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Current Status and Perspectives of the Availability of Primary and Recycled Raw Materials for a European Traction Battery Industry

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Executive Summary

Over the next few years, companies in the automotive industry in Europe will need large-scale access to materials to produce traction batteries. However, on the continent the primary raw materials for the most important active materials are only available in very small quantities or not at all. Against this background, it is expedient to contribute to a reliable supply of companies in the automotive industry by recycling traction batteries at the end of their product life cycle in the vehicle. This publication examines the availability and potential of primary and recycled raw materials, their prerequisites, prices and costs as well as measures to promote recycling. Recommendations for action for politics and business to strengthen the European value chain and avoid dependencies are presented as a conclusion.

Keywords: Batteries, Materials for EVs, Supply and value Chain, Recycle & Re-use, Mining

1 Introduction

The electric drivetrain is gaining increasing support from industry, politics and society. For European companies, the limited supply of raw materials, particularly in the area of traction batteries, and the associated dependencies on global raw material supply chains are becoming increasingly apparent. This publication therefore examines whether the availability of raw materials for the European production of traction batteries is secured in the long term by primary raw materials and what influence recycled raw materials could have.

2 Demand for Raw Materials and Current Sources

Companies in the automotive industry in Europe will need large-scale access to materials to produce energy storage systems in the coming years. According to current forecasts, demand for traction batteries on the continent will grow by a factor of more than twelve from a total of just under 90 GWh in 2022 to over 1,200 GWh by the middle of the next decade [1], [2]. According to announcements, up to 1,500 GWh are to be produced in Europe in 2030 [3]. The currently most important active materials for battery cells to provide the capacities mentioned are lithium, nickel, manganese, cobalt and graphite. However, their availability for European companies is limited compared to the other materials [4], [5].

The quantity of active materials used in a battery cell depends on the respective publication. On average across all publications and material compositions, slightly more than 100 g lithium, just under 750 g nickel, 90 g manganese, 90 g cobalt and 900 g graphite were used per kWh in 2022. It is expected that these values will have fallen to an average of less than 90 g lithium, 600 g nickel, 70 g manganese, 70 g cobalt and 600 g graphite per kWh over the next ten years [6], [7], [8], [9], [10], [11]. The aforementioned data and their average development in the meantime are summarized in Tab. 1.

Table 1: Average material usage in traction batteries per kWh (Fraunhofer IAO, data from [6], [7], [8], [9], [10], [11])

Active material considered	Around 2022	Around 2025	Around 2030	Around 2035
Lithium	105 g	100 g	94 g	88 g
Nickel	745 g	710 g	658 g	574 g
Manganese	91 g	86 g	78 g	66 g
Cobalt	93 g	88 g	81 g	70 g
Graphite	900 g	800 g	700 g	570 g

One general reason for the decrease in the quantity of active materials required per kWh apparent in Tab. 1 is technological progress. In addition, the change in the shares of the various material compositions in all battery cells produced has an impact. The material compositions considered here include the current and foreseeable relevant variants of lithium-ion batteries with NCA cathode (active materials are lithium, nickel, cobalt, aluminum and oxide), NMC cathode (lithium, nickel, manganese, cobalt and oxide) and LFP cathode (lithium, iron and phosphate). Furthermore, cells with NMC cathode are specified according to the ratio of nickel, manganese and cobalt to each other. As a result, the spread of batteries with NMC811 cathode and, in the future, NMC9.5.5 cathode mean that the usage of manganese and cobalt is declining more sharply compared to nickel. Moreover, the usage of all of the aforementioned materials per kWh shrinks due to the use of LFP cathodes which are free of nickel, manganese and cobalt.

The demand for the active materials lithium, nickel, manganese, cobalt and graphite in Europe to provide an energy capacity of about 1,200 GWh up to 2035 with the material usage per kWh mentioned in Tab. 1 is shown in Fig. 1. In the middle of the next decade, about 107 kt of lithium are required and, thus, more than ten times the quantity of 2022. In the case of nickel, growth is only slightly lower with a factor of around 9.75 but starts at a higher level and reaches 696 kt. Manganese and cobalt grow with a factor of around 9.4 and reach 80 kt and 85 kt respectively. Graphite also starts at a comparatively high level in 2022, reaching 691 kt even with a growth factor of just 8.

