# The Cobalt Market

## 2022-2030F

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# Executive Summary

Cobalt is an important raw material, with its demand split into new and old economy drivers. New economy drivers include lithium-ion batteries and superalloys. Old economy drivers are typically industrial uses that include steels, tools, industrial chemicals and magnetic materials.

The most significant driver of cobalt demand in the coming decade is lithium-ion batteries. Consumer electronics, electric vehicles (EVs) and energy storage systems (ESS) are the dominant uses for lithium-ion batteries. While cobalt is present in most portable devices that are part of daily lives, in 2021 EVs surpassed electronics as the major source of demand. The combination of EV purchase subsidies (part of post-COVID economic stimulus in the EU and China) and the pandemic-driven shift in consumer spending patterns significantly accelerated demand in 2020 and 2021. Global EV sales reached 6.75 million units in 2021, +108% vs 2020. A key decision point for the take up of EVs remains ownership costs. Consensus estimates predict that EVs and internal combustion engine (ICE) vehicles will reach price parity by 2024.

Nearly all of cobalt produced in the world is a by-product of either nickel or copper mining (5-15% of mine revenues). Cobalt production is thus incentivised by firmer nickel or copper prices, rather than on its own price cycle. The Democratic Republic of the Congo (DRC) produces 71% of cobalt today. The top 5 cobalt producers control ~53% of global supply, typically sourced from DRC based operations. China then processes ~70% of global intermediates producing cobalt metal or cobalt salts (for use in batteries).

Secondary supply of cobalt (scrap/recycled cobalt) today remains small scale but is expected to increase post 2025F as increasing quantities of EV batteries enter the recycling ecosphere.

Although a structural deficit is not on the horizon over the next few years, a new price cycle will be required in mid-2020s to incentivise new sources of supply to keep the market in balance.

### Table 1 - Market Balance 2021-2030F

| 000 tonnes | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|
| Supply | 144 | 134 | 157 | 193 | 210 | 230 | 245 | 263 | 285 | 298 |
| Demand | 141 | 149 | 177 | 194 | 213 | 233 | 254 | 278 | 304 | 332 |
| **Market Balance** | 3 | -15 | -20 | -1 | -3 | -3 | -9 | -14 | -18 | -34 |

*Source: Cobalt Blue Holdings, Wood Mackenzie*

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# 1 Background

## 1.1 Metal Properties

Cobalt (chemical symbol Co) is a magnetic and lustrous steel grey metal possessing similar properties to iron and nickel in terms of hardness, tensile strength, machinability, thermodynamic properties, and electrochemistry. Cobalt is one of only three naturally occurring magnetic metals (with iron and nickel). The melting point of cobalt metal is a relatively high 1,493°C (2,719°F) with the boiling point 3,100°C (5,600°F), making it ideal for alloy applications where high-temperature strength is important

Cobalt is an important raw material for the production of battery materials, superalloys, high-temperature alloys, cutting tools, magnetic materials, petrochemical catalysts, pharmaceuticals and glaze materials. When used as an alloy, cobalt improves the high temperature strength and corrosion resistance of more common metals, especially nickel and chromium.

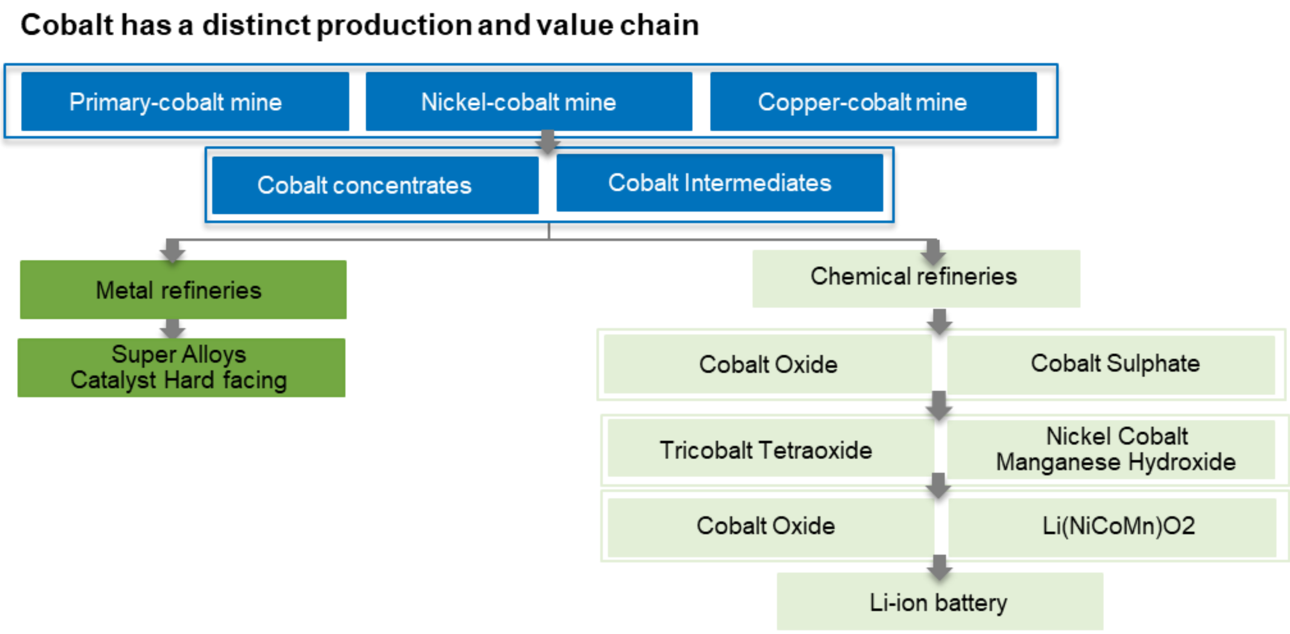
## 1.2 Cobalt Production Chain

Cobalt salts, derived from mined raw materials, are processed according to commercial uses, fall under three categories:

- Lithium-ion batteries created from cobalt oxides, sulphates and metallic hydroxides.
- Super Alloys, Magnetic Materials and Catalysts created from electro deposited cobalt. Superalloys have excellent heat resistant properties and retain their stiffness, strength, toughness and dimensional stability. Superalloys can operate for long periods of time at temperatures of 800–1000 °C.
- Hard Alloys created from cobalt powders.

Figure 1 below shows the global cobalt industry chain.

Figure 1 - Global Cobalt Industry Chain



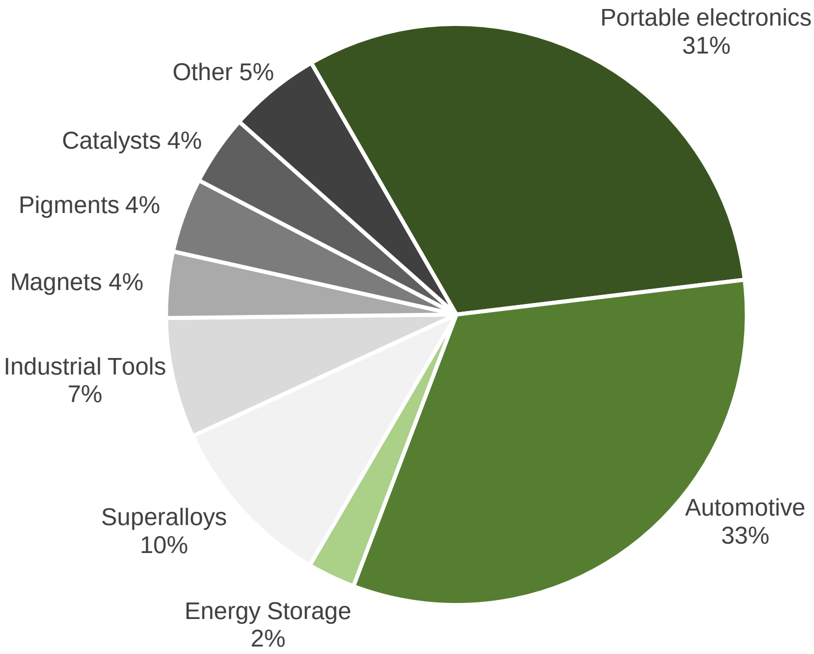

*Source: Benchmark Mineral Intelligence*

# 2 Demand

## 2.1 Overview

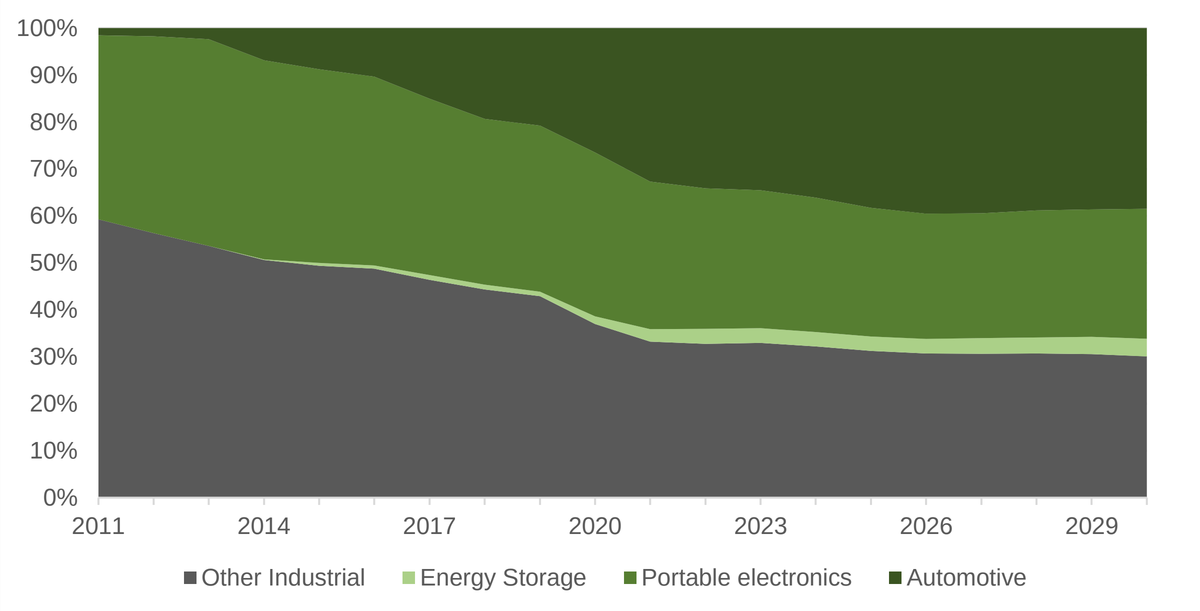
Cobalt demand was traditionally dominated by industrial applications, namely as an input into superalloys, magnets and chemical catalysts. It's use in batteries has increased since the 1990s with the advent of portable electronics and by 2015 overtook other applications as the dominate call on demand. In 2021, batteries commanded 65% of cobalt consumption vs 40% 10 years ago. 2021 is also notable as it was the first year use in auto batteries demanded more cobalt than portable electronics.

Figure 2 - Cobalt Demand 2021




*Source: Wood Mackenzie*

Figure 3 - Cobalt Demand 2011-2030




*Source: Wood Mackenzie*

## 2.2 Lithium-ion Batteries

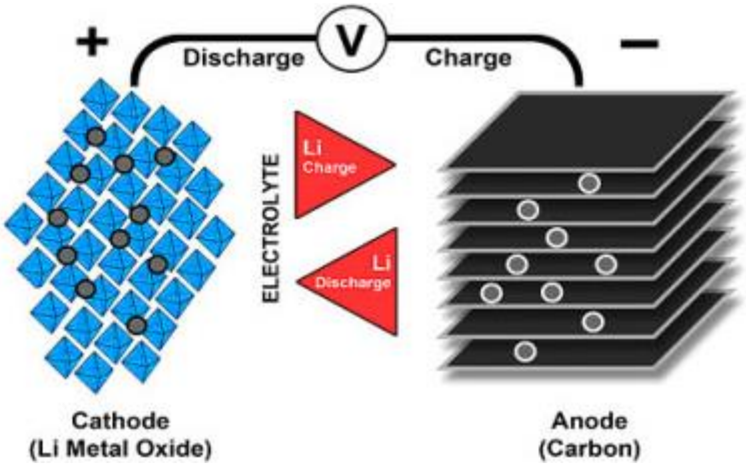
The cobalt-based lithium-ion battery was first commercialised in 1991 by the Sony Corporation of Japan. This technology has several physical characteristics that represent a significant improvement on the incumbent Nickel Metal Hydride (NiMH) and Nickel Cadmium (NiCd) battery technologies. Lithium-ion batteries possess high specific energy (energy/weight), low rates of self-discharge and are generally maintenance free.

Lithium-ion batteries use a cathode (positive electrode), and anode (negative electrode) and electrolyte as a conductor

- The cathode that contains lithium mixed with nickel and other minerals such as cobalt, manganese or aluminium
- The anode, made of carbon graphite and sometimes silicon
- The electrode is a liquid, usually made from lithium salt that is dissolved in a solvent.

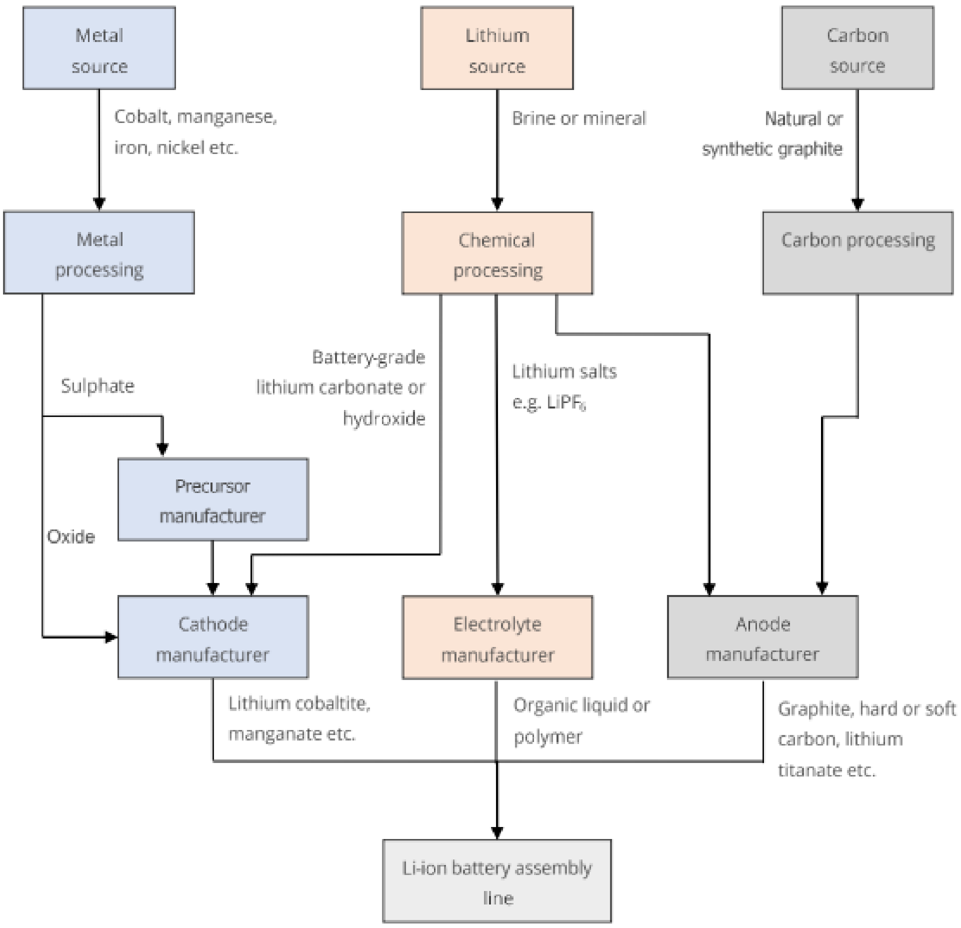
When the battery cell is charged, lithium ions are driven from the cathode to the anode. As the cell is discharged, the ions move back to the cathode, releasing energy.

## Figure 4 – Ion flow in lithium-ion battery




*Source: Battery University*

## Figure 5 – The Lithium-ion battery value chain




*Source: Wood Mackenzie*

Lithium-ion batteries are classified as being cobalt versus non-cobalt based, with major commercial types shown below:

### 2.2.1 Cobalt Based Battery Technologies

Cobalt alloys form part of the battery cathode material. There are three dominant cobalt-based cathode materials; namely:

(i) Lithium Cobalt Oxide - ($LiCoO_2$) ~60% Co, commonly called LCO

LCO batteries were developed as an early generation lithium-ion battery and have subsequently taken mass market share, particularly for small portable devices. The drawback of LCO is a relatively short life span, low thermal stability, and limited load capabilities (specific power). LCO is maturing and newer systems include nickel, manganese and/or aluminium to improve longevity, loading capability and cost. Uses include mobile phones, tablets, laptops, and cameras.

(ii) Lithium Nickel Manganese Cobalt Oxide: ($LiNiMnCoO_2$) up to 15% Co, commonly called NMC

NMC batteries have improved lifespan and specific energy relative to LCO batteries. Uses include EVs, medical devices, and industrial applications.

(iii) Lithium Nickel Cobalt Aluminium Oxide ($LiNiCoAlO_2$) ~9% Co, commonly called NCA

NCA batteries are a more recent development and possess even higher energy densities than NMC batteries. However, they have lower life spans. Uses include EVs (specifically for Tesla's), medical devices and industrial applications.

### 2.2.2 Non-Cobalt Based Battery Technologies

(iv) Lithium Manganese Oxide ($LiMn_2O_4$), commonly called LMO

LMO batteries possess specific energies that are typically lower than LCO. However, the technology has greater design flexibility that allows for batteries to be optimised for longevity (life span), power or specific energy. Uses include power tools, medical devices and electric powertrains.

(v) Lithium Iron Phosphate ($LiFePO_4$) (no cobalt), commonly called LFP

LFP batteries possess good power characteristics, high current ratings and a long-life span. The chemistry also provides thermal stability and enhanced safety for high temperature or demanding conditions. The drawback of LFP batteries are the relatively low energy density and poor performance at lower temperatures. LFP batteries are predominantly a Chinese market technology and remain suitable for low range EVs. We discuss the debate over LFP substituting nickel-cobalt based batteries in a section below.

### 2.2.3 Chemistry Comparison

Lithium-ion batteries initially used cathodes that were about one-third nickel. However, in recent years, automakers have increased the percentage of nickel in cathodes to boost the batteries' energy density and increase vehicle range. Most are now using cathodes that contain at least 60% nickel. The differing attributes of EV cathode chemistry is shown in the simplified figure below, courtesy of Citi Research. The key conclusion remains that NMC/NCA chemistries exhibit superior characteristics.

Figure 6 – Cathode Chemistry Comparison

NMC's combination of energy density and stability makes it the EV material of choice

| | LFP | NCA | NMC | LCO |
|---|---|---|---|---|
| Energy Density | Ordinary | Excellent | Excellent | Excellent |
| Power Density | Ordinary | Good | Good | Ordinary |
| Stability | Excellent | Good | Excellent | Ordinary |
| Lifespan | Excellent | Good | Good | Ordinary |
| Cold Temperature Performance | Ordinary | Excellent | Excellent | Ordinary |

Excellent Good Ordinary

*Source: Citi Research*

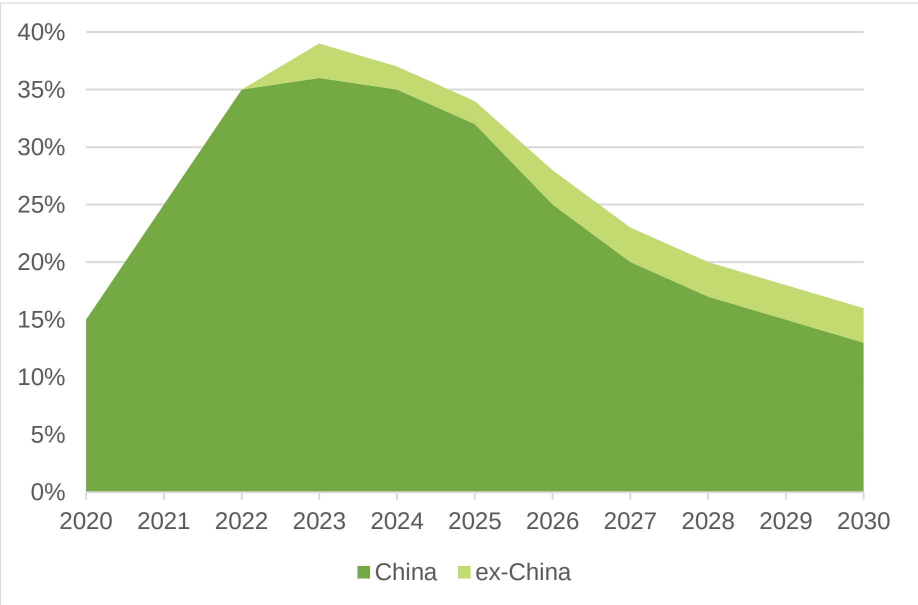
This trend has gained pace over the past two years, in part to reduce or eliminate cobalt, and in part to increase density for premium applications. For example, the cathodes in cells that Korean battery maker LG Chem supplies to Tesla are 90% nickel.

## The LFP debate: Will EV makers accept the trade-off of lower energy density?

Another trend that has gained pace in recent years is greater use of LFP batteries. LFPs have already been accepted by the stationary battery energy storage system sector (ESS), where energy density (thus weight) tends to be a less decisive factor. But given ESS only makes up a relatively low share of total battery raw material demand, the use of non-nickel / cobalt bearing batteries will not materially impact demand.

However, over the past couple of years, some EV makers have started to accept this trade-off of lower energy density for lower cost advantage in some of their car models. While this trend has so far been almost exclusive to auto makers in China, the data demonstrates LFP has gained market share over past 2 years.

Figure 7 – LFP global share increasing from 15% in 2020 to 36% by 2023




*Source: UBS*

## Trade-offs:

There are two important trade-offs when comparing LFP with nickel / cobalt bearing batteries for automobiles:

- Energy density; and
- Cost.

Both trade-offs favour LFP over the next 2-4 years but swing back to nickel-cobalt's advantage in the mid-2020s.

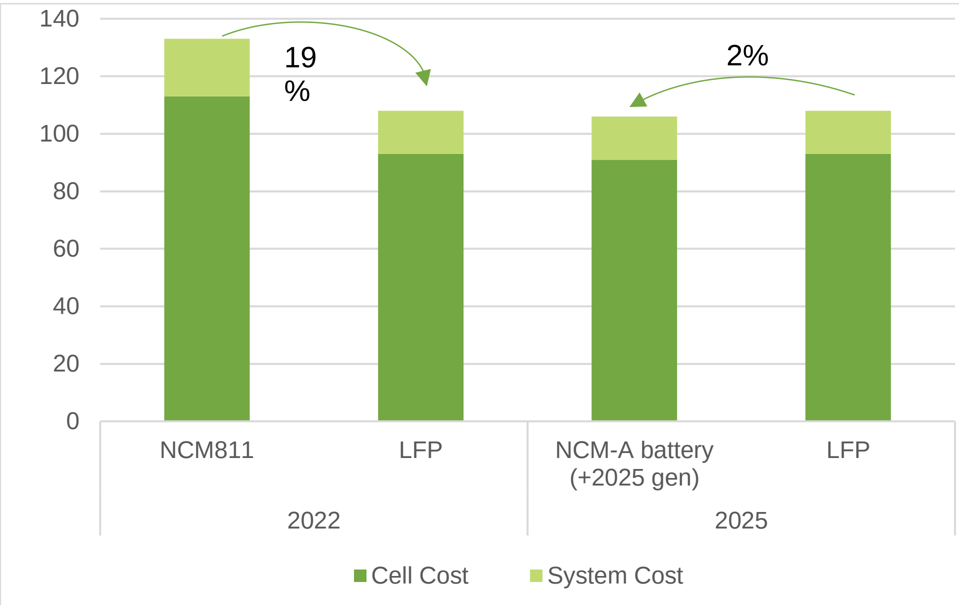
**Energy density**

LFP batteries possess good power characteristics, enhanced safety for high temperature or demanding conditions and a long-life span. However, they have relatively low energy density and poor performance at lower temperatures. While they can be fully discharged and charged without as much damage to the cell over time, LFP batteries do not generally deliver the same range as NCA and other types. This is a trade-off some automakers / consumers are willing to make, especially in high-population centres where range is not as large of an issue as places where people tend to travel further distances outside of cities. However, this technical advantage with iron-based cells has largely plateaued. Whereas with nickel-cobalt based technology, there is a clear technological path to raise energy density through the end of the decade, thus eroding LFP's attractiveness.

**Cost**

In the current, inflationary market conditions, iron cells have cost advantage over nickel / cobalt. According to UBS, LFP has a 19% cost advantage as compared to the mainstream NCM 8 series. However, over time, technological advances will even out that advantage. While nickel cells will see iterative upgrades every 18-24 months, the LFP cathode crystal structure puts a cap on lithium-ion storage capacity – meaning iron cells will tread water over the next decade and eventually be phased out.

