Issue paper Cluster Electric Mobility South-West

Circular economy of traction batteries from Europe: The potential of recycling and second-life applications

electric mobility south-west

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Management summary

The increasing market penetration of electric vehicles in public and commercial transport is bringing about a marked increase in the annual installed capacity of traction batteries from 270 GWh in 2024 to an expected 1,800 GWh in 2035. The transition to sustainable, resource-conserving economic practices requires innovative approaches to the utilisation and recycling of traction batteries. Second-life applications offer a promising opportunity to extend the lifetime of batteries and reduce their ecological footprint. At the same time, recycling plays a decisive role in recovering valuable materials and strengthening the circular economy.

An increasing number of batteries are no longer being used in vehicles due to loss of capacity and ageing and are available for second-life applications. Stationary energy storage systems, in particular, can benefit from these batteries by using them for grid stabilisation, emergency power supply or in fast charging stations, which both reduces the product carbon footprint and enables cost savings.

The repurposing of end-of-first-life batteries requires their removal from vehicles, testing and transport to repurposing facilities. There, further testing and potential disassembly at the module level are carried out to allow the utilisation of the batteries in new applications. Entire battery packs can also be used to minimise efforts required for disassembly and to reuse key components, such as the battery management system. The challenges involved include non-transparent data, a lack of standardisation and time-consuming testing processes. In addition, falling prices for new batteries and the recycling value may limit the economic potential afforded by second-life applications. From 2031, EU regulations on the recyclate quota in new batteries could prioritise recycling and compromise second-life efforts.

Multiple European pilot projects and series products have verified the feasibility of second-life applications. Close partnerships between automotive OEMs and repurposing facilities could improve data transparency and simplify the repurposing process. Interviews with industry representatives have revealed that lorry and bus batteries have a shorter first life, which is why they can be increasingly used for second-life applications. The digital battery passport, which will be developed by 2027, should provide the necessary data from the first life cycle. Standardisation initiatives and the training of specialists are also required. Funding for industry and research projects at various levels may enable companies to evaluate second-life models as an alternative and develop local business models.

Ensuring the availability of raw materials through recycling

In the coming years, European automotive companies will require considerably more materials for the production of energy storage systems. The demand for traction batteries will increase from just under 90 GWh in 2022 to over 1,200 GWh by the middle of the next decade. The supply of raw materials must neither impair competitiveness nor lead to dependence on a small number of suppliers outside the EU. Lithium, nickel, manganese, cobalt and graphite are mainly extracted outside Europe. To date, Portugal the only known lithium producer in Europe.

Recycling traction batteries at the end of their life cycle could potentially contribute to a reliable supply. A proposal of the EU regulation concerning batteries and waste batteries states that, from the middle of the next decade, newly manufactured batteries must contain a certain proportion of recycled materials. Specifically, recycling processes must be able to recover 80%

of lithium and 95% each of nickel and cobalt. In the medium term, the majority of recycled materials will originate from production waste, with the proportion decreasing with increasing experience. While the recycling of nickel and cobalt is a well-established process, hitherto experience with lithium is limited. The recycling of manganese and graphite is a less attractive option in economic terms, but may improve the reliability of the material supply.

In Europe, traction batteries will reach the end of their life cycle in vehicles in significant quantities starting in 2030. Of the 11.4 million vehicles taken out of service each year, however, only 6.6 million are sent to a recycling plant. The ultimate whereabouts of around 3.8 million vehicles remain unknown, which impacts the recycling rate and the supply of recycled materials. Second-life applications can prevent materials from being recycled for an additional number of years, prolonging the process.

Innovative business models, such as selling the vehicle to the manufacturer or 'Battery-as-a-Service', can potentially promote the return of batteries to the European cycle. Standards and harmonised rules must be established across the EU and cooperation improved.

Introduction and approach

This issue paper, 'Circular economy of traction batteries from Europe: The potential of recycling and second-life applications', is a summary of the topic paper 'Material cycle of traction batteries from Europe' prepared by the Fraunhofer Institute for Industrial Engineering IAO and the topic paper 'Material cycle of traction batteries from Europe: The potential of second-life applications' prepared by P3 automotive GmbH. The issues analysed in both publications were developed within the Battery recycling and circular economy working group of the Cluster Electric Mobility South-West. The results and recommendations for action are discussed in the working group and provide a basis for future research and development projects. The Electromobility Cluster would also like to exchange ideas on these topics with its international partners. For this reason, we have made the issue paper available in English for the first time.

The issue paper 'Circular economy of traction batteries from Europe: The potential of recycling and second-life applications' presents an account of the current developments with regard to second-life batteries, the potential they afford and the influence of recycled raw materials on European raw material supply. The paper takes technological, economic and regulatory issues into consideration and thereby provides a comprehensive overview of the sustainable utilisation and recycling of battery resources.

End-of-life of a traction battery from an electric vehicle

Sustainability is becoming increasingly important in the modern economy, and nowhere more prominently than in electromobility. The main focal points in this regard are the efficient use and reuse of traction batteries from electric vehicles on the one hand and ensuring the availability of raw materials on the other. Second-life applications offer a promising opportunity to extend the lifetime of these batteries, thereby reducing their ecological footprint. At the same time, the availability of primary raw materials poses a challenge that can be mitigated through recycling and diversified procurement.

The useful life of traction batteries from electric vehicles often ends due to loss of capacity, accidents or defects. After disassembly, these batteries can be repaired, recycled or reused in second-life applications. The latter offers an opportunity to extend the lifetime of the batteries and generate additional revenue. Since the 2010s, numerous pilot projects have been carried out to test this concept, especially by OEMs. In recent years, many more projects have been launched in Germany and the EU, and start-ups have been founded to produce battery systems with second-life batteries (see Table 1). Possible applications range from peak load capping in industrial companies to utilisation as buffer storage in fast charging stations, with the second-life period ranging between 4 and 20 years.

