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Comparison of EV motors, the EV sector's demand of commodities and the Chinese market influence – A brief review

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Abstract
Electric vehicles (EV) are not a recent invention, but because of technological advancements and growing pollution-control awareness, they now represent the future of transportation. The electric motor is the main part of an EV that replaces internal combustion engines, aside from the electric vehicle batteries that replace the fuel tank. A market for various types of electric motors to be used in electric vehicles has been created because of rapid improvements in power electronics and control systems. The most common raw materials used in EVs, and the related motors include copper, nickel, manganese, cobalt, lithium and Rare Earth Elements (REE). An EV and its motor need on average about 66.3 kg of graphite, 53.2 kg of copper, 39.9 kg of nickel, 24.5 kg of manganese, 13.3 kg of cobalt, 8.9 kg of lithium and 0.5 kg of REE. Considering the available reserves and the way that they are used in other technologies, such as wind turbines and solar panels, there is no way to produce one generation of EVs with the available raw materials. The currently available reserves are in case of copper approx. 20% of the needed tonnage, and nickel is estimated at approx. 10%. The reserves account for only 2.33% for lithium, 3.48% for cobalt, 3.57% for graphite and 3.7% for vanadium. Thus, the whole sector is in lack of reserves and will have a severe supply issue in the future.

The current situation on the EV market can be described as a battle between Tesla and Chinese carmakers for the future dominance in this segment. Four of the five most built motors contain permanent magnets which again reflects the future possible Chinese competitive advantage. Furthermore, China is in possession of the required Critical Raw Materials through its own production or through import. It has the refined products and smelters needed for future dominance. The sector is extremely subsidised by the Chinese government.

Keywords
EV motors, commodities, carmakers, supply & demand, production rates

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Globally

Map sheet

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1 INTRODUCTION

Electric vehicles EVs and their batteries were one of the research subjects in the Circular Design Network Project 2020−2022 (CircDNet), funded by Academy of Finland. The purpose of this report is to complement the picture on the raw material needs and markets of EVs.

Electric vehicles are not a recent invention, but because of technological advancements and growing pollution-control awareness, they now represent the future of transportation. The electric motor is the main part of an EV that replaces internal combustion engines, aside from the electric vehicle batteries. A market for various types of electric motors to be used in electric vehicles has been created because of rapid improvements in power electronics and control systems.

The typical motors for EVs can be distributed to four major and one minor used aggregate. All are complex structured and need critical as well as currently non-critical raw materials.

Permanent Magnet Synchronous Motor (PMSM)

The rotor of this motor has permanent magnets, which makes it similar to a BLDC (Permanent Magnet Brushless DC Motor) motor (see next). Similar to BLDC motors, these motors provide traction qualities such as high-power density and efficiency. While the back EMF (electromotive force) of a BLDC is trapezoidal, that of a PMSM is sinusoidal. There are synchronous motors with higher power ratings. For high-performance applications like cars and buses, PMSM is the best choice. Due to their improved efficiency, PMSMs provide induction motors significant competition despite their high cost. Similarly, PMSM motors cost more than BLDC motors. In hybrid and electric vehicles, most automakers, including Toyota, Ford, Chevrolet, Nissan, etc., employ PMSM motors.

Permanent Magnet Brushless DC Motor (BLDC)

A brushless DC motor is an electronically commutated DC motor that does not use brushes (also known as a BLDC motor or BL motor). The synchronous motor's speed and torque are controlled by the controller's current pulses, which are sent to the motor windings. These motors are incredibly effective at producing a significant amount of torque over a broad speed range. In brushless motors, the difficulty of attaching electricity to the armature is overcome by permanent magnets rotating around a fixed armature. Electronic transportation offers a wide range of options and adaptability.

Since the frequency of the current rather than the voltage determines the speed of permanent brushless motors, they are more effective. The two categories of BLDCs are outer rotor motors and inner rotor motors. They also have the benefit of typically being able to run at great speeds. Additional electromagnets could be used on the stator for more precise control.

Three Phase AC Induction Motor (ACIM)

Induction motors do not have a strong initial torque like DC series motors while operating at constant voltage and fixed frequency. However, this characteristic can be altered by using alternate control strategies like FOC.

The field-oriented control (FOC) method uses two orthogonal components to regulate the stator at a variable frequency in a three-phase AC induction motor drive. One describes the stator's magnetic flux, while the other relates to the torque caused by the motor's speed, which is defined by the rotor position. By using these control approaches, which are appropriate for traction applications, the motor's maximum torque is made available at start-up. Squirrel cage induction motors have a long lifespan and require little maintenance. It is possible to build induction motors with efficiency between 92% and 95%. An induction motor's drawback is that it requires a challenging inverter circuit and is challenging to run.

The Tesla Model S is a standout illustration of the high-performance potential of induction motors when compared to its rivals. It is possible that Tesla employed induction motors to lessen their dependency on permanent magnets. A three-phase induction motor also powers the Mahindra Reva e2o.

Permanent Magnet Switched Reluctance Motor (PMSRM)

Motors with switched reluctance are portable and strong. The rotor of the PMSRM is composed of laminated steel and has no permanent magnets or windings. As a result, the rotor's inertia is decreased, aiding in quick acceleration. PMSRM is suitable for high-speed applications due to its ruggedness. One prerequisite for electric vehicles is tremendous power density, which SRM also offers. Since the majority of the heat produced by the motor is typically confined in the stator, cooling it is simpler. The higher control complexity and switching circuit complexity of the PMSRM are its principal drawbacks. Additionally, there are certain issues with electromagnetic noise. PMSRM has the potential to eventually replace PMSM and induction motors once it enters the commercial market.

The most common raw materials used in EVs, and the related motors include copper, nickel, manganese, cobalt, lithium, and Rare Earth Elements. An EV and its motor needs in average about 66.3 kg of graphite, 53.2 kg of copper, 39.9 kg of nickel, 24.5 kg of manganese, 13.3 kg of cobalt, 8.9 kg of lithium and 0.5 kg of Rare Earth Elements (Fig. 1). In case of the motor solely, it contains up to 20 kg of copper depending on the motor size and power rating. It also contains tens of kg of steel and aluminum depending on the motor size and its design. Thus, approx. 118 kg of non-critical raw materials (NCRM) (copper, nickel, manganese) and approx. 89 kg of critical raw materials (CRM) (graphite, cobalt, lithium, Rare Earth Elements) are used in EVs and their related motors (cf. EU CRM list 2020). Considering that copper and nickel as well as manganese will be in a deficit concerning supply and demand between 2025−2030, all other needed raw materials for EVs will be CRM. Thus, EV production, meaning batteries, motors, electronics, and chassis, will be on an extreme supply risk if the policymakers are not able to establish a serious transformation plan from fossil fuel driven vehicles to EVs.

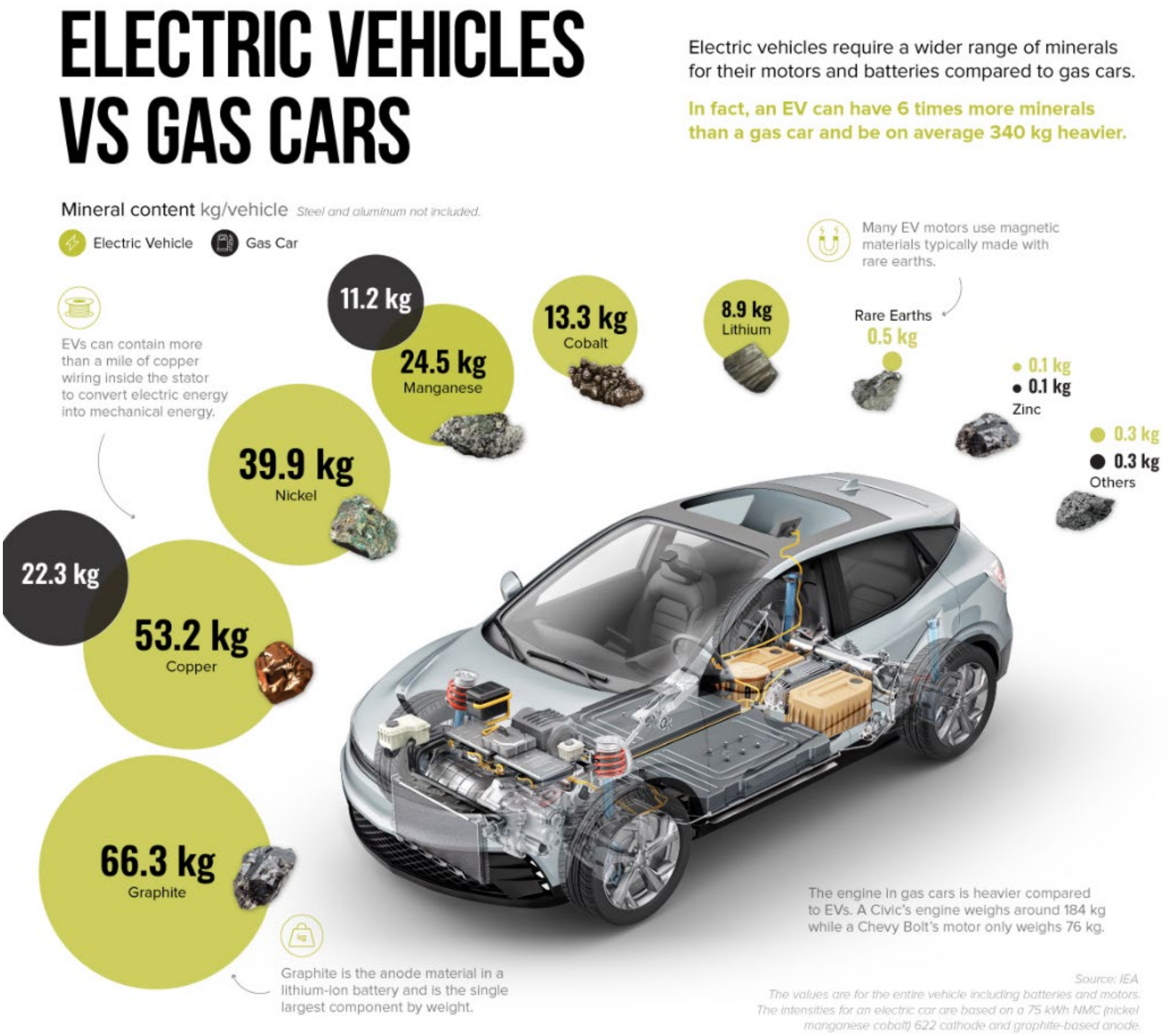


Figure 1: Commodities needed for EVs in general and EV motors (Visualcapitalist 2022).

Given the sharp increase in raw material prices in the second half of 2021, battery prices may potentially start to increase for the first time in 2022. For manufacturers, especially those in Europe, this presents a challenging climate as they must expand EV sales to achieve average fleet emissions rules. These car companies may now have to decide between lowering their profit margins or passing expenses forward, running the risk of discouraging consumers from buying EVs. Figure 2 illustrates how the average cost of automotive battery packs, adjusted for inflation, decreased from almost US-$1,200 per kWh in 2010 to just US-$132 in 2022 (Statista 2021a).

The entry-level EV models typically have a 50-kWh battery capacity (Figure 2). That battery now costs about US-$6,600 instead of the US-$60,000 it would have cost in 2010, assuming an average price of US-$132 per kWh.

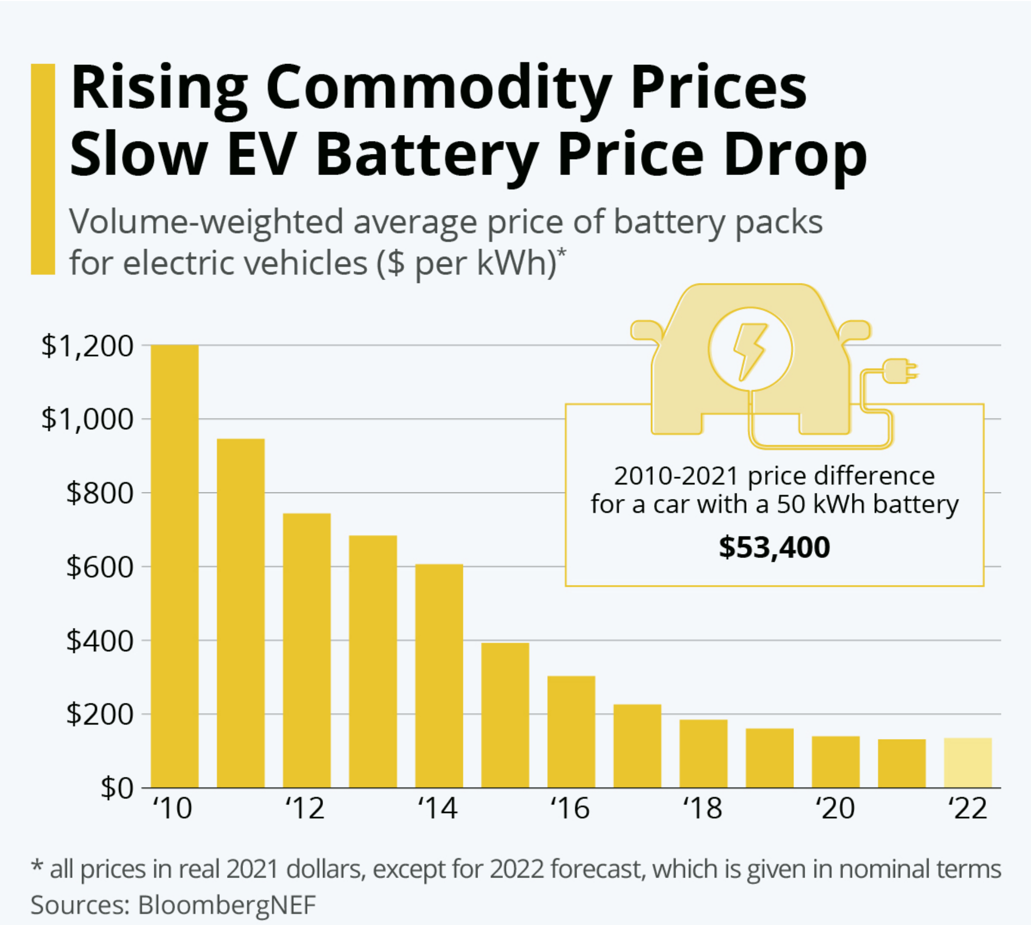


Figure 2: Prices for battery packs (Statista 2021a).

Despite supply chain constraints impacting the industry, sales of electric cars are still rising. From January to May 2022, nearly 3 million fully electric vehicles were sold globally, up from 1.7 million at the same time in 2021 (an increase of more than 80%). The prediction is that the market should surpass the landmark of 7 million cars shipped in 2022, because the last months of the year are normally good for sales (Statista 2022a). Electric vehicles are becoming more and more popular, which is fuelling fiercer rivalry among manufacturers.