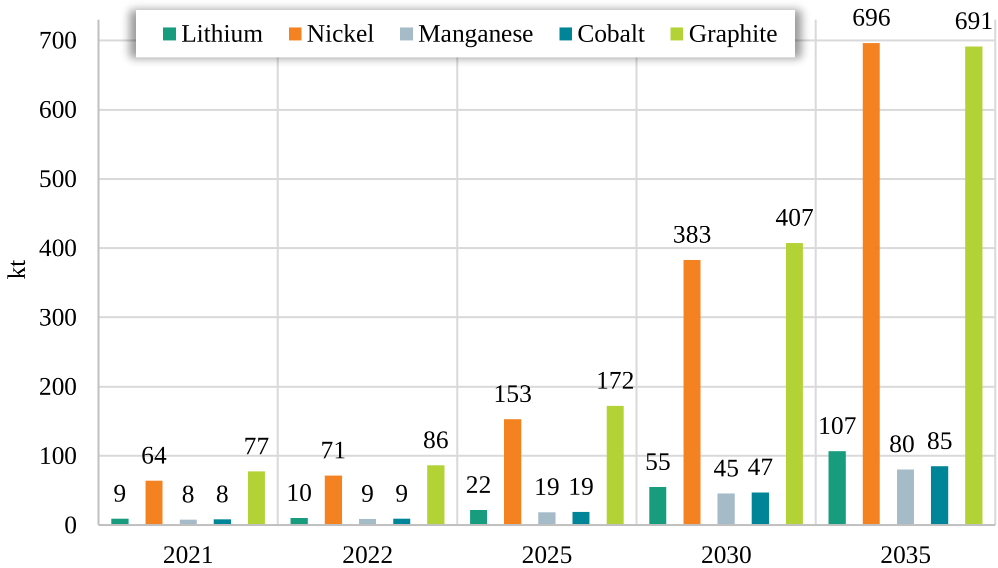


Figure 1: Demand for active materials in Europe to provide an energy capacity of about 1,200 GWh up to 2035 with the material usage per kWh mentioned in Tab. 1 (Fraunhofer IAO, own representation)

In 2021, around 100,000 t of lithium, around 2.7 Mt of nickel, around 20 Mt of manganese, around 170,000 t of cobalt and around 1 Mt of graphite were produced worldwide for processing [12]. The shares of the various regions of the world in the quantities produced varied greatly, also depending on the raw material, and in the past were divided roughly as shown in Fig. 2. The emergence of this division was favored, among other things, by advantageous framework conditions in the respective countries, such as particularly extensive local raw material deposits combined with the political and economic will to produce. Fig. 2 illustrates that of the raw materials for the most important active materials lithium is mainly extracted on the South American continent and in Australia, nickel in Southeast Asia, manganese and cobalt on the African continent and graphite for further processing in China.

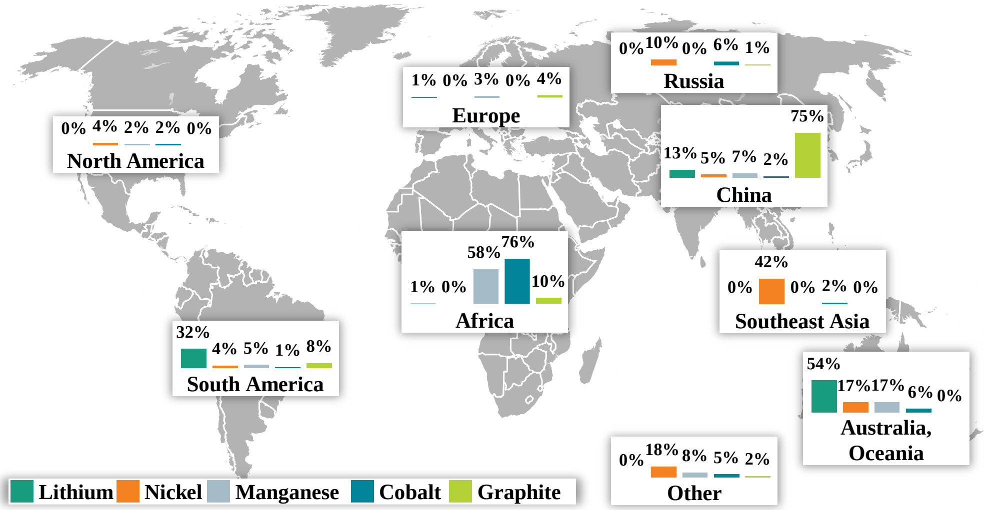


Figure 2: Contributions to the amount available worldwide by 2022 (Fraunhofer IAO, own representation, data from [12], [13])

For traction batteries alone, the global demand for raw materials for active materials will soon be many times greater than that shown for Europe in Fig. 1. This makes it clear that (except for manganese and graphite) the total demand will far exceed the above-mentioned supply of materials produced in 2021 in just a few years. Accordingly, a significant increase in production capacities must take place quickly and the mining of newly discovered deposits must begin. Thereby, the procurement of the materials required to meet demand must neither impair the competitiveness of companies nor lead to a dependency on a few suppliers based outside the European Union. However, Europe can only act on its own initiative to a limited extent, as most of the primary raw materials required for active materials are only available on the continent to a very limited extent or not at all. Only lithium is still available to such an extent over and above the quantity already mined today (most recently 900 t in Portugal) that its inclusion would lead to a significant increase in the proportion stated for Europe in Fig. 2 [12]. From 2025, 24,000 t of lithium hydroxide are to be extracted annually in the Upper Rhine Graben [14]. With this and other mining projects, for example in the Czech Republic, Serbia and Portugal, around 20,000 t of lithium are to be produced on the European continent by 2030 [15], [16]. Against this background, it is expedient to contribute to the reliable supply of companies in the automotive industry by recycling traction batteries at the end of their product life cycle in the vehicle.

