

The global electric car fleet grew to 10.9 million vehicles in 2020 [1], which amounts to three million more than in the previous year. With more than five million electric cars on the road, China is still the undisputed leader, followed by the USA, with 1.77 million. Germany has made its way into third place with almost 570,000 electric vehicles [1]. In 2020, the number of newly registered electric cars reached a record high of 3.18 million units. From 2030 onward, they could make up between 25 and 75 % of new registrations. This will lead to a demand for battery power of between 1 and 6 TWh per year, depending on which study one reads [2].

As electric vehicles become more widespread, the demand for special raw materials for the vehicles and, in particular, for the batteries will continue to grow. All the forecasts indicate that lithium-ion batteries will be the standard solution for electric cars over the next ten years and so the main substances needed will be the chemical elements

graphite, cobalt, lithium, manganese and nickel. Despite the developments in cell chemistry, the proportion of lithium by weight in each cell of around 72 g/kg is not likely to reduce noticeably during this period, according to estimates by the Fraunhofer Institute for Systems and Innovation Research (ISI). However, the proportion of cobalt could fall significantly from 200 g/kg of cell weight to around 60 g/kg. Therefore, the demand for primary raw materials for vehicle battery production by 2030 should amount to between 250,000 and 450,000 t of lithium, between 250,000 and 420,000 t of cobalt and between 1.3 and 2.4 million t of nickel [2].

#### ASSESSMENT OF RAW MATERIAL DEPOSITS

When assessing the deposits of raw materials, two different figures need to be taken into consideration: on the one hand, the resources generally available on the planet and, on the other,

the deposits that can be extracted cost-effectively using today's technology at current market prices. At this point, one can give the all-clear for lithium-ion vehicle batteries. Scientists have confirmed that enough raw materials are available. In most cases, the total deposits will significantly exceed the predicted demand, even if the amount of raw materials needed were to increase in parallel as a result of more demand in other areas.

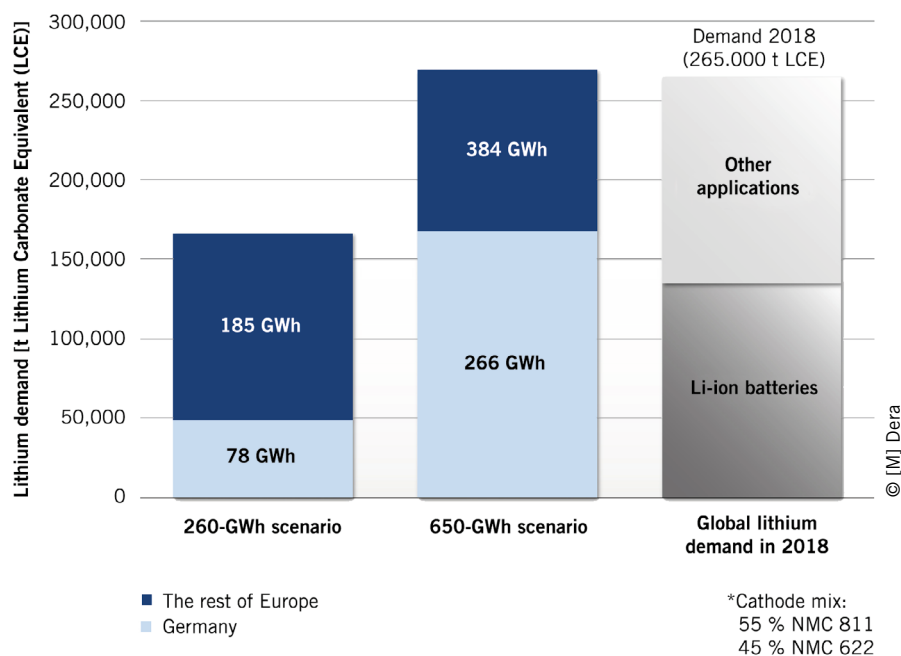
However, several studies indicate that temporary shortages or price increases for individual raw materials are certainly possible, for example if new production sites have to be opened, if the demand is too great or if there are problems with exports from producing countries [2]. The situation varies considerably across the different metals, as an in-depth analysis and assessment by the German Mineral Resources Agency (Dera) shows [3], which is described in more detail in the following for the five chemical elements.

