GOVERNMENT OF BRAZIL MINING SECTOR TECHNICAL SUPPORT AND COOPERATION

Cobalt – Market Analysis and Competitiveness Report

Prepared for:
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Acronyms

ASM	Artisanal and Small-Scale Mining
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CPRM	Geological Survey of Brazil
CCZ	Clarion-Clipperton Zone
DOS	Department of State
DRC	Democratic Republic of the Congo
EMGP	Energy and Mineral Governance Program
ENR	Bureau of Energy Resources
ESG	Environment, Social, and Governance
EV	Electric Vehicles
IEA	International Energy Agency
kt	Thousand Tonnes
LFP	Lithium-Iron-Phosphate
LME	London Metal Exchange
MME	Ministry of Mines and Energy
Mt	Million Tonnes
NCA	Nickel-Cobalt-Aluminum
NCM	Nickel-Cobalt-Manganese
OEC	The Observatory of Economic Complexity
OEM	Original Equipment Manufacturer
PGM	Platinum Group Metal
REE	Rare Earth Elements
USGS	U.S. Geological Survey

EXECUTIVE SUMMARY

Deloitte is implementing the *Government of Brazil Mining Sector Technical Support and Cooperation* Task Order (the Project) under Deloitte's Blanket Purchase Agreement (BPA) with the U.S. Department of State (DOS) in support of the Bureau of Energy Resources' (ENR), Energy and Minerals Governance Program (EMGP). The Deloitte team is providing technical assistance to support the Government of Brazil's Ministry of Mines and Energy (MME) and the Geological Survey of Brazil (CPRM) as they seek to improve their ability to:

- Develop safe, sustainable, and effective mine closure procedures and use of tailings, including methods of tailings sampling and characterization, based on international leading practices, to protect and improve the legacy of ongoing and future projects, thereby realizing sustainable benefits from the extractives industry;
- Manage a growing mineral sector and compete effectively in the global market, given a growing market and accelerated demand for critical minerals that are essential to the development of innovative technologies to advance the global clean energy transition (electric vehicles, batteries, and battery storage systems, etc.); and
- Streamline the structure of Brazil's nickel-cobalt data inventory, so Brazil can improve its understanding and increase development of critical minerals.

Under *Task 2A: Economic Viability and Global Market Competitiveness of Specific Minerals*, the Deloitte team will develop a series of reports focused nine minerals including, graphite, lithium, nickel, cobalt, rare earth elements (REEs), titanium, vanadium, tantalum, and copper. The purpose of these Reports is to provide recommendations to the Government of Brazil on where and how Brazil could compete most effectively and inform their long-term strategic planning for commercialization of minerals based on global market trends and challenges to mineral resource development that may inhibit Brazil's overall market competitiveness. The Deloitte team's recommendations will also inform the National Plan for the Brazilian Mineral Sector 2050 and future policy actions for the Government of Brazil. This Report is focused on cobalt.

Key Findings

- **Brazil has limited cobalt reserves and no production.** Brazil has not produced cobalt since 2016. The country's cobalt reserves are small, at 430 thousand tonnes (kt)[1]. This represents 1.7 percent of the 25 million tonnes (Mt) of global cobalt resources in 2021 estimated by the U.S. Geological Survey (USGS). The Democratic Republic of Congo (DRC) accounts for 46 percent of global reserves and approximately 72 percent of mine production. China is the largest cobalt concentrates and chemicals processor, refining 67 percent of global cobalt supply.
- **Brazil has a limited number of new cobalt development projects underway.** The Deloitte team assembled a database of 30 global brownfield and greenfield cobalt projects that could potentially come onstream by 2030. Of these projects, 80 percent include planned brownfield expansions[2], are under construction, or are at final investment decision stage. However, due to financing, permitting, or other issues, it is possible that some of these projects may not reach the production stage by 2030.

[1] See Table 2, in Section 3.1

[2] A brownfield expansion refers to the expansion of an existing mine.

The above analysis includes one Brazilian advanced-stage nickel-cobalt exploration project (Piauí), which has a small targeted average production level (0.9 kt/y) that is scheduled to start in late 2024. The analysis does not include Brazil's two earlier-stage nickel-cobalt exploration projects (Vermelho and Jacaré) because these are unlikely reach production by 2030. These projects look prospective, although the primary target commodity is nickel, and only small amounts of cobalt are expected to be recovered as a by-product.

- **Strong demand for lithium-ion batteries is driving up cobalt demand.** Roskill forecasts cobalt demand to increase to 258 kt by 2030. This represents a compound annual growth rate (CAGR) of 6.7 percent, from the Cobalt Institute's estimate of 135 kt consumption in 2020. Cobalt is primarily used in manufacturing batteries, which accounted for 57 percent of global cobalt consumption in 2020. Other major cobalt uses include nickel-base alloys mainly used in turbine engine components (14 percent of consumption), and hard materials used in carbides for cutting tools (8 percent). Brazil's imports of cobalt are relatively small, in line with its limited battery manufacturing capacity.
- **Forecasters project cobalt prices to decline from their current highs as the market moves into surplus by 2030.** The Deloitte team's analysis shows that cobalt supply from mine production and recycling could increase to 311 kt by 2030, a CAGR of 8.1 percent, from 142 kt in 2020. Roskill forecasts demand of approximately 258 kt. These forecasts imply a significant surplus of 59 kt by 2030. Cobalt prices are expected to decline from their current high levels but remain around $57,000/t − well above historical average prices of $39,400/t since 2010. The impact on Brazil will be limited given that it does not currently produce cobalt, and new production out to 2030 will be small.
- **Cobalt consumers are concerned with environmental, social, and governance (ESG) challenges surrounding cobalt production.** ESG is an important issue for cobalt consumers, given that the majority of production currently comes from the DRC (a country under the spotlight for its track record on human rights and child labor), and much new cobalt capacity is anticipated to come from Indonesia (where land clearance, habitat loss, and high energy consumption from coal-fired power stations also raise ESG concerns). Both DRC and Indonesia are attempting to address these challenges, but such ESG concerns may potentially provide a market opportunity for Brazil's cobalt projects to be developed in a more ESG-friendly manner. For example, Brazil's predominant use of hydroelectricity, compared to the use of thermal (coal) generation in Indonesia, means that Brazil's mining industry has an inherent competitive advantage in terms of its carbon footprint. This is becoming increasingly important to manufacturers of lithium-ion batteries and original equipment manufacturers (OEMs) when sourcing raw materials, and it may provide an opportunity for Brazil to secure off-take agreements for cobalt and associated nickel products, potentially at a price premium.

Key Recommendations

The Government of Brazil could look to further develop its resources and encourage investment in the longer term by:

- **Streamlining access to, and circulation of, up-to-date domestic cobalt resource data to domestic and international exploration companies to encourage exploration and to promote cobalt development in Brazil.** This may require gathering and distributing more extensive information for those regions considered to have significant cobalt potential. Legacy CPRM geological data, reports, and studies should be broadly published online and in multiple languages. Brazil should also actively 'market' these documents to expand their circulation, use, and impact.

- **Promoting the ESG advantages of Brazilian cobalt projects to accelerate access to development finance and facilitate regional investment.** Nickel-cobalt projects in Brazil have systemic ESG advantages relative to DRC copper-cobalt and Indonesian nickel-cobalt producers. Access to low-cost, low-emissions hydroelectricity in Brazil gives nickel-cobalt producers a competitive advantage in both operating costs and carbon footprint. This advantage could potentially lead to better mine offtake terms, improved access to ESG-focused sources of development finance, and similarly enabled downstream regional investment in cathode-manufacturing facilities and lithium-ion battery manufacturing.

1. INTRODUCTION

1.1. Purpose of this Report

This Report provides a detailed analysis of the global cobalt market, the current and future dynamics of the industry, plus potential opportunities and possible risks associated with cobalt development. The Report analyzes global cobalt resources, supply and demand dynamics, technological and industrial drivers, current and future mineral producers and processors, and cobalt market economics. The Report also examines Brazil's position within the current cobalt market, and its potential positioning in the future, thereby enabling MME and CPRM to make informed decisions about future policy actions for Brazil's cobalt industry and resources.