Application	Use case description	Location	Battery origin	ESS integrator	End user
Peak shaving	In 2023, BatteryLoop, Stena Fastigheter and Ikano Bostad installed Sweden's largest storage system, which is made from reused Mercedes-Benz batteries. The 2.8 MW storage system reduces energy costs in the sustainable Humlestaden district and supplies the local grid with electricity during peak periods (elective, 2023).	Göteborg, Sweden	*	BATTERYLOOP	Stena Fastigheter IKANO Bostad
Emergency power supply, optimisation of self-consumption	A 1.6 MWh energy storage system from e.battery systems was commissoined in September 2023. Coupled to a 9,000 m² photovoltaic system, the Bischof Lagerhaus AG storage facility is used to optimise self-consumption and provide an emergency power supply with a self-sufficiency level of around two days (e.battery systems AG, 2024).	Sennwald, Switzerland	*	battery systems	Bischof LEBENSMITTELLOGISTIK
Reference storage for commercial operations	In May 2022, EnBW started a pilot project in cooperation with Audi to use second-life batteries. A reference storage system is being built on the company premises in Heilbronn consisting of 12 traction batteries from the Audi e-tron test fleet with a total capacity of approx. 1 MW (EnBW, 2022).	Heilbronn, Germany		* EnBW	* EnBW
Peak shaving, grid stabilisation	As part of a research project conducted together with Fraunhofer ISE and Enel X, a 5 MW storage system has been supporting the energy supply at Leonardo da Vinci Airport in Rome since January 2022. The storage system consists of used vehicle batteries from various OEMs and is used to optimise the use of surplus photovoltaic energy to cover evening peak demand and to provide additional grid services (Fraunhofer ISE, 2024).	Rome, Italy	-	* Fraunhofer ISE enel x	ADR Aeroporti di Roma
EV charging infrastructure	In 2022, the start-up Mob-Energy implemented an autonomous charging robot for electric vehicles powered by second-life batteries from Mercedes-Benz. The robot charges vehicles with a DC charging capacity of 7.4 kW to 30 kW and is employed at the headquarters of Mercedes-Benz France (Mercedes-Benz France, 2022).	Montigny-le-Bretonneux, France	*	MOBI ENERGY	*
Grid operating reserve, frequency stabilisation	In autumn 2016, Vattenfall installed a 2 MW storage system in the Port of Hamburg using decommissioned BMW battery modules from the models Active-e and i3. Bosch took charge of the system development and integration. The purpose of the project is to balance frequency fluctuations in order to stabilise the grid frequency (Vattenfall, 2018).	Hamburg, Germany	BMW	* BOSCH	VATTENFALL
Emergency power supply, peak shaving	In cooperation with Eaton, The Mobility House and BAM, a 3 MW storage system was commissioned at the Johan Cruijff Arena in 2018. Equipped with decommissioned Nissan LEAF batteries, the battery storage system is used for emergency power supply and to balance peak loads during concerts (The Mobility House, 2018).	Amsterdam, Netherlands	NISSAN	THE MOBILITY HOUSE * EATON bam	JOHAN CRUIJFF ARENA
Industrial storage	In November 2021, TGN Energy will receive a 216 kWh energy storage system that uses reused Mercedes-Benz batteries to supply energy to industrial and commercial applications (Evyon, 2022).	Oslo, Norway	*	Evyon	TGN
Optimisation of self-consump-tion, peak shaving	As part of a research project, Smart Power GmbH delivered a 100 kW storage system made from decommissioned Mercedes-Benz batteries in 2018. It is used to optimise Saubermacher AG's own energy needs and to collect data on battery lifetimes in industrial applications (Smart Power, 2023).	Graz, Austria	*	smart POWER	Saubermacher

*Members of the Cluster Electric Mobility South-West: Robert Bosch GmbH, Fraunhofer ISE, Eaton Germany GmbH, EnBW Baden-Württemberg AG, Mercedes-Benz Group.

Source: (elective, 2023; e.battery systems AG, 2024; EnBW, 2022; Fraunhofer ISE, 2024; Mercedes-Benz France, 2022; Vattenfall, 2018; The Mobility House, 2018; Evyon, 2022; Smart Power, 2023; Own illustration)

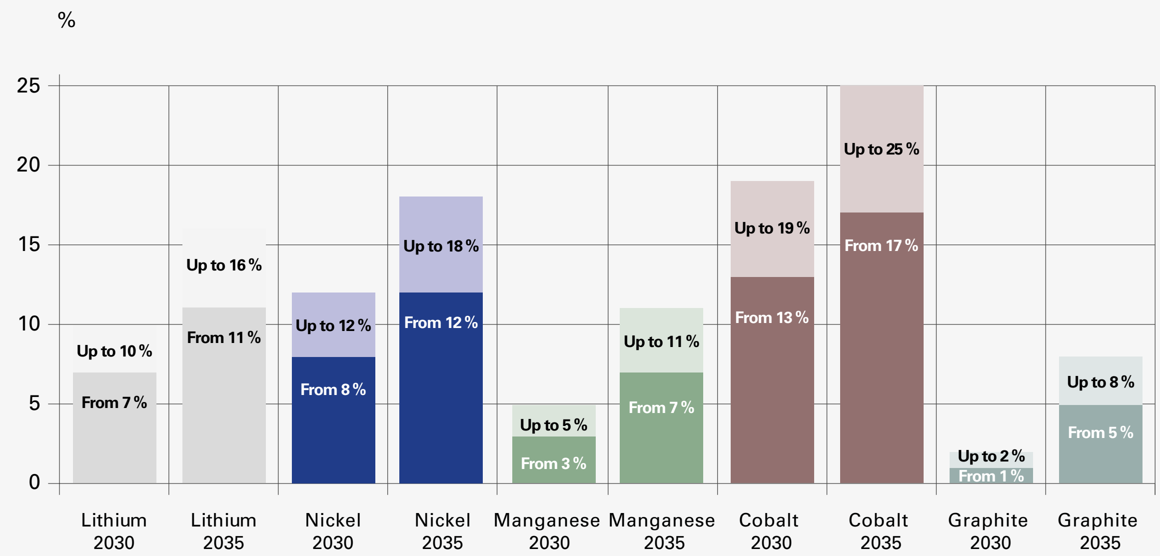
Table 1: Examples of second-life battery projects (Issue paper: Material cycle of traction batteries from Europe: The potential of second-life applications, p. 15)

The integration of these batteries into second-life applications requires a considerable amount of repurposing and integration work. A lack of data transparency necessitates complex tests after dismantling – a problem that the battery passport to be introduced in the EU starting in 2027 is intended to remedy. The effort required can be reduced by integrating entire battery packs. Technical hurdles exist in the optimal coordination of different battery systems. Crucial factors for profitability are the costs of new batteries, the effort required for repurposing and the recycling costs. New EU regulations could increase the demand for recycled materials and make recycling more attractive. Second-life applications also offer the opportunity to test new technologies, such as vehicle-to-grid, thereby delaying recycling.

