Running out of metals?

A perspective on the looming raw material shortage and how it will affect automotive electrification

White Paper

Giving substance to a new reality.

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Management Summary

While conventional cars mainly consist of steel, aluminium and plastics, electric vehicles require very different raw materials. Electric motors need rare earths for their permanent magnets while batteries require lithium, and other raw materials. Most of these materials are in short supply and need to be sourced from outside of Europe.

Demand for these materials will increase dramatically within this decade as electrification takes off – for example in 2030, demand for automotive magnets will be six times that of 2022. In 2030, the market value for magnet materials will reach almost 8 billion Euro at prices from early February 2022. Motor designs which require less, or no permanent magnets are an alternative and will increase but we expect permanent magnet motors to remain the mainstream solution.

Growing electric vehicle (EV) sales will increase annual demand for batteries from 402 GWh in 2022 to 2,736 GWh in 2030 – increasing focus on materials such as lithium, nickel, manganese, and cobalt, which are required for most current battery chemistries. If battery capacities per vehicle remain high, automotive batteries will require huge amounts of these materials. Assuming current mining and processing capacities, we expect lithium, cobalt and nickel demand will outstrip supply by 2026 the latest.

Another main challenge is price fluctuation for these materials. We have modelled the sensitivity of price changes for raw materials, showing that for example cell prices for the currently popular NMC622 chemistry rise by 3.1% and 3.4% for every 10% price increase of the nickel and cobalt. In contrast, LFP cells do not contain nickel, manganese or cobalt but react to a 10% raw material price increase of lithium or copper with a cell price increase of 3.2% and 4.4%.

Securing access to and establishing recycling structures will be crucial for OEM and cell suppliers. We recommend OEMs to pursue a strategic battery cost reduction approach combining five levers, among them are new battery integration concepts and standardized cells. We also believe that battery recycling will become essential to ensure raw material availability and increase margin control for OEMs.

Will the looming raw material shortage stop electrification?

For decades, there have been mainly three materials required to manufacture an automotive vehicle: Iron/ steel, aluminium, and different kinds of (reinforced) plastics. Automotive OEMs and suppliers have mastered procuring and transforming them into the automotive hardware. With the shift towards electrification, materials for batteries and electric motors come into focus of the automotive industry, especially nickel, cobalt, manganese, lithium, and graphite for batteries, and so-called 'rare earths' like neodymium, praseodymium or dysprosium used in permanent magnets for electric motors. The name 'rare earths' is however misleading, the US geological society estimates the reserves to 120 million tons, more than for example there is of nickel. Copper is already the main material for automotive wiring harnesses, but its importance is increasing even more as anode base material in battery cells, for higher wire diameters, busbars that connect cell modules and windings for electric motors. This new set of materials poses new challenges for the automotive industry.

Compared to steel and aluminium, the raw materials for EV batteries are in short supply and the demand for those has just recently increased mostly due to growing demand for electric mobility with immediate effect on their prices: For the last year, Tradingeconomics shows price increases for lithium of 437% – compared to 5% for steel. Other essential materials like cobalt or nickel also increased in price by at least 40% in the same time span.

437%

Price increase for lithium carbonate in 2021

Another challenge becomes obvious when looking at the origin of these materials. Whereas our previous white paper "Electrification takes off" showed that the European market will be the fastest growing EV-market, it has hardly any reserves of these crucial minerals. While extraction capacity is diversified among main supplying countries such as Indonesia (nickel), D.R. Congo (cobalt), Australia (lithium) or Chile (copper), China is the main location for processing of all these raw materials. Secure access to these materials for making electric vehicles and stable intercontinental supply chains are at risk – especially given recent disruptions from COVID-19 and the war in Ukraine. Among automotive OEMs, BMW went ahead and signed a supply agreement with lithium producer Ganfeng already in 2019 followed by an agreement with Livent in 2021, as did Tesla who closed a three-year supply contract also with Ganfeng in 2021 to secure access to vital battery materials.

Electric Motors – Running out of magnets?

Electric motor is one of the two automotive components in scope that the shift towards electric mobility will affect. Two basic types of electric motors are currently powering electric vehicles – asynchronous motors (ASM) and permanent magnet synchronous motors (PMSM). While ASMs are built mostly from steel and copper, the material mix of PMSMs is more complex – and more costly.

The main materials required for magnets are neodymium, iron (in the form of ferrite) and boron to build crystalline structures of the NdFeB- or NIB-magnets. Dysprosium and/or terbium are added to increase temperature stability, praseodymium is mixed with or can replace neodymium to increase the strength of the magnetic field.

High geographical concentration in China is observed in almost every supply chain stage of magnet production, especially when moving downstream towards magnet manufacturing. According to the U.S. Department of Energy, apart from China occupying almost 60% of current and planned mining capacity worldwide, China dominates the rest of the supply chain stages with at least 90% of the market. To make it more tangible, as of today, Europe has about 1,000 tons of magnet manufacturing capacity, while imports from China each year are almost 15 times higher.

Such kind of dominance is partially due to China's leading position in upstream processing stages, as NdFeB alloys and powders are commonly produced close to magnet manufacturing to minimize transporting magnet powders. To increase supply chain resilience, OEMs start to rebuild local supply chain capabilities. For example, General Motors targets "building a strong, sustainable, scalable and North America-focused EV supply chain". Therefore, the company has established local supply agreements with U.S. supplier, MP Materials and a German supplier, Vacuumschmelze (VAC). The deal encourages VAC to build up a manufacturing site in the United States. On the other hand, MP Materials aims to become a vertically-integrated player in NdFeB magnet supply.

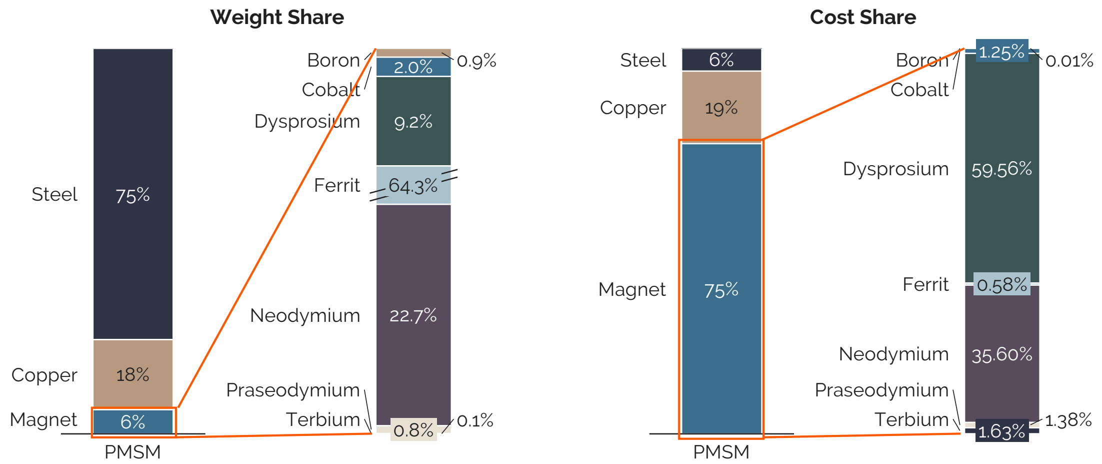

Figure 1: Weight and cost shares of a PMSM-motor – although the magnet makes up only 6% of the weight, it represents 75% of total motor cost

Focus of this white paper is a typical PMSM with 150 kW peak power, that is expected to become a standard motor for EVs. Such a motor without any additional powertrain parts like reducer or inverter weighs approx. 32 kg, of which 24 kg are steel laminations, 5.8 kg copper are stator windings while the magnet materials add up to around 2kg or 6% of total motor weight as shown in figure 1. An ASM is much simpler, consisting roughly of three quarters of steel and one quarter of copper with value shares roughly the opposite.

With this motor as a representative for all motors sold for EVs and conservatively assuming a motor market distribution of roughly 80% PMSM and 20% ASM, the demand for magnet materials rises from 4,900 tons in 2022 to 29,000 tons in 2030. The market demand for magnet materials grows from 2 bn € to 7.9 bn € at early February 2022 prices, not considering price increases due to higher demand. Compared to these values, the demand increase from 0.33 million tons of steel and copper to 1.9 million tons in 2030 for PMSMs and ASMs comes at a bargain, since even with higher volumes, market value only increases from 0.8 bn € to 4.4 bn €.