Figure 8 – 2022-2024 battery system costs




*Source: UBS*

## Broadening choices

Despite the longer-term advantages of the nickel / cobalt bearing batteries, some automakers, such as Tesla and Rivian are moving forward with LFP cells to diversify their model offerings, expand available supply and broaden the cost base. Volkswagen in March will also use LFP batteries in its "entry-level" EVs.

Concern over nickel and cobalt supply security and bouts of unsettling price volatility also led to those decisions. However, this strategy, while favouring the lower-end of the EV market, has its limits. The installed capacity base of LFPs and existing expansion plans appear to have plateaued. Battery researchers Roskill (now Wood Mackenzie) estimate 95% of LFP cathode manufacturing is based in China, and expansion plans have drastically slowed. Moreover, there has not been a financial investment decision (FID) on iron EV battery capacity outside of China. From FID to commercialization large scale battery factories require 3-5 years. Consequently, until there is more investment in the segment, there is a near-term cap on LFP's share.

Currently the big three South Korean battery makers (LG Energy Solution, Samsung SDI and SK On) are focusing on high-nickel containing NCM and NCA batteries (products with a nickel content of at least 90%).

In conclusion, while LFPs have gained some market share over the past two years, those gains are expected to plateau and eventually erode due to continued performance enhancement in nickel / cobalt batteries.

### 2.2.4 Non-Lithium Battery Technologies

Apart from lithium-ion batteries, the other dominant rechargeable chemistries remain NiMH and NiCd. NiMH batteries contain nickel (50%), rare earths (30%) and cobalt (6-10%) while NiCd batteries similarly include nickel but also use the toxic heavy metal, cadmium. They are a potential source of pollution/contamination and the European Union has taken legislative steps to ban these batteries.

### 2.2.5 Lithium-ion Battery Demand

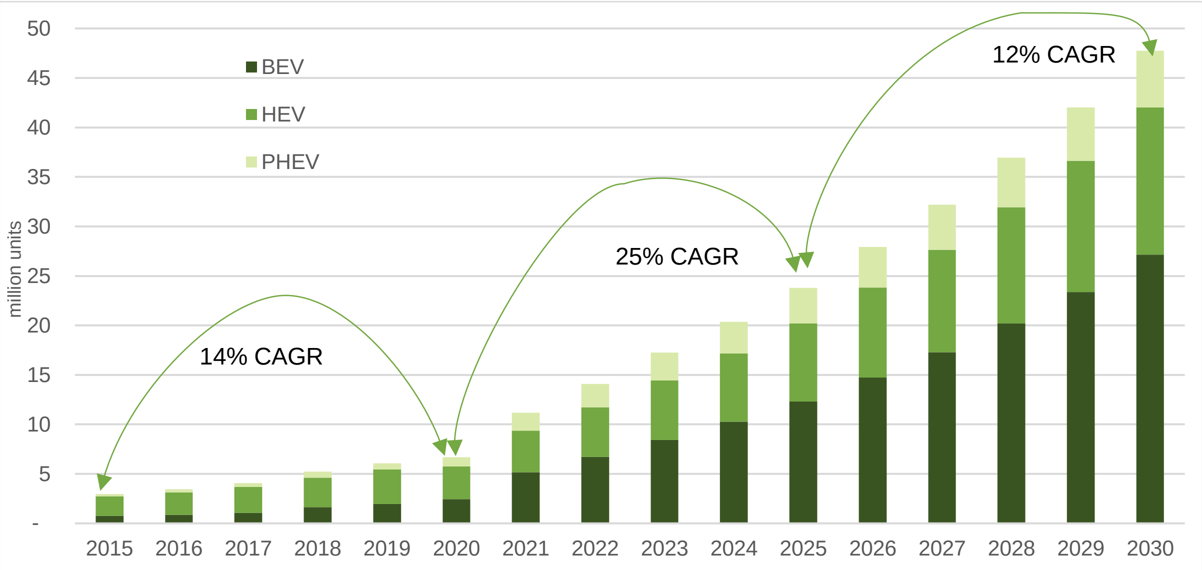
Lithium-ion battery demand is driven by three broad categories of end use:

1. Electric Vehicles
2. Portable Electronics
3. Energy Storage Systems

## Electric Vehicles

Electric vehicles include Battery Electric Vehicles (BEVs) and Plug in Hybrid Vehicles (PHEVs), Hybrid Electric Vehicles (HEVs), commercial trucks, buses, and electric bikes.

Figure 9 – EV sales 2015-2035e

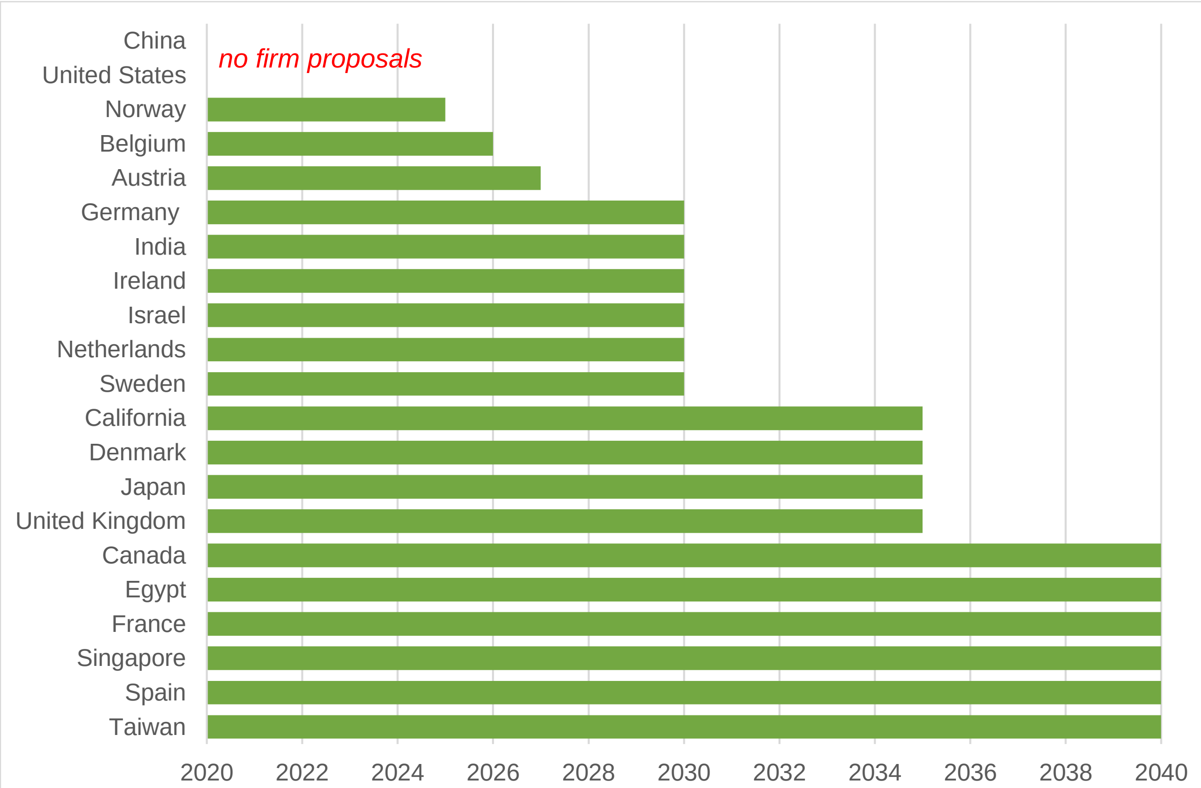



*Source: Wood Mackenzie*

Global EV sales reached 6.75 million units in 2021, +108% vs 2020. Sales in 2021 were especially strong thanks to significant Government policy support. While some of these policies were put in place to assist with the Covid economic recovery and are winding down, many will remain in place for some time to come. Such policies are, in effect, direct subsidies typically designed to deliver energy security, improve air quality, and reduce Greenhouse Gas (GHG) emissions. The EU, US, Japan, and China have continuously raised standards during the last 15 years for vehicle fuel economy and GHG emissions by incentivising automotive manufacturers to develop electric alternatives to traditional internal combustion engine designs. And importantly, consumer preference is increasingly shifting toward owning a more environmentally friendly vehicle.

Figure 10 below shows the current state of international ICE vehicle bans.

Figure 10 – International Bans on ICE Vehicles.




*Source: UBS Bank*

Whilst no national policy currently exists within the US, California has led the way to ban ICE vehicles sales from 2035F with a total of 12 States aligning themselves with this phase out date.

**EVs should achieve total cost parity by 2026**

Electric vehicles could be cheaper than cars powered by petrol or diesel in just four years, according to Bloomberg New Energy Finance. The research suggests larger types of electric vehicles such as SUVs and sedans could be the first to achieve parity by 2026, with smaller models following a year later. According to Bloomberg's report, by 2026 it's thought the average price of a mid-size vehicle powered by either electricity or fossil fuels will be €19,000 and by 2030 the predicted average cost of an EV will be €16,300 versus the average ICE vehicle at €19,900.

**EV subsidies growing globally** – Globally, EV subsidies are occurring on an increasingly larger scale, targeting both EV purchase assistance and bailouts for incumbent auto OEMs:

i. Europe, China and other major countries are mandating lower CO2 emissions.
ii. Germany - increased subsidies to €9,000 for BEVs (below €40k price); €5,000 for EVs (between €45k and €65k), PHEVs receive €6750 (below €40k) and €3.75k (price between €45k and €65k); no subsidy above €65k.
iii. UK - government grants (through dealers) are 35% of BEV purchase price, up to £3,500, and 20% of the purchase price for BEV vans up to £8,000. New cars and vans powered wholly by petrol and diesel will not be sold in the UK from 2030, and
iv. California - Governor has announced the ban the sale of ICE vehicles from 2035, mandating that all new cars sold from that point will be emissions-free.

## Portable Electronics

Portable electronics includes typically small and portable devices such as laptops, tablets and mobile phones. Mobile electronics represents small battery size combined with longer cycle life and held the dominant end use share of lithium-ion batteries for nearly two decades leading up to 2010. The small rate of mobile electronics battery growth, caused by already high rates of market penetration, relative to EV and ESS applications will see forecast market share compress from 90% in 2011 to just 40% in 2030F.

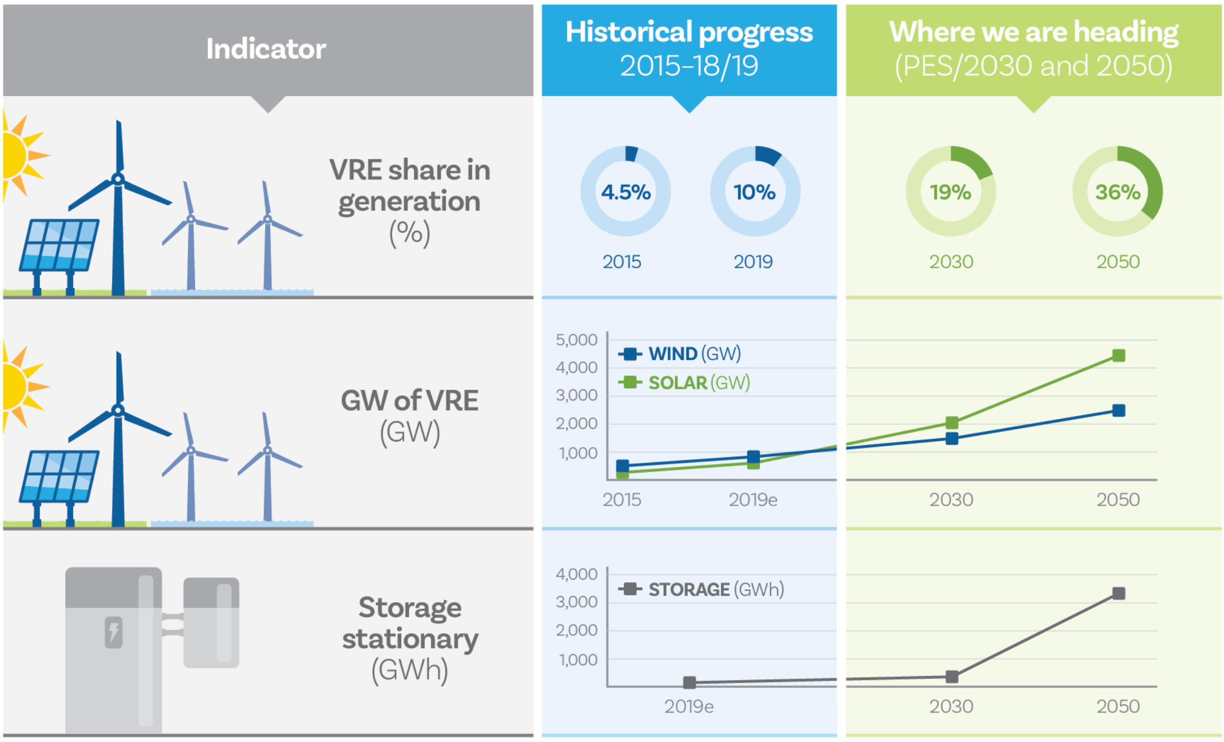
China has a capital and labour cost advantage and dominates lithium-ion battery production for the customer electronics market. It also remains a major processing hub for the lithium-ion raw materials, lithium, cobalt and graphite, so domestic battery manufacturers have a logistical advantage over exported intermediate products.