The demand for raw materials for the production of traction batteries in Europe will rise sharply in the coming years and exceed the current production of primary raw materials. While new raw material projects are being developed to meet this demand, raw material prices are expected to rise in the short term. Europe is heavily dependent on reliable supplies from various regions of the world, as important primary raw materials are only available locally to a limited extent. The diversification of supply sources can potentially minimise the risk of supply shortfalls.

Recycled raw materials are becoming increasingly vital. By 2035, they could cover significant proportions of raw material demand, e.g. 11–16% for lithium and 17–25% for cobalt (see Figure 1). Recycled raw materials make a major contribution to ensuring an adequate supply. Availability can be further increased if European organisations invest more in exploration and mining activities or establish trade relations with established metal exchanges. The storage of primary raw materials can help to bridge temporary bottlenecks.

All in all, second-life applications and the recycling of raw materials offer key strategies for reducing the need for primary raw materials and promoting sustainability in electromobility.



Source: (Fraunhofer IAO, own illustration)

Figure 1: Percentage of demand for production capacities registered in Europe that can be covered by recyclate (Issue paper: Material cycle of traction batteries from Europe, p. 21)

Economic analysis of second-life operation and recycling

One method of assessing the economic viability of second-life batteries is to compare their net costs with those of first-life batteries (see Figure 2). When purchasing a new automotive battery for stationary energy storage systems (ESS), the ESS manufacturer incurs costs of around €140/kWh after recovering the recycling value of around €10/kWh at the end of the lifetime.

The OEM has two options for handling returned batteries: either recycle the battery and receive €10/kWh or sell it to a second-life business that is willing to pay more than €10/kWh (rate assumed here: €25/kWh). Figure 2 compares the net costs for a new automotive battery with a repurposed battery. The second-life business then takes over the repurposing of the battery, which costs approx. €5/kWh, yielding a total cost of around €30/kWh for ready-to-use batteries. First-life batteries need to be replaced halfway through their lifetime, which costs another €30/kWh. However, the recycled value of €10/kWh is recovered simultaneously. This results in a net cost of approx. €40/kWh, making second-life batteries economically viable.

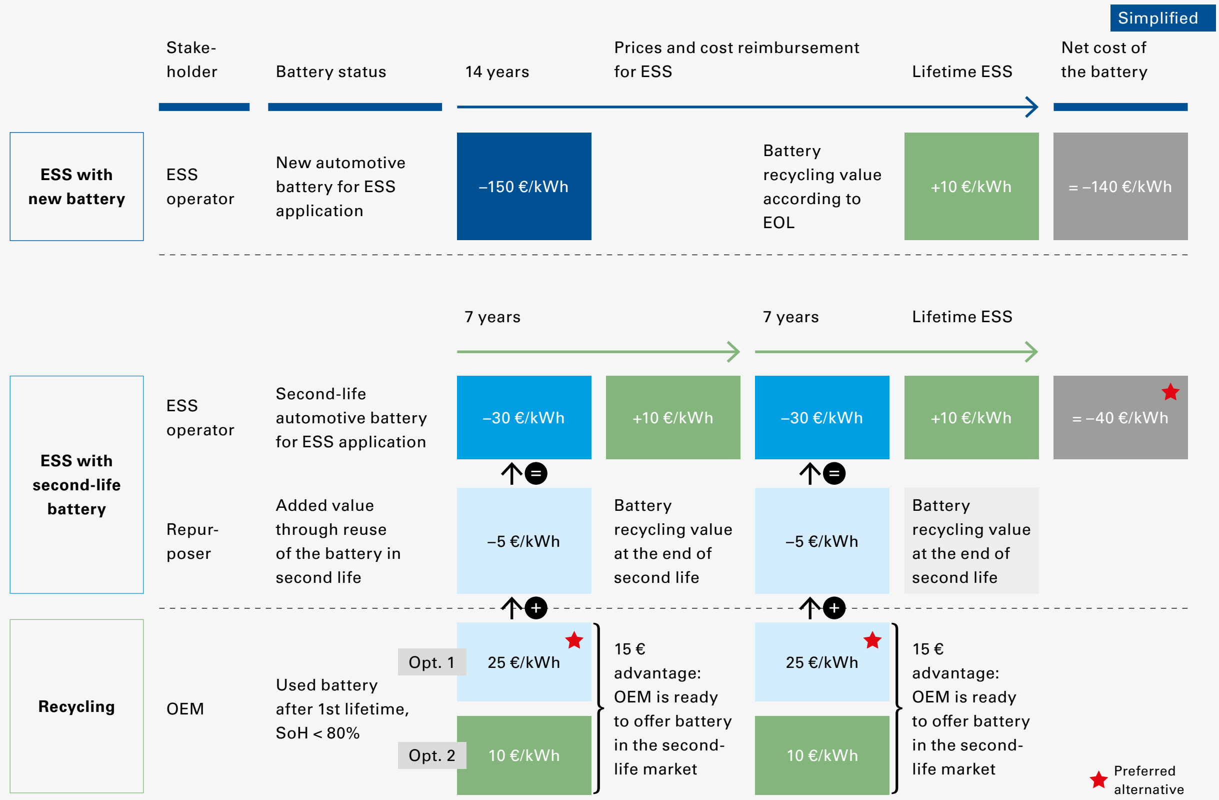
As can be seen from this economic assessment, second-life batteries are less costly than new batteries. However, batteries and processes are individual in nature and sensitive in their response to price fluctuations for individual components, for which reason this analysis only applies to the premises presented here..

With recycling, it is evident that the cost of recycled materials per kilogramme is higher than that of primary raw materials. However, this can change with rising material prices, as can be seen in the example of the current price of lithium. A comparison on the basis of kilowatt hours indicates a positive recycling value, which becomes even more favourable if material prices rise. However, profitability can depend heavily on metal prices.

The current state of the art makes it possible for companies to recover lithium, nickel and cobalt from these batteries in a quality comparable to primary raw materials. In the case of manganese and graphite, recovery in the quality required for traction batteries is technically possible, yet it entails a highly complex process that has not yet been realised in a satisfactory way on an industrial scale.

