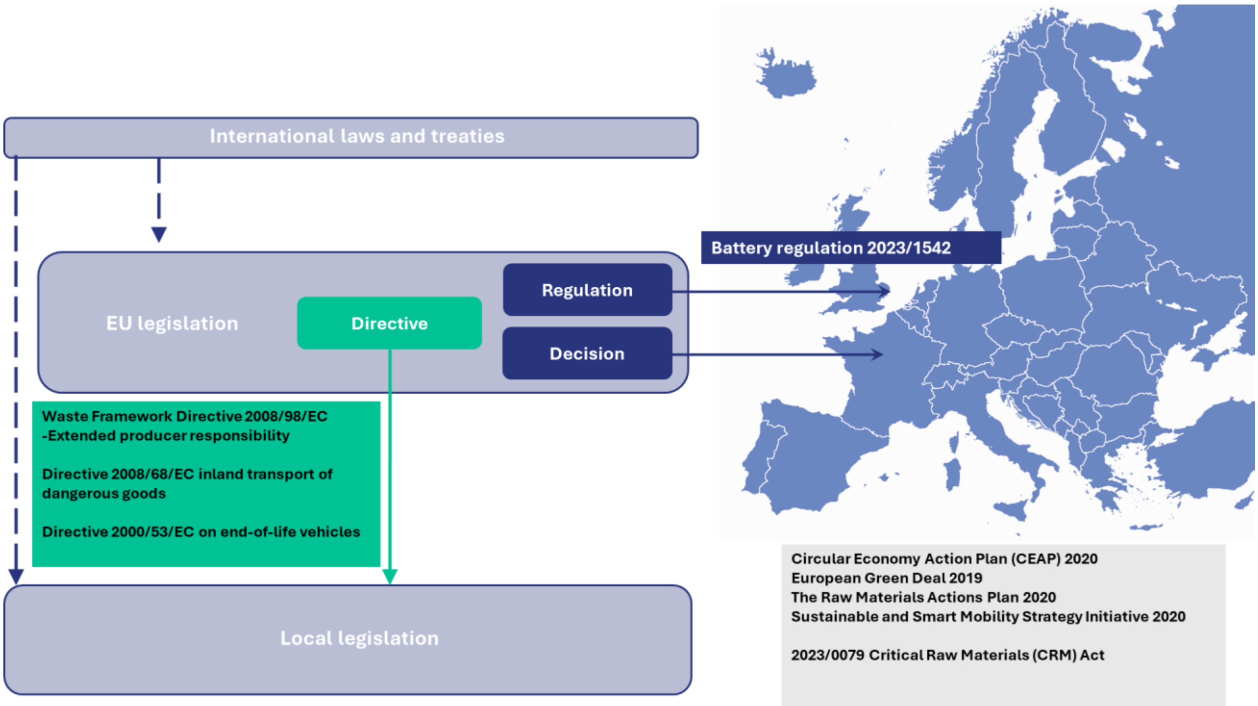

Figure 28. EU legislations influencing the LIB industry

Table 3. EU policies relevant to EV LIBs (Quinteros-Condoretty et al., 2025)

Policy	Aim	Objectives relevant to EV LIBs and CE strategies adoption
Circular Economy Action Plan (CEAP)	Transition the European economy to a circular model	• Improve battery durability, reusability, upgradability, reparability, and resource and energy efficiency • Reduce hazardous chemicals and environmental and carbon footprints • Support recycling, remanufacturing, and product-as-a-service business models • Standardize European battery recycling
European Green Deal	Transform the EU into a resource-efficient, fair, competitive, and carbon-neutral economy by 2050	• Adopt the use of a life-cycle approach • Create a predictable and simplified regulatory environment
The Raw Materials Action Plan	Ensure sufficient and sustainable supply of CRMs	• Promote sustainable product design, innovation, extended product lifetimes, and use of secondary raw materials • Develop resilient EU value chains and sourcing; source 80% of lithium from Europe by 2025 • Diversify sources and promote responsible sourcing from third countries
Sustainable and Smart Mobility Strategy (2020)	Build a resilient and sustainable mobility network for Europe	• Achieve 90% reduction in CO2 emissions from mobility by 2050 • Achieve at least 30 million zero-emission vehicles by 2030 • Achieve almost 100% zero-emission vehicles by 2050
2023/0079 Critical Raw Materials Act	Develop circular and sustainable European raw materials supply chains by increasing self-sufficiency and diversifying supply	• Strengthen the European CRMs value chain • Diversify CRM imports • Improve Europe's capacity to monitor and mitigate supply disruption risks • Ensure functioning markets for CRMs, maintain a high level of environmental protection, and improve circularity and sustainability • Increase recycling and use of secondary CRMs • Promote ecodesign to reduce resource use and increase durability, reparability, and reusability and to ensure recycling, remanufacturing, or recovery
New Battery Regulation 2023/1542	Facilitate the reuse, repurposing, and recycling of batteries	• Achieve performance and durability requirements • Recover 90% of cobalt, nickel and copper and 35% of lithium from batteries by 2025 • Recover 95% of cobalt, nickel and copper and 70% of lithium from batteries by 2030 • Achieve the following recycled battery content requirements by 2030: 12% cobalt, 85% lead, 4%

		lithium and 4% nickel; and the following by 2035: 20% cobalt, 10% lithium and 12% nickel
Waste Framework Directive 2008/98/EC	Legal framework for waste management within the EU emphasizing protection of environment and human health.	• Extended producer responsibility as a key tool for waste management • All member states to implement EPR schemes • Aim to reduce waste and improve recycling
Directive 2008/68/EC inland transport of dangerous goods	Ensure safe transport of dangerous goods between Member States and third countries according to the ADR, RID, or ADN	• Ensure that LIBs are packed and labeled correctly, and transported in a vehicle equipped with appropriate safety features • Ensure that LIBs with a capacity of more than 100 Wh are transported as dangerous goods • Ensure that all damaged or defective LIBs are transported as dangerous goods
End of Life Vehicles Directive 2000/53/EC	Encouraging sustainable design of vehicles, elimination of hazardous substances, recycling and recovery rates for vehicles	• Reduce waste through efficient recycling and reuse • Limitations to the use of specific hazardous materials

3.2. Battery Regulation 2023/1542

The new Battery Regulation 2023/1542 sets out a large number of different requirements for EV and industrial LIB, presented in Table 4. The regulation introduces five new classifications for batteries: portable, light means of transport (LMT), starting, lighting and ignition (SLI), industrial, and EV batteries. REINFORCE's focus is on Industrial (LIBs that weigh more than 5 kg and do not fit into any other battery category) and EV LIBs of more than 25kg designed for electric or hybrid vehicles. Before the new regulation, batteries were classified into three groups: portable, automotive, and industrial.

New batteries are required to contain a fraction of recycled materials by 2031, and the target recycled contents will nearly double in 2036. New collection rates are also set for lithium-ion batteries, 65% by 2026, followed by a target of 70% in 2031. These two requirements heavily incentivize recycling, as batteries already on the market contain high amounts of CRMs, they are more likely to be recycled (than reused) for secondary materials, and to reach the required collection rates, the focus will be even more on collecting and recycling batteries. Regarding design, batteries must be designed so that they are removable and replaceable, however, it is noteworthy that there are currently no specific design standards on for example battery packs, modules, or cells.

The battery regulation enforces requirements on carbon emissions as well. All new batteries placed on the market must contain a carbon declaration, which considers the carbon footprint of the full lifecycle of the battery. In addition, the regulation sets carbon footprint limits for each battery type. Extended producer responsibility (EPR) is now regulated on a more binding level, member states must meet the minimum requirements set by the regulation and all industrial and EV LIB will have recycling costs embedded into their selling prices. Finally, the regulation aims to improve the traceability and transparency of batteries through the battery passport (detailed requirements are listed in Table 5 below) and through the labeling requirements of batteries.

Table 4. Battery Regulation 2023/1542 targets for EV and industrial batteries (European Union, 2023)

Chapter	Requirements	Implications
Classification	Five types of battery classifications	Before this, there were only 3 types of battery classifications (Portable, automotive, industrial). Now there are portable, LMT, SLI, Industrial, and EV batteries.
Recycled content requirements (Article 8)	2031 (a) 16 % cobalt (b) 85 % lead (c) 6 % lithium (d) 6 % nickel 2036 (a) 26 % cobalt (b) 85 % lead (c) 12 % lithium (d) 15 % nickel	New LIB will need to contain a fraction of different recycled materials by 2031, after which the recycled content requirements will increase significantly again in 2036.
Collection rate (EV and industrial LIB) (Article 71)	2026 65% LIBs 2031 70% LIBs	Collection rate requirements incentivize recycling over reuse. The more batteries are collected and recycled, the closer producers are to their collection rate goals.
Removability and replaceability (Article 11)	EV and industrial batteries must be easily removable and replaceable.	There is no specification on types of battery packs, modules, or cells. Standardization applies to easy removability and replaceability.
Carbon footprint for EV LIBs	Carbon footprint declarations need to be provided for the whole lifecycle of the battery and a maximum carbon footprint is set per battery type.	All new batteries to enter the market need to have a carbon footprint declaration and consider the maximum footprint limit per battery type.
Extended producer responsibility (EPR) (Articles 55-56, 59 – 61)	Minimum requirements for EPR introduced regarding collection targets per battery category.	Before this EPR has been addressed on a directive level allowing member states to apply it to their legislation as they wish, as long as goals set by the EU are achieved. The new regulation is binding and is setting minimum requirements for EPR in batteries in all EU countries.

		The selling price of EV and industrial LIB will include the recycling/handling costs of end-of-life LIB.
Battery Passport (Article 77)	Information on: • Battery model • Dismantling of the battery • Safety measures for dismantling • Detailed composition of the battery model Information is essential to allow repairers, remanufacturers, second life operators and recyclers to conduct their respective economic activities.	Enhanced traceability and transparency of batteries on the market. The battery passport may help drive the develop of a second life market for LIBs in the long run. This is however highly dependent on the level of access to the data provided in the battery passport.
Labeling and other information requirements (Articles 13 and 14)	Information on CRMs, external labeling and markings on possible rechargeability etc.	New batteries need to include details such as battery category, manufacturer, capacity, weight and chemical characteristics. In additional rechargeable batteries need to contain information on charging attributes.

While the new Battery Regulation 2023/1542 sets a lot of new standards for the battery industry, it is heavily focused on recycling and raw material efficiencies. The expanding global EV market is driving increased demand for CRMs. EU has its own interests in securing its own supply of CRMs by focusing on local sourcing within EU member states as well as enhancing recycling of end-of-life LIBs, as reflected in the battery regulation's emphasis on recycling over reuse. The Critical Raw Materials Act sets goals for 2030 for domestic capacity: 10% of the EU's annual needs for extraction; 40% for processing and 25% for recycling. No more than 65% of EU's annual needs of CRMs at any relevant stage of processing should come from a single third country (European Commission, 2024b).

The largest volumes of CRMs for batteries lie in industrial and EV LIBs. Should a second life market develop, it is arguable whether it would significantly hinder reaching EU's goal of 25% of materials acquired from recycling. Developing a viable market for reuse of LIBs also requires developing new business models and infrastructure. Focusing on recycling is, hence, the easier way out as we already have existing infrastructure, processes and viable business models in this area. Consequently, the regulation prioritizes recycling over battery life extension, likely reflecting the EU's strategic goal of reducing reliance on foreign CRM suppliers.

The timeline for implementation of the new legislation is presented in Figure 29 below.

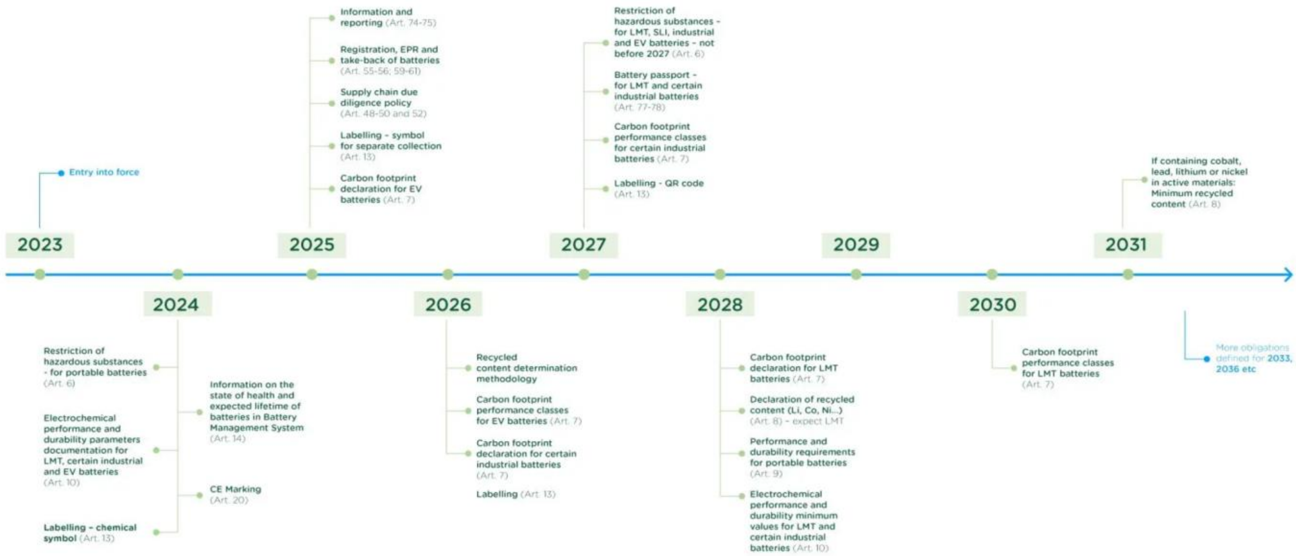

Figure 29. Timeline for the new Battery Regulation 2023/1542 implementation (Ramboll, 2024)

3.3. Lifecycle extension strategies in the new battery regulation

While the new battery regulation encourages reuse, repurposing and remanufacturing of EV and industrial LIBs, it fails to provide concrete incentives to shift the current recycling focused model to a more circular one, which sets product lifecycle extension into more focus. The new Battery Regulation highlights lifecycle extension strategies through to exemptions on reporting the carbon footprint, recycled content requirements, and performance and durability requirements of reused, repurposed or remanufactured LIBs that have been set out in the market before the regulation was put into force. While not direct incentives, these may contribute to the future development of the second life battery market. Table 5 outlines the parts of the new battery regulation that mention reuse, repurposing and remanufacturing.

Some requirements of the regulation, for example on designing batteries so they are easily removable and replaceable, developing a standardized way for testing second life; repurposed, repaired, and remanufactured batteries' carbon footprint requirements, labeling and the battery passport could facilitate the development of a second life market for LIBs indirectly, but it is unlikely that the focus of the industry will shift its focus from recycling to reuse because of these factors.

Table 5. Lifecycle extension strategies in the new Battery Regulation 2023/1542 (European Union, 2023)

Article	Title	Requirements	Relevance	Reference
Article 7 Paragraph 5	Carbon footprint of EV batteries, rechargeable industrial batteries, and light means of	Paragraphs 1, 2, and 3 shall not apply to a battery that has been subject to preparation for re-use, preparation for repurposing, repurposing or remanufacturing if the battery had already	Batteries that are prepared for reuse, repurposing, or remanufacturing (related to older LIBs in	2023/1542 page 31

	transport batteries (LMT)	been placed on the market or put into service before undergoing such operations.	the market) are exempted from carbon footprint requirements.	
Article 8 Paragraph 4	Recycled content in industrial batteries, EV batteries, LMT batteries, and starting lighting, and ignition (SLI) batteries	Paragraphs 1, 2, and 3 shall not apply to batteries that have been subject to preparation for re-use, preparation for repurposing, repurposing, or remanufacturing if the batteries had already been placed on the market or put into service before undergoing such operations.	Batteries that are prepared for reuse, repurposing, or remanufacturing (related to older LIBs in the market) are not subject to recycled content requirements.	2023/1542 page 34
Article 10 Paragraph 4	Performance and durability requirements for rechargeable industrial batteries, LMT batteries, and EV batteries	Paragraphs 1, 2, and 3 shall not apply to a battery that has been subject to preparation for re-use, preparation for repurposing, or remanufacturing, where the economic operator placing that battery on the market or putting it into service demonstrates that the battery, before undergoing such operations, has been placed on the market or put into service before the dates on which those obligations become applicable by those paragraphs.	Performance and durability requirements for EV LIBs put on the market before the regulation was put in force are exempt from specific performance and durability requirements.	2023/1542 page 35
Article 45 Paragraph 1	Obligations of economic operators placing on the market or putting into service batteries that have been subject to preparation for re-use, preparation for repurposing, repurposing or remanufacturing	Economic operators placing on the market or putting into service batteries that have been subject to preparation for re-use, preparation for repurposing, or remanufacturing shall ensure that the examination, performance testing, packing, and shipment of those batteries, and such batteries' components subject to any of those operations, is carried out following adequate quality control and safety instructions.	Companies involved in providing reused, repurposed and remanufactured LIBs are subject to quality control and safety measures.	2023/1542 page 50
Article 45 Paragraph 2	Obligations of economic operators placing on the market or putting into service batteries that have been subject to preparation for re-use, preparation for repurposing, repurposing or remanufacturing	Economic operators placing on the market or putting into service batteries that have been subject to preparation for re-use, preparation for repurposing, repurposing or remanufacturing shall ensure that the battery complies with the requirements of this Regulation, any relevant product, environmental, human health protection and transport safety requirements in other Union law, taking into account the fact that, as a result of those operations, the battery might fall under a different battery category. For remanufacturing operations, such economic operators shall provide, upon request, market surveillance authorities with the documentation necessary to demonstrate that the battery	Companies involved in providing reused, repurposed and remanufactured LIBs must consider that batteries may fall into a different category in the regulation. Documentation must be provided to authorities, especially for remanufactured batteries.	2023/1542 page 50

		has been subject to remanufacturing in accordance with this Regulation.		
Article 73 Paragraphs 1-4	Preparation for re-use or preparation for repurposing of waste LMT batteries, waste industrial batteries, and waste EV batteries	Details in the battery passport and details on the battery's state of health should be available to help prepare batteries for a possible second life.	EU is requesting standardization on the testing of batteries for second life, repair, and repurposing.	2023/1542 page 68

3.4. Standardization

The lack of standardization in battery design (on all levels from pack to cell) and testing is significantly hindering the development of a market for repurposing or reusing EVs and industrial LIBs. The new battery regulation brings replaceability and removability requirements to batteries as well as additional data on battery chemistries, state of health, design, and recyclability through the battery passport, but these together are not going to drastically change the industry. The question of who can access what information on the battery passport arises. OEMs will continue to design their batteries by prioritizing the first use of the battery. Each OEM has different battery designs and chemistries which are not compatible with different LIBs.

Companies piloting second life applications of used LIBs will still need to adopt their processes each time they come across a different battery type. The same applies for battery recyclers, however it is likely that they will have access to a certain level of information through the battery passport, but still each time a new battery type is recycled, the recycling process needs to be adapted to that specific battery types. Replaceability and removability requirements (this however only applies to smaller and portable LIB) along with the battery passport may alleviate certain factors in these processes, but it is not the key to developing the market for the second life of LIB. Article 45 of the battery regulation requests standardization on testing and safety on remanufactured battery systems, meaning that repurposed battery systems need to meet the same safety and quality requirements.

3.5. Battery passport

The battery passport has been discussed as a game changer for the battery industry. Industry actors however have expressed security and intellectual property rights (IPR) concerns on the levels of data that need to be provided for the battery passport. The concerns of these companies are based mainly on the lack of knowledge and understanding of the technologies that can be used in providing the requested data. The technology (blockchain-based technologies) for the battery passport exists and with the right levels of encryption, companies can provide the necessary data but limit the levels of access to that data as they please. The data of the battery passport is accessible through a QR code. Understandably, a lot of the companies operating in the LIB industry have these concerns as a lot of them are either direct or indirect competitors of each other and this raises questions of what data can be shared and in what way so that it does not create a risk to the business.