## Energy Storage Systems (ESS)

ESS is a system that stores surplus power and supplies that produce power when needed to improve power efficiency. There are various types of ESS such as pumped hydro storage (PHS), flywheel energy storage (FES), compressed air energy storage (CAES), and battery energy storage systems (BESS).

A key driver of growth in energy storage has been the co-location of renewable energy production facilities with energy storage assets, which stabilises production and ensures firmer capacity during peak demand periods. According to the International Renewable Energy Agency (IRENA) the share of renewable energy in global final energy consumption has increased only slightly since 2010, staying around a threshold of about 10%. In simple terms, while renewables are increasing, so is energy demand. As shown in Figure 11, the share of modern renewable energy in final energy supply will increase to 19% by 2030F and 36% by 2050F.

Figure 11 – Renewable Energy and ESS Forecasts

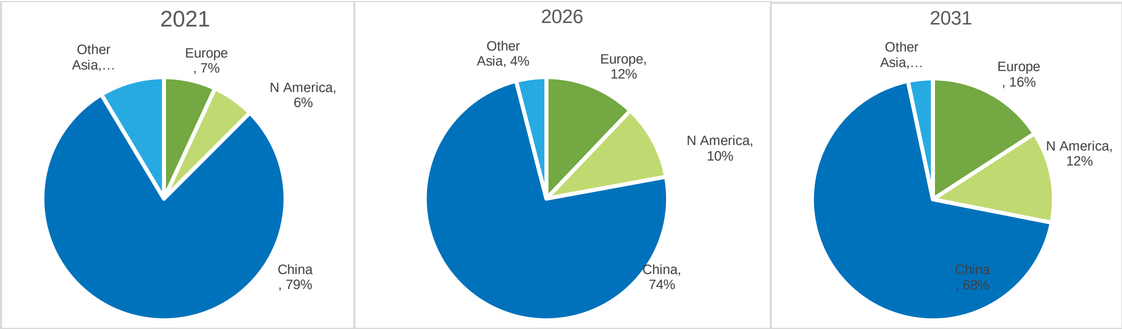



*Source: IRENA. Note: VRE = Variable Renewable Energy (Solar Photo Voltaic & Wind Turbine)*

### 2.2.6 Cathode Capacity and Market Share

Production of lithium-ion batteries is dominated by a triumvirate of China, Japan and Korea which hold >90% of global market share, of which China holds ~80%. World-class production is predicated upon economies of scale coupled with intensive research and development programs. Each of these Asian powerhouses has a long-term focus on battery technology, design and manufacture. Given its initial research and development, Japan had a head start on early generations of lithium-ion design and manufacture but has steadily been losing share as lower cost centres in Korea and China gain share. More recently, active commitments from EU nations have triggered an arms race to install battery factories (“Giga Factories”), aimed to primarily service the EU, today the largest regional EV market in the world.

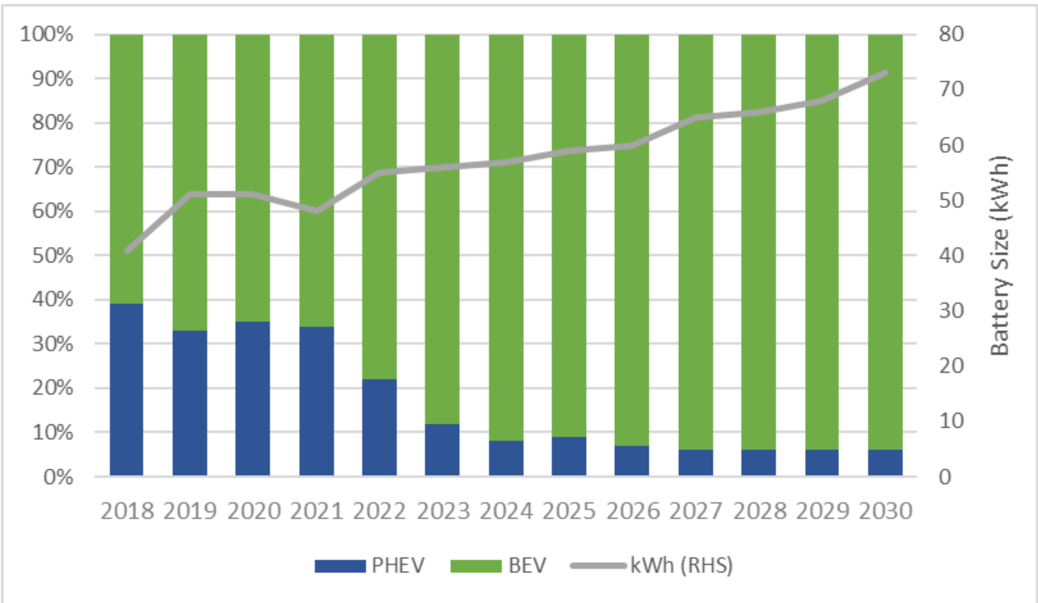
Figure 12 – Lithium-ion Battery Cell Capacity by Region

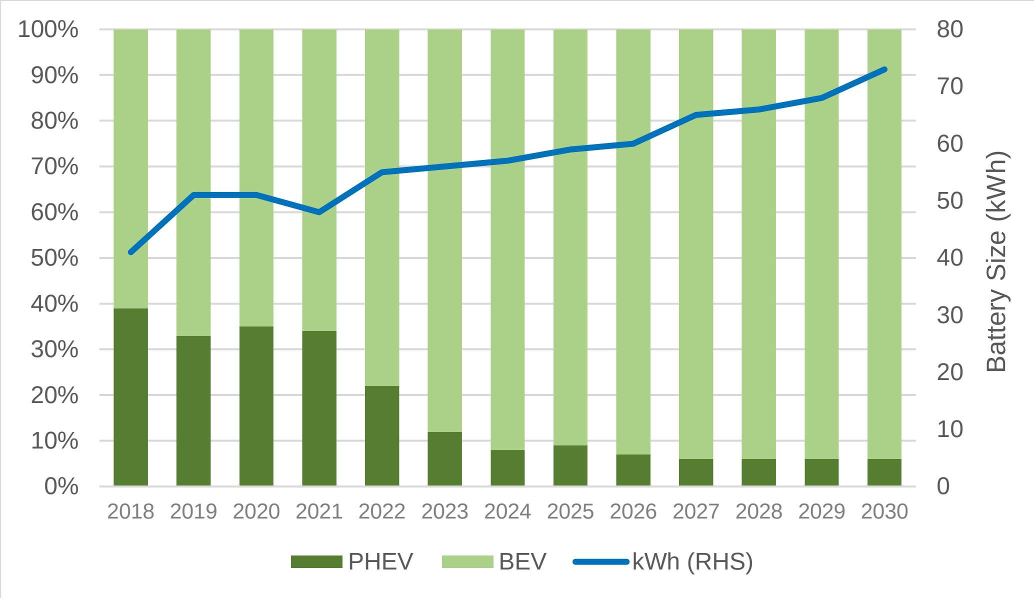



LCO, NMC and NCA cathode technologies today supply ~75% of the global lithium-ion battery market or ~94% of the EV battery segment. Forecasting EV cobalt demand relies on vehicle growth, vehicle market trends (e.g.: battery sizes required for BEVs are typically 40-50kWh versus PHEVs which are typically 15-20kWh) and cathode chemistry.

Figure 13 shows UBS research forecast growth by EV segment, which forecasts average battery sizes to increase form ~40kWh to ~70kWh per vehicle by 2030F.

### Figure 13 – BEV vs PHEV - Market Share Forecast



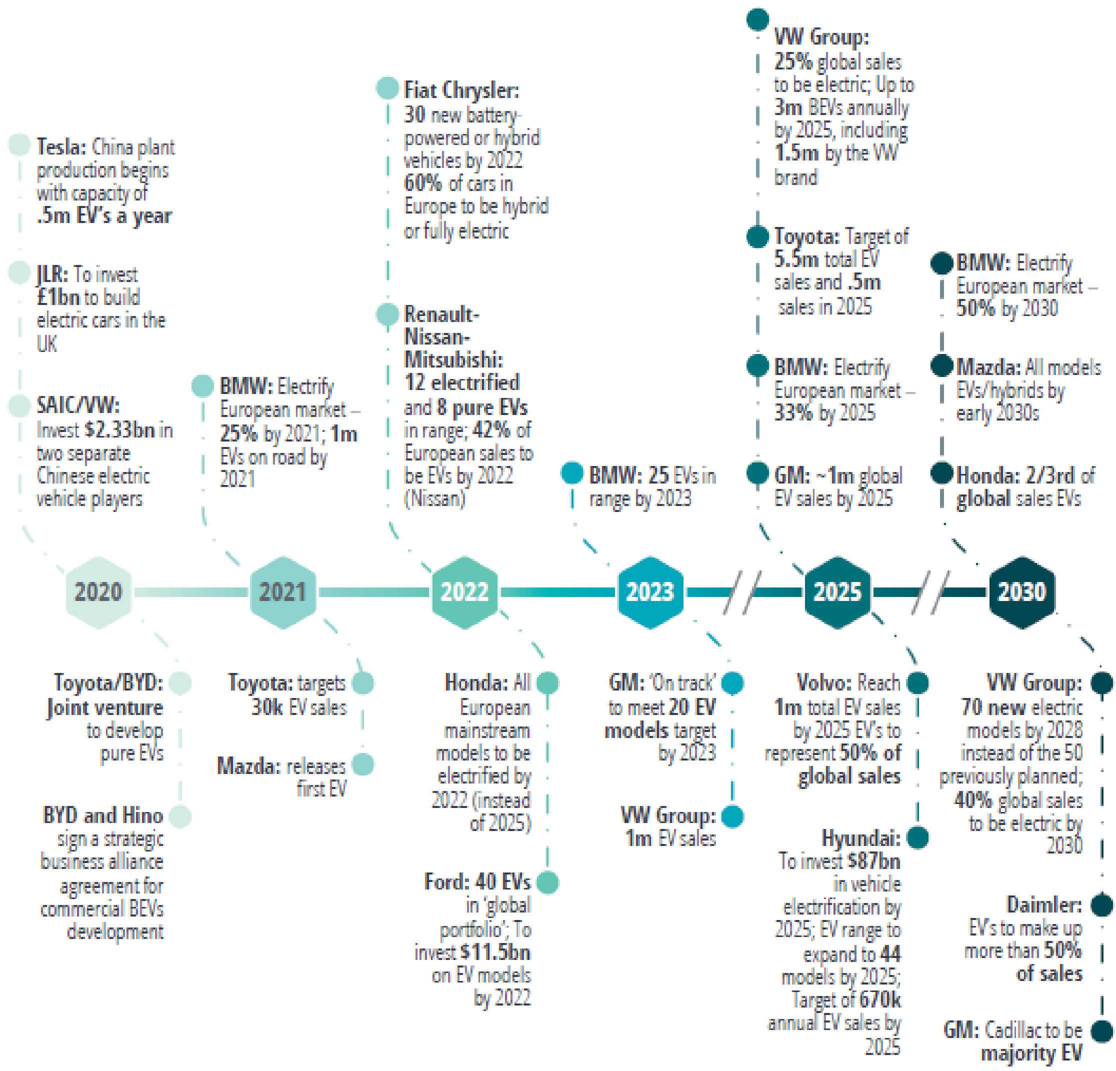



*Source: UBS*

The sheer scale of EV capital investment (estimated to be over US$500Bn between 2020-2025F) is captured by

Figure 14 below.

Figure 14 – Timeline of Strategic OEM Targets for EVs



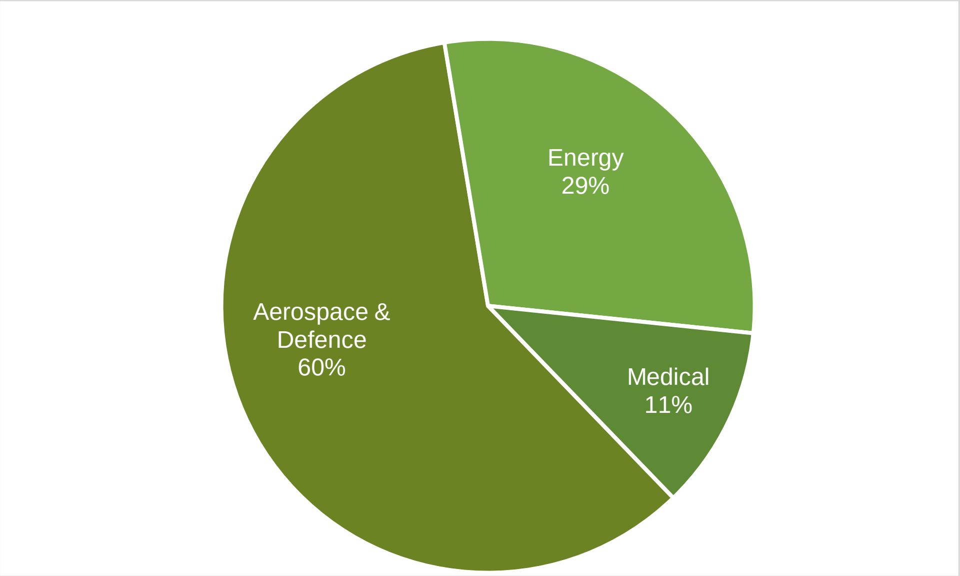

*Source: Deloitte*

## 2.3 Superalloys

Superalloys are capable of withstanding high temperatures, typically >600$^{0}$C, high stresses and often highly oxidizing atmospheres.  Cobalt is one of the main alloying elements. Superalloys are used primarily in aerospace, nuclear power, gas turbines and automobiles. Iron and nickel-based superalloys typically contain 10-20% cobalt.

Chinese trade statistics highlight the widening gap in supply and demand over time, with high-end superalloys increasingly being imported. However, energised by a supportive, domestically focussed industrial policy, Chinese superalloy production is expected to grow rapidly during the next decade to support national aerospace, nuclear power, and other downstream industries. The largest superalloy application currently is aerospace, which accounts for ~50% of total consumption (consisting of commercial, business, and rotary wing segments), the power sector 20% and machinery 10%.

Figure 15 – Cobalt Based Superalloy Applications




*Source: ResearchInChina,*

## 2.4 Cobalt Demand for Industrial Applications

Cobalt alloys are used for a variety of industrial applications. At a machining level, cobalt alloys provide the hardness required for cutting tools. Blending cobalt with iron or nickel-based metals creates a higher melting point alloy than its constituents, imparting more strength, toughness and fatigue properties at higher operating temperatures. Cobalt-based alloys also typically exhibit superior corrosion resistance, particularly at elevated temperatures, making them ideal for gas turbines/jet engine applications.

### 2.4.1 Hard Alloys

Hard alloys are used broadly as tooling materials for cutting cast iron, non-ferrous metal, plastic, glass and stone, or cutting difficult to machine materials like heat resistant steel and tool steel. As a binder metal for hard alloys, cobalt typically makes up 10-15% of the content of the tool. Currently, the global hard alloy market is maturing and displaying increased cost sensitivity and commoditisation. Global hard alloy producing countries include the US, Russia, Sweden, China, Germany, Japan, the UK and France. Global hard alloy output has grown steadily in recent years, but at a slowing pace. As the largest hard alloy producer worldwide, China’s output makes up 38% of the total, closely followed by Europe with 26%.

At present, there are approximately 600-700 hard alloy producers in the world. Larger producers include Sandvik (Sweden), Kennametal (US), Iscar (Israel), Mitsubishi Materials (Japan), Toshiba Tungalloy (Japan) and Ceratizit (Luxembourg). Hard alloys are defined in terms of their raw material composition - Table 2 below classifies cobalt based hard alloys.

Table 2 - Classification of Cobalt Based Hard Alloys

| Type | Abbreviation | Features and Application |
|---|---|---|
| Tungsten Cobalt Alloy | YG | Flexural strength, medium hardness and workable particularly at low cutting speeds. Used for machining cast iron, non-ferrous alloys and insulating materials |
| Tungsten Cobalt Titanium Alloy | YT | High hardness and abrasion resistance, lower toughness, used primarily for machining more plastic materials such as steel |
| Tungsten Titanium Tantalum (Niobium) Cobalt Alloy | YW | High hardness and good temperature resistance. Used for machining alloys steels, cast iron and carbon steels, often used as a general hard alloy |
| Titanium Carbide-Based Alloy | YN | Excellent hardness and high temperature oxidation resistance. Used for high speed cutting tools to finish steel |
| Coated Alloy | CN | Abrasion and oxidation resistant, high matrix strength. Used for steel, cast iron, non-ferrous metals and related alloy machining tools |

*Source: ResearchInChina*

### 2.4.2 Magnetic Materials

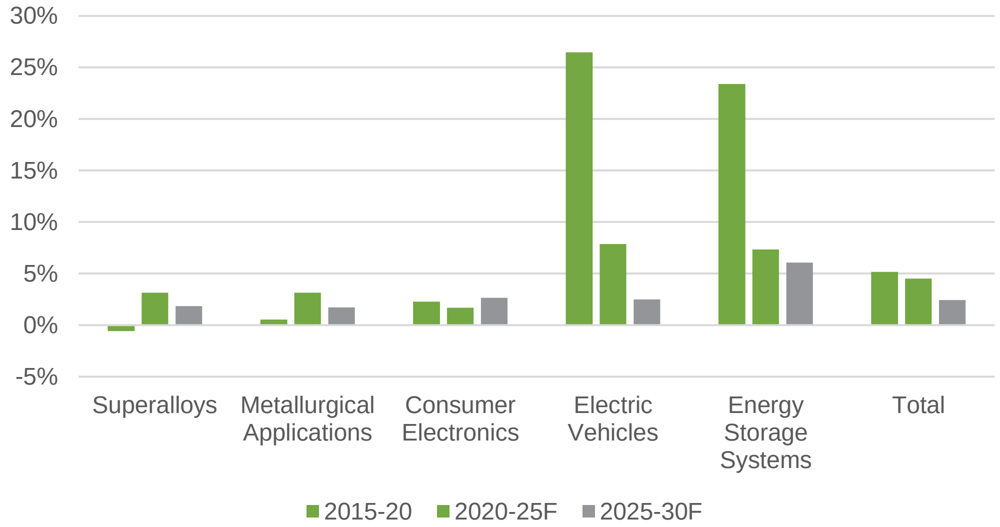
Cobalt, nickel, and iron are ferromagnetic materials exhibiting unique magnetic behaviours. Traditionally, the use of magnetic materials was aimed at rotating machines, such as generators and motors, and electrical power transformers. However, the development of specialty magnets in the 1980s, such as neodymium-iron-boron (NdFeB), aluminium-nickel-cobalt (AlNiCo) and samarium-cobalt (SmCo) magnets led to a large increase in available magnetic energy, at the same time as new devices such as computer disk drives, magnetic resonance imaging scanners and high efficiency direct current motors required increasingly powerful magnets.

Breaking down the magnetic materials demand segment, 40% of cobalt is used within AlNiCo permanent magnetic alloys, 30% for SmCo alloys, and 30% for other rare earth permanent magnet materials. Around 2011, the soaring price of rare earths witnessed a demand shift to the non-rare earth containing magnetic materials such as AlNiCo permanent magnet alloys.

## 2.5 Cobalt Market Segments - Forecast

Battery demand remains buoyant and will reflect underlying EV and ESS growth along with more GDP like growth from the consumer electronics segment. There are several core drivers for battery demand. The first is improvement in EV driving range and ownership economics, with subsequent consumer take up. Next is increased penetration of ESS devices, both household and utility scale. Then there is an increase in the stability and safety performance of lithium-ion batteries. Figure 16 shows the cobalt market segment forecast.

Figure 16 – Cobalt Market Segment Forecast - CAGR (%pa)




*Source: Wood Mackenzie*

## 2.6 Cobalt Substitution

As cobalt prices rise, substitution of cobalt will become inevitable. The simplest substitution is in chemical applications (approx 15-18% of demand) within the non-battery sectors. Next, more moderate substitution will take place in permanent magnets and superalloys.

Higher cobalt prices and the need for EVs to reach cost parity with ICE vehicles will put lower cobalt weighting as a key target. We expect significant reduction of cobalt content in cathodes but not for full demand destruction or a “cobalt free” chemistry.

Nickel will increasingly take share of the cathode built, but a “cobalt free” solution is not an immediate risk. A lot of research and development is ongoing to build a battery with lower costs, higher energy density, improved safety but commercialization remains elusive. Lithium-ion battery designs with cobalt cathodes are still likely to dominate the battery market at least for the next 10+ years given the delays to commercialisation and ongoing technical challenges.

Our forecast incorporates an aggressive 70% penetration of EV cathodes will be nickel heavy NMC 811 by 2030F). BYD, one of the largest battery makers, is planning to push out an LFP battery design (aka “Blade technology”). The low energy density of LFP (NMC 811 has approximately 1.5x the energy density of LFP) makes weight a significant barrier as demands rise. LFP cathodes will tend to dominate low range and low cost vehicles, typically focussed on a segment of the Chinese market. As pack costs of NMC 811 are only 8-9% higher than LFP, a mature market share of ~15% will be difficult to increase without substantial breakthroughs in energy density. For PHEVs where energy density is less restrictive, cobalt- nickel free LFP batteries are expected to remain more dominant.

## Table 3 – Cobalt - a Critical Material

Cobalt remains a critical material, substitutes are available for most but with loss of performance

| | % of cobalt demand | End users | Advantages of cobalt | Substitution Possibility | Comments |
|---|---|---|---|---|---|
| Superalloys | 12-16% | Turbine blades for gas turbines and jet aircraft engines | Higher melting point than nickel-based, retains strength at higher temperatures, superior weldability, hot corrosion, and thermal fatigue resistance | There are nickel-based single crystal alloys or iron based super alloys or other materials composites that may substitute cobalt based super alloys but, in some cases, there will be loss of performance. | Availability of substitutes will ensure loss of market cobalt |
| Magnets of all types | 5-6% | Generators, pump couplings, sensors, motors, marine applications, and in the automotive, aerospace, military and food and manufacturing industries | Higher temperatures and the only magnets that have useful magnetism even when heated red-hot | New variation of samarium cobalt magnet has been developed which consumes lower amounts of cobalt | Commercialisation of the new samarium cobalt magnet is most likely a couple years away |
| Hard materials – Carbides, Diamond Tooling | 8-10% | Diamond tools | The high solubility of tungsten carbide (WC) in the solid and liquid cobalt binder at high temperatures provides a very good wetting of WC and results in an excellent densification during liquid phase sintering and in a pore-free structure | Substitutes are available however there is a certain loss in performance | Availability of substitutes will ensure loss of market cobalt |
| Batteries | 48-50% | Mobiles, EVs | High energy density | New variants of lithium battery, air batteries etc in R&D phase | In the near term NMC811 will help reduce cobalt requirements and post 2020 ELNO could take away market share |
| Chemical Applications | 15-18% | Pigments, Oil and Gas, Chemicals | | Substitution in these applications with Cerium, iron, lead, manganese, and vanadium is possible though not with the same results | Availability of substitutes will ensure loss of market cobalt |

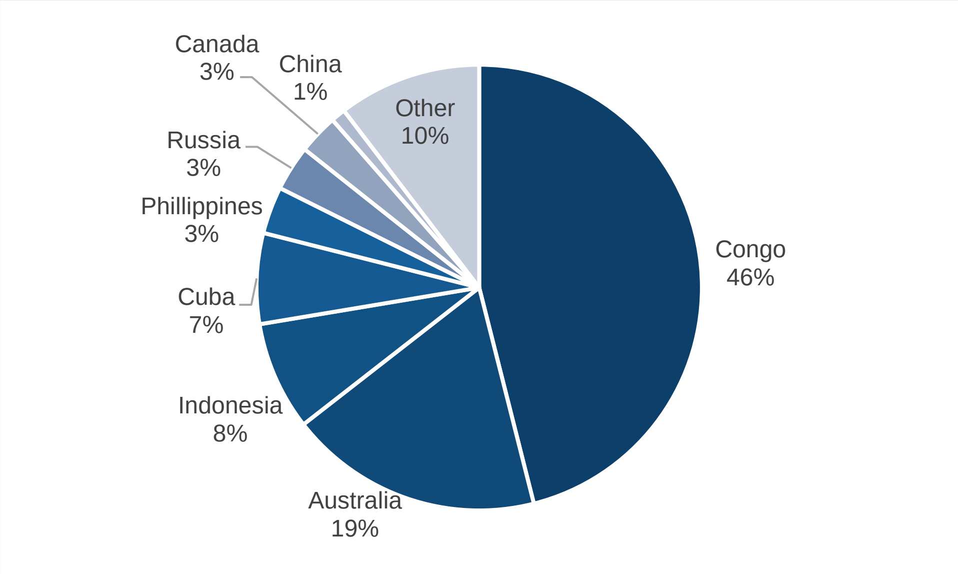
*Source: Cobalt Institute, Citi Research*

# 3 Supply:

## 3.1 Cobalt Sources

Cobalt ranks 33rd in abundance of all metals in the earth's crust and is widely scattered, however it appears in economic quantities in less than 20 countries globally. In 2019, global cobalt reserves totalled approximately 7.6 mt, concentrated in the Democratic Republic of Congo (DRC), Australia, Indonesia and other countries that are dominate in copper and/or nickel production.

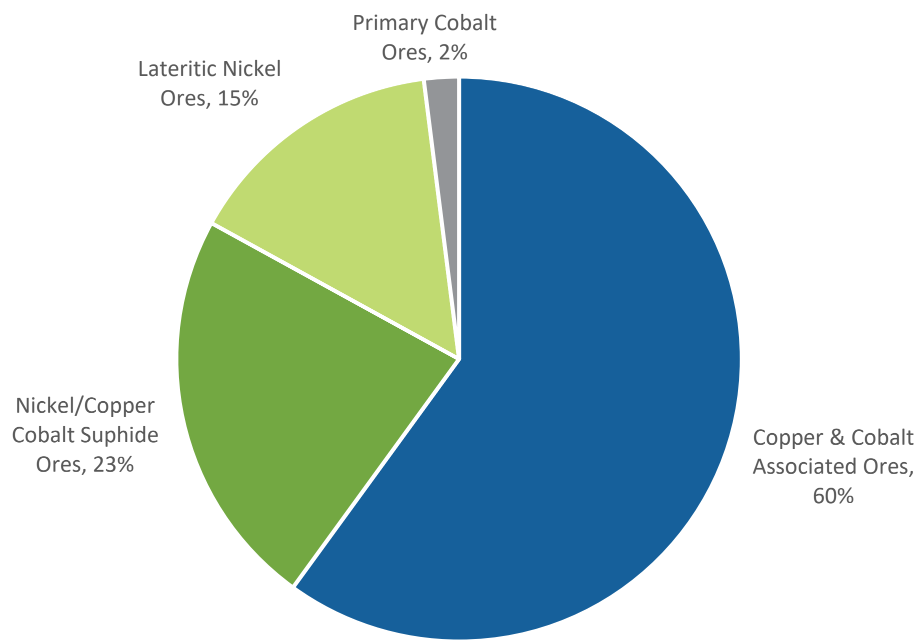
Figure 17– Global Cobalt Reserves – 2021 Estimates




*Source: USGS*

Global cobalt production comes mainly from associated ores, of which copper and cobalt-associated ores accounts for 60%, nickel–copper–cobalt sulphide ores 23%, lateritic nickel-cobalt ores 15%, and primary cobalt ores and other only 2%. Thus, primary cobalt ores contribute only a fraction of global supply.

Figure 18 – Global Cobalt Production by Resource Type (%)

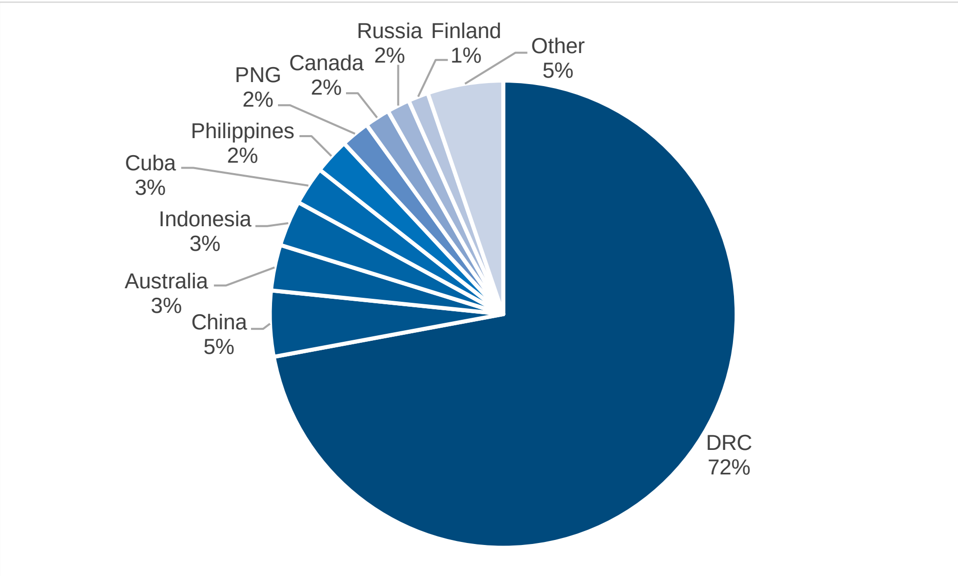



*Source: USGS*

## 3.2 Cobalt Production by Region

The global cobalt market (2021) is highly concentrated with the top five countries supplying >80% of the global market. The DRC alone supplies 71% of the global market, highlighting the dependence the cobalt market has on one country to supply, and keep on supplying, this strategic metal.

Figure 19 – Global Cobalt Production– 2021




*Source: Wood Mackenzie*

## 3.3 The Democratic Republic of the Congo

The Democratic Republic of the Congo (DRC) is one of the poorest and most corrupt countries in the world. The DRC ranks:

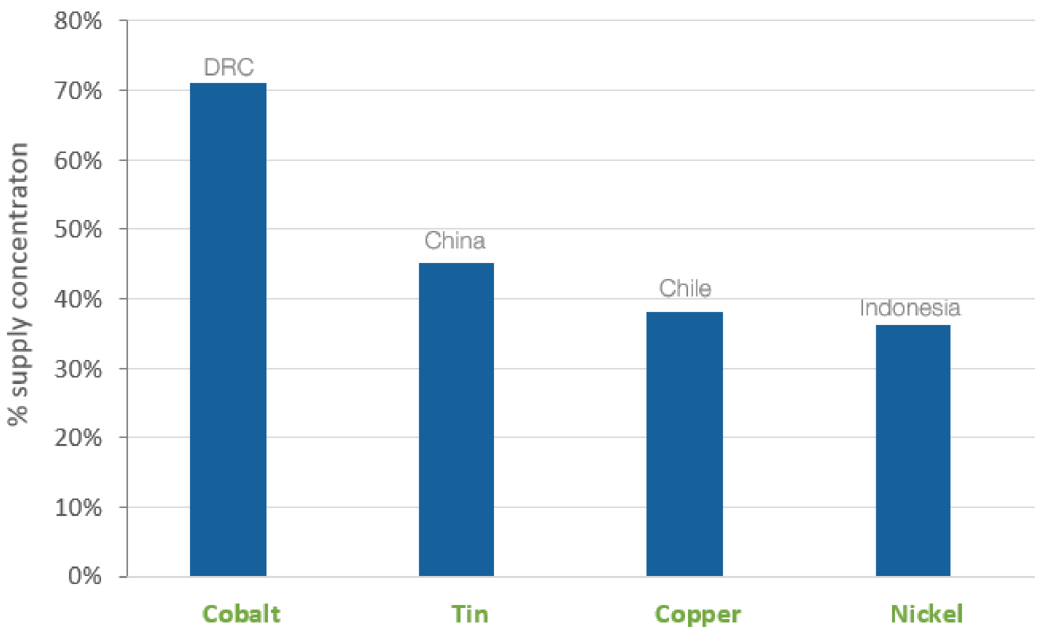
- 151 out of 159 countries in the Human Freedom Index
- 176 out of 188 countries in the Human Development Index
- 178 out of 184 countries in terms of GDP per capital
- 148 out of 169 countries in the corruption perceptions index.
- 82 out of 83 in the Fraser Institute of mining risk survey

*Source: Visual Capitalist*

The DRC Government estimates that 20% of all cobalt production within the country comes from artisanal miners – independent workers who dig holes and mine ore without sophisticated machinery. There are at least 100,000 artisanal cobalt miners, with UNCEF estimating that up to 40,000 children are involved in mining, some as young as 7 years old.

Cobalt's supply exposure to the DRC is set to peak at 72% in 2021 and is unlikely to go below 60% before 2040F. This concentrated geo-political supply risk is unseen in any other large-scale commodity and in is a region where supply and regulatory risks run high.

Figure 20 – Other examples of Supply Concentration – DRC and Cobalt an outlier




*Source: Citi Research, Wood Mackenzie*

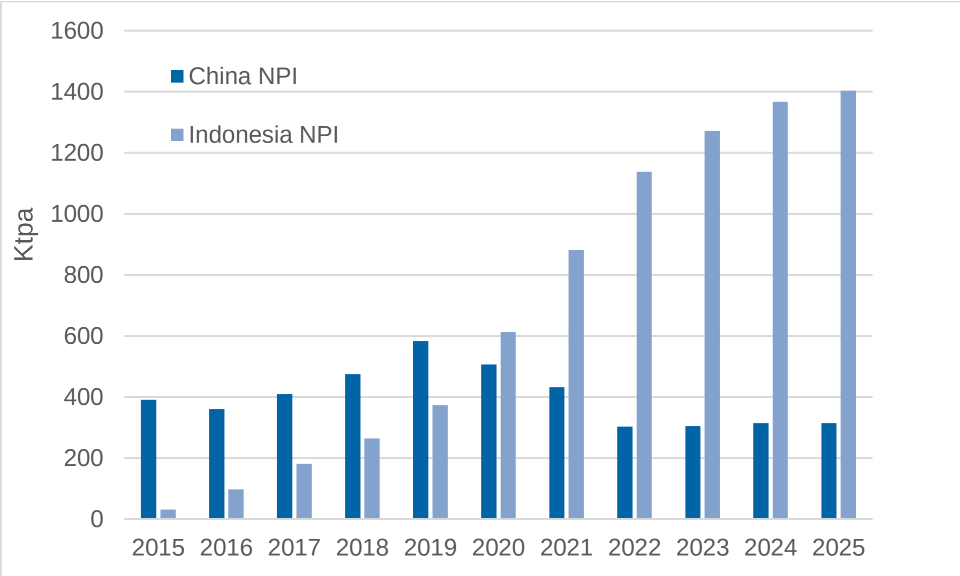
## 3.4 The Emergence of Indonesia

Indonesia has long been a nickel producer, predominately supplying China's massive stainless steel sector. Indonesia's nickel is primarily found in near-surface laterite deposits where the nickel is recovered though open-pit mining methods (differing from underground deposits in other leading producing countries such as Canada and Russia). The marketable nickel produced in Indonesia was traditionally is in the form of nickel ore (unprocessed nickel) and then shipped to China where it was processed into nickel pig iron (NPI) and ferronickel – both are lower-grade intermediates used in stainless steel. Very little cobalt was recovered in this process at either end of the trade.

However, in 2014 Indonesia began to enforce a 2009 ban on exports of unprocessed ores (including nickel) to support the development of its own downstream nickel processing sector. Chinese NPI and ferronickel producers were more than willing to move the industry to Indonesia given the high energy and ultimately environmental impact.

In the ~7 years since, over US$30 billion (primarily by Chinese firms) has been invested into NPI production facilities and stainless-steel plants with associated power stations, infrastructure development, industrial zone developments, and skills development. Currently around 50 million tonnes of laterite nickel ore is processed into 800kt of nickel metals in the form of NPI and stainless steel. Indonesia currently produces around 30% of global nickel supply and has the largest proven reserves in the world.