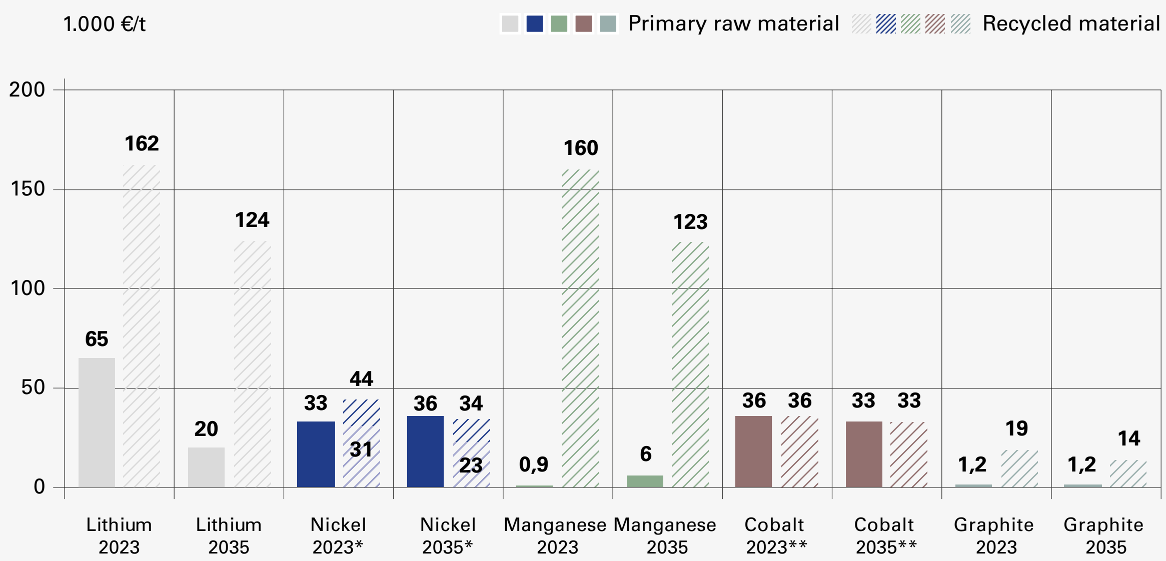
The recovery rate is currently around 50% for lithium and up to 95% for nickel and cobalt. Despite the high costs, the recycling of nickel and cobalt is still economically competitive compared to primary raw materials (see Figure 3). This also helps to reduce the dependency on countries like Russia and the Democratic Republic of Congo.

However, because recycled lithium is more expensive than the primary raw material, recycling lithium is a costly process – a circumstance that is not expected to change in the foreseeable future. In this case, the environmental targets applicable in the European Union and the reduction of dependencies are the driving forces behind the recovery of lithium from traction batteries.



Source: (own illustration)

Figure 2: Simplified representation to determine the net cost of batteries for new automotive batteries compared to repurposed batteries (Issue paper: Material cycle of traction batteries from Europe: The potential of second-life applications, p. 35)



*The costs of extracting the recyclate using hydrometallurgy (lower value) and pyrometallurgy (upper value) are specified here.
**Costs comparable to those of primary raw materials are assumed, as recycling has been established for a long time.

Source: (Fraunhofer IAO, own illustration)

Figure 3: Price of primary raw material and cost of recyclate in 2023 and forecast for 2035 (Issue paper: Material cycle of traction batteries from Europe, p. 43)

In the case of manganese and graphite, the technical challenges and high costs represent the biggest obstacles. Owing, in part, to the structures in place for the extraction, refining and distribution of primary raw materials, the prices of these materials are lower than the costs of recycling them. In the case of graphite, the result is a dependency on China, in particular.

Despite the high costs, recycling can make a valuable contribution to reducing this dependency as well as protecting the environment, though suitable guidelines are required before this can happen. The framework conditions need to be continuously optimised in order to improve sustainability.

The comparison of first-life and second-life applications reveals cost advantages for second-life applications. It remains to be seen whether end-of-first-life batteries (EOFL) should be recycled directly or used as raw material storage in second-life applications in order to generate revenue. An interview with an OEM clearly showed that the actual business model is to sell vehicles and to ensure that raw materials that are important for battery production are available, for which reason the recycling route tends to be favoured. However, due to the high recycling costs, the second-life application is an attractive alternative, as OEMs are also interested in retaining ownership of the batteries (P3 Interview – OEM, 2023). This underscores the need to continuously review assumptions about profitability and to adapt them to changing market conditions and price fluctuations.

Ecological assessment of second-life operation and recycling

In light of increasing efforts to reduce the product carbon footprint (PCF), the ecological analysis of batteries and their materials is particularly essential. This study analyses the emissions in the recycling process for LFP and NMC811 battery cells by first calculating the PCF for batteries made from primary materials and then for batteries made from recycled materials.

The chemical input differs only slightly, resulting in 1.4–1.6 kg CO2e per kilogramme of input. The main driver of emissions is the energy required for heating and cooling during the hydrometallurgical process. The 'mech + hydro' process generates 2.5 kg CO2e per kilogramme (9.7 kg CO2e per kWh), while the 'pyro + mech + hydro' process generates 3.5 kg CO2e per kilogramme (13.6 kg CO2e per kWh). Pyrolysis leads to an additional 0.9 kg CO2e per kilogramme of input (see Figure 4).