In the case of EV and industrial LIBs recycling, coordination is often handled by a producer organization familiar with the OEM, or directly between the OEM and the recycling operator. This limited stakeholder group facilitates the sharing of crucial information, such as battery disassembly procedures and chemistries. While the exact role of the battery passport in EV and industrial LIB recycling remains to be seen, it is seen as an overall positive initiative.

Regarding the second life market, the limited accessibility to critical battery passport data, encrypted for specific stakeholders and timeframes, raises uncertainty about its role in advancing second life applications for EV and industrial LIBs. Given these restrictions, it is unlikely that the battery passport will significantly boost the second life battery market.

3.6. National battery strategies

Most EU member states have shown growing interest in batteries, electrification, and different types of ESSs, and countries have developed national energy storage or battery strategies. For example, Finland, Sweden, Spain, France, Italy, Hungary, Portugal, and the Netherlands, have specific strategies focused on batteries and the battery value chain. It is however evident, that most EU countries have a strategic interest in batteries, as those that do not have a strategy yet, are either developing one now or have initiated discussions on one being necessary.

For example, Finland's battery strategy is focused on strengthening the battery sector in Finland, through growth of the existing battery and electrification cluster, investments, enhancing international awareness, and responsibility, identifying key stakeholders in the battery sector's value chain as well as identifying emerging value chains and promotion of circular economy as well as digital solutions. The Finnish National Battery Strategy aims for Finland to become an important actor in the battery and electrification industry. (Ministry of Economic Affairs and Employment of Finland, 2021) Sweden's Strategy for a Sustainable Battery Value Chain is quite like Finland's, with a focus on achieving their fossil-free by 2045 goals. Similar to Finland, Sweden emphasizes the importance of collaboration across various sectors, investments, and securing raw mineral supply, while promoting CE. (Fossil Free Sweden, 2020)

The French battery strategy is more focused on gigafactories and securing the production of EVs and batteries but also emphasizes the importance of a full value chain. While the strategy

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document itself is shorter, it is similar to Finland and Sweden, and highlights the importance of CRMs, investments as well as research and innovation. (Ministre de l'Économie, des Finances et de l'Industrie, 2023) Those EU member states that have national battery strategies recognize their own country's unique potential and the importance of securing their roles in the value chain; be it securing raw materials or securing gigafactories for production or recycling. Table 6 provides an overview of EU member states' energy storage and battery strategies, as well as ongoing initiatives and projects.

Table 6. National battery and energy strategies of EU member states

Country	Summary	Link
Belgium	National energy and climate plan 2021–2030	Link
Bulgaria	N/A	-
Czechia	N/A	-
Denmark	Currently no national strategy, but one is in planning	Link
Germany	Energy storage strategy	Link
Estonia	Project on grid resilience and preparations on shifting away from Russian energy.	-
Ireland	Electricity Storage Policy Framework (2024)	Link
Greece	Ongoing projects on energy storage for grid resilience and renewable energy	-
Spain	Estrategia de Almacenamiento de Energía y Marco de Vehículo Eléctrico (2019-2030)	Link
France	Plan national pour les batteries (2018-2023)	Link
Croatia	National Hydrogen Strategy	Link
Italy	Piano Nazionale per le Batterie e lo Storage dell'Energia (2018-2023)	Link
Cyprus	Projects in private sector energy storage.	Link
Latvia	Developing national energy strategy	Link
Lithuania	Projects on improving grid resilience and energy storage parks.	-
Luxembourg	N/A	-
Hungary	National Battery Industry Strategy	Link
Malta	N/A	-
The Netherlands	Dutch Battery Strategy	Link
Austria	N/A	-
Poland	N/A	-
Portugal	Plano Nacional de Gestão de Resíduos (2019-2022) National Energy and Climate Plan - Plano Nacional de Energia e Clima 2030	Link Link
Romania	National battery strategy in development	Link
Slovenia	Ongoing projects on improving energy grid resilience and developing BESS	-
Slovakia	Investments in battery cell manufacturing,	-
Finland	The National Battery Strategy	Link
Sweden	The national strategy for a sustainable battery value chain	Link

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3.7. Extended producer responsibility

The EU Battery Regulation, implemented in February 2024, mandates extended EPR for all manufacturers and importers of batteries and accumulators, encompassing EV and industrial batteries.

OECD (2024) defines EPR: "*as an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's lifecycle. An EPR policy is characterized by: 1) the shifting of responsibility (physically and/or economically; fully or partially) upstream toward the producer and away from municipalities; and 2) the provision of incentives to producers to take into account environmental considerations when designing their products*". EPR schemes, based on the polluter-pays principle, are implemented in multiple sectors and product categories, such as electrical and electronic equipment, packaging, paper, batteries, vehicles, and tires.

There is not one single way to implement EPR, but it is implemented differently in different sectors and different countries. This is due to EPR being priorly under the Waste Framework Directive, allowing member states to organize their collecting schemes, as long as they meet the goals set by the EU. In some cases, individual firms have established their systems, in most cases, EPR is implemented through a system of Producer Responsibility Organizations (PROs) that are responsible for collecting, treating, and recycling. Often, they also have a responsibility to raise awareness of recycling among consumers. The number of PROs differs between countries and sectors. The system is based on the logic that producers pay a fee to the PRO based on the amount of products they place on the national market.

There are multiple different ERP actors in the EU. One of the most well-known is European Recycling Platform which acts as a PRO umbrella organization, meaning that the European Recycling Platform organizes all recycling and reporting related to waste management, through different PROs and recycling actors. European Recycling Platform is part of the Landbell group and operates in multiple EU countries. The European Recycling platform is an ideal PRO umbrella organization for multinational companies operating in different EU countries.

The new Battery Regulation 2023/1542 sets out specific minimum requirements for EPR in all EU member states. Some of the most relevant sections addressing ERP for EV and industrial LIBs are listed in Table 7.

Article 55 outlines the requirements for the establishment of a producer registry to monitor the compliance of producers (further requirements for producers are outlined in the chapter). This includes everything from requirements of an electronic data-processing system for registration applications, information that should be included in each application, how the producer meets the requirements set out in the regulation, and what authorities and other parties are involved. The article also states that producers need to register to a registry in the country where they first set the battery into the market.

Article 56 of the battery regulation delves into the EPR of repurposed batteries and second life applications. Producers selling battery systems made from repurposed batteries must be part of a PRO. The cost-sharing arrangements between the original equipment manufacturer and the repurposed battery manufacturer are still unclear. PROs will play a pivotal role in the EPR of repurposed batteries, though the exact implementation details remain to be seen. In addition, Article 57(1) of the battery regulation states the following:

"producer responsibility organizations shall make available to end-users and distributors the following information regarding the prevention and management of waste batteries with regard to the categories of batteries that they supply within the territory of a Member State:

(a) the role of end-users in contributing to waste prevention, including by information on good practices and recommendations concerning the use of batteries aimed at extending their use phase and the possibilities of re-use, preparation for re-use, preparation for repurposing, repurposing and remanufacturing" (Regulation 2023/1542).

PROs need to therefore provide end users and distributors of batteries with information on waste prevention and means of lifecycle extension of batteries, information on reuse, preparation for reuse, repurposing, and remanufacturing.

Table 7. Extended producer responsibility requirements in the new Battery Regulation 2023/1542 (European Union, 2023)

Article	Theme	Requirements	Relevance	Reference
Article 1 Paragraph 1	Subject matter and scope	Minimum requirements for extended producer responsibility, the collection and treatment of waste batteries, and reporting.	Before this regulation, member states were allowed to implement EPR freely just as long as the goals set out in the Waste Framework Directive were reached.	2023/1542 page 25
Article 55 Paragraphs 1 -13	Register of producers	Specifications on producer registry in each country	Detailed guidelines on how a producer registry should be established and how producers can register.	2023/1542 page 56

			Producers need to be registered in a country registry where the battery is placed on the market for the first time.	
Article 56 Paragraphs 1-5	EPR	Producer responsibility guidelines	Information on how producers can meet the requirements of EPR	2023/1542 pages 57-58
Article 56 Paragraph 2	EPR	An economic operator that makes available on the market for the first time within the territory of a Member State a battery that results from preparation for re-use, preparation for repurposing, or remanufacturing operations shall be considered to be the producer of such battery for the purposes of this Regulation and shall have extended producer responsibility.	Repurposed battery system providers are considered producers and are responsible for organizing producer responsibility of the repurposed batteries through a PRO.	2023/1542 page 58
Article 56 Paragraph 5	EPR	In the case of making available batteries that have been subject to preparation for re-use, preparation for repurposing, repurposing, or remanufacturing, both the producers of the original batteries and the producers of the batteries that are placed on the market as a result of those operations, may establish and adjust a cost-sharing mechanism, based on the actual attribution of costs between the different producers, for the costs referred to in paragraph 4.	Costs of the repurposed batteries EPR may be shared among the original equipment manufacturer and the repurposed battery system manufacturer.	2023/1542 page 58
Article 57 Paragraphs 1-8	PRO	Requirements for PROs	Outlined requirements for PROs and how EPR can be organized in different ways.	2023/1542 page 191/58
Article 61 Paragraphs 1-4	Collection of waste SLI, industrial, and EV batteries	Specifications for end-of-life EV and industrial LIBs collection take-back schemes	Outlined requirements of how the collection of waste batteries can be organized. Guidelines for different scenarios are also provided.	2023/1542 page 191/63

3.7.1. Battery compliance schemes in different countries of Europe

All EU member states organize EPR through different kinds of compliance schemes for battery take-back. Battery compliance schemes, also known as PROs, help producers comply with battery regulations by managing the collection, recycling, and proper disposal of waste batteries. The battery compliance schemes of each EU country are listed in Table 8 below.

Table 8. Battery compliance schemes/PROs in different EU Countries

Country	Compliance scheme
Belgium	Bebat
Bulgaria	N/A
Czechia	Ecobat
Denmark	DPA, European Recycling Platform
Germany	GRS batterien
Estonia	EES- Ringlus
Ireland	WEE Ireland, European Recycling Platform
Greece	AFIS S.A.
Spain	Ecopilas, European Recycling Platform (Spain)
France	Corepile; Screlec
Croatia	C.I.O.S. Group subsidiary CE-ZA-R (Centar za reciklažu)
Italy	COBAT and ERP Italia
Cyprus	AFIS Cyprus Ltd
Latvia	Latvijas Zaļais punkts (Latvia's Green Dot)
Lithuania	UAB Aplinkosaugos investicijų agentūra (Environmental Investment Agency)
Luxembourg	REBAT
Hungary	National Waste Management Authority and MOHU MOL
Malta	WasteServ Malta Ltd
The Netherlands	Stibat
Austria	European Recycling Platform (ERP) Austria GmbH
Poland	Reba
Portugal	Ecopilhas
Romania	ROMBAT (Lead acid batteries), Recuperare S.A.
Slovenia	ZEOS, d.o.o. (Zavod za Eko Sisteme)
Slovakia	SEWA and European Recycling Platform
Finland	Suomen Autokierätys Oy
Sweden	El-Kretsen, European Recycling Platform

3.7.2. Example: Producer responsibility for batteries in Finland

For EV LIBs, in Finland, the PRO is Suomen Autokierrätys Oy, also known as Finnish Car Recycling Ltd. Due to the EU Battery Regulation, a separate PRO for large and industrial LIBs is being developed in Finland. Finnish Car Recycling is responsible for the collection, treatment, and recycling of end-of-life vehicles and EVs, including their LIBs by the End-of-Life Vehicles (ELV) directive. In Finland, there are around 300 take-back or collection points for end-of-life vehicles, ranging from repair shops to collection points organized by the producer association. These collection points also collect batteries from EVs separately. Finnish PROs focus solely on LIB collection and recycling, with no emphasis on reuse or second life applications.

The PRO has separate contracts with each producer and depending on the producer, they either recycle the EVs and LIBs through the PRO or in rarer circumstances, the producer wants to collect end-of-life batteries themselves. Most producers, however, are registered with a PRO. During the lifecycle of an EV battery, if it requires repair, it's usually sent directly back to the producer for analysis, reuse, or recycling. Regarding data access, PROs don't receive specific notifications when an EV battery is replaced. Instead, they track and follow up on battery orders for spare parts. In the case of vehicle recalls involving LIBs, all affected batteries are returned to the producer.

However, given Finland's slow EV adoption, there are currently no end-of-life EVs, and only about 2,700 vehicles on the road are over 10 years old.

3.8. Example: Norway’s regulatory framework

Norway, not an EU member but a part of the EU’s internal market (European Economic Area, EEA), leads the world in EV adoption, with EVs currently accounting for approximately 89% of its market share (Statista, 2024), as shown in Figure 30.

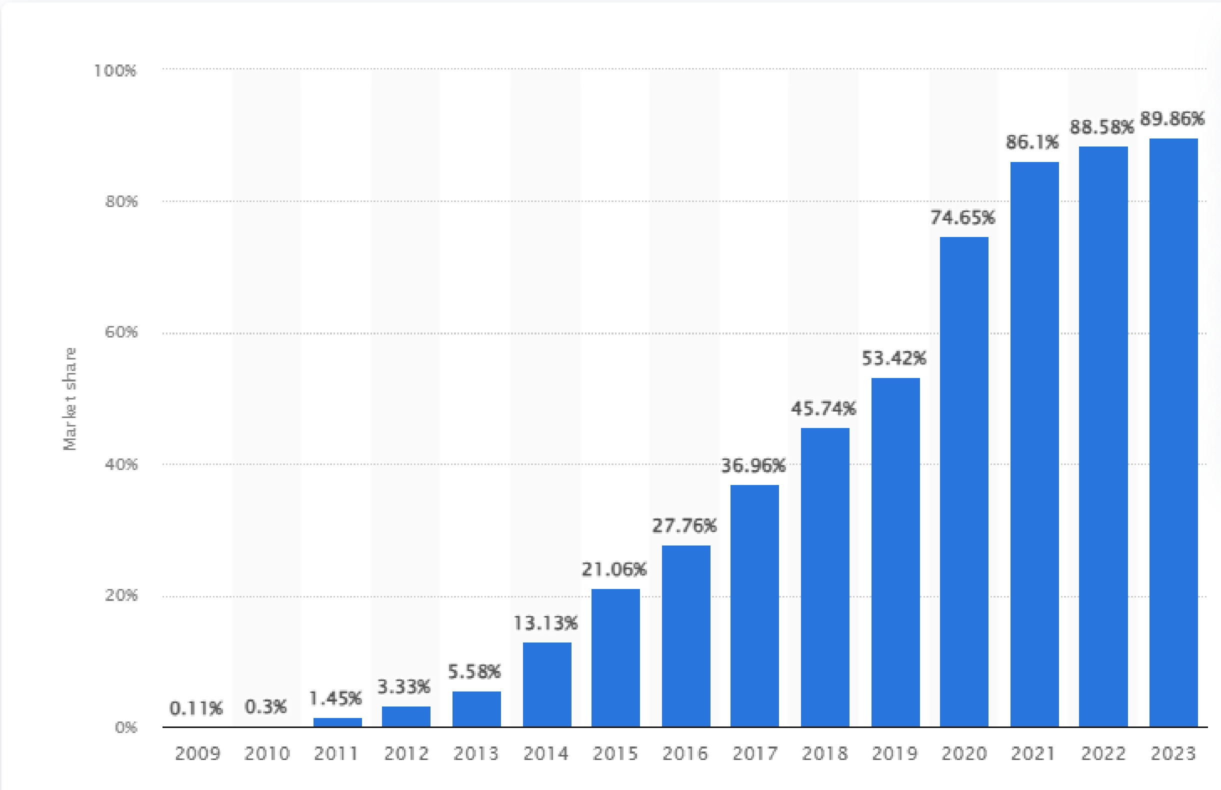

Figure 30. Norway's EV market share (based on new registrations) between 2009–2023 (Statista, 2024)

Norway has been able to cherry-pick parts of EU legislation that they deem a good fit and apply it to their local legislation, for example, EU climate and energy-related legislation. As depicted in Figure 31, Norway's systematic approach to legislation, infrastructure development, and consumer incentives has driven significant EV adoption. Tax benefits implemented between 1999 and 2010, combined with lower long-term ownership costs compared to gas vehicles, and investments in charging infrastructure have created a favorable environment for EV ownership. Figure 32 provides an overview of the various policy incentives implemented in Norway between 2005 and 2023 to encourage EV adoption.

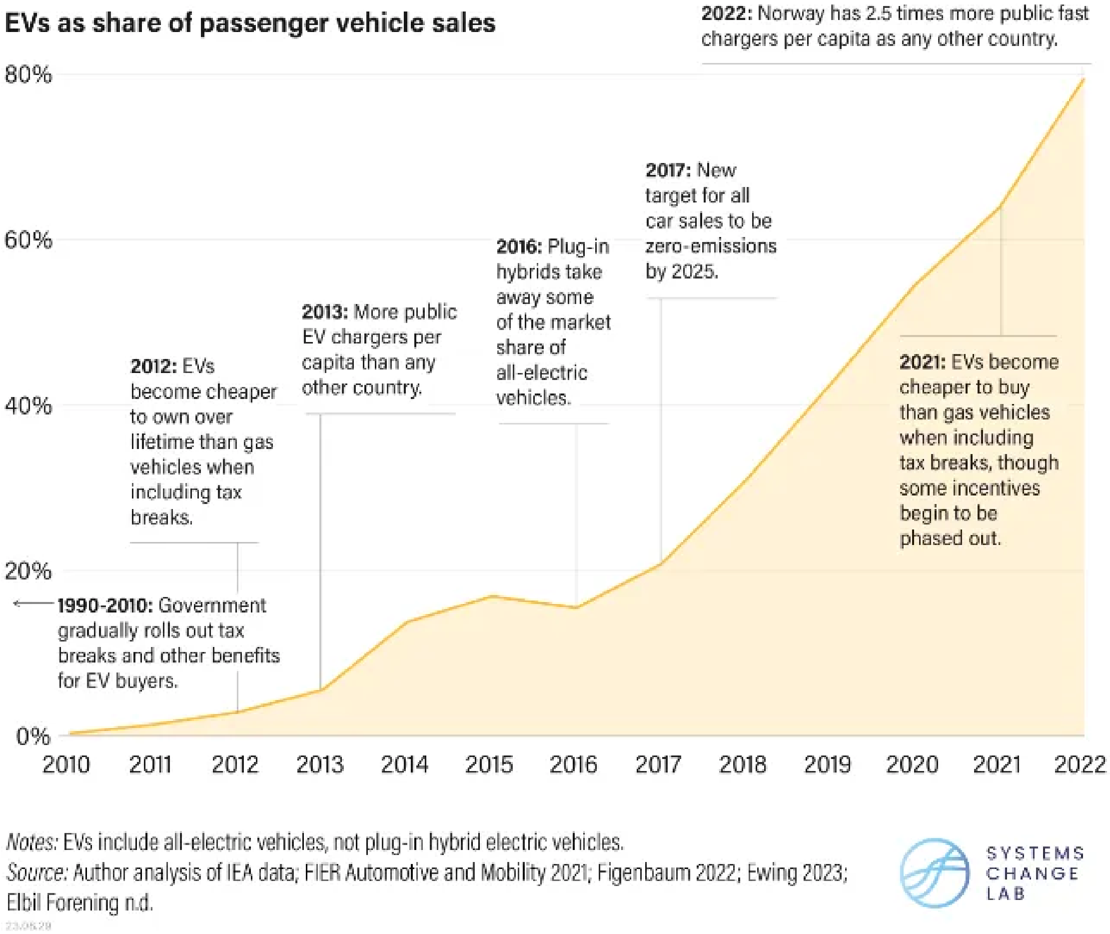

Figure 31. Norway's EV adoption timeline and governmental incentives (Asurza Engineers, 2024)

Policy	Category	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
VAT exemption (a)	registration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗
Threshold VAT — a subsidy scheme (a)	registration	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	→ SOON	→ SOON	✓
Exemption from / deduction of new car registration fee (b)	registration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Annual motor vehicle tax Exemption (c)	ownership	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗
Road traffic insurance tax deduction (c)	ownership	.	.	.	.	.	.	.	.	.	.	.	.	→ SOON	✓	✓	✓	✓	✓	✓
Access to bus lanes (kollektivfelt) (d)	ownership	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗
Access to bus lanes (kollektivfelt) — conditional (d)	ownership	.	.	.	.	.	.	.	.	.	.	.	→ SOON	✓	✓	✓	✓	✓	✓	✓
Road tolls exemption (e)	ownership	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗
Road tolls deduction (e)	ownership	.	.	.	.	.	.	.	.	.	.	.	.	.	→ SOON	✓	✓	✓	✓	✓
Free parking in public (municipal) spaces (f)	ownership	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗
Free ferries (g)	ownership	.	.	.	→ SOON	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗
Ferry price deduction (g)	ownership	.	.	.	.	.	.	.	.	.	.	.	→ SOON	→ SOON	→ SOON	✓	✓	✓	✓	✓
Oslo EVSE procurement installation (h)	infrastructure	.	.	→ SOON	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗
All new cars sold by 2025 should be zero-emission (j)	ownership	.	.	.	.	.	.	.	.	.	.	.	.	→ SOON	→ SOON	→ SOON	→ SOON	→ SOON	→ SOON	→ SOON
Zero emission zone in Oslo (k)	ownership	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	→ SOON

Notations: → SOON Pending (decided and waiting to be implemented); ✓ In force; ✗ Discontinued.