1.2. Organization of this Report

This Report is organized into nine main sections and three annexes:

- **Section 1: Introduction** – Presents the purpose of this Report, background and context on nickel, and a summary of market trends and outlook for cobalt.
- **Section 2: Cobalt Characteristics** – Provides information on cobalt properties, sources, and uses and applications.
- **Section 3: Cobalt Resources** – Provides information on global cobalt resources and reserves.
- **Section 4: Cobalt Supply** – Gives an overview of the global production of cobalt ores and cobalt products, recent supply trends, and the outlook for cobalt supply to 2030.
- **Section 5: Cobalt Demand** – Explains global cobalt uses, consumption trends based on end-user markets, and the outlook for cobalt demand to 2030.
- **Section 6: Cobalt Trade and Prices** – Provides information on key features of global cobalt trade and presents historical pricing data for cobalt.
- **Section 7: Market Balance and Price Outlook** – Examines whether there is sufficient cobalt supply to match future global demand by 2030 and provides insights on price forecasts for trade in the future.
- **Section 8: Economic Competitiveness** – Summarizes production and cost information of existing mines for use as a benchmark to assess the economic competitiveness of the sector and exploration projects in Brazil.
- **Section 9: Conclusions and Key Recommendations** – Summarizes the Deloitte's team analysis of the cobalt market, including potential global opportunities. This section also presents key recommendations for the Government of Brazil to inform its future policy actions with respect to the nickel industry.
- **Annex 1** – Provides a description of cobalt ores and resources.
- **Annex 2** – Provides a description of mining and processing of cobalt ores.
- **Annex 3** – Provides a description of cobalt uses.

1.3. Background and Context

The shift from high-carbon fossil fuels to low-carbon energy sources (via wind, solar, hydrogen, and battery technologies) is crucial to meeting the world's climate change goals. Cobalt is a key component of batteries, which are particularly important for developing hybrid and electric vehicles (EVs). Lithium-ion batteries are the preferred technology for almost all EVs on the market today and will continue to be for the foreseeable future. Cobalt is not used in all lithium-ion batteries but is used in nickel-cobalt-manganese (NCM) battery cell formulations, which account for approximately 70 percent of the battery market. Cobalt is used because it boosts charge rates and has a stabilizing effect. These uses help to extend battery life and prevent cathode corrosion (a characteristic that can cause batteries to explode or catch fire).

Brazil has some of the largest and most diverse mineral deposits in the world, yet 98 percent[3] of its 2021 revenues and mining sector activities focus on core commodities of iron ore, gold, copper, and bauxite. While the production of these resources remains important, there is growing demand and new opportunities for Brazil to develop its output of cobalt and other critical minerals.

Brazil currently does not produce cobalt directly, although small quantities of (unrecovered) cobalt are contained within domestic ferronickel production. Brazil hosts both sulfide and laterite nickel resources, with most of the laterite deposits containing cobalt. Brazil's reserves of cobalt, however, are very small compared to total global cobalt reserves. Brazil has one nickel-cobalt exploration project at a relatively advanced stage (Piauí), and two projects at pre-feasibility stage (Vermelho and Jacaré). These projects look prospective, although the primary commodity at all three locations is nickel and only small amounts of cobalt are expected to be recovered as a by-product.

The Deloitte team drafted this Report following the Russian invasion of Ukraine. Russia is a major producer of cobalt, accounting for 5 percent of global production in 2021, and although the scale of possible sanctions to this output are not yet fully clear, such restrictions may have the potential to create major supply disruptions. This Report does not comprehensively analyze the possible consequences of future sanctions on Russian production, but some of the associated risks are discussed in Section 9.[4]

1.4. Summary of Market Trends and Outlook for Cobalt

1.4.1. Cobalt Resources

Cobalt deposits of economic importance are found in diverse geological locations, but most cobalt is produced as a by-product of copper or nickel mining, with small quantities coming from platinum group metal (PGM) deposits. The USGS reports that identified land-based reserves of cobalt are 7.65 Mt and resources are approximately 25 Mt. The DRC accounts for 46 percent of total reserves, Australia 18 percent, Indonesia 8 percent, and Cuba 7 percent. Significant amounts of cobalt are also found in manganese crusts and nodules on the ocean floor, although metal recovery from deep-sea sources has not yet been proven to be economic. Brazil has very small 'company reported' cobalt resources, of approximately 430 kt; these principally occur in association with nickel deposits.

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[3] ANM Global

[4] In developing this Report, the Deloitte team extracted data from publicly available sources including: (i) company reports; (ii) industry sources such as Wood Mackenzie, Benchmark Minerals Intelligence, and Roskill; (iii) government and other public institutions, including the USGS, British Geological Survey (BGS), International Cobalt Study Group (INSG), Cobalt Institute, International Stainless-Steel Forum (ISSF), and the European Union (EU); and (iv) industry conferences and webinars.

1.4.2. Cobalt Supply

In 2021, global production of mined cobalt totaled 165 kt, according to the USGS. Global production of cobalt is highly concentrated, with the DRC accounting for approximately 72 percent of production, Russia 5 percent, and Australia three percent. Cobalt is principally produced as a by-product which means that its production is often not driven by its own supply and demand fundamentals but rather the dynamics of the copper and nickel industries − although for many operations cobalt can be an important source of additional revenue.

Intermediate cobalt products are further processed into refined cobalt products. China was the largest cobalt refining country in 2020, accounting for 67 percent of the global total, followed by Finland (10 percent), and Japan (5 percent). At present, cobalt recycling is not a significant factor in the economics of the cobalt market, however, it is expected to increase rapidly and become an important source of cobalt feedstock to the supply chain as the recycling of lithium-ion batteries increases.

ESG is an important issue for cobalt consumers, given that the majority of production currently comes from the DRC (a country under the spotlight for its track record on human rights and child labor), and much new cobalt capacity is anticipated to come from Indonesia (where land clearance, habitat loss, and high energy consumption from coal-fired power stations also raise ESG concerns). Brazil does not currently produce cobalt and has only one advanced stage exploration nickel-cobalt project (Piauí), which is anticipated to have a minor amount of cobalt output. The Deloitte team assembled a database of 30 global cobalt-related projects that have the potential to come onstream by 2030. The Deloitte team calculates that expansions from existing producers, new projects under construction, and late-stage development projects, as well as projects at feasibility stage, have the potential to add up to 145 kt of cobalt production that could come onstream by 2030. There is no guarantee that all these projects will reach production, however, it suggests mine production of cobalt could be approximately 288 kt by 2030. The forecast from Roskill implies cobalt mine production of 272 kt by 2030.

1.4.3. Cobalt Demand

Global cobalt consumption in 2020 was approximately 135 kt, according to the Cobalt Institute. Cobalt is primarily used in manufacturing of batteries, and in 2020, 57 percent of global cobalt consumption was derived from battery manufacture. Other significant uses include nickel-base alloys (up to 20 percent cobalt by weight) mainly used in turbine engine components (14 percent) and hard materials used in carbides for cutting tools (8 percent).

China is the largest consumer of cobalt, accounting for approximately 32 percent of demand in 2020. Cobalt use in China is driven by the country’s substantial battery industry, with secondary uses including magnets, tool materials, and pigments. The rest of Asia accounted for a further 17 percent of cobalt demand. Europe accounted for 23 percent and North America accounted for 18 percent of consumption, where cobalt is primarily used for strengthening nickel-based alloys and tool materials.

Demand for cobalt is expected to increase to 258 kt/y by 2030, according to Roskill, equivalent to a CAGR of 6.7 percent per annum from 2020 levels. This compares with a CAGR of 6.1 percent from 2014 to 2020. This growth is expected to be largely driven by increased demand from lithium-ion batteries, principally from increased demand for EVs. Cobalt use in lithium-ion batteries is forecast to increase at a CAGR of 8.4 percent through 2030 despite ongoing advances in battery composition that are expected to lead to lower cobalt requirements per unit.

1.4.4. Future Market Outlook

Deloitte team analysis shows that global cobalt supply from both mine production and recycling has the potential to increase to 311 kt/y by 2030, an increase of 168 kt/y compared with worldwide supply of 142 kt/y in 2020. This compares with a demand forecast of approximately 258 kt/y from Roskill and implies a potential significant surplus of 53 kt/y by 2030. There are likely to be delays to projects and some new projects may not achieve production; however, it does appear that the market is likely to be in surplus by 2030. Moreover, producers may be slow to adjust capacity to the potential surplus because nearly all the mine production is produced as a by-product of other metals and therefore driven by market signals for those commodity products.

Historically, the price of cobalt has experienced periods of extreme volatility. Cobalt prices have increased sharply in the past year due to strong increases in battery demand for EVs, combined with COVID-19 supply disruptions. The consensus forecast is that prices will decline from the current high levels but remain at around $57,000/t out to 2030, which is high relative to historical trends (see Figure 17).