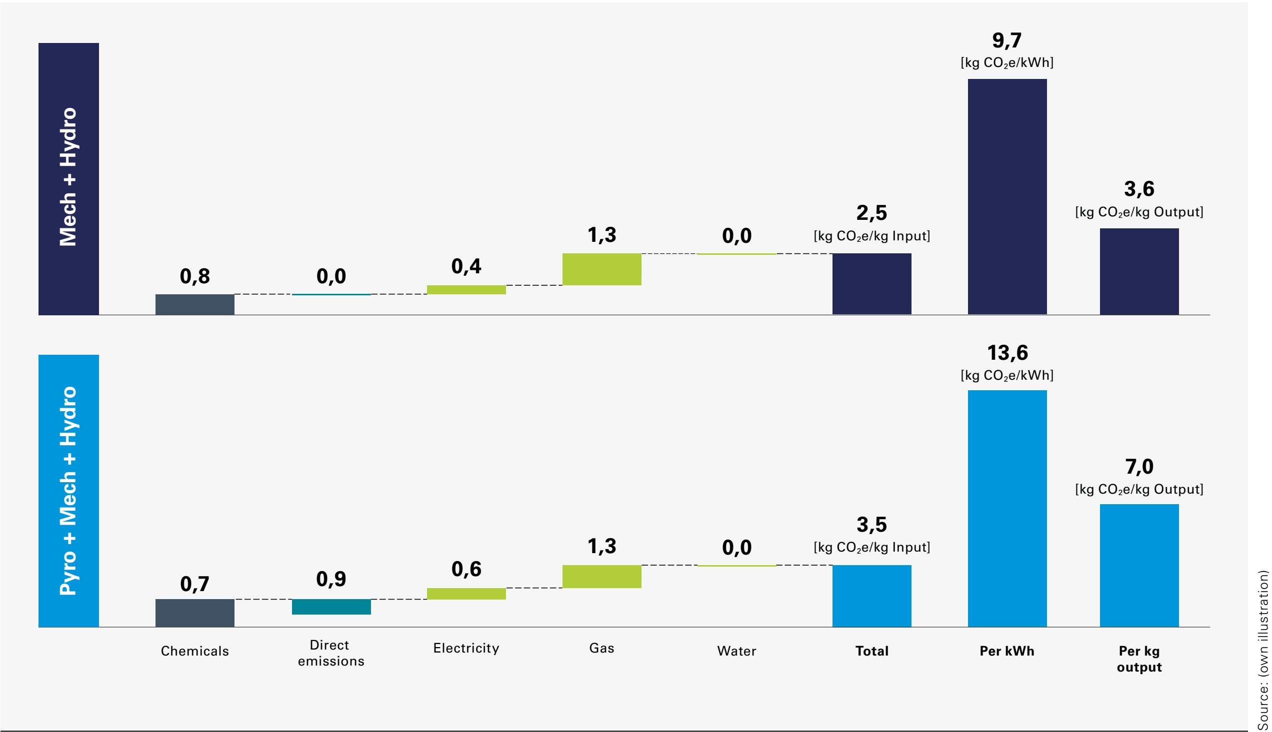


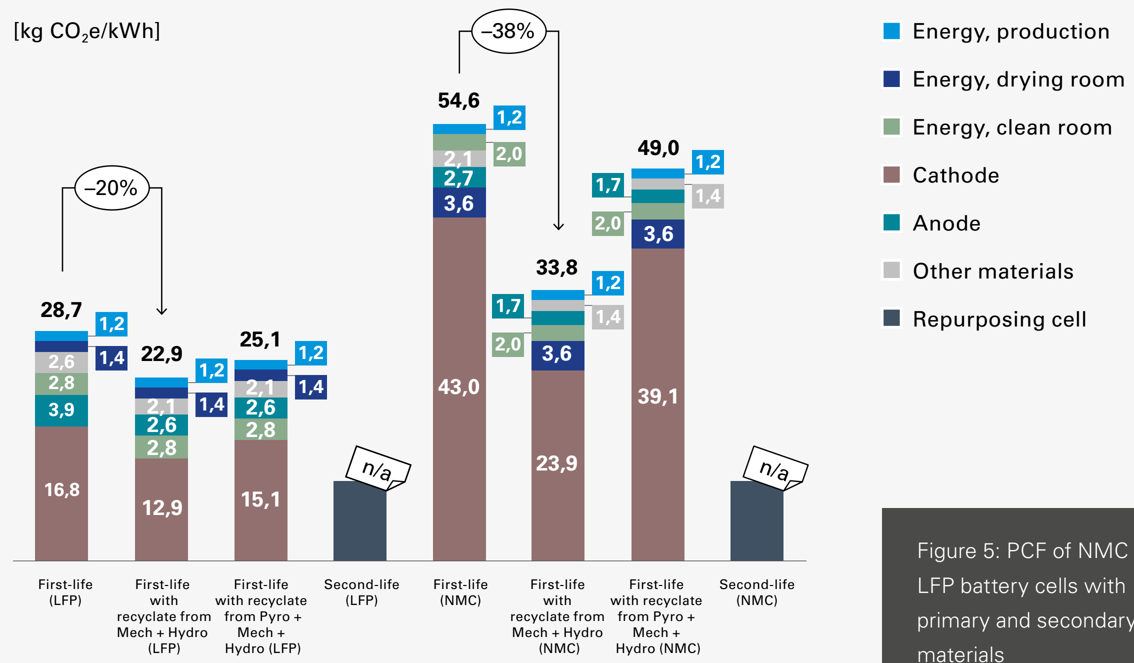
Figure 4: CO2e emissions of the 'mech + hydro' and 'pyro + mech + hydro' recycling process in kilogrammes of CO2e per kilogramme of input, kilowatt hour and kilogramme of output

The economic allocation of emissions to output materials is based on economic value and output quantity. Due to the high economic value of lithium, it accounts for large quantities of the emissions generated. The PCF of lithium carbonate is lower, as it is usually extracted from salt lakes and processed through natural drying, which is low in carbon emissions. In contrast, lithium hydroxide is usually produced from ores with low concentrations of lithium and a high PCF, which means that the 'mech + hydro' process has a significantly lower PCF. The emissions are precisely allocated to the output materials, which enables a detailed assessment of the environmental impact of the recycling process.

In order to determine the PCF (product carbon footprint) of batteries with recyclate, first-life and second-life batteries, a parts list is first drawn up (see issue paper Material cycle of traction batteries from Europe: The potential of second-life applications, p. 38). The production process involves manufacturing the electrodes by mixing active material, binder and carbon black, as well as the processes of drying, calendering and cutting. The electrodes are then stacked or wound with a separator, inserted into a housing, impregnated with electrolyte and undergo a moulding process. After degassing, the cell is aged, tested, sorted and packaged.

For the analysis, prismatic cells with LFP and NMC811 cathodes and graphite anodes were investigated. LFP cells have a capacity of approx. 1000 Wh, NMC811 cells approx. 650 Wh. The production capacity amounts to 14 GWh/year. Emission factors: electricity ~350 g CO2/kWh, gas ~270 g CO2/kWh. The majority of emissions originates from the cathode, with LFP cathodes accounting for around 60% of the emissions. Drying and forming are energy-intensive steps that increase the PCF to over 3 kg CO2e/kWh. Recycling can reduce the PCF for LFP cells by up to 20%.

For NMC811 cells, the cathode accounts for about 80% of the PCF. Processing requires a dry room atmosphere, which reduces the PCF to approx. 34 kg CO2e/kWh. Recycling can reduce the PCF here by up to 38%. For second-life batteries, the emissions are compared at the pack level. The repurposing process reduces emissions by around 65% compared to first-life alternatives and can reduce the PCF by up to 81% for NMC811 packs. The differences between LFP and NMC811 packs reflect the higher energy density of NMC811 and the advantages it offers in the recycling process.