In addition to Europe, measures to increase the production of lithium have already been taken on other continents. This mainly applies to the existing mining countries. For this reason, the production volume forecast for 2030, which will then have increased significantly to around 220,000 to 400,000 t, will be distributed between the various regions of the world in a similar way to that shown in Fig. 2. The same applies to cobalt, of which 240,000 to 340,000 t are expected to be produced in 2030, as well as to manganese and graphite, the availability of which is not critical worldwide. However, the availability of nickel is critical and the war in Ukraine could exacerbate the shortage of nickel on the global market, as Russia will have contributed 10 percent of the nickel available worldwide by 2022 (see Fig. 2). In any case, as a result of measures to increase production, particularly in Indonesia, Southeast Asia's share of the 3.3 to 4.2 Mt forecast to be produced in 2030 will be significantly higher than shown in Fig. 2 [15], [16].

Despite very small or non-existent local deposits, companies from Europe can obtain primary raw materials by purchasing them via exchanges (e.g., London Metal Exchange LME) or commodity traders. However, in the vast majority of cases, these are based in Europe, but not in the European Union. In addition, long-term supply contracts can be concluded directly with mining companies and refineries, which is currently the most common way of securing global access to raw materials. In order to diversify, different suppliers from different regions of the world should be selected. An investment in a current raw materials operation or a raw materials project under development is also an option. However, the development of a mine alone takes around a decade from discovery to production and ties up considerable investment over several decades. There are currently only a few large, globally active exploration, mining and trading companies based in Europe. Its global share of mining activities has fallen from 40 to 3 percent over the last hundred years. As soon as primary raw materials have been successfully procured, some of them can be stored to overcome temporary supply bottlenecks. After their use in a product, recycling is therefore very useful at the end of its life cycle [17], [18].

3 Potential of the Regulations in Europe to Promote Recycling

By reusing active materials through recycling at the end of the product life cycle, it is possible to reduce the need for primary raw materials for traction batteries. For this to succeed, however, several prerequisites must first be created. For example, the industry must be encouraged to use recycled materials, which also promotes their production. Against this background, in the European Union, the regulation concerning batteries and waste batteries will require newly manufactured batteries to contain 6, 6 or 16 percent recycled lithium, nickel or cobalt respectively by 2031. The values increase to 12, 15 or 26 percent respectively by 2036 [19]. Furthermore, process efficiency requirements have recently been introduced in the European Union concerning the active materials lithium, nickel and cobalt. Of them, by 2027, 50, 90 and 90 percent respectively must be recovered in a quality comparable to that of primary raw materials. By 2031, the material yield to be achieved will increase to 80, 95 and 95 percent respectively [19].

The efficiency mentioned above refers only to the recycling process and therefore to nothing more than the dismantling, mechanical pre-treatment and metallurgical recycling of batteries. Thereby, it is important that different material compositions can be processed simultaneously in the process, for example batteries with NMC111 to NMC811 cathode as well as with LFP cathode. Otherwise, a costly pre-sorting process would have to be set up before recycling, which would lead to several parallel metallurgical recycling processes with correspondingly lower throughputs and higher fixed costs [20].

With regard to nickel and cobalt, it should be noted that the recovery efficiency of both materials in industrially established pyrometallurgical and hydrometallurgical recycling processes is already between 90 and 95 percent. In the case of lithium, however, the metallurgical process is very complex and therefore not yet economically viable. This is why the topic of recycling lithium is only now attracting increasing attention. Manganese and graphite have also not been recycled on an industrial scale in the past for economic reasons. Though, in view of the foreseeable market development, it seems likely that this will at least begin in the future. Before this can happen, however, processes for recycling manganese and graphite must first be developed, which, according to industry experts, will take several years [21].

The quantity of recycled materials of comparable quality to primary raw materials, also known as recyclates, available in the coming years depends not only on the aforementioned efficiency in the recycling process and the recycling capacities in operation, but also to a large extent on the so-called return quantities in which batteries are sent for recycling. The return quantities come from consumer electronics and stationary energy storage systems, among other things. In the medium term, production waste from the manufacture of battery cells, modules and systems accounts for two thirds to three quarters of the return quantities. The reason for this is that the scrap rate for the commissioning of facilities for the production of battery cells is 10 to 30 percent [22]. Accordingly, production waste accounts for around 70 GWh of the production capacity announced for Europe in 2025 (see Chap. 2).

This value will grow to around 120 GWh by 2030 as a result of the sharp increase in production capacity over time and a simultaneous fall in the scrap rate to between 5 and 15 percent. By then, the proportion of production waste in the return quantities will have fallen to around 50 percent. The other 50 percent will continue to come from consumer electronics, stationary energy storage systems and, from the next decade onwards, to a significant extent from traction batteries at the end of their life cycle. Their share of return quantities will then grow rapidly to around 70 percent in 2035 [8], [22], [23], [24]. There will still be a large amount of production waste by then, but its quantity will grow at an ever slower rate due to increasing experience with the production of battery cells, despite the continued increase in production capacity.