1.4.5. Economic Competitiveness

It is difficult to compare the economic competitiveness of cobalt production across countries and mines because cobalt is produced principally as a by-product. Furthermore, cobalt-specific data is unavailable for Brazil's sole advanced-stage nickel-cobalt project (Piauí), and its two-pre-feasibility stage nickel-cobalt projects (Vermelho and Jacaré).

That said, there would appear to be an opportunity to accelerate investment towards Brazil's Piauí nickel-cobalt project, due to its lower carbon footprint and lower social risks, relative to the ESG profiles of DRC and Indonesia. The Piauí project's developers may also be able to more easily secure off-take agreements for their cobalt and associated nickel products (potentially at a price premium) and access ESG-focused development finance.

2. COBALT CHARACTERISTICS

Cobalt is a lustrous, greyish-silver, brittle metal that has a broad range of uses based on certain key properties, including ferromagnetism, hardness, and wear-resistance when alloyed with other metals, low thermal and electrical conductivity, and high melting point. Cobalt is mainly used in cathodes in rechargeable batteries and in superalloys for turbine engines in jet aircraft.

There are approximately 30 principal cobalt-bearing minerals and over 100 more which contain minor amounts of the metal or include cobalt as a substitute for other elements. Cobalt can be found in economic concentrations in three principal deposit types − stratiform sediment-hosted copper-cobalt deposits, nickel-cobalt laterite deposits, and magmatic nickel-copper-cobalt-PGM sulfide deposits. The USGS reports that identified land-based reserves of cobalt are 7.65 Mt and land-based resources are approximately 25 Mt. The Democratic Republic of Congo (DRC) accounts for 46 percent of total reserves, Australia 18 percent, Indonesia eight percent, and Cuba seven percent. Significant amounts of cobalt are also found in manganese crusts and nodules on the ocean floor, although metal recovery from deep-sea sources is not yet economic.

Cobalt's unique ferromagnetic electrical properties make it useful in energy storage and it is a component of the cathode in lithium-ion batteries. In conventional battery designs, cobalt boosts charge rates and has a stabilizing effect which helps to extend battery life and prevent cathode corrosion. These characteristics are important in mitigating the potential for batteries to explode or catch fire. In 2020, lithium-ion batteries accounted for 57 percent of global refined cobalt consumption[5].

Cobalt is also a technologically important metal in the aerospace industry, and in 2020 nickel-base alloys accounted for 14 percent of cobalt demand. Such alloys are also used in tool manufacturing (8 percent), and smaller amounts of cobalt are used in pigments, soaps, catalysts, and magnets. The primary end use of cobalt is still for use in batteries used in portable electronics such as smartphones and laptops (35 percent of global demand), however its use in batteries for automotive applications (22 percent) is growing strongly.

Annex 1 contains detailed information on cobalt ores, Annex 2 contains detailed information on cobalt mining and processing, and Annex 3 contains detailed information on cobalt end-use consumption.

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[5] Cobalt Institute. - https://www.cobaltinstitute.org/about-cobalt/cobalt-life-cycle/cobalt-use/

3. COBALT RESERVES AND RESOURCES

Table 1 presents the USGS' estimates of cobalt reserves in 2021, which total 7.65 Mt. The USGS further reports that identified land-based resources are approximately 25 Mt of cobalt. The vast majority of these resources are in sediment-hosted stratiform copper deposits in the DRC and Zambia, nickel-bearing laterite deposits in Australia, Indonesia, the Philippines, New Caledonia, and Cuba, and magmatic nickel-copper sulfide deposits hosted in mafic and ultramafic rocks in Australia, Canada, Russia, and the United States. The DRC accounts for 46 percent of total reserves, Australia 18 percent, Indonesia 8 percent, and Cuba 7 percent.

The USGS reports that more than 120 Mt of cobalt resources have been identified in polymetallic nodules and crusts on the floor of the Atlantic, Indian, and Pacific Oceans. These are not yet judged to be economic, and numerous environmental challenges remain to be resolved, but deep-sea mining technologies continue to be developed and are expected to facilitate access to these resources in the future.

Table 1: Global Cobalt Reserves (kt cobalt)

Country	Reserves kt Co	% of Total
DRC	3,500	46
Australia	1,400	18
Indonesia	600	8
Cuba	500	7
Philippines	260	3
Russia	250	3
Canada	220	3
Madagascar	100	1
China	80	1
United States	69	1
PNG	47	1
Morocco	13	0
Other countries	610	8
Total	**7,649**	**100%**

Source: USGS.

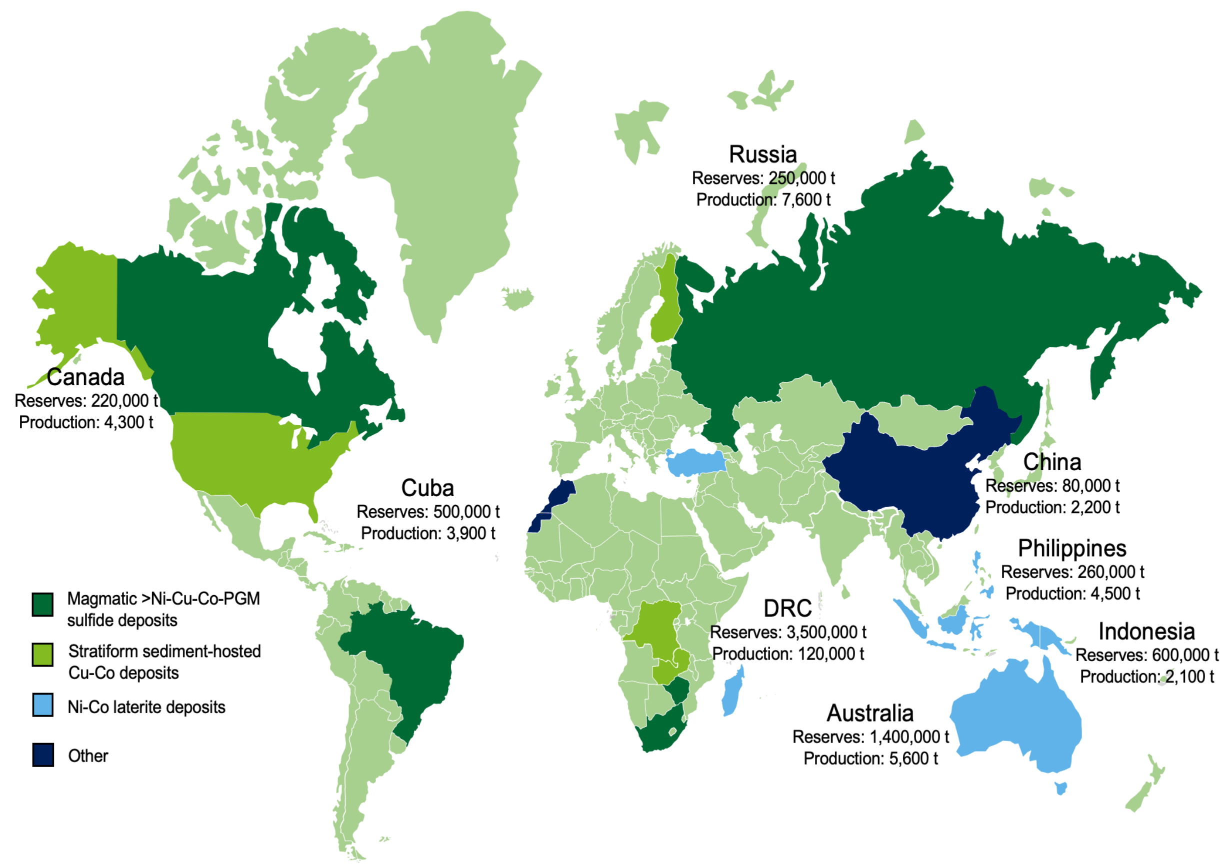
Cobalt deposits of economic or potential economic importance are diverse in terms of their geologic setting, age, morphology, mineralogy, geochemistry, origin, and grade-tonnage relations. The principal deposit types that account for most of the world's cobalt mine production are stratiform sediment-hosted copper-cobalt deposits, nickel-cobalt laterite deposits, and magmatic nickel-copper (-cobalt-PGMs) sulfide deposits.

- Stratiform sediment-hosted copper-cobalt deposits are typically mined for copper with cobalt as a by-product. These deposits represent the world's second largest source of copper (after porphyry deposits) and the largest source of cobalt. The most significant deposits of this type are found in the Central African Copperbelt, which spans the south of the DRC and the north-west of Zambia.