Figure 21 – China's nickel pig iron (NPI) decline vs Indonesia's rise

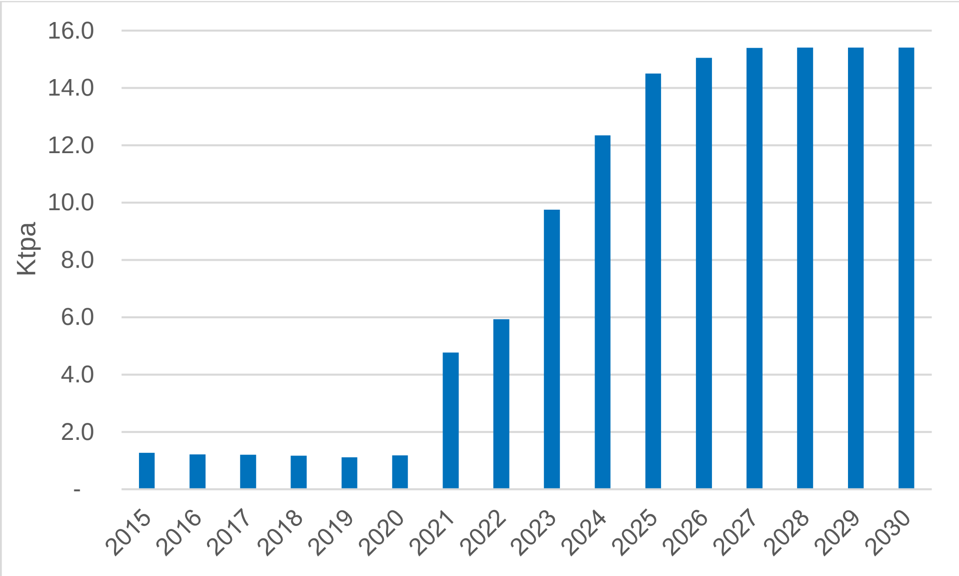



Following the success of this downstream investment, many of the same firms around 2018 began investing further downstream to construct high-pressure acid leach (HPAL) and matte projects to produce more refined products, namely nickel hydroxide and sulphate for the battery industry. Consequently, production of cobalt as a by-product leapt from 1.2kt to 4.8kt in 2021 and is expected to reach 15kt by 2026.

The rise of Indonesian cobalt output posses another ESG risk to cobalt consumers. The main issue for Indonesia from an environmental perspective is it reliance on coal fired power. With abundant coal supplies, a large reason for the rapid growth in its nickel sector has been the availability of cheap domestic coal power to enable producers such to be highly cost competitive in the market.

Another issue is tailings disposal, which is a challenge for HPAL projects. Indonesia's mountainous island topography makes finding locations for land based tailings dams more difficult. But close proximity to the sea makes deep sea tailings disposal a more economic option. From an ESG perspective, deep sea tailings disposal is no longer considered a viable option by many investors, potentially rendering cobalt sourced from Indonesia also “unethical.”

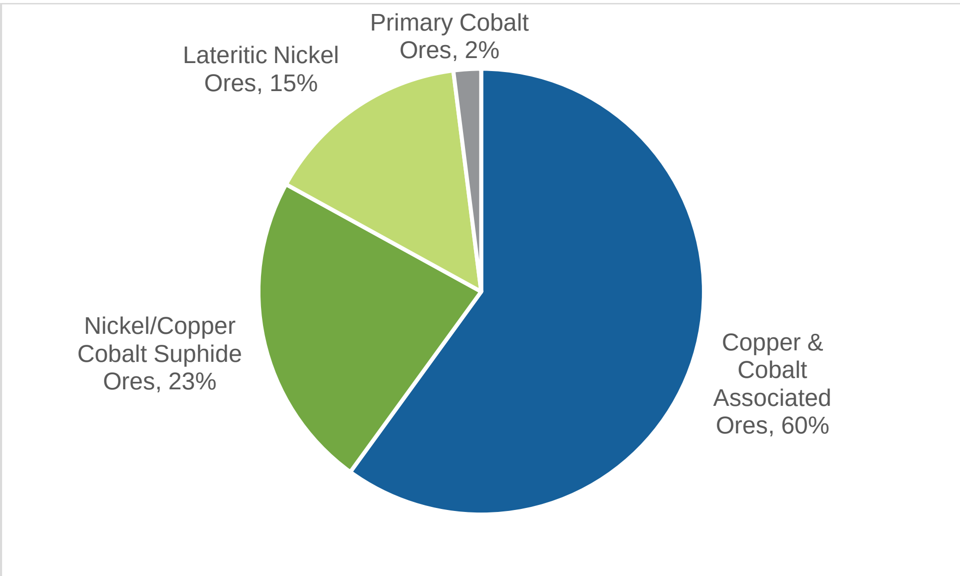
Figure 22 – Indonesia's annual cobalt output




## 3.5 By-product of Copper/Nickel Mining

The majority of cobalt (98%) is mined as a by-product of either copper (largely African sources) or nickel (rest of world). Cobalt production is thus incentivised by firmer nickel or copper prices, rather than on its own merits This makes it difficult to expand cobalt production to meet market requirements.

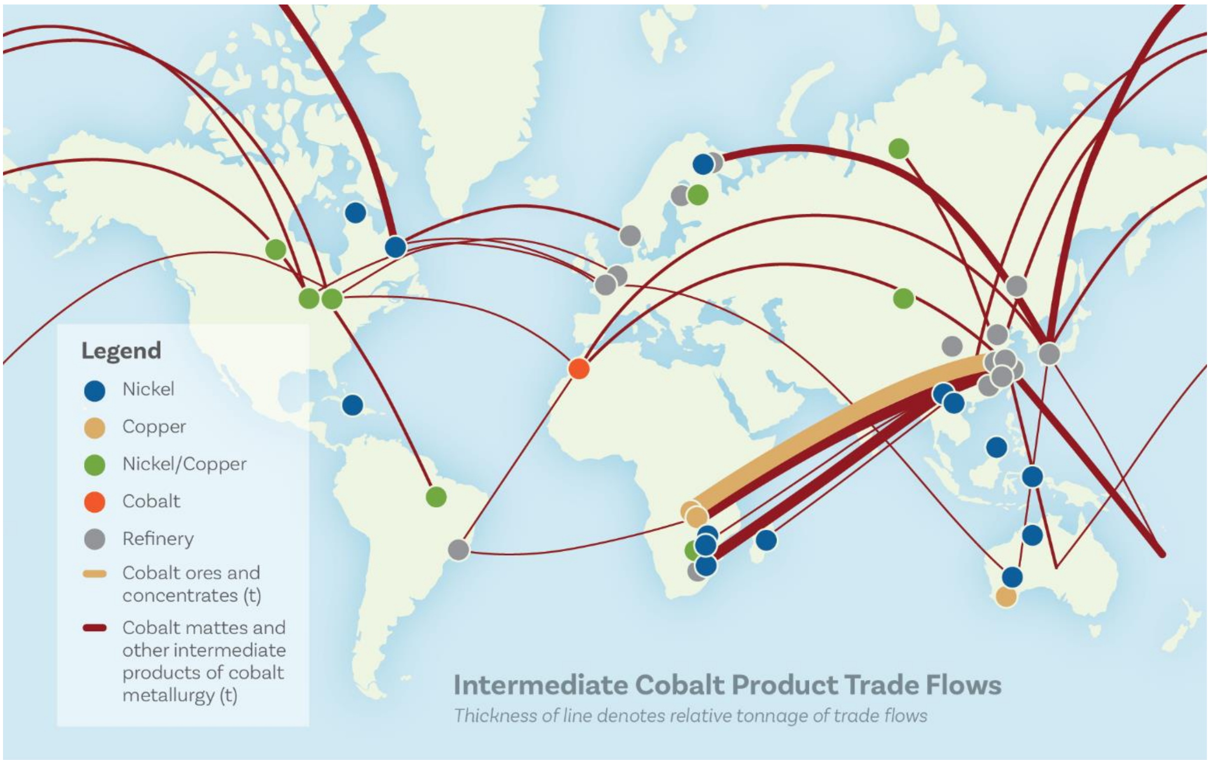
Figure 23 – Global cobalt production by resource type



## 3.6 Cobalt Trade Flows

The dominance of DRC production and the processing pathways through China are shown in the graphic below.

Figure 24 – Global Cobalt Trade Flows

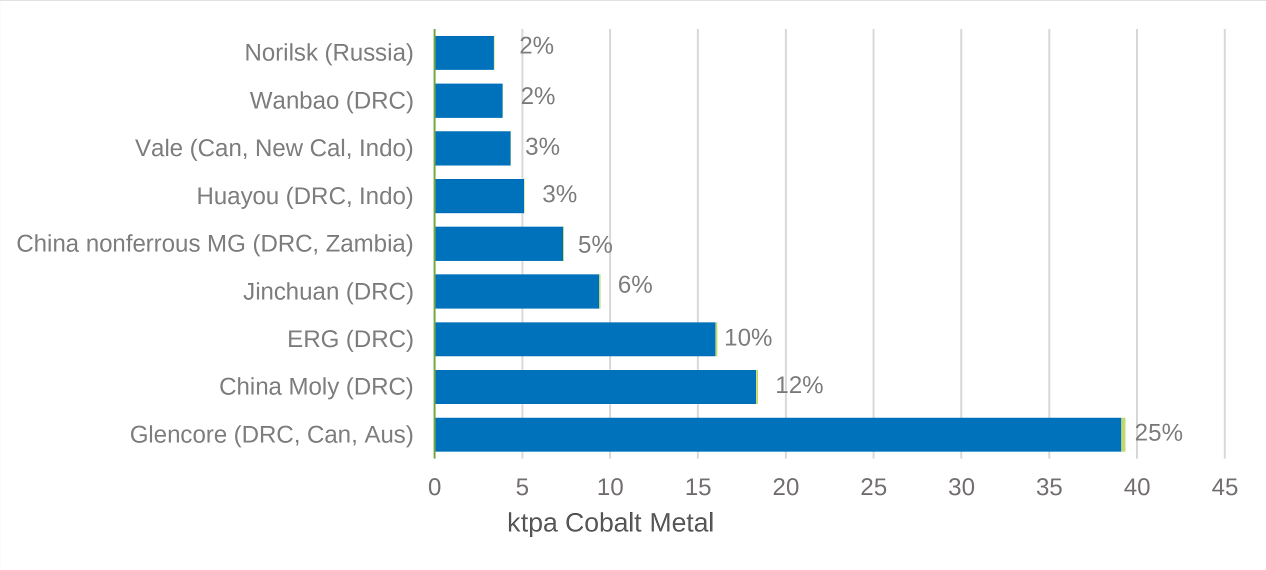



*Source: Cobalt Institute*

## 3.7 Cobalt Supply by Company

The cobalt market is highly concentrated, with the top five producers controlling ~50% of global production. These producers are typically sourcing cobalt feedstocks from DRC based operations. With DRC production expanding at a pace similar to demand growth the degree of consolidation is likely to remain until at least 2030F.

Figure 25 – Leading Cobalt Producers 2021 – volumes (ktpa) and global market share (%)



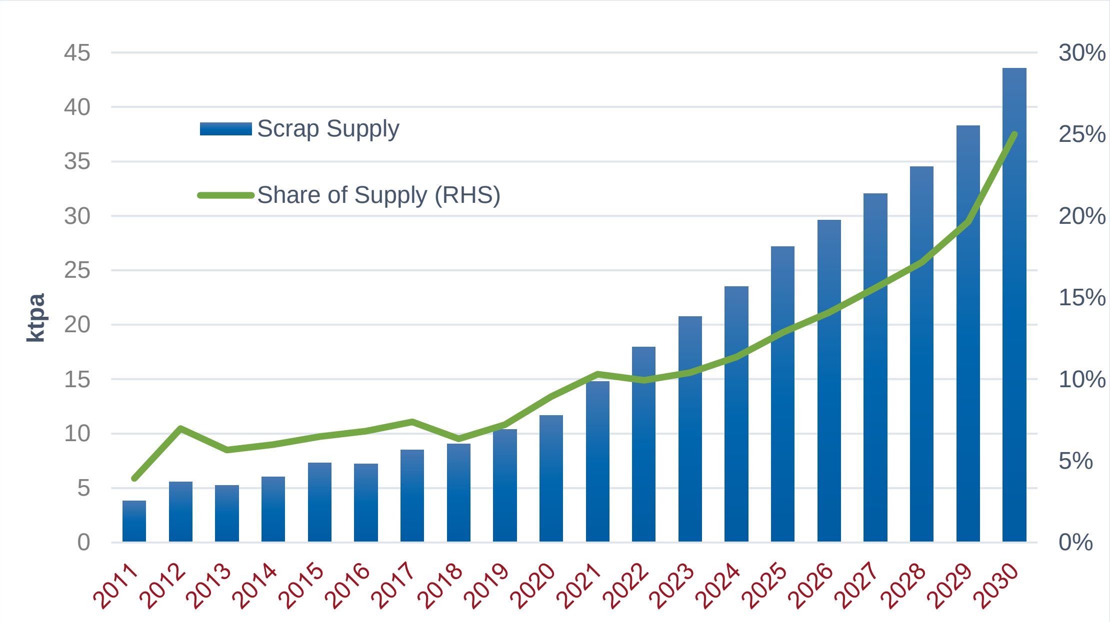

*Source: Wood Mackenzie*

## 3.8 Cobalt Scrap (Secondary supply)

Similar to other metals, there are various forms of secondary cobalt that re-enter the supply chain that form additional feedstock sources for refined production. Around 65% of the scrap is generated from batteries, but other sources include superalloy scrap, cemented carbide scrap and spent catalyst

As cobalt prices rise the scope for increasing recycling from the consumer electronics pool is significant. However, current recycling rates remain low, with only ~20% of collected e-waste (computers, televisions, printers, mobile phones — any electronic device) being recycled. In 2021, ~15kt of cobalt, or 10% of refined / feedstock supply, was recovered from secondary sources. However, scrap supply is expected to progressively grow on increasing consumer battery demand. Spent EV batteries only get sizeable from 2025F given the 8-10 year typical battery warranty. We expect the contribution of secondary supply will steadily increases from the current 10% to 13% by 2025F and 25% by 2030 – similar rates to copper and lead scrap supply.

Figure 26 – Cobalt Secondary Supply (Scrap) (tpa) Forecast




*Source: Wood Mackenzie*

# 4 Market Balance:

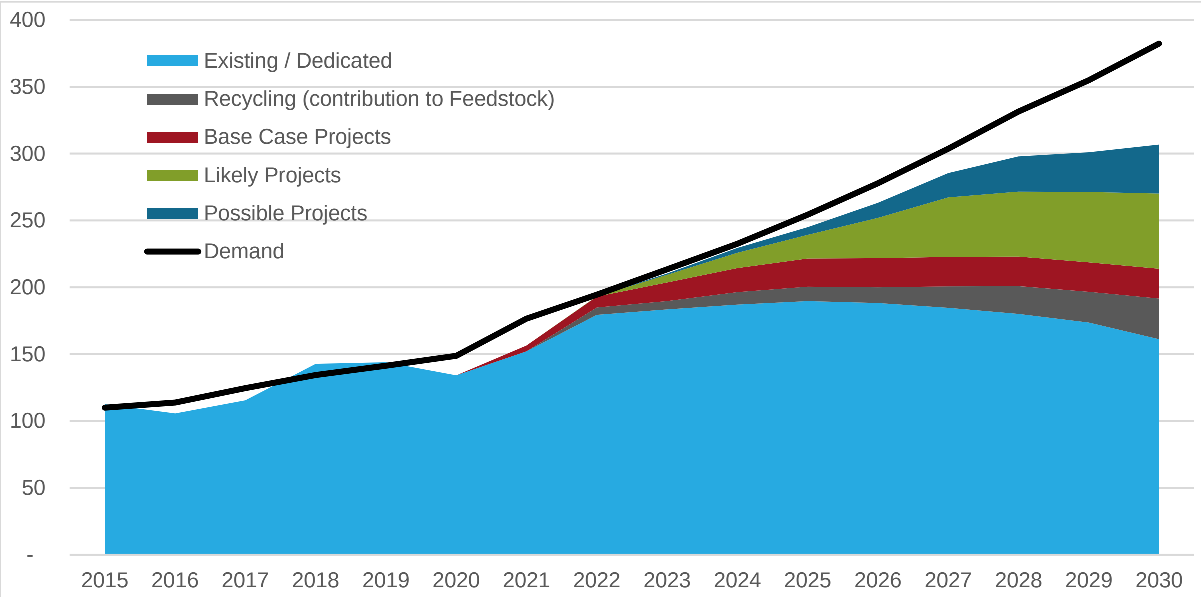
## 4.1 Cobalt Market & Price Forecast

On the supply side, the growing political and economic risks within the DRC, as well as moderate copper and nickel prices could lead to a significant shortfall in by-product cobalt supply. Looking forward, over the course of the upcoming decade, another 100-140kt of 'likely' and 'possible' cobalt expansion projects, in conjunction with the secondary market (totalling over 40kt, theoretically available, by 2030F) will come into play.

The cathode market will continue to dominate cobalt demand, with 2,000 GWh of demand forecast by 2030F. Even assuming an aggressive timetable for cobalt thrifting in EV batteries and LFP substitution in ESS systems, there is simply not enough supply to keep the market in broad balance and allow >60 days of surface stocks beyond 2023F.

The forecast market balance implies the base case and 'likely' projects will struggle to meet growing demand my the mid-2020s. A sustained price cycle is required to help incentivize the 'possible' projects and other feedstock sources (nationalized artisanal mining, recycling).

Figure 27 – Cobalt supply (by type) and demand, 2015-2030F




Further, the maturing of the cobalt derivatives market with larger customers increasingly enthusiastic to hedge supply risk over longer time frames, will create positive spot price pressures

In the near term, cobalt will continue to be split into two-tier pricing, with conflict free/ethically sourced metal commanding a premium. Consignments that do not meet the standard of proof will become limited to buyers exempt from regulation, including what's already in place for the US (Dodd Frank 2010 act) and from 2021 the EU conflict minerals regulation.

Whether the development of a more transparent market is aided by China is difficult to forecast. The result nationalisation of artisanal cobalt by Gecamines (DRC Government) reflects its financial pressures and a willingness to control supply, and its downstream influence is yet to be seen. Artisanal cobalt mining involving child exploitation is abhorrent and needs to be eliminated. However, the metal represents peoples' livelihoods and those legitimately involved in mining cobalt deserve a living wage and a safe working environment. With the assistance of Western consumer industries these objectives will be met, and thus ethical artisanal supply will continue to flow.

The cobalt market forecast shown below is in real $2021 dollars. The market balance and associated inventory drawdown can certainly justify higher forward pricing, however our view is to impose a long term price outcome (US$28/lb) at (t + 5) years or 2027F at time of drafting. For perspective, the long term real average price is around US$25/lb, supporting this forecast, particularly when considering growing EV battery demand. This rapid demand growth against a backdrop of concentrated supply, risk in the DRC is a situation unlike any other base metal.

### Table 4 – Cobalt Market Balance (t) and Pricing (US$/lb)

| | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Supply** | 113 | 106 | 115 | 143 | 144 | 134 | 157 | 193 | 210 | 230 | 245 | 263 | 285 | 298 | 301 | 307 |
| **Demand** | 110 | 114 | 125 | 134 | 141 | 149 | 177 | 194 | 213 | 233 | 254 | 278 | 304 | 332 | 355 | 382 |
| **Market Balance** | 3 | -8 | -9 | 8 | 3 | -15 | -20 | -1 | -3 | -3 | -9 | -14 | -18 | -34 | -54 | -76 |
| **Cobalt Price (US$/lb)** | $14.7 | $13.2 | $29.2 | $40.0 | $17.4 | $16.3 | $24.2 | $37.3 | $35.7 | $33.2 | $33.5 | $33.5 | $28.0 | $28.0 | $28.0 | $28.0 |

*Source: Cobalt Blue Holdings, Wood Mackenzie*

## 4.2 Cobalt Market – Longer Term Contracts Emerging

Longer dated, large volume contracts are emerging, a sign that customer security of supply concerns for battery raw materials are dominating the miner/battery maker relationship. These long-term supply contracts have pricing typically tied to public references and are replacing short term (12 months or less) contracts.

To date, Glencore has signed long term deals with Umicore (deal terms unknown), Samsung SDI (upto 21kt - 5 year deal), SK Innovation (upto 30kt – 6 year deal), GEM (minimum 21.5kt - 5 year deal). At time of drafting Tesla and BMW were also in negotiations focussed upon a long-term supply deals with Glencore. (Data source: Benchmark Mineral Intelligence)

There are two market factors at play here:

1. **Demand Side** - The stabilisation and recovery of the cobalt price over 2019-2020 has forced battery makers (and their EV clients) to negotiate longer dated offtake arrangements, to support their EV market growth plans. Incoming EV models are typically based on 7+ year production runs, requiring security of supply (quality and quantity) of key raw materials. With spot pricing below long-term averages, purchasing decisions are simplified. However, as the cobalt market improves (30 year average price ~US$25/lb), customers are forced to switch towards longer dated contracts.

2. **Supply Side** – Miners require longer dated offtake to justify economic returns for expansions and new projects. Stronger pricing allows producers to optimise their sales portfolio using both price and duration to support their strategic planning/financing needs.

Overall, the trend towards longer dated supply contracts speaks to a maturing cobalt market. Two years ago, very few contracts had a duration over 12 months. Excluding Tesla and BMW, the contracts identified above make up over 70kt of cobalt (~50% annual market). Further announcements concerning longer dated contracts are expected in the years to come. Sufficient volume of longer dated material is required to underpin forward/futures contract development, which we believe is inevitable for the global cobalt market.

## 4.3 Cobalt Pricing – A word of caution using LME pricing

Cobalt is traded as a company-to-company commodity. There is no liquid, terminally traded market, a situation similar to the lithium market. Consultants provide transparency by accumulating company to company transactions (provided they meet market specifications) and report, on a subscription basis, these outcomes periodically. For example, at time of drafting, Fast Markets (formerly Metal Bulletin) was quoting cobalt metal (99.8% grade) twice weekly. Overall, pricing data for cobalt metal (various grades) and cobalt chemicals (typically hydroxides and sulphates) are available, however, this data is not **freely** available.

The London Metals Exchange first listed cobalt metal in 2010 and has provided pricing data according to the contract specifications below.

Table 5 – LME Cobalt – Contract Specifications

| LME Cobalt – Contract Specifications | |
|---|---|
| Quality | Cobalt with a minimum of 99.8% purity. As specified by producers of each brand in the LME-approved list |
| Shape | Cathodes (broken or cut), ingots, briquettes, rounds and coarse grain powder |
| Lot size | 1 tonne |
| Warrant | 1 tonne (with a tolerance of +/- 2%) |

| | |
|---|---|
| Brands | All cobalt deliverable against LME contracts must be of an LME-approved brand |

*Source: LME*

There are over 550 LME-approved storage facilities in 33 locations across the USA, Europe and Asia. The LME does not own or operate warehouses, nor does it own the material they contain. It simply authorises warehouse companies and the warehouses they operate to store LME-registered brands of metal, on behalf of warrant holders, and issue LME warrants through their London agent for material delivered into their approved warehouses.

At time of drafting (2021), LME global stock was only 450t of cobalt (0.3% of annual global market production) with typical monthly trading (averaging) ~40t of cobalt. The metal is generally used for financial speculation/hedging purposes and bears little resemblance to the commercial market.

We therefore recommend investors avoid using LME price data as a proxy for cobalt pricing, however, acknowledge the direction of the LME pricing will mimic the broader commercial market. The LME recognises the shortcoming of this market and are examining solutions, including listing cobalt chemical products.

# 5 Risks

## 5.1 Upside Risks

Increasing popularity of EVs is the single greatest upside risk to prices. If new battery manufacturing facilities (e.g., Panasonic-Tesla, Samsung SDI and LG Chem) reach their slated capacities, EV demand could increase to nearly double base-case expectations.

DRC production irregularities caused by political and/or fiscal constraints. The latter would involve unilateral revision to the country's Mining Code by adjusting cobalt royalty, operating taxes, or project equity ownership by Gecamines (DRC State Mining Company).

Moderate copper and nickel prices could lead to a significant shortfall in by-product cobalt supply. Unless additional primary cobalt projects or high-grade mixed sulphide projects are bought online, cobalt mine supply will lag chemical demand growth.

Increasing popularity of NMC batteries in the ESS sector could add considerable sulphate demand over the next ten years. We have modelled conservative demand for this sector and believe that spent EV batteries could be reused as storage devices.

## 5.2 Downside Risks

If there is a sustained improvement in nickel and copper prices, we could see a number of existing mines and metal refineries increase their utilisation rates, leading to additional by-product supply growth. Improving cobalt concentrate prices could also incentivise an increase in artisanal supply growth in the DRC.

The substitution of cobalt-rich batteries for less cobalt intensive technologies could lead to a drop in demand. The substitution of LCO batteries with NMC in portable devices and the potential dominance of LFP batteries in the EV sector could lead to stagnation in demand growth.

Increasing recycle rates for superalloys, carbides, catalysts and batteries could negatively impact primary demand.

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