According to the above statements, comparatively little recyclate can be recovered by the end of the decade. Until a significant amount of recyclate is available, vehicles with electric powertrains or their traction batteries must first reach the end of their life cycle in large numbers. Publications estimate a period of around ten years for this [8], [21], [25]. The average age of existing passenger cars in Germany is also around ten years [26]. In the European Union, the average age of existing passenger cars is just under twelve years [27]. Analyses of the recyclate volumes that can be achieved on this basis have to take into account shares for losses during collection, through exports or through further use of the batteries, for example as stationary energy storage ("second life"). [8], [16], [21], [24].

With the amount of material recovered on the basis of the assumptions and calculations mentioned above, by the end of the decade the demand for the production capacities announced in Europe for lithium can be covered by around 7 to 10 percent, for nickel by around 8 to 12 percent, for manganese by around 3 to 5 percent, for cobalt by around 13 to 19 percent and for graphite by around 1 to 2 percent using recycled material. By 2035, the shares will increase by an average of five percentage points in each case, meaning that the demand for lithium can be covered by around 11 to 16 percent, for nickel by around 12 to 18 percent, for manganese by around 7 to 11 percent, for cobalt by around 17 to 25 percent and for graphite by around 5 to 8 percent using recycled materials. The contribution of recycled raw materials to securing the supply is therefore very large. The values are summarized in Fig. 3.

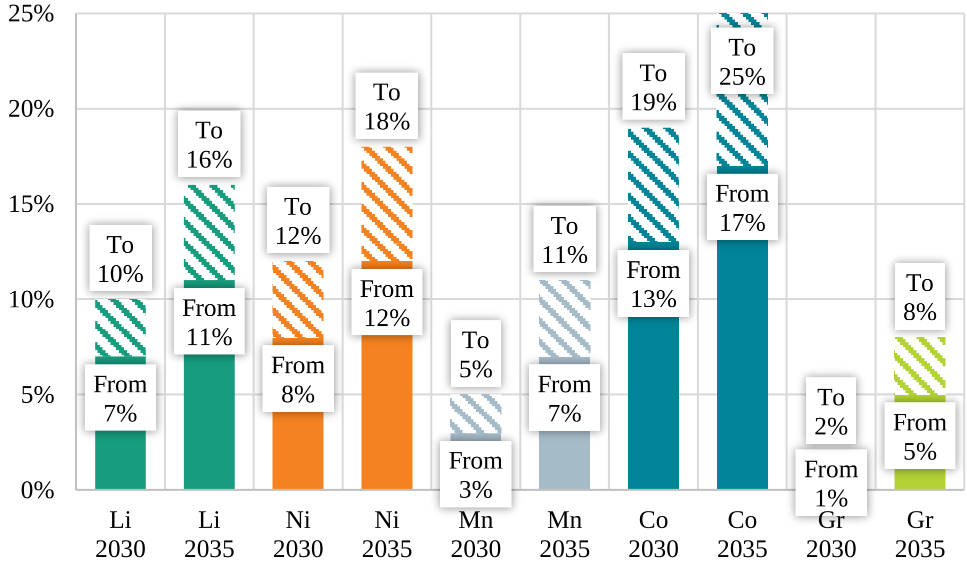


Figure 3: Share of demand for the production capacities announced in Europe that can be covered by recycled materials (Fraunhofer IAO, own representation)

In addition to the circumstances described above, which affect the utilization of important materials for the benefit of Europe, an important role is played by the fact that once raw materials are available on the continent, they should remain there wherever possible. Directive 2000/53/EC, for example, which regulates the handling of vehicles at the end of their life cycle in Europe, makes a significant contribution to this [28]. On their basis, in the past, of the 11.4 million vehicles that left the European Union stock each year an average of around 6.6 million vehicles were sent to an authorized recycling facility. On average, around 1 million vehicles that were still in working order were exported to a country outside the European Union. The whereabouts of around 3.8 million vehicles were unknown [29]. These may well have been transported to another European country or already recycled in Europe without their whereabouts being correctly reported to the relevant authorities. However, it is also conceivable that vehicles that are no longer functional could be illegally exported to a country outside the European Union. The latter must be prevented in the future, particularly with regard to the traction battery of battery electric vehicles, so that active materials are available for recycling and are not lost. The promotion of the collection and issue of a certificate of destruction when an end-of-life vehicle is sent to a recycling facility is an example in this context [30].

4 Economic Aspects of Recycling Traction Batteries

A prerequisite for high-quality and economically attractive recycled materials from traction batteries is that the battery cells can be efficiently and automatically dismantled and removed from the energy storage units. The fact that the traction batteries of different vehicles are constructed differently still stands in the way of this in the long term. For this reason, it has not yet been possible to automate the dismantling process. In order to be able to automate disassembly, it is necessary for the traction batteries of different vehicles to be more similar to each other and more accessible compared to today and to be provided with more easily detachable connections [31]. Following dismantling, further processes must be used to recover materials from traction batteries.

