DERA German Mineral Resources Agency
Federal Institute for Geosciences and Natural Resources

# Booklet

## Battery raw materials for E-mobility

# Introduction

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In addition to autonomous vehicles and car sharing schemes, electric vehicles ("e-mobility") represent the mobility of the future. The electrification of drives and the storage of the necessary energy in high-performance traction batteries are intended to cut both emissions that are hazardous to our health, and carbon dioxide, which is harmful to the climate. This is a fundamental change for the automotive sector and its upstream industries: in terms of monetary value, the battery will in future be by far the largest cost factor in a car.

Business decisions that will result in either the development of in-house production capacities for cells and battery modules, or the procurement of battery cells or entire modules are therefore of major importance. These decisions also affect the way we consider the complex value chain for lithium-ion batteries (LIBs). Depending on their type, LIBs contain different materials, such as aluminium, graphite, cobalt, copper, lithium, manganese and nickel. As commodities, graphite, cobalt, lithium and nickel are of particular importance.

Taking into account the dynamic development of e-mobility, and given the large cost share of battery materials in the overall manufacturing process, raw material procurement should be a key issue in the debate on the mobility revolution. It equally affects the development of local cell production capacities and the procurement of cells. In both cases, market risks need to be considered, to ensure a competitive and reliable, but also sustainable procurement of raw materials and precursors.

This brochure aims to contribute facts and data on e-mobility, with regard to the markets for battery raw materials. In recent years, DERA has carried out in-depth studies on battery raw materials. Please contact us to benefit from our expertise.

# Lithium-ion batteries

Lithium-ion batteries have a high energy density compared to other battery types. They can therefore store and release more energy where space is limited, such as in a car. Other advantages of LIBs are their high efficiency during charging and discharging, and low self-discharge. Rechargeable batteries, which are important for electric vehicles, come in various types. Since no particular LIB type has become established as dominant yet, the following is a general description of their basic structure.

In LIBs for electric vehicles, individual battery cells are connected to form a module. Several modules are then connected in series or in parallel to form a battery system that is monitored and controlled (for instance, temperature or cell voltage monitoring) by a battery management system. A battery cell either has a steel-aluminium case or – as in the pouch cell design – it is coated with an aluminium composite foil. Battery cells can account for around half of the total mass of a traction battery.

Every battery cell comprises stacked or wound electrodes, physically and electrically isolated from each other by a separator (generally a porous polymer membrane).

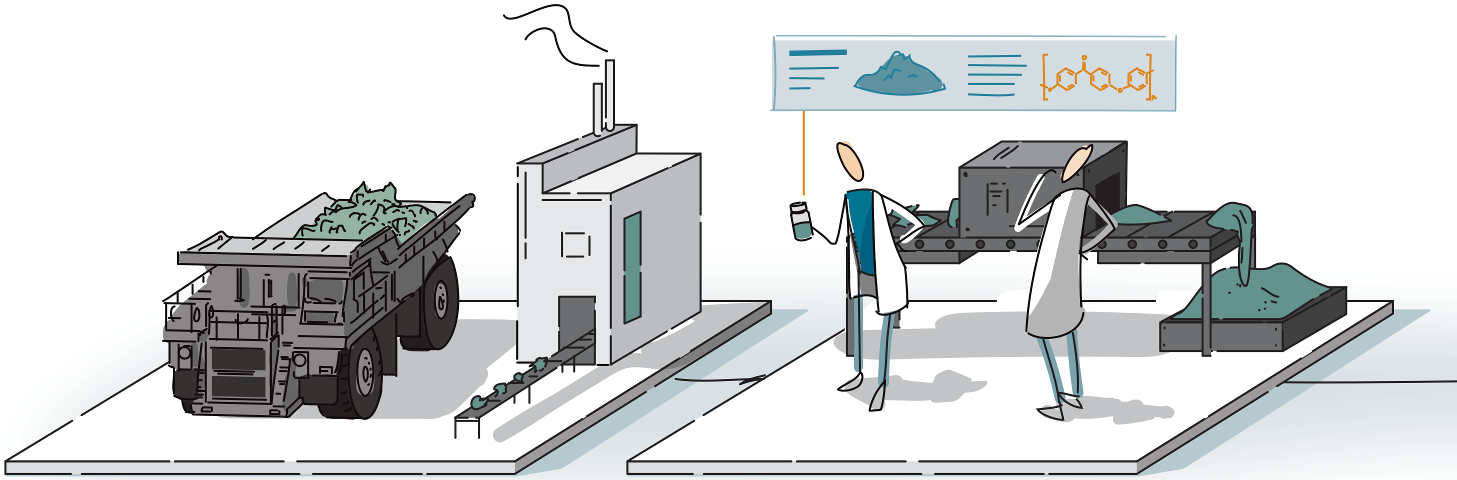
The cell cathode consists of an aluminium collector foil coated with a lithium-metal oxide. The anode is generally a copper collector foil coated with graphite. Lithium ions can move between the two electrodes through a saline electrolyte (generally a lithium salt such as $LiPF_6$ in an organic solution). During discharge of the battery, electrons flow from the negative anode to the positive cathode, and the positively charged lithium ions are inserted into the host lattice of the cathode active material. During charging of the battery cell, this flow is reversed: the lithium ions accumulate in the layers of the graphite electrode, which then becomes the cathode.

To date, two types of LIB have proved successful as traction batteries for use in cars: those with a nickel, manganese and cobalt (NMC) cathode, and those with a nickel, cobalt and aluminium (NCA) cathode. Other cathode materials used in electric vehicles are lithium iron phosphate (LFP) and lithium manganese oxide (LMO).

Battery components and their estimated weight. *(Source: Accurec Recycling GmbH 2020)*

| Battery components | Material | Weight-% |
|---|---|---|
| Casing | Steel or aluminium | 20–25 |
| Cathode | LCO, NMC, NCA, LFP or LMO | 25–35 |
| Anode | Graphite | 14–19 |
| Electrolyte | Lithium salt in an organic solution | 10–15 |
| Cathode collector foil | Aluminium | 5–7 |
| Anode collector foil | Copper | 5–9 |
| Separator | PP, PE polymers | 1–4 |
| Additives | Carbon black, Silicon etc | |

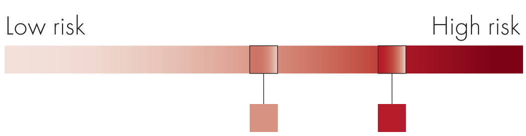
# Supply chain of a lithium-ion battery

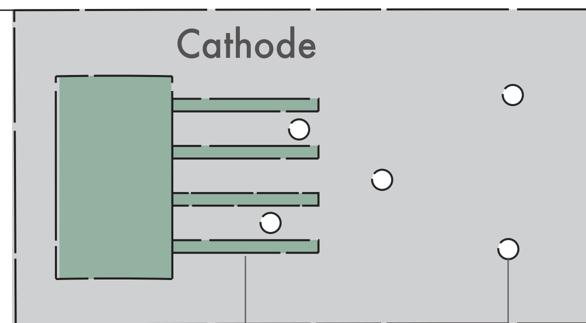


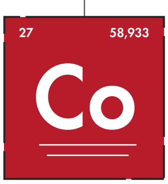
Mine production and refining

Precursor manufacturing (powder, paste)

## Raw material supply risk

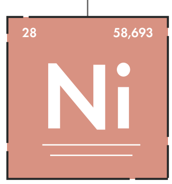


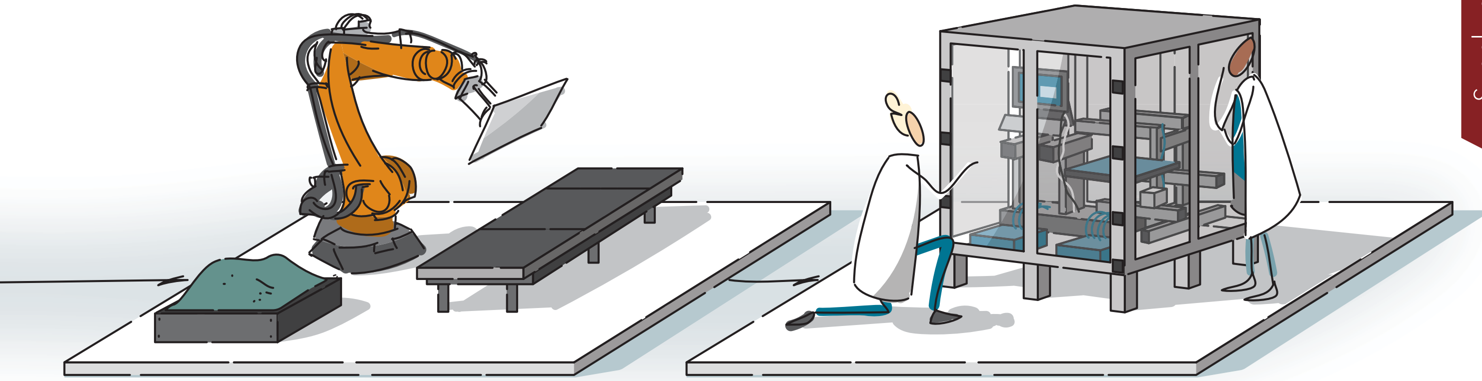

### Cobalt
**High supply risk**

- Political instability in the DR Congo
- Reputational risks associated with the use of cobalt from small-scale mining
- Potential supply deficit in mining
- China expands market share in mining
- China controls processing, with a market share > 60 %



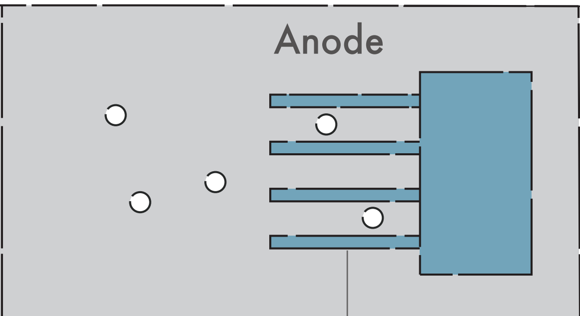

### Nickel
**Indonesia is key**

- Battery production will become largest driver of growth in global demand
- New processing capabilities, esp. in Indonesia (export ban for nickel ore)
- Environmental damage from processing
- Recently moderate concentration of supply in production and processing

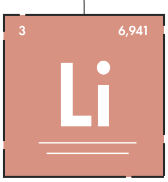


Cathode, anode & electrolyte manufacturing

Cell manufacturing and battery pack assembly



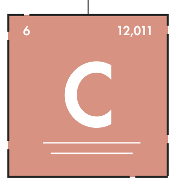

Market Environment Government




## Lithium

### All in on future demand

- Electric vehicles provide strong stimulus for demand
- Massive expansion of cell capacity with no supply deficit in the medium term
- High concentration of supply in production and processing
- Sharp price increase between 2016 and 2018
- Challenges in the downstream sector




## Graphite

### Chinese dominance

- China dominates mining of flake graphite and production of synthetic graphite
- Processing of natural graphite has high environmental impact
- New capacities in flake graphite mining
- Recent price increase in battery grades

# E-mobility: modern traction batteries

## need many mineral raw materials

**Today, cell manufacturers use a mixture of aluminium, cobalt, lithium, manganese and nickel for the cathode, and graphite as the anode material. In a growing electric vehicle market, the demand for these battery raw materials will rise sharply.**

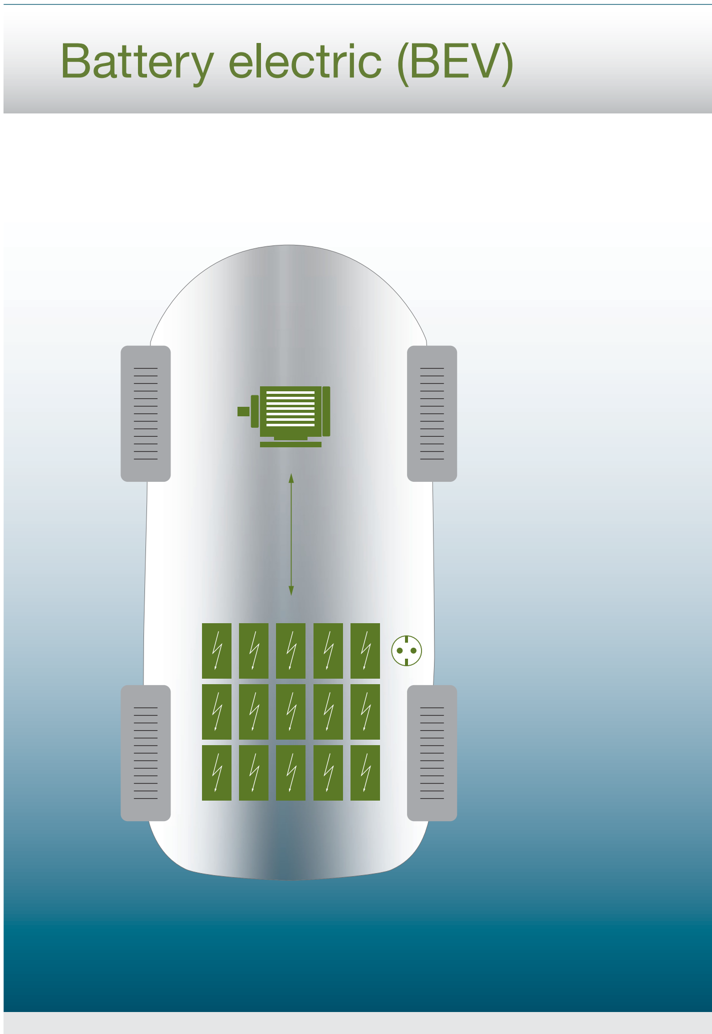
The term e-mobility covers a range of different electric drive concepts. In addition to a full battery-electric vehicle (BEV) powered exclusively by an electric motor, hybrid concepts also exist. In "simple" hybrid vehicles (HEV), the vehicle is powered by an internal combustion engine (ICE). Energy is recovered during braking, stored in a battery and can then be used for acceleration. A plug-in hybrid electric vehicle (PHEV) has an ICE, too, but its battery can also be recharged externally. Fuel cell electric vehicles (FCEV) also temporarily store the generated energy in a battery.

Electric drive energy is stored in rechargeable traction batteries, which are going to fundamentally change future raw material demand in the mobility sector. Particularly the increase in demand for lithium and cobalt for electric vehicles is having – and will continue to have – a major impact on raw material markets. And the markets for nickel and graphite are also changing considerably with the increased use of these raw materials in LIBs.

Global R&D is currently focused on the development of new generations of cells with a higher specific capacitiy. For NMC cathodes, the goal are optimised cells with an NMC 811 ratio, i.e., using nickel, manganese and cobalt in a ratio of 8:1:1. Compared to an NMC ratio of 1:1:1, this corresponds to a reduction in cobalt content by about 70 % and a doubling of the nickel content. Efforts are being made to further reduce cobalt or even eliminate it completely.

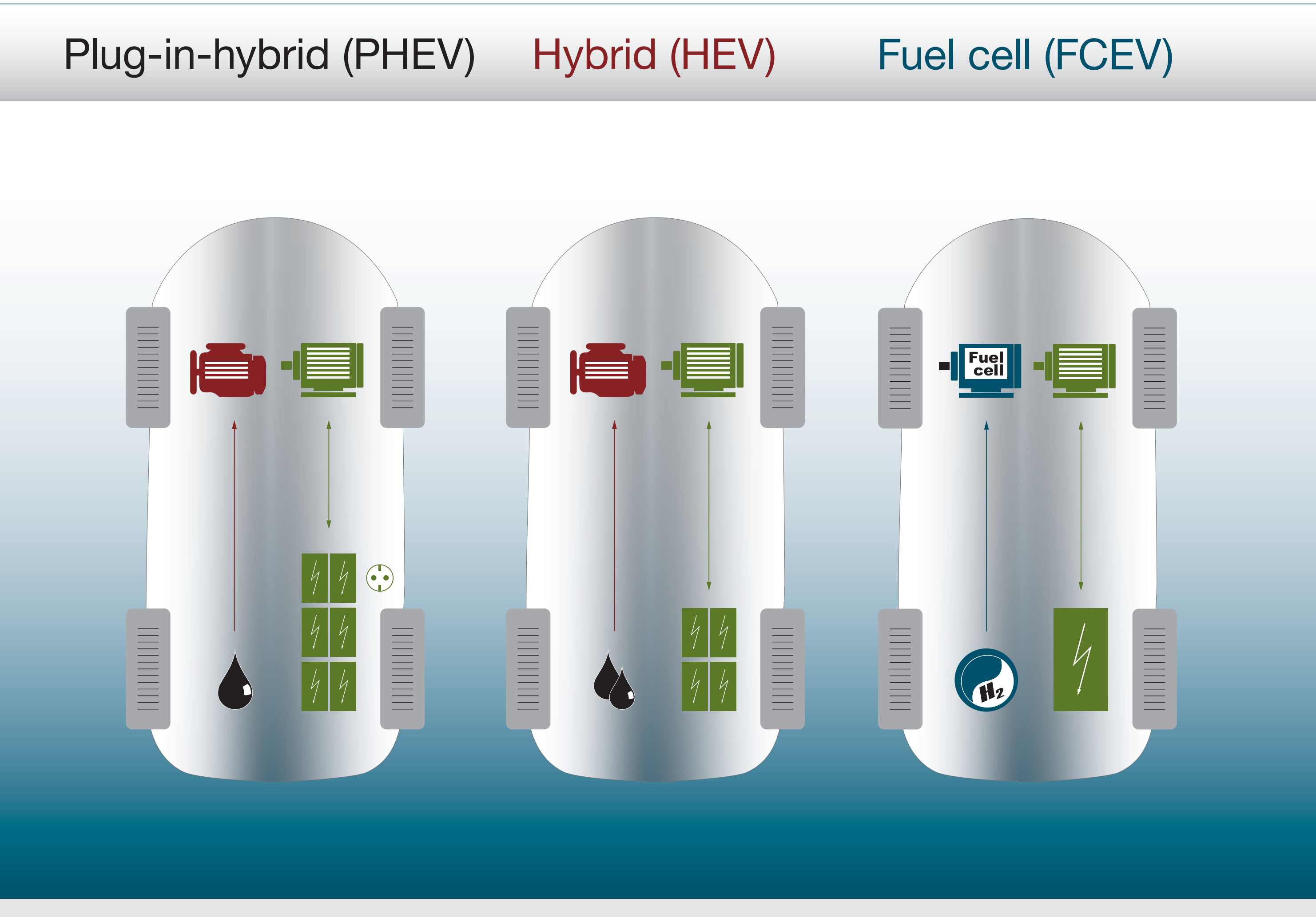
Research is also being carried out on the anode. Graphite is the state of the art in anode materials for LIBs. In addition to good availability and relatively low cost, key factors are in particular the material's specific capacity and its low operating voltage, which permits a high cell voltage. But especially silicon, with a specific capacity about ten times higher than graphite, has in recent years gained greatly in importance as a potential anode material.

Today, it is sometimes used as an additive in graphite-based anodes. Obstacles preventing the wide-




spread commercial use of silicon anodes, however, are major structural and volume changes during charging and discharging, which lead to losses in capacity, lifespan and cycle stability.

The total capacity of a battery is limited by the material with the lowest lithium ion storage capacity. This is generally the cathode. Consequently, given the relatively low specific capacity of current commercially available cathode materials, a capacity




increase of the anode will only help increase the total cell capacity up to a certain degree. Graphite can be assumed to remain the anode material of choice in the medium term.

DERA bases its modelling of demand for LIB cells for electric vehicles until 2030 on the scenarios developed by Fraunhofer ISI and Fraunhofer IZM as part of the commissioned study "Raw materials for emerging technologies". The optimistic scenario predicts global growth in demand for LIB cells for electric vehicle applications from 500 gigawatt-hours (GWh) in 2020 to 3,000 GWh in 2030.

# Battery cell production in Germany –
## expansion is progressing

**To date, modern traction batteries have been developed and produced mainly in Asia. With political support, German industry is now starting to establish domestic cell research and production, affecting Germany's raw material demand.**

**Volkswagen**
Location: Salzgitter
Capacity: 16 (40)* GWh
Start: 2025

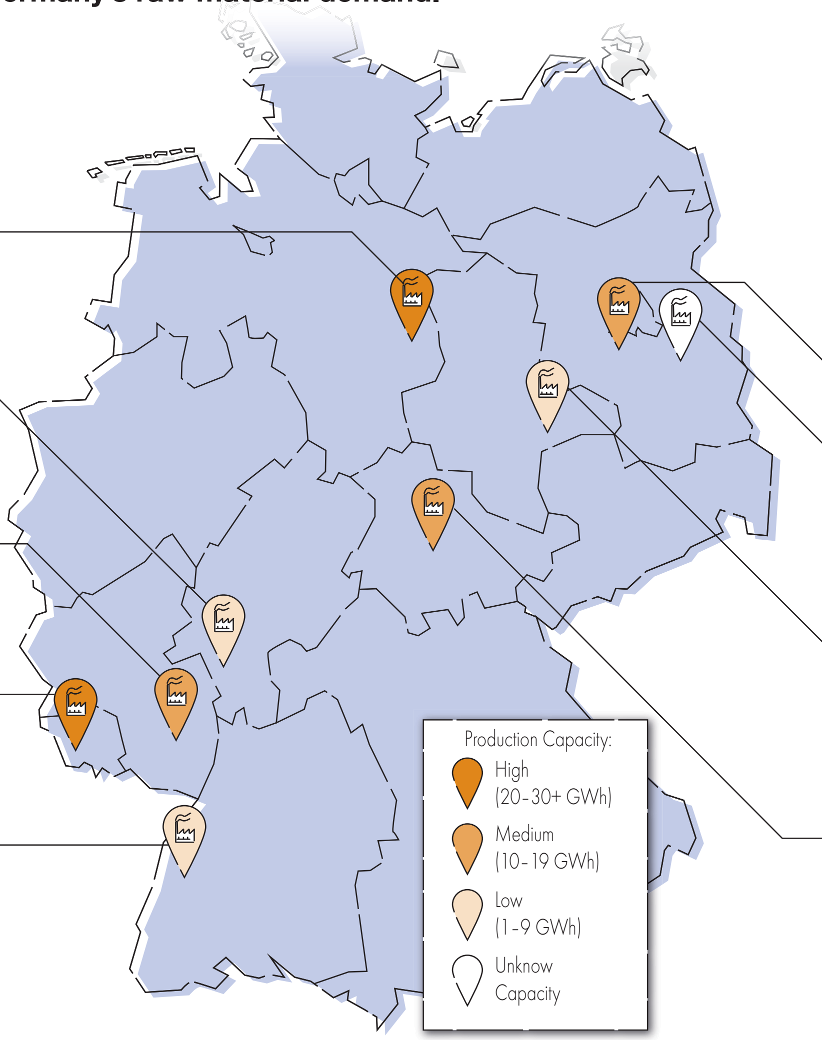
*Values in parenthese describe planned extension stages

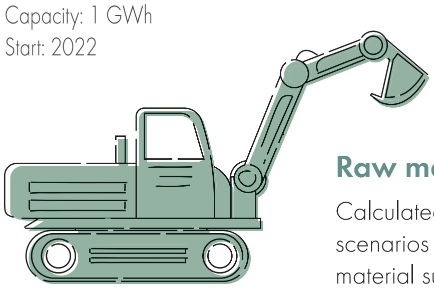
**Akasol**
Location: Darmstadt
Capacity: 2,5 (5)* GWh
Start: 2021

**Saft PSA Groupe**
Location: Kaiserslautern
Capacity: 16 (64)* GWh
Start: 2022

**SVolt**
Location: Überhern
Capacity: 24 GWh
Start: 2022

**Leclanché**
Location: Willstätt
Capacity: 1 GWh
Start: 2022



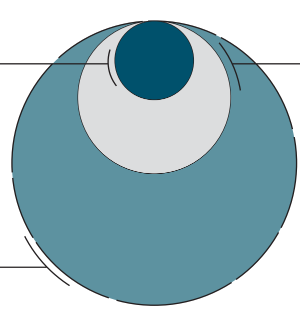
### Raw material demand in Germany

Calculated demand for lithium, cobalt and nickel for cell manufacturing capacity scenarios of 55 GWh** and 215 GWh** respectively, and implications for raw material supply based on 2018 production figures.

### Lithium (Li)

At 55 GWh**
7.000 t
8 % of 2018

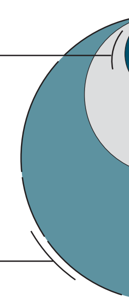
At 215 GWh**
28.000 t
38 % of 2018



Global total in 2018:
91.000 t lnh.

### Cobalt (Co)

At 55 GWh**
14.000 t
10 % of 2018



Global total in 2018:
140.000 t lnh.

Politicians and industry leaders in Germany are working to establish battery cell production and advance research. Car makers such as BMW are relying on established cell manufacturers: the Chinese company CATL, for instance, will be producing LIBs in Arnstadt, Thuringia from 2022 to cover part of BMW's demand. Daimler and the French PSA Group have also embarked on strategic partnerships with battery manufacturers; they are planning to build production facilities for traction batteries in Germany, or have already done so.

**Microvast**
Location: Ludwigsfelde
Capacity: 12 GWh
Start: 2021

**Tesla**
Location: Grünheide
Capacity: ?
Start: 202X

**Farasis**
Location: Bitterfeld-Wolfen
Capacity: 6 (10)* GWh
Start: 2022

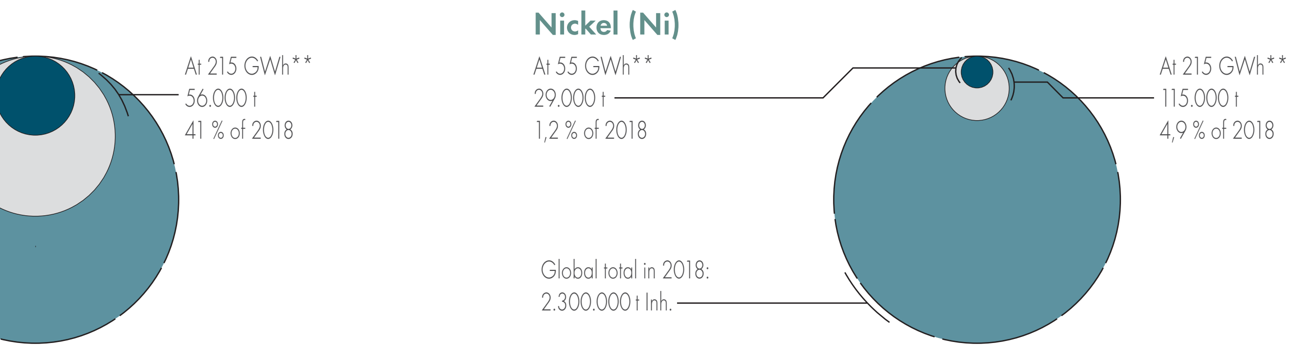
**CATL**
Location: Arnstadt
Capacity: 14 (60/100)* GWh
Start: 2022

The raw material demand for various levels of expansion has been calculated based on existing or planned cell production capacities. If all known projects start production with the initial capacity specified, a total annual capacity of 55 GWh will result. If the various sites are developed and expanded over the next few years as planned, annual capacity could rise to between 215 and 245 GWh.

The expansion of cell production capacities in Germany will affect raw material demand. In order to determine the demand in different scenarios, a number of assumptions were made regarding market penetration of the various NMC cathode specifications. NCA batteries, which are mostly used by Tesla, were not included in the calculations. The resulting demand was then expressed as a share of the 2018 mining output for each raw material.

The 55 GWh scenario results in annual demand of around 7,000 t of lithium and of around 14,000 t of cobalt; this is equivalent to 8 % and 10 % of annual global mining output of lithium and cobalt respectively. Because of the size of the nickel market, the share for nickel is relatively small at around 1 %.

**** Market share**

# Cobalt: DR Congo as key supplier –

## price volatility reflects supply uncertainty

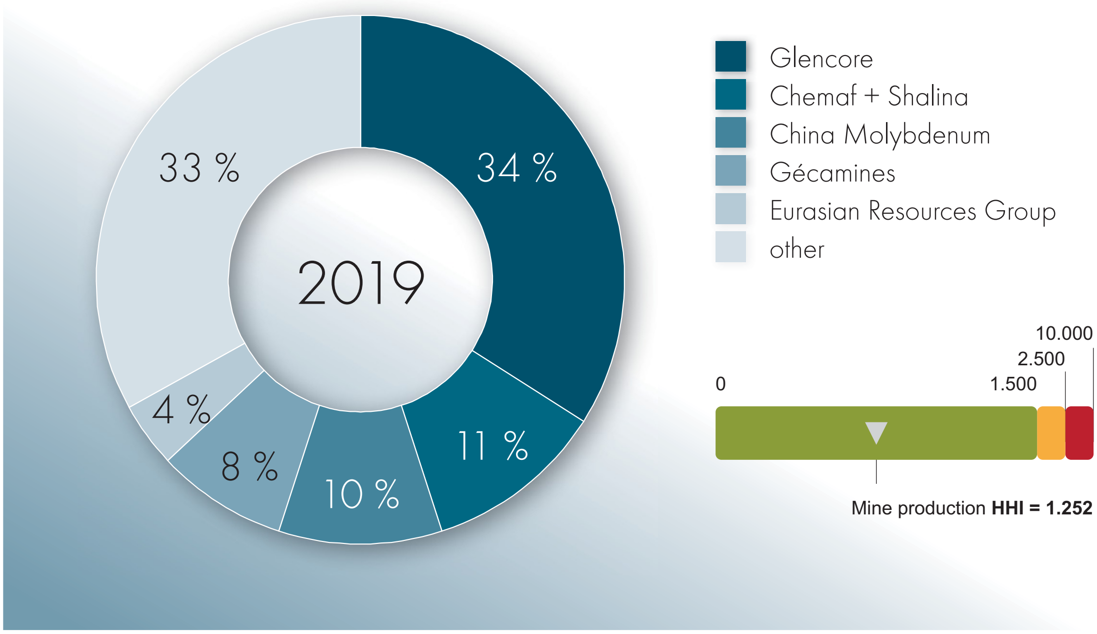
**Cobalt currently has the highest supply risk of all battery materials. Reasons are especially the expected dynamic demand and the resulting potential supply shortages. In particular the role of the DR Congo, by far the largest producing country, is causing high risks for strategic planning.**

In the next few years, the demand for cobalt will be highly dynamic. Rechargeable batteries, which use cobalt as a cathode material, are the main driver of growth. LIBs for electric vehicles will account for the largest share of this growth; additional factors in the overall rise in demand are the storage of renewable energy and mobile applications, as well as the use of cobalt for tool steel applications and superalloys.

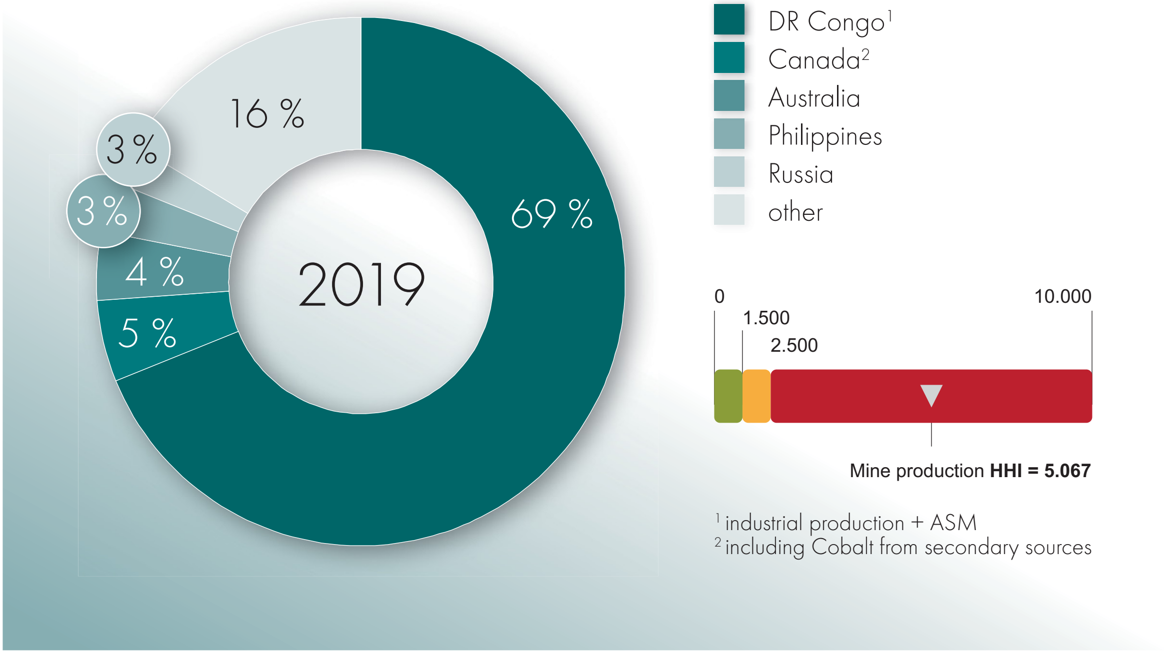
Because of the large number of very dynamic variables, the modelling of cobalt demand that is likely to result from the future key growth segment electric vehicles is complex and subject to uncertainties. Growth of the electric vehicle market and the chemical composition of LIB cathodes will have the greatest impact on future cobalt demand. With advances in the development of low-cobalt or even cobalt-free cathodes and of alternative drive technologies, overall demand could be considerably reduced. Based on current demand scenarios, cobalt demand for electric vehicles could rise by a factor of 20 to up to 315,000 t in 2030, presenting a major challenge for the mining industry.

Cobalt extraction from Congolese copper mines has dominated the global market for over ten years, and this is not likely to change in the foreseeable future. If demand rises further, the DR Congo could even expand its market share well beyond its considerable current level of 69 %. A rise in copper and cobalt prices could certainly justify recommissioning of the Mutanda copper-cobalt mine in the DR Congo.

Before the mine was put on care and maintenance, 25,100 t of cobalt were extracted here annually until the end of 2019. Other major projects are currently under development. Outside Central Africa, cobalt is a by-product from nickel and nickel-copper mines. However, production at the Ambatovy




Company concentration of mine production (Source: S&P Global Market Intelligence LLC 2020)




Country concentration of mine production (Source: S&P Global Market Intelligence LLC 2020)

(Madagascar) and Goro (New Caledonia) mines has been stopped for the time being, because of the recent low price for nickel.

The highly volatile cobalt price is presenting a major challenge for both the mining industry and end users. When the cobalt price last peaked, in 2018, one short-term effect was that necessary investment decisions were made to expand new production capacities. The price surge also resulted in a massive growth in artisanal and small-scale cobalt mining.

The two largest artisanal mines in the DR Congo, Kasulo und Mutoshi, each achieved annual production of several thousand tonnes of cobalt content. Overall, the price peak resulted in a surplus from the highly responsive small-scale mining sector, which marked the start of a price decline from June 2018 onwards.

Over the last two years, China has further developed its processing capacities and now dominates the refining of cobalt chemicals in particular. Europe has restructured its reprocessing capacities and will expand them further, above all to better meet European demand in the future.

The high concentration in supply in both mining and processing, the uncertainties regarding future market supply, and particularly the sometimes precarious mining conditions in small-scale production all result in a higher supply risk. Around 10–20 % of cobalt from the DR Congo is extracted in small-scale mines. Associated problems such as poor environmental and social standards require a high level of supply chain due diligence. Several initiatives therefore aim to create maximum transparency of the cobalt value chain, for instance, to effectively and sustainably stop child labour. This is even more crucial since the DR Congo will continue to be by far the largest producer of cobalt in the next few years.

# Nickel: Indonesia assumes a key role –

## LIBs are future drivers of growth

**Nickel is used mainly for the production of stainless steel and nickel alloys. In future, however, battery production will be the main driver of demand. Indonesia, by far the largest producer of nickel, plays a key role in this respect.**

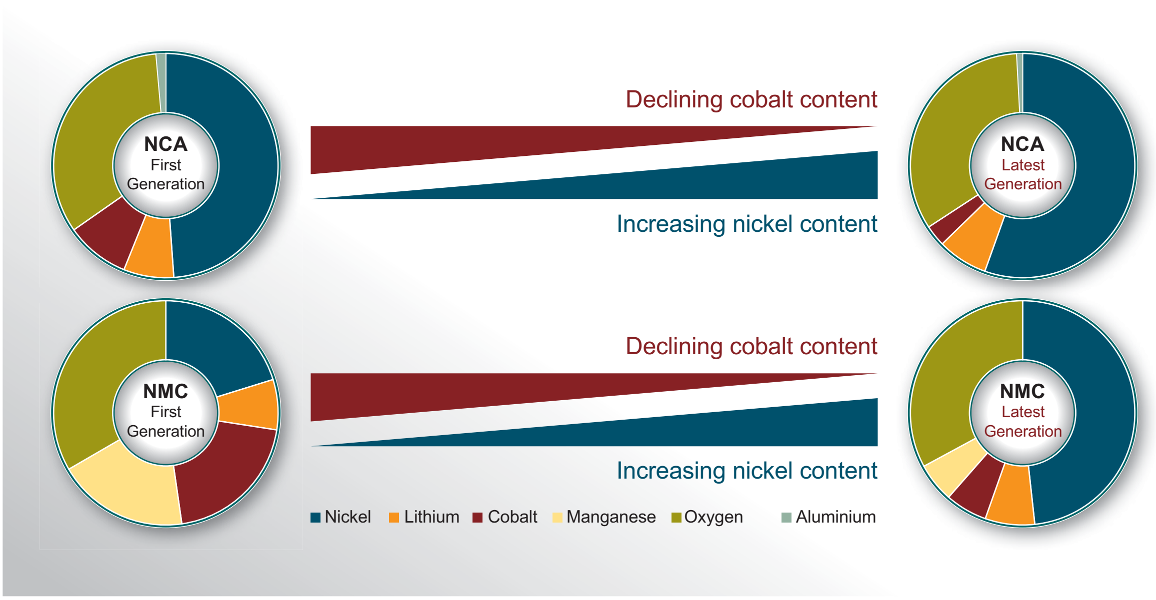
Nickel is traded on the major metal exchanges, which permits transparent hedging of prices for this raw material. But there are uncertainties affecting future supply: less than half of the nickel currently produced globally can be processed into battery-grade nickel sulphate in an economically viable way.

A significantly higher nickel content in optimised cells increases the energy density of LIBs. This makes nickel demand for batteries the first-use application with the highest future growth rates. In 2019, global LIB demand for nickel from primary and secondary sources already amounted to more than 150,000 t, which was roughly equivalent to 5 % of global demand for primary nickel. By 2025, demand from the electric vehicle segment could rise to around 500,000 t annually, becoming about 15 % of total global demand.

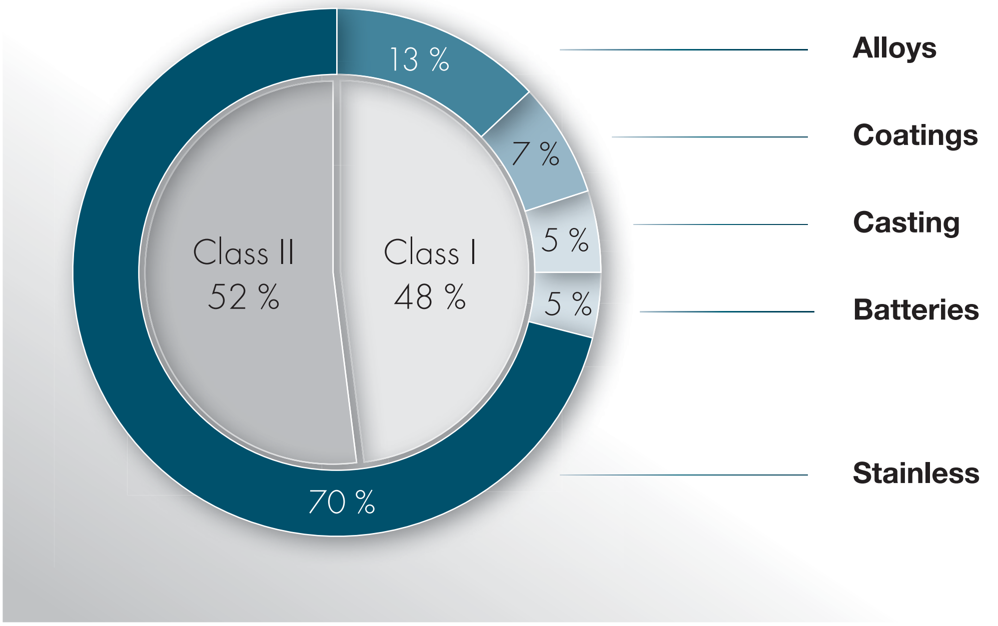
At more than 70 %, the main use of nickel will still be stainless steel production, where class I nickel (nickel content > 99 %), and particularly nickel from secondary raw materials and class II nickel (nickel content < 99 %) are used. While most class II nickel is extracted from laterites, class I nickel is produced primarily from sulphide ores and increasingly also from laterites.

Nickel sulphate is used as a precursor in LIB manufacture. Relative to the total supply of nickel, battery-grade nickel sulphate is still a niche product. It is produced from class I nickel, a range of intermediate products from nickel production, and secondary raw materials.

Because of the high investment cost and the recent extended low-price period for nickel, only few nickel sulphide projects, most of them for class I nickel, have been further explored or brought (back) into production in recent years. As a result, the supply of new class I nickel or nickel sulphate produced from it has also stagnated. It is essential that new produc-




Changes in cell chemistry. Evolution of cell chemistry will lead to an increase in nickel content. This implies that the future demand for nickel is not only dependend on the breakthrough of E-Mobility in general but also dependend on the evolution of cell technology.