# Battery Raw Materials – Where from and Where to?

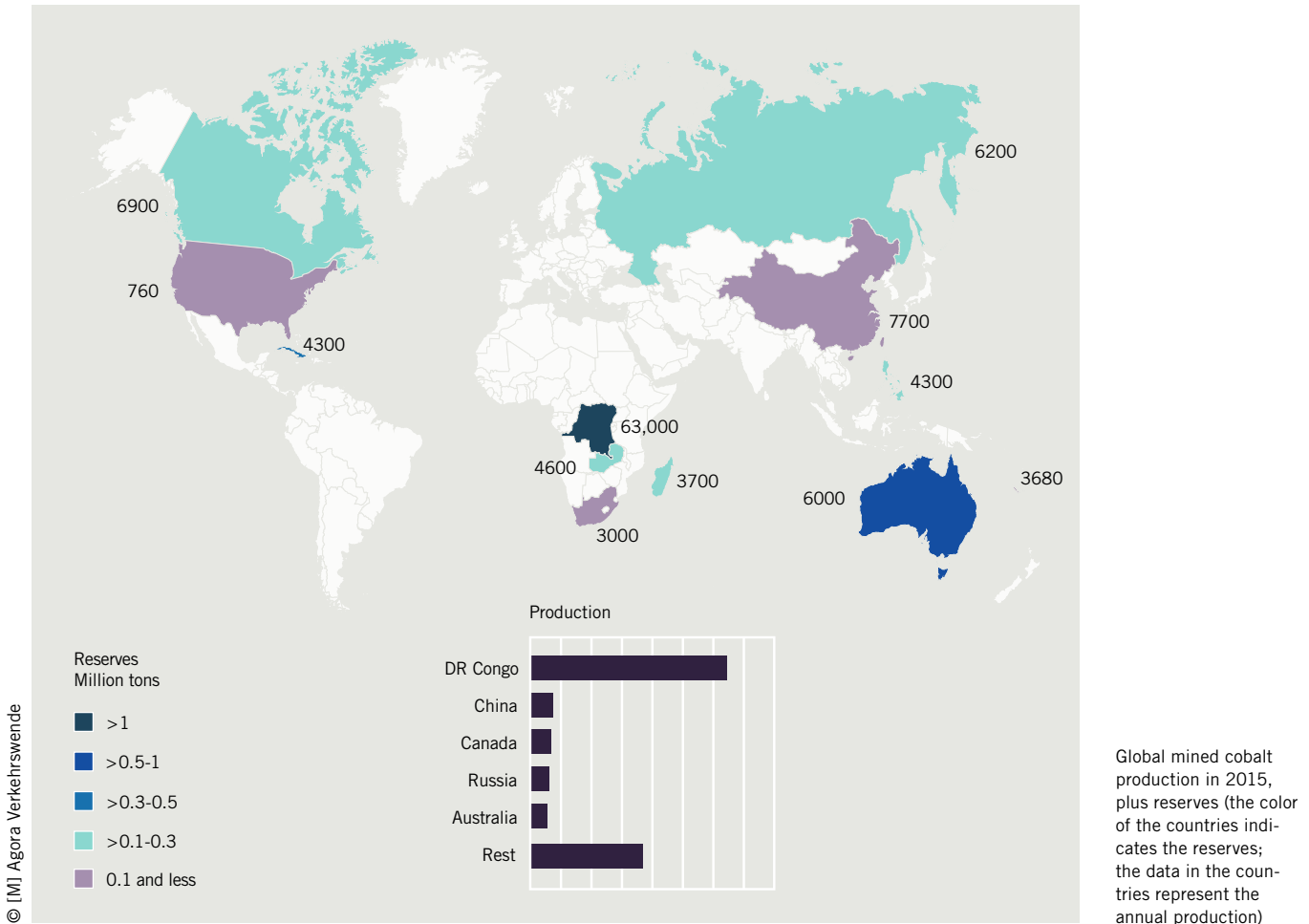
Electric cars make up a growing share of the market, which means that larger numbers of batteries will need to be produced and this in turn will lead to an increasing demand for raw materials. In particular during the ramp-up phase of electric mobility, there are likely to be occasional supply bottlenecks. At a later stage, recycling concepts for used battery cells could relieve the pressure on supply chains.