Source: (own illustration)

Figure 5: PCF of NMC and LFP battery cells with primary and secondary raw materials

Challenges of second-life operation and recycling

The analysis of second-life batteries and recycling shows that both are potentially economical and environmentally friendly approaches, yet each entails different challenges. Battery recycling and especially NMC chemistry may be advantageous due to statutory recyclate quotas and rising raw material prices, while second-life applications may become more attractive with falling raw material prices and high recycling costs. Due to their cycle stability, LFP batteries are more suitable for second-life applications.

The economic viability of second-life batteries depends on the price of end-of-life batteries and the cost of first-life batteries. The net cost of second-life batteries is often lower, especially in stationary applications. However, repurposing costs can vary depending on the complexity of the integration and the need to adapt cooling systems and electronics. In all scenarios, carbon emissions are lower than in the production of first-life batteries. This is why recycling and repurposing are the recommended alternatives. EU regulations could increase the pressure to reduce the carbon footprint, which could make repurposing more attractive.

All scenarios are technically feasible, but the integration of battery pack modules and standardisation pose certain challenges. A lack of data on end-of-life (EOL) batteries and differences in utilisation may complicate repurposing efforts. An economic and an environmental analysis are necessary to choose the best option.

Business models in second-life operation and recycling

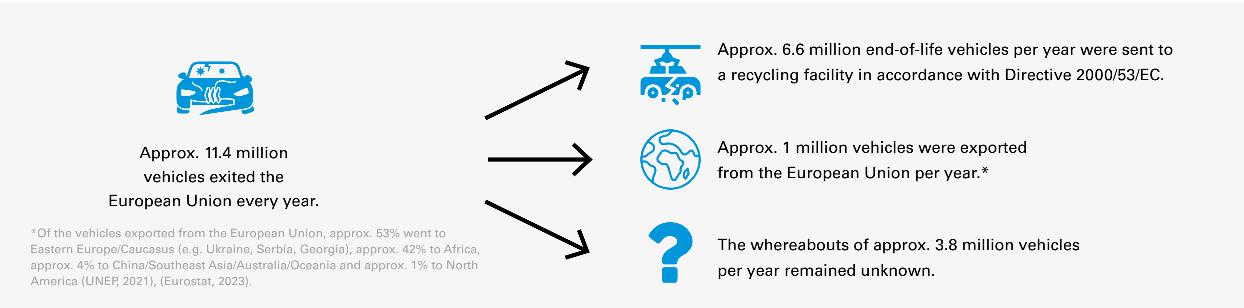
This section addresses the question of how to retain as many raw materials as possible in the European circular economy after the EOL of traction batteries. Until now, the main incentive for users to recycle an end-of-life vehicle was the exemption from recurring charges. Commercial operators were legally obliged to recycle end-of-life vehicles. However, the EU is pursuing the goal of reducing dependencies on raw materials, resulting in new incentive systems and regulations. Intelligent solutions that take into account the recovery of materials at the beginning of the life cycle, such as Design For Recycling (DFR), are necessary and enable more efficient cooperation across several stages of the value chain.

Innovative business models offer additional incentives for users to keep valuable materials in Europe. Selling the vehicle back to the manufacturer could be a promising model for keeping materials from traction batteries in the European cycle. High-priced electric vehicles are often fully owned by users, which makes battery rental models unattractive.

Whether business models with a deposit or customised ownership structures work depends on the interests of the stakeholders involved. Regulatory requirements could make battery exports more favourable from an economic and ecological perspective. A combination of different measures is necessary to ensure the participation of all stakeholders. The forthcoming EU regulation on batteries creates a suitable framework for this.

The fulfilment of recycling quotas and the state of health (SOH) of 80% have a strong bearing on the use of batteries for second-life applications. Factors such as different battery pack and module designs, missing battery data and the export of EOL vehicles out of the EU also influence the availability of EOFL batteries for second-life applications. The SOH of the battery, energy density, compatibility with peripheral devices and access to the battery management system (BMS) are crucial. A high proportion of EOL vehicles exit the EU, with fewer batteries available for second-life applications as a result.

In the past few years, an average of around 1 million vehicles have been exported to countries outside the European Union. Of these, the Eastern Europe / Caucasus region (e.g. Ukraine, Serbia, Georgia) received the most in 2020, totalling around 530,000 units. In addition to the targeted export of vehicles, there are still several million units whose end of life in Europe is not documented, therefore remaining unknown to the authorities (see Figure 6).



Source: (Fraunhofer IAO, own illustration, Data from (Öko-Institut, 2018), (Trinomics, 2020), (UBA, 2020), (UNEP, 2021), (Eurostat, 2023))

Figure 6: Fate of vehicles at the end of their life cycle in Europe on average in the period up to 2022 (Issue paper: Material cycle of traction batteries from Europe, p. 26)

By 2030, 2% to 5% and, by 2035, 10% to 31% of the demand for energy storage systems in the EU could be covered by EOFL batteries, depending on the scenarios selected. In addition to technical requirements, economic, ecological and political factors also play a role in the successful implementation of second-life applications.

The factors that influence the ramp-up of second-life applications are diverse and complex. Three scenarios illustrate different possibilities for second-life volumes (see Figure 7). According to realistic estimates, 5% to 15% of the total EOL volume can be exploited for second-life applications.

In the 5% scenario, the defined factors have a highly negative impact on the availability and utilisation of EOFL batteries for second-life applications. In the 15% scenario, these effects are less pronounced, meaning that more EOFL batteries can be used for second-life applications.

Theoretically, between 2% and 5% of the demand for energy storage systems in the EU could be met by 2030 with the appropriate EOFL batteries. By 2035, this figure could potentially increase to between 10% and 31%, depending on the scenario. In this regard, it is not only crucial to meet technical requirements; economic, ecological and political factors also play an important role in the successful implementation of second-life applications.