Figure 32. EV supporting policies in Norway between 2005–2023 (Qorbani et al., 2024)

3.9. Transportation of dangerous goods regulations

Prior to the new battery regulation, used LIBs were considered as hazardous waste and therefore transportation (even in cases where a LIB would be repurposed for a second life application) was regulated similarly as battery waste. Article 73 of the new Battery Regulation 2023/1542 sets new standards for the definition of a waste LIB and one that is considered for reuse. For a used EV or industrial LIB to meet the standards of reuse or repurposing the following information needs to be presented:

- (a) Evidence of a state of health evaluation or state of health testing carried out in a Member State in the form of a copy of the record confirming the capability of the battery to deliver the performance relevant for its use following preparation for re-use or preparation for repurposing;

- (b) further use of the battery that has been subject to preparation for re-use or preparation for repurposing, is documented by means of an invoice or a contract for the sale or transfer of ownership of the battery;

- (c) evidence of appropriate protection against damage during transportation, loading and unloading, including through sufficient packaging and appropriate stacking of the load. (Regulation 2023/1542)

In addition, Annex XIV of the Battery Regulation further defines the requirements for testing, state of health, presence of hazardous substances, documentation, transport documentation and a declaration of responsibility by the liable party. If these specific details are not provided, the battery will be classified as waste. The requirements set in Annex XIV and article 73, along with the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) and the International Maritime Dangerous Goods (IMDG) Code, are presented in Table 9.

Table 9. Legislation related to the transportation of batteries

Legislation	Requirement
Battery Regulation 2023/1542 Article 73 Chapter 1	Evidence of appropriate protection against damage during transportation, loading, and unloading, including through sufficient packaging and appropriate stacking of the load.
Battery Regulation 2023/1542 *ANNEX XIV* Points 1, 2, and 3	Annex XIV of the Battery Regulation sets the minimum requirements for shipments of used batteries. **Point 1 covers the following documentation requirements:** (a) a copy of the invoice and contract relating to the sale or transfer of ownership of the batteries which states that the batteries are destined for direct re-use and that they are fully functional (b) evidence of evaluation or testing in the form of a copy of the records, such as the certificate of testing, proof of functionality for every battery or fraction thereof in the consignment, and the protocol containing all information on the record in accordance with point 3

	(c) a declaration made by the holder that none of the material or equipment within the consignment is waste as defined by Article 3, point (1) (definition of waste) of the Waste Framework Directive 2008/98/EC (d) appropriate protection against damage during transportation, loading, and unloading, in particular through sufficient packaging and appropriate stacking of the load. **Point 2 describes situations in which point 1(a), 1(b), and point 3 do not apply; which is demonstrated by documentary proof that the shipment is taking place in the framework of business-to-business transfer agreements and that:** (a) the used battery is sent back to the producer or a third party acting on its behalf for repair under warranty with the intention of re-use; or (b) if the used battery is for professional use, it is sent to the producer or a third party acting on its behalf or a third-party facility in countries to which OECD Council Decision C(2001)107/Final on the Control of Transboundary Movements of Wastes Destined for Recovery Operations applies, for refurbishment or repair under a valid contract with the intention of re-use; or (c) if the used battery is for professional use and is defective, it is sent to the producer or a third party acting on its behalf for root cause analysis under a valid contract, in cases where such an analysis can only be conducted by the producer or third parties acting on its behalf. **Point 3 addresses the testing requirements for shipping of used batteries:** In order to demonstrate that the batteries being shipped constitute used batteries, rather than waste batteries, its holder shall carry out the following steps for testing and record-keeping: Step 1: Testing All batteries need to be tested for state of health and the presence of possible hazardous substances needs to be evaluated. The results of these tests need to be documented. Step 2: Record The record of the battery testing (state of health and presence of hazardous substances) needs to be attached to either the battery itself or the packaging. The record needs to be accessible without removing the packaging. The record needs to contain the following information: - the name of the battery or fraction thereof, - identification number of the battery or fraction thereof, where applicable (specified in Annex XIV of the battery regulation) - year of production, if available, - name and address of the company responsible for testing the state of health, - types of tests performed for step 1, - the result of the tests performed for step 1, including the date of the tests.

Battery Regulation 2023/1542 *ANNEX XIV* Points 4 and 5	**Point 4 introduces additional documentation requirements for points 1, 2, and 3, when every load of used batteries (for example shipping container or lorry), should be accompanied by:** (a) a relevant transport document; and (b) a declaration of responsibility by the person liable. **Point 5 addresses situations in which obligations set out in points 1, 2, 3, and 4 are not met:** In the absence of proof that an object is a used battery, and not a waste battery, in the form of the appropriate documentation required in points 1, 2, 3, and 4, and of appropriate protection against damage during transportation, loading, and unloading, in particular through sufficient packaging and appropriate stacking of the load, which are the obligations of the holder that arranges the transport, the object shall be considered waste and it shall be presumed that the load comprises an illegal shipment. In such cases, the load shall be dealt with in accordance with Articles 24 (Take-back when a shipment is illegal) and 25 (Cost for take-back when a shipment is illegal) of Shipments of Waste Regulation (EC) No 1013/2006.
ADR - road	ADR regulation sets the standard for the transportation of different types of waste batteries. Lithium-ion batteries and cells need to be marked with UN3090 or UN3480. In addition, information on the battery's state of charge, and battery type need to be provided. LIBs that hold a capacity of over 100 Wh as well as defective LIBs need to be transported as dangerous goods. LIBs need to be packed so that they can withstand changes in temperature during their transit. In addition, LIBs need to be securely packed so that the outer packaging protects the battery from any damage and leaking. To transport LIBs, a driver who is qualified and understands safety requirements related to the transportation of dangerous goods is required. LIBs can only be transported using vehicles that have special safety features such as fire extinguishers.
IMDG - sea/ waterway	Under IMDG code EVs are considered dangerous goods and need to be classified as UN3171 BATTERY POWERED VEHICLE or BATTERY POWERED EQUIPMENT. EVs that are shipped in shipping containers require clear documentation and clear labeling of UN3171. EVs are in some cases inspected before loading to ensure that the EV LIB is stable. In addition, the state of charge of the battery should be at a minimum level (industry recommendation is between 20 – 50%. In some cases, the battery management system of an EV may be accessed to ensure battery health and safety. Special containers are not a requirement but are recommended. Containers with monitoring and fire extinguishing systems helps further mitigate risks of sea transport. Currently, EVs are not required to be separated from other cargo (for example flammable liquids etc.), which poses risks if the EV containers are loaded in close proximity to other dangerous goods.

4. VALUE CHAIN FOR USED BATTERIES

This Chapter provides a detailed overview of the value chain for used batteries, highlighting various lifecycle extension strategies. A particular emphasis is placed on the repurposing of LIBs for second life applications, as illustrated in Figure 33.

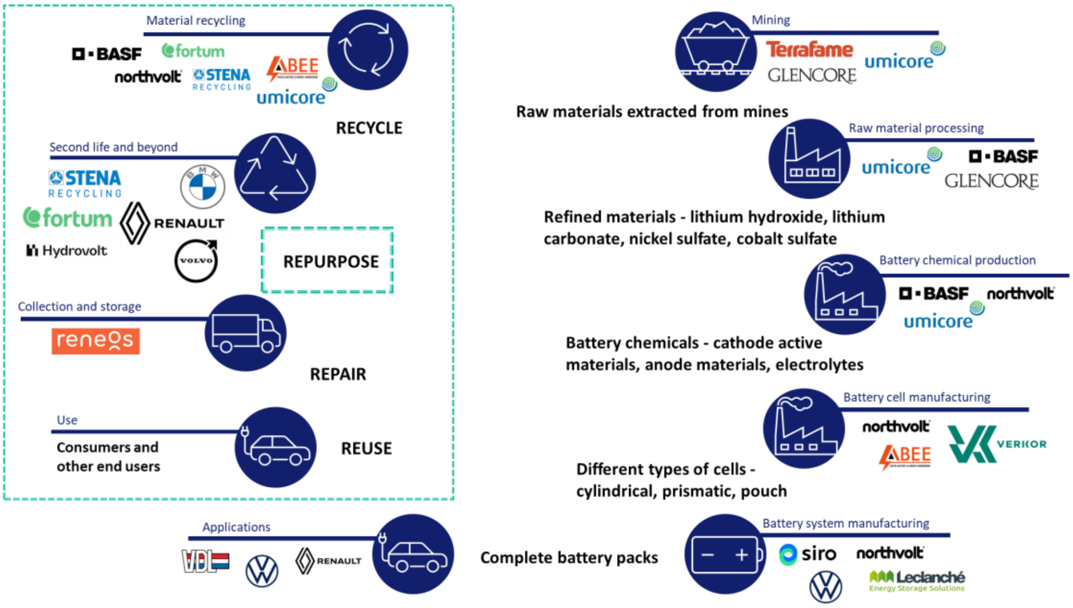

Figure 33. Lifecycle extension of LIBs

4.1. Circular economy strategies for battery lifecycle extension

CE strategies for LIBs involve extending the lifespan of batteries through reuse, repair, remanufacturing, repurposing, and ultimately, recycling. To determine when repurposing is a relevant strategy, a comprehensive analysis of these strategies is necessary.

Reuse entails employing a battery in the same application as its original purpose without alterations (Börner et al., 2022). In practice, this means using batteries (battery modules) as replacement batteries. Sometimes only one module in a battery fails, and it needs to be replaced. A new module cannot be installed in a used battery pack; all modules in a battery pack must have the same capacity. If there are differences in the capacity of the modules, the battery will fail again.

Battery **repair** means replacing defective or broken components before reusing the battery for the same purpose. Design for repair is essential in the early phases of product development (Albertsen et al., 2021). Repairs can be carried out at the battery pack, module, and cell levels. This allows for the replacement of individual defective cells, thereby mitigating the risk of complete battery failure. However, often the root cause of the malfunction lies elsewhere than in the cell itself.

Battery **remanufacturing** is a process that involves refurbishing used batteries to restore their performance and extend their lifespan. Remanufacture rebuilds batteries for their original purpose by reusing and repairing used components while replacing some components with new ones (Börner et al., 2022). The optimal strategy for a given battery depends on its health. High-quality batteries are ideal for remanufacturing, while those with lower performance are repurposed for less demanding applications.

Battery **repurposing** means the complete or partial use of a battery in a different application than its original purpose. Critical to the effective repurposing of a battery is its compatibility with the intended second life scenario (Börner et al., 2022), such as the ESS (Baars et al., 2021) in both larger industrial systems and smaller residential applications. The repurposing process involves constrained disassembly and reassembly of the battery, such as modifying connectors to integrate the EV battery into a stationary ESS aimed at reusing key assemblies and minimizing the extent of disassembly (Börner et al., 2022).

Batteries that have reached their end-of-life are recycled to recover valuable materials and minimize waste. Battery **recycling** involves reclaiming raw materials from used batteries (e.g. lithium, cobalt, nickel, graphite) for manufacturing new batteries, for example. Recycling methods include mechanical, pyrometallurgical, and hydrometallurgical processing, and direct recycling of active materials (Börner et al., 2022).

Figure 34 illustrates the product and material flows of different CE strategies for EV batteries (Slattery et al., 2024). EV batteries may be retired due to malfunction, performance degradation, or physical damage. The specific pathway for a retired battery depends on its condition and warranty status.

A. If a battery is still under warranty, an EV is returned to the dealership. Technicians assess the battery's remaining state-of-health and remove the battery pack from the vehicle. Based on the state of health, the OEM decides whether to repair, remanufacture, repurpose, or recycle the battery. However, it is crucial to understand that there is significant variation in the strategies and procedures employed by different OEMs. Tesla and BMW models serve as prime examples of these differences.
B. EVs damaged in collisions enter the existing vehicle afterlife market as "total loss vehicles". These vehicles are typically sold at insurance auctions and acquired by dismantlers, rebuilders, exporters, or scrap metal recyclers. Dismantlers sell usable parts, rebuilders restore the entire vehicle, and exporters sell them internationally. Older vehicles with minimal value are sent to scrap metal recyclers. Dismantlers and recyclers may become significant sources of EV batteries for reuse or repurposing in the future.

C. Out-of-warranty EVs can follow several paths. They may be repaired by independent garages or remanufactured into replacement battery packs. Alternatively, these vehicles may be directly sold to dismantlers or scrap recyclers by owners or tow truck operators, or they may be donated or reclaimed by state programs. However, given the relatively recent adoption of EVs, this market is still developing.
D. LIBs with adequate remaining capacity can be repurposed for stationary storage applications. Section 4.3 describes the stages of the repurposing process.
E. Eventually, the batteries will be recycled to recover valuable materials.

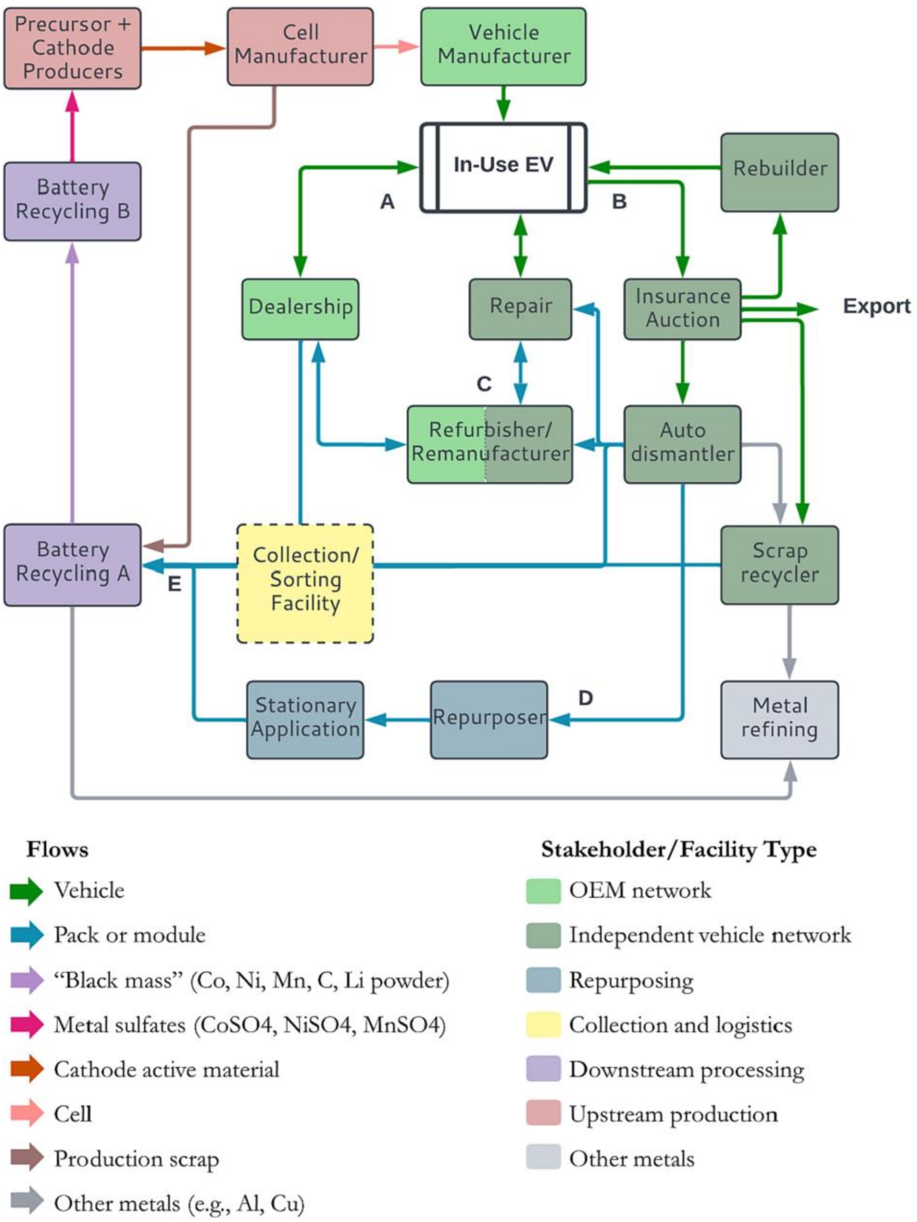

Figure 34. Product and material flows of different circularity strategies, Notes: "A" represents batteries that are returned under warranty. "B" represents batteries that are removed due to a car collision. "C" represents batteries that are remanufactured or refurbished and reused in another vehicle, which could be performed within the dealership/OEM network (represented by the light green color) or by an independent operator (dark green). "D" represents batteries that do not have sufficient SOH for reuse in another vehicle but are repurposed as stationary storage. "E" represents all retired batteries and production scrap that are sent to a battery recycler. Battery recycling consists of two steps: pre-treatment ("Battery Recycling A") and material recovery ("Battery Recycling B"). (Slattery et al., 2024)

4.2. Pathway decisions for sustainable circular battery value chain

Figure 35 depicts a complex LIB value chain with multiple CE strategies: reuse, repair, repurposing, redesign, and recycling (Prenner et al., 2024). A robust stakeholder ecosystem is essential to facilitate the development of sustainable first- and second life battery solutions. Due to numerous internal and external factors, a one-size-fits-all approach to transitioning to a CE is not feasible. Consequently, to promote the adoption of CE strategies, including repurposing, a supportive policy framework is needed. Additionally, future technological advancements in batteries and recycling could significantly impact the market landscape. Therefore, it is crucial to consider design-for-repurpose strategies during the initial stages of battery development. **Design** plays an important role in shaping decisions about sustainable end-of-life management of batteries. The key design decisions that influence the following pathway decisions are made before cell manufacturing.

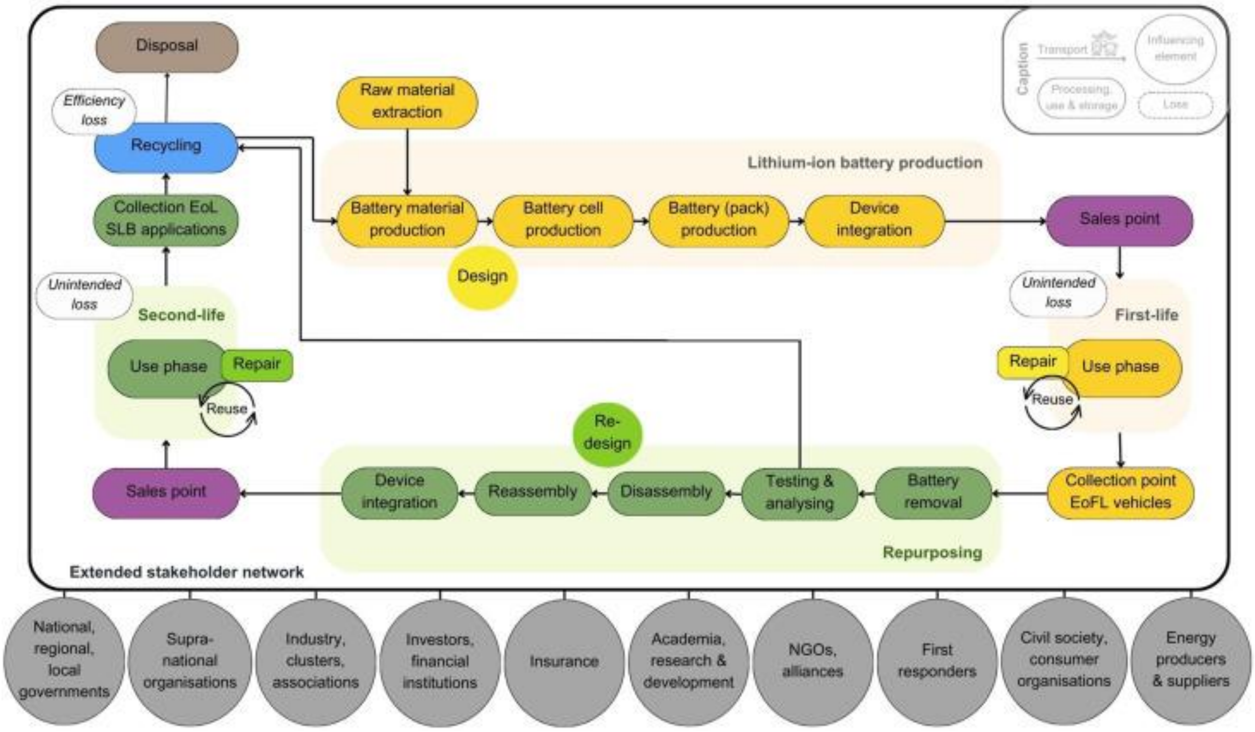

Figure 35. LIB value chain with CE strategies (Prenner et al., 2024)

The decision on whether to repurpose or recycle used batteries is complex, with both economic and environmental implications. To build a sustainable circular battery value chain, it is important to carefully consider the factors that influence these decisions (Ma et al., 2024) (Figure 36). The project deliverable 7.4 - Sustainability assessment of REINFORCE innovations – encompasses a comprehensive approach to impact assessment focusing on the results of life cycle assessment

(LCA), social life cycle assessment (SLCA) and life cycle costs (LCC). The economic aspect is discussed briefly in the next section (4.3).

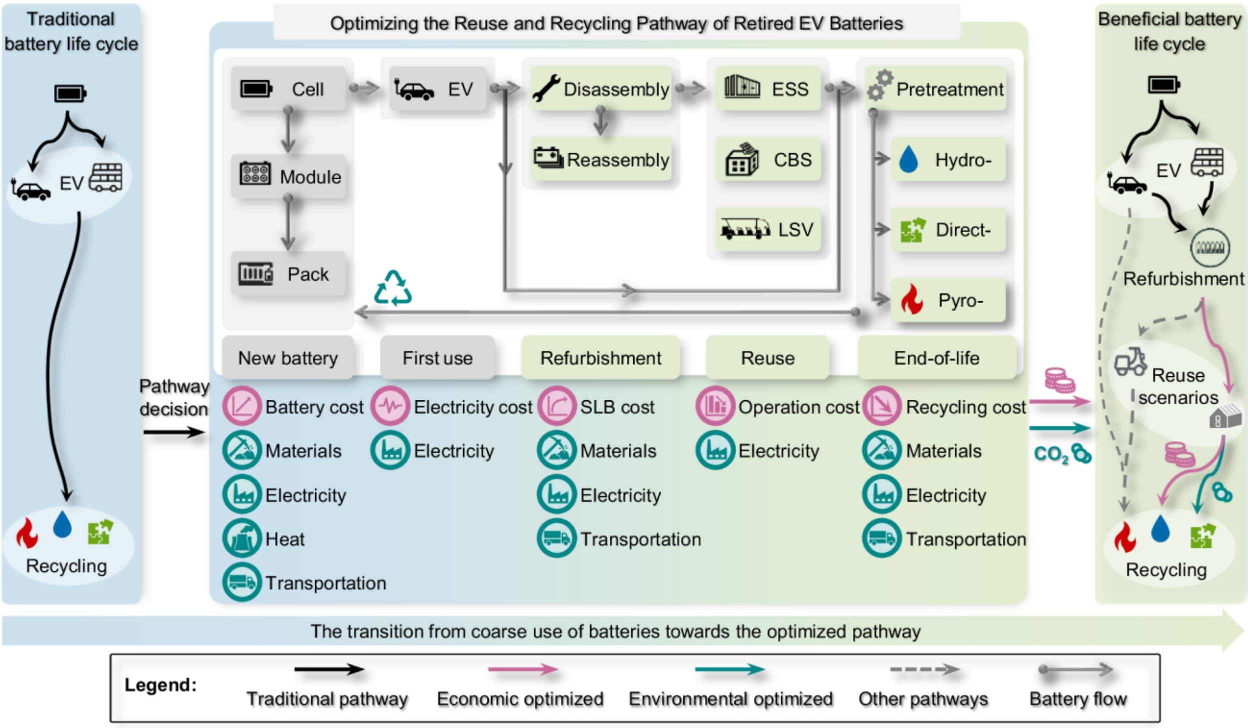

Figure 36. Pathway decisions for reuse and recycling of retired LIBs considering economic and environmental functions, Note: ESS = energy storage system, CBS = communication base station, LSV = low-speed vehicle (Ma et al., 2024)

4.3. Process flow model of batteries repurposing

Repurposing batteries holds the potential for economic and environmental benefits, but their successful implementation requires the development of cost-effective repurposing processes. Repurposing typically involves disassembling battery packs into modules, assessing their health, and reconfiguring them with new BMS systems. While pack-level repurposing is simpler and less time and labor-cost-intensive (White and Swan, 2023), module-level repurposing offers longer life and higher energy density (Slattery et al., 2024).

LIBs are also disassembled down to the cell level for recycling and repurposing. Disassembling EV battery packs to the cell level increases the concentration of cobalt, lithium, and nickel, which are essential components of the cathode active material (Leon and Miller, 2020). However, from the point of view of repurposing, disassembling, and testing battery packs at the cell level is proved infeasible due to the high labor costs involved (Lieskoski et al., 2024; Rallo et al., 2020). To ensure sustainable and efficient disassembly for diverse battery types, automated processes are under development (Choux et al., 2024; Lu et al., 2023).

Following Zhu et al. (2021), the technical procedure of repurposing includes (Figure 37):

1. Assessment of the retired battery system based on historical information,
2. Disassembly of retired battery packs or modules,
3. Battery performance (mechanical, electrochemical, and safety) evaluation,
4. Sorting and regrouping, and
5. Developing control and management strategies for second life applications.

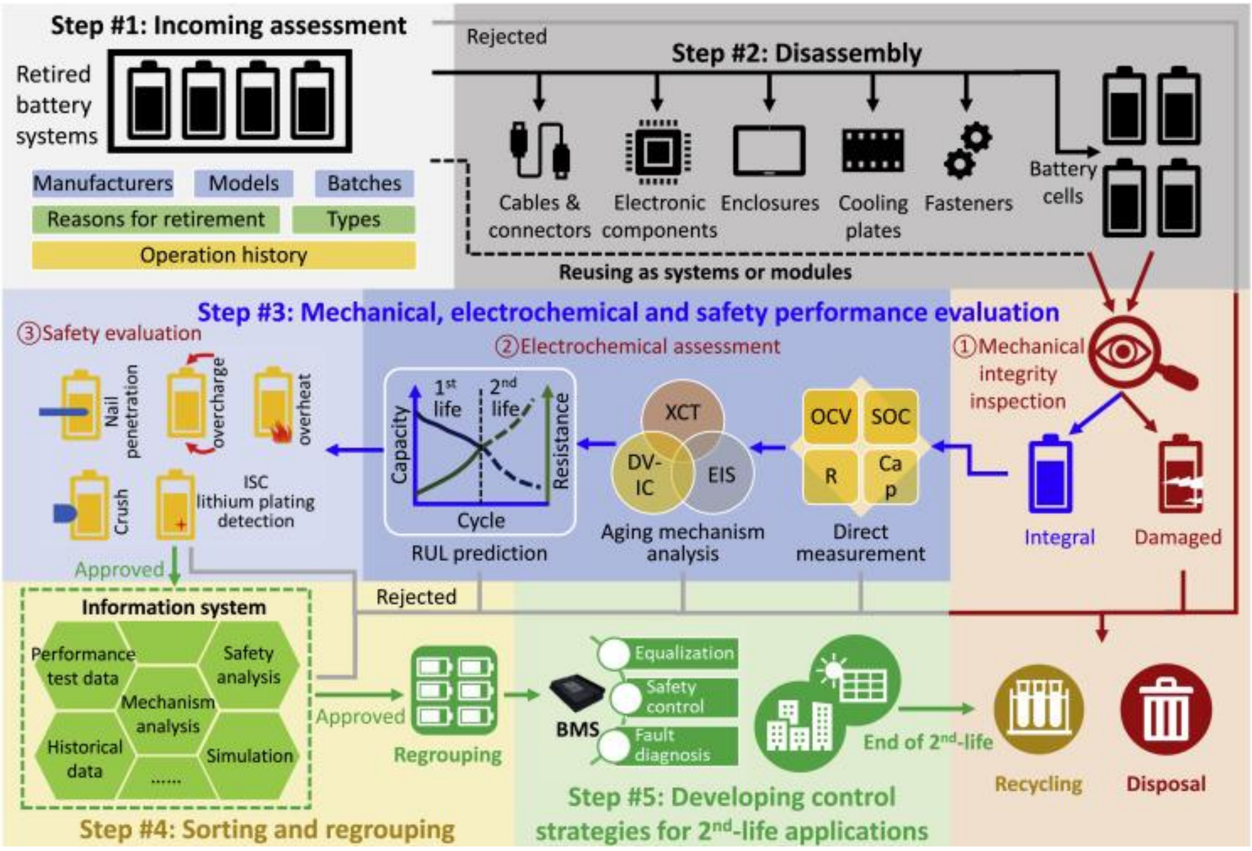

Figure 37. Assessment procedure of retired LIBs (Zhu et al., 2021)

It is worth noting that multiple rounds of inspections and assessments are typically conducted in practice, some at the module level and others at the cell level. Overall, the technical feasibility of second life applications of retired EV batteries largely relies on whether these steps could be performed effectively and efficiently. In the REINFORCE project, battery assessment is developed under work package 4, and disassembly process automatization and evaluation under work package 5.

The feasibility of repurposing is affected by the repurposing process stages and the battery type. For example, White and Swan (2023) show significant performance differences among the five EV battery packs studied: 2012 Lishen EV-LVP (LFP battery), 2012 Nissan Leaf (lithium manganese oxide battery (LMO) battery), 2015 BMW i3 (NMC battery), 2018 Chevrolet Bolt (NMC battery), and 2019 Tesla Model 3 SR+ (NCA battery), particularly between older (2012–2015) and newer (2018–2019) designs due to evolutions in energy density and thermal management. In second life

ESSs, the 2019 Tesla Model 3 battery (tested with active-liquid cooling) is projected to deliver optimal overall performance (Figure 38), whereas the 2015 BMW i3 battery (tested with passive-air cooling) is projected to maximize profit margins in applications where energy loss minimization is critical.

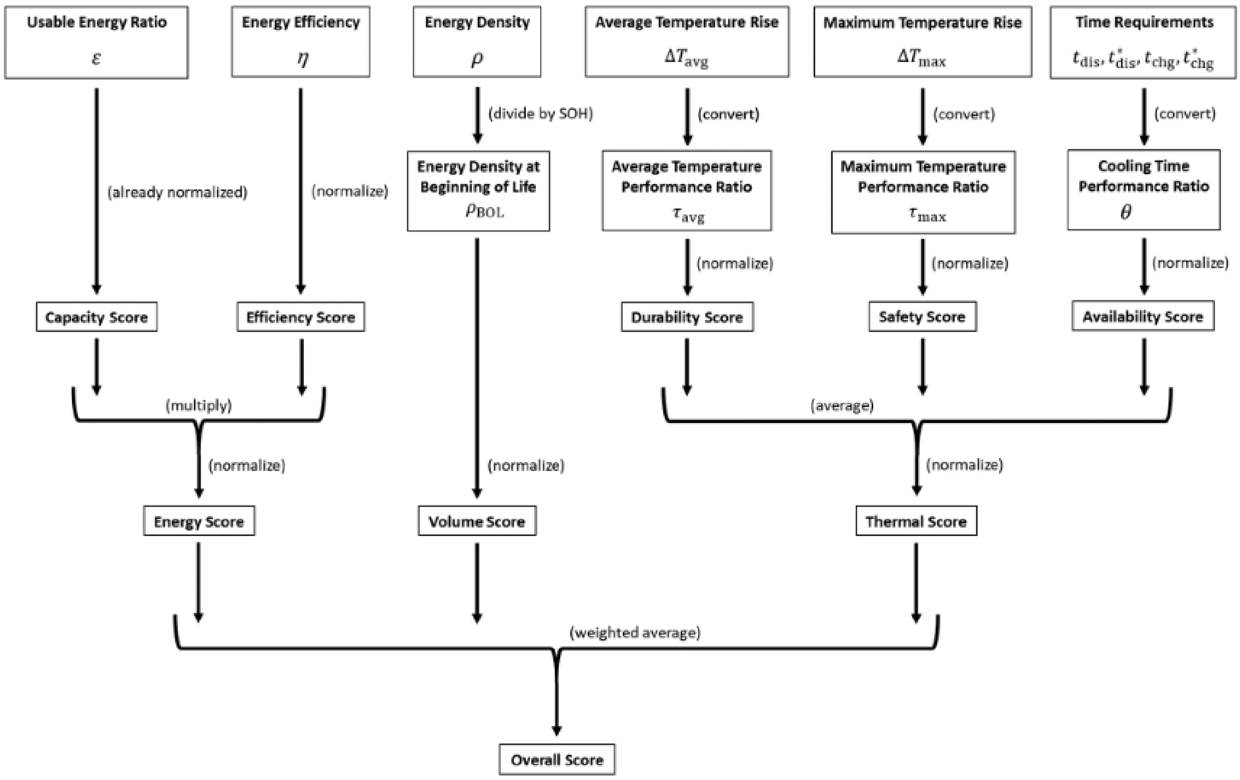

Figure 38. Graphical summary of analytical techniques used to produce overall performance scores (White and Swan, 2023)

4.4. Evolution of second life battery projects

The concept of repurposing EV batteries for second life applications dates back to the 1990s, with early research and reports from academic institutions and national laboratories. However, large-scale industrialization of second life battery technologies did not begin until the early 2010s. A study conducted around the year 2020 (Zhu et al., 2021) (Figure 39) of publicized industrial projects revealed several key trends. Firstly, there has been a significant increase in the number of second life battery projects. Secondly, major automotive OEMs are increasingly involved in these initiatives, often collaborating with battery suppliers or third-party companies. Thirdly, large-scale stationary ESSs are becoming more prevalent. Finally, the range of second life applications is expanding beyond traditional stationary storage, exploring diverse use cases. These trends have continued in recent years, but also other actors than automotive OEMs have entered the business, summarized in section 4.5.

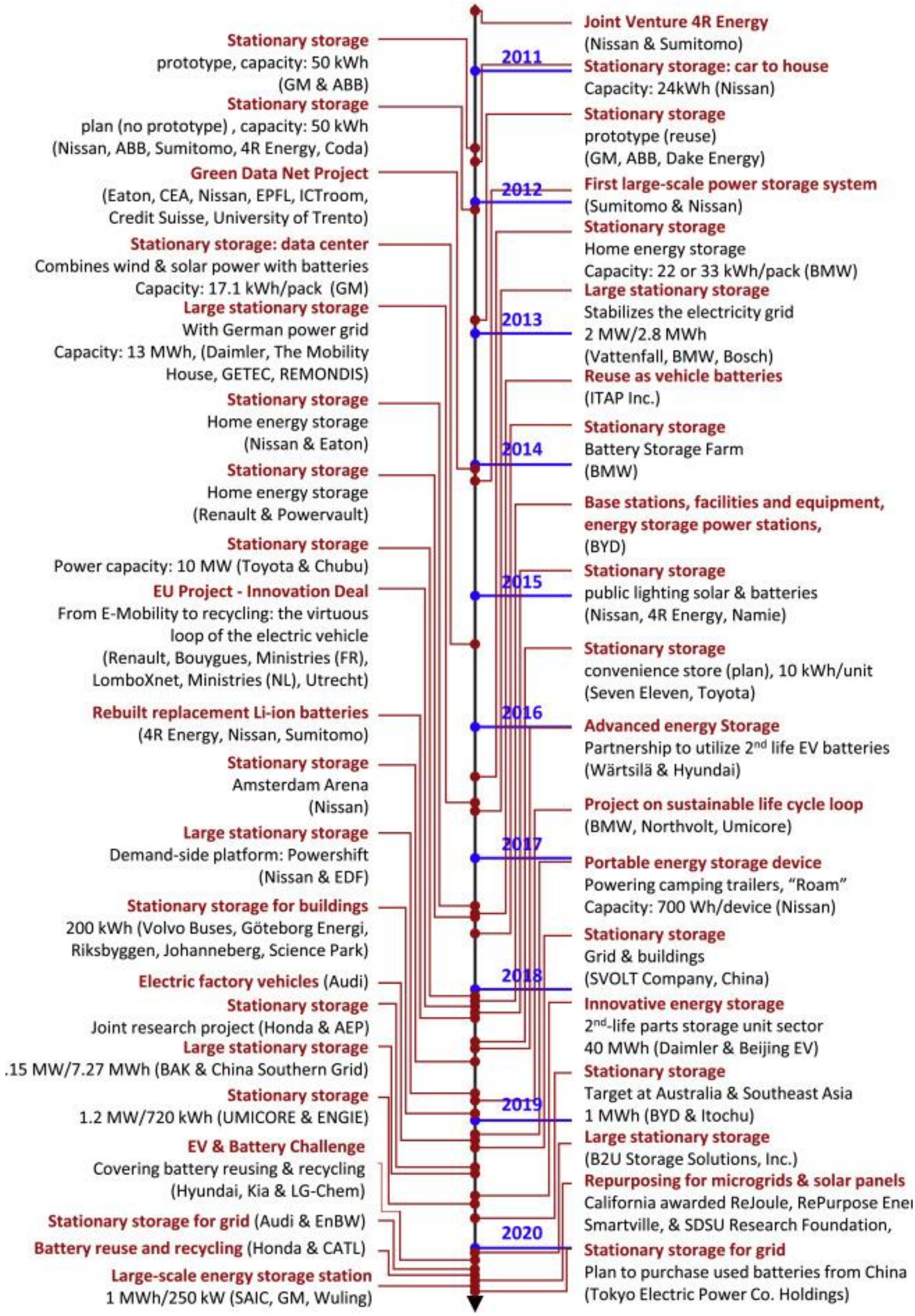

Figure 39. A historical overview of industrial projects of second life battery applications (Zhu et al., 2021)

4.5. Organizational models for second life business for used batteries

Actors along the LIB value chain have different incentives to extend the lifecycle of batteries through repurposing, and OEMs play a key role as they have the highest control over feedstock.

Based on data collected through interviews as well as secondary sources, six organizational models for second life business for used batteries are identified (Figure 40): 1) EV companies (automotive OEMs) entering the energy storage business; 2) Recycling companies piloting their own second life solutions; 3) Energy companies offering second life solutions for batteries, 4) Battery manufacturing companies closing the resource loop; 5) New businesses and startups; and 6) Marketplace platforms.