With more than 13% of sales in the first five months, Tesla continues to lead the world in "all-electric" vehicle registrations when comparing year-to-date new registrations. However, the gap between it and (and between) its rivals is closing. With a market share of 9.3%, the SAIC-GM-Wuling joint venture is in second position, followed closely by China's BYD (up significantly) and Germany's Volkswagen at 8.5% apiece.

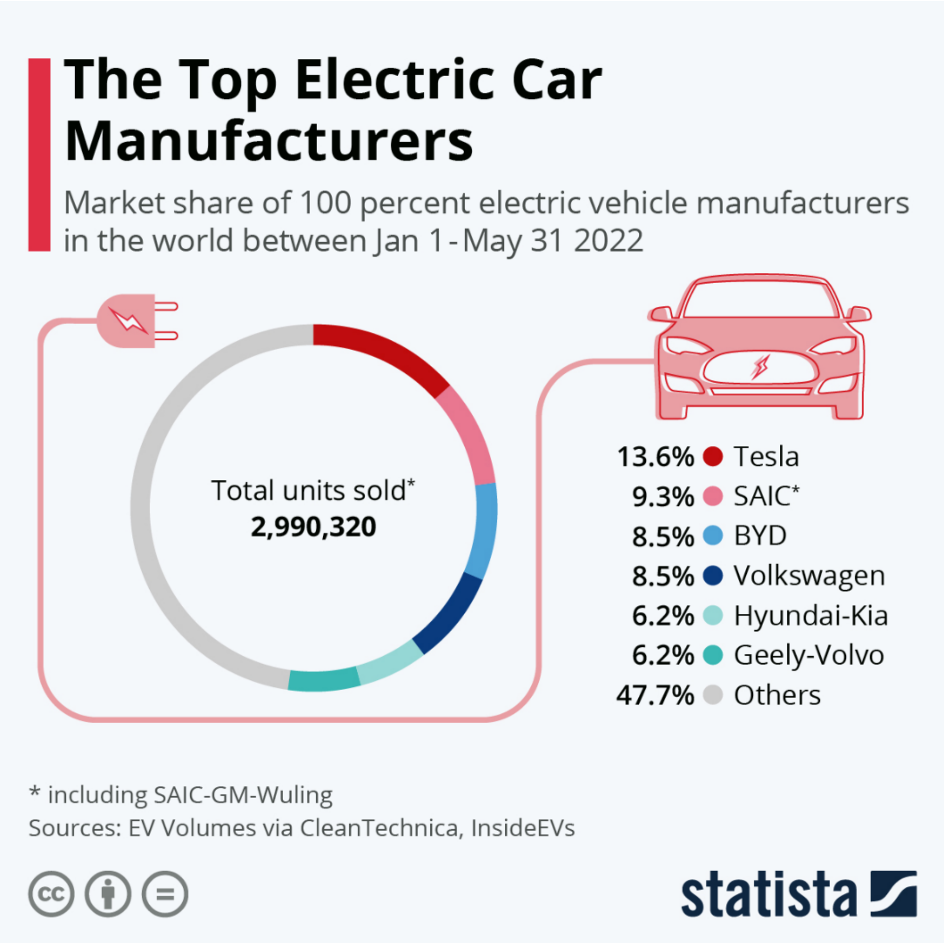


Figure 3: Top EV manufacturers worldwide (Statista 2022a).

2 EV MOTORS

2.1 Permanent Magnet Synchronous Motor (PMSM)

A permanent magnet synchronous motor (PMSM) is an AC motor whose permanent magnet generates field excitation and that has a sinusoidal back EMF waveform. This type of motor is very efficient, brushless, fast and generates a high dynamic performance. The main compartments of the PMSM are a stator core, a bar wound wire, a rotor hub, rotor core sections with steel plates, bearing support assembly and magnets (Fig. 4).

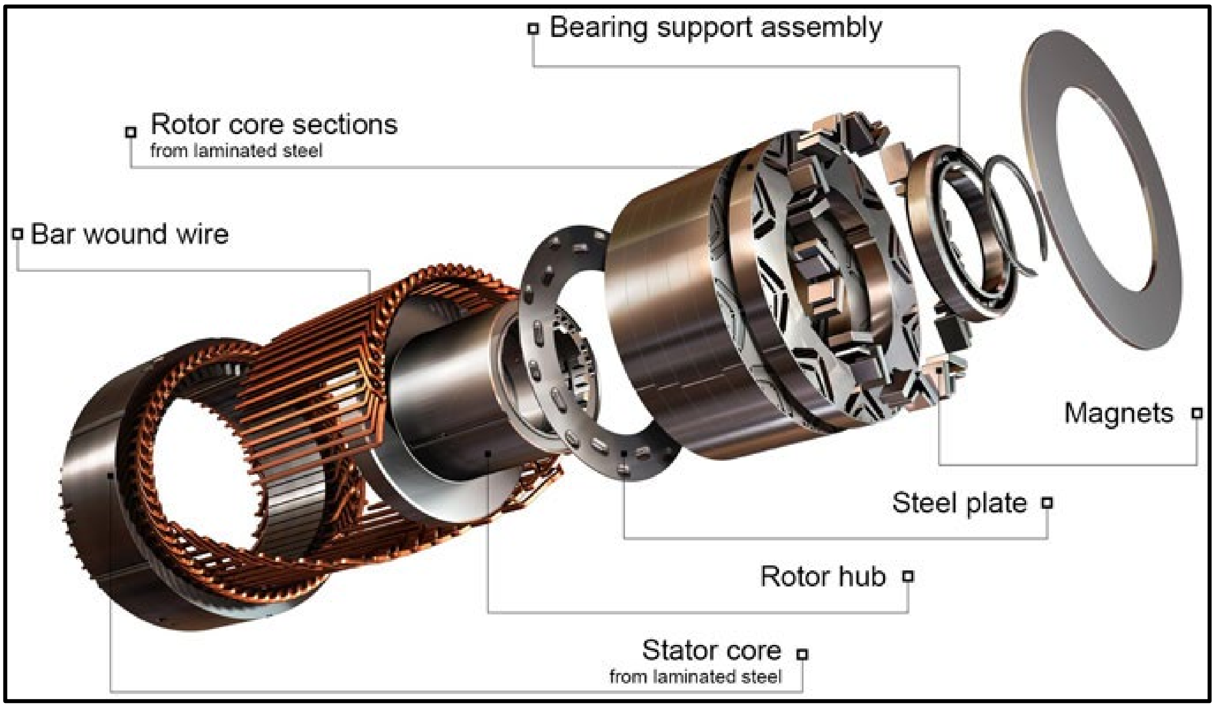


Figure 4: Permanent Magnet Synchronous Motor (PMSM) (Levkin 2022).

In order to maintain a consistent magnetic field, permanent magnets incorporated in the steel rotor are used in permanent-magnet synchronous motors (PMSM) (Levkin 2022). An AC supply is connected to the stator's windings, which create a revolving magnetic field (as in an asynchronous motor) (Fig. 4). The stator's revolving magnetic field and the rotor's constant magnetic field are both necessary for the PMSM to operate. In order to produce a constant magnetic flux, permanent magnets are utilized as the rotor, which operates and locks at synchronous speed (Levkin 2022). Field poles are made using permanent magnets. Because of their increased permeability, samarium-cobalt, iron and boron are utilized to create the permanent magnets used in the motor. Neodymium-iron-boron (NdFeB) is the most commonly used permanent magnet due to its low cost and simplicity of supply. Comparable to synchronous motors, permanent magnet synchronous motors operate on a similar principal. The interaction between the rotor's constant magnetic field and the stator's revolving magnetic field forms the basis of the operating principle. It is dependent on the synchronously rotating magnetic field that produces electromotive force. A spinning magnetic field is produced between the air gaps when the stator winding is powered by a three-phase supply (Levkin 2022).

When the rotor field poles maintain the revolving magnetic field at synchronous speed while the rotor rotates constantly, this provides the torque (Levkin 2022). These motors require a variable frequency power supply because they do not self-start.

2.2 Brushless DC Motor (BLDCM)

Electrically commutated motors, also known as BLDC motors or brushless DC electric motors (Fig. 5) (Association for Advancing Automation 2018), are driven by a DC power supply through an external motor control. Unlike brushed motors, BLDC motors achieve commutation through external controllers. Brushes are no longer required to rotate the electromagnetic field in a DC motor, which is practically turned inside out (Association for Advancing Automation 2018). Permanent magnets are located on the rotor of brushless DC motors, while electromagnets are located on the stator. The electromagnets in the stator are then charged by a computer to rotate the rotor 360 degrees (Association for Advancing Automation 2018).

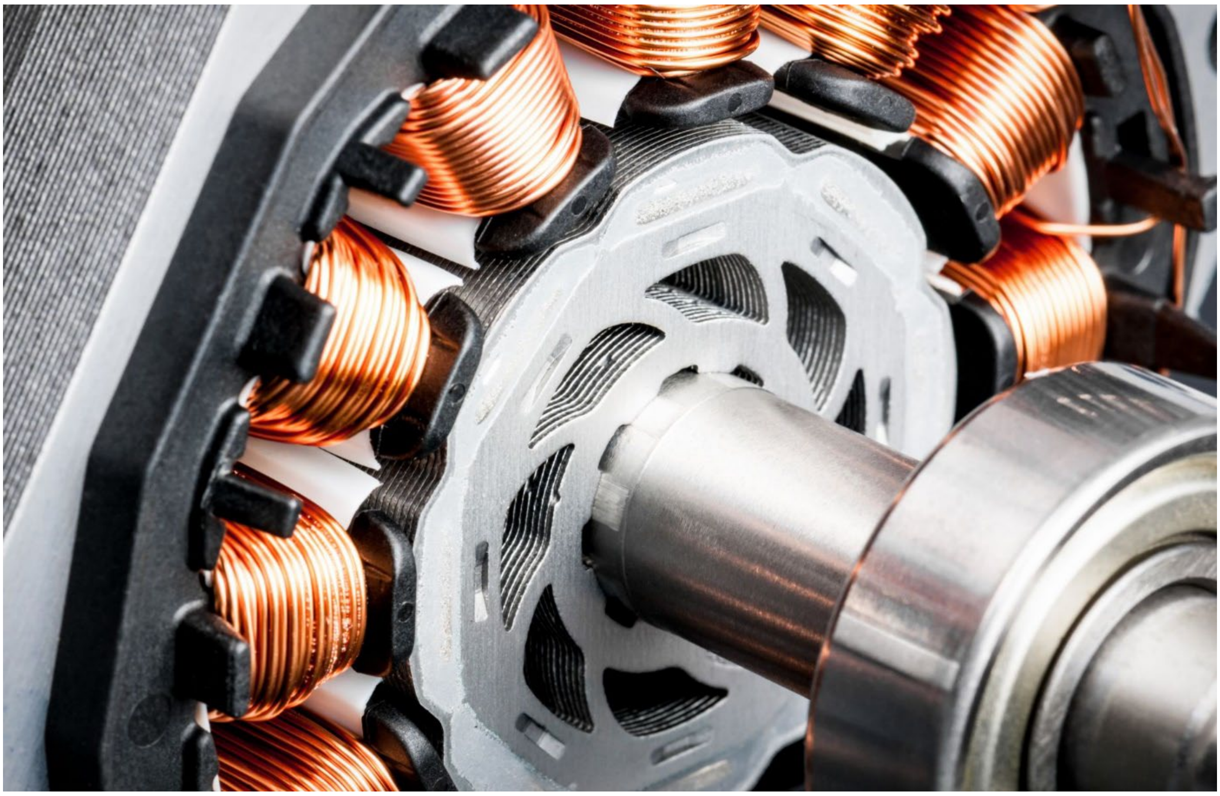


Figure 5: Brushless DC electric motors (Association for Advancing Automation 2018).

Compared to brushed motors, which are often only 75–80% efficient, brushless DC motors typically have an efficiency of 85–90% (Association for Advancing Automation 2018). The lifespan of a brushed motor is gradually reduced by brushes wearing out, which can occasionally result in dangerous sparking (Association for Advancing Automation 2018). DC motors that are brushless are quieter, lighter, and last a lot longer. Brushless DC motors can provide significantly more precise motion control since computers are in charge of the electrical current (Association for Advancing Automation 2018).

Due to all these benefits, brushless DC motors are frequently used in contemporary electronics that need to be quiet and cool, particularly those that operate continually. Washing machines, air conditioners and other consumer devices may fall under this category. They might even serve as the primary source of energy for service robots, necessitating extremely precise force management for safety (Association for Advancing Automation 2018).

Brushless DC motors have several advantages over other electric motor types, which is why they are used in so many domestic objects. They may also play a significant role in the development of service robots both inside and outside the industrial sector.

2.3 AC Induction Motor (ACIM)

The AC Induction Motor (ACIM) is employed to transform electrical energy into mechanical energy. Motors are divided into AC motors and DC motors based on the kind of supply (Electricaltechnology 2022).

Induction motors, particularly three-phase induction motors, are common AC motors used in industrial applications to provide mechanical power. Of all the motors used in industries, three-phase induction motors make up over 80% of the total. As a result, of all motor types, the induction motor is the most significant (Electricaltechnology 2022).

A three-phase induction motor is a type of AC induction motor that requires a three-phase supply to operate as opposed to a single-phase supply for a single-phase induction motor. The three-phase supply current creates an electromagnetic field in the stator winding of the three-phase induction motor, which causes the rotor winding to produce torque (Fig. 6) (Electricaltechnology 2022).

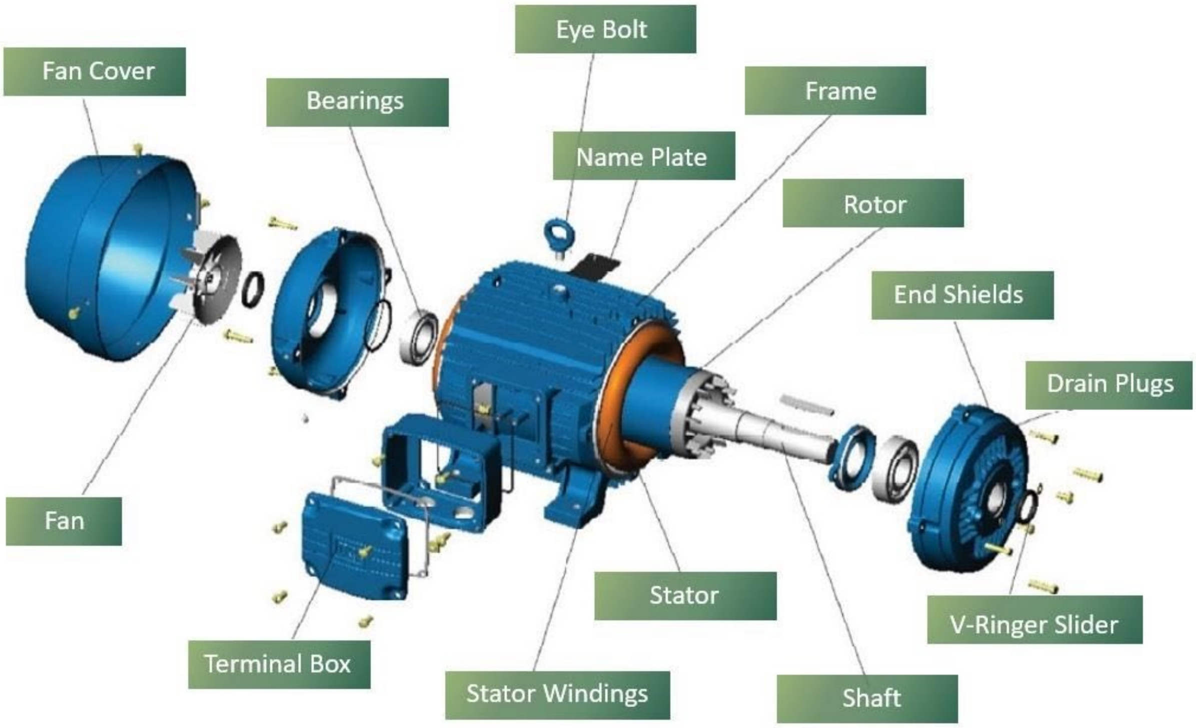


Figure 6: The components of a general-purpose AC induction motor (FläktGroup 2020).

