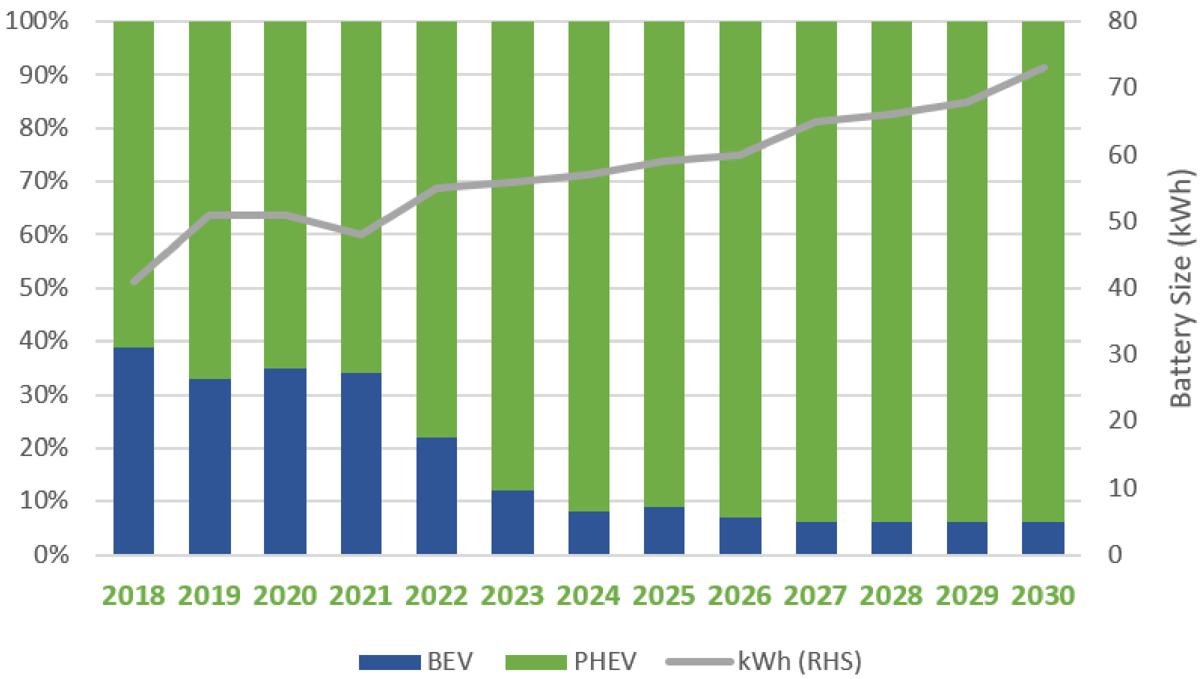
Contents

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.

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

Figure 6 – BEV vs PHEV - Market Share Forecast

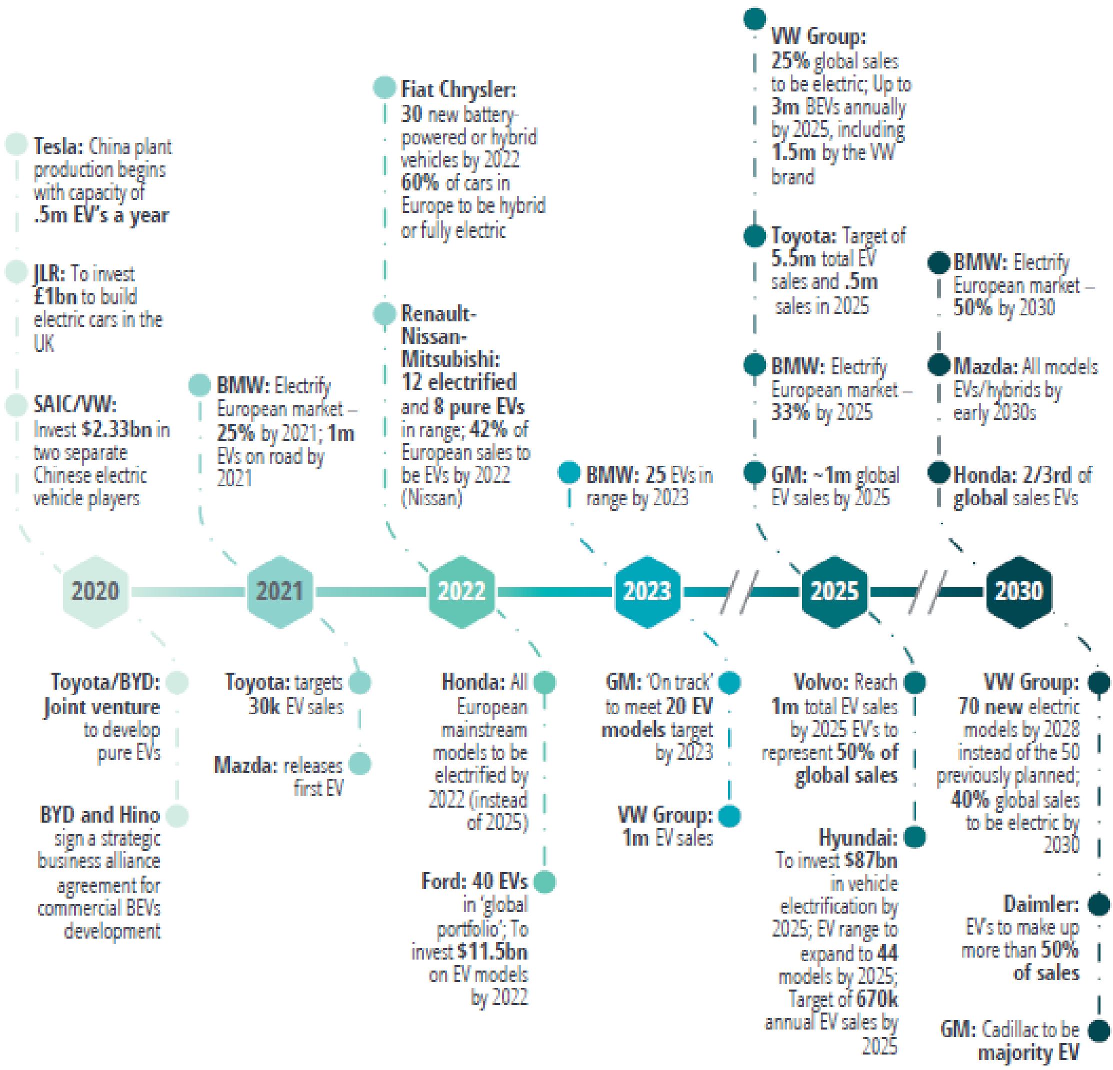


Source: UBS

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.

The sheer scale of EV capital investment (estimated to be over US$500Bn between 2020-2025F) is captured by Figure 9 below.

Figure 9 – Timeline of Strategic OEM Targets for EVs

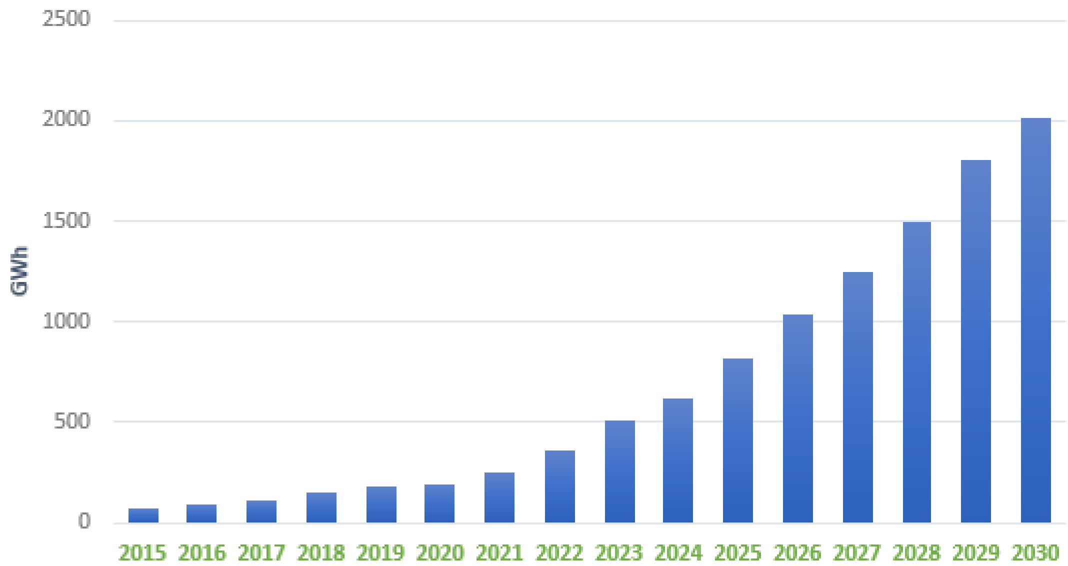


Source: Deloitte

2.2.4 Cathode Market Growth

The global battery market is forecast to expand from ~180GWh today to over 2,000GWh by 2030F, representing a significant 27.2% demand CAGR. Cathode production will be reflected in strong demand from both EV and ESS segments.

Figure 10 – Battery Market Growth (GWh)



Source: Kaderavek

2.3 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.

2.3.1 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, Western World 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

2.3.2 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.

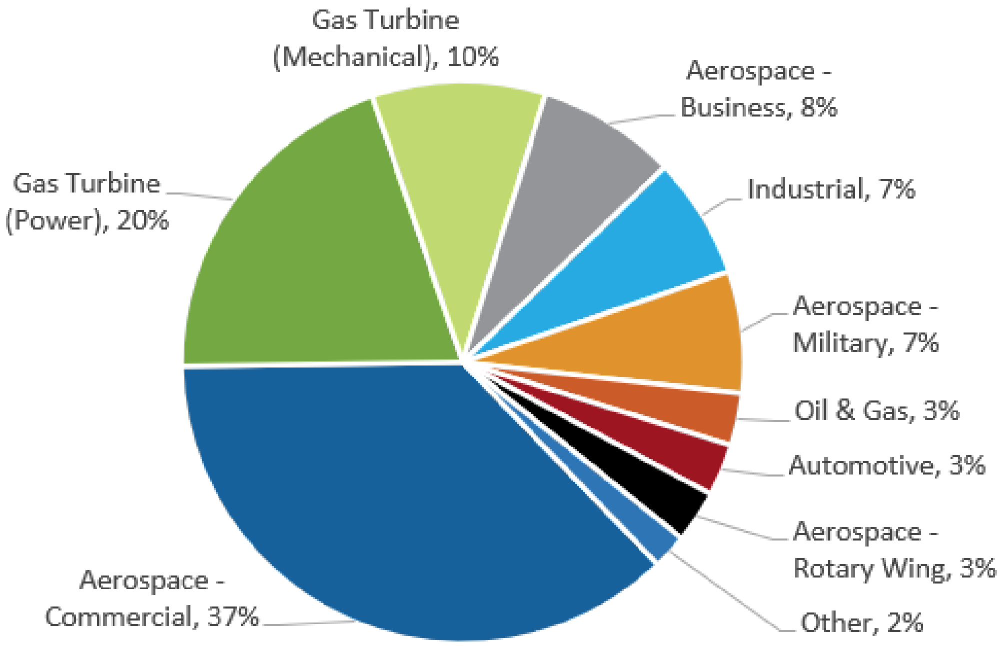
Breaking down the magnetic materials demand segment, 40% of cobalt is used within AlNiCo permanent magnetic alloys, 30% for SmCo alloys, and 30% for other rare earth permanent magnet materials. Around 2011, the soaring price of rare earths witnessed a demand shift to the non-rare earth containing magnetic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

2.4 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 11 – Cobalt Based Superalloy Applications



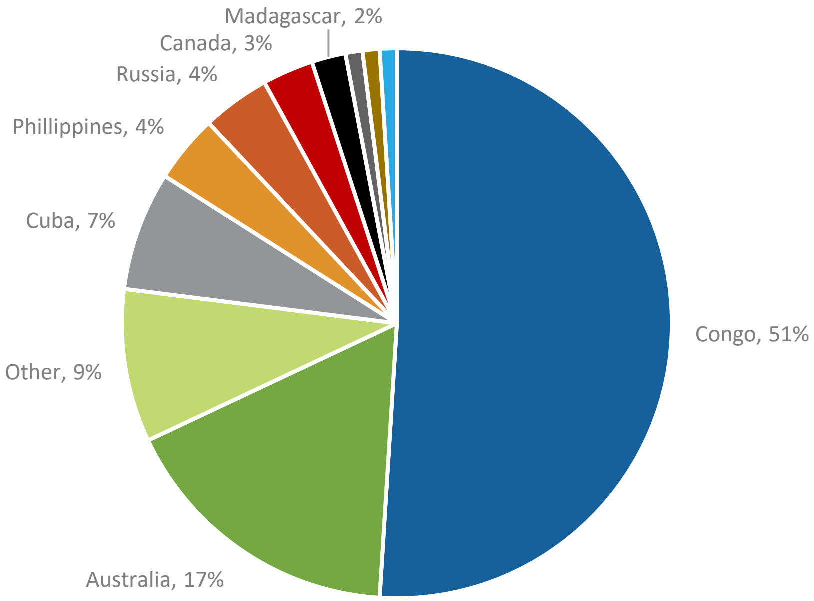
Source: ResearchInChina,

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 7.1 mt, concentrated in the Democratic Republic of Congo (the DRC or Congo), Zambia, Cuba, Australia, and other countries. The DRC ranked first globally with a cobalt reserve of 3.4mt; Australia and Cuba occupying second and third places respectively with 1.1mt and 0.5mt

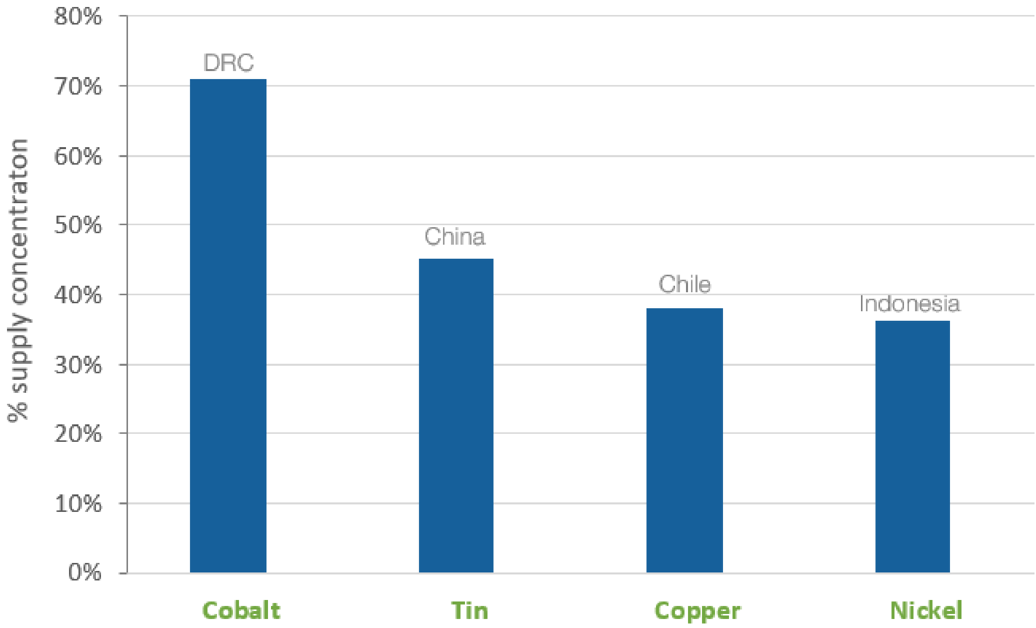
Figure 12– Global Cobalt Reserves – 2019 Estimates



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 14 – DRC Cobalt Supply Concentration



Source: Citi Research, WoodMackenzie

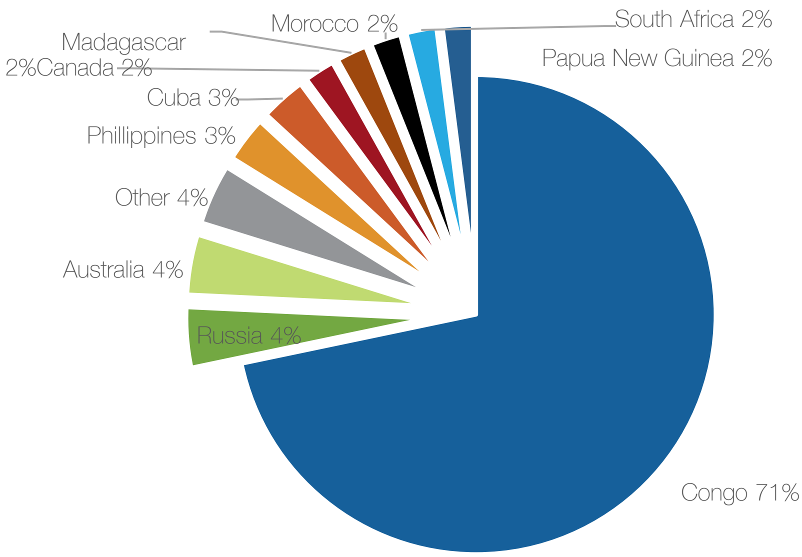
3.3 By-product of Copper/Nickel Mining

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.

3.4 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 15 – Global Cobalt Production– 2019 Estimates



Source: USGS

3.5 Cobalt Trade Flows.

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

Figure 16 – Global Cobalt Trade Flows

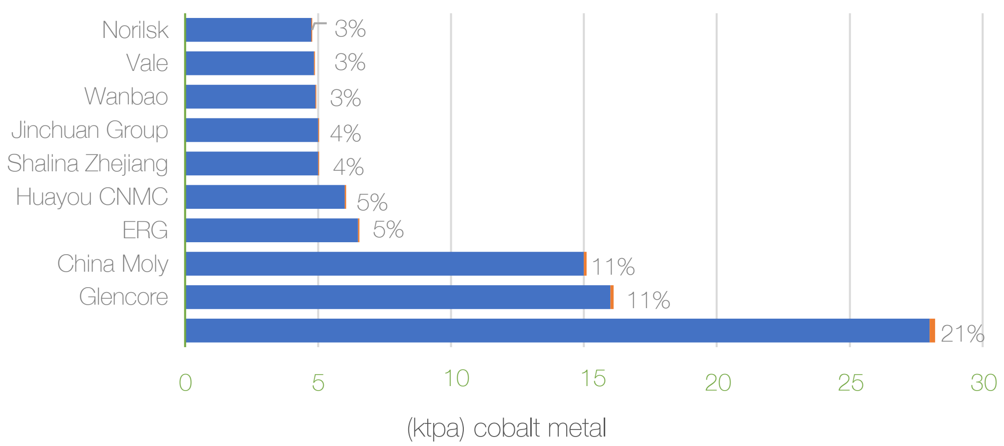
Mines 2016	Refineries 2016	Intermediate Cobalt Product Trade Flows
Nickel (17) Copper (12) Nickel and/or Copper (10) Cobalt (1)	All items (23)	Cobalt ores and concentrates (tonnes): Cobalt mattes and other intermediate products of cobalt metallurgy, cobalt and articles thereof (tonnes):

Source: Cobalt Institute

3.6 Cobalt Supply by Company

The cobalt market is highly concentrated, with the top five producers controlling ~53% 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 17 – Leading Cobalt Producers 2020



Source: WoodMackenzie, UBS Bank

3.7 Cobalt Scrap (Secondary supply)

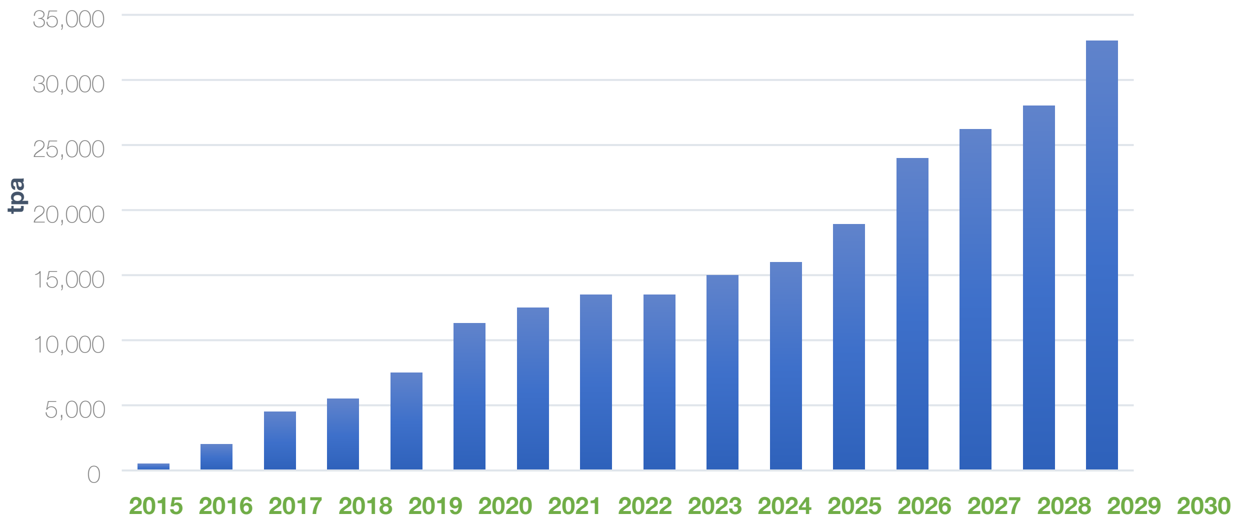
Recycling cobalt will also rise with prices to moderate market deficits. Today, recycling already contributes c.10kt of supply and is expected to grow short term on increasing consumer battery demand, while spent EV batteries only get sizeable from 2025F onwards. Cobalt is currently recycled primarily from hard metal and cemented carbide tools or NiMH and Li-ion rechargeable batteries (used in consumer electronics).

Spent EV batteries are not likely to return to the market in any real size until 2025F onwards given the 8-10 year typical battery warranty. From 2025F the contribution of secondary supply steadily increases from 7 to 15%. Recovering cobalt will increasingly dominate the profitability of lithium-ion battery recycling.

As cobalt prices rise the scope for increasing recycling from the consumer electronics pool is significant. However, current recycling rates remain low. During 2020 only ~20% of ~95mt of e-waste (consists of computers, televisions, printers, cellphones — any electronic device) was recycled. In China, the volume of used batteries will total 200kt in 2020 and increase to 350kt in 2025F, according to China Automotive Technology and Research Center. GEM, a large battery recycler in China, is investing US$500m to increase its recycling capacity. Apple Inc recently announced plans to expand its recycling programmers quadrupling the locations US customers can send their iPhone to be disassembled.

Commercial development of large-scale EV recycling is still some years away. Nissan currently re-purposes EV batteries and wants to recycle cobalt and nickel in 3 years but lacks the technology to do so. Mitsubishi Materials announced plans to start experiments into recycling nickel and cobalt from Li-ion EV batteries and will decide after mid 2020 on commercialization. Meanwhile the most promising is Japan's Sumitomo Metal Mining method to recycle EV batteries, the company has set up a test plant to prove the viability of the recycling method. Figure 18 highlights the secondary supply of cobalt.

Figure 18 – Cobalt Secondary Supply (Scrap) (tpa) Forecast



Source: Kaderavek

4 Market Balance:

4.1 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 Curie temperatures and re 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

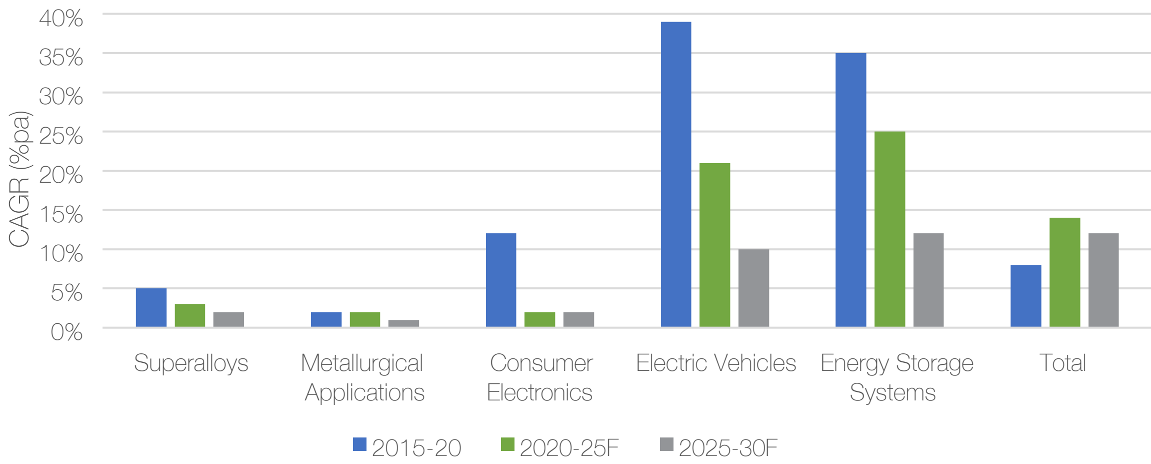
Source: Cobalt Institute, Citi Research

4.2 Cobalt Market Segments - Forecast

Established superalloy and metallurgical applications market histories provide well-grounded expectations for future demand behaviours. Five-year demand growth of 5% and 2% respectively is expected for these segments. In particular, superalloys are expected to suffer demand destruction as a direct result of COVID and its influence on air travel over 2020-2023F.

On the other hand, 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. EV batteries will dominate the 2021 battery market, accounting for an aggregate 54.7% of all battery materials and growth between 2016-21 of 23.7% CAGR. ESS demand will aggregate 24.4% of all battery materials and provide even more impressive growth between 2016-21 of 36.7% CAGR. The net effect will drive strong growth in battery materials demand of 30.3% CAGR between 2016-21. Figure 19 shows the cobalt market segment forecast.

Figure 19 – Cobalt Market Segment Forecast - CAGR (%pa)



Source: Kaderavek

4.3 Cobalt Market & Price Forecast

In the aftermath of COVID, cobalt prices have edged lower. Despite the immediate effects upon cobalt demand the cumulative market balance is becoming tighter, balanced in the near term by economic demand stimulus, particularly for the EV sector, which is gradually eroding surface stocks.

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 48,000 t of Likely and Possible cobalt expansion projects, in conjunction with the secondary market (totalling over 30,000 t 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.

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.

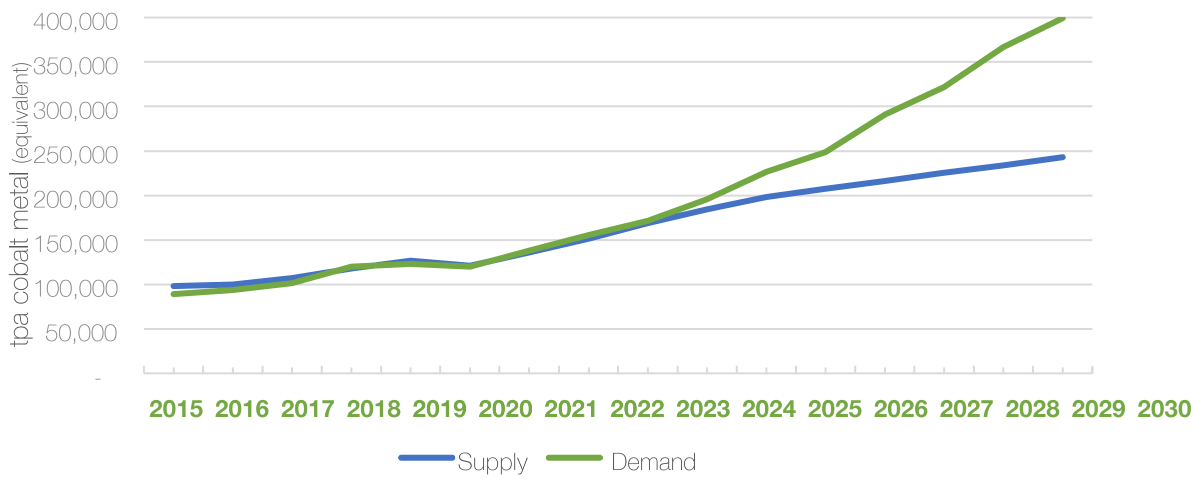
The cobalt market forecast shown below is in real $2020 dollars. The market balance and associated inventory drawdown can certainly justify higher forward pricing, however our view is to impose a long term price outcome (US$28/lb) at (t + 5) years or 2026F at time of drafting. For perspective, the long 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	98,113	99,899	107,218	117,898	126,089	120,988	135,987	151,494	168,929	184,530	198,262	207,282	216,209	225,353	234,030	243,000
Demand	89,089	93,432	101,231	119,763	122,921	120,099	138,211	155,432	171,322	195,786	226,369	248,526	290,876	321,620	366,866	399,279
Market Balance	9,024	6,467	5,987	-1,865	3,888	889	-2,224	-3,938	-2,393	-11,256	-28,107	-41,244	-74,667	-96,257	-132,836	-156,279
Cobalt Price (US$/lb)	$12.67	$12.09	$24.98	$25.10	$16.54	$15.92	$20.15	$23.00	$25.30	$27.50	$31.50	$28.00	$28.00	$28.00	$28.00	$28.00

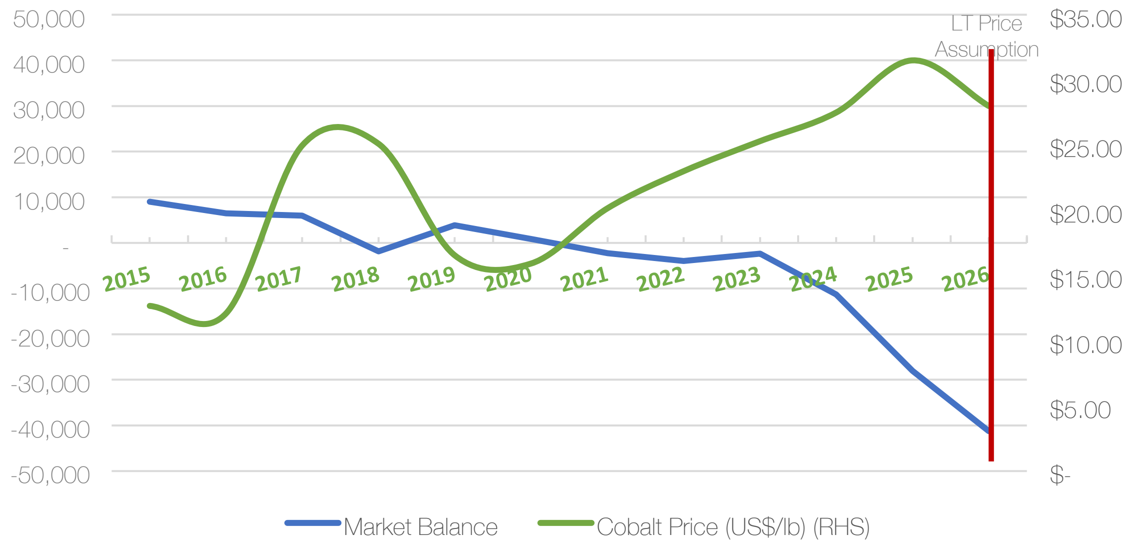
Source: Kaderavek

Figure 20 – Cobalt Market Supply/Demand Forecast



Source: Kaderavek

Figure 21 – Cobalt Market Balance and Price Forecast



Source: Kaderavek

4.4 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:

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 Conclusion:

5.1 Key Conclusions

- The cobalt market is tightening 2021+. Post COVID demand is firming aided by significant government sponsored subsidies.
- A cobalt market inflection point from 2023F+ is likely unless further demand destruction occurs.
- The EV market will drive strong demand for cobalt across 2021-2030F
- Lithium-ion battery designs with cobalt cathodes are likely to dominate the battery market for at least next 10+ years.
- Battery makers/end customers will increasingly invest upstream to assure security of supply

5.2 Risks

5.2.1 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.

5.2.2 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.