Pyro- and hydrometallurgy are the two most promising processes for recycling traction batteries today. They are still preferable to “direct recycling”, at least in the medium term. Depending on the objective, they are combined with each other as required and supplemented by pyrolytic or mechanical pre-treatment or both. Thereby, from the active materials in batteries, lithium, nickel and cobalt are currently recovered separately. In the further considerations, they are assumed to be available as recyclates and thus in comparable quality to primary raw materials. Recycling companies are already achieving this today [20], [32]. Manganese and graphite are currently not recovered on an industrial scale for economic reasons. Nevertheless, potential costs are considered for the sake of completeness.

Various parameters must be taken into account when determining representative values for the costs per process, on the basis of which information on the price of recovered materials can subsequently be provided. These include expenditure for

- operation, maintenance and servicing of systems,
- operating materials, such as electricity, water and natural gas,
- processed materials, such as lye and other auxiliary materials.

In addition, employees and rents, insurance fees and taxes have to be paid. Using values from 2019 for the aforementioned variables, the cost of recycling traction batteries in Europe using pyrometallurgy was calculated at around 19 to 20 €/kWh and around 13 to 14 €/kWh using hydrometallurgy [33], [34]. Due to the increase in the price of electricity and the consumer price index since then, the cost of recycling traction batteries in Europe using pyrometallurgy is estimated at 24 €/kWh and hydrometallurgy at 17 €/kWh in 2022. It is then assumed that costs will no longer rise to the same extent as recently and that, in view of the increasing supply of traction batteries at the end of their life cycle (see Chap. 3), comparable productivity increases of around 2 percent per year will also be achieved by recycling companies in the automotive industry. The subsequent and current costs for recycling traction batteries on this basis are shown in Fig. 4.

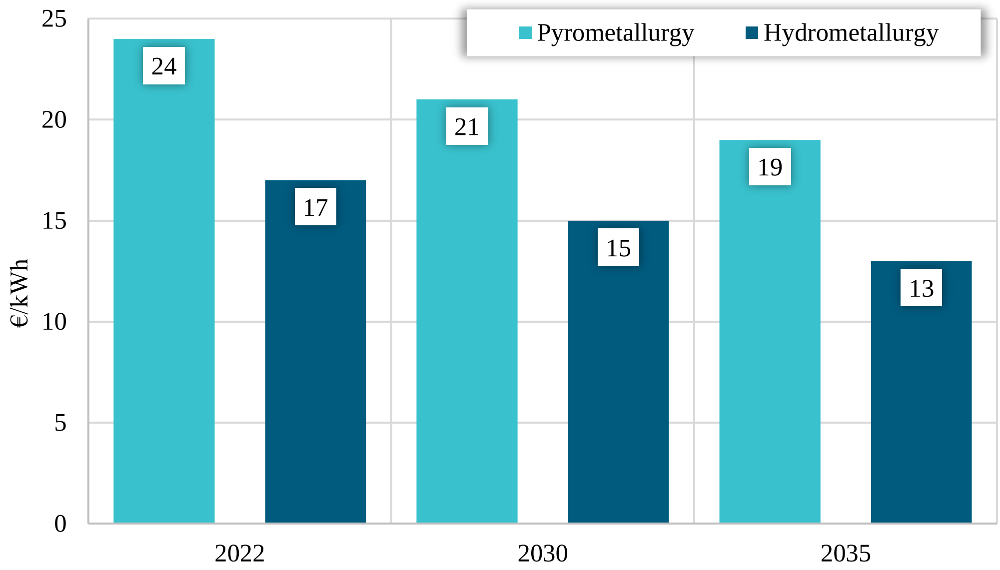
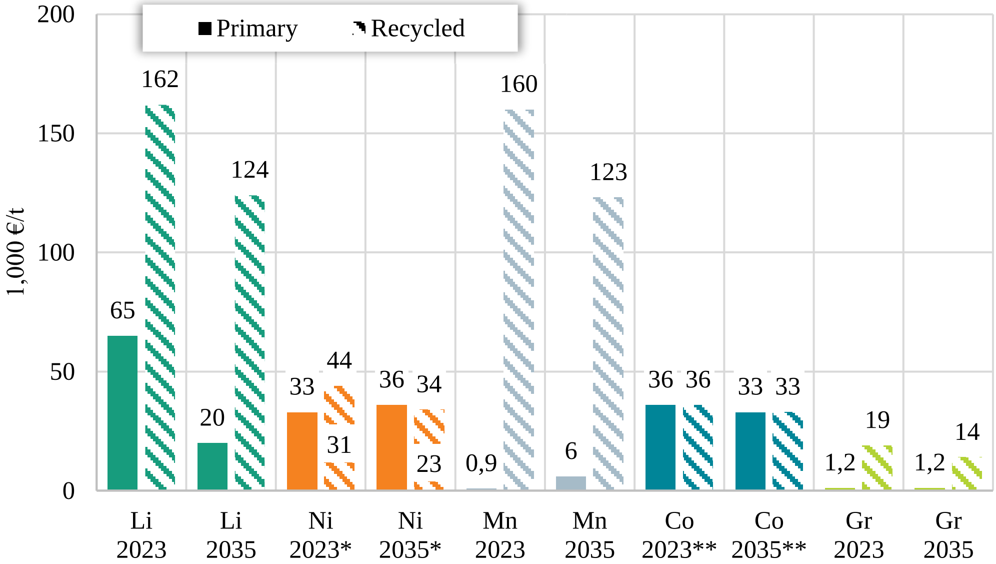