An induction motor has a very straightforward and durable construction. The stator and the rotor are the two major components. A portion of the motor that is stationary is the stator. There are three basic components to the stator of an induction motor (stator frame, stator core and stator winding) (Fig. 6).

The stator frame is the outer part of the motor. The function of the stator frame is to provide support to the stator core and stator winding.

It gives the interior components of the motor mechanical strength. For heat dissipation and motor cooling, the frame's exterior is covered in fins (Electricaltechnology 2022). The frame is manufactured for a large machine and is cast for small machines. The frame is built of die-cast or manufactured steel, aluminium/aluminium alloys, or stainless steel depending on the requirements (Electricaltechnology 2022).

The stator core's job is to convey the alternating magnetic flux that causes eddy current loss and hysteresis. The core is laminated by high-grade steel stampings with a thickness of 0.3 to 0.6 mm to reduce these losses. Varnish serves as a barrier between these stampings (Electricaltechnology 2022). The stator core is formed by stamping every piece together and fixing it with the stator frame. There are several slots in the stator core's inner layer (Electricaltechnology 2022).

In the stator core's accessible stator slots, the stator winding is installed. A stator winding is positioned as a three-phase winding (Electricaltechnology 2022). Additionally, the stator winding receives a three-phase supply (Electricaltechnology 2022). The internal connection of the stator winding determines a motor's number of poles, which in turn determines the motor's speed (Electricaltechnology 2022). If there are more poles, the pace will be slower, and if there are less poles, the speed will be higher. The total number of poles is therefore always an even amount.

A component of the motor that rotates is the rotor. The induction motor can be categorised as a Squirrel Cage Induction Motor (SCIM), a Phase Wound (Wound Rotor) Induction motor or a Slip-ring Induction Motor depending on the type of rotor (Electricaltechnology 2022). Both varieties of induction motors have the same stator structure. In the section on different kinds of three phase induction motors that follows, we will go through the different kinds of rotors utilized in these motors (Electricaltechnology 2022).

Based on the rotor winding (armature coil winding), three-phase motors are primarily divided into two categories: squirrel cage and slip ring (wound rotor motor).

Due to the rotor's resemblance to a squirrel's cage, the squirrel cage induction motor is sometimes known as a squirrel cage induction motor. This kind of rotor has a very straightforward and durable design. Therefore, a squirrel cage induction motor makes up roughly 80% of the induction motors (Electricaltechnology 2022).

The rotor has slots around the outside of its cylindrical laminated core. The slots are not parallel, but rather they are angled in some way. They aid in avoiding magnetic locking of the rotor and stator teeth. It makes things run more smoothly and muffles humming noise. It lengthens the rotor conductor, increasing the rotor resistance as a result (Electricaltechnology 2022).

Instead of rotor winding, the squirrel cage rotor is made of rotor bars. Copper, brass or aluminium make up the rotor bars. End rings permanently short the rotor bars. In the rotor circuit, this creates a complete close path as a result (Electricaltechnology 2022). To give mechanical support, the end rings are braced or welded to the rotor bars. There is a short-circuit in the rotor bars. Therefore, it is not possible to increase the rotor circuit's external resistance (Electricaltechnology 2022). The slip rings and brushes are not utilized in this sort of rotor. As a result, this kind of motor is easier to build and more durable.

Wound rotor motors are another name for slip-ring induction motors. The rotor is made out of a laminated cylindrical core that has slots around the edge. One inserts the rotor winding into the slots. The wound rotor of this type of rotor has the same number of poles as the wound stator. A star or a delta can be used to link the rotor winding.

The slip rings are attached to the end terminals of the rotor windings. This motor is hence referred to as a slip-ring induction motor (Electricaltechnology 2022). Through the slip ring and brushes, the external resistance can quickly link with the rotor circuit. Additionally, it is highly helpful for regulating the motor's speed and enhancing the three-phase induction motor's beginning torque (Electricaltechnology 2022).

2.4 Permanent Magnet Switched Reluctance Motor (PMSRM)

A type of AC synchronous motor known as a PMSRM stimulates the field with permanent magnets, which generate sinusoidal back EMF (Fig. 7) (E-vehicleinfo 2022). The rotor is a permanent magnet that generates a magnetic field, although the stator and rotor are identical to those of an induction motor (Fig. 7) (E-vehicleinfo 2022). As a result, there is no need to wind the rotor's field winding. Three-phase brushless permanent sine-wave motor is another name for it. The PMSRM is controlled by the magnetic field that produces electromotive force and rotates simultaneously. When the stator winding is turned on by a three-phase supply, a spinning magnetic field is created between the air gaps.

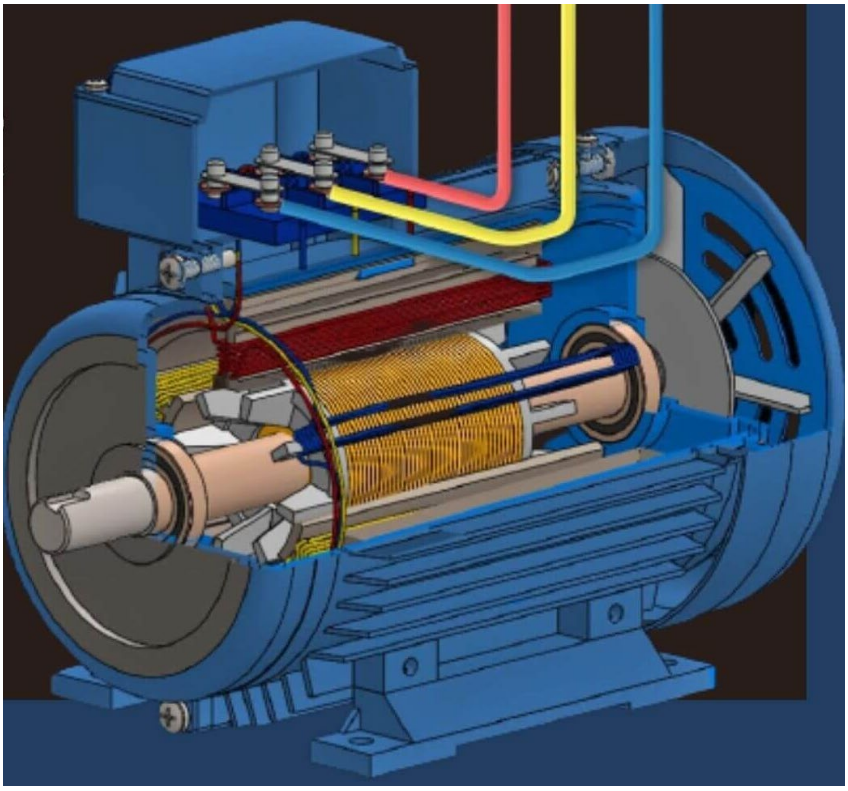


Figure 7: Permanent Magnet Switched Reluctance Motor (PMSRM) (E-vehicleinfo 2022).

The torque is generated when the rotor rotates continuously, and the rotor field poles keep the rotating magnetic field rotating at synchronous speed. Because these motors cannot start on their own, a variable frequency power supply is needed.

Typical advantages of a PMSRM are that torque ripples are absent. It has a high-performance efficiency (output to input ratio), and it is available in different sizes as well as smooth torque.

Disadvantages of PMSRM are that PMSRM are no self-starting motors. Further, there is a high initial cost involved and the performance of PMSRM depends on the quality of the magnet used.

2.5 Interior Permanent Magnet Motor (IPMM)

A promising option for traction and auxiliary motors in EV markets is the interior permanent magnet motor (IPMM), which has a rotor embedded with permanent magnets (Fig. 8). IPM motors are 30% more efficient than ferrite magnet motors because of the employment of strong neodymium magnets. They require fewer parts and have a higher power density than induction motors, which allows for a smaller motor.

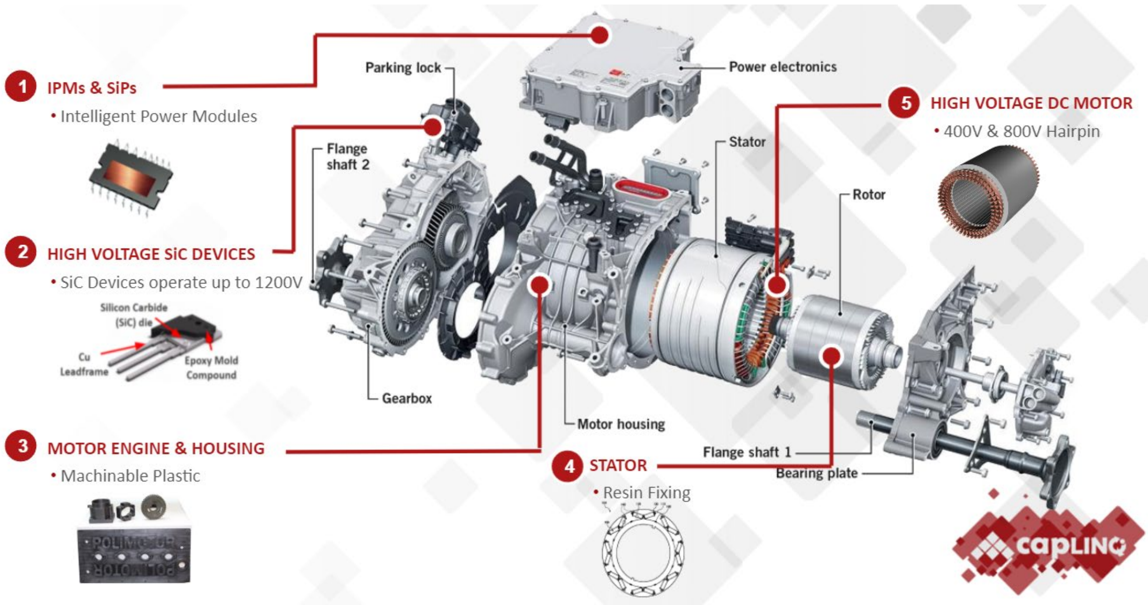


Figure 8: Interior Permanent Magnet Motor (Caplinq 2022).

In order to minimize space and weight, the industry is moving toward merging electric motors with power conversion systems and increasingly miniaturizing components. Higher power density and a greater chance of motor failure are the results (Caplinq 2022). Materials used in motors often need to resist ATF, adhere to AEC-Q200 standards and be long-lasting (Caplinq 2022). These motors frequently include or are near ATF (Automatic transmission fluids). The maximum temperature for ATF is 140°C, with 80°C being the optimal temperature (Caplinq 2022).

High voltages are typically used by EV motors. Traditional DC motors run at 12–24 V AC, first-generation IPMs run at 400 V AC, and next-generation motors will run at 800 V AC (Caplinq 2022).

3 COMMODITIES

The raw material intensity of different types of electric vehicle (EV) motors can vary based on their design and construction. PMSM motors use permanent magnets, typically made from Rare Earth Elements (such as neodymium, dysprosium, and praseodymium), to generate a magnetic field. The raw material intensity of PMSM motors is relatively high due to the use of these Rare Earth Elements, which are considered critical materials. While the quantities of Rare Earth Elements required for a single motor are relatively small (measured in grams or a few kilograms), their extraction and processing can have significant environmental and geopolitical implications. Induction motors, also known as asynchronous motors, do not require permanent magnets. Instead, they rely on the induction of a magnetic field in the rotor. As a result, the raw material intensity of induction motors is generally lower compared to PMSM motors. These motors primarily use copper for their windings and steel for the core, making them less dependent on Rare Earth Elements. The quantities of copper and steel required for induction motors can vary based on the motor's size and power rating. SRM motors utilize the principle of magnetic reluctance to generate torque. They typically consist of copper windings and steel components. Compared to PMSM motors, SRM motors have a lower raw material intensity as they do not require permanent magnets. The quantities of copper and steel needed for SRM motors are generally similar to those of induction motors.

3.1 Lithium

Lithium-containing brines from salt lakes and minerals found in pegmatites are the two main sources of lithium (especially spodumene). These are used to produce lithium concentrate, hydroxide, carbonate and chloride, which are then converted into other chemicals, reduced to metal or added directly to the finished goods. Lithium brines found in Argentina, Chile and China, as well as mining operations in Australia and China, account for the majority of the world's lithium production. A total of 80 million tonnes (Li_2O) are thought to be available in the world for lithium. The Americas, particularly Bolivia, Argentina, Chile and (to a lesser extent) the USA, are home to two thirds of these (Sun 2017, Bradley 2017, Schmidt 2017).

The significant change in the demand structure for batteries is the most remarkable trend on the lithium application side. Lithium now makes almost 65% of all demand in batteries, having roughly tripled over the past ten years. This structural trend is being driven, among other things, by the increased demand for lithium-ion battery-powered electronic mobile devices and will do so going forward primarily due to e-mobility.

Only 18% of the overall demand of lithium is now met by ceramics and glasses, which were once the most significant applications for lithium a few years ago. Ceramics are directly produced using lithium concentrate, primarily lithium-spodumene, which lessens the vulnerability of the resulting products (such as ceramic hobs) to strong acids.

The demand for lithium will increase from 500,000 metric tons of lithium carbonate equivalent (LCE) in 2021 to between three and four million metric tons in 2030 (McKinsey 2022). Direct lithium extraction (DLE) and direct lithium to product (DLP) can be the driving factors behind the industry's ability to react more quickly to soaring demand, in addition to expanding the conventional lithium supply, which is anticipated to increase by over 300% between 2021 and 2030.