These organizational models represent the summary of the emerging battery second life business and can overlap due to the diverse cooperation agreements and joint ventures between the actors.

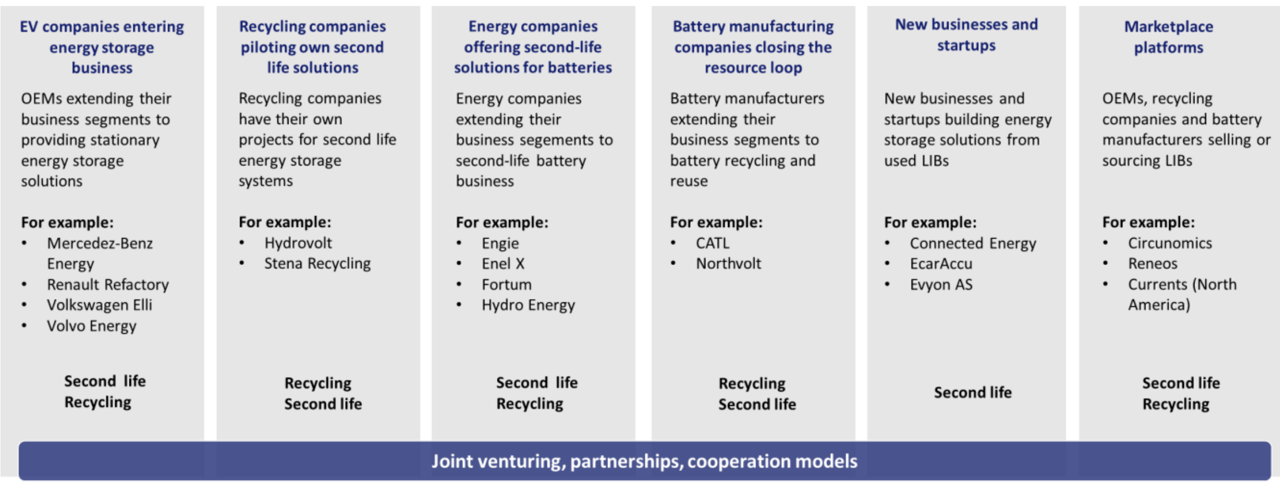

Figure 40. Six organizational models for second life business for used EV batteries

4.5.1. Electric vehicle companies entering energy storage business

Automotive OEMs, i.e., EV companies, are extending their business segments to providing stationary ESSs both with and without second life batteries (Figure 41). By entering the energy storage business, EV companies can diversify their revenue streams and reduce their reliance on the automotive market. Stationary large-scale storage systems are an important component in tomorrow's energy system, and the demand for these solutions will increase throughout Europe in the coming years. They also ensure that the replacement batteries have an extended lifecycle and that sustainability commitments are met. OEMs can develop innovative ESSs by leveraging their expertise in automotive battery technology.

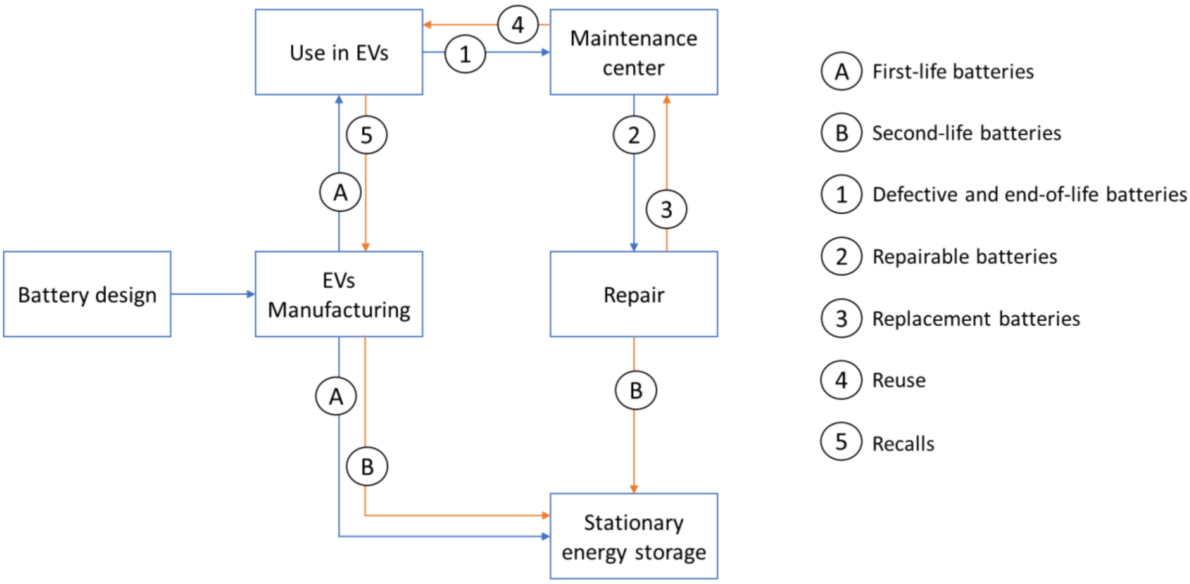

Figure 41. Organizational model 1: Product and material flow model

Business model examples

Volkswagen Elli is a subsidiary of Volkswagen Group focused on providing energy and charging solutions. In 2024, Elli made a public announcement regarding its expansion into energy storage using second life batteries (Volkswagen Group, 2024). Elli, in partnership with others, will develop and operate large-scale energy storage projects, initially targeting up to 350 MW of capacity and 700 MWh of storage. The first project could be launched in Germany as early as 2025.

Similarly, **Volvo Energy**, founded in 2021, offers charging solutions, energy storage, battery optimization, and battery lifecycle management (Volvo Energy, 2024). Their battery ESSs will be suitable for both temporary and stationary installations, providing reliable backup power and grid stability. While Volvo predominantly employs new batteries, they have initiated projects related to second life batteries. For example, Volvo Energy is developing battery circularity by repurposing EV batteries into energy storage with **Connected Energy**.

Founded in 2021, **Renault Refactory** operationalizes Renault Group's CE strategy through four interconnected divisions (Renault Group, 2024). One of these divisions, RE-ENERGY, focuses on repurposing used EV batteries for new applications, such as ESSs. RE-ENERGY's model includes collecting and sorting used batteries from Renault's EVs, testing batteries to assess their remaining capacity and reconditioning them to optimize performance, and re-integrating (refurbished) batteries into stationary ESSs for residential, commercial, and industrial use.

4.5.2. Recycling companies piloting own second life solutions

Recycling companies not only focus on recycling but also are extending towards providing second life ESSs and have their own pilot projects. Recycling companies receive batteries from different sources, including OEMs, cell manufacturers, and car dismantling companies. In the first stage of the recycling process, they sort batteries based on their condition into repurposable packs and those requiring recycling (Figure 42).

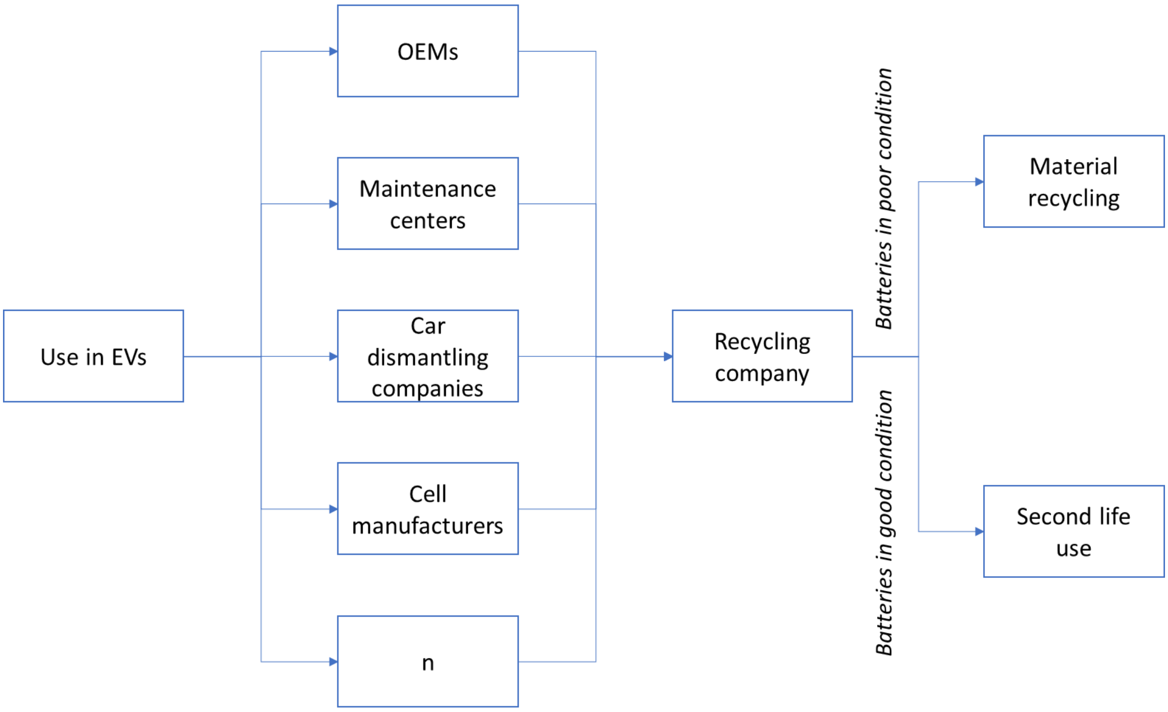

Figure 42. Organizational model 2: Product and material flow model

Business model examples

Norwegian company **Hydrovolt**, a joint venture between Norsk Hydro and Northvolt, is a battery recycling and raw materials company established in 2020. Hydrovolt's business model involves receiving used batteries from OEMs and battery cell manufacturers. They assess these batteries to identify repurposable packs and those requiring recycling. Non-repurposable batteries are disassembled, sorted, and processed into black mass, which they supply to battery cell manufacturers, aligning with regulations mandating the use of recycled materials in new batteries. By investing in battery material companies, cell manufacturers, and system integrators, Hydrovolt aims to establish a closed-loop battery value chain. Although Norway has a substantial EV fleet, Hydrovolt's current battery supply primarily stems from recalls rather than end-of-life vehicles. Due to the nascent EV market, there are fewer truly end-of-life batteries available. Recalls involving large batches of cars are a significant source of batteries for their recycling operations. While up to 50% of batteries from recalls could potentially be reused/repurposed, current industry practices hinder their actual reuse. While Hydrovolt has not implemented a pilot project yet, they have developed a second life battery storage solution. Most of their current installations use new, first life batteries. However, second life applications are technically feasible and could be explored in the future. To address complex logistics (collection), Hydrovolt is considering establishing collection support hubs in various European regions and centralizing crushing and sorting facilities. In July 2024 Hydrovolt announced the expansion of its business to France.

Swedish company **Stena Recycling** offers comprehensive LIB recycling services. Stena Recycling collects and sorts used batteries and battery production waste, ensuring safe transportation to their certified facilities (Stena Recycling, 2024). Stena Recycling assesses each battery for reusability, recycling those that cannot be reused into valuable raw materials. Stena Recycling collaborates with battery manufacturers, automotive OEMs, and various industries to ensure safe and responsible recycling and reuse of used batteries and production waste. Stena Recycling operates certified Battery Centers in Sweden, Denmark, Finland, Germany, and Poland, with planned expansions to Italy and Norway. This enables the recycling of LIBs on an industrial scale across Europe. Countries without Stena Recycling’s facilities, partner with trusted logistics providers to safely transport batteries to the nearest certified center.

4.5.3. Energy companies offering second life solutions for batteries

Energy companies are increasingly recognizing the potential of second life batteries to contribute to more sustainable and efficient energy systems. Energy companies often implement their models (Figure 43) in close cooperation with other companies in the value chain, for example, Engie has partnered with Renault to receive used batteries. Collaborating with OEMs allows for not only sourcing used EV batteries but also sharing knowledge and resources to optimize battery repurposing and recycling.

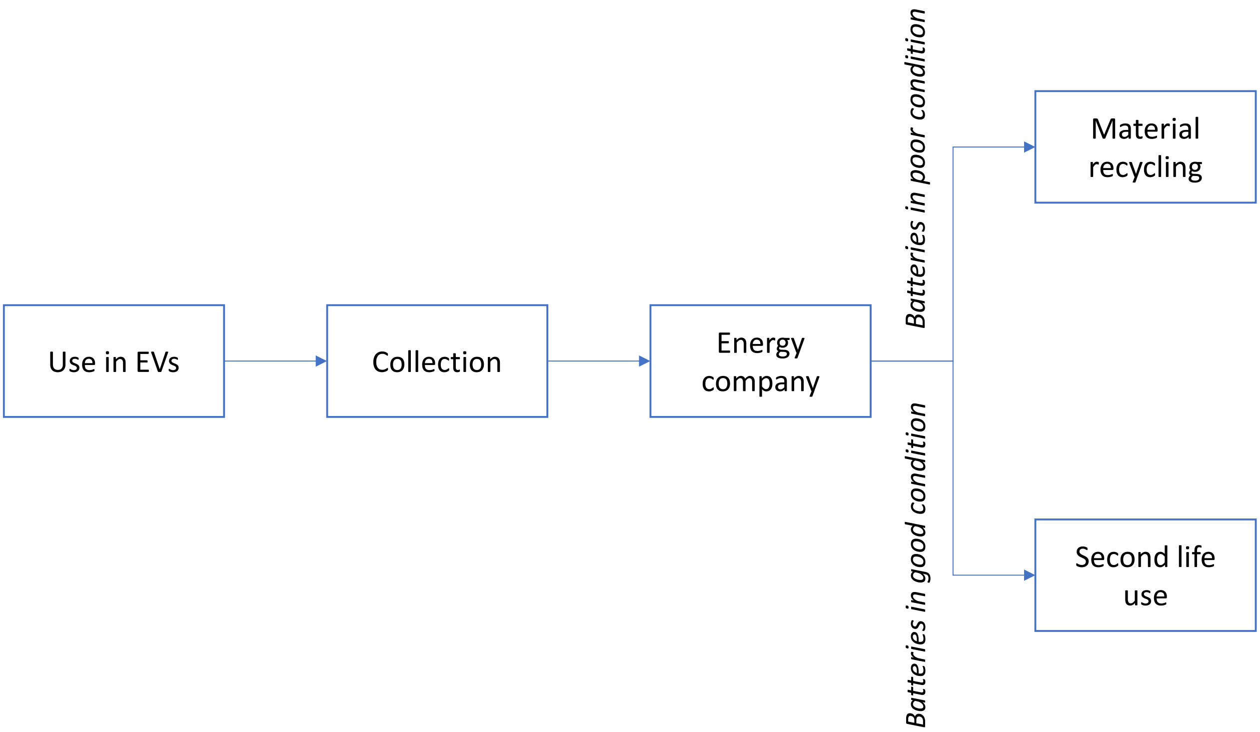

Figure 43. Organizational model 3: Product and material flow model

Business model examples

The French multinational energy company **Engie** has several collaborators in this field. The collaborations started several years ago. For example, in 2018, Engie, in collaboration with **Connected Energy**, successfully implemented a pioneering project in Rotterdam, Netherlands (Renewable Energy World, 2018). This project involved deploying a second life battery storage system, powered by repurposed **Renault** EV batteries, to provide essential grid balancing services. Later, ENGIE collaborated with Umicore to repurpose used EV batteries for stationary energy storage (Engie, 2020).

The Finnish **Fortum** is an energy company that also plays a significant role in the recycling industry. Fortum has launched Europe's largest battery recycling plant in Finland, utilizing hydrometallurgical technology to recover critical metals from end-of-life batteries. Fortum is also piloting second life solutions for batteries, for example, Fortum has a pilot project with **Volvo** and **Comsys** for a second life energy storage system for a Hydropower plant (Fortum, 2024).

4.5.4. Battery manufacturing companies closing the resource loop

Battery cell manufacturers have expanded their businesses into battery recycling and reuse to promote a circular economy, strengthen their position in the value chain, and secure the future availability of secondary raw materials (Figure 44).

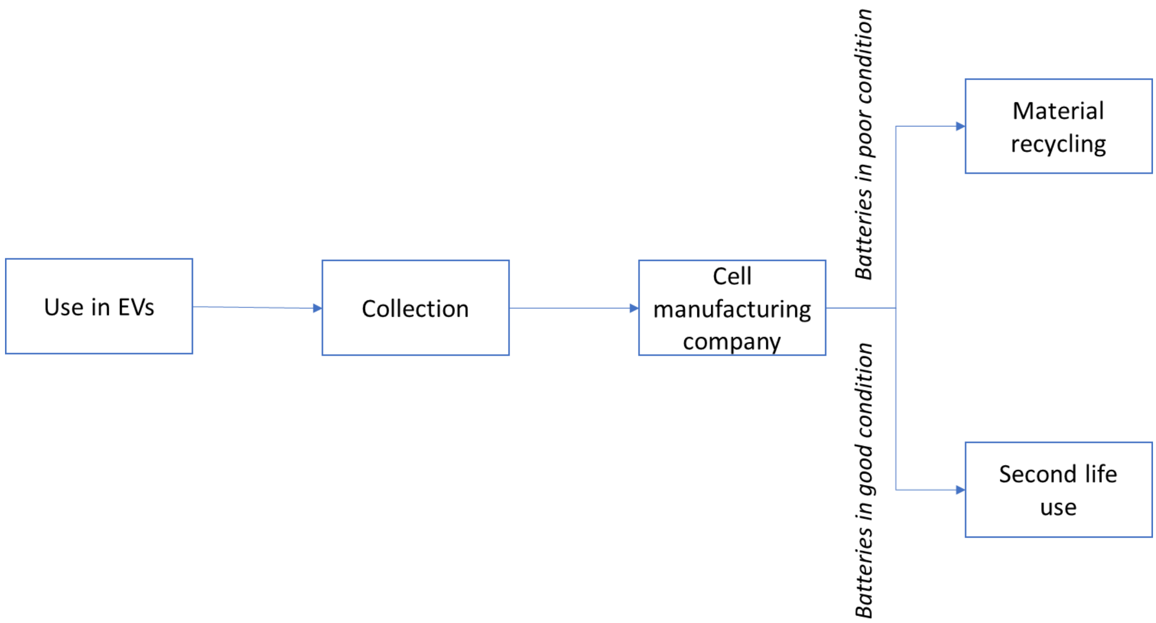

Figure 44. Organizational model 4: Product and material flow model

Business model examples

Chinese company **CATL** (Contemporary Amperex Technology), supported by its subsidiary Brunp, is collaborating to establish a closed-loop battery value chain (CATL, 2023). This involves battery production, application, cascade utilization, and recycling (Figure 45). In Europe, CATL is exploring strategic partnerships for battery recycling to promote local presence and develop a sustainable battery value chain. As an example, CATL and **Volvo Cars** have partnered to create a closed-loop battery recycling system.

Northvolt's battery production process is built on the principle of a closed-loop supply chain, with material recycling as a fundamental component (Northvolt, 2024). Northvolt's Revolt program provides a complete recycling solution, from picking up materials at your site to delivering high-purity recycled metals, although battery repurposing is not yet part of its offering.