Figure 4: Assumed current and forecast costs for recycling traction batteries in relation to their energy capacity using different processes (Fraunhofer IAO, own representation, data from [33], [34])

In pyrometallurgy, high costs are incurred for operating materials such as electricity and natural gas and in hydrometallurgy for caustic and other processed materials. In both processes, the majority of costs are incurred for the operation, maintenance and repair of plants. Compared to other continents, labor costs in Europe are particularly high. In addition to energy and personnel, logistics also have a major impact [35]. Traction batteries at the end of their life cycle have to be collected and transported for further processing. Thereby, high fire protection requirements must be complied with. As a result, the recycling costs listed in Fig. 4 increase by a further 10 to 30 percent due to transportation. Accordingly, it makes sense to set up a close-knit network of collection points and recycling plants [34], [36].

An assessment of the costs of recovering materials from batteries in a suitable recycling process at present and in the middle of the next decade can be made by comparing them with the respective prices of the primary raw materials for the active materials lithium, nickel, manganese, cobalt and graphite. The prices are taken from well-known trading platforms [37], [38], [39]. Forecasts for their development up to the year 2035 are prepared in view of the expected development of supply and demand. The values obtained are summarized and compared in Fig. 5.



* The costs of recovering the recycled material using hydrometallurgy (lower value) and pyrometallurgy (upper value) are shown [33], [34].

** Costs comparable to the primary raw material are assumed, as recycling has long been established.

Figure 5: Price of the primary raw material and cost of the recycled materials in 2023 and forecast for 2035 (Fraunhofer IAO, own representation)

Recycling lithium is associated with such high costs that the recyclate is currently significantly more expensive than the primary raw material. This will not change in the future. Herewith, the European Union's goals of reducing dependencies are the main driving force behind the recovery of the material from traction batteries. In the case of manganese and graphite, not only is the technical implementation for recovery not yet fully developed, but the costs would also exceed the price of the primary raw materials many times over. In the case of graphite, this creates a dependency on China in particular. Despite the high costs, recycling can make a valuable contribution to reducing or eliminating this dependency, even if the reason for this must first be created by means of guidelines.

5 Measures for a Secure Supply of Raw Materials

Until recently, the main incentive for users to send an end-of-life vehicle for recycling was the exemption from recurring fees through deregistration. On the commercial side, companies dealing with end-of-life vehicles were and are obliged to comply with legal requirements [28], [40]. These respective motivations are changing in view of the European Union's efforts to reduce existing dependencies on raw materials. Against this backdrop, new incentive systems and regulations are becoming increasingly attractive, such as those that promote the consideration of the subsequent recovery of materials at the beginning of the life cycle (so-called “design for recycling”). The use of water-based binder systems for electrode materials is an example of the pursuit of appropriate properties for traction batteries already during the development of the battery design. This can reduce the use of toxic solvents during recycling [41]. Promising design for recycling requires specific information flows and measurement parameters that allow the design to be assessed with regard to the recycling process that takes place later in the life cycle [42]. In line with the idea of design for recycling, the industry should coordinate across companies as far as possible and focus on the modularization of traction batteries as early as the product development phase. In the future, a reduction in the number of material composition variants could help to further improve the recyclability of traction batteries.

Furthermore, innovative business models offer users attractive incentives to actively participate in keeping valuable materials in Europe. In the medium term, selling your own vehicle back to its manufacturer appears to be the most promising business model for keeping as many materials from traction batteries as possible in the European recycling loop. This is because the majority of cars with an electric powertrain currently available in Europe are very expensive and experience shows that users want to own high-priced products outright. For them, rental payments or similar costs for a component of the product they have purchased, which in this case would be the traction battery, are not attractive.

In the future, when more affordable vehicles are available in larger numbers in Europe and digitalization has further entered people's everyday lives, “Battery as a Service” seems very promising, which can be deduced from the success of the “... as a Service” solution in other industries such as logistics. Whether the business models are varied with collateral to be deposited (e.g., deposit) or by adjusting the ownership structure depends, among other things, largely on the interest of the stakeholders involved. These measures can be flanked by regulatory requirements, which can bring not only economic but also global ecological benefits, particularly in the area of battery exports. In order to maximize the retention of raw materials in Europe, a coherent combination of individual measures should be sought in order to achieve the participation of both economic players and customers.