These numbers show that cost share of magnets is far more significant than their weight share. Ferrite – although accounting for almost two thirds of magnet weight – makes up less than one percent of the cost, and the small amount of boron can be disregarded. It is rare earths that make magnets costly. At current raw material prices (early February 2022) – not considering any processing of the raw materials, R&D, transportation, or production processes - exemplary motor costs are estimated at around 260 €, of which 190 € , or 73% are rare earths. This high-cost share for only 6.5% of the motor weight translates to a high dependency on raw material prices. The effects of raw material price increases on motor prices are also significant, especially for dysprosium, neodymium, and copper. The first two are affected by increasing raw material prices due to their already high price levels meaning that a raw material price increase of 10% of these materials affects the overall motor price by 4.5% and 2.7% - meaning almost half and a quarter of the raw material price increase in percentage is directly reflected in the e-motor price. For copper this value is 1.9%, based on the high amount of copper that is required per motor as illustrated in figure 2.

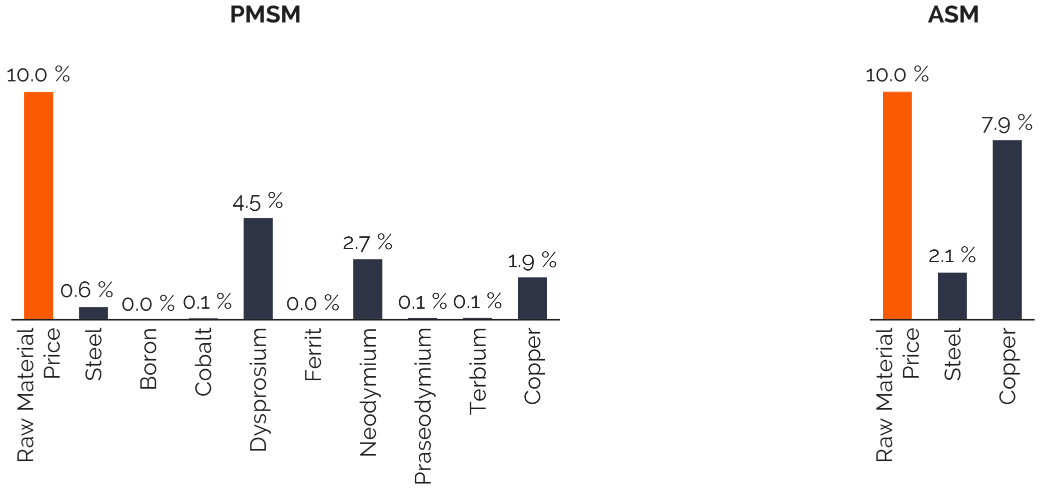

Figure 2: Price sensitivity per electric motor type: The graph depicts the effect of 10% price change of the respective raw material. PMSMs react the strongest to a price change for dysprosium while ASMs mostly react to copper price changes.

A sensitivity analysis for an ASM indicates its price is mainly dependent on raw material prices for copper, with a 7.9% price increase with each percent copper prices are rising. However, the raw material price risk is greatly reduced for ASMs because its two main materials are very common, widely available, and also already recyclable.

Battery Metals Demand Overview

While prices for electric motors are comparably low, battery costs – of which raw materials make up a significant share – are by far the strongest factor in producing battery-electric vehicles at competitive prices. This often results in higher sales prices and is thus a major obstacle for higher adaption of EVs in the market.

For our research, four representative chemistries are assumed – the currently popular NMC622, its potential successor NMC811, the affordable and robust LFP, and NCA which is expected to remain in the market beyond 2030.

NMC cells are named after their main cathode materials nickel, manganese and cobalt, while the numbers in figure 3 represent the shares of those materials that are considered to be rare and comparably expensive. NCA and LFP cells do not require manganese, while the latter also avoids the need for cobalt and requires a large amount of easily obtainable iron instead.

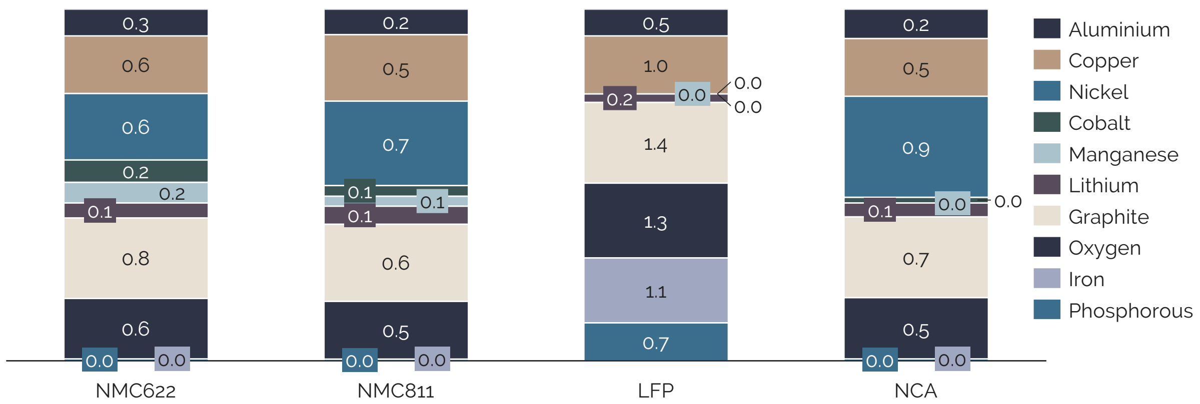

Figure 3: Material weight share in kg per kWh battery capacity for the main battery chemistries.
Source: Sanford C. Bernstein

> 4.000

Average mobile phone batteries combined have the capacity of a C-segment BEV (60 kWh)

All cell types require lithium which has recently experienced an enormous price increase – which has been especially detrimental for LFP-costs due to high lithium per kWh content.

For material requirement calculations, we have assumed that all EV and PHEV batteries sold are one of the four chemicals with NMC622 making up 45% of the market in 2022 and the others around 20%, while in 2030 NMC811 makes up roughly half of the market, NMC622 5% and the other two types 20% each. Based on the battery capacity sold, the overall demand increases from 402 GWh in 2022 to 2,736 GWh in 2030. This increase by almost seven times has a huge effect on battery material requirements which increase from 1.4 million tons in 2022 to 9.7 million tons in 2030. The demand for each of the materials is increasing by at least 350%, lithium by almost 700% as are copper and aluminium, which act in battery cells as carrier material for anode and cathode. Iron and phosphor are increasing further but due to their low prices and abundance, these are not critical materials.

Based on pure raw material prices from early February 2022, not considering e.g. refining of materials, R&D, manufacturing, integration, and transportation, one kilowatt hour of LFP-cells cost around 20 €/kWh which makes it by far the cheapest cell chemistry in scope, followed by NCA at about 30 €/kWh. NMC811 cells are expected to cost 32 €/kWh while NMC622 cells are 40 €/kWh – double the costs of LFP cells.

These values shift depending on price fluctuation for raw materials. Cell price changes are based on raw material price changes of 10% and affect the cell price per kWh in both directions. NMC622 reacts mostly to price movements of cobalt and nickel, leading to cell price changes of around 3%. Due to different material composition, NMC811 reacts most to nickel (4%) and lithium (1.5%) price changes. The latter is also affecting LFP cells strongly (3%) but is exceeded by copper (4.5%). NCA prices are stable regarding most materials except nickel, which pass on more than half of the percentual raw material price movements to the cell.

Battery metal shortage – Will it kill EV sales?

The main challenge for battery raw materials though will be availability. Next to the high geographical concentration of material extraction and especially their processing as described above, supply of materials can become the next big challenge to produce electric vehicles due to limitations of mining and refining capacity. The increased demand from the automotive industry will especially outstrip supply of lithium, cobalt, and nickel.

Lithium is used in most batteries. Due to high EV battery capacities per vehicle, the automotive sector is expected to make up for at least 80% of global demand. However, an obvious imbalance of investment is observed between lithium mining and battery production. According to Benchmark Minerals, downstream EV supply chains grow at twice the pace of upstream. There are several major roadblocks in front of investors in terms of return of investment on lithium projects: Long time periods to get permissions and ramp up production, massive investment and uncertainty of payoff (at least before electrification in automotive industry took off). Political risks and environmental concerns may as well exacerbate the supply shortage of lithium. In early 2022, the Serbian government revoked its license to Rio Tinto's lithium mining project which would have been the biggest lithium investment in Europe and sufficient for producing 1 million 60kWh batteries, as the environmentalists in the country accused the $2.4-billion project of potentially polluting its drinking water. Without considering a potential surplus in lithium extraction in previous years, the current mining capacity according to the US Geological Society of 100 kt can lead to excess demand already in 2023 as indicated in figure 4.