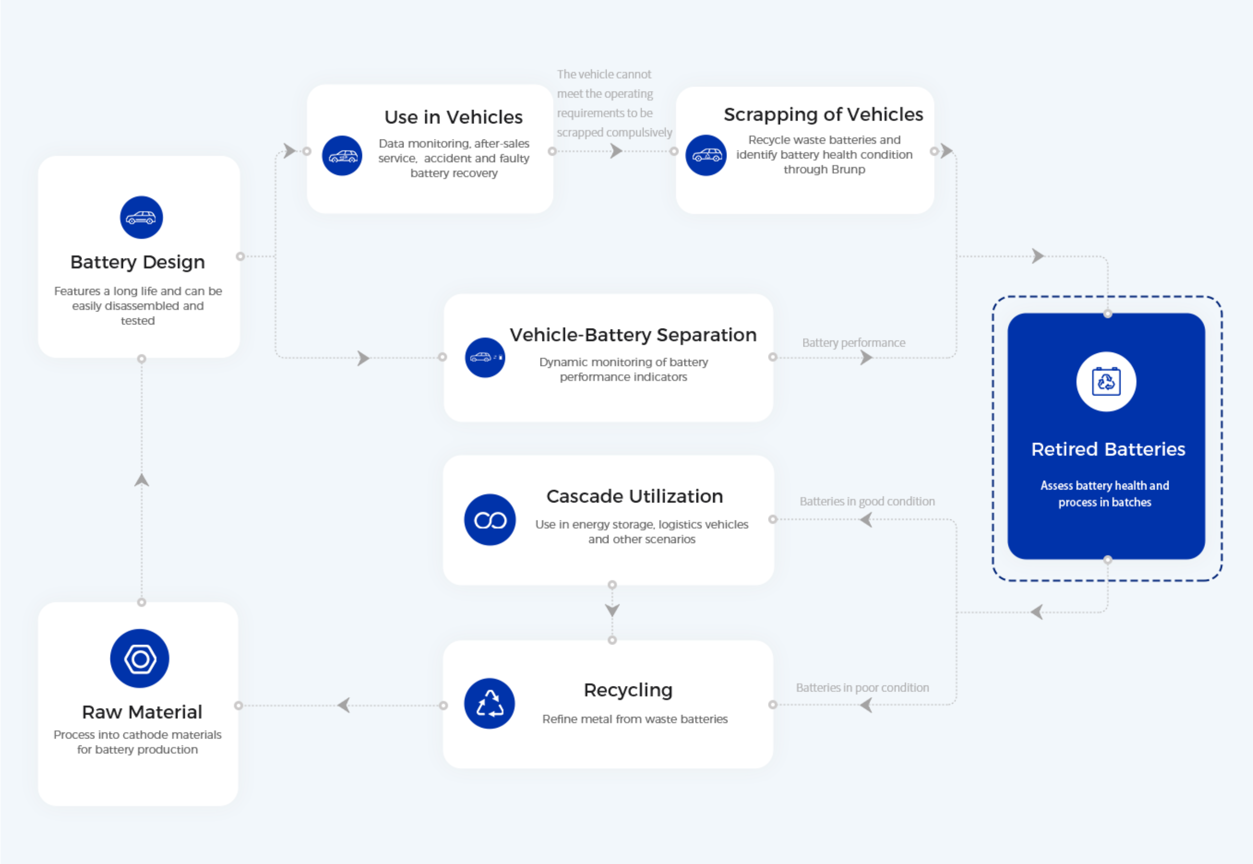

Figure 45. Battery recycling model by CATL (CATL, 2023)

4.5.5. New businesses and start-ups

The used EV battery market has spawned a new generation of companies and startups, each with unique business models. Several of these new ventures have collaborations with automotive OEMs and battery manufacturers.

The surge in EV adoption will generate a growing number of used batteries, some of which can be repurposed. As the EV market expands, manufacturers need to address battery end-of-life management responsibly, creating opportunities for second life battery solutions and room for new business models.

Business model examples

Connected Energy (UK), founded in 2013, is a global leader in developing, building, and operating stationary battery energy storage systems using second life batteries (Connected Energy, 2024). Connected Energy's core product, E-STOR, is a modular energy storage system that can be tailored to various applications, including grid stabilization, peak shaving, and backup power. By leveraging the energy capacity of used EV batteries, E-STOR offers a cost-effective and environmentally friendly solution for energy storage needs. The company has built strong partnerships with major automotive manufacturers like Renault Group, Caterpillar, and Jaguar Land Rover, collaborating to develop innovative second life battery solutions (Figure 46).

EcarAccu (NL) collects used EV batteries and dismantles them to the module/cell level. After rigorous testing, the healthy modules/cells are refurbished and sold to partners for various second life applications, such as energy storage systems (EcarAccu, 2024). The remaining materials, including steel, plastic, and other metals, are directed to recycling.

Use in EVs → Collection (e.g. OEM) → New business → Energy storage

Figure 46. Organizational model 5: Product and material flow model

Other examples are: Eco Stor (NO), Circu Li-on (LU), Revolta/Watt4Ever (BE), Octave Energy (BE) Evyon AS (NO), Alltabat (ES), Cidetec (ES), CIC energiGUNE (ES), BeePlanet (ES), Libattion (CH), Cactos (FI), Ztsvv (SK), and Covalion (DE).

4.5.6. Marketplace platforms

The growing number of EVs presents a significant opportunity for a battery marketplace that connects buyers and sellers of used batteries, facilitating the trade of second life batteries (Figure 47). However, there are still very limited active platforms. The nascent market for used EV batteries presents a strategic dilemma. While immediate entry carries risks due to limited supply, delaying could result in significant first-mover disadvantages (Forbes, 2024).

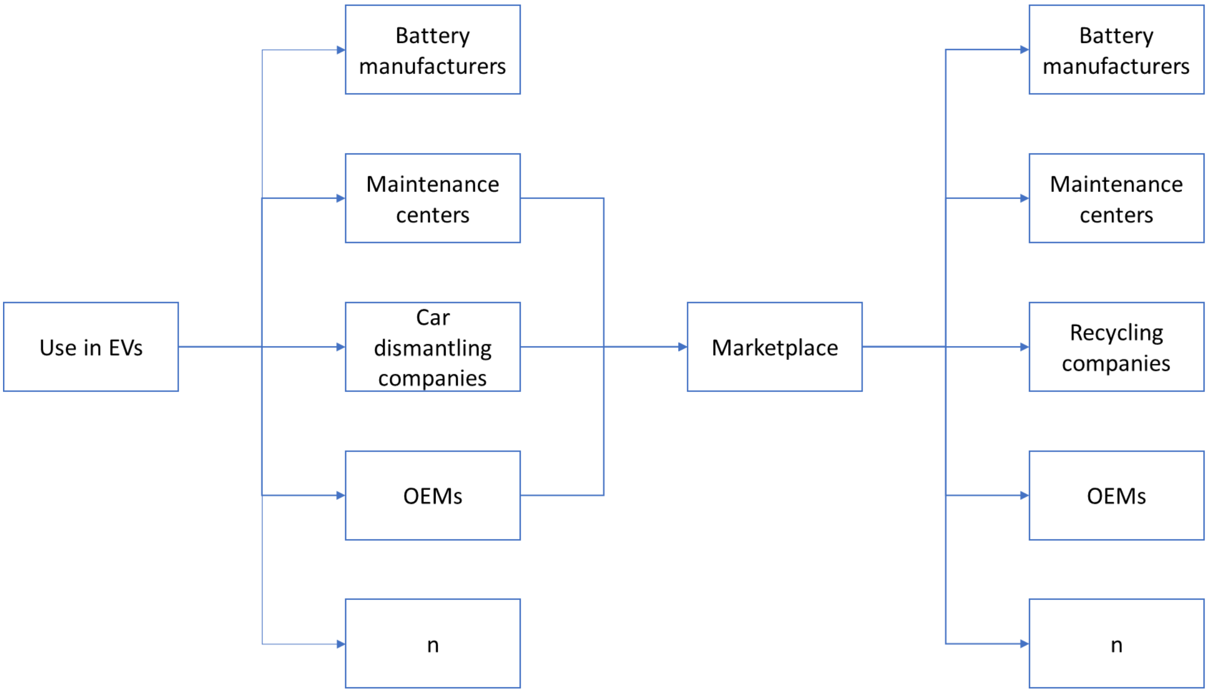

Figure 47. Organizational model 6: Product and material flow model

Business model examples

Circunomics operates a B2B online marketplace facilitating the trade of second life LIBs (Circunomics, 2024). The platform connects businesses within the battery supply chain, such as OEMs, recycling facilities, and energy storage providers. By offering a centralized hub for buying and selling used EV batteries, Circunomics aims to streamline the process, enhance transparency, and promote the circular economy within the battery industry. By rigorously screening all participants, the platform ensures quality control, enabling buyers to make confident decisions.

Currents operates on the same principle, but it only serves North America (Currents, 2024). By providing a transparent and efficient marketplace, Currents aims to facilitate the recycling and repurposing of batteries by connecting sellers and buyers of used LIBs.

4.6. End-user characterization

After the first life, batteries can be used for second and third life applications, such as on-grid and off-grid stationary energy storage, backup power and Uninterruptible Power Supply (UPS), and urban electromobility and micro batteries (Quinteros-Condoretty et al., 2025). In this context, repurposed batteries can provide ESSs for a wide range of sectors, such as:

- **Commercial sector**, to power small EVs like e-bikes and scooters, portable power solutions for power tools, laptops, and mobile devices, and supporting EV charging stations. Additionally, repurposed batteries can be used in uninterrupted power supply for data centers and power telecommunications infrastructure, especially in remote areas with limited grid connectivity.

- **Residential and healthcare sector**, to store excess solar energy generated by rooftop solar panels, providing backup power for essential appliances like refrigerators, medical equipment, and security systems, and contributing to community ESSs.
- **Industrial and energy sector**, to store energy from renewable plants and other sources. This energy can be used for self-consumption, recharging infrastructure, providing backup power for critical infrastructure, and powering warehouse equipment and automated systems such as material handling equipment and robots.

The **value proposition** offered to the end-user varies by application and sector. Overall, repurposing batteries presents a promising solution to the increasing demand for sustainable and cost-efficient energy storage. Based on the value propositions of various organizations in this field, key benefits for end-users include:

- **Sustainability and environmental performance** – Prolonging battery life enhances resource efficiency, reduces carbon footprint, promotes a circular economy, prevents waste generation, and contributes to decarbonization efforts.
- **Cost-effectiveness and affordability** – Repurposed batteries can be more affordable than new ones, and by optimizing ESSs, they can lower operational costs.
- **Customized solutions** – Repurposed batteries can be configured with flexibility and tailored to meet the specific requirements of diverse applications.
- **Reliability and performance** – Repurposed batteries undergo stringent testing to ensure quality and performance. Battery warranties can be applied in some cases.

In some cases, the primary value proposition is ensuring a reliable **energy supply**, such as powering schools in rural Kenya (Kebir et al., 2023).

Embracing a CE significantly enhances the value proposition of end-of-life batteries. By providing complete battery lifecycle management, companies minimize waste and environmental impact through closed-loop solutions, including repurposing, recycling, and material recovery. Robust tracking systems ensure transparency regarding the origin and lifecycle of batteries, fostering trust among consumers. Leveraging AI and modeling, companies optimize battery usage, extending lifespan and maximizing the recovery of valuable materials at the end-of-life stage. This circular economy approach offers a compelling value proposition for environmentally conscious consumers and businesses.

The CE model has fostered innovative **ownership strategies**, such as **Battery-as-a-Service (BaaS)**, where providers retain ownership and responsibility throughout the battery's entire life cycle. This could be advantageous as it simplifies the circular value chain, by placing the responsibility of battery treatments and end-of-life management on the battery manufacturer. Manufacturers can optimize battery usage, repurposing them for second life applications or recycling them efficiently. Manufacturers can also track battery usage and performance, enabling better data-driven decisions. The BaaS can take several forms, including leasing, renting, or a pay-per-use model.

As evidenced by current organizational models for second life business for used EV batteries, direct sales remain the most common model for battery acquisition. However, OEMs like Renault and Nissan are increasingly exploring alternative models, such as battery leasing schemes, particularly for first life EV batteries. Marketplace platforms like Circunomics enable the transfer of ownership of used batteries between sellers and buyers without intermediates retaining ownership. In contrast, business models that focus on battery repurposing, such as ECO STOR, EcarAccu, Watt4Ever, or BeePlanet, retain ownership of used batteries to be prepared for repurposing and then sold to the end-user.

5. CHALLENGES AND UNCERTAINTIES IN THE CIRCULAR BATTERY VALUE CHAIN

In this Chapter, the key challenges in the circular battery value chain, and uncertainties in the development of a market for repurposing of EV and industrial batteries are outlined.

5.1. Availability of used batteries

While currently small, a market for repurposing EVs and industrial LIBs is emerging. Companies are increasingly interested in repurposing these batteries for various ESS applications, including grid storage, off-grid power, and EV charging infrastructure. One of the key bottlenecks in market development is the lack of available used batteries. There are not enough batteries available for recycling and therefor also not enough batteries available for repurposing and development of second life solutions. This is due to a multitude of reasons.

Firstly, most EV batteries last longer than initially expected, and this is delaying the number of batteries reaching their availability for second life use and recycling. Further, the traditional assumption that EV batteries come to the end of their useful life at 80% capacity (Ali et al., 2021) is challenged by consumer behavior. Many drivers continue using their EVs beyond this threshold, suggesting a longer lifespan for EV batteries than previously estimated.

In addition, ensuring that EVs that are brought to the EU, stay in the EU is a challenge. There is a significant amount of used EVs that are sold to Eastern Europe and developing countries. Whether this can be considered as "battery leakage" is up for debate but adds to the point that there still may be the possibility of using these EVs in other markets even when most consumers consider the capacity of the LIB to be too low. According to the Used Vehicles and the Environment: Update and Progress 2024 report, by the UN Environment programme, between 2017–2022, the EU, Japan, and South Korea together exported over 105 thousand electric vehicles (EVs, hybrid and plug-in hybrids) to Asia-Pacific, EECCA, Africa, LAC, and the Middle East (Figure 48). The highest number, roughly 38 percent of EVs were transported to the EECCA region. (UN Environment Programme, 2024)

Moreover, while the number of EVs in the EU is on on the rise, their market share remains comparatively low. In 2023, EVs accounted for only 22.7% of new car registrations. Despite previous growth, EV sales have decreased in 2024 due to factors such as high inflation and the significant price premium of EVs compared to traditional combustion engine vehicles, resulting in a three-year low (Reuters, 2024b). Figure 49 shows the growth curve of EV registrations in EU member states between 2010–2023.

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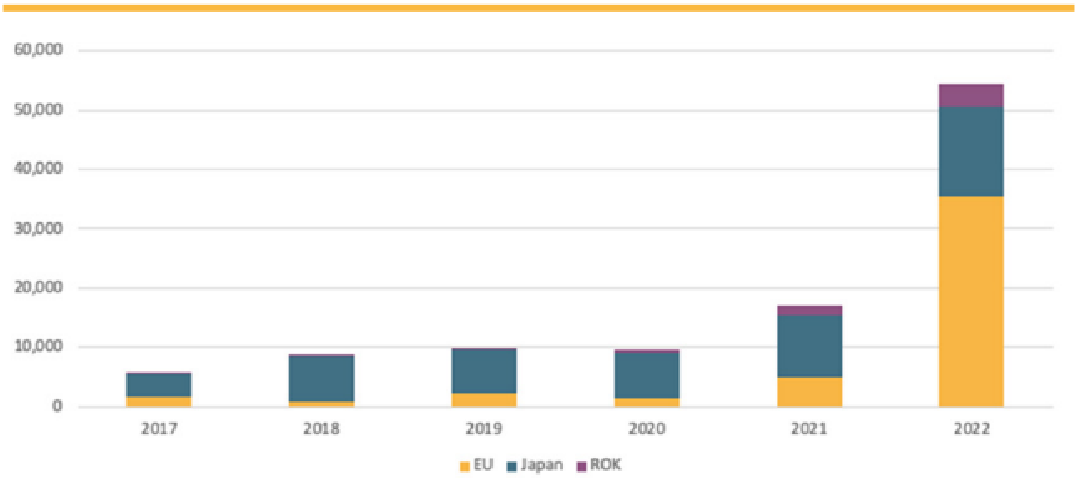


Figure 48. Used EVs exported by the EU, Japan and Republic of Korea between 2017–2022 (UN Environment Programme, 2024)

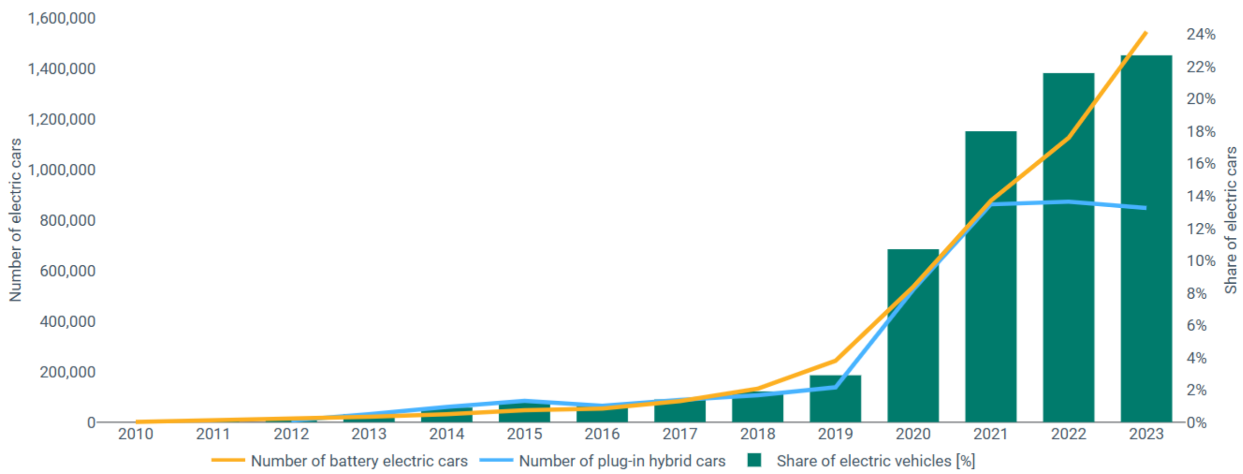


Figure 49. Newly registered EVs in the EU (EEA, 2024)

5.2. Battery ownership

Ownership structures of EVs and LIBs both drive and hinder the development of a market for lifecycle extension. Many OEMs have created their energy business segments, to expand their business to second life and other battery applications. OEMs are slowly becoming present in nearly all phases of an EV LIB lifecycle, from raw material sourcing to battery design, production, diagnostics, and repair, to reuse, repurposing, second life, and recycling. For example, when an EV LIB has a defect and needs repair, the model for most OEMs is that the whole LIB is swapped to a new one at an authorized repair shop. The LIB could be directly recycled using operators the OEM has chosen (with the PRO), but in most cases, these LIBs are sent back to OEM's facilities for further diagnostics and testing. OEMs are storing LIBs at their facilities and are not willing to provide them to possible second life or recycling operators. Time will tell whether the ownership model for EVs will change to one where OEMs sell their customers only the vehicle, but ownership of the LIB would be the OEMs'. Renault has a similar model to this with their car model Renault ZOE, where the purchase price of the EV is low because the battery ownership remains to the OEM (Renault Group, 2023).

Based on current legislation OEMs need to be part of a producer organization to ensure that once their vehicles reach end-of-life, proper collection and recycling is provided. Although current legislation allows for OEMs to arrange their producer responsibility, it is still quite uncommon and most OEMs opt for paying an annual membership fee to a PRO, which in turn organizes everything on their behalf. However, it is important to note that even though an OEM belongs to a producer organization, they still have the right to arrange recycling or collection of used LIBs to their facilities, if necessary. In conclusion, OEMs have a huge advantage in the management of defect and used LIBs in the market and it is unlikely that a repurposing or second life market will develop for used LIBs if OEMs remain fully in control of their products' lifecycles.

5.3. Legislation favoring recycling route over repurpose

At first glance, it may seem that there are a lot of different regulations on EU level that play a significant role in the LIB value chain, but the most influential legislation is the new Battery Regulation 2023/1542. While it establishes concrete targets for the industry, it heavily prioritizes recycling, offering minimal incentives for reuse, repair, repurposing, and second life applications.