## GRAPHITE

Graphite is used as the anode material in lithium-ion batteries. It has the highest proportion by volume of all the battery raw materials and also represents a significant percentage of the costs of cell production. China has played a dominant role in almost the entire supply chain for several years and produces almost 50 % of the world's synthetic graphite and 70 % of the flake graphite, which requires pre-treatment before being used in batteries. Over the last few years, increasing exploration has been taking place, in particular in Africa. New extraction sites in Mozambique, Tanzania and Madagascar could relieve the pressure on the highly concentrated world market. However, the risks involved in the processing of flake graphite also present a problem for the security of supply, because this is carried out almost entirely in China, together with the production of anodes. Research is currently underway into new anode materials [4], which if



Lithium requirements for European electric vehicle battery production in 2030, in relation to the cell production capacity (NMC 811: 80 % nickel, 10 % manganese, 10 % cobalt; NMC 622: 60 % nickel, 20 % manganese, 20 % cobalt)



they were used in mass-produced batteries could have an impact on the future demand for graphite.

**COBALT**

Like nickel and manganese, cobalt is required for battery cathodes. It currently presents the greatest procurement risks of all the battery raw materials. This is due in particular to the expected dynamic growth in demand and the resulting potential supply bottlenecks. “On the basis of current scenarios, the demand for cobalt for electric vehicles could increase to as much as 315,000 t by 2030, which is 20 times the current amount,” says Siyamend Al Barazi from Dera. The ongoing development of low-cobalt or even cobalt-free cathodes could result in a considerable reduction in overall demand. The role of the Democratic Republic of Congo, which is by far the largest producer, presents major risks for strategic plan-

ning. “Cobalt mining there has dominated the global market for more than ten years, with a current market share of 69 %, and the country could increase its production considerably if demand continues to grow,” explains Al Barazi.

**LITHIUM**

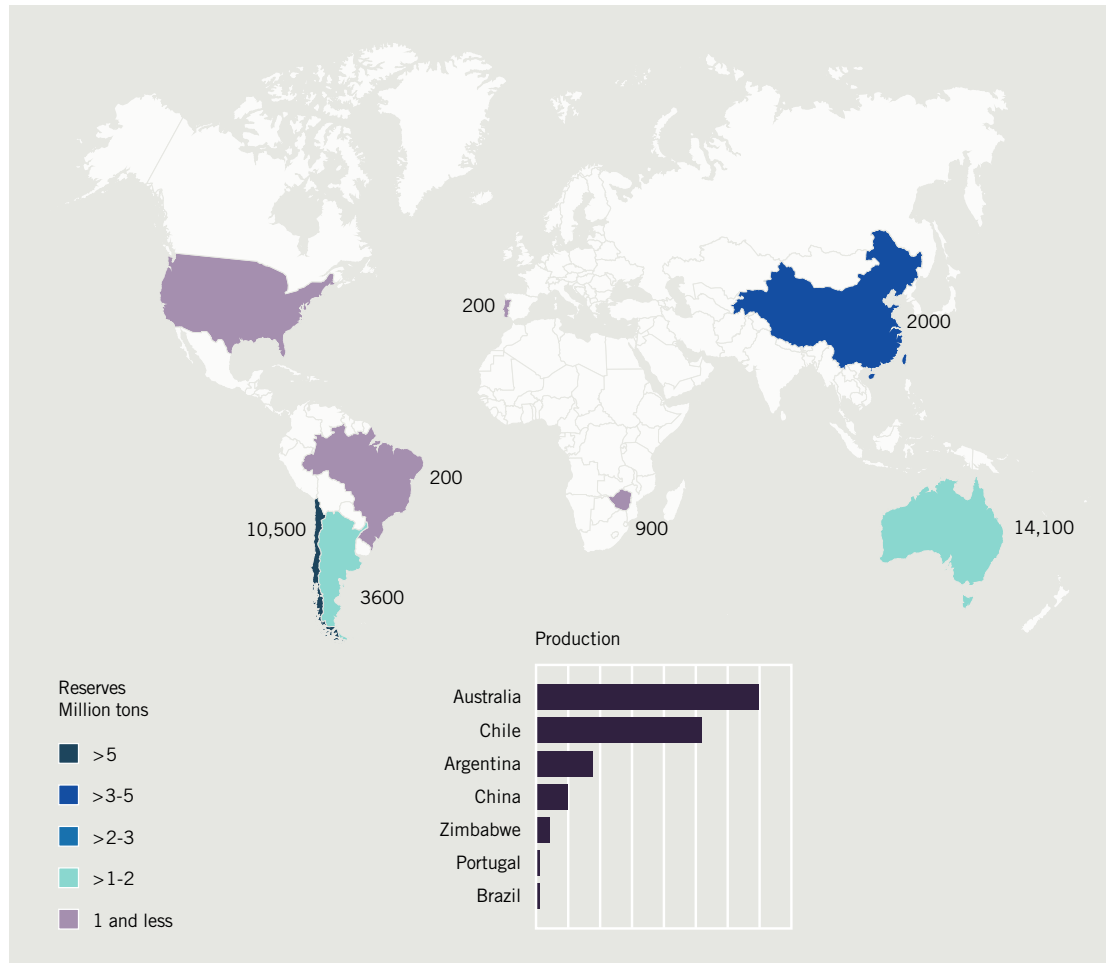
As the lithium market is relatively small, the expected increase in demand is particularly high in relation to current production levels. “Our calculations show that the supply needs to triple by 2026 simply to cover future demand,” says Michael Schmidt from Dera. The extraction of lithium is currently restricted to Australia, Chile and Argentina and to a few companies, with only four businesses controlling almost 60 % of global production. However, the boom in lithium over recent years has demonstrated that the lithium market is facing major changes. Alongside the expansion of existing facilities,