However, meeting the demand for lithium will not be an easy task. Despite the effects of COVID-19 on the automobile industry, sales of EVs increased by almost 50% in 2020 and more than doubled to about seven million units in 2021. When compared to a five-year average of about $14,500 per metric ton, lithium prices have risen by about 550% in a year due to the surge in EV demand (McKinsey 2022). By the beginning of March 2022, the price of lithium carbonate had surpassed $75,000 per metric ton and the price of lithium hydroxide had surpassed $65,000 per metric ton.

Almost all traction batteries used today in EVs and consumer gadgets are produced using lithium. Other uses for lithium-ion (Li-ion) batteries include everything from energy storage to air travel. There are numerous unknowns regarding how the battery market will impact future lithium demand because battery content changes depending on the active materials mix and new battery technologies are entering the market. For instance, compared to the currently popular mixes using a graphite anode, a lithium metal anode, which increases energy density in batteries, has roughly quadruple the lithium needs per kilowatt-hour.

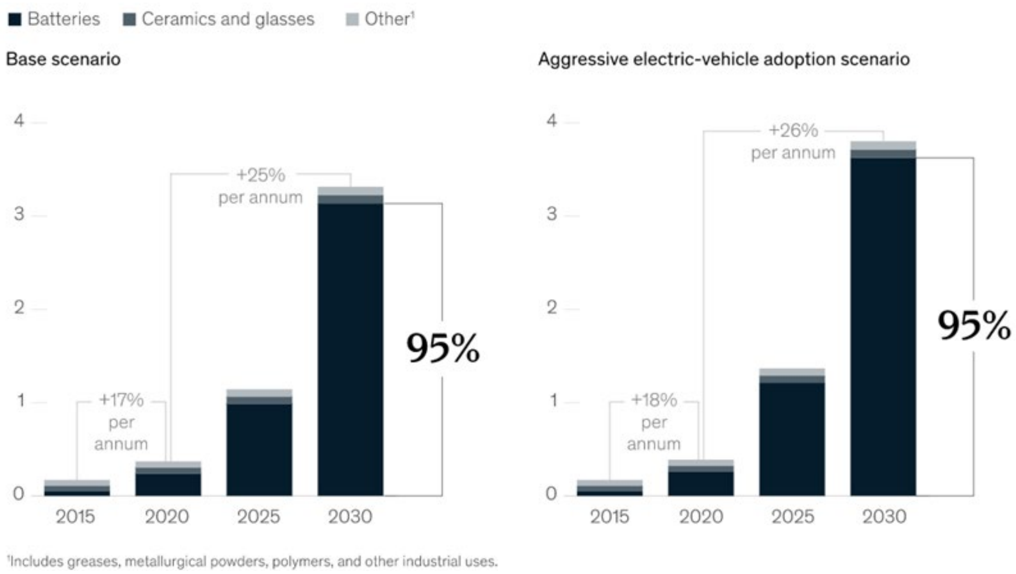


Figure 9: Lithium usage in batteries, comparing scenarios (McKinsey 2022).

However, the release of additional electric vehicle models by automakers and the growing usage of renewable energy, which necessitates increasing use of energy storage technology, will be the key drivers of a future increase in demand for lithium-ion batteries over the next ten years. Commodity Insights predicts that as a result of this energy transformation, lithium demand would increase quickly through 2030, rising from 313 kt of lithium carbonate equivalent (LCE) in 2019 to 1,465 kt LCE in 2030 (Minerals Council of Australia 2022). This projection shows overall increase of 368% during the forecasted period, or a CAGR of 15.1% annually (Minerals Council of Australia 2022).

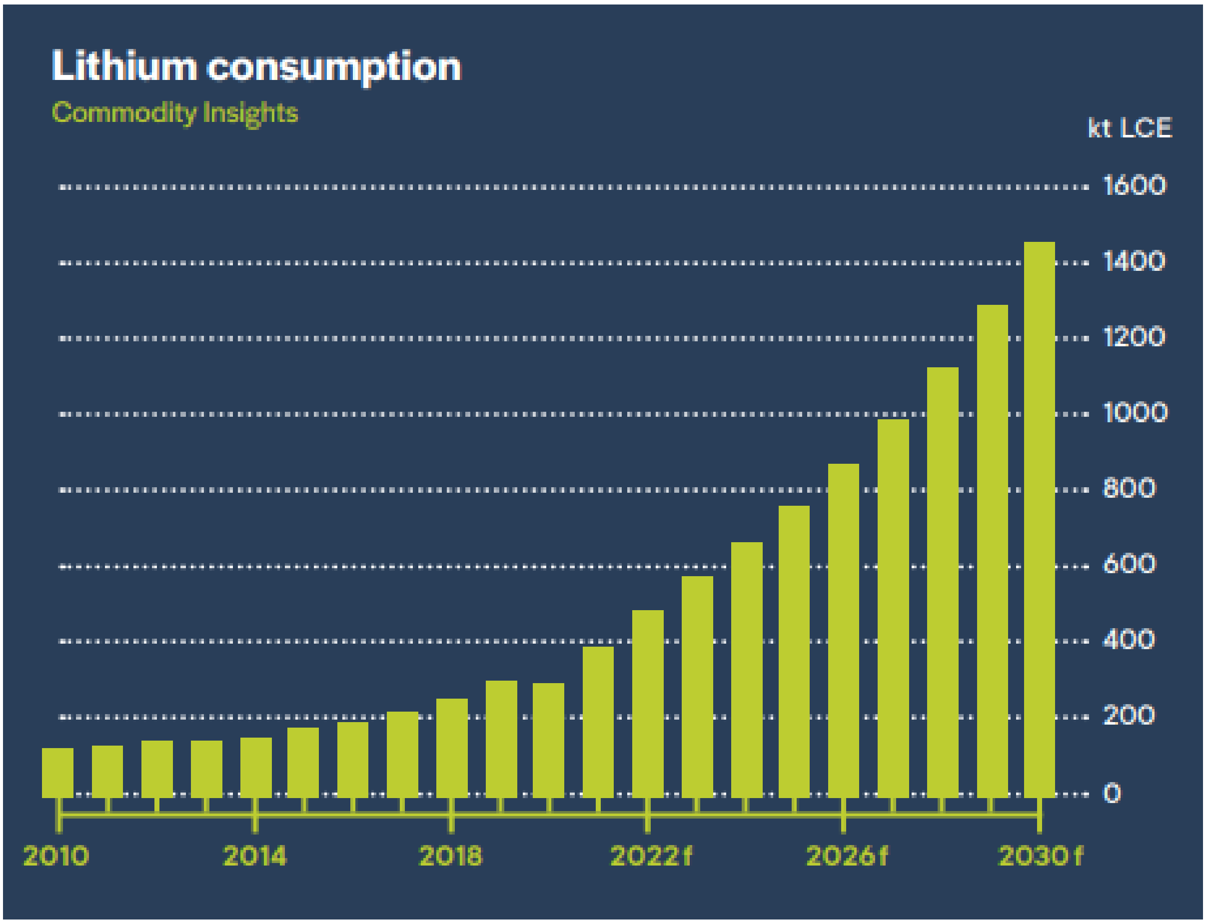


Figure 10: Lithium consumption, forecast for 2030 (Minerals Council of Australia 2022).

3.2 Cobalt

The market recovered in 2021, gaining 22% year over year (y/y) to 175 kt after being unchanged during the early phases of the Covid-19 pandemic. Compared to 51 kt in the five years from 2015 to 2021, the demand increased by 32 kt in 2021 alone (Cobalt Institute 2022). Lithium-ion battery applications drove growth, contributing 85% of year-over-year growth and 63% of yearly demand (Cobalt Institute 2022). The demand for cobalt from EVs surpassed that from other battery applications to become the largest end use sector in 2021, accounting for 34% of the total demand of 59 kt (Cobalt Institute 2022). The fact that EV sales doubled over 2020 levels and that China accounted for more than half of worldwide sales and 64% of y/y growth helped to support this (Cobalt Institute 2022). Due to their better energy density and performance, cobalt-containing cathodes continue to account for the majority of lithium-ion battery chemistries used in the EV sector. Cobalt is crucial for stability and safety. Nickel- and cobalt-based chemistries accounted for 74% of the demand for light-duty electric vehicle batteries globally in 2021, versus 25% for lithium iron phosphate (LFP) (Cobalt Institute 2022). In 2021, after declining in 2020, supply also resumed growing, with mine supply increasing 12% year over year to 160 kt (Cobalt Institute 2022). In 2021, the Democratic Republic of the Congo (DRC) was the source of 87% (15 kt) of the yearly growth and generated 74% of the mined cobalt (Cobalt Institute 2022). The artisanal and small-scale mining (ASM) industry is predicted to have boosted production to 14.5 kt in 2021, approximately 12% of the entire supply in the DRC (Cobalt Institute 2022).

China continues to be the world's leading producer of refined cobalt, accounting for over 70% of both the 2021 refined supply and year-over-year growth. Primary refined supply climbed 14% y/y to 144 kt. Together, Finland, Indonesia and Madagascar contributed 27% of the increase in the refined supply in 2021 (Cobalt Institute 2022). By the end of the year, European metal prices had doubled from $16 per pound in January to $32 per pound (Cobalt Institute 2022). European prices for metal were on average $2.5 less expensive than Chinese prices in 2021 as a result of the relative market weakness that had existed since mid-2020 (Cobalt Institute 2022). Due to extremely significant chemical demand growth from the lithium-ion battery sector, cobalt sulphate prices also continued to be higher than metal, averaging $3.6/lb (Cobalt Institute 2022).

Future cobalt demand is predicted to increase significantly as the EV transition picks up speed, approaching 320 kt in the next five years from 175 kt in 2021, with the EV industry accounting for 70% of growth (Cobalt Institute 2022). In the medium run, supply will match demand, but supply chain bottlenecks continue to be a major issue. The normalization of freight routes was supposed to start in the second half of 2022, but this is likely to be delayed by the effects of the war in Ukraine and the Covid-19 lockdowns in China. The market is predicted to shift back into a deficit starting in 2024 as supply growth falls short of demand. Prices will continue to be high in order to encourage additional investment and avoid wide deficits developing (Cobalt Institute 2022).

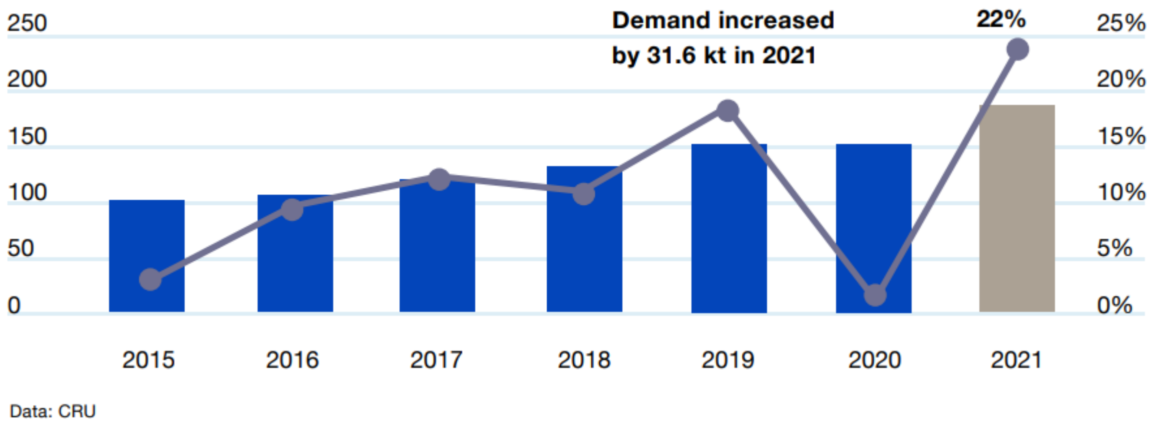


Figure 11: Cobalt demand (kt) from 2015 to 2021 (Crugroup 2022).

Li-ion battery applications accounted for 63% of the total demand in 2021. As shown in the pie charts below, this sector accounted for a sizable percentage of y/y increase. Cobalt sulphate had a surge of 70.5% thanks to the Li-ion battery industry, which accounted for 85% of demand growth. Cobalt oxide was the next most common product type, mostly used in industrial applications but also for battery applications (Crugroup 2022).

Due to the growing significance of batteries in the demand landscape, cobalt chemicals have maintained their market share since surpassing the metal segment in the early 2000s. Cobalt chemicals made up three-quarters of the cobalt market in 2021. Since 2015, the CAGR for metal applications has increased by 3.7%, compared to 14.7% for chemical applications.

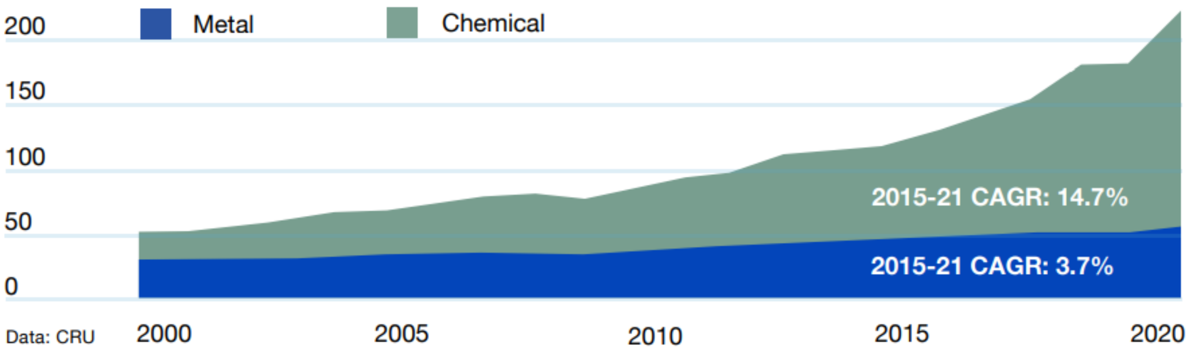


Figure 12: Chemicals continue to rise in importance in the cobalt market (Crugroup 2022).

3.3 Graphite

The market for graphite comprises of natural graphite that has been mined and synthetic graphite made in a blast furnace using complicated methods. The three main types of natural graphite are gangue graphite, microcrystalline graphite and macrocrystalline graphite (also known as flake graphite). Depending on the final use, natural graphite ores and concentrates require a number of preparation and processing processes; however, when producing synthetic graphite, the required qualities can be specifically altered during the production process.

It can be that only a part of graphite resources can be processed to battery-grade quality for use as anode material in lithium-ion batteries. Currently, the most important mining country for natural graphite is China; the country also holds a leading position in the mining of flake graphite (USGS 2019b, Damm & Zhou 2020). The production of synthetic graphite is currently also dominated by China.

Table 1: Graphite supply situation in 2010, 2013 and 2018 (BGR-DERA 2021).