The new Battery Regulation 2023/1542 sets targets for collection and recycling rates of used LIBs and recycled content requirements for new LIBs. Due to the recycled content requirement in new LIBs, the prices of secondary raw materials will likely grow, making recycling LIBs an even more profitable business. As the EU already has the existing infrastructure to build an efficient recycling value chain, it is unlikely that battery repurposing and second life will become a key initiative in the upcoming years. Shifting the focus from recycling to reuse will require a strong regulatory backbone and is unlikely to be driven by businesses alone.

The EU's Critical Raw Materials Act also sets targets for how much of the raw material needs for the EU need to be fulfilled through recycling and it is notable that both industrial and EV LIBs contain the highest amounts of these materials. On a global level, EU member states use over 20% of all Critical Raw Materials, with the majority of these materials originating from outside the EU. The EUs own capacity at producing these raw materials is only a small fraction of what is needed on an annual basis (GTK, 2024).

Figure 50 illustrates the capital share of holdings in mining companies by raw materials of China, the United States, and the EU and even further emphasizes the dominant role of China's ownership in mining companies, strengthening their access to raw materials specifically related to CRMs needed for batteries. As illustrated in the figure below, the EU has very little capital holdings in mining companies.

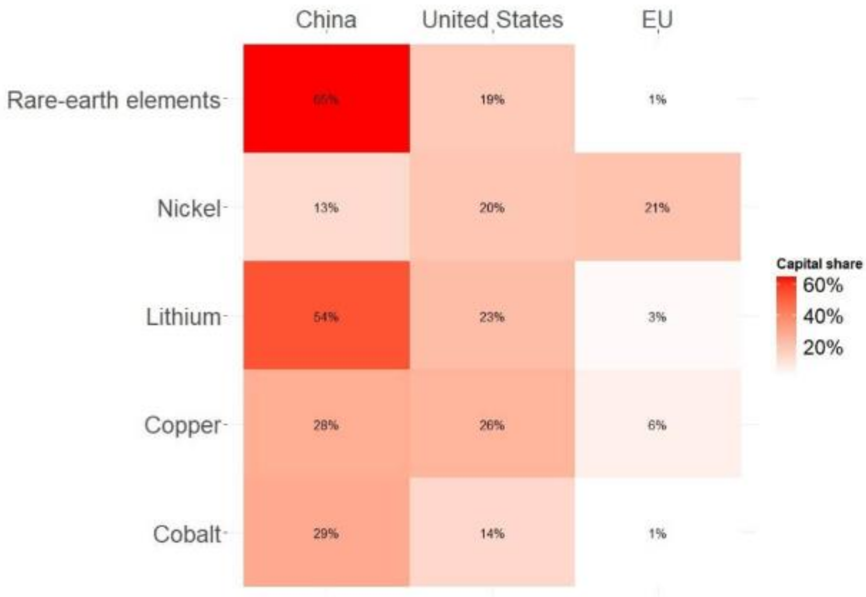


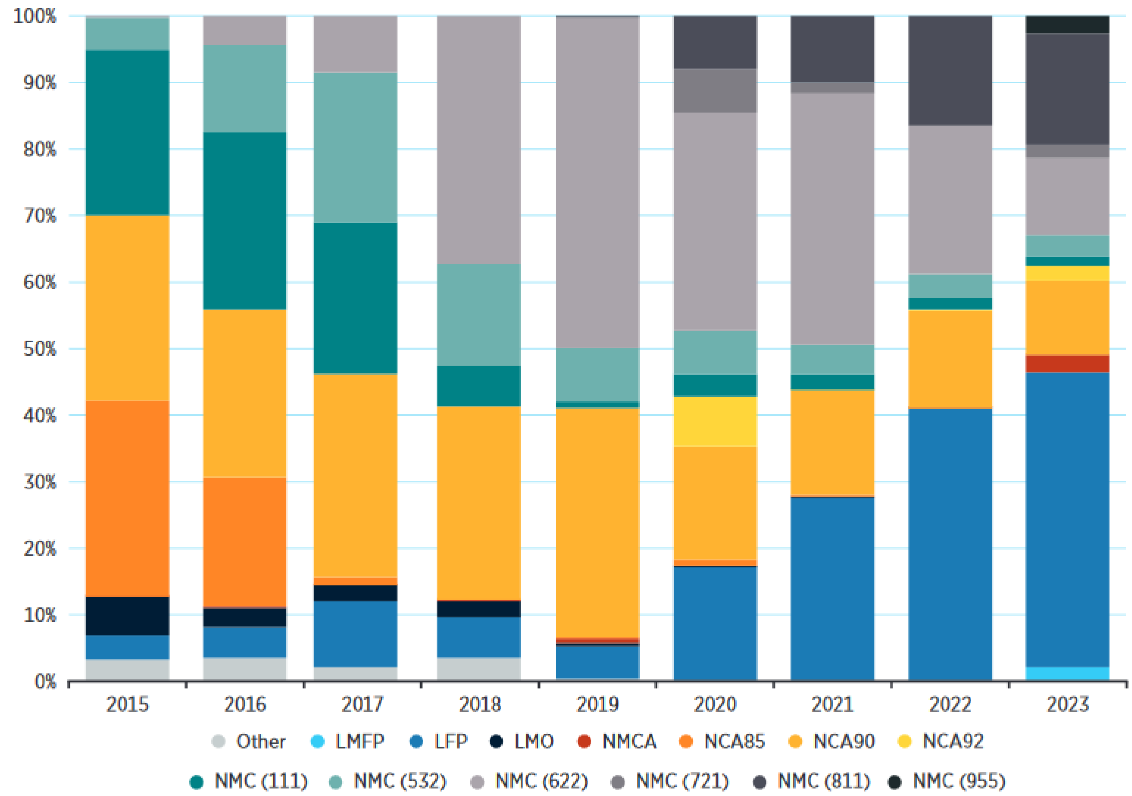
Figure 50. Geographical origin of capital-holding mining companies by raw material (%) (Banque de France, 2023)

5.4. Lack of standardization

The lack of standardization in battery technologies and design as well as the lack of standardized processes for assessing battery health are key issues in the LIB value chain. While the regulation proposes some industry-wide standards on removability and replaceabilty of battery packs, it does not go into specifics for example on battery design. In addition, the regulation proposes a standardization for battery health diagnostics. Most of the data needed for battery health diagnostics can be accessed through the BMS (and details in the battery passport) but it is still unclear how this will look in practice and what level of information will be accessible to what group of stakeholders. Regarding second life batteries, the regulation does not provide any direct incentives but does offer exemptions on reporting the carbon footprint, recycled content requirements as well as performance and durability requirements of second life battery systems built from LIBs that have been put into the market before the regulation.

5.5. Economic viability

The rapid development of battery technologies is both a challenge and an opportunity for the circular LIB value chain. As battery technologies develop, newer technologies will likely be less dependent on CRMs. LFP batteries have experienced significant growth in the EV battery market, now accounting for nearly half of the passenger vehicle battery market (Figure 51) (IRENA, 2024). Expanding the scope to include energy storage systems and heavy-duty vehicles, such as buses, mining equipment, and ships, would further increase LFP's market share. Such rapid changes pose challenges for increasing circularity, as recycling methods are not technology-neutral and the cost-effectiveness of second life battery applications is hindered by the increasing affordability of new LFP batteries. LFP batteries, which primarily utilize iron phosphate, offer a lower cost compared to NMC and NCA batteries, which rely on more expensive nickel and cobalt. On the other hand, newer battery technologies that use fewer CRMs may help facilitate the development of an industry for repurposing and second life applications, if the focus from optimizing recycling and material recovery (and maximum profits for secondary CRMs) shifts to extending the lifecycle of LIBs, simply because recycling is no longer as a profitable business (due to smaller volumes of CRMs).



Source: BNEF (2024a).
Notes: LFP = lithium iron phosphate; LMFP = lithium manganese iron phosphate; LMO = lithium manganese oxide; NCA = nickel cobalt aluminium oxide; NMC = nickel manganese cobalt oxide; NMCA = nickel manganese cobalt aluminium oxide.

Figure 51. Global EV cathode chemistry mixes for passenger vehicles 2015-2023 (IRENA, 2024)

Furthermore, battery prices have generally been declining (Figure 52) as prices for key primary minerals have returned to pre-pandemic levels (Figure 53) (IEA, 2024b). If a new battery is more affordable than a used one, the demand for repurposed batteries is likely to be low. Battery prices in the EU are significantly higher than in China, posing a challenge to a vibrant EU battery value chain. Chinese batteries are currently competitive in terms of price and performance. Europeans buy Chinese EVs, and Chinese companies supply batteries to various car manufacturers, including European brands.

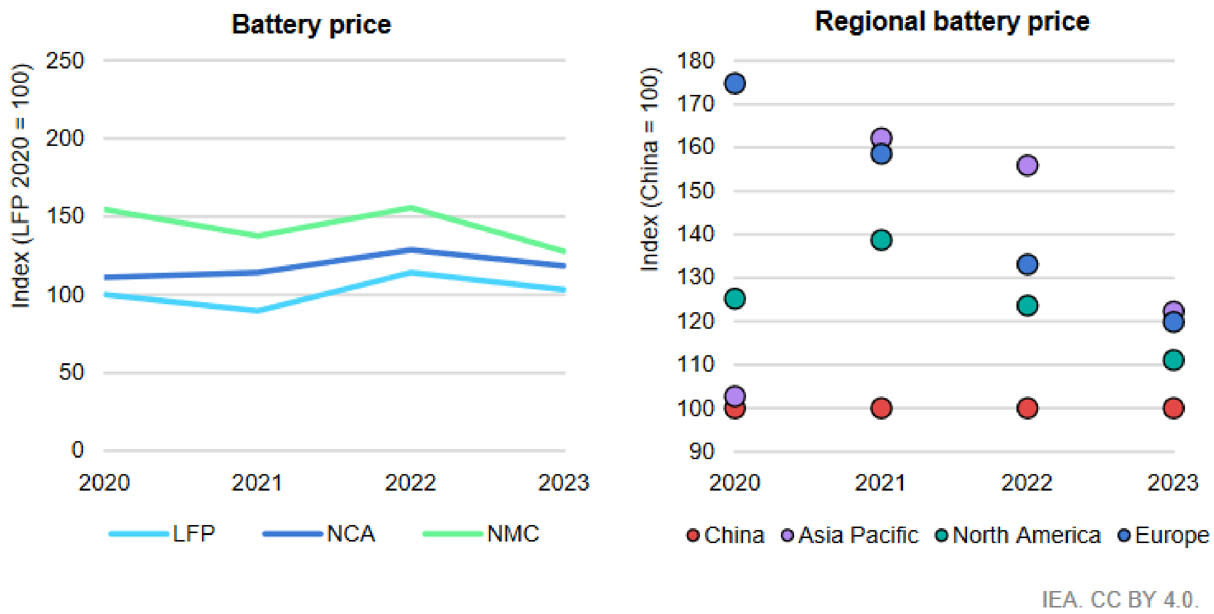


Figure 52. Average battery price index by selected battery chemistry and region 2020-2023, Notes: LFP = lithium iron phosphate; NMC = lithium nickel manganese cobalt oxide; NCA = lithium nickel cobalt aluminium oxide. Asia Pacific excludes China. Each year is indexed with respect to China price (100). Battery prices refer to the average battery price in a given region, including locally produced batteries and imports. (IEA, 2024b)

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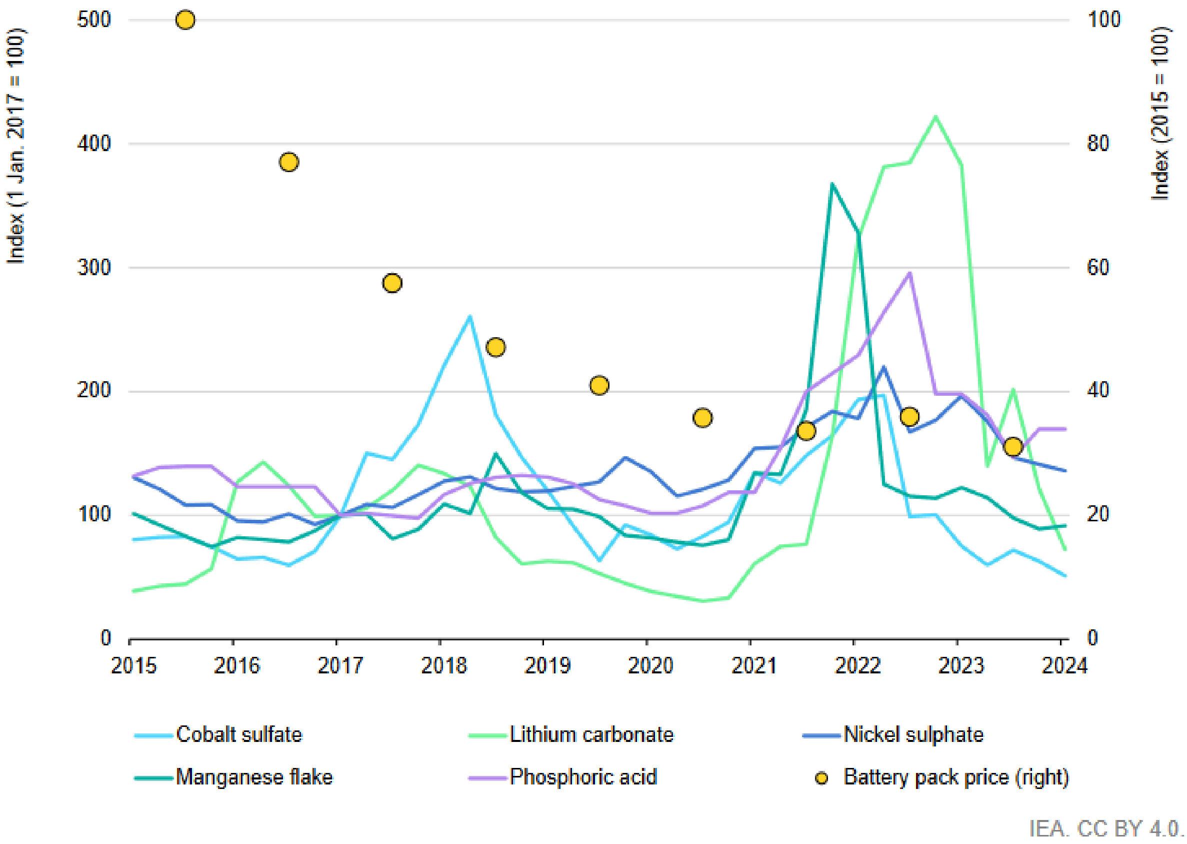

Figure 53. Price of selected battery metals (left) and lithium-ion battery packs (right) 2015-2024, Note: "Battery pack price" refers to the volume-weighted average pack price of lithium-ion batteries over all sectors (IEA, 2024b)

6. FUTURE CONSIDERATIONS

This concluding Chapter considers the future of the European circular battery value chain from various perspectives. The LIB value chain is projected to undergo significant growth and transformation as a result of increasing demand for EVs and renewable energy storage. This transformation offers both opportunities but also involves uncertainties, relating to geopolitical landscape, technological advancements, and market dynamics, for example.

There is global competition between China, the US, and Europe. China dominates the refining and processing of key raw materials like lithium, cobalt, and nickel. China holds the largest share of global battery manufacturing capacity and is establishing new gigafactories in Europe. Chinese companies like CATL and BYD are global leaders. China also has the world's largest market for EVs, providing a strong domestic demand for batteries. While China dominates battery production, its resulting overcapacity has forced a reliance on exports, which is impacting profit margins (IEA, 2024b). From another perspective, price competition is regarded as China's strategy to gain market share. Simultaneously, Europeans are buying cheaper Chinese batteries and investing in the development of European circular battery value chain, focusing on recycling technologies and battery lifetime extension. Ensuring a stable and sustainable supply of CRMs remains a major challenge. Diversification of supply chains and strategic partnerships will be crucial. Second life applications may reduce geopolitical risk by leveraging used batteries that are available domestically.

While there are announcements of gigafactories, recycling initiatives, and new batteries second life start-ups, the battery industry is still working to establish the most effective circular value chain. It remains to be seen which CE strategies will prevail and how the value chain will be structured. The second life battery market is still in its early stages and the future market is uncertain, with various organizational models and approaches being explored. To develop successful second life solutions, businesses must identify suitable applications and a deep understanding of customer needs and market dynamics is required. While regulations play a role, the primary focus should be on developing viable business models and technical solutions that make second life batteries a competitive and attractive option.

Regarding the development and scaling of a battery repurposing business, the most significant uncertainties – the realization of which could prove to be a turning point in development – relate to:

Battery availability: EV LIBs last longer than initially expected and larger volumes are forecasted to reach the end of their useful life within the next 5–10 years. As the number of used batteries grows, repurposing and recycling will become increasingly important to increase the EU's selfdependence and reduce environmental impact. These figures are expected to grow exponentially, but there are a lot of uncertainties in market development as a lot of it is dependent on technology development of batteries, consumption habits, and battery leakage. While LIBs currently dominate the market, emerging technologies like sodium-ion batteries could offer a more cost-effective and sustainable alternative for specific applications. Their widespread adoption would change the entire battery market.

Economic viability: If battery technologies develop to contain only minimal volumes of CRMs, likely, the recycling industry will no longer be viewed as profitable as before, and the focus will shift towards repurposing used LIBs. It is important to however consider, that if battery technologies in the future have lower volumes of CRMs, this is likely to affect the pricing of new batteries as well. If battery prices decrease (as they already have), it may also hinder the development of a second life industry. If an ESS built with used LIBs is more expensive than one built with new LIBs, the choice is clear. Currently, the use of second life LIBs in ESS applications is primarily a reputational decision, as new LFP batteries are often more cost-effective than repurposed ones. The latest trend is towards sodium-ion batteries, which offer the potential for even lower production costs.

The competition between CE strategies: While second life applications can contribute to sustainability by extending battery lifetime on a product level, they delay recycling. Competition also exists between repurposing and repair. There are already emerging actors in the market that offer repair services for different types of EV LIBs. These repair services are often used by EV owners that have passed their 8-year or 160,000 kilometers battery warranty period and are looking to extend their EV LIB lifecycle, by swapping out for example defective battery modules for functioning ones. The model for repairing and refurbishing EV batteries at authorized repair shops is currently structured in a way where instead of repairing or swapping modules or other parts of the battery, the whole battery pack is changed to a new one. This is an expensive service for a consumer that no longer has a warranty for the battery. This has generated a new market for third-party repair shops that repair, repurpose, and refurbish EV LIBs. The price point for switching out a single module in comparison to the complete LIB is significantly cheaper.

The evaluation of different CE strategies is heavily influenced by the level at which they are studied. From a perspective of the level of circularity (Figure 3) and overall sustainability and performance, the following aspects should be considered:

Approach to lifecycle extension: It is also important to consider whether a market for second life LIBs is needed in the future if the lifecycle of a LIB can be extended in its first use through repair and refurbishment. Further, continuous innovation in battery chemistry and materials will lead to higher energy density and longer battery life while using fewer CRMs, thus encouraging the replacement of older batteries with newer ones and the recycling of the former for materials recovery. Instead of using terms like "first life" and "second life," a more continuous model where batteries progress through different stages could be considered. This could be analogous to childhood, adulthood, and later stages of life. While a battery may reach its end-of-life for high-power applications, it can still be used for less demanding tasks, or the best course of action is recycling. This concept aligns with the idea of extending the useful life of batteries at the product level and maximizing their value throughout their lifecycle. By understanding the different stages and applications, the level of battery technology development, and the market, battery lifecycle management can be optimized.

Vehicle and battery size: The current EV market is dominated by large and sport utility (SUV) sized vehicles (Figure 54). As with global trends, new EVs in the EU are growing in size, leading to larger batteries and increased demand for CRMs. Large vehicle and SUV batteries are on average 25 percent larger than those in smaller vehicles. The significant price difference between small and large EVs raises the question of whether prioritizing smaller, more affordable models could accelerate EV adoption in the EU. Conversely, if the current trend toward larger EVs persists, high prices (pending the development of less CRM-dependent battery technologies) may hinder adoption. The current trend towards larger cars conflicts with CE strategies, which emphasize reduction as a primary goal (Figure 3). Larger batteries increase the need for CRMs, and a lower adoption rate of EVs does not sufficiently reduce the use of internal combustion engine vehicles.