large-scale projects are being planned and implemented in other countries, such as Canada, Mexico and Bolivia. Europe also has significant potential. Bottlenecks in the supply of lithium are currently unlikely, but experts have indicated that the concentration on just a few producer countries will remain unchanged. “In addition, Asian battery manufacturers in particular have secured large quotas by entering into long-term supply contracts and acquiring stakes in companies. This has reduced considerably the amount of lithium freely available on the world market,” says Schmidt.

**MANGANESE**

Battery applications make up only a small part of the manganese market. The main customer for manganese is the steel industry, which uses around 90 % of the global supply. Currently only approximately 0.2 % of the manganese extracted

Global mined lithium production in 2015, plus reserves (the color of the countries indicates the reserves; the data in the countries represent the annual production)



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throughout the world is used in lithium-ion batteries. In the future, this figure will only increase to around 1 %.

## NICKEL

The global demand for nickel to produce lithium-ion batteries was more than 150,000 t in 2019 [3]. This amounts to less than 5 % of the world market volume of primary nickel. By 2025, the demand from the electric vehicle sector could increase to approximately 500,000 t per year, which would be the equivalent of 15 % of the total global market. To increase the energy density of lithium-ion batteries, a much greater proportion of nickel is used in the cells. This means that demand will rise disproportionately to the increase in battery production. Nickel sulfate is needed for lithium-ion batteries, which is a niche product produced from class-I nickel (over 99 % purity). To meet the growing demand in the future, new manufacturing methods

for nickel sulfate need to be developed. The market is highly dependent on the supply of primary nickel from South East Asia and, in particular, from Indonesia, which is by far the biggest nickel mining country. In 2020, Indonesia imposed a ban on exports of nickel ore to ensure that large parts of the value chain remained in the country. After China, it is now the world's second largest nickel producer, but only of class-II nickel (less than 99 % purity). Many projects are underway in Indonesia with the aim of manufacturing higher-quality nickel products for battery production.

## RECYCLING LITHIUM-ION BATTERIES

To reduce the world's dependence on the raw material producing countries referred to above, establishing a comprehensive recycling structure will become increasingly important in the future. Processes for recovering raw materials from small

lithium-ion batteries, such as those in cell phones, are in part already being implemented. However, vehicle batteries are much larger, heavier and more powerful, which makes industrializing the recycling process more complex. The German Federal Ministry for Economic Affairs and Energy (BMWi), together with Vinnova, Sweden's innovation agency, is funding the Libero research project at RWTH Aachen University as part of the Central Innovation Program for SMEs (ZIM). The German-Swedish consortium, consisting of two partners from industry and two from the research world in each country, is working on developing a robust, flexible and largely waste-free process for recycling batteries. The goal of the project, which began in 2019, is to plan a plant with an annual recycling capacity of 25,000 t of battery mass [5]. The Finnish company Fortum, which is half state-owned, has already developed a process for recycling lithium-ion batteries from electric vehicles [6].



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Head of Business Line Batteries at Fortum

One of the pioneers in the field of commercial battery recycling is Umicore. The process developed by the company consists of a pyro-metallurgical and a hydro-metallurgical phase. The initial thermal processing stage produces an alloy that contains cobalt, nickel and copper and a slag fraction. The metals are recovered in the subsequent hydro-metallurgical stage of the process. Umicore’s first recycling plant has a capacity of 7000 t of battery mass per year, which corresponds to around 35,000 electric-vehicle batteries.