	2010	**2013**	**2018**
Mine production [t]			
- natural graphite	1,719,400	1,055,800	1,700,000
…flake graphite	860,700	731,900	1,156,300
Production [t]			
- synthetic graphite	1,428,000	1,514,000	1,573,000
Reserves [t]			
- natural graphite	71,000,000	130,000,000	300,000,000
Resources [t]			
- natural graphite	>800,000,000	>800,000,000	>800,000,000
Largest mining countries			
- natural graphite	China 90% Brazil 5% Canada 1%	China 80% Brazil 9% India 3%	China 74% Mozambique 6% Brazil 6%
- flake graphite	China 81% Brazil 11% Canada 2%	China 74% Brazil 13% India 4%	China 69% Mozambique 9% Brazil 8%

Largest producing countries			
- synthetic graphite	China 42% Japan 22% USA 14%	China 43% Japan 21% USA 13%	China 49% Japan 19% USA 10%
Country concentration* in Mining			
- natural graphite	8,054	6,423	5,938
- flake graphite	6,658	5,537	4,961
Country concentration* in Production (based on 92% world production)			
- synthetic graphite	3,287	3,199	3,556
Weighted country risk** in Mining			
- natural graphite	-0.51	-0.46	-0.35
- flake graphite	-0.5	-0.49	-0.28
Weighted country risk** in Production (based on 92% world production)			
- Synthetic graphite	0.19	0.16	0.21
Price [USD/t] (Fine crystalline, 94–97% C, +100–80 mesh, CIF European port FCL)	1,329.84	1,170.83	1,025.94

** Herfindahl-Hirschman Index (HHI). The HHI is a ratio that indicates the concentration in a market. With an HHI below 1,500, a market is considered to be low, between 1,500 and 2,500 as moderately concentrated and above 2,500 as highly concentrated.*

***The weighted country risk is calculated as the sum of the countries' share of mine production multiplied by the country risk. Values above 0.5 are considered low risk, between +0.5 and -0.5 the risk is considered moderately high and values below -0.5 are considered critical.*

3.4 Copper

South American countries have significant copper reserves, and Chile was the world's top producer of copper with 5.7 Mt, or 28.5% of all mined production in 2020. According to estimates, annual production will increase steadily from the 16 Mt in 2010 to 21 Mt in 2021. The worldwide supply of copper is enormously abundant, and more than half of it has not yet been found. Approximately 700 million metric tons of copper have been produced worldwide to date, according to USGS.

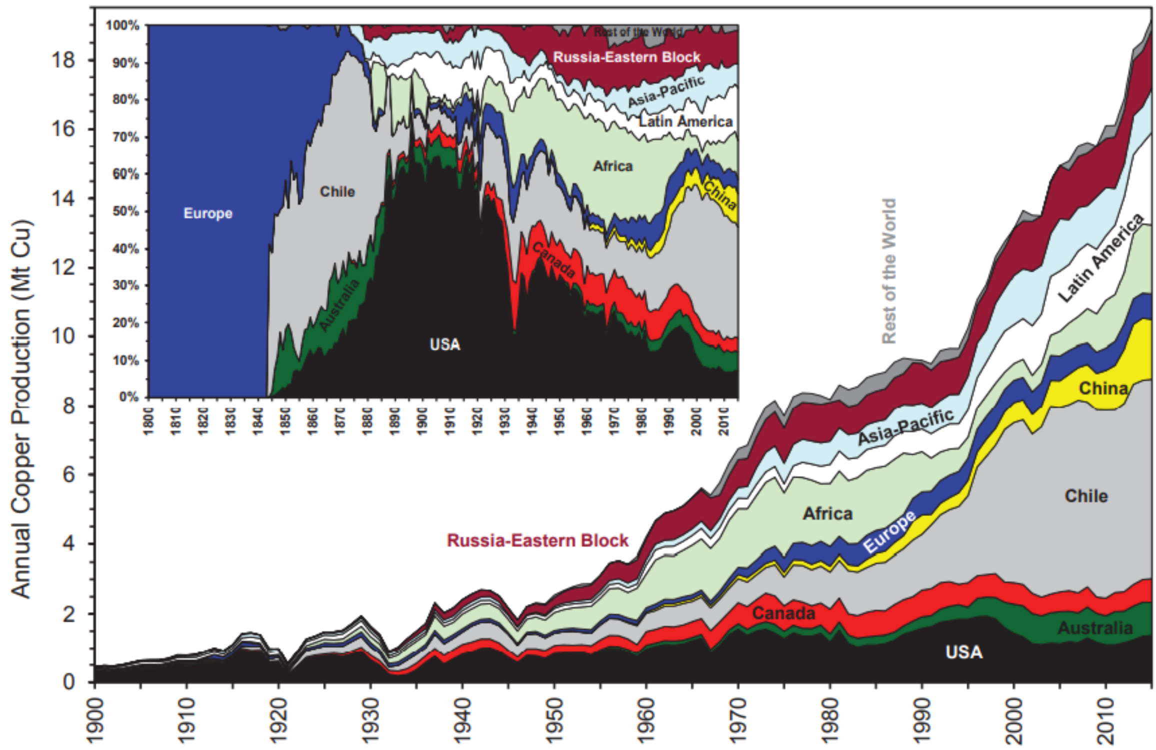


Fig. 1. World historical copper production by country or region (1900–2015). Inset figure is proportional production over time; data synthesized from U.S. Bureau of Mines (1932–1993), Schmitz (1979), U.S. Geological Survey (1994–2014, 1996–2017), British Geological Survey (2001–2015), and *The Mineral Industry: Its Statistics, Tehchnology, and Trade* (published by McGraw-Hill, 1982–1940). Note: data prior to ~1850 is clearly incomplete.

Figure 13: World historical copper production by country or region in 1900−2015 (Mudd 2018). Inset figure is proportional production over time.

The anticipated remaining amount of copper in known deposits is still 2.1 billion metric tons, bringing the total amount of copper discovered to 2.8 billion metric tons. A further estimate places the amount of copper in untapped deposits at around 3.5 billion metric tons, which would mean that there are roughly 6.3 billion metric tons of copper on Earth.

By 2030, the demand for copper is expected to increase (75−100%) from the current 20 Mt per year to about 35−40 Mt per year. This tendency is mostly related to population expansion and development in SE Asia, China and India. Some of these projections go back to 2009, and they did not even take into account the increase in copper demand brought on by decarbonization and the introduction of EVs to the market (Crugroup 2022).

According to CRU Group analysts, new projects and a rise in output at Escondida, the biggest copper mine in the world, will contribute to a 4.3% increase in copper mine supply in 2022. Despite this growth, there is still a shortage of about 100 kt. It is anticipated that a large deficit in copper supply would materialize in the middle of the 2020s, becoming structural in the early 2030s, necessitating significant copper investment in mining operations to meet demand (Barrera 2022).

According to a number of experts, by 2030 there will be a greater demand than supply for copper, which is used to manufacture consumer electronics and EVs. By the end of the decade, copper demand is expected to increase by 16%, reaching 25.5 million tonnes per year (tpa) by 2030, while supply is predicted to decline by 12% from 2021 levels. According to projections based on ongoing and future projects, supply will amount to 19.1 million tonnes annually, far less than the amount required to satisfy demand.

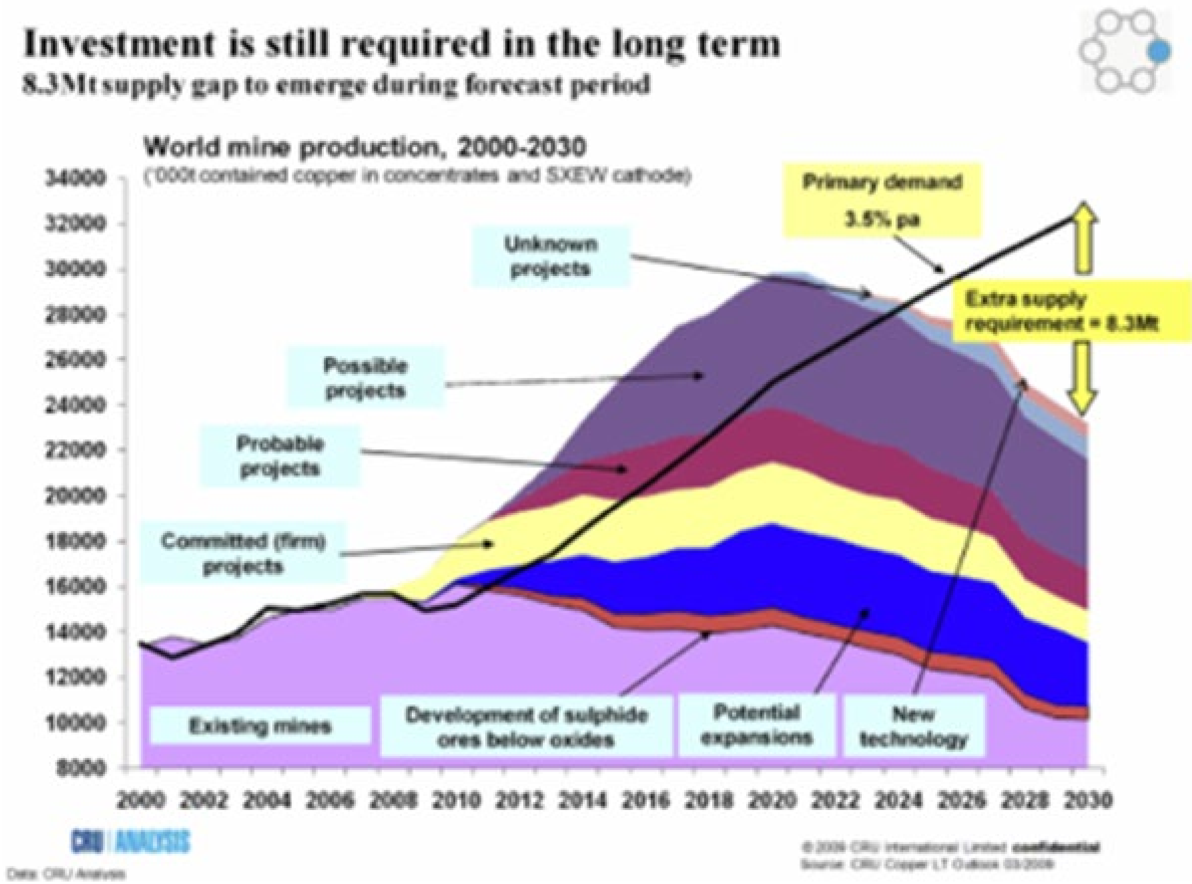


Figure 14: Copper production forecast (Crugroup 2022).

3.5 Nickel

Numerous industries use nickel, mostly to make stainless steel and nickel alloys. In addition to this, a significant rise in the demand for nickel for battery manufacture globally is anticipated in the coming years, in part because of the global upsurge in electric transportation. The three product categories that make up the worldwide nickel market are:

- Class I nickel, which is high-purity nickel metal that contains more than 99% nickel
- Class II nickel, which includes ferronickel and nickel pig iron
- nickel chemicals (NPI).

Around 65% of the world's refined main nickel supply in 2021 came from Class II nickel, 30% from nickel metal, and 5% from nickel compounds (mostly nickel sulfate) (GoldmanSachs 2022). The production of stainless steel, which accounted for over 73% of the world's demand in 2021, was nickel's most significant application, followed by use in batteries (11%) and the production of nonferrous alloys (6%) (Szurlies 2022).

Over the coming ten years, there is expected to be a strong demand for nickel for the production of stainless steel due to the need for high-grade steel to construct taller structures and secure transportation systems due to global trends of increasing urban populations, increasing city population density and increased infrastructure investment. The next ten years will see a substantial shift in the market's use of nickel as a result of the increased demand for nickel that is battery-grade. Nickel is the perfect material to utilize as the cathode in both grid and electric vehicle batteries due to its high energy density. Although there are many distinct battery chemistries, nickel is a crucial element in many of them. By 2030, the battery industry will consume more than 1 Mt of nickel annually, increasing its market share of nickel usage to 26% (GoldmanSachs 2022). This will support a 67% increase in nickel demand from 2.4 Mt in 2019 to 3.9 Mt in 2030 (GoldmanSachs 2022). The mining industry will have considerable challenges in meeting this anticipated demand rise over the coming ten years, especially as supply chains increasingly prioritize access to nickel from sustainably derived sources (Minerals Council of Australia 2022).

The predominant battery chemistry will have a significant impact on how demand for electric mobility evolves in the future. In the last several years, the amount of nickel in the cathode material of lithium-ion batteries has increased significantly. However, nickel-free lithium iron phosphate batteries, which were formerly mostly utilized in China, have recently dramatically grown their market share, accounting for more than half of the batteries made there in 2021 (Szurlies 2022).

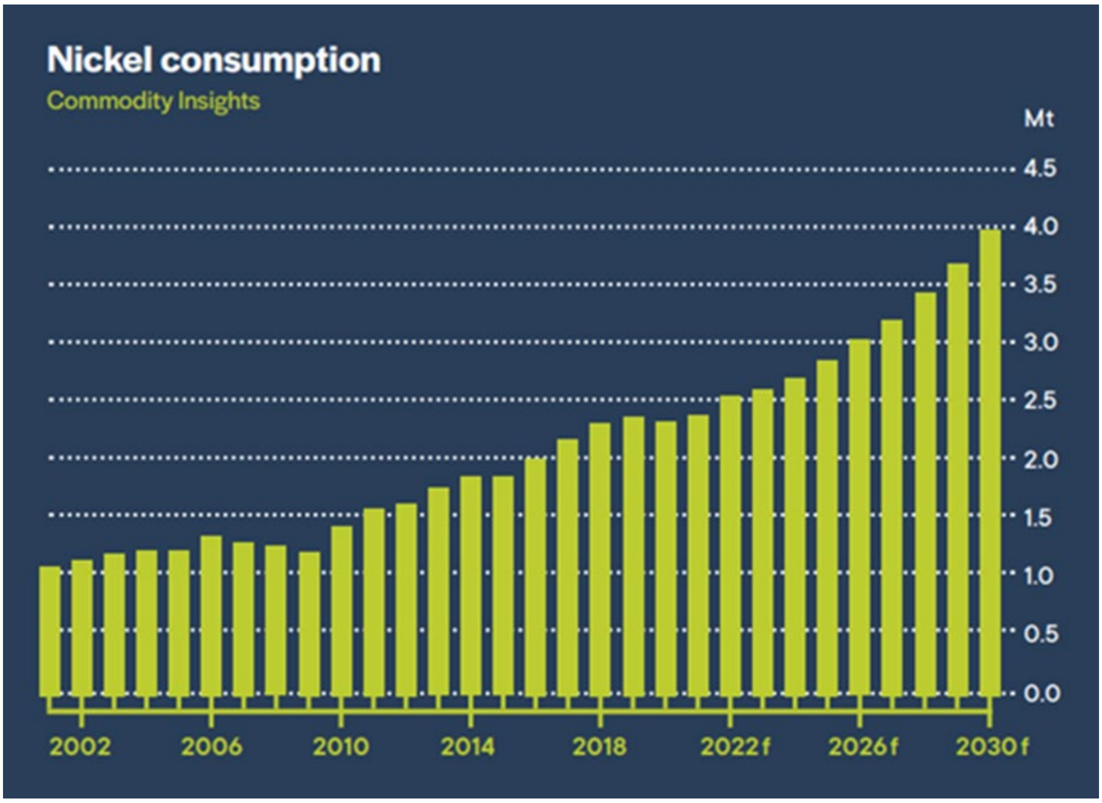


Figure 15: Nickel consumption forecast (Minerals Council of Australia 2022).