Compared to lithium and nickel, cobalt grades contained in most deposits are too low to invest in dedicated mining projects. As a result, cobalt is a by-product of mining copper and nickel. There are about 25 million tons of (identified) cobalt resources, but only around 30% can be economically extracted as global reserves. Cobalt is also highly geographically concentrated, with over 70% global production in Democratic Republic of Congo whose political instability and labour issues have been big concerns recently. With current mining capacities and global reserves, our forecast on future demand suggests that cobalt shortage may hit the supply chain as early as 2024. However, the shortage is not expected to reach its peak before 2028 due to increasing share of cobalt-reduced cell chemistries used in BEVs.

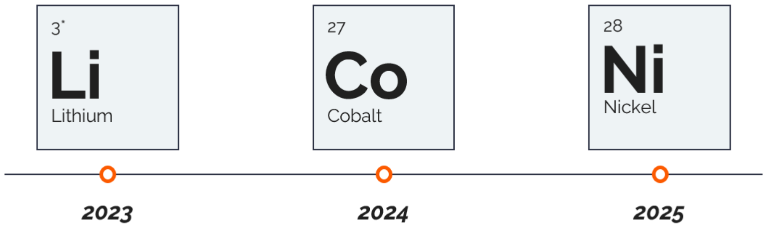

Figure 4: Raw material shortage timeline: Lithium demand is expected to exceed supply by 2023 already, followed by Cobalt and Nickel whose shortage is estimated to take place in 2024 and 2025 respectively // *atomic number

Nickel is seen as a critical element for EV battery's energy density. Automotive-grade nickel should have high-purity, so-called "Class One" classification. However, not many mining projects are able to process such high-purity nickel. An alternative is to extract Nickel from laterite but the relevant CO_2 footprint along the energy-intensive extraction process is expected to be 15 to 20 times higher according to Henri van Rooyen, CEO of Talon Metals. Again, geopolitical instability plays an important role in the uncertain future of Nickel supply. Kremlin of Russia produces great amount of high-grade nickel, which is why there was an incredible price spike in early March of 2022 when the war on Ukraine started. While nickel production is at a level of 2.7 million tons in 2021 and the automotive sector only accounts for 20% of total demand far behind stainless steel production, by 2025, nickel could be short in supply as well, endangering the further expansion of electric mobility and consequently a big share of automotive business of the future.

Implications & Outlook

Batteries are already the most expensive part of electric vehicles and our calculation do not indicate a relieve any time soon. Even if the material prices for batteries would remain constant, raw materials for a 60 kWh battery cost at least 1,200 € with LFP-cells, or up to double that amount with NMC cells. Cell raw materials are only a fraction of the final battery price though. Electric vehicle powertrains and hence BEVs are not expected to become less expensive any time soon. The prices are a consequence of recent drastic price increases for cell materials, which are hardly going to slow down since demand is increasing drastically. Depending on the material, demand growth from 350 % to 900 % is expected – further affecting raw material prices.

We do not expect the potential raw material shortages to dramatically limit EV sales and market penetration though. Prices will be a strong regulator as well as mitigating possibilities available to OEMs and their battery suppliers. We see five ways of doing this:

1. Switching to cheaper cell chemistries like LFP
2. Increase scale though dramatic standardization
3. Insource cell manufacturing
4. Drive down costs of non-cell structural parts, thermal management, and battery management system
5. Introduce Cell-to-Pack and Cell-to-Chassis designs to get rid of module structures

These levers need to be aggressively pursued to outweigh cell (material) costs hikes, especially given the anticipated supply shortages for critical raw materials just around the corner.

Recycling of battery raw materials will add another dimension. All estimations for material supply do not consider potential raw material recycling since it is not available at scale yet. Being able to build up a recycling value chain for rare earths and battery materials like it is already in place for steel, copper or aluminium will be essential for OEMs going forward. Not only will recycling allow to at least ease upcoming impending material shortages while preventing speculative and demand-driven price increases, it will also allow for much better cost control within the whole value chain.

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