In early 2021, Volkswagen began operations at a pilot plant for recycling high-voltage vehicle batteries at its site in the German town of Salzgitter. The plant will recover 100 % of the lithium, nickel, manganese and cobalt, plus 90 % of the aluminum, copper and plastic [7]. The plant is currently designed to recycle up to 3600 battery systems per year, which is the equivalent of around 1500 t of battery mass. However, the system can be scaled up to process larger volumes when more used batteries become available. According to Volkswagen, the recycling process does not involve smelting in a blast furnace, which would use large amounts of energy. The used battery systems delivered to the plant are deep discharged and disassembled. The individual parts are shredded to form

## 2 QUESTIONS FOR ...

**What are the special features of your recycling concept for lithium-ion batteries from electric vehicles?**

**HOLLÄNDER** \_ The traditional way to recycle lithium-ion batteries has been using a thermal approach. Fortum is using a combination of mechanical and hydro-metallurgical recycling, which has a significantly lower CO<sub>2</sub> footprint. With this technology, the ability to separate different metals is also much better and a much larger proportion of the battery’s active materials are recovered; in other words, we are able to recover up to 95 % of the scarce and valuable metals in a battery’s black mass. We patented our own lithium separation method at the start of this year.

**When do you expect the process to be industrialised, when will there be enough batteries available to operate the plant economically?**

**HOLLÄNDER** \_ We are already operating at an industrial scale with our current recycling capacity being about 3000 t per year, equivalent to about 10,000 electric car batteries. Our mechanical recycling plant in Ikaalinen is currently in the ramp-up phase and we have an industrial pilot plant for hydrometallurgical recycling in Harjavalta. Our goal is to build a larger-scale hydrometallurgical plant in Harjavalta enabling us to handle a larger amount of materials in the future.

granulate and this is then dried. The process produces aluminum, copper and plastics and, most importantly, a black powdery mixture that contains the essential battery raw materials: lithium, nickel, manganese, cobalt and graphite. Specialist partners of Volkswagen are subsequently responsible for separating and processing the individual elements by means of hydro-metallurgical processes that use water and chemicals.

“This allows the key components of old battery cells to be used to manu-

facture new cathodes,” explains Mark Möller, Head of the Technical Development and E-Mobility division of Volkswagen Group Components. “As there will be a big increase in the demand for batteries and therefore also for raw materials, we can make good use of every gram of material that we recover.” Other car manufacturers, such as Mercedes-Benz, are thinking along the same lines. As the company explained on request, it is planning a recycling plant for high-voltage batteries at its Gaggenau site in Germany.

Recyclable material	Proportion by weight [kg] (based on a total battery mass of 400 kg)
Aluminum	126
Graphite	71
Nickel	41
Electrolyte	37
Copper	22
Plastic	21
Manganese	12
Cobalt	9
Electronics	9
Lithium	8
Steel	3
Residual	41

Proportion by weight of the recyclable material in a lithium-ion battery (source: Volkswagen)

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## SECOND-LIFE APPROACH

The re-use of old vehicle batteries in stationary applications could extend their service life before there is a need to recycle them. There is currently no practical experience on how many batteries would meet the requirements for second use in terms of their remaining storage capacity and service life. In general, the second-life concept is only suitable for applications where old batteries with a low energy density can be used. In addition, issues such as standardization and warranties need to be resolved [8].

According to the Fraunhofer ISI, higher failure and replacement rates can be expected than is the case with new batteries, which means that the high levels of reliability needed from decentralized battery storage systems for residential buildings, for example, cannot be guaranteed. Because of the necessary redundancy levels, the number of cells needed and therefore the cost of the batteries would be greater. The assumption of the Fraunhofer ISI is that only a fraction of the old traction batteries could actually be given a second life [2].

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## OPINION

“As is always the case, the entire supply chain of raw materials for lithium-ion batteries is only as strong as its weakest link. Battery production can only operate smoothly when all the necessary raw materials are available at the right time and in sufficient quantity. To achieve this goal and enable a rapid expansion of electric mobility, all the politicians and business leaders on an international level must be traveling in the same direction. The fatal impact that minor problems in the supply chain can have on the whole automotive production process has been clearly demonstrated by the ship that blocked the Suez Canal and the shortage of electronic components caused by the Covid-19 pandemic.”



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