Given that EV batteries typically contain 55 kg of nickel and that EV sales are expected to expand quickly, the nickel demand from EV batteries will increase from 194 kt in 2021 (7% of the global need) to 313 kt in 2022 and 566 kt in 2025. Up to approx. 1.5Mty of nickel demand, or 32% of the world's nickel demand, will be used by EV batteries by 2030 (Fig. 16).

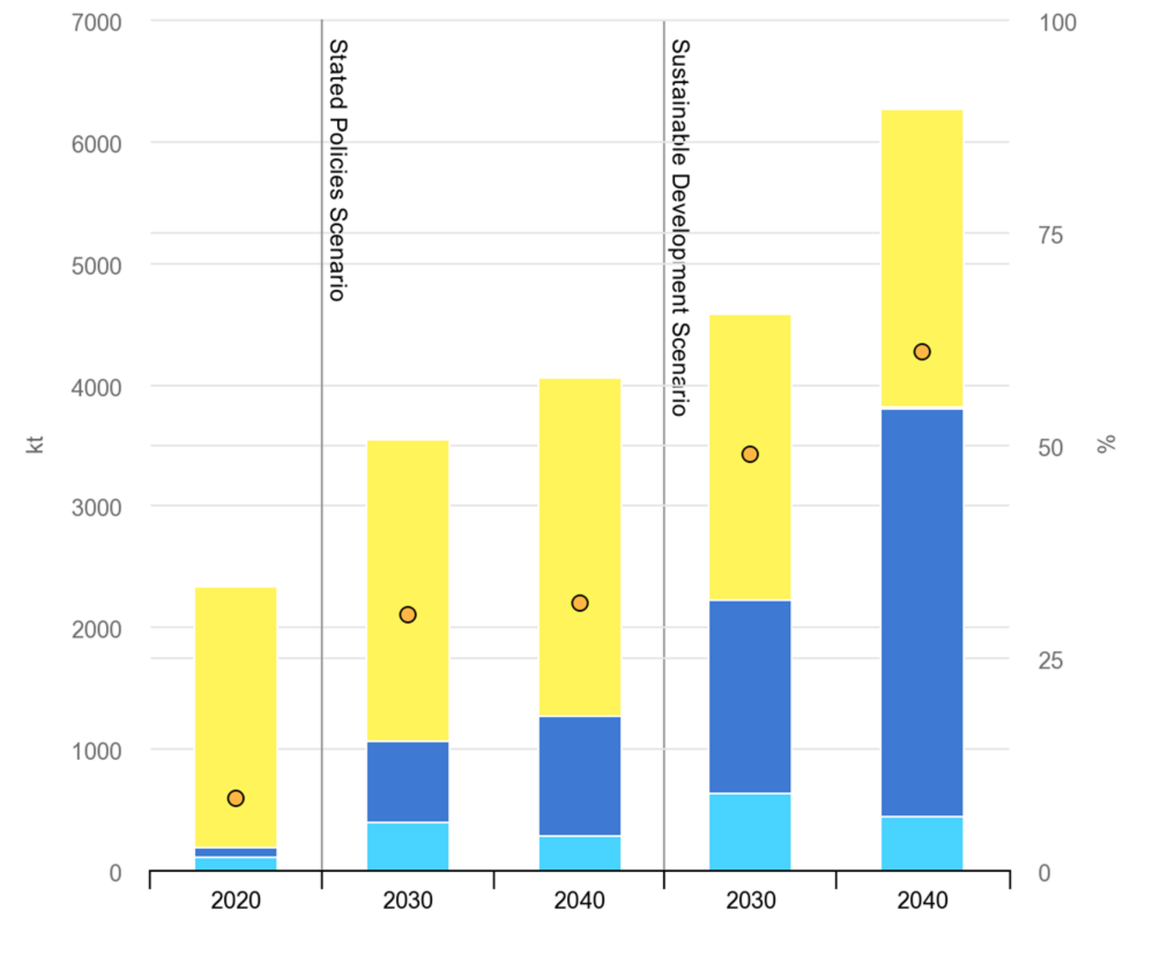


Figure 16: Total nickel demand by sector and demand, 2020–2040 (EVs and storage are marked in dark blue) (IEA 2021).

Additional green demand routes exist: an estimated 20 kty from stationary energy storage installations, where non-nickel-intensive batteries represent roughly 70% of the market, and an estimated 47 kty from wind installations, where nickel is used to improve the toughness of alloy steels, reduce weight and increase the reliability of the turbine gearbox (Minerals Council of Australia 2022).

The demand for various battery chemistries will depend on the technological advancements being made to improve safety, lower cobalt content and lower cost. Nickel-based Li-ion batteries are more prevalent in the current chemistry mix. High pure nickel is needed for nickel-rich batteries, and it can be generated using chemicals or class 1 metal dissolution. The nickel-based chemistries, such as nickel-cobalt-aluminum (NCA) and nickel-manganese-cobalt (NMC), contain 500–700 g of nickel per kWh. As car manufacturers prepare to switch the more price-sensitive automobile segments to LFP-based batteries, the case for LFP batteries is becoming more compelling. The global auto industry's action comes as LFP patents are set to expire, allowing producers outside of China to create and develop LFP batteries. LFP batteries are worth looking into for two reasons: first, they do not contain cobalt, a metal with a difficult time finding a sustainable supply; and second, improvements in cell-to-pack (CTP) battery technology have helped allay worries about low energy density. However, the adoption of LFP may be hampered by rising lithium prices and a lack of industrial know-how outside of China. In this scenario, we observe a moderated and average 15% pa growth in the demand for nickel batteries (down from 21% in our base case) 2026−2030E (Szurlies 2022).

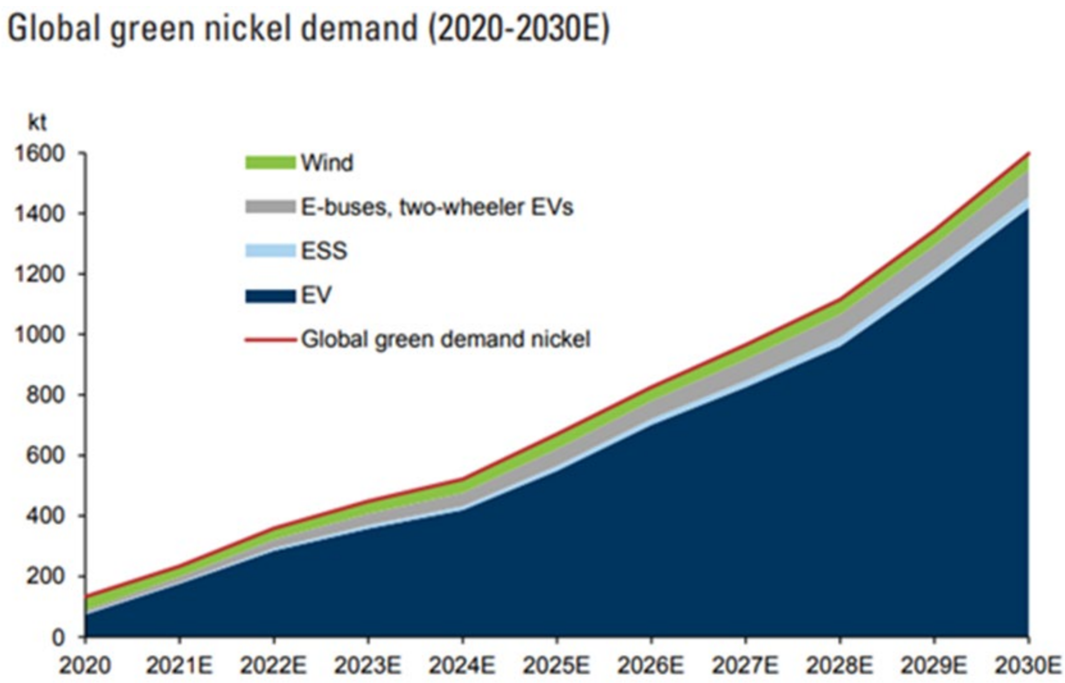


Figure 17: Global demand for green nickel.

The need for green nickel, which will account for 21% of the world's demand in 2025E and 34% in 2030E, will accelerate nickel consumption. The demand for nickel used in stainless steel will increase to 1.978Mt (+0.49% y/y) in 2022 (GoldmanSachs 2022). China and Indonesia, which use the majority of class 2 nickel (high grade NPI) because it is around 20% less expensive than utilizing refined nickel or scrap, will produce about 85% of the additional stainless steel that is produced in the future (GoldmanSachs 2022). The global mining of laterite and sulphide ores is the principal source of nickel metal. 26 nations mined nickel ores in 2021 to create a variety of refined goods (GoldmanSachs 2022). The two largest mining nations in the world, Indonesia and the Philippines, primarily employ laterite ores to produce Class II nickel (NPI), nickel sulphate and to a lesser extent metal.

Sulphidic nickel ores are processed pyro- and hydrometallurgically to create the majority of the nickel metal. 80% of the world's yearly production of nickel metal was produced in 2021 by mining these ores in Brazil, the United States, Canada, Finland, Norway, the Russian Federation, Zambia, Zimbabwe, South Africa, China and Australia (GoldmanSachs 2022). The remaining 20% or so of the metal was created hydrometallurgically from laterites, which are oxide-silicate ores (GoldmanSachs 2022). A little under 780,000 t of nickel metal were produced in 2021 in 17 locations across eleven nations. China had the highest proportion, with around 160,000 t, followed by the Russian Federation (15.6%), Canada (13.1%) and Australia (12.7%) (Szurlies 2022). Nearly 300,000 t, or 38% of the world's supply, was produced in Europe, with France and Finland alone accounting for only 6% of the metal available (Szurlies 2022). Last year, there were around a dozen businesses producing nickel metal. The biggest output, with more than 160,000 t, was produced by PJSC MMC Norilsk Nickel (Nornickel), followed by Jinchuan Group (18.7%), Glencore Plc. (16.1%) and Vale S. A. (13.8%) (Szurlies 2022). Together, these four businesses generated just about 70% of all nickel metal in 2021 at eight different locations. Together, Nornickel and Eramet Group made up about 6% of the world's metal supply in the EU. The Eramet Group obtained intermediate products for its refinery in France from Finland, while Nornickel obtained them from the Russian Federation for its refinery in Finland (Szurlies 2022).

The nickel market is currently not set up to handle this explosive increase in EV battery-related demand. In 2021, the refined nickel market recorded a record-high deficit of 162 kt, and an increase in the class 1 market deficit is anticipated. The units needed for the electrification of the world's road transportation industry cannot be obtained from the nickel market. Given the existing extremely low class 1 inventories and the added supply-related uncertainties, the market is likely to see a severe scarcity episode this year. The class II nickel market will have a surplus of 112 kt in 2022, whereas the main nickel market will have a deficit of 196 kt as a result of supply growth being concentrated in NPI production. With its present basic gearing, the upcoming surge in green demand has led the nickel industry badly unprepared. Given their lower cost compared to the rest of the globe, Indonesian projects will partially close the LT supply gap regardless of the future nickel price. According to consultant statistics, 850 kt of potential projects in Indonesia are scheduled to go up after 2025, which by itself might close the LT deficit. However, after 2025, environmental worries gain momentum. Indonesia is one of the most polluting nations, and it is likely that efforts to enact stronger environmental regulations will grow over time, endangering the growth of the nickel supply (Szurlies 2022). An estimated 320 kt would be in danger, leaving 300 kt for greener ex-Indonesia projects to fill in the LT gap (Szurlies 2022).

Metal salts are necessary for nickel-based battery cathodes and are made from nickel sulphate, which is obtained from class 1 nickel or nickel chemicals. Producers of refined nickel have to find another solution because there would not be enough supply of this battery grade nickel in 2021 to meet the demand for EV batteries. The quickest fix for the battery grade shortfall has been identified as the overabundance of NPI in the class 2 market and the simplicity with which NPI can be transformed into matte (which can then be further processed by refineries into battery-grade sulphate). This represents a debottlenecking between the NPI excess and battery grade deficiency rather than new increases to the overall supply, unless linked to more NPI lines. The present NPI-to-matte supply capacity and alternative sulphate supply pathways, such as high-pressure acid leaching (HPAL), are insufficient to meet the current demand coming from batteries despite this recognized as a viable shortage remedy. The demand for EV batteries is growing quickly, therefore even with the substantial growth in supply of battery grade nickel predicted through 2022–2024, there will still be shortages of class 1 nickel.

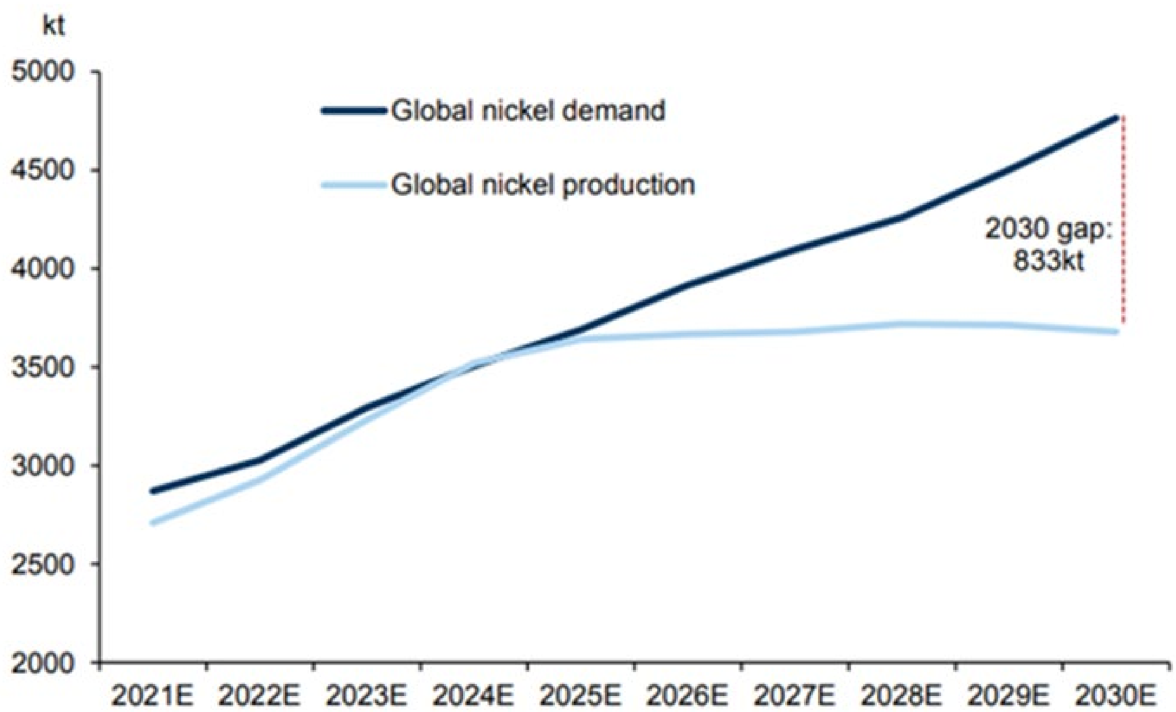


Figure 18: Global nickel demand vs. supply until 2030E (GoldmanSachs 2022).