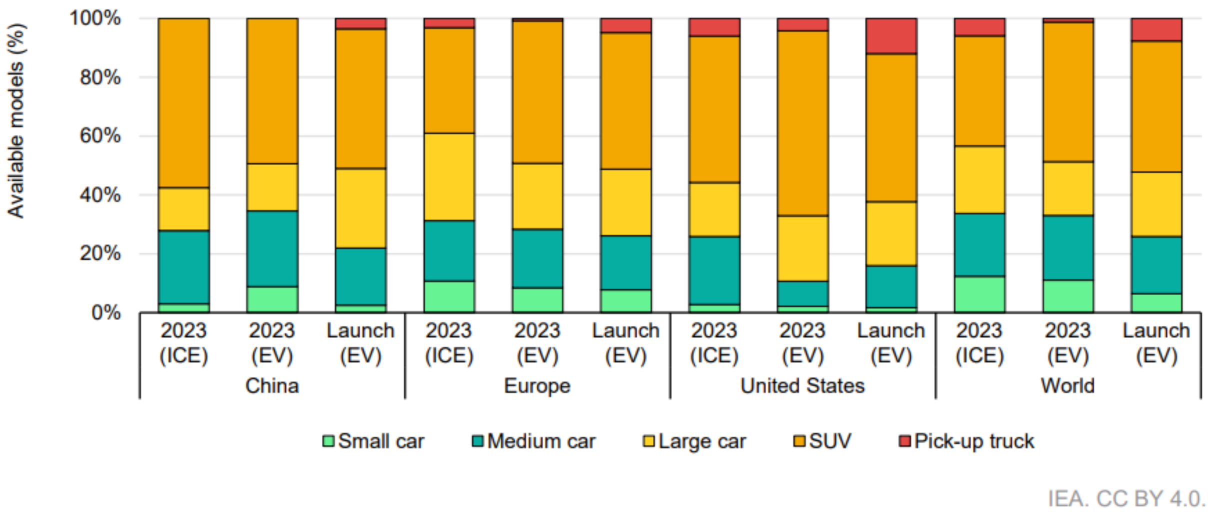

Figure 54. Available car models (EVs and internal combustion engine (ICE)) forecasts for 2024 – 2028 Note: SUV = sport utility vehicle. EVs include both battery electric cars and plug-in hybrids. (IEA, 2024b)

Carbon emissions targets: Companies operating in the EU are required to report on their sustainability efforts, including scope 1, 2 and 3 emissions of their business. Naturally, this comes with setting targets to lower these emissions on an annual basis. Scope 1 refers to direct emissions from owned or controlled sources, e.g., emissions from industrial facilities. Repurposing existing batteries avoids the energy consumption and emissions associated with manufacturing new ones.

Scope 1 also provides an incentive for developing efficient repurposing facilities. Scope 2 emissions are indirect emissions associated with the purchase of electricity, steam, heat, and cooling. As switching to renewable energy can help reduce carbon footprint, scope 2 targets may also play a role in the development of second life battery ESSs. Scope 3 emissions are indirect emissions that result from activities in a company's value chain but for which it does not directly control, including both upstream and downstream activities, e.g., emissions from the extraction of raw materials, transportation of goods, and end-of-life treatment of batteries. As the development of battery technologies has taken a trend where minimal CRMs are used, this will directly impact carbon emissions throughout the LIB supply chain. The closer materials are sourced, and the fewer CRMs are used, the smaller the carbon emissions of the LIBs are. From the perspective of batteries end-of-life management, recycling processes for used batteries have their emissions. By extending the lifespan of batteries through second life applications, the frequency of recycling is reduced, lowering Scope 3 emissions associated with end-of-life treatment.

Both the new Battery Regulation 2023/1542 and the Corporate Sustainability Reporting Directive (CSRD), including the calculation of Scope 1, 2, and 3 emissions, have only recently come into force. It remains to be seen how these will further develop and affect the development of the battery second life market. Within the value chain, automotive OEMs play a key role in how the repurposing business landscape will develop in the future.

References

AESC, 2024. About AESC. Retrieved from https://www.aesc-group.com/en/aboutus.html

Albertsen, L., Richter, J. L., Peck, P., Dalhammar, C., & Plepys, A. (2021). Circular business models for electric vehicle lithium-ion batteries: An analysis of current practices of vehicle manufacturers and policies in the EU. Resources, Conservation and Recycling, 172, 105658.

Ali, H., Khan, H. A., & Pecht, M. G. (2021). Circular economy of Li Batteries: Technologies and trends. Journal of Energy Storage, 40, 102690.

Asurza Engineers, 2024. These Countries are Adopting Electric Vehicles the Fastest. Retrieved from https://www.asurza.ca/these-countries-are-adopting-electric-vehicles-the-fastest/

Baars, J., Domenech, T., Bleischwitz, R., Melin, H.E., Heidrich, O., 2021. Circular economy strategies for electric vehicle batteries reduce reliance on raw materials. Nature Sustainability, 4(1), 71-79.

Battery-News, 2024a. Battery Active Materials in Europe (January 2024). Retrieved from https://battery-news.de/en/2024/01/26/active-materials-in-europe-january-2024/

Battery-News, 2024b. Battery Cell Production in Europe (as of May 2024). Retrieved from https://battery-news.de/en/2024/05/24/battery-cell-production-in-europe-may-2024/

Battery-News, 2024c. Battery System Manufacturing as of April 2024. Retrieved from https://battery-news.de/en/2024/04/22/battery-system-manufacturing-as-of-april-2024/

Battery-News, 2024d. Second-Life Battery Applications in Europe (February 2024). Retrieved from https://battery-news.de/en/2024/02/09/second-life-battery-applications-in-europe-february-2024/

Battery-News, 2024e. Battery Recycling in Europe. Retrieved from https://battery-news.de/en/2024/09/06/battery-recycling-in-europe/

Banque de France, 2023. Critical raw materials: the dependence and vulnerabilities of the EU. Retrieved from https://www.banque-france.fr/en/publications-and-statistics/publications/critical-raw-materials-dependence-and-vulnerabilities-eu

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.

Börner, M. F., Frieges, M. H., Späth, B., Spütz, K., Heimes, H. H., Sauer, D. U., & Li, W. (2022). Challenges of second life concepts for retired electric vehicle batteries. Cell Reports Physical Science, 3(10).

CATL, 2023. Battery Recycling. Retrieved from https://www.catl.com/en/solution/recycling/

Circunomics, 2024. Circular Battery Trade. Retrieved from https://www.circunomics.com/b2b-marketplace

Choux, M., Pripp, S. W., Kvalnes, F., & Hellström, M. (2024). To shred or to disassemble–A techno-economic assessment of automated disassembly vs. shredding in lithium-ion battery module recycling. Resources, Conservation and Recycling, 203, 107430.

Connected Energy, 2024. About us. Retrieved from https://connected-energy.co.uk/about-us/

Currents, 2024. Enabling Battery Commerce. Retrieved from https://www.currents.market/

Dunn, J., Ritter, K., Velázquez, J. M., & Kendall, A. (2023). Should high-cobalt EV batteries be repurposed? Using LCA to assess the impact of technological innovation on the waste hierarchy. Journal of Industrial Ecology, 27(5), 1277-1290.

EcarAccu, 2024. Second-Life EV battery cells. Retrieved from https://ecaraccu.nl/second life/

EEA - European Environment Agency, 2024. New registrations of electric vehicles in Europe. Retrieved from https://www.eea.europa.eu/en/analysis/indicators/new-registrations-of-electric-vehicles?activeAccordion=309c5ef9-de09-4759-bc02-802370dfa366

Engie, 2020. A "Second Life" For Electric Car Batteries: Award-Winning Innovation For The Energy Transition. Retrieved from https://innovation.engie.com/en/news/news/new-energies/a-second-life-for-electric-car-batteries-award-winning-innovation-for-the-energy-transition/13586#:~:text=ENGIE%20and%20Umicore%20connected%20the,collective%20energy%20to%20form%20one

European Commission, 2024a. Waste Framework Directive. Retrieved from https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en

European Commission, 2024b. European Critical Raw Materials Act. Retrieved from https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan/european-critical-raw-materials-act_en

European Council, 2024. An EU critical raw materials act for the future of EU supply chains. Retrieved from https://www.consilium.europa.eu/en/infographics/critical-raw-materials/

European Union, 2023. 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 (Text with EEA relevance). Retrieved from https://eur-lex.europa.eu/eli/reg/2023/1542/oj

Forbes, 2024. The Billion-Dollar Potential Of A Used EV Battery Marketplace. Retrieved from https://www.forbes.com/councils/forbesbusinesscouncil/2024/09/09/the-billion-dollar-potential-of-a-used-ev-battery-marketplace/

Fortum, 2024. Second life batteries, expertise and a can-do attitude – innovation boosts hydropower plant. Retrieved from https://www.fortum.com/about-us/our-company/strategy/decarbonisation-joint-effort/second-life-batteries-hydropower-plant

Fossil Free Sweden, 2020. Strategy for fossil free competitiveness: Sustainable battery value chain. Retrieved from https://fossilfrittsverige.se/wp-content/uploads/2020/12/Strategy_for_sustainable_batter_value_chain.pdf

Fraunhofer ISI, 2023. Recycling of lithium-ion batteries will increase strongly in Europe. Retrieved from https://www.isi.fraunhofer.de/en/blog/themen/batterie-update/recycling-lithium-ionen-batterien-europa-starke-zunahme-2030-2040.html

Gaines, L., Dai, Q., Vaughey, J. T., & Gillard, S. (2021). Direct recycling R&D at the recell center. Recycling, 6(2), 31.

Geissdoerfer, M., Pieroni, M.P.P., Pigosso, D.C.A., Soufani, K., 2020. Circular business models: A review. Journal of Cleaner Production, 277, 123741.

Gourcerol, B., Gloaguen, E., Melleton, J., Tuduri, J., & Galiegue, X. (2019). Re-assessing the European lithium resource potential–A review of hard-rock resources and metallogeny. Ore Geology Reviews, 109, 494-519.

GTK, 2024. The EU Critical Raw Materials Act (CRMA) Entered Into Force. Retrieved from https://www.gtk.fi/en/current/the-eu-critical-raw-materials-act-crma-entered-into-force/

Hobson, J. A. (2018). Imperialism: A study. Routledge.

Horn, S., Gunn, A. G., Petavratzi, E., Shaw, R. A., Eilu, P., Törmänen, T., ... & Wall, F. (2021). Cobalt resources in Europe and the potential for new discoveries. Ore Geology Reviews, 130, 103915.

IDTechEx, 2023. Second-life Electric Vehicle Batteries 2023-2033. Retrieved from https://www.idtechex.com/en/research-report/second life-electric-vehicle-batteries-2023-2033/924

IEA, 2023. Critical Minerals Market Review 2023. Retrieved from https://iea.blob.core.windows.net/assets/c7716240-ab4f-4f5d-b138-291e76c6a7c7/CriticalMineralsMarketReview2023.pdf

IEA, 2024a. Global Critical Minerals Outlook 2024. Retrieved from https://iea.blob.core.windows.net/assets/ee01701d-1d5c-4ba8-9df6-abeeac9de99a/GlobalCriticalMineralsOutlook2024.pdf

IEA, 2024b. Global EV Outlook 2024. Retrieved from https://iea.blob.core.windows.net/assets/a9e3544b-0b12-4e15-b407-65f5c8ce1b5f/GlobalEVOutlook2024.pdf

IEEP, 2024. Sourcing critical raw materials through trade and cooperation frameworks. Retrieved from https://ieep.eu/wp-content/uploads/2024/03/Sourcing-critical-raw-materials-through-trade-and-cooperation-frameworks-IEEP-2024.pdf

Intercalation, 2024. Deep Dive Into Battery Software - An overview of battery software startups. Retrieved from https://intercalationstation.substack.com/p/deep-dive-into-battery-software-part-e72

IPCEI, 2024. Battery cell production in Europe: Status quo and outlook. Retrieved from https://www.ipcei-batteries.eu/fileadmin/Images/accompanying-research/publications/2024-05-BZF_Kurzinfo_Marktanalyse_Q2_engl.pdf

IRENA, 2024. Critical materials - Batteries for electric vehicles. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Sep/IRENA_Critical_materials_Batteries_for_EVs_2024.pdf

Kebir, N., Leonard, A., Downey, M., Jones, B., Rabie, K., Bhagavathy, S. M., & Hirmer, S. A. (2023). Second life battery systems for affordable energy access in Kenyan primary schools. Scientific Reports, 13(1), 1374.

Kirchherr, J., & Piscicelli, L. (2019). Towards an education for the circular economy (ECE): Five teaching principles and a case study. Resources, Conservation and Recycling, 150, 104406.

Lieskoski, S., Tuuf, J., & Björklund-Sänkiaho, M. (2024). Techno-economic analysis of the business potential of second life batteries in Ostrobothnia, Finland. Batteries, 10(1), 36.

Liu, K., Wei, Z., Zhang, C., Shang, Y., Teodorescu, R., & Han, Q. L. (2022). Towards long lifetime battery: AI-based manufacturing and management. IEEE/CAA Journal of Automatica Sinica, 9(7), 1139-1165.

Leon, E. M., & Miller, S. A. (2020). An applied analysis of the recyclability of electric vehicle battery packs. Resources, Conservation and Recycling, 157, 104593.

Lu, Y., Maftouni, M., Yang, T., Zheng, P., Young, D., Kong, Z. J., & Li, Z. (2023). A novel disassembly process of end-of-life lithium-ion batteries enhanced by online sensing and machine learning techniques. Journal of Intelligent Manufacturing, 34(5), 2463-2475.

Ma, R., Tao, S., Sun, X., Ren, Y., Sun, C., Ji, G., ... & Zhou, G. (2024). Pathway decisions for reuse and recycling of retired lithium-ion batteries considering economic and environmental functions. Nature Communications, 15(1), 7641.

Ministre de l'Économie, des Finances et de l'Industrie, 2023. La stratégie nationale sur les batteries de France 2030: au cœur de la décarbonation des mobilités. Retrieved from https://presse.economie.gouv.fr/30052023-la-strategie-nationale-sur-les-batteries-de-france-2030-au-coeur-de-la-decarbonation-des-mobilites/

Ministry of Economic Affairs and Employment of Finland, 2021. National Battery Strategy 2025. Retrieved from https://julkaisut.valtioneuvosto.fi/handle/10024/162685

Northvolt, 2024. Recycling lithium-ion batteries. Retrieved from https://northvolt.com/recycling/

OECD. (2024). Extended Producer Responsibility. Retrieved from https://www.oecd.org/environment/extended-producer-responsibility.htm

Prenner, S., Part, F., Jung-Waclik, S., Bordes, A., Leonhardt, R., Jandric, A., ... & Huber-Humer, M. (2024). Barriers and framework conditions for the market entry of second life lithium-ion batteries from electric vehicles. Heliyon, 10(18).

Qorbani, D., Korzilius, H. P., & Fleten, S. E. (2024). Ownership of battery electric vehicles is uneven in Norwegian households. Communications Earth & Environment, 5(1), 170.

Quinteros-Condoretty, A. R., Laukkanen, M., Kainiemi, L., Pinto, S. M., Lourenço, E. J., Oliveira, L., ... & Barbiellini, B. (2025). Conceptual model for extending electric vehicle battery lifetime. Resources, Conservation and Recycling, 212, 107943.

Rallo, H., Benveniste, G., Gestoso, I., & Amante, B. (2020). Economic analysis of the disassembling activities to the reuse of electric vehicles Li-ion batteries. Resources, Conservation and Recycling, 159, 104785.

Ramboll, 2024. New EU Batteries Regulation: what it means for manufacturers. Retrieved from https://www.ramboll.com/insights/resource-management-and-circular-economy/new-eu-batteries-regulation-what-it-means-for-manufacturers

Reike, D., Vermeulen, W. J., & Witjes, S. (2018). The circular economy: new or refurbished as CE 3.0?—exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options. Resources, Conservation and Recycling, 135, 246-264.

Renault Group, 2023. All you need to know about Renault ZOE battery leasing. Retrieved from https://www.renaultgroup.com/en/magazine/energy-and-motorization/all-you-need-to-know-about-battery-leasing-for-the-renault-zoe

Renault Group, 2024. Refactory: The Flins site enters the circle of the circular economy. Retrieved from https://www.renaultgroup.com/en/magazine/our-group-news/re-factory-the-flins-site-enters-the-circle-of-the-circular-economy

Renewable Energy World, 2018. Engie Reuses EV batteries for Energy Storage Project. Retrieved from https://www.renewableenergyworld.com/storage/engie-reuses-ev-batteries-for-energy-storage-project/

Reuters, 2023. Volkswagen to partner on Indonesia EV battery ecosystem -minister. Retrieved from https://www.reuters.com/business/autos-transportation/volkswagen-partner-with-vale-ford-huayou-indonesia-ev-battery-ecosystem-minister-2023-04-17/

Reuters, 2024a. China's global battery ram will be hard to stop. Retrieved from https://www.reuters.com/breakingviews/chinas-global-battery-ram-will-be-hard-stop-2024-09-06/

Reuters, 2024b. EU car sales at 3-year low in August, EV sales plunge 44%. Retrieved from https://www.reuters.com/business/autos-transportation/eu-car-sales-3-year-low-august-ev-sales-down-439-acea-says-2024-09-19/

Slattery, M., Dunn, J., & Kendall, A. (2024). Charting the electric vehicle battery reuse and recycling network in North America. Waste Management, 174, 76-87.

Sovacool, B. K., Ali, S. H., Bazilian, M., Radley, B., Nemery, B., Okatz, J., & Mulvaney, D. (2020). Sustainable minerals and metals for a low-carbon future. Science, 367(6473), 30-33.

Statzon, 2024. E-Mobility Europe: An Overview of Europe's Latest Electric Vehicles Data. Retrieved from https://statzon.com/insights/e-mobility-europe-an-overview-of-europes-latest-electric-vehicles-data

Statista, 2024. Market share of electric cars (BEV and PHEV) in Norway from 2009 to 2023. Retrieved from https://www.statista.com/statistics/1029909/market-share-of-electric-cars-in-norway/

Stena Recycling, 2024. Recycling of vehicle batteries - We close the circle. Retrieved from https://www.stenarecycling.com/globalassets/what-we-offer/documents/positionspapper_batteri_digital_en_update.pdf

S&P Global, 2023. New lithium mining, refining projects set to strengthen Europe's battery supply chains. Retrieved from https://www.spglobal.com/commodityinsights/pt/market-insights/latest-news/metals/121123-new-lithium-mining-refining-projects-set-to-strengthen-europes-battery-supply-chains

UN environment programme, 2024. Used Vehicles and the Environment: Update and Progress 2024. Retrieved from https://www.unep.org/resources/report/used-vehicles-and-environment-global-overview-used-light-duty-vehicles-flow-scale

Volkswagen Group, 2024. Elli enters the industrial energy storage business. Retrieved from file:///C:/Users/e0370432/Downloads/PM_Elli_enters_the_industrial_energy_storage_business.pdf

Volvo Energy, 2024. Volvo Energy. Retrieved from https://www.volvoenergy.com/en/

White, C., & Swan, L. G. (2023). Pack-level performance of electric vehicle batteries in second life electricity grid energy services. Journal of Energy Storage, 57, 106265.

Zhao, J., Qu, X., Wu, Y., Fowler, M., & Burke, A. F. (2024). Artificial intelligence-driven real-world battery diagnostics. Energy and AI, 18, 100419.

Zhu, J., Mathews, I., Ren, D., Li, W., Cogswell, D., Xing, B., ... & Bazant, M. Z. (2021). End-of-life or second life options for retired electric vehicle batteries. Cell Reports Physical Science, 2(8).

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