Current nickel supply and demand. Only half of the currently produced Nickel is suitable for the production of LIB. (Source: modified after Vale 2018).

tion channels are found or existing ones expanded, to increase the supply of nickel sulphate and thus satisfy the future growth in demand.

The additional primary supply will come mostly from laterite deposits. Already today, a significant share of class I nickel and nickel sulphate is produced from laterites using the hydrometallurgical process of high pressure acid leaching. Large parts of this supply will continue to come mainly from Australia and Oceania, as is the case today.

An additional supply of nickel sulphate will become available from LIB recycling. Substituting class I nickel in stainless steel production can also improve the availability of high-purity nickel. And in times where nickel prices are very high or the availability of high-purity nickel too low, some class II products may be used, too.

Much will in future depend on the vast supply of primary nickel from laterites in Southeast Asia, and particularly Indonesia, the largest nickel-producing country by far. Indonesia banned the export of nickel ores in 2020, pursuing a strategy of establishing additional parts of the value chain domestically. Today, Indonesia is the world's second largest producer of so far only class II nickel, after China. Particularly given the many nickel processing projects currently under development or construction in Indonesia (also for the production of nickel sulphate or its precursors), the country will have to cover most of the demand forecast, including the demand for higher-quality nickel products for LIB production.

In addition to simply meeting future demand, the focus is especially on the environmental aspects of producing and processing nickel (such as land use, use of water and energy, emissions, and the handling of mining residues).

# Lithium: not just part of the name –

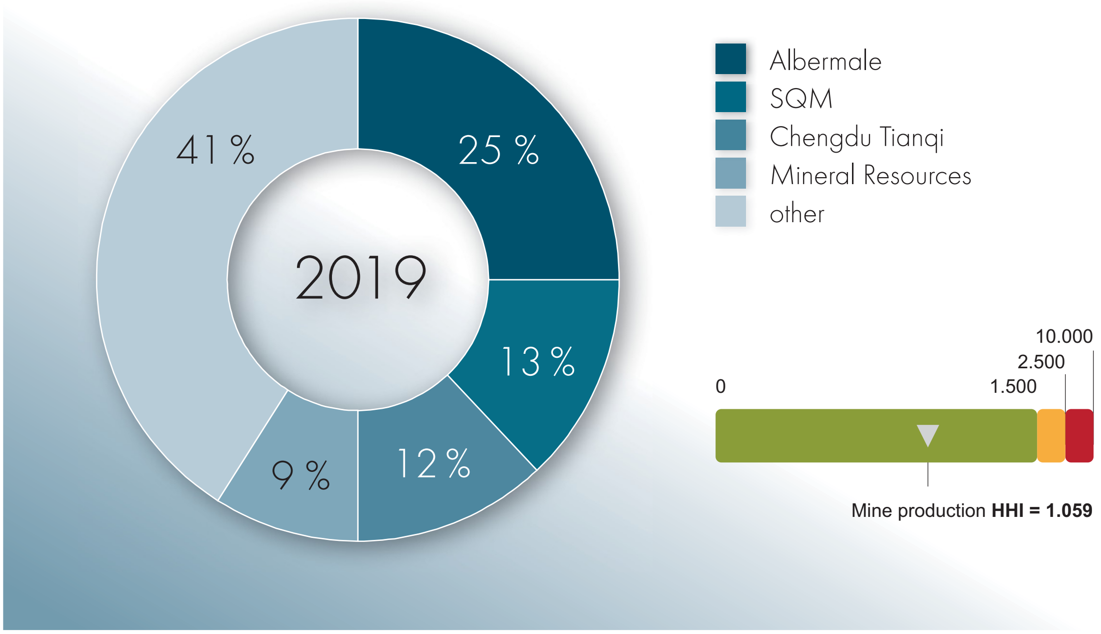
## an essential part of a traction battery

**Despite the surge in demand, there will be sufficient lithium resources in the long term for growth of the electric vehicle market. As a result of the lithium boom, many new projects have been developed and large investments initiated. But these new projects will hardly reduce the high concentration in supply from just a few countries and companies.**

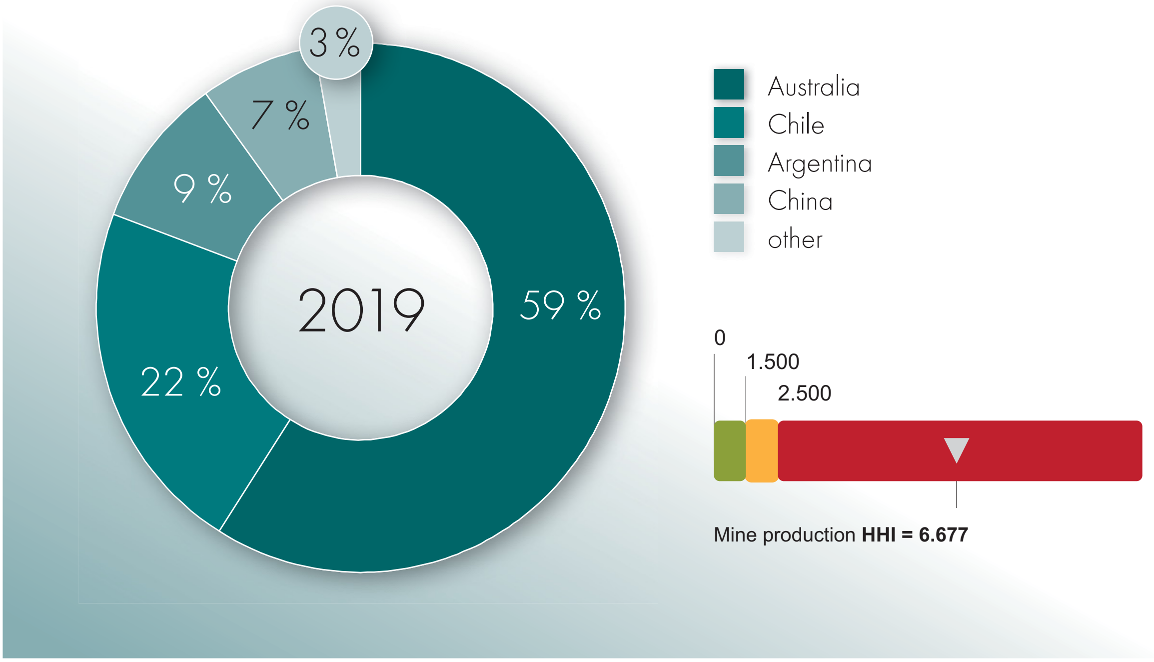
Accounting for 6–12 wt%, lithium is not the largest constituent of a modern traction battery by either quantity or value. But all generations of cells – NMC, NCA, LMO or LFP – use lithium in the cathode material. And since the lithium market is small, the expected rise in demand relative to today's production level is particularly high. Our demand scenarios show that supply would have to triple by 2026 just to meet the future demand for electric vehicles.

Today, lithium mining is concentrated in three countries. Australia has stepped up production considerably in recent years and is now the main mining country. Lithium is mined there from hard rock and the concentrate is exported mainly to China, where it is processed into battery-grade lithium carbonate and/or hydroxide. South America, particularly Chile and Argentina, is the second major mining region, where lithium is produced from brines and processed into lithium carbonate mostly locally. South America also has the largest lithium reserves. Each of the two lithium sources, hard rock and brine, accounts for about 50 % of the market, with a strong trend towards hard rock deposits.

At present, the lithium market is dominated by only a handful of companies, with just four of them controlling almost 60 % of global production. But as the lithium boom in recent years has shown, the market is facing major changes. A sharp rise in the lithium price, which has tripled since mid-2016, resulted in a veritable regular investment boom, particularly in Australia. Very swiftly, new projects went into production. In South America too, existing projects were expanded and new projects launched, some




Company concentration of mine production (Source: S&P Global Market Intelligence LLC 2020)




Country concentration of mine production (Source: S&P Global Market Intelligence LLC 2020)

of them with large capacities. The background for this development is the desire to exploit the existing cost advantage over Australian hard rock projects in order to secure or expand market shares. Large projects are also at the planning or implementation stage in Canada, Mexico and Bolivia.

And Europe, specifically Germany, has lithium resource potentials, too. An assessment of these new projects by DERA shows that there is an adequate supply of lithium, even in an optimistic scenario for electric vehicles. Surplus quantities, such as we are seeing at the moment, and a delay in demand have led to a sharp drop in prices. To counteract further price erosion, the implementation of some projects and the scaling up of production have therefore been delayed.

But even with these new projects, the high concentration of just a few supplier countries will continue. And particularly customers from Asia have secured their supply with long-term procurement contracts, which considerably reduces the lithium quantities freely available on the global market. Recently reported strategic investments and takeovers in the lithium market, such as the investment by the Chinese company Chengdu Tianqi in the Chilean mining firm SQM (Sociedad Quimica y Minera de Chile SA), could have an adverse effect on competition in the long term.

The processing industry is likely to acquire even larger stakes in primary production. Especially Asian manufacturers of cells and precursors (cathode powders and pastes) are trying to secure direct access to lithium through backward integration and investments in mines.