- Magmatic nickel-copper-cobalt-PGM deposits are a major source of global nickel supply with copper, cobalt and PGMs being important by-products. Countries exploiting these deposits to produce cobalt include Canada, Russia, and South Africa. The number of economic nickel sulfide deposits has declined over recent years.
- Nickel-cobalt laterite deposits are now the world's major source of nickel, accounting for 70 percent of global nickel supply in 2020. Notable deposits from which cobalt is produced are found in Australia, Cuba, New Caledonia, Madagascar, Papua New Guinea, Indonesia, and the Philippines.

There are several other deposit types that may contain significant amounts of cobalt, some of which currently produce cobalt or have produced it in the past. Figure 1 shows a simplified map of the cobalt resources by mine-producing country and main deposit type, as well as reserve and production data for the key cobalt producing countries.

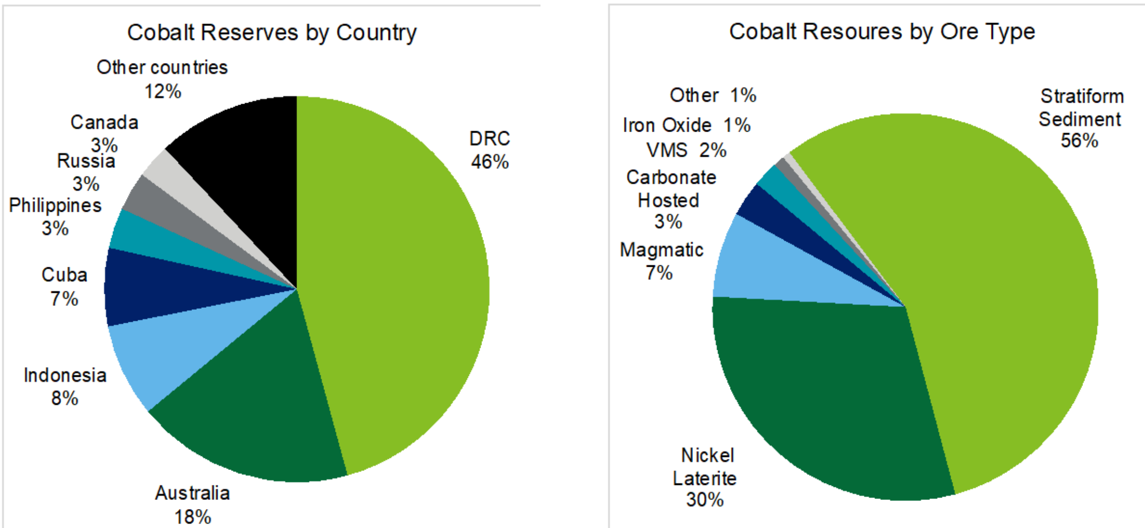
Figure 1: Cobalt Resources by Mine producing Country and Main Deposit Type, 2020



Source: Deloitte, Roskill, USGS.

Figure 2 shows a breakdown of the cobalt reserves by country as well as a breakdown of cobalt resources by ore type. The map in Figure 3 shows the location of significant cobalt deposits.

Figure 2: Global Cobalt Reserves by Country and Resources by Ore Type



Source: USGS 2022. Resource type based on 191 mining operations, and development and exploration projects.

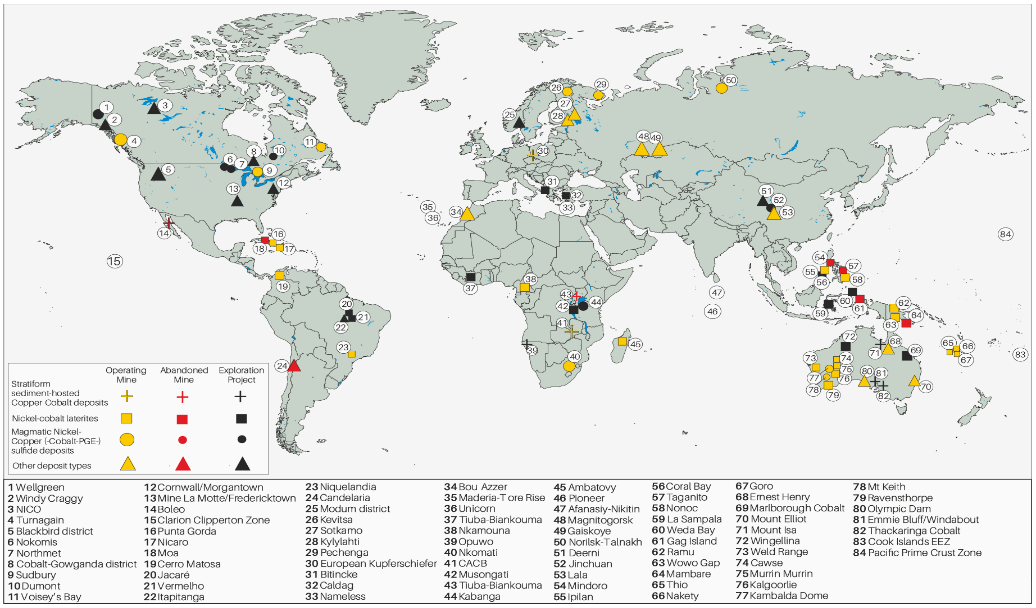
The USGS reports that identified land-based reserves of cobalt are 7.65 Mt and land-based resources are approximately 25 Mt. The Democratic Republic of Congo (DRC) accounts for 46 percent of total reserves, Australia 18 percent, Indonesia 8 percent, and Cuba 7 percent. Significant amounts of cobalt are also found in manganese crusts and nodules on the ocean floor, although metal recovery from deep-sea sources is not yet economic.

China was the largest consumer of cobalt in 2020, accounting for approximately 32 percent of demand. Cobalt use in China is driven by the country's substantial battery industry, with secondary uses including magnets, tool materials, and pigments. The rest of Asia accounted for a further 17 percent of cobalt demand. Europe accounted for 23 percent and North America 18 percent of global cobalt consumption in 2020. These regions primarily use cobalt for strengthening nickel-base alloys and tool materials.

The DRC is the world's leading source of mined cobalt, supplying 72 percent of world cobalt mine production in 2021. The next largest producers are Russia (5 percent) and Australia (3 percent).[6] China is the world's leading producer of refined cobalt, most of which is produced from partially refined cobalt imported from the DRC. Most cobalt (84 percent) is produced as a by-product of copper or nickel mining, except for a small number of cobalt-only deposits (such as Bou-Azzer in Morocco) and artisanal-mined cobalt mainly in the DRC. The estimated value of the cobalt market based on average 2021 prices is $8.5 billion, versus $195 billion for copper.

[6] USGS

Figure 3: Location of Significant Cobalt Deposits



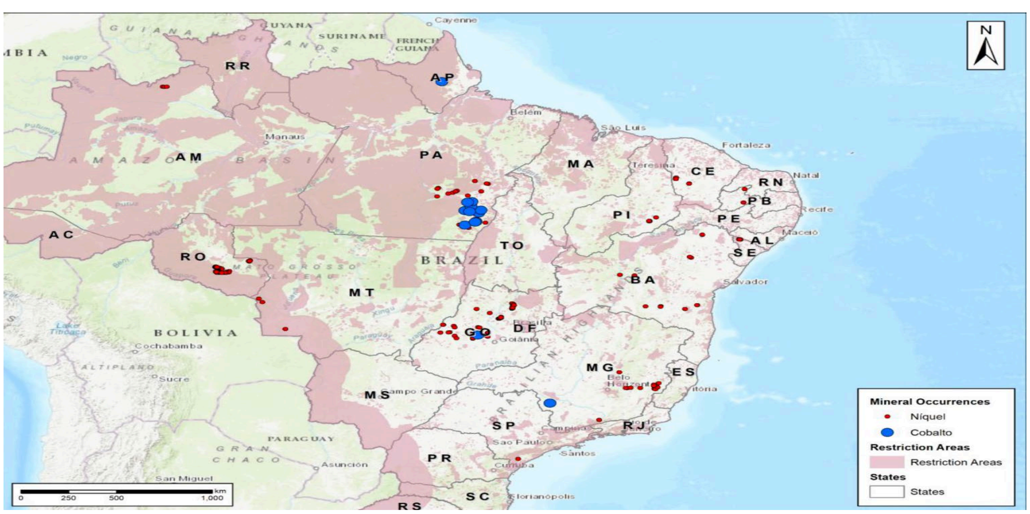
Source: BGS 2019.