3.6 REE

The high degree of non-transparency in the various trading methods has led to a complicated structure of demand and supply on the market for Rare Earth Elements (REEs). Since REE are not publicly traded and are not listed on stock exchanges, the channels of trade and pricing are frequently fairly unclear (Radon J. e. 2012). The exchange of REE goods, such as oxides, metals and powders, takes place directly between the seller and the customer. The majority of the trading systems used in the REE market operate in accordance with the Over-the-Counter (OTC) principle, and they fall into three groups. Broker System, Online Platforms and Direct Contact are among these types (Radon J. e. 2012).

The REE market could be described as a seller's market because supply and demand are out of balance. The definition of a seller's market is that when demand outpaces supply, the seller has greater control over the market than the buyer (Feess 2004). In addition to creating the possibility of price fixing and margin, the combination of a monopolistic market and a seller's market also creates the possibility of creating submarkets (Feess 2004). The market becomes bipolar as a result of this process (Feess 2004).

The present price disparity is another factor contributing to the bipolarity of the REE market. The China Domestic (CD) pricing and the Free-on-Board (FOB) price differ on the REE market. The classification of two consumer groups that must pay different prices is linked to a third-order price difference (Feess 2004). Third order price differentiation divides consumers of a good into various groups and assigns each group a different price based on their willingness to pay (Feess 2004). China divides consumers into two categories: those who reside on domestic territory and those who do not. As a result, CD and FOB's two-price feature appears. China therefore erected formidable obstacles to market entry.

REE Market current situation:

Based on the concept of resource conservation, China's geo-strategy for storing REE involves buying new mining licenses, particularly in Africa, as well as the related production and transit of the extracted REE back to China. In order to maintain its market dominance in the production of permanent magnets (China produces more than 95% of the world's supply), China must guarantee ongoing access to HREE, particularly dysprosium. This is a result of China's worry about the depletion of its main HREE supplies (Ion-Adsorption-Clay deposits, Southeast China), or possibly the worry about a lack of supply for the production of permanent magnets and potential issues. GrandviewResearch estimates that the market for permanent magnets will be worth around 20.5 billion US dollars by 2022. The revenue forecast for 2030 is about 40 billion US-$. The growth rate is expected to increase to 8.4% from 2022 to 2030.

As a result, the RoW is likely to be self-sufficient in LREEs, with the exception of neodymium, but still reliant on Chinese supplies of HREEs (Heavy Rare Earth Elements), particularly dysprosium and terbium. The supply from the RoW is secured primarily from LREE (Light Rare Earth Elements) enriched deposits (bastnaesite, monazite, xenotime, loparite). The only two highly enriched HREE resources outside of China are those at Northern Minerals' Browns Range and John Galt (projects) in Australia. Both deposits are not yet in the production stage. With an approximate grade of 8%, the Browns Range deposit has high dysprosium values that are comparable to those of the Chinese South-Eastern Ion Adsorption Clay deposits.

REE Production:

According to USGS projections for 2021, the People's Republic of China will produce about 60% of the world's REE. China has held the undisputed monopoly in the last ten years, accounting for close to 90% of global manufacturing. From 2018, a greater portion of the world's production has gone to nations including the USA, Australia and Burma. This occurs as a result of China's export restrictions and the growing importance of stockpiling REE to meet domestic demand for REE end products like permanent magnets.

Table 2: REE production from 2013 to 2021 in thousands of tons (USGS 2022).

Years/ Countries	2013	2014	2015	2016	2017	2017 %	2018	2019	2020	2021	2021 %
China	95	105	105	105	105	79.55 %	120	132	140	168	60.00 %
USA	5.5	5.4	5.9				18	28	39	43	15.36 %
Burma							19	25	31	26	9.29 %
Australia	2	8	12	15	19	14.39 %	21	20	21	22	7.86 %
Thailand	0.8	2.1	0.76	1.6	1.3	0.98 %	1	1.9	3.6	8	2.86 %
Madagascar							2.0	4	2.8	3.2	1.14 %
India	2.9		1.7	1.5	1.8	1.36 %	2.9	2.9	2.9	2.9	1.04 %
Russia	2.5	2.5	2.8	2.8	2.6	1.97 %	2.7	2.7	2.7	2.7	0.96 %
Brazil	0.33		0.88	2.2	1.7	1.29 %	1.1	0.71	0.6	0.5	0.18 %
Vietnam	0.22		0.25	0.22	0.2	0.15 %	0.92	1.3	0.4	0.4	0.14 %
Burundi							0.63	0.2	0.3	0.1	0.04 %
Malaysia	0.18	0.24	0.5	0.3	0.18	0.14 %					
Others							0.060	0.066	0.3	0.3	0.11 %
World total (round.)	110	123	130	129	132	100 %	190	220	240	280	99 %

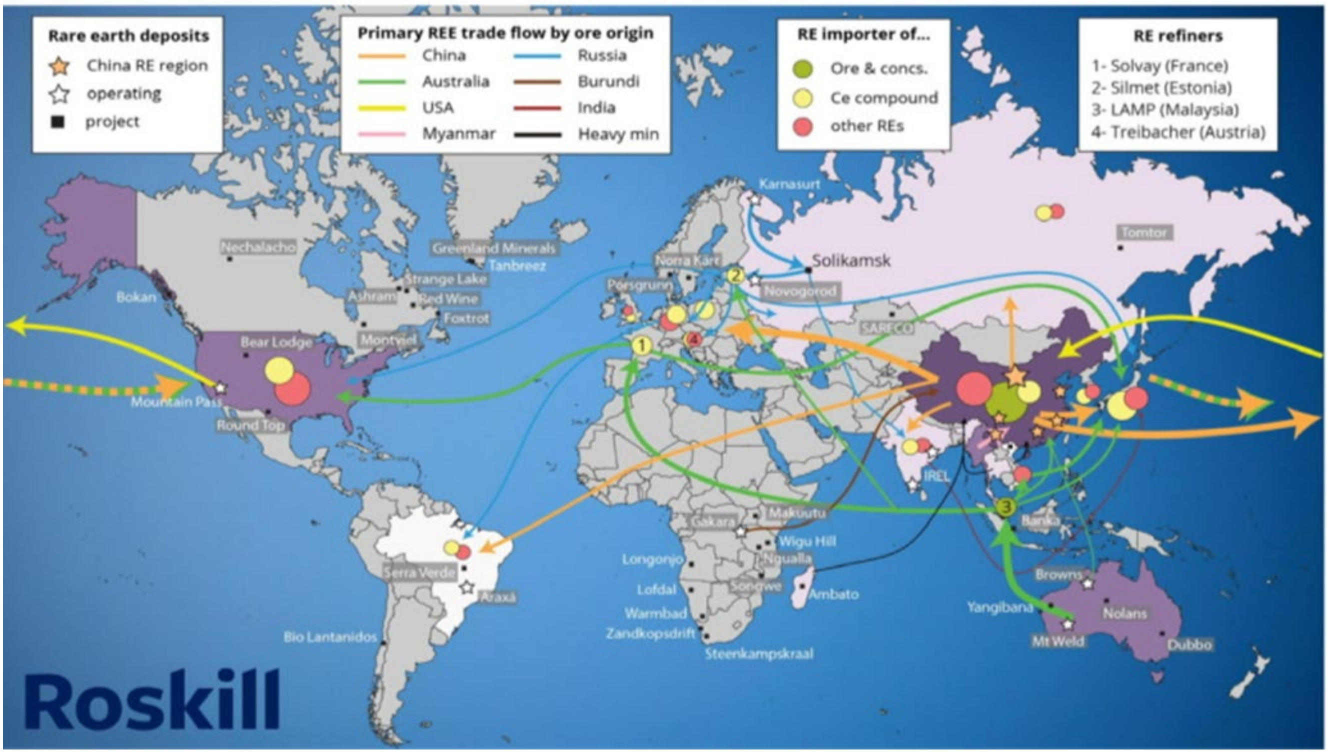


Figure 19: World map of Rare Earth Element deposits, production and trade flow, 2019 (Roskill 2019).

4 CHINA

Nearly half of all EV sales worldwide are produced by Chinese companies. The push for electrification is increasing rapidly since last five years. While Tesla may currently be the most popular brand, there are not much information regarding the initiatives Chinese brands are pursuing in this market. Chinese ICE vehicles may not be revolutionizing the industry, but they are unquestionably and steadily growing in importance to the EV market. Between January and September 2021, 2.97 million pure electric passenger cars were sold worldwide (Jato Dynamics 2021). The amount was 149% greater than the volume observed during the same time last year (Jato Dynamics 2021). The rapid acceleration is impressive given the market's meagre overall growth of just +11%. From 2.6% in January 2020 to 5.8% as of September 2020, the BEV market share increased significantly (Jato Dynamics 2021).

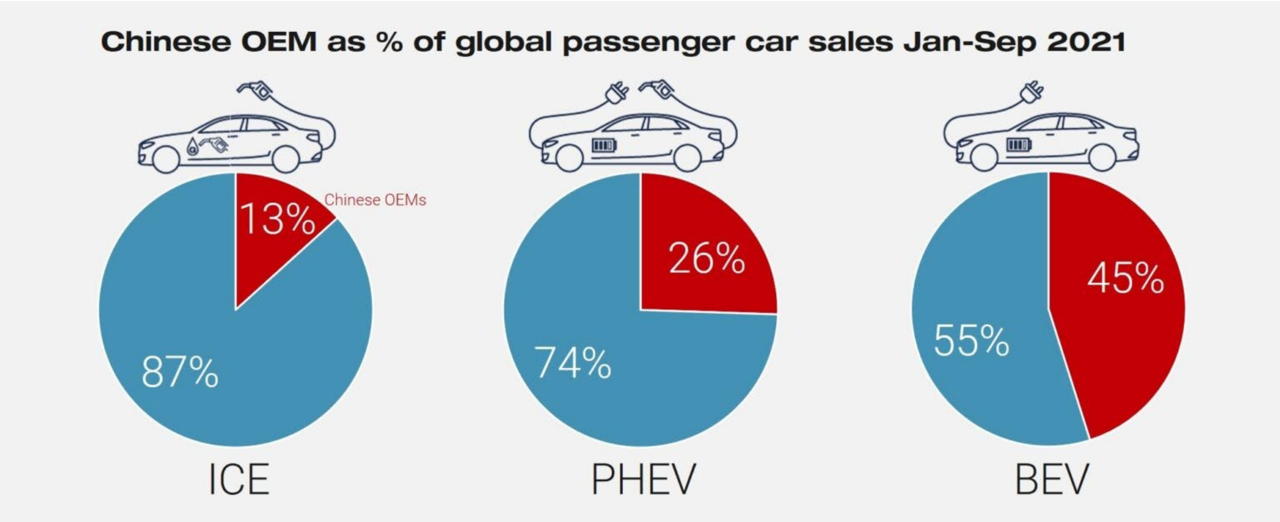
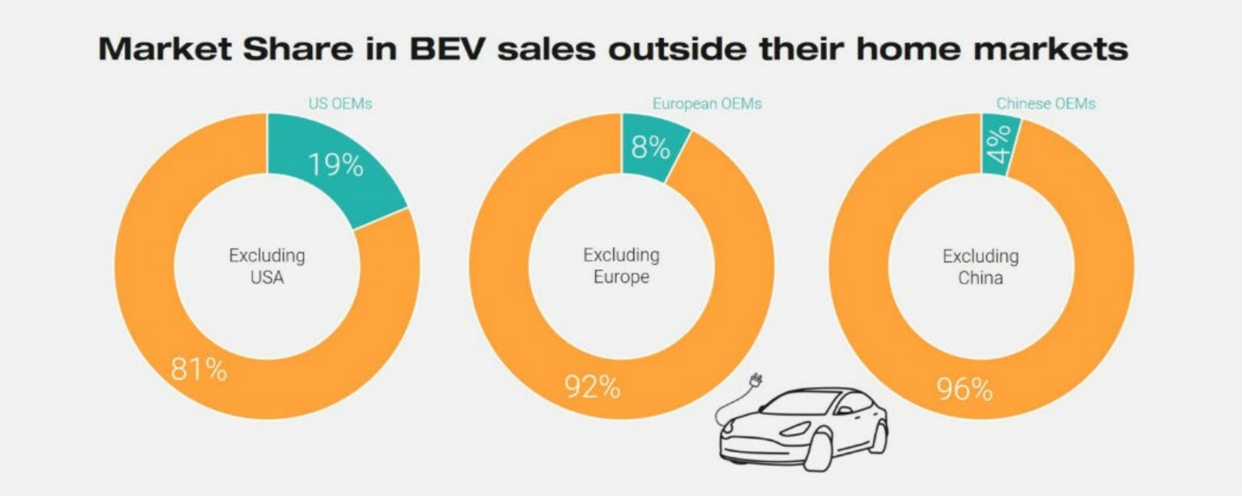


Figure 20: Chinese OEMs, global car sales (Jato Dynamics 2021).

It is interesting to note in this context how China dominates the market for BEVs and the brands that sell them. Chinese automakers sell 45% of all cars sold worldwide, compared to the 15% market share they hold for the whole passenger car market (when including all fuel types) (Jato Dynamics 2021). This clearly demonstrates that EVs increase the market share of China's cars by 30%. But it is vital to consider that domestic demand accounts for a sizable portion of the success that Chinese BEVs have experienced. With a notably low level of worldwide penetration, about 95% of the volume sold by these brands remained in China. However, the robust sales are a definite sign of what may lie ahead if governments continue to encourage the switch from ICE to BEVs.



JATO

Figure 21: Comparison BEV sales, domestically and globally (Jato Dynamics 2021).

China's dominance extends beyond only sales. According to the statistics, China produced six out of every ten BEVs sold worldwide through September 2021. China accounts for 60% of worldwide production even though it only accounts for 45% of global sales, which means that foreign automakers are already building BEVs there. They include BMW, Volvo, Polestar, and Tesla. In reality, the Gigafactory in Shanghai, which has produced the majority of the Tesla Model Y registrations in Europe to date, produced nearly half of Tesla's global sales between January and September 2021 (Jato Dynamics 2021). For Chinese automakers, the electrification of the sector represents a golden opportunity to finally break into the international market. There have been no head starts in the EV business, meaning Chinese operators today have two key advantages: significant government support and a sizable and accepting domestic market.

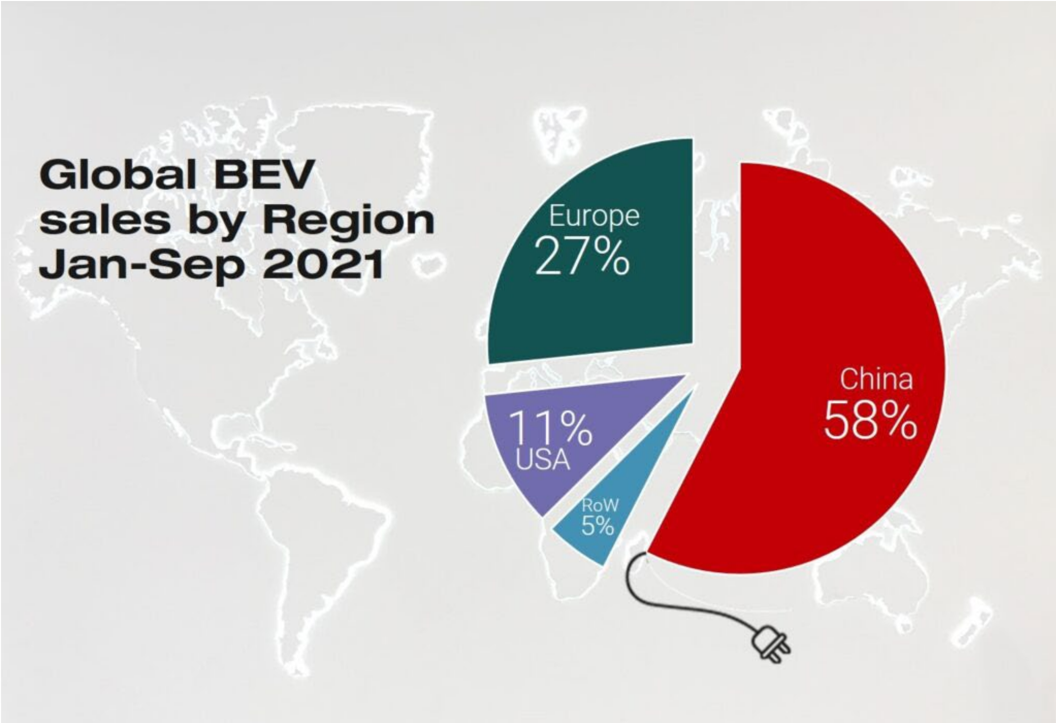


Figure 22: Global BEV sales by region, 2021 (Jato Dynamics 2021).

The ranking by OEMs also reflects China's latest ranking. With a 23% market share in the global BEV market, Tesla is the market leader. The joint venture of SAIC, General Motors and Wuling, which is currently China's top-selling BEV, is in competition (Statista 2022b).

Due to their low emissions and excellent energy efficiency, electric vehicles (EVs) are seen as a road toward sustainable transportation in China, just like in many other nations across the world. China's government has made significant investments in EV research and development, giving it the top score on Roland Berger's e-mobility index for 2021 (Statista 2022b). Notably, China has the world's largest EV industry by a wide margin. China, the world's largest EV producer, produced 3.5 million EVs in 2021, up 1.6 times from the previous year. The Asia-Pacific region saw the largest EV market revenue totals for the year, at around US$102.2 billion (Statista 2022b).

With expected sales of 2.9 million and 600,000 units, respectively, in 2021, battery electric cars (BEVs) have become more popular than plug-in hybrid electric vehicles (PHEVs) (Statista 2022b). In China, BEV's market share surged to 10.9% over the course of the year, and this number is anticipated to rise even further in the years to come. Driving a BEV allows one to be independent from oil use, emits zero CO_2 and makes very little noise, which is why BEVs are widely promoted in China. The growing EV charging infrastructure in China also contributes to the appeal of BEVs. By 2021, China had about 1.2 million and 1.5 million public and private EV charging stations, respectively (Statista 2022b).

However, due to the restricted energy storage capacity of the batteries, BEVs have a shorter driving range than PHEVs. However, it does not prevent most Chinese consumers from purchasing them. Chinese consumers anticipated buying a BEV with a driving range of 258 miles during an online customer poll conducted in October 2021, whereas those from the United States predicted at least 518 miles (Statista 2022b). Chinese EV producers are rising to prominence as the global EV market expands. BYD, the leading EV manufacturer in China, achieved an 8.8% market share globally in 2021, trailing only Tesla and Volkswagen Group. Six Chinese models were among the top 10 in the list of the EVs with the highest global sales that year. With sales of over 424,350 units in 2021, SAIC-GM-Wuling is the market leader in China for passenger BEVs, outpacing both Tesla and BYD (Statista 2022b). Right after the Tesla Variant 3, the Hongguang Mini EV model was rated as the second best-selling vehicle worldwide.

Chinese electric vehicle start-up Xpeng Motors has constructed a sizable manufacturing plant in southeast China and is constructing a matching factory close by (Statista 2022b). Nio, a different Chinese electric vehicle manufacturer, has constructed a sizable factory in central China and is getting ready to construct a second one nearby (Statista 2022b). Last month, Zhejiang Geely, the company that owns Volvo, unveiled a massive new electric car facility in eastern China that rivals in scale some of the biggest assembly plants on the planet. Evergrande, a problematic Chinese real estate tycoon, has constructed electric car factories in Shanghai and Guangzhou with the goal of producing nearly as many totally electric automobiles as North America by 2025 (Statista 2022b). According to LMC Automotive, a worldwide data company, China will produce over eight million electric vehicles annually by 2028, up from just one million in 2017 (Automotive 2022). By then, Europe will have produced 5.7 million totally electric vehicles. According to LMC, North American automakers are on track to produce just 1.4 million electric vehicles annually by 2028, down from 410,000 the year before (Automotive 2022).

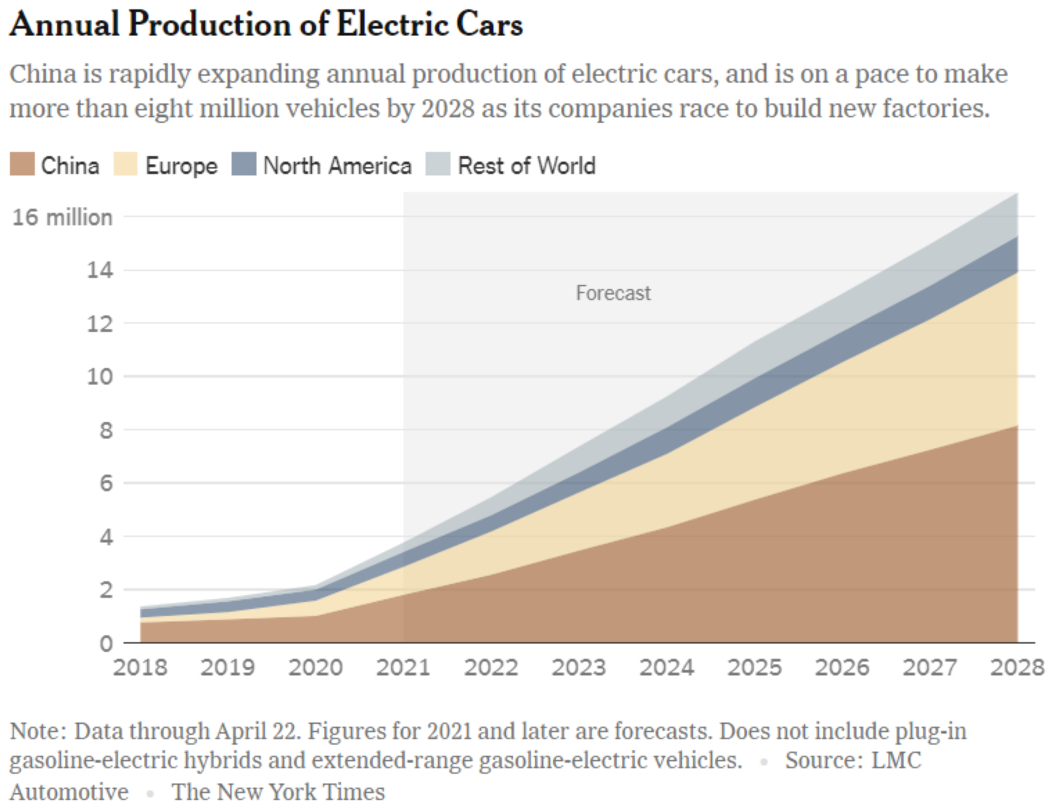


Figure 23: Annual production of EVs and forecast to 2028.

5 OUTLOOK

The current situation can be described as a battle between Tesla and Chinese carmakers for the future dominance in the EV market. Four of the five most built motors contain permanent magnets which again reflects the future possible Chinese competitive advantage. Furthermore, China is in possession of the required CRM through its own production or through import. It has the refined products and smelters needed for future dominance. The sector is extremely subsidised by the Chinese government.

Considering the current reserves and their usage in other segments, there is no way to produce one generation of EVs with the available raw materials (Michaux, in prep). The available reserves for production of EVs, wind turbines, batteries and solar panels are in case of copper approx. 20% of the needed tonnage, nickel is estimated for approx. 10%. The reserves account for lithium are only 2.33% and for cobalt 3.48%, for graphite 3.57% and for vanadium 3.7%. Thus, the whole sector is in lack of reserves and will have a severe supply issue in the future.

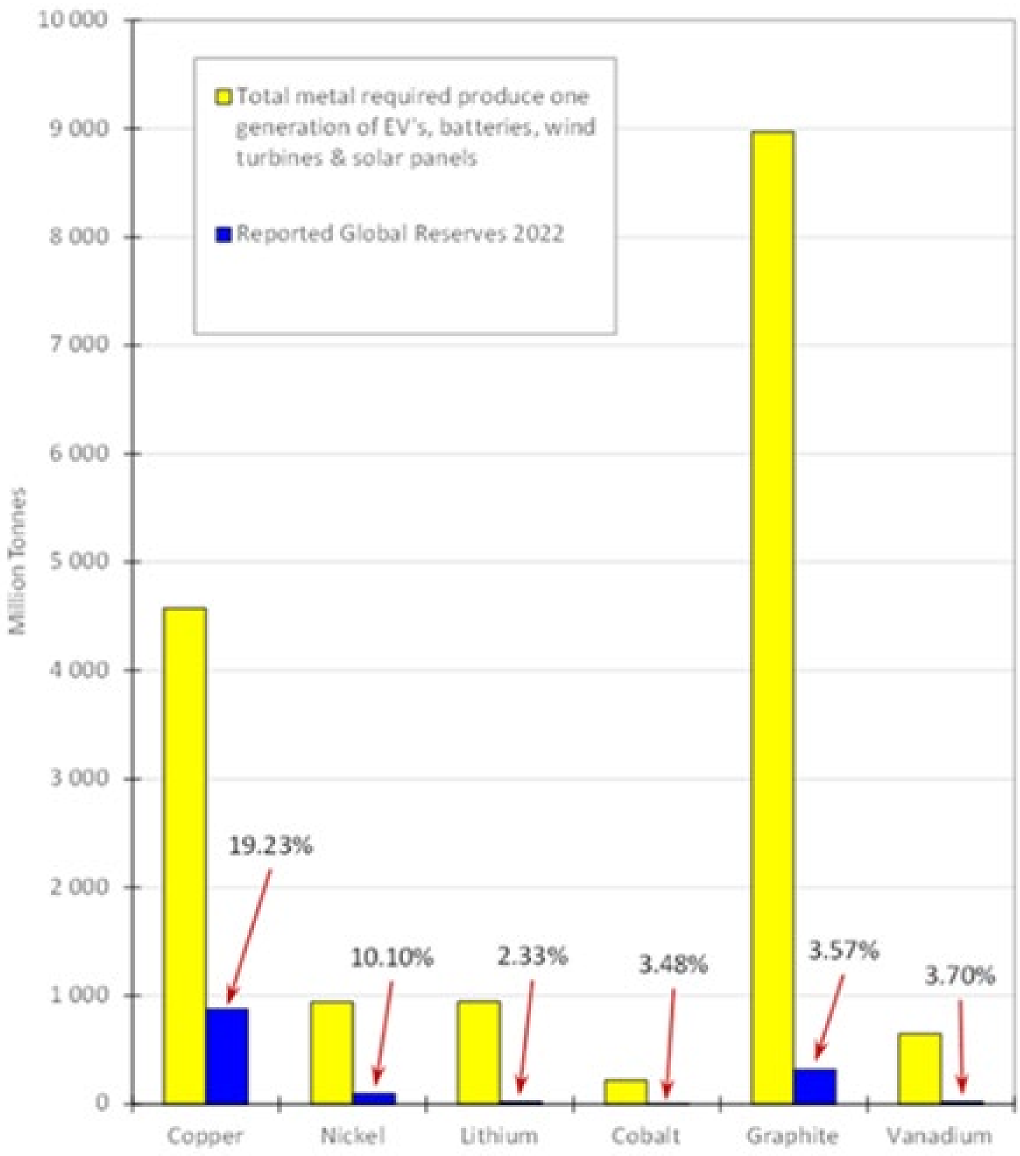


Figure 24: Quantity of metals need to manufacture one generation of renewable technology (Michaux, in prep).

Besides, the situation concerning EV production and motor production in China (chapter 5) as well as China's strategical path to own the majority of the value chain for EVs, is the fact that China produces 95% of the world's permanent magnets. The only way to compete against China for car making companies like Tesla, GM, Volkswagen, BMW, Mercedes, Audi and others is to focus on ACIM motors which do not need Rare Earths and thus, permanent magnets.

Further, EV charging is another issue that has to be considered in case of the whole EV transformation. As the worldwide market adopts EVs at a quicker rate, the demand for charging infrastructure will expand dramatically over the next five years. The technology is still developing, and there are still a number of problems that need to be solved, such as cutting down on charging times and installing charging stations all around a community to make it easier for customers to take long trips. Fast-charging stations are accessible; however, some countries only have a small number of them, and they still require improvement. Charging stations are still used by a larger percentage of EV owners to recharge their vehicles.

Additionally, due to the Russian-Ukraine war and the result of extremely increasing energy prices which deeply influenced all sectors of EV production and motor producing segments, this also has an extreme effect on EV charging costs. If all the above-mentioned problems are considered, policymakers and industrial companies have to rethink the strategy of Green Transition in the accounted rapid way until 2035. Before the Russian-Ukraine war it seemed to be very ambitious to fulfil the plan but currently it is definitely not manageable.

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