In Germany, for example, the Circular Economy Initiative [43] and the Circular Economy Standardization Roadmap published in January 2023 [44] have already implemented several measures aimed at avoiding waste and reusing or recycling products at the end of their life cycle. Both of the aforementioned activities also focused to a large extent on traction batteries. On this basis, it now makes sense to initiate a working group at European Commission level with industry experts from politics, industry and science. Based on the strategies that have so far only been developed for Germany, for example, further proposals can be developed to close the recycling loop for energy storage systems from vehicles with electric powertrains on the continent.

European companies spread across the entire product life cycle face numerous challenges. Manufacturers have to select suppliers for the raw materials they need, most of whom are still based in countries outside the European Union, and often have no way of reacting to unfavorable economic, environmental or political developments. Companies that have previously recycled conventional cars with their known components must now convert their facilities for the recycling of vehicles with electric powertrains and retrain their employees to handle traction batteries. In addition, cooperation between companies should also be initiated across several stages of the value chain, whereby relevant information and data should also be exchanged. Cluster initiatives offer a suitable platform here. On the one hand, they ensure compliance with all regulations, such as antitrust principles. On the other hand, they offer players from research and industry a neutral platform and promote the exchange and initiation of joint research and development projects, which in turn form the basis for future value creation.

6 Conclusion and Outlook

A major challenge in the near future will be to be able to reliably produce the traction battery, one of the most important components of the automotive industry in the near future, to meet demand and at a competitive price. To date, the raw materials required for this have generally been acquired mainly on a cost-driven basis. This has led to limited security of supply and dependence on countries outside the European Union. Recycling traction batteries can make a significant contribution to improving this situation. In order for this potential to be exploited, the active involvement of politicians and industry is required on the basis of the recommendations for action formulated in this publication.

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References

[1] *Adamas Intelligence*, https://www.adamasintel.com/record-battery-capacity-deployed-in-2021/, accessed on 2024-02-14

[2] V. Beermann et al., *Heavy Commercial Vehicles Boost Future Battery Demand*, Berlin, VDI/VDE Innovation + Technik GmbH, 2022

[3] *Fraunhofer ISI*, https://www.isi.fraunhofer.de/de/presse/2022/presseinfo-17-Batteriezellfertigung-Verzehnfachung-2030.html, accessed on 2024-02-14

[4] European Commission, *Study on the EU's list of Critical Raw Materials – Final Report*, ISBN 978-92-76-21049-8, Luxembourg, Publications Office of the European Union, 2020

[5] European Commission, *Critical Raw Materials for Strategic Technologies and Sectors in the EU – A Foresight Study*, ISBN 978-92-76-15336-8, Luxembourg, Publications Office of the European Union, 2020

[6] E. A. Olivetti et al., *Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals*, Joule, ISSN 2542-4351, Volume 1, Issue 2, October 11, 2017, 229–243

[7] L. Mathieu et al., *From dirty oil to clean batteries*, Brussels, Transport & Environment, 2021

[8] *Nationale Plattform Zukunft der Mobilität (NPM)*, https://www.plattform-zukunft-mobilitaet.de/wp-content/uploads/2021/10/NPM_AG4_Batterierecycling.pdf, accessed on 2024-02-14

[9] M. Hackmann, *Europe's position in a contested battery (raw) material market – challenges and potential approaches*, Electrive.net LIVE, 2022-09-14

[10] *Strategy&*, https://www.strategyand.pwc.com/de/en/industries/energy-utilities/gigafactories-and-raw-materials.html, accessed on 2024-02-14

[11] F. Maisel et al., *A forecast on future raw material demand and recycling potential of lithium-ion batteries in electric vehicles, Resources, Conservation and Recycling*, ISSN 0921-3449, 192(2023), 106920

[12] U.S. Geological Survey, *Mineral commodity summaries 2022*, ISBN 978-1-4113-4434-1, Reston, VA, U.S. Department of the Interior, 2022

[13] H. Heimes et al., *Battery Atlas 2022*, ISBN 78-3-947920-18-1, Aachen, RWTH Aachen University, 2022

[14] *electrive*, https://www.electrive.net/2023/02/13/vulcan-energy-will-mehr-lithium-im-oberrheingraben-foerdern/, accessed on 2024-02-14

[15] M. Schmidt, *Rohstoffrisikobewertung – Lithium 2030*, Deutsche Rohstoffagentur (DERA), 2022-06-23

[16] L. Gregoir et al., *Metals for Clean Energy: Pathways to solving Europe's raw materials challenge*, Leuven, KU Leuven, 2022

[17] C. Hilgers et al., *Ist die deutsche Ressourcenstrategie resilient?*, Karlsruhe, THINKTANK Industrielle Ressourcenstrategien, 2021

[18] K. Steinmüller, *Resiliente Rohstoffversorgung und verantwortliche Lieferketten für die Industrie*, THINKTANK Industrielle Ressourcenstrategien, 2021

[19] *European Union*, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32023R1542, accessed on 2024-02-14

[20] C. Hagelüken, *Ein zweites Leben nicht für jede - Das Recycling von Lithium-Ionen-Batterien stellt hohe Anforderungen an die industrielle Praxis*, ENTSORGA-Magazin, 02/2021 (40. Jg.), 27-31

[21] C. Kresse, *Lithium-Ionen-Batterierecycling in Deutschland und Europa*, Berlin, Deutsche Rohstoffagentur (DERA), 2022

[22] *Arthur D. Little*, https://www.adlittle.com/en/insights/viewpoints/european-battery-recycling-emerging-cross-industry-convergence, accessed on 2024-02-14

[23] *Benchmark Source*, https://source.benchmarkminerals.com/article/battery-production-scrap-to-be-main-source-of-recyclable-material-this-decade, accessed on 2024-02-14

[24] *Transport and Environment*, https://www.transportenvironment.org/discover/a-european-response-to-us-inflation-reduction-act/, accessed on 2024-02-14

[25] *EURACTIV*, https://www.euractiv.com/section/circular-economy/news/critical-minerals-recycling-not-a-silver-bullet-industry-says/, accessed on 2024-02-14

[26] *KBA*, https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Fahrzeugalter/fahrzeugalter_node.html, accessed on 2024-02-14

[27] *ACEA*, https://www.acea.auto/figure/average-age-of-eu-vehicle-fleet-by-country/, accessed on 2024-02-14

[28] *European Union*, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32000L0053, accessed on 2024-02-14

[29] *United Nations Environment Programme*, https://www.unep.org/resources/report/used-vehicles-and-environment-progress-and-updates-2021, accessed on 2024-02-14

[30] E. Lecointre et al., *Final report: Global Overview of Incentive Schemes aiming to bring ELVs through Authorised Processing Channels*, Angers, Agence de la transition écologique, 2019

[31] S. Michaelis et al., *Recycling of Lithium-Ion Batteries*, Frankfurt, PEM RWTH Aachen University, 2021

[32] O. Velázquez-Martínez et al., *A Critical Review of Lithium-Ion Battery Recycling Processes from a Circular Economy Perspective*, Batteries, ISSN 2313-0105, Volume 5, Issue 4, December 2019

[33] N. Vekić, *Lithium-Ionen-Batterien für die Elektromobilität – Status, Zukunftsperspektiven, Recycling*, Karlsruhe, THINKTANK Industrielle Ressourcenstrategien, 2020

[34] L. Lander et al., *Financial viability of electric vehicle lithium-ion battery recycling*, iScience 24, ISSN 2589-0042, 102787, July 23, 2021

[35] Q. Dai, *EverBatt: A Closed-loop Battery Recycling Cost and Environmental Impacts Model*, Alexandria, U.S. Department of Energy, 2019

[36] *Berylls*, https://www.berylls.com/battery-recycling-circular-economy-on-the-example-of-e-mobility/, accessed on 2024-02-14

[37] *Shanghai Metals Market*, https://www.metal.com/price, accessed on 2024-02-14

[38] *TRADING ECONOMICS*, https://tradingeconomics.com/commodities, accessed on 2024-02-14

[39] *Fastmarkets*, https://www.fastmarkets.com/our-products/price-data/metals-and-mining-prices, accessed on 2024-02-14

[40] C. Kitazume et al., *Effectively tackling the issue of millions of vehicles with unknown whereabouts*, Dessau-Roßlau, Umweltbundesamt, 2020

[41] J. Neumann et al., *Recycling of Lithium-Ion Batteries—Current State of the Art, Circular Economy, and Next Generation Recycling*, Advanced Energy Materials, ISSN 1614-6840, Volume12, Issue17, May 5, 2022

[42] *Fraunhofer IAO*, https://www.iao.fraunhofer.de/de/presse-und-medien/aktuelles/lebenszyklusorientierte-entwicklung-von-fahrzeug-komponenten.html, accessed on 2024-02-14

[43] A. Kwade et al., Resource-Efficient Battery Life Cycles – Driving Electric Mobility with the Circular Economy, Munich/London, acatech/SYSTEMIQ, 2020

[44] *DIN e. V.*, https://www.din.de/en/innovation-and-research/circular-economy/standardization-roadmap-circular-economy, accessed on 2024-02-14

Presenter Biography

Daniel Borrmann is a mechanical engineer and has been a research associate at the Fraunhofer IAO in Stuttgart since 2010. His work includes the analysis and evaluation of new technologies, especially in the field of vehicle propulsion, as well as the modeling and evaluation of technical and social science contexts. In previous projects, he investigated the effects of the spread of electric vehicles on employees in production and in research and development at car manufacturers and suppliers as well as in the vehicle trade and repair business. Currently, he is working on the qualification of employees for the production of cells for traction batteries.