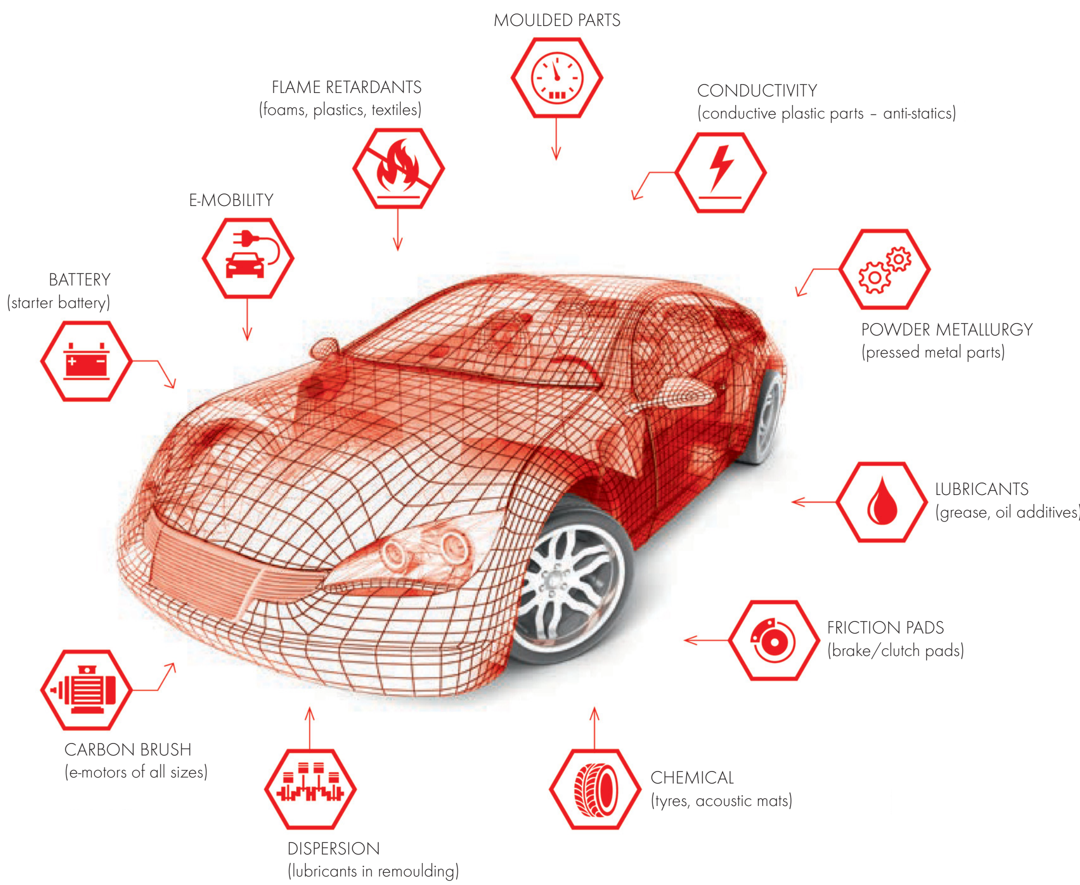
# Graphite: high market concentration –

## along the entire value chain

**In terms of quantities, graphite is the most important constituent of modern lithium-ion batteries, and demand will therefore rise sharply in the next few years. The risks lie primarily in the high concentration of supply, with China controlling almost the entire value chain.**

While a range of compositions compete on the cathode side, current LIB anodes are predominantly graphite-based. Graphite has the highest volume fraction of all battery materials, as well as accounting for a major share of the cost in cell production. Moreover, graphite is used in a range of other automotive applications.

is produced by graphitisation in furnaces. But a comparison of the two raw materials in terms of their suitability as an anode material is not straightforward. Particularly the chemical and thermal purification process steps required for very high-purity batteries tend to be more complex for natural graphite and can drive up costs.



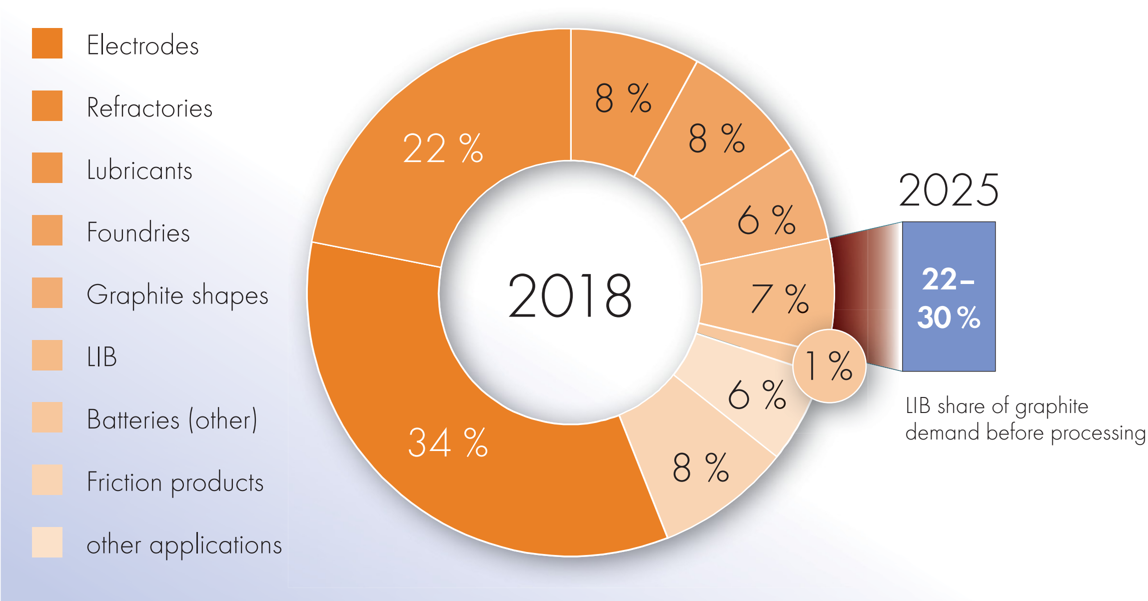

Graphite in automotive appications (Source: Kropfmühl GmbH 2020)

LIBs use both natural graphite in the form of flake graphite, and synthetic graphite. The choice of raw material is primarily dependent on cost, but also on application, and mixing the two graphite types is common. Natural graphite is a mining product and as such cheaper than its synthetic counterpart, which

When looking at future supply, both graphite types and the entire value chain including battery grades and anode production therefore have to be taken into account. It is noticeable that China has dominated almost the entire supply chain and the market for both graphite types for years. It currently accounts

for just under 50 % of global production of synthetic graphite, and market concentration is even higher for flake graphite. As regards the mining of flake graphite, China has large deposits, particularly in the Northeast, and has dominated global mining of natural graphite for many years. Flake graphite currently accounts for just under 70 % of the total quantity of natural graphite mined globally, with China's share also at just under 70 %. For some years now, exploration efforts and investments in new graphite deposits have increased, especially in East Africa. New projects in particular, some of them on a large scale, in Mozambique, Tanzania and Madagascar are already contributing to the supply of the global market with flake graphite, while others could do so in future. This would help ease the situation on this highly concentrated market.

Although increasing diversification of mining could help ease the situation on the global graphite market, there are risks to a secure supply related to the processing of flake graphite to battery grades. Flake graphite has to be purified in a series of high-energy, chemical-intensive process steps and shaped into spherical graphite to be used as an anode material. Processing to this specification takes place almost exclusively in China. Also coating, the final process step to improve the properties of the anode material, is currently carried out mostly in China, although Japan, the former global leader in this technology, still holds major market shares, particularly in anode material for use in high-end applications. Country concentration is also high in anode production, where, again, Chinese companies dominate the market. Increased supply risks resulting from high market concentration exist for both graphite types and along the entire value chain for battery-grade graphite.




Application of graphite and estimated future demand for LIB until 2025 (Source: Roskill 2025)

Other experimental anode materials are currently at the development stage, such as silicon, lithium metal or lithium titanate. But until they are ready for the market, graphite can be expected to remain the commercially most significant anode material in the medium term.

# Manganese

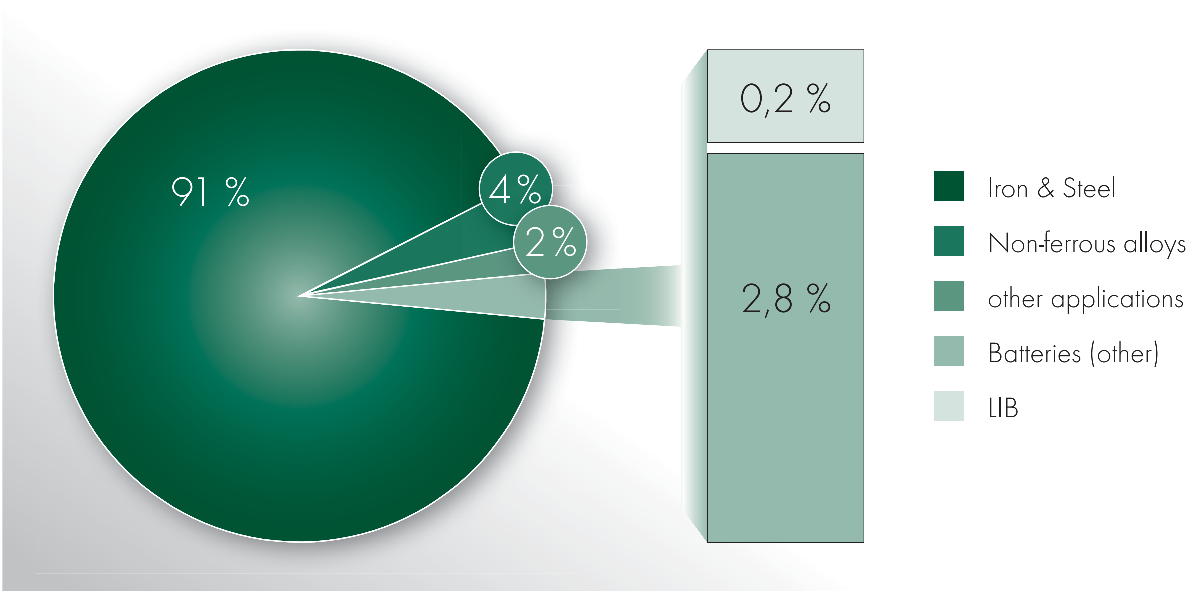
**The use of manganese in lithium-ion batteries is steadily increasing. Efforts are being made to use more manganese and nickel in batteries while eliminating cobalt as far as possible.**

Manganese is currently used in a range of battery types, but battery applications are still of minor importance for the manganese market. At present, only about 0.2 % of manganese produced globally is used in LIBs, with all battery types accounting for 3 %. The most important area of application for manganese at more than 90 % is still the steel industry. In 2019, 64.2m t of manganese ore were extracted, which is equivalent to 22.5m t of manganese. The main producing country is South Africa (33 %), followed by Australia (14 %) and Gabon (11 %). Depending on their manganese content, manganese ores are classified as low, medium or high grade, each used for different applications.

LIBs use manganese in NMC and LMO cathodes. In NMC cathodes, it is used in the form of high-purity manganese sulphate. This can be produced either directly from high-grade (or battery-grade) manganese ore by leaching, or via the production of electrolytic manganese metal (EMM) from ores of any grade. LMO cathodes use manganese in the form of electrolytic manganese dioxide (EMD), produced mostly from high-purity (high-grade) manganese ores. China is currently the largest importer of manganese ore worldwide, with a share of more than 70 %, and the main producer of intermediate products also for battery production, such as EMD (99 %) for LMO cathodes, or EMM (94 %) and high-purity manganese sulphate (91 %) for NMC cathodes.

Because of the rising demand for LIBs for electric vehicles, more manganese will be used, particularly in the form of manganese sulphate and manganese dioxide. But even if the current manganese demand for battery applications doubles or triples, the market share for LIBs is not expected to exceed 1 % (or 5 % for all battery types). The steel industry can be expected to continue as the main driver of demand in the manganese market.

Manganese supply is currently not considered critical, since global demand for manganese will not exceed supply in the medium term. Nevertheless, an eye should be kept on the high concentration of processing for battery applications in China.




Application of manganese. (Source: Roskill 2015, 2019)

# Aluminium and copper

**Other than cathode and anode materials, additional raw materials such as aluminium and copper are also needed for traction batteries. Both of these are used as carrier materials; aluminium as the carrier for the cathode material (cathode collector foil) and copper as the carrier for the anode material (anode collector foil).**

When several battery cells are combined into modules, they have to be electrically connected and held together by copper and aluminium materials. Several battery modules are then combined into a battery pack, again, using aluminium and copper materials. Aluminium therefore accounts for around 25 % of the weight of a battery pack, copper for around 12 %.

A battery pack and cooling system installed in a battery case together form the battery system. The battery case has the important task of providing lasting protection for the traction battery from external impacts, especially damage. Battery cases are made from aluminium and steel.

Although the demand for copper and aluminium will rise as battery production expands, this is not likely to lead to major changes in demand for these two raw materials. Compared to the existing supply, the absolute demand for LIBs is still very low. In 2018, refinery production from mined and recycled copper was at around 24m t, refinery production of aluminium even at almost 80m t. The relatively small quantities needed for traction batteries have no significant impact on these markets.

# Commodity prices: high volatility –

## a surge followed by a slump

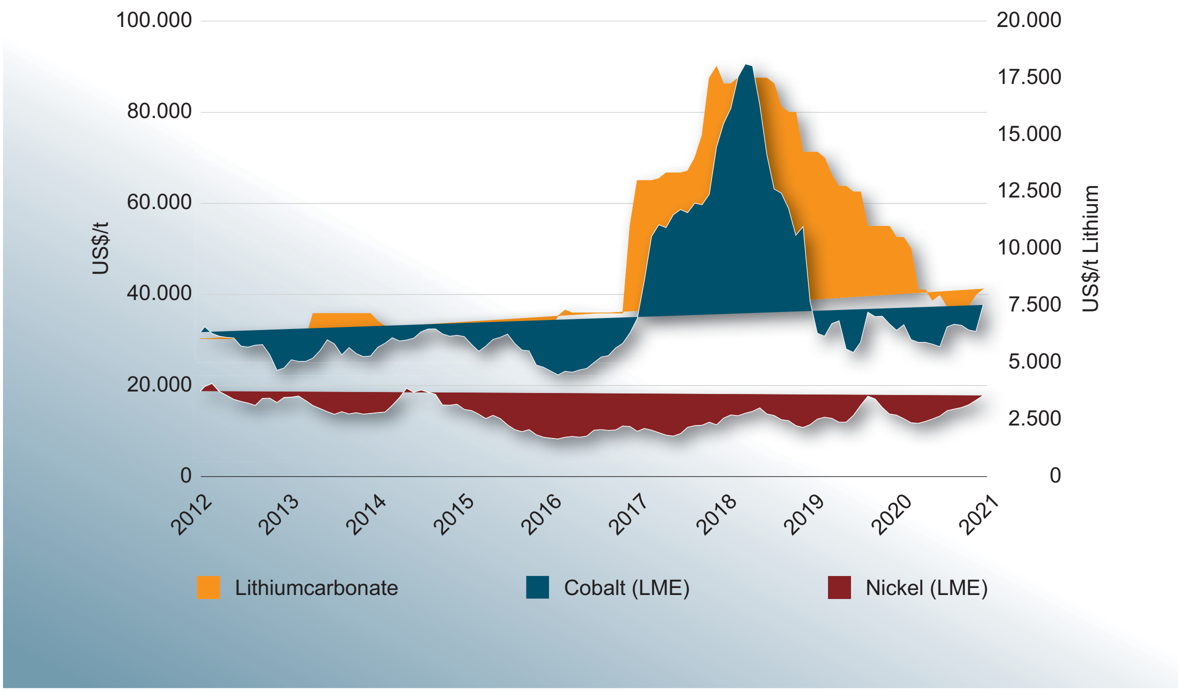
**After the rapid price surges and euphoria of 2017/2018, prices for lithium and cobalt fell again significantly. Demand could not absorb the rapid expansion in production.**

Over the past four years, prices for battery raw materials have been volatile. The price rally was driven in particular by expectations of a sharp increase in demand for battery raw materials and the resulting concern about possible delivery and supply shortages. While the situation caused commodity buyers sleepless nights, the hype led to a veritable gold rush atmosphere among investors.

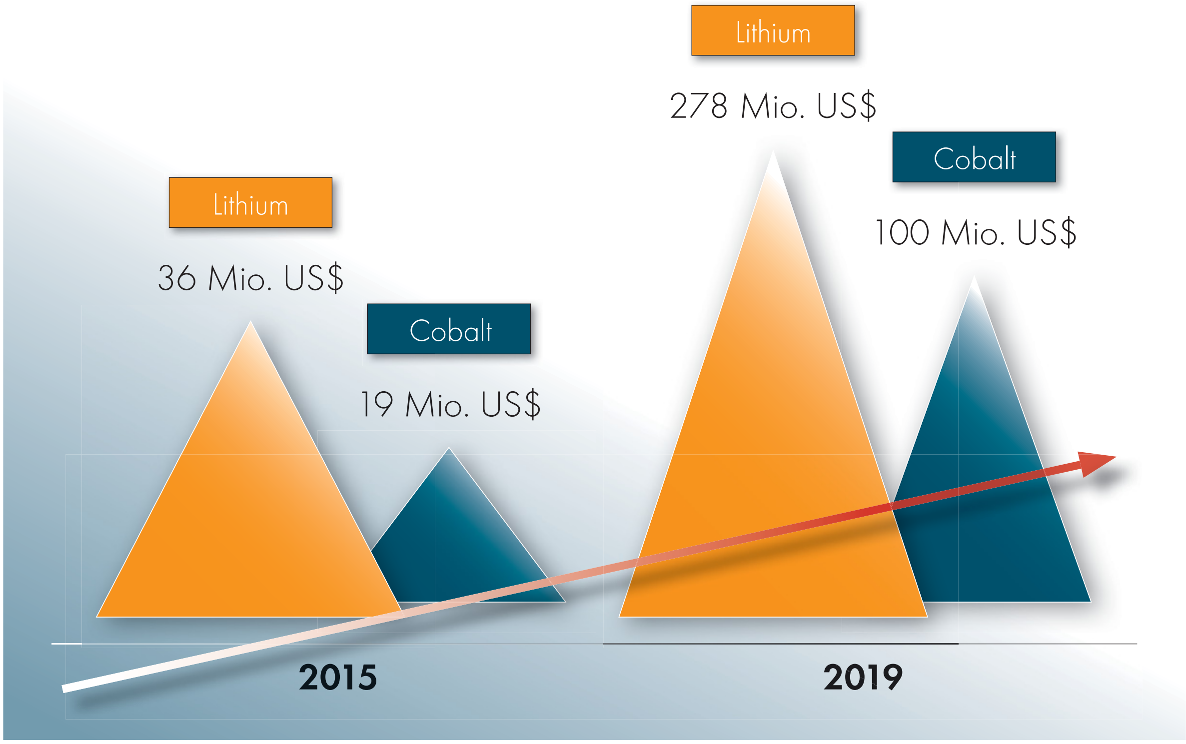
Skyrocketing prices for two battery raw materials in particular caused a stir, also in the media. By the end of 2015, the price for lithium had tripled within just 24 months. Shortly afterwards, the cobalt price started to soar, quadrupling within two years. This was followed by a price correction in 2018, with prices dropping back to the level before the commodity price boom. The price increase previously observed prepared the ground for the rapid drop in prices. As a result of the sharp increase in prices and optimistic forecasts of future demand, raw material production quickly expanded. The market was, however, unable to absorb these additional units of cobalt and lithium. Excess supply pushed prices down to almost the 2015 level.

But recently, the lithium market has clearly been regaining momentum, with lithium prices on the rise again since December 2020. The price for cobalt has also significantly increased since autumn 2020. Thanks to incentive grants for car buyers and tax cuts, demand for electric vehicles rose considerably worldwide in 2020. This increase in demand is reflected currently in a rise in commodity prices.

The rise in prices and forecasts has also led to a rapid increase in capital expenditure on new mining




Price developement of the most important cathode raw materials. Price rally in lithium and cobalt.




Surge in exploration spending over the past years. (not to scale)

projects. Global expenditure on lithium exploration rose by a factor of eight between 2015 and 2019, on cobalt, by a factor of five.

In 2019, exploration expenditure on lithium still continued to rise, but at a much slower rate. According to the Chilean lithium producer SQM, previous forecasts of annual growth were around 20 % higher than actual growth rates. As a result, the two largest lithium producers, Albermarle and SQM, announced their intention to reduce their capacity expansion and postpone investments in new projects.

In 2019, the rise in exploration expenditure for cobalt came to an end with a fall of around 10 % compared to the previous year. The current price for cobalt has caused a sharp decline in artisanal and small-scale mining (ASM) in the DR Congo. During the 2017/2018 price boom, the ASM sector in the DRC had supplied large quantities of cobalt within a very short time.

At the moment, considerable consolidation is in progress in both the lithium and the cobalt markets.

Unprofitable projects are being cancelled or temporarily halted. Small projects with potentially higher production costs may be forced out of the highly competitive market. Large producers have therefore positioned themselves strategically to ride out this period.

# Assessing supply risks –

## raw materials for traction batteries

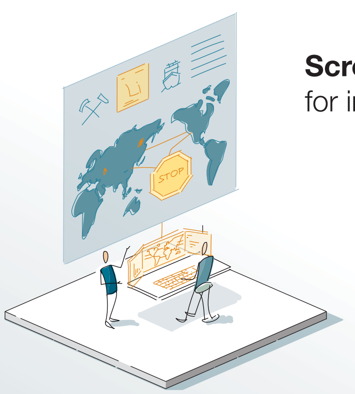
**An assessment of supply risks always reflects specific parameters at a specific point in time. Clearly this also applies to the risks and market situation in mining. An assessment of price and supply risks is therefore never static, but changes over time.**

In spring 2021, we look back on five turbulent years for battery raw materials: particularly the markets for lithium and cobalt have been affected by price and supply risks. The surge in prices for both commodities starting in 2016 was an expression of uncertainty regarding the future supply situation; it was also the trigger for an exploration boom and a considerable expansion of production.

In our view, the most significant supply risks are still found with cobalt – mainly because of political uncertainties in the DR Congo. Overall, however, many battery raw materials are associated with high risks because of high demand expectations: lithium mainly in mining, nickel mostly in processing, and graphite in both areas.

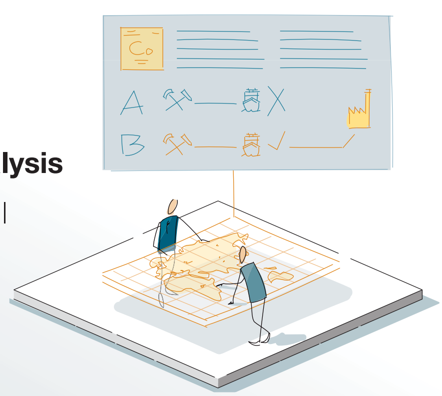
**Relevance analysis**

What is the monetary and strategic relevance of the raw materials used?




**Screening**
for international distortion of competition

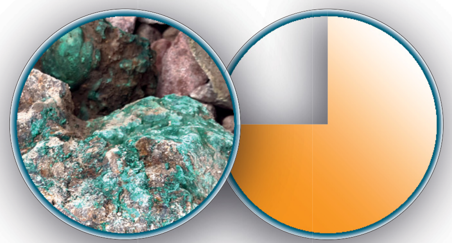
Which potentially critical raw materials of systemic importance are subject to additional trade restrictions?




**Detailed analysis**

What other supply risks exist for these potentially critical raw materials of systemic importance?

○ Low supply risk ● High supply risk



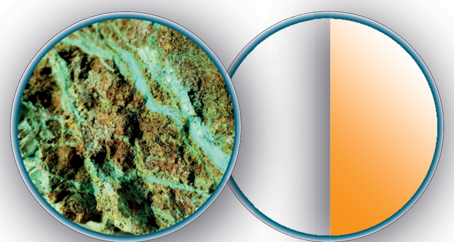
**Cobalt:**
High supply risk

Political uncertainties in the DR Congo, the largest mining producer (69 %)

Reputational risks associated with the use of cobalt from small-scale mining

Potential supply deficit in mining

China controls processing with a market share of more than 60 %, makes strategic investments in mining and processing



**Nickel:**
Indonesia as the key

Battery production will become largest driver of growth in global demand

New processing capabilities, esp. in Indonesia (export ban for nickel ore)

Environmental damage from processing

Recently moderate concentration of supply in production and processing

**Lithium:**
All in on demand

Electric vehicles provide strong stimulus for demand, but currently well below expectations

Massive expansion of cell manufacturing capacity no supply deficit expected in the medium term

High concentration of supply in production and processing

Sharp price increase between 2016 and 2018, since then price decline to 2015 level

Challenges in the downstream sector

**Graphite:**
Chinese market power

China dominates the mining of flake graphite and the production of synthetic graphite

China controls processing to battery grades

Processing of natural graphite has high environmental impact

New capacities in flake graphite mining

Recent price increase in battery grades

# Recycling of lithium-ion batteries –

## a circular economy for battery raw materials?

**After their use in traction batteries, LIB cells can be reused for power storage. If that is not possible, they have to be recycled. At the moment, not all raw materials contained in traction batteries are recovered.**

Concepts for the reuse of traction batteries, particularly as stationary power storage systems, are currently being tested. There is a lack of practical experience so far with regard to the level of capacity remaining in individual cells or modules after use in traction batteries. Business models have to be financially viable regarding collection and the cost of disassembly and reinstallation, and safety aspects need to be resolved. There is a general need for further research in this area.

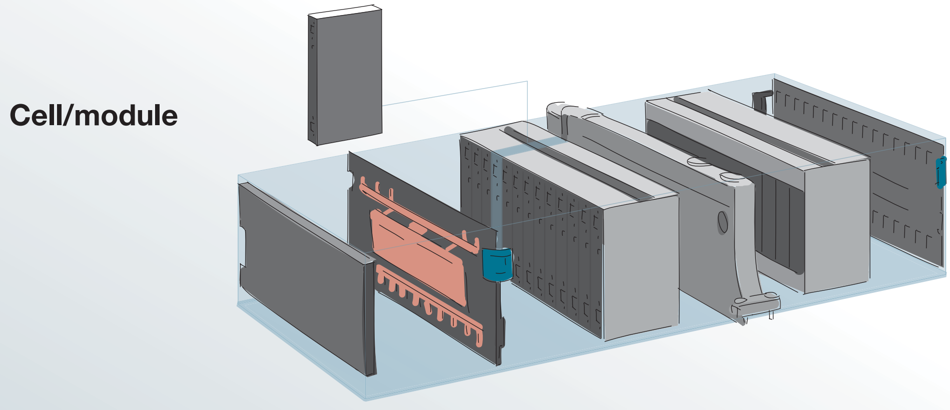
If traction batteries cannot be reused, they have to be properly disposed of. The recycling of small LIBs from portable electronic devices such as powertools or smartphones, for instance, is already well established. But the LIBs used in vehicles are much larger and store more energy, which is why safe and environmentally friendly recycling is more complex and more expensive. Particularly the high flammability and toxicity of some materials present major challenges for disposal companies. Multi-level complex separation processes are required, and standardisation is not yet an option, because of the wide range of cell chemistries and battery designs. The number of cells and modules in a traction battery varies widely, depending on battery power and type, and the manufacturer. The weight of a single cell, for instance, can range from approx. 50 g to up to 2 kg. In a traction battery with a capacity exceeding 80 kWh, several thousand cells can be connected.

At the moment, recovery is mostly limited to the economically valuable metals cobalt, nickel and copper. A lower cobalt content in traction batteries of

### Simplified structure of a lithium-ion battery

A single battery cell consists of stacked or wound electrodes (anode and cathode), isolated from each other by a separator.

Several cells are connected to form a module. A battery pack and a cooling and management system are then installed in a battery case, together forming the battery system.



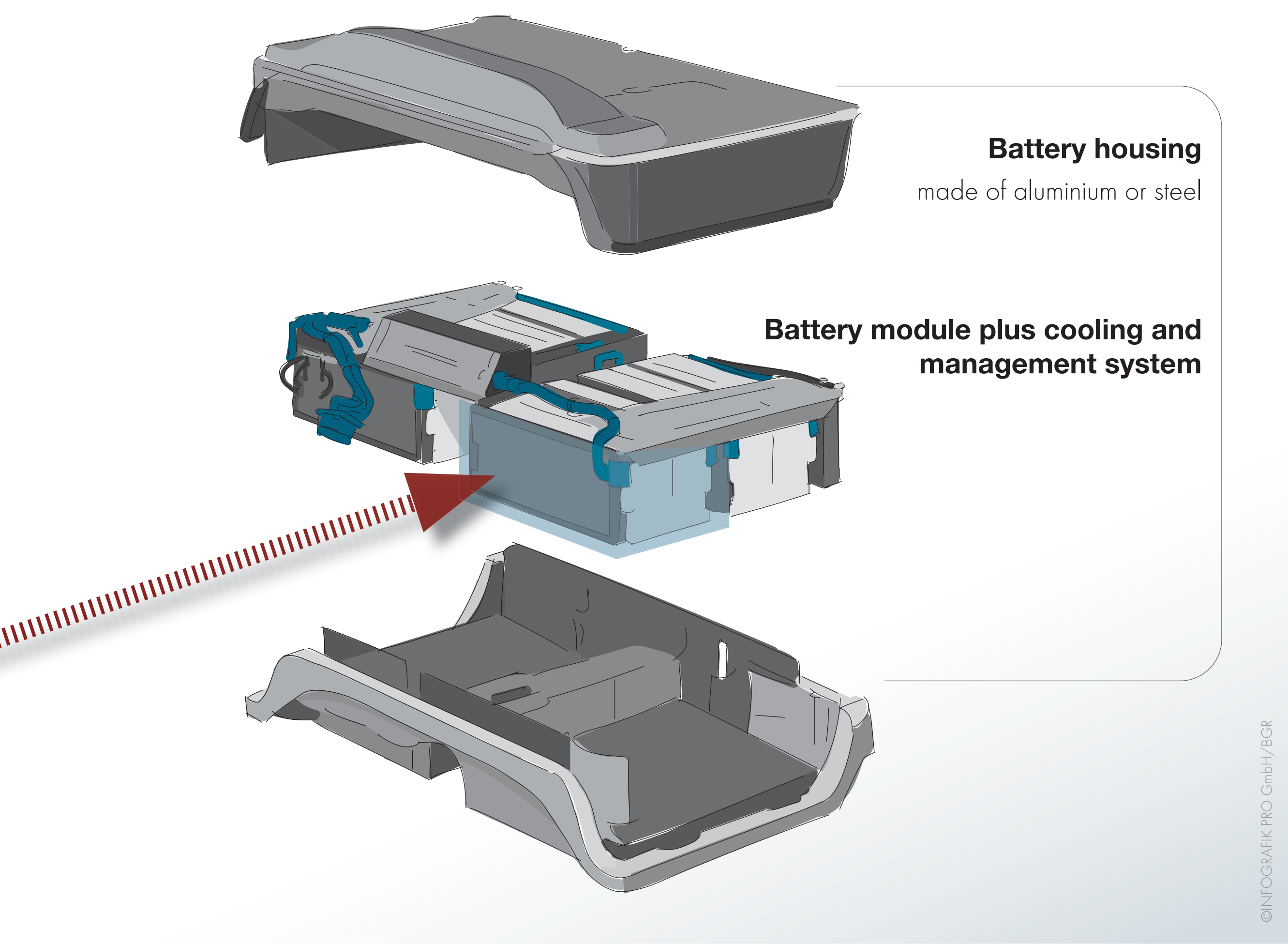
the next generation could have a negative impact on the economic recovery of battery raw materials.

In the optimisation of process methods, the focus is increasingly also on lithium and graphite: at present, complete recovery with a purity that would permit reuse in batteries is not (yet) economically viable. Studies on energy and material efficiency, and on the economic efficiency of recycling processes for individual raw materials in view of the changes in cell chemistry, are still ongoing. Most processes are still under development and only implemented on a small scale.

Traction batteries are classed as industrial batteries and as such are governed by EU Directive 2006/66/EC on batteries, currently under review by the EU. An update of this directive is necessary for implementation of the new EU Circular Economy Action Plan, to take into account technical developments and the future battery applications expected.

The EU Commission has proposed mandatory requirements for all batteries distributed in the EU. They include, for instance, the use of responsibly sourced raw materials, the limited use of hazardous substances, a minimum content of recycled materials, specification of a $CO_2$ footprint, and compliance with collection and recycling targets. The recycling of process waste is another major factor.

In a growing electric vehicle market, recycling will play a major role in the raw material cycle, taking into account the lifespan and potential reuse of batteries. The top priority should be a circular economy.



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