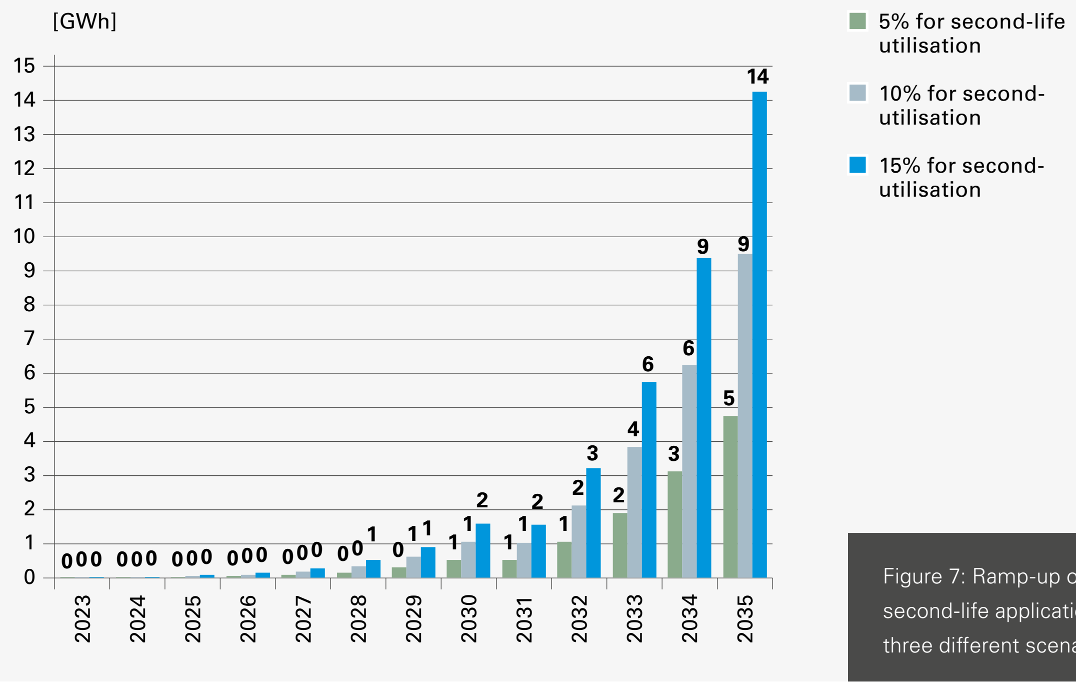


Figure 7: Ramp-up of second-life applications in three different scenarios

Source: Issue paper: Material cycle of traction batteries from Europe: The potential of second-life applications, p. 55

Recommendations for action for policy

The new EU Battery Regulation, which was published on 28 July 2023 and entered into force on 18 February 2024, governs the recycling and reuse of traction batteries. Article 56(2) introduces extended producer responsibility, which classifies operators who place repurposed or remanufactured batteries on the market for the first time as producers and makes them responsible for their disposal, but without specific targets for second-life applications.

Circular economy of traction batteries

To promote second-life batteries and the circular economy, traction batteries must remain in the European material cycle. A major obstacle is the export of non-roadworthy electric vehicles to non-EU countries. Subsidised scrapping programmes and strict export rules could help here. In addition, the End-of-Life Vehicles (ELV) Directive provides for facilitated vehicle dismantling, the use of recycled materials, a ban on exporting non-roadworthy vehicles and extended producer responsibility.

Recycling quotas and second-life applications

EU quotas for recycled material in new batteries stipulated for 2031 to 2035 are to be met by materials from European battery cell factories and used batteries. As the introduction of stricter quotas starting in 2036 will potentially compromise second-life business models, extended compliance options for second-life applications should be considered.

Battery passport

The battery passport introduced in 2027 is designed to promote the use of second-life applications by providing access to data from the battery's first life cycle and reducing the need for additional testing. Clear rules are required to make effective use of the battery passport. The EU should promote the circular economy of traction batteries and support relevant research initiatives and industrial projects.

Research initiatives and funding

At the EU and federal level, funded research projects on second-life applications are already underway. However, funding for battery research has been significantly reduced until 2028, and this could jeopardise new projects and innovative capacity, particularly in Baden-Württemberg. In order to strengthen the local value chain, industrial projects at the state level should be intensified and key stakeholders supported.

Circular Economy Initiative and EU working group

Initiatives such as the Circular Economy Initiative and the German Standardisation Roadmap Circular Economy aim to reuse or recycle products at the end of their life cycle. An EU working group made up of industry experts may develop strategies to close the material cycle.

Recommendations for action and harmonisation

Recommendations for action include clear definitions of the scope of the regulation, standardised calculations of carbon footprints and the introduction of a digital battery passport. National and transnational regulations should be harmonised to strengthen the material cycle of traction batteries. Research and development directed towards improving battery recycling should be continuously evaluated and adapted, particularly with regard to logistics, which accounts for a sizeable proportion of recycling costs.

Raw material availability and local conditions

In the interest of increasing the availability of raw materials, EU companies should receive support for exploration, mining and trading activities worldwide. A portion of the primary raw materials procured should be stored in order to mitigate supply bottlenecks. In addition, attractive local conditions should be created for the establishment or founding of facilities in Europe to assure competitiveness in the long term.

Recommendations for action for industry

The following measures and recommendations for action aim to fully harness the economic and ecological potential of second-life batteries and to promote a circular economy in the EU.

Promoting second-life applications

Second-life batteries offer a way to use valuable raw materials longer and reduce the ecological footprint. However, falling prices for first-life batteries and the recycling value are limiting factors when it comes to the economic attractiveness of second-life applications. To fully exploit the potential of these applications, the following measures are required:

1. Establish a closed-loop material cycle:

OEMs should partner with specialised companies for the repurposing and recycling of batteries. Such collaborations make it possible to put batteries to secondary use after their first life cycle in electric vehicles and then, at the end of their second life, to recover the valuable raw materials through recycling processes. This creates a sustainable, closed cycle that offers both ecological and economic advantages.

2. Product design for second-life applications:

Battery packs should be designed for a second use as early as the product development process. This includes both ensuring the reusability of connections, plugs and sensors and simplifying disassembly through the use of detachable connections. The standardisation of such components would further reduce the cost of repurposing.

3. Access to the battery management system:

OEMs should enable access to the BMS, including communication protocols, to allow the reutilisation of the original system. In order to preserve the proprietary know-how, this can be realised by way of contractually regulated partnerships.

4. Data transparency and battery passport:

It is crucial to improve data transparency at the battery level. The battery passport planned by the EU, which will be introduced in 2027, should include comprehensive information about the battery, including its condition and an estimate of its remaining lifetime. This data should be accessible to second-life operators in order to minimise any required additional testing.

5. Specialist qualification:

The qualification of specialists is essential along the entire value chain. This includes training and further education for the disassembly, repurposing and maintenance of battery systems Companies should invest in the further training of their employees and ensure that experienced employees are capable of passing on their knowledge. Training institutions, companies and research institutes should work together to promote the transfer of knowledge, as they did in the project QualiBattBW (Qualification Measures for Baden-Württemberg's Battery Ecosystem).

6. Use of obsolete batteries:

Current projects should be exploited to optimise processes for second-life use. OEMs could release obsolete batteries from their inventories and after-sales batteries for stationary applications in order to identify and reduce obstacles at an early stage.

7. Inclusion of lorry and bus batteries:

In addition to passenger car batteries, second-life applications should include batteries from lorries and buses, as these offer more up-to-date cell technologies and higher capacities due to their shorter periods of use.

Improvement of the circular economy

1. Design For Recycling:

As early as the product development phase, emphasis should be placed on the modularisation of traction batteries. Efforts should be made to harmonise material compositions. Cluster initiatives can promote the exchange and initiation of joint projects.

2. Innovative business models:

Business models such as loan and deposit systems, leasing, sharing, 'Battery-as-a-Service' and 'Material-as-a-Service' should be developed and negotiated in a transparent manner. Cluster initiatives may provide information and bring together potential stakeholders.

3. Collection, logistics and dismantling capacities:

Capacities should be established and expanded in line with foreseeable quantities. Moreover, investments in technologies and infrastructure, as well as comprehensive digitalisation, are required. Cluster initiatives such as the Cluster Electric Mobility South-West can promote understanding and cooperation.

4. Recycling technologies:

Recycling technologies should be further developed to achieve optimal recovery rates. Funded projects can identify and address current technologies and research needs.

5. Qualification and further education:

Institutions should start with the qualification and further education of employees in good time. Cluster initiatives can help identify the required qualifications and select the right measures.

6. Cooperation and exchange:

Cooperation across several stages of the value chain should be initiated in due consideration of competition law. Cluster initiatives can serve as a legally compliant format that fosters trust.

Improving the availability of raw materials and local conditions

1. Exploration, mining and trading activities:

In the interest of increasing the availability of raw materials, EU companies should receive support in exploration, mining and trading activities worldwide. Storing some of the primary raw materials procured may help to mitigate temporary supply bottlenecks.

2. Attractive local conditions:

The creation of attractive local conditions for the settlement or establishment of facilities in Europe should be promoted to be able to compete with established metal exchanges and commodity dealers in the long term.

These recommendations aim to maximise the economic and environmental benefits of second-life applications and to strengthen the recycling of traction batteries in the EU.

Outlook

The future of second-life applications and recycling of traction batteries offers promising potential for promoting sustainable and cycle-oriented economic models. Reusing batteries from electric vehicles extends their life cycle, reduces waste and conserves resources, while also offering economic advantages. The use of second-life batteries could play a key role in grid stabilisation, emergency power supply and fast charging stations, which will be further promoted by falling prices for new batteries and increasing experience.

Technological advances, particularly in battery management and the standardisation of interfaces and components, are crucial to the success of second-life applications. In this regard, the digital battery passport to be introduced by 2027 will play an important role by providing the necessary data for the repurposing and assessment of batteries. Political support in the form of legislation and funding programmes is also essential when it comes to creating the necessary framework conditions for the market and providing incentives for investment.

From an ecological perspective, the analysis of the carbon footprint of batteries is becoming an increasingly important tool. The 'mech + hydro' process and the 'pyro + mech + hydro' process are expected to exert an influence on emissions. Reducing the carbon footprint through recycling and repurposing will assume a more and more important role. It is expected that recycling and second-life applications hold the promise of significantly reducing the carbon footprint, which brings both environmental and economic benefits. One challenge that remains is the low volume of recyclable battery scrap available in the medium term, which is presently mainly derived from consumer electronics and will continue to do so in the next few years. Measures to ensure that traction batteries and the raw materials they contain remain in the European material cycle are therefore of particular importance. Intelligent solutions that enable the recovery of materials right at the beginning of the life cycle require a suitable regulatory and operational framework. The standardisation of certain components and the battery architecture may increase the efficiency and attractiveness of recycling.

In the long term, lithium recovery could become more economically viable if prices rise again. Deposit systems and innovative business models such as leasing and 'Battery-as-a-Service' could control the life cycle of vehicles and batteries, balance the availability of raw materials and shape the material cycle. Such models can ensure that batteries remain in the EU and prevent the illegal export of batteries with an insufficient recycling infrastructure.

The entry into force of the EU Regulation on Batteries and Waste Batteries in 2024 will set the course for decisive measures. The scaling of recycling processes and compliance with the recyclate percentages from 2027 and 2031, respectively, already require preparations to be made by the companies concerned. While initial structures for the collection and recycling of traction batteries are already emerging, it will take time to establish cross-border cooperation and to meet the demand among cell manufacturers at the beginning of the next decade.

It is essential to promote targeted, cross-border cooperation between companies and across several stages of the value chain. In order to achieve this, we need to harmonise rules and regulations and break down personal reservations. Successful initiatives could make a major contribution to keeping important materials in the European material cycle and to enhancing the competitiveness of industry.

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List of abbreviations

GWh	Gigawatt-hours
kWh	Kilowatt-hours
EU	European Union
OEM	Original Equipment Manufacturer
LKW	Lorry
ESS	Energy Storage System
EOFL	End of First Life
LFP	Lithium iron phosphate
NMC	Nickel-Manganese-Cobalt
Kg	Kilogramme
Wh	Watt-hours
EOL	End of Life
SOH	State of Health
BMS	Battery Management System
ELV	End-of-Life Vehicle

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Authors
P3 automotive GmbH
Niklas Bittniok, Jürgen Döring, Rachel Höss, Jannik Pfeuffer, Hermann Pyschny

Fraunhofer Institute for Industrial Engineering IAO
Daniel Borrmann, Dr. Florian Herrmann, Sebastian Stegmüller, Lukas Block, Lukas Keicher

Editing and coordination
e-mobil BW GmbH
Felicitas Behr

Layout/typesetting/illustrations
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e-mobil BW GmbH
State Agency for New Mobility Solutions and Automotive
Baden-Württemberg

Leuschnerstraße 45 I 70176 Stuttgart
Phone +49 711 892385-0 I Fax +49 711 892385-49
info@e-mobilbw.de