3.1. Brazilian Cobalt Reserves and Resources

Brazil hosts both sulfide and laterite nickel resources, with most of the laterite deposits containing cobalt. Brazil's reserves of cobalt are small relative to other national reserves of cobalt, as shown in Table 1.

The Agência Nacional de Mineração reports current Brazilian cobalt reserves of 1,250 t of cobalt, contained in 2.8 Mt of ore at an average grade of 0.04 percent cobalt. This is contained in the municipalities Americano do Brasil, Goiás (850 t) and Sao Felix do Xingu, Pará (400 t). Figure 4 shows a map of cobalt mineral occurrences in Brazil.

Figure 4: Significant Brazilian Cobalt Mineral Occurrences



Source: CPRM.

Table 2 shows that the company reported resources[7] in Brazil total 429.5 kt of cobalt, contained in 865 Mt of ore at an average grade of 0.05 percent cobalt. This represents 1.7 percent of the USGS' estimates of 25 Mt of global cobalt resources in 2021.

Table 2: Company Reported Brazilian Cobalt Reserves and Resources

Mine/Project	State	Owner	Dev. Stage	Status	Grade Co %	Cobalt Tonnes
Araguaia	Pará	Horizonte Minerals	Constr. Planned	Active	0.056	113,600
Montes Claros	Goiás	Unknown	Preproduction	Inactive	0.060	95,000
Santa Fe/Ipora	Goiás	Teck Resources	Prefeas/Scoping	Inactive	0.058	81,000
Vermelho	Pará	Horizonte Minerals	Prefeas/Scoping	Active	0.050	78,700
Piaui	Piauí	Brazilian Nickel	Limited Prodn	Active	0.048	34,700
Jaguar	Pará	Centaurus Metals	Feasibility Started	Active	0.026	20,600
Santa Rita	Bahia	Appian Capital Advisory	Operating	Active	0.010	5,900
Total					**0.050**	**429,500**

Source: S&P Global Intelligence.

7 S&P Global Intelligence

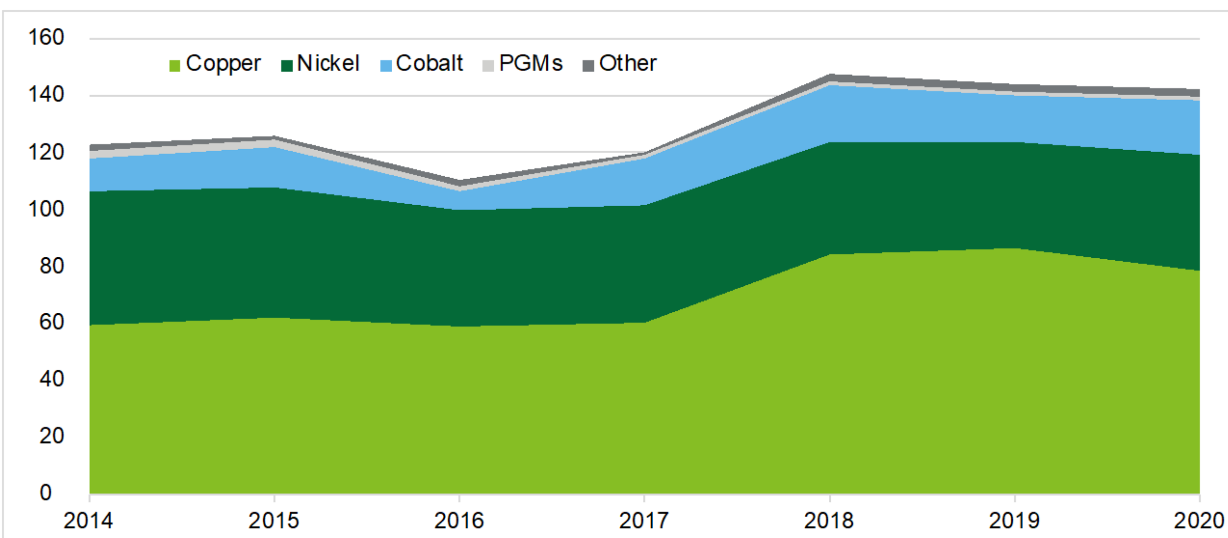
4. COBALT SUPPLY

In 2021, global production of mined cobalt totaled 165 kt, according to the USGS. This represents an increase of 16 percent over the COVID-impacted total for 2020. Figure 6 and Table 3 show that mine output of cobalt is highly concentrated, with the DRC accounting for approximately 72 percent of global production. Russia is the second largest cobalt miner, accounting for around 5 percent of output, followed by Australia (3 percent) and other countries, including Philippines, Cuba, and Canada which contribute a smaller share of global production. DRC cobalt production, in particular, can vary significantly from year to year, due to the prominence (and price sensitivity) of local artisanal mining, which accounts for 13 percent of national output.

4.1. Cobalt Mining

Figure 5 shows that approximately 86 percent of cobalt comes to market as an associated by-product of large-scale commodity mining operations, predominantly copper and nickel. The exception is a single primary cobalt mine in Morocco, plus a series of smaller-scale artisanal cobalt mining operations mainly in the DRC. This means that the production of cobalt is not driven by its own supply and demand fundamentals, but rather by the dynamics of the broader copper and nickel markets. Those primary economic factors notwithstanding, cobalt is often an important source of supplemental revenue to large copper and nickel operations.

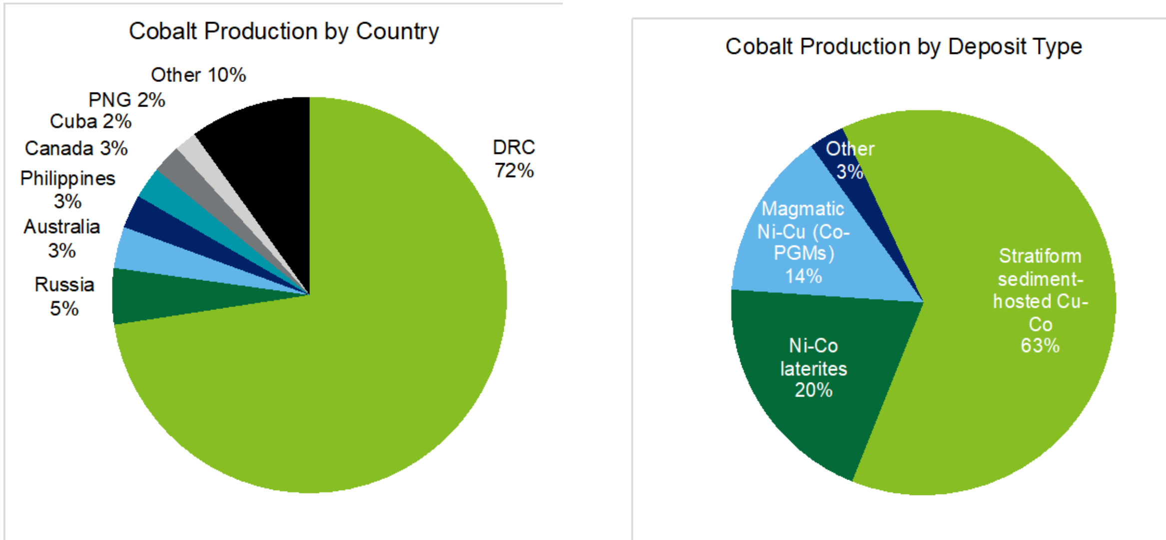
Figure 5: Global Mine Production of Cobalt by Primary Product Source (kt)



Source: Cobalt Institute, Roskill.

The Cobalt Institute estimates that 55 percent of cobalt mined in 2020 was a by-product of copper, 29 percent a by-product of nickel, and 2 percent by-products of iron ore mining in China and the production of platinum group metals in South Africa and Zimbabwe. The remaining 14 percent was derived from primary sources, including Morocco but mainly from artisanal and small-scale mining sites mainly in the DRC (Figure 7). This percentage of artisanal production is slightly higher than in recent years, likely attributable to pandemic-related production cuts and labor layoffs at formal mining operations in 2020.

Figure 6: Global Mine Production of Cobalt by Country and Deposit Type



Source: USGS 2021, BGS 2017.

Cobalt is also contained in nickel laterite ores that are treated by Nickel Pig Iron (NPI) and ferronickel processing routes where cobalt is not recovered but does flow into final stainless-steel products without being recorded.

See Annex 1 for more information on cobalt ores and Annex 2 for more information on cobalt mining and processing.

Table 3: Global Cobalt Mine Production by Country (t cobalt)

Country	2016	2017	2018	2019	2020	2021e
DRC	64,000	73,000	104,000	100,000	98,000	120,000
Russia	5,500	5,900	6,100	6,300	9,000	7,600
Australia	5,500	5,030	4,880	5,740	5,630	5,600
Philippines	4,100	4,600	4,600	5,100	4,500	4,500
Canada	4,250	3,870	3,520	3,340	3,690	4,300
Cuba	4,200	5,000	3,500	3,800	3,800	3,900
PNG	2,190	3,310	3,280	2,910	2,940	3,000
Madagascar	3,800	3,500	3,300	3,400	850	2,500
Morocco	2,080	2,200	2,100	2,300	2,300	2,300
China	*	3,100	2,000	2,500	2,200	2,200
Indonesia	350	350	350	350	1,100	2,100
United States	690	640	490	500	600	700
South Africa	2,300	2,300	2,300	2,100	1,800	*

Country	2016	2017	2018	2019	2020	2021e
New Caledonia	3,390	*	2,100	1,600	*	*
Zambia	3,000	*	*	*	*	*
Other	5,170	7,300	5,190	4,370	5,840	6,600
Total	**110,520**	**120,100**	**147,710**	**144,310**	**142,250**	**165,300**

Source: USGS 2021, *included in Other.

4.2. Cobalt Producing Mining Companies

Globally, about 56 companies produced cobalt in 2020. Table 4 lists the largest cobalt producing companies which cumulatively accounted for 80 percent of global output. The two largest producers are Glencore and China Molybdenum Corporation (CMOC), both operating mines in the DRC. Gécamines, owned by the DRC Government, is the third largest producer.

In the illiquid cobalt market, operational changes to a single high output mine can have a significant impact on the market. For example, in August 2019, in response to lower copper and cobalt prices, Glencore suspended operations at the Mutanda mine (DRC), which at the time produced 20 percent of the world's cobalt supply. This reduced supply and allowed the market to stabilize. In December 2021, as demand recovered and cobalt prices strengthened, Glencore restarted the mine.

Table 4: Top 20 Cobalt Mining Companies Attributable Production (t cobalt)

	Company	Domicile	2018	2019	2020
1	Glencore	United Kingdom	35,444	33,735	25,946
2	China Molybdenum	China	10,498	12,878	12,349
3	Gécamines	DRC	8,345	10,164	11,663
4	Shalina Resources	DRC	6,650	14,650	10,650
5	Eurasian Group	Kazakhstan	1,470	6,000	10,500
6	Zhejiang Huayou Cobalt	China	NA	NA	5,390
7	Jinchuan Group	China	5,440	5,846	5,390
8	Vale SA	Brazil	4,619	3,801	4,192
9	Norilsk	Russia	5,692	4,097	4,102
10	Nickel Asia Corp.	Philippines	2,267	2,448	2,848
11	Groupe Forrest	Belgium	NA	1,750	2,800
12	Managem	Morocco	1,803	2,392	2,411
13	CN Nonferrous Mining	China	2,068	2,408	2,097
14	Sherritt International	Canada	1,959	2,036	1,685
15	General Nickel	Cuba	1,617	1,688	1,685
16	Metallurgical Corp. (MCC)	China	1,866	1,658	1,675
17	Pacific Metals	Japan	1,238	1,323	1,569

	Company	Domicile	2018	2019	2020
18	Sumitomo Corp.	Japan	1,360	1,382	1,550
19	Korea Resources	South Korea	642	653	1,311
20	Terrafame	Finland	1,208	1,148	1,215
	Total		**94,186**	**110,057**	**111,028**

Source: S&P Global Intelligence, company reports, Deloitte estimates.

Table 5 outlines the largest 17 cobalt mining operations, their location, and ownership, accounting for 71 percent of total production in 2020. The largest is the Mutanda mine and the second largest is the Kamoto mine, both located in the DRC, and both owned by Glencore.

Table 5: Largest Cobalt Mine Operations

	Mine	Country	Owner	Prodn 2019 t Co	Prodn 2020 t Co
1	Mutanda	DRC	Glencore	25,100	0
2	Kamoto	DRC	Glencore	17,054	23,900
3	Tenke Fungurume	DRC	China Moly/Gécamines	16,098	15,436
4	Metalkol RTR	DRC	Eurasian Group	6,000	10,500
5	Etoile	DRC	Shalina Resources	7,000	7,000
6	Luiswishi	DRC	Zhejiang Huayou	0	5,390
7	Sudbury Ops	Canada	Glencore	4,400	4,400
8	Ruashi	DRC	Jinchuan/Gécamines	5,070	4,158
9	Lubumbashi Slag Hill	DRC	Groupe Forrest	2,500	4,000
10	Mutoshi	DRC	Shalina Resources	8,000	4,000
11	Moa Bay	Cuba	Sherritt/General Nickel	3,376	3,370
12	Murrin	Australia	Glencore	3,700	3,300
13	Ramu	PNG	Metallurgical Corp.	2,911	2,941
14	Ambatovy	Madagascar	Sumitomo/ Korea Res.	2,900	2,862
15	Polar Division	Russia	Norilsk	2,579	2,702
16	Taganito	Philippines	Nickel Asia/Pacific Metals	2,647	2,549
17	Bou-Azzer	Morocco	Managem	2,397	2,416

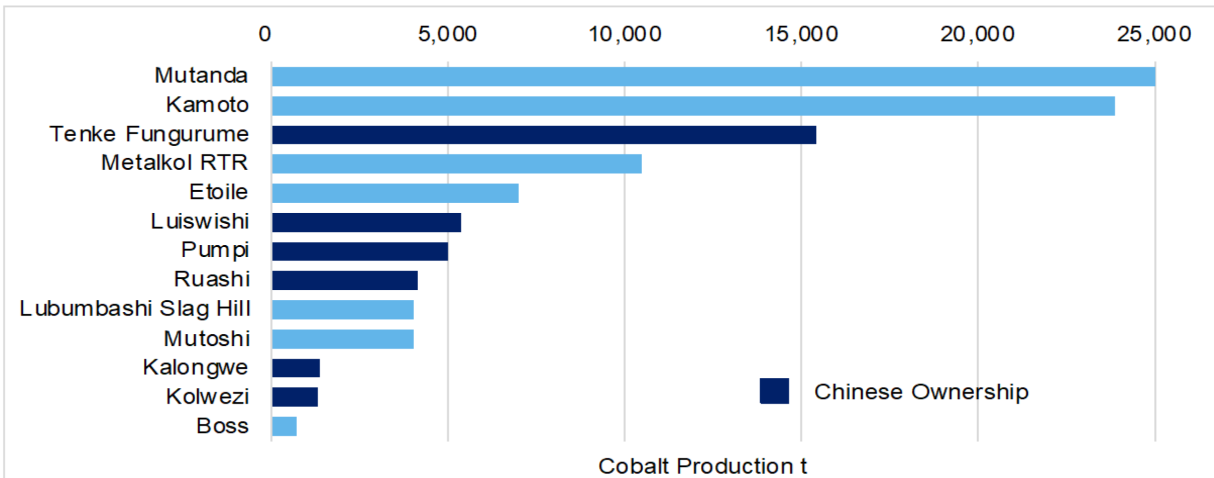
Source: S&P Global Intelligence, company data.

4.3. Mine Production in the DRC

The DRC accounted for approximately 72 percent of global cobalt production in 2021, equivalent to 120 kt of output, versus 165 kt globally. Approximately 30 percent of the DRC's cobalt capacity is currently controlled by Chinese companies. Figure 7 shows cobalt production across the DRC, highlighting those mines under Chinese ownership.

The third largest cobalt-producing mine globally and in the DRC is Tenke Fungurume owned by CMOC. The company purchased its ownership in two tranches: from Freeport McMoRan in 2016 and Lundin Mining in 2020. In early March 2022, a court suspended CMOC's management rights for six months at Tenke Fungurume due to reported possible underpayment of royalties and restricted access to CMOC technical information by the DRC Government. The DRC Government also threatened to review the $6 billion "infrastructure-for-minerals" deal from 2008[8] made between the DRC Government and Chinese state-owned construction companies. However, in March 2022, the DRC suspended this judicial procedure in favor of a third-party review, allowing CMOC to continue operations.

Figure 7: DRC Production of Cobalt by Mine



Source: Company data, NB Boss mine on care & maintenance. Mutanda Re-opening.

4.3.1. Artisanal and Small-Scale Mining (ASM)

Artisanal and small-scale mining (ASM) in the DRC remains an important contributor to cobalt supply producing around 16 kt/y of cobalt. Cobalt is mined as a primary product by artisanal workers in the DRC and the dynamics of ASM operations are complex. Estimates of the number of individuals engaged in the mining, sorting, washing, transporting, and trading of cobalt in the DRC vary widely but most analysts believe more than 100,000 individuals may be involved. The Bundesanstalt für Geowissenschaften und Rohstoffe[9] reports that there were a total of 67 copper and cobalt producing artisanal mines registered in 2020. The number of people involved, and the volumes produced, vary considerably from year to year depending on the cobalt price and its attractiveness relative to other commodities, principally copper.

In 2016, Amnesty International published a report entitled "This Is What We Die For", which highlighted the issue of child labor in DRC mines and other human rights violations. It received a lot of media attention, spurred OEMs to look again at their supply chains, and encouraged battery producers to innovate ways to lower their dependency on cobalt.

[8] Reuters News: https://www.reuters.com/world/africa/congo-court-appoints-temporary-administrator-run-china-molys-tenke-mine-2022-03-01/

[9] Mining Conditions and Trading Networks in Artisanal Copper-Cobalt Supply Chains in the Democratic Republic of the Congo – April 2021

Many OEMs have since evolved their thinking and now recognize that ASM provides a critical source of income for many people; removing that source of income could paradoxically exacerbate the problems highlighted in the Amnesty International report. This evolution is represented by the London Metal Exchange's (LME) decision to adopt a policy of non-discrimination between large-scale mining and ASM. Current industry initiatives such as the Fair Cobalt Alliance and the Responsible Minerals Initiative now emphasize formalization of ASM sites so that standards are upheld, and actions are taken to address the root causes of child labor.

In November 2019, the DRC government launched a national strategy to reform artisanal mining, including mitigating the use of child labor. In addition, in December 2019, it was announced that a new state-owned company was being set up to regularize the ASM sector and buy and market all ASM cobalt. The company, Entreprise Générale du Cobalt (EGC), is controlled by Gécamines and has been granted monopoly powers to purchase and market cobalt from the ASM sector. The DRC has also signed international conventions prohibiting child labor, including ILO Conventions No. 138 on the Minimum Age of Employment and No. 182 on the Worst Forms of Child Labor. Its labor and mining codes generally meet international standards in prohibiting child labor, forced labor, and child trafficking, however, child labor persists where ASM activities take place outside the legal structure, according to the International Energy Agency (IEA)[10].

It is so far unclear how the formation of EGC has impacted the ASM sector in the DRC, although the IEA reports that there is some evidence that ASM formalization can be effective at reducing child labor concerns. There has not been a recent survey of the ASM sector in the DRC, but the country does appear to be working towards resolving the social and human rights issues of the past.

In November 2020, Trafigura announced that it had signed a five-year deal with EGC to finance the creation of controlled artisanal mining zones, buying centers, and logistics in the DRC.

4.4. Mine Production in the Rest of the World

Cobalt supply from individual countries outside of the DRC is relatively smaller scale. Only a small group of countries, including Russia, Australia, Philippines, Canada, and Cuba produce substantial volumes, as shown in Figure 8. A small amount of cobalt is recovered as a by-product of PGM production in South Africa and Zimbabwe. The largest individual cobalt producers outside of DRC are the Sudbury operations in Canada owned by Glencore, Moa Bay in Cuba owned by Sherritt, and Murrin in Australia, also owned by Glencore. Bou-Azzer mine, located in the Atlas Mountains of Morocco, is currently the only primary cobalt operation in the world. It is owned by Managem and produced an estimated 2.3 kt of cobalt in 2021.

4.4.1. Cobalt Production in Brazil

Brazil has not produced cobalt since 2016, when the country produced 408 t of cobalt from nickel sulfide ore. Brazil produced an average of 2,041 t/y of cobalt between 2010 and 2016. Initiatives to explore for and produce cobalt in Brazil include the Cobalt Project and a CPRM project investigating deep-sea nodules. The Cobalt Project is a CPRM initiative, together with the Federal Institute of Geosciences and Natural Resources of Germany (BGR), and the Mineral Technology Center (CETEM) that aims to develop a novel bioleaching technology to enable the development of Brazil's cobalt-containing lateritic profiles. CPRM - through the Mineral Resources project of the Brazilian Continental Shelf - has also been carrying out research to map polymetallic sulfides in the Mid-oceanic Cordillera of the South, and Equatorial Atlantic Ocean.

[10] IEA – The role of critical Minerals in clean energy transitions. May 2021.

4.5. Substitution

Substitution possibilities for cobalt are limited in many applications because of its unique properties. Due to recent price spikes and the ESG issues associated with ASM cobalt supply in the DRC however, battery makers have been reducing the cobalt content in lithium-ion batteries by using higher volumes of nickel and lower volumes of cobalt in NCM cathode chemistries. In late 2020, Tesla announced that it would move to a cobalt-free battery, although no time frame was given. Actual cobalt substitutes have not been widely adopted due to inferior performance, and functional cobalt substitution is severely restricted for superalloys and hard materials.

4.6. Recycling

At present, cobalt recycling is not a significant factor in the economics of the cobalt market. Secondary recovery, or recycling, of cobalt is expected to increase rapidly and become an important source of cobalt feedstock to the supply chain. The Cobalt Institute estimates annual secondary sources at 10.6 kt in 2020 with 65 percent from batteries (end-of-life or manufacturing waste), 24 percent from tungsten carbide scrap, and 11 percent from alloy scraps and spent catalysts. Over the past nine years the ratios between this supply have remained steady.

Glencore and Umicore SA operate smelters and refineries in Canada, Finland, Belgium, United States, and China for recycling magnets, hard metals, scrap, and alloys, but there are also several start-ups employing hydrometallurgical methods to recycle lithium-ion batteries. This process involves converting retired batteries into a paste referred to as "black mass." For NMC batteries, this is comprised of nickel, manganese, cobalt oxides, and carbon.

Other companies working on advancing recycling include BASF Catalyst that intends to recycle batteries at its existing plants in the United States and Europe; Redwood Materials (Nevada); Li-Cyle (Canada) which uses a hydrometallurgical process (operation in Rochester, New York); and Retriev Technologies (Canada and Indiana).

Consequently, there is expected to be a considerable increase of cobalt supplied through recycling by 2030. Increasingly, growth in cobalt recycling is being driven by battery recycling, as the practice achieves a greater commercial scale with the increased availability of end-of-life batteries. Roskill forecasts that cobalt supply from recycled sources could reach 34 kt/y by 2030, an increase of 23.4 kt/y, with over 80 percent of that volume coming from battery recycling.

4.7. Cobalt Intermediates

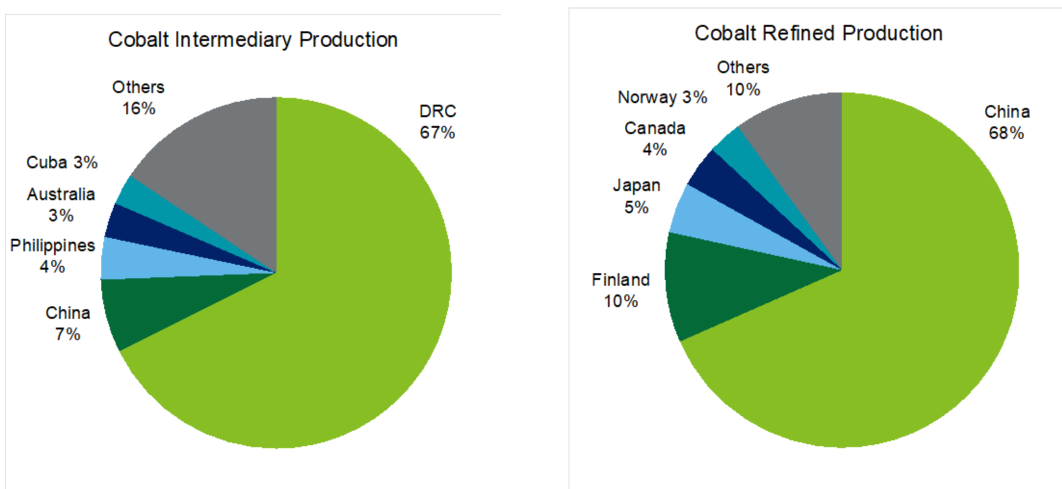
A wide range of cobalt intermediates are produced from mined cobalt. In 2020, the main form of intermediate produced by volume was crude cobalt salts (mostly crude hydroxide and carbonate typically containing more than 30 percent cobalt), the majority of which comes from the by-product stream of copper operations employing hydrometallurgical processes in the DRC. The next largest group of cobalt intermediates includes nickel and cobalt bearing mattes, and hydroxide and sulfide products, which are a by-product of the smelting of nickel sulfide or laterite ores from countries including Australia, Cuba, and the Philippines.

The DRC, as the world's largest cobalt mining country, is by far the largest producer of cobalt intermediates. The DRC produced 87.7kt of cobalt contained in intermediates in 2020, accounting for 68 percent of global supply. China was the world's second-largest producer of cobalt intermediates in 2020, accounting for 7 percent of global production. Chinese intermediates are mainly based on imported ores and concentrates from the DRC, with the balance accounted for by Jinchuan Group's (JNMC) integrated production.

4.8. Refined Production

Intermediate cobalt products are further processed into refined cobalt products. Global production of refined cobalt totaled 132 kt in 2020. China was the world's largest cobalt refining country in 2020, with refined production totaling 89.2 kt or 67 percent of the global total. Finland was the second largest producer (10 percent), followed by Japan (5 percent), Canada (4 percent), and Norway (3 percent).

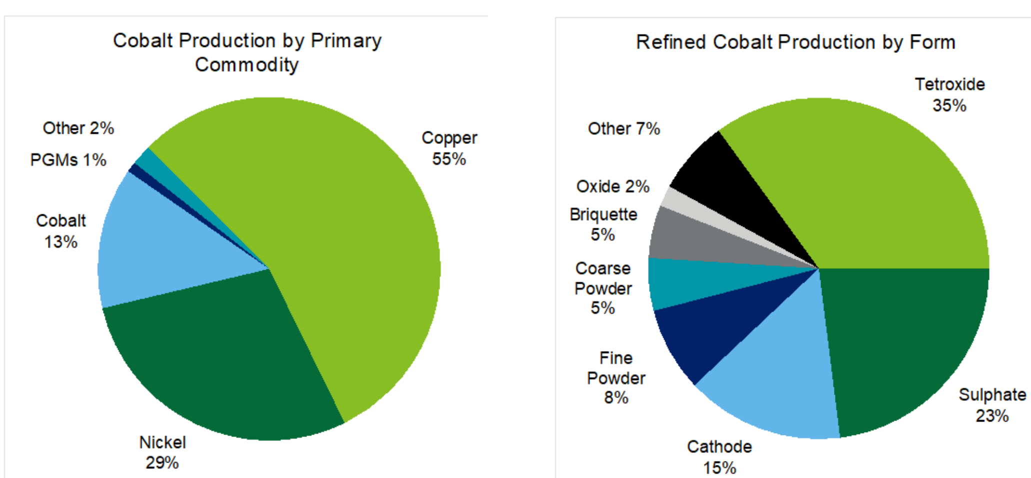
Figure 8: Global Intermediary and Refined Production of Cobalt



Source: Cobalt Institute, Roskill.

Refined cobalt is produced into a variety of metal and chemical forms. The commercialization and growth in demand for lithium-ion batteries has resulted in significant new demand for cobalt chemicals (mainly tetroxide and sulfate). The share of cobalt refined products made into chemicals increased to 65 percent in 2020 and is expected to increase further as demand for cobalt in lithium-ion batteries increases.

Figure 9: Mine Production by Primary Product Source and Refined Products by Type 2020



Source: Cobalt Institute, Roskill.

There are five main types of cobalt metal product: cathode, briquette, coarse powder, fine powder, and rounds. The Cobalt Institute reports that there has been no ingot production since 2017. In addition, there are nine types of cobalt chemical product: carbonate, chloride, hydroxide, monoxide, oxalate, oxide, sulfate, tetroxide, and other minor variants. Conversions from one refined product to another are common - for instance, chlorides can be converted to tetroxides, carbonates and oxalates can be processed into powders, hydroxides can be a feedstock for sulfate production, and metals are sometimes dissolved to produce chemicals. The highest chemical production volumes in 2020 were of cobalt tetroxide, followed by sulfate and cathode.

China, the world's largest producer, produces all the refined forms listed above - although sulfate and tetroxide, used in lithium-ion batteries, dominated. In Finland, the world's second largest producer, coarse cobalt powder dominates output. In Japan, the world's third largest producer, most production was of cobalt metal in the form of cathodes.

4.9. New Cobalt Mine Supply

The Deloitte team has assembled a database of 30 global cobalt projects that have the potential to come onstream by 2030. The data has been collected directly from company reports, technical papers, webinars, and news sources. These sources notwithstanding, data for cobalt production plans is sometimes difficult to isolate, as it is usually a by-product of the primary commodity. Also, mine data for Indonesian laterites is somewhat opaque because most of the focus is centered on nickel smelters, smelter capacity, and may include the direct shipping of ore. As such, the database excludes those projects intending to directly ship nickel-cobalt ore, to avoid double counting.

4.9.1. Existing Producers Expansion Plans

The Deloitte team also analyzed the major producers of cobalt to identify any brownfield expansions and restarts that are planned over the next decade. Table 6 shows these projects, which are expected to add 62.8 kt/y of cobalt to existing production by 2030. The majority of the growth in cobalt production from these sources over the next decade will come from the DRC, a product of that country's vast copper-cobalt resource base.

The largest new addition of cobalt capacity comes from Glencore, which restarted the Mutanda mine at the end of 2021 and which is expected to produce up to 22 kt/y from 2022 onwards. The future exploitation of Mutanda's copper-cobalt sulfide reserves is a stated priority for Glencore, but no further detail on this expansion is given by the company.

In 2021, CMOC completed an enhancement project at Tenke Fungerume, raising copper and cobalt production by 20 percent. The company is now undertaking an expansion of the mine - investing $2.5 billion across three new processing streams with an expected completion date in 2023. These projects are forecast to more than double Tenke Fungerume's copper and cobalt production. The mine produced 15.4 kt of cobalt in 2020 and is expected to increase cobalt supply to around 34 kt/y after 2023, making Tenke Fungerume the world's largest cobalt mine by production.

Metalkol RTR tailings reprocessing project, operated by Eurasian Natural Resources, reached full Phase 1 production in 2020 and the company has recently completed the construction of Phase 2 and is now ramping up to a target potential capacity of 24 kt/y of cobalt and 120 kt/y of copper.

In March 2022, MMG committed to extending the life of the Kinsevere copper operation by exploiting the copper-cobalt sulfide resource and will increase production of copper cathode to 80 kt/y and produce 4.0 to 6.0 kt/y of cobalt for the first time. Construction will commence in 2022 with first cobalt production expected in 2023.

Table 6: Expansions and Restarts by Existing Cobalt Producers (kt)

Mine	Country	Owner	Production 2020 kt	Production 2030 kt	Production Change kt
Mutanda	DRC	Glencore	0.0	22.0	22.0
Tenke Fungerume	DRC	China Molybdenum	15.4	34.0	18.6
Metalkol RTR	DRC	Eurasian Natural Res.	10.5	24.0	13.5
Kinsevere	DRC	MMG	0.0	5.0	5.0
Kolwezi	DRC	Zijin Mining Group	1.4	3.2	1.8
Voisey's Bay	Canada	Vale SA	1.6	2.8	1.2
Savannah	Australia	Panoramic Resources	0.0	0.7	0.7
Total			**28.9**	**91.7**	**62.8**

Source: S&P Global Intelligence, company reports.

4.9.2. New Mine and Plant Production

The Deloitte team has identified eight new global cobalt projects that are currently under construction or newly commissioned and a further four projects that are at late-stage development awaiting a final investment decision. Table 7 shows these projects, which are expected to add 53.2 kt/y of cobalt production by 2030. It is possible that some projects may not reach full capacity, particularly the High Pressure Acid Leaching (HPAL)[11] smelter projects in Indonesia. (Historically, HPAL projects have rarely consistently achieved nameplate capacity, and ramp-up times are often protracted).

Table 7: New Projects Under Construction and Late-Stage Development (kt)

Project	Primary Metal	Country	Status	Owner	Production kt Co
Weda Bay	Nickel	Indonesia	Construction	Huafei Nickel Cobalt	15.0
Morowali-IP	Nickel	Indonesia	Commissioning	Huayue Nickel Cobalt	7.8
Musonoi	Copper	DRC	Construction	JinchuanGroup	6.5
Pumpi	Copper	DRC	Operating	Managem SA	5.0
Obi Island 1	Nickