MARKET INTELLIGENCE REPORT

COBRA

KEY TECHNICAL, POLICY AND MARKET DEVELOPMENTS INFLUENCING THE ELECTRIC VEHICLE BATTERY LANDSCAPE

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RAW MATERIAL SOURCING

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INTRODUCTION

Li-ion batteries are the essential technology to facilitate the green energy transition in the mobility sector. While the EV stock in 2018 amounted to 5.1 million vehicles, forecasts have estimated a growth up to EV stock of 130-250 million vehicles globally by 2030 **[1]**. This sparks a demand for Li-ion battery materials. Figure 1 shows the global lithium demand forecast per end-use category until 2025, illustrating the large impact of battery-powered electric vehicles (EVs).

With respect to Europe, an analysis by Vulcan **[2]** shows that 1000GWh worth of overall Li-ion battery manufacturing capacity is planned by 2030. For lithium hydroxide only, this would drive up European lithium demand up to >1,000kt, more than twice the entire global market today **[3]**.

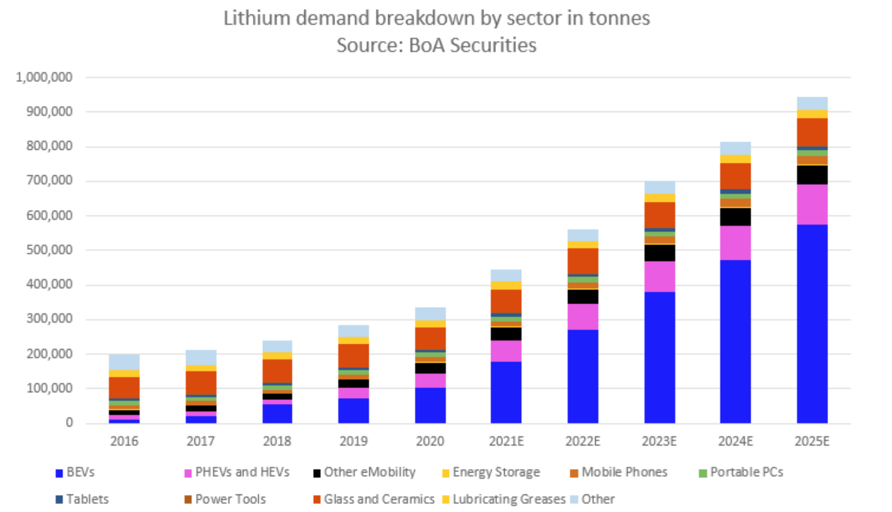

Figure 1. Global lithium demand forecast per end-use category (Source: BoA Securities)

The growing demand leads to increased pressure on the sourcing of the (critical) raw materials needed to produce the current Li-ion batteries. When looking at battery materials, the most critical are lithium and cobalt, followed by nickel, graphite, and manganese **[8]**. This report looks at the sourcing of these materials, the challenges encountered and potential solutions that will reduce supply risks and ensure a more stable and sustainable supply chain needed to source and produce Li-ion batteries.

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OVERVIEW

RAW MATERIAL SOURCING

When looking at raw material sourcing, we focus on the first steps in the life cycle of the battery. This involves the process from natural resource to battery-grade mineral ready for further anode/cathode manufacturing. Within this process, three steps are considered: mining, refining and processing (see figure 2). Mining includes the process from natural resource to minerals, followed by refining, which includes ore processing to produce concentrates. Under the processing stage, metal and chemical refineries produce battery-grade minerals from the concentrates [4].

Figure 2. Focus on raw material sourcing stages in battery lifetime

LI-ION BATTERY MATERIALS

In current global EV Li-ion battery production, two battery types occur the most, named after their cathode materials: the Lithium Iron Phosphate (LFP) and Lithium Nickel Manganese Cobalt Oxide (NMC) battery. It is expected that the long-term winner of the current battery market battle will be the NMC battery [5]. This is mainly due to its higher energy density (energy/kilogram) and more reliable production quality [6]. However, it comes at a higher price due to the inclusion of the costly minerals nickel and cobalt. To illustrate, the most popular NMC battery pack (NMC532) contains around 8 kg of lithium, 35 kg of nickel, 20 kg of manganese and 14 kg of cobalt [7].

An NMC battery includes a variety of different materials out of which the following are considered critical raw materials [8]: lithium, nickel, cobalt, manganese, graphite. The latter is used in the anode, while the rest are used in the cathode. Different versions of NMC batteries are used within the EV market, varying in their composition of cathode materials to achieve certain battery performances (e.g., price and energy density). So far, the trend within the EV market has been focused on achieving higher energy density, which has increased pressure on nickel production [9]. Interestingly, Tesla has recently announced their switch to LFP batteries for their low-cost models, to reduce their dependency on nickel and cobalt supply [10]. Their consumer strategy offers two variants of the Tesla Model 3: a low-cost standard range model using an LFP battery and a higher-cost high range model using an NCM battery. Two other ambitious EV carmakers, Volkswagen and Ford, have also announced the same strategy for their low-end models [11].

All of the abovementioned materials are included in the Critical Raw Materials (CRMs) index from the European Commission [12]. Every 3 years since 2014, the European Commission has published a list of CRMs. The list is based on two parameters: supply risk and economic importance. Supply risk is calculated by four factors: supply concentration, governance, export policy and recycling percentage of the raw material. Economic importance is calculated by three factors: the share of use of the raw material in a specified industry, the size of the respective industry and the substitution possibilities for the raw material.

Facilitating the shift towards large-scale electrification of mobility is vital to achieving our climate targets. EVs are the most promising solution, which means batteries are expected to become more and more important. Thus, it is important to ensure an increasing supply of raw battery materials. At the same time, stability and sustainability should be ensured by reducing supply chain risk and negative socio-economic impacts.

MATERIAL ORIGINS

Looking at the origin of the different materials identified above, we see that their sources and production quantities vary largely. Figure 3 illustrates the global mining of CRM output per country. For most CRM, mining is dominated by a few countries that have the largest reserves.

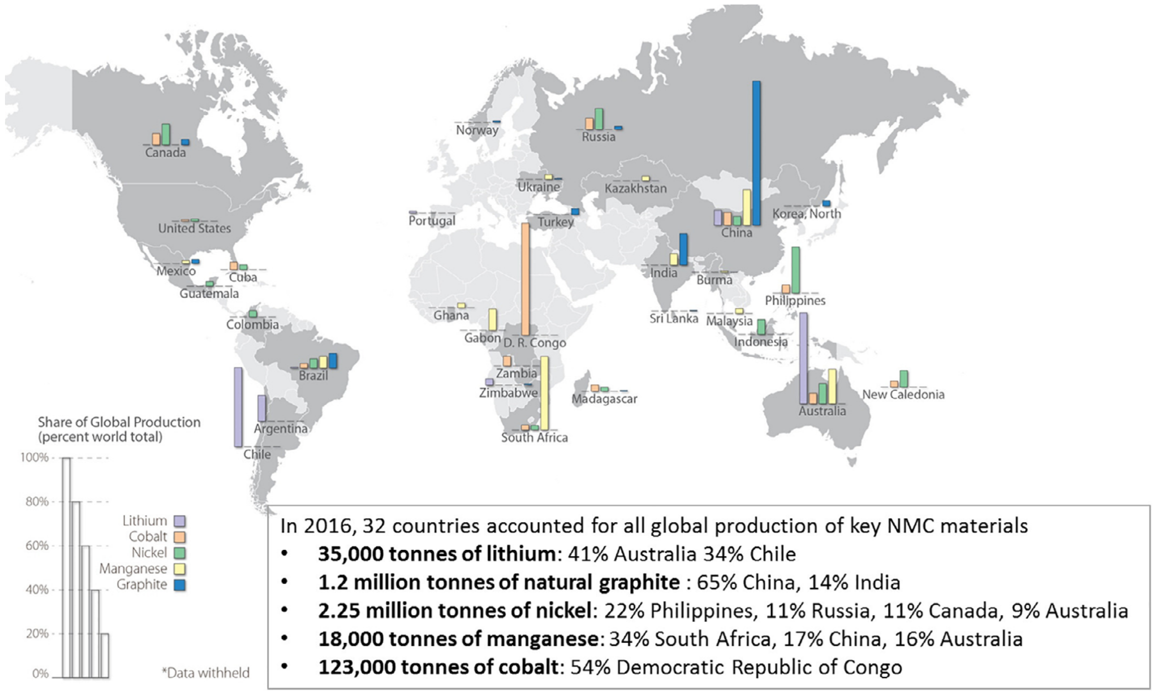

Figure 3. Global production of Critical Raw Materials used in Li-ion batteries (Source: Mayyas et al., 2018)

For lithium, the two most common extraction methods are lithium brine reservoirs and hard rock mining. Underground lithium brine reservoirs in South America are called salars, where salt-rich water is pumped from a saline aquifer, followed by adding freshwater and evaporating to extract the mineral. Hard rock mining involves mining from an open pit, followed by roasting minerals using fossil fuels **[13]**. Cobalt, manganese, natural graphite and nickel are similar in their extraction: through an open pit and/or underground mining. Roughly speaking, these minerals are subsequently crushed and refined using chemical and metal refining **[14]–[17]**.

When looking at refining and manufacturing *(previously defined here as processing)*, the distribution of activities becomes very different. See figure 4 for an overview of the production distribution globally. For most minerals, refining and processing stages are dominated by China, which is in line with their overall manufacturing dominance worldwide. Here, graphite processing is almost entirely carried out in China, the country that is also dominant in its mining **[18]**.

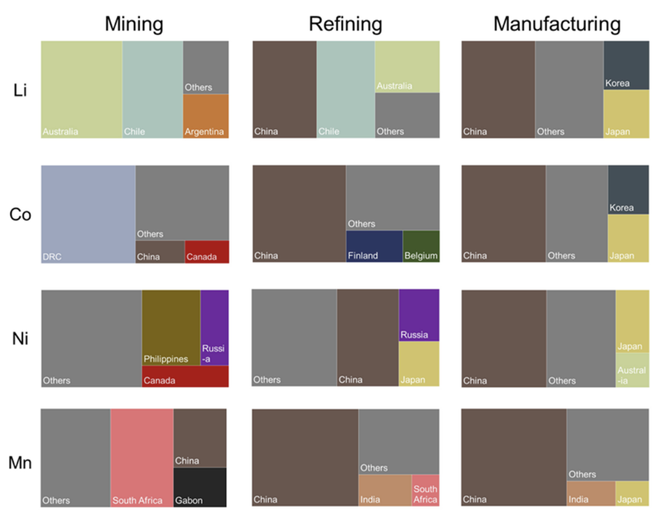

Figure 4. Production distribution across stages (Source: Sun, 2019)

manufacturing is referred to as processing in this report

SUPPLY CHAIN CHALLENGES

Regarding the supply chain of CRMs, three main challenges have received the most attention: social & environmental impacts, highly concentrated supply shares, and looming supply shortages.

SOCIAL & ENVIRONMENTAL IMPACTS

As mentioned in **one of our previous market intelligence reports**, several negative social and climate-related externalities arise from mining operations for Li-ion battery raw materials. These include large CO2 emissions in refining or processing, human rights violations, excessive land and water usage as well as contamination of land, air and water at mining operations. Figure 5 shows the global hotspot analysis of social and environmental risks as well as governance and conflict risks in mining countries. Whereas every country observed (except for Finland) shows some level of criticality related to environmental performance, countries differ largely on governance, conflicts and human/ social rights. Importantly, it shows that conflicts can be related to raw material extraction, especially in developing and low-governance countries [19]. Thus, even though downstream car manufacturers and consumers do not directly deal with sourcing, the responsibility is shared.

		Materials supply (mining stage)			Governance		Conflicts			Human and social rights			Environment	
Material	Country	% reserves and resources	% global mining production	% EU sourcing	Resource Governance Index	Worldwide Governance Indicators	INFORM - HH	Fragile State Index	Global Peace Index	Child labour*	Fair salary*	Global Slavery Index	Environmental Performance Index	Water Risk Index
COBALT	Australia	10	4	1	1	1	1	1	1	1	1	1	2	3
	Congo DR	46	57	69	3	4	4	4	4	4	2	4	3	1
	Finland	1	1	14	n.a.	1	1	1	1	1	1	1	1	1
LITHIUM	Argentina	20	12	5	n.a.	2.5	1	2	1	2	1	1	2	2
	Australia	8	36	65	1	1	1	1	1	1	1	1	2	3
	Bolivia	21	0	0	n.a.	3	3	3	2	4	3	2	2	1
	Chile	12	38	0	1	2	2	2	1	2	1	1	2	3
	Portugal	0	0	10	n.a.	2	1	1	1	2	2	2	2	3
	USA	13	3	0	1	1.3	3	2	3	1	1	1	2	2
MANGANESE	Australia	14	17	1	1	1	1	1	1	1	1	1	2	3
	Brazil	1	7	17	n.a.	3	3	3	2	2	1	1	2	1
	China	2	17	0	n.a.	3	3	3	2	3	2	2.5	2	3
	Gabon	10	10	20	n.a.	3	3	3	2	4	1	3.5	3	1
	South Africa	41	28	25	2	2.5	3	3	3	n.a.	1	2	3	3
	USA	10	0	0	1	1.3	3	2	3	1	1	1	2	2
NATURAL GRAPHITE	Brazil	1	7	12	n.a.	3	3	3	2	2	1	1	2	1
	China	0	64	47	n.a.	3	3	3	2	3	2	2.5	2	3
	India	0	11	0	n.a.	2.5	3	3	3	1	2	2.5	3	3
	Mozambique	68	0	0	n.a.	3	2	3	2	4	1	3	3	2
	Tanzania	13	0	0	2	3	2	3	1	4	1	3	3	3
NICKEL	Australia	13	11	0	1	1	1	1	1	1	1	1	2	3
	Canada	7	10	7	n.a.	1	1	1	1	1	1	1	2	1
	China	3	4	47	n.a.	3	3	3	2	3	2	2.5	2	3
	Greece	1	1	10	n.a.	2.5	2	2	1	1	1	3	2	3
	Indonesia	17	18	0	1	3	3	3	1	2	1	2.5	3	3
	Philippines	10	17	0	2	3	4	3	3	2	3	3	2	3
	Russian Federation	11	11	0	n.a.	3	3	3	4	2	1	3.5	2	1
	South Africa	4	2	14	2	2.5	3	3	3	n.a.	1	2	3	3

Figure 5. Social & Environmental risks of CRM-producing countries (Source: Mancini, 2020)

RISKS OF HIGHLY CONCENTRATED SUPPLY SHARES

Calculating supply chain risks is widely performed using the Herfindahl-Hirschman Index (HHI), which indicates the supply share of a given country. Looking at figure 4, every CRM at some stage is dominated by one country, which is often China in refining and processing stages. However, when considering the Worldwide Governance Indicator (WGI) - a worldwide governance ranking based on 6 dimensions (e.g., political stability), the perception of supply chain risks shifts. Whereas Australia has the largest lithium mining production worldwide, its WGI is strong, especially compared to the Democratic Republic Congo (DRC) which has the second lowest WGI score. Thus, even though the concentration of supply can be dominated by single countries, it does not per se create a significant supply chain risk.

The supply chain risk analysis by Sun et al. [20] brings forward the Supply Risk Indicator of Li-ion batteries (SRIL), to analyse supply risks of nickel, cobalt, lithium and manganese (excluding graphite). The SRIL indicator is based on the concentration of production, WGI, the prominence of respective minerals in different supply chains and the contribution share of minerals to Li-ion batteries. They conclude that the risks of the cobalt mining stage, cobalt refining stage, cobalt processing stage, lithium refining stage, lithium manufacturing stage, and manganese manufacturing stage are the highest. Here, the weak WGI score of China (148th of 214 countries) impacts the refining and processing risks of most materials negatively. Interestingly the SRIL perspective does not share the concerns of OEMs regarding nickel (and manganese alike) since these minerals are used in other industries at a high rate. However, since the Li-ion battery industry is expected to grow tenfold by 2050, the supply risks are still expected to increase significantly **[20]**.

Besides the supply chain risk, there is also the issue of overall competitiveness and market power. **China currently accounts for 53% of the global battery manufacturing capacity, which is also true for the lion's share of Li-ion batteries raw material refining and processing activities. Moreover, much of the cobalt mining operations in Congo and parts of the Australian lithium production are controlled by Chinese companies [8]**. This leaves the European car industry less competitive and sovereign, which is one of the key focus points of the European Commission.
Here, the current shortage of semiconductors for Autonomous Vehicles could serve as an analogy, with political interests aimed at boosting European economic independence **[21]**.

LOOMING SUPPLY SHORTAGES - LIMITED PRODUCTION CAPACITY

Due to the rapid growth of the EV market, material shortages are likely to arise for lithium, cobalt, nickel, graphite as early as 2025 **[22]**. Figure 6 shows the forecasted supply and demand gap for lithium, with similar dynamics expected for the other CRMs. Since emerging battery technologies differ in their material usage, the coming years will be interesting. Material demand will be influenced by the technology battle between NMC and LFP batteries, which is highly influenced by the design choices of OEMs (among others). Here, the problem is not necessarily reserve scarcity, it is more related to production scarcity of the upcoming material demand surge. Successful capacity expansion relies on the combined effect of investments, improved methods, and commercial and government **[23]**.

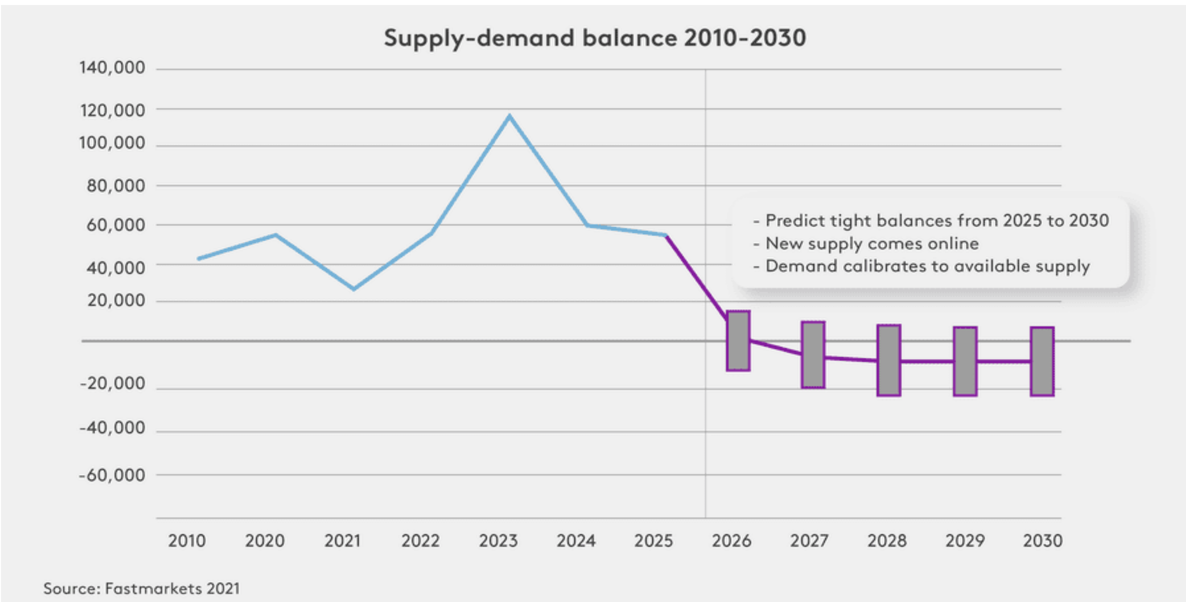

Figure 6. Lithium supply and demand (Source: Adams, 2021)

INNOVATIONS AND SOLUTIONS

To overcome the supply chain risks, competition, social and environmental challenges encountered in Li-ion battery material sourcing, solutions arise in three different groups:

1. **Improve current processes or use new raw material sources**
2. **Recycle batteries to reduce the need for raw materials**
3. **Reduce or remove critical raw materials from battery cells**

IMPROVE CURRENT PROCESSES OR USE NEW SOURCES

In 2022, the revised Battery Regulation by the European Union is expected to go into effect. This revision of existing battery regulation puts stringent requirements on batteries placed in the European market. Environmental and social due diligence will be required for raw materials sourcing, as well as incrementally increasing carbon footprint thresholds [24]. For example, article 39 of the regulatory proposal states that battery producers, or organisations on their behalf, are to be registered and responsible for the collection, reuse and recycling of batteries at their end of life [25]. **Whereas previously, the responsibility for negative impacts of raw material sourcing was left up upstream, the European Union has moved the responsibility closer to home.** These strict import laws differ from the past efforts regarding the environmental impacts of batteries, which have mostly focused on international treaties. This has often left space for local regulations, which were not always strict enough [26].

Related to materials processing, nickel has been undergoing changes. Within nickel mining and processing, a shift is taking place to nickel laterite ore, a typically lower grade yet much more abundant ore than the traditional sulphate ores [27]. In the last few years, an Australian consortium has developed a new acid refining method that is more cost-effective and environmentally friendly compared to the previous refining method [28]. The newly developed version of the high-pressure acid leaching (HPAL) method enables the reuse of nitric acids used in the process, which eliminates wastewater problems. However, successful scaling up this method is still unsure, given the industry's historical delays, budget overruns and inability to reach design capacity [29]. Moreover, the method for refining nickel laterite ore through HPAL remains highly energy-intensive [30].

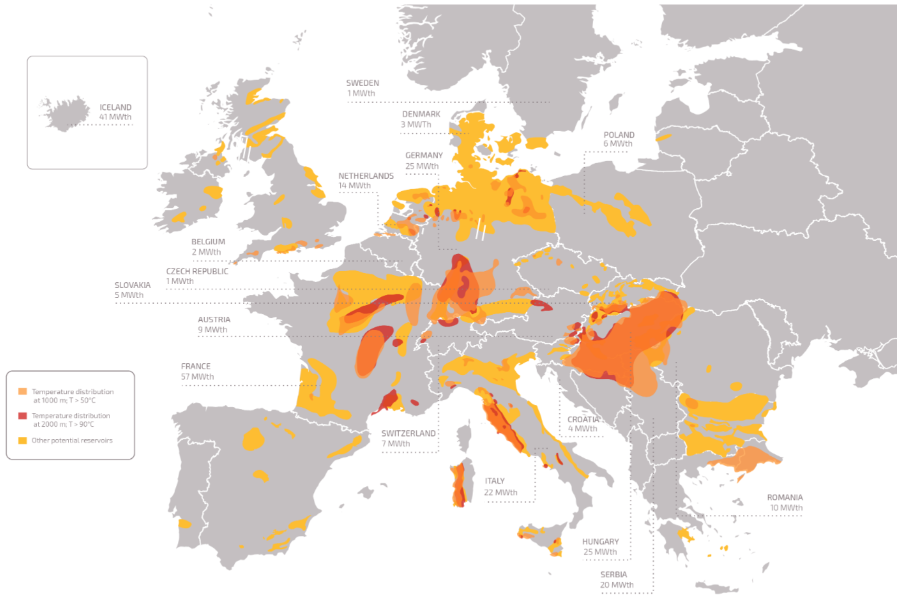

Figure 7. Geothermal lithium potential Europe (Source: EGEC, 2021)

Within lithium production, Europe is showing high potential for geothermal lithium mining. While hard rock mining and using underground reservoirs are associated with large carbon emissions and water usage respectively, geothermal mining has shown promise with regards to environmental impacts. Figure 7 shows the European potential for geothermal lithium mining. Two examples of current investments and developments in European geothermal lithium mining are Cornwall and the Rhine valley [31], [32]. Lastly, in the past decades, deep-sea manganese nodule mining has regained interest from the mining industry because of increased metal demands. Manganese nodules are authigenic deposits composed principally of manganese oxides enriched in iron, cobalt, nickel and copper, most of which are needed in battery materials. However, scientists say that this technology has not been tested enough to avoid devastating long-lasting damage to seabed ecosystems [33].

RECYCLING

Currently, a substantial momentum in the European Union is forming in the field of Li-ion batteries recycling. It could serve as one of the key pillars to solving the issues related to CRMs, once the first generation of fully electric vehicles come to their end-of-life stage. The renewed Battery Regulation can act as an incentive to the battery ecosystem to design for sustainability: annually 65% of Li-ion batteries are targeted to be recycled by 2025 and 70% by 2030 [34]. **As of now, the EU already has the largest total battery recycling capacity in the world, see figure 8, whereas Asia dominates the production of virgin batteries. With the surge of end-of-life EV batteries and Western countries seeking economic independence, recycling is expected to grow drastically.**

One of the large barriers to recycling, however, is the use of less valuable materials in LFP or cobalt-free batteries. This makes the recycling process less attractive for recyclers and therefore less economically sustainable. Increased economies of scale, induced by the EV end-of-life battery market, could be the answer to this issue [1].

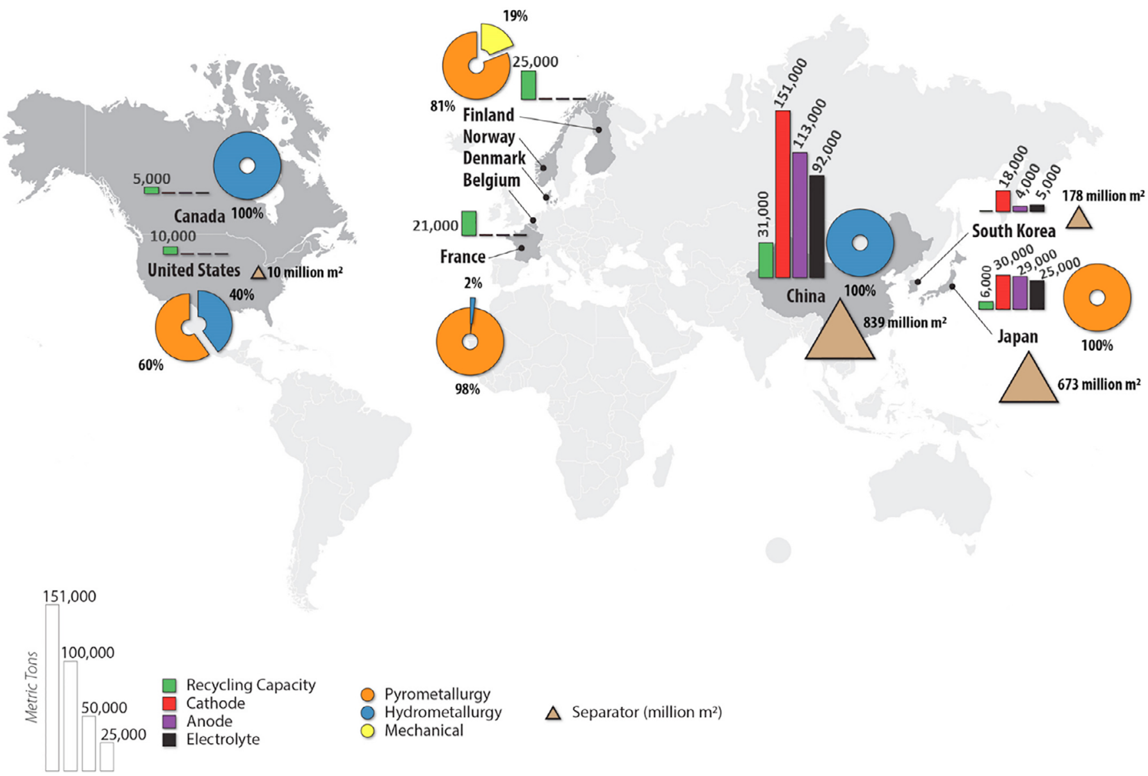

Figure 8. Global battery recycling and production capacity (Source: Mayyas, 2018)

REMOVE MATERIALS

The third solution to the abovementioned CRM issues is to reduce or entirely remove "problematic" raw materials used in batteries. **Cobalt in particular has been the centre of attention for several European battery innovation projects.** Several OEMs and battery suppliers have also shown activity in developing cobalt-free batteries: Volkswagen through a partnership with the SME Nano One, Tesla through their planned in-house battery production and SVOLT through a partnership with Great Wall vehicles. Key to developing these innovative batteries is retaining high cycle life and thermal stability **[35]**. This is also the focus of the COBRA project, the main aim of which is to eliminate cobalt from the cathode, while ensuring adequate electrochemical performance (750Wh/l), long cycle life (>2,000 cycles), fast charging (3C), and ensure safety and recyclability, while complying with competitive cost targets (<90€/kWh at pack level). To achieve this, COBRA brings together partners working on all components of the battery pack (anode, cathode, electrolyte, cell manufacturing, sensors, BMS, ...) who through an iterative process will find the best combination of component technologies that comply with the ambitious objectives.

TECHNICAL DEVELOPMENTS

NEXT-GENERATION DIRECT RECYCLING USING FROTH FLOTATION

Researchers at the Michigan Technological University have developed a new direct recycling method, which relies on a flotation process. Normally, cathode materials are hard to separate in recycling. However, by introducing a collector chemical, one cathode material (i.e. NMC111) is made hydrophobic, whereas another (i.e. LMO) is made hydrophilic. Thereby, the two materials separate in water, without changing their structure or morphology.

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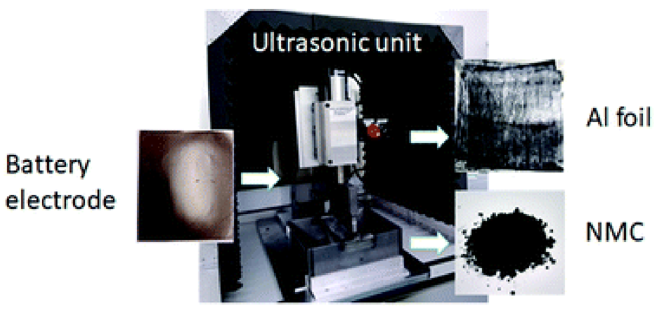
GROUND-BREAKING INVENTION: RECYCLING LI-ION BATTERIES USING SOUND

Researchers at the University of Leicester have invented an innovative Li-ion battery recycling method. While current battery recycling processes rely mostly on battery shredding, followed by heat treatment (pyrometallurgy) or leaching (hydrometallurgy), ultrasonication can take apart batteries with sound. The key process works as follows: *"Cavitation at the electrode interface enables rapid and selective breaking of the adhesive bond, enabling an electrode to be delaminated in a matter of seconds"*. This ultimately leads to a much faster recycling process, less energy usage and higher purity of recycled materials. The process has been successfully applied to the four most common battery types.



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SELECTIVE EXTRACTION OF LITHIUM FROM CLAY MINERALS

In July 2021, Tesla has put forward their own patent to the extraction of lithium from lithium clay, which follows their ambition to insource the sourcing of lithium. The method includes the process of extracting lithium from mineral-rich clay, using sodium chloride, essentially table salt. While current processes are highly inefficient due to the impurities that come with lithium, the new method (including sodium chloride) incurs fewer impurities. This method opens a new stream of lithium, of which production is currently dominated by Australia, Chile and Argentina. Large clay deposits in Nevada have already been acquired by the car manufacturer. Moreover, due to the efficiency gains, lithium costs can be reduced.

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MINING 4.0: DIGITALIZATION OF MINING OPERATIONS

The last decade has seen many industrial enterprises apply industry 4.0 technologies, like Internet-of-Things, Artificial Intelligence and Machine Learning. Similarly, information processing in the mining industry is gradually moving towards the Industry 4.0 vision. The operational gains could be an enabler of production capacity expansion worldwide, leveraging nickel and manganese reserves. Researchers from Johannesburg have studied the case of a Namibian uranium mining company. Based on their findings at the site, improvements could be made using IoT, AI, big data. Envisioned advantages include production monitoring, fuel consumption monitoring, equipment management, operational fleet efficiency, tyres and rims management and overall agility.

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NORTHVOLT PRODUCES FIRST BATTERY FROM 100% RECYCLED NICKEL, MANGANESE AND COBALT

In Västeras, Sweden, Northvolt has produced the first battery cell which includes 100% recycled nickel, manganese and cobalt. The material recovery process included low-energy hydrometallurgical treatment using an aqueous solution. Thereby, Northvolt has validated their recycling capabilities and aim to produce cells with 50% recycled material by 2030. In their own words: *"Ultimately, a commitment to circularity will not only significantly reduce the environmental impacts of the battery industry, but also contribute to our vision to set a new benchmark for sustainability in manufacturing"*. Interestingly, both their battery recycling and production facilities are located on the same site.

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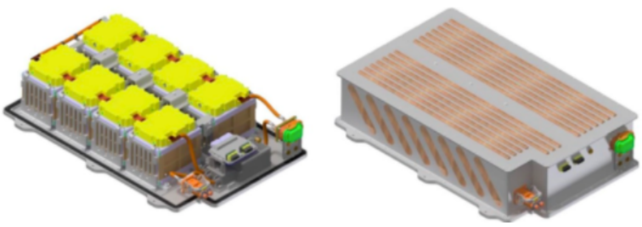
COBRA

The EU-funded project COBRA has set out to develop a new generation of cobalt-free Li-ion batteries for Electric Vehicles. COBRA plans on developing an LNMO cathode in combination with a composite anode based on nanometer silicon and graphite as active particles. Eliminating cobalt from batteries improves the overall environmental and social sustainability of Li-ion batteries. The project runs from January 2020 until 2024. Currently, the project is working towards implementing the generation 1 COBRA components into a cell for performance testing, and in parallel working towards the development of generation 2 components, based on feedback from the performance of generation 1.



Concept design of COBRA battery pack

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MARKET AND POLICY DEVELOPMENTS

GEOTHERMAL LITHIUM DEVELOPMENTS

Several European developments are aimed at increasing geothermal lithium capacity from geothermal sources. The combination of geothermal energy and lithium extraction is proving to be a combined strategy.

EUGELI PROJECT IS AIMED AT RAMPING UP EUROPEAN LITHIUM PRODUCTION BY GEOTHERMAL

Stakeholders from the chemistry, mining and automotive industry as well as mining research institutions are led by ERAMET (multinational mining company), to accelerate the European geothermal mining industry. Their strategic approach includes prospecting European geothermal lithium reserves as well as developing an industrial implementation plan. Their focal technological contribution is the validation of an active-solid lithium processing method. In early 2021, they have successfully piloted the novel method at the Rittershofen geothermal power plant in north-eastern France.

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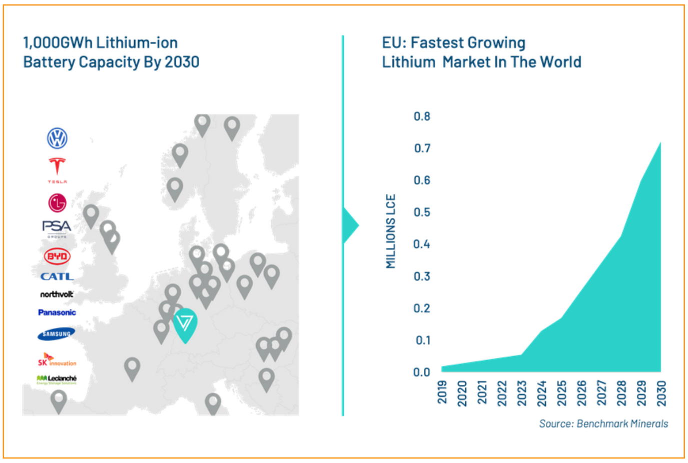
GEOTHERMAL LITHIUM FROM NORTH RHEIN VALLEY, GERMANY

One of the largest lithium brine deposits lies in the depths of the North Rhein Valley in Germany. The Australian lithium developing company Vulcan has completed a (positive) pre-feasibility study on their geothermal zero-carbon lithium mining operation. Required investments are approximated at €1,74 billion and the definitive feasibility study is expected to be completed in 2022. Currently, a pilot plant is already operational and Vulcan has closed a second deal with Renault to deliver lithium over a 5-year span. The goal is to have a full commercial production in 2023-2024.



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GEOTHERMAL LITHIUM FROM CORNWALL, UK

Geothermal Engineering Ltd, which originally started as a British geothermal power plant, is planning on expanding its operations towards lithium extraction. In 2022, their electricity plant is due to become operational and they are currently working on a pilot plant for lithium extraction. This site displays the dual benefits of geothermal water, providing both energy and lithium.

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MOVE BACK TO LFP: CARMAKERS USE LFP FOR LOWER END VEHICLES

Whereas in previous years LFP batteries were assumed to become non-existent in the EV market, this summer brought uncertainty to that assumption. Ford, Tesla and Volkswagen stated that they will return to LFP Li-ion batteries for a certain segment of their fleet. This move originated from a combination of 1) upcoming nickel and cobalt shortages 2) the lower prices of LFP. Still, it could be argued that NMC batteries will ´win´ the technology battle between both battery types, because of the expected cost reductions after upscaled NMC recycling activities.

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EUROPEAN RAW MATERIAL ALLIANCE (ERMA) PUBLISHES ACTION PLAN FOR RARE EARTH MAGNETS AND MOTORS

Similar to critical raw materials, electric vehicles make use of rare earth magnets and motors, whose supply chain is dominated by China. Moreover, these magnets and motors are considered equally critical by the European Commission, due to their economic importance and high supply risk. The focus areas of their action plan include 1) create an equal playing field with Chinese manufacturing industry 2) ask OEMs to source locally 3) create regulation to retain materials within the EU 4) trigger private investments through state match-funding. The ERMA is an alliance that provides a forum for discussion and analysis to strengthen European market power. Their recently published action plan for magnets and motors will be followed by an action plan for critical raw materials, which were the subject of this market intelligence report. They were able to consult 180 industry stakeholders for their previous action plan, indicating the strategic relevance of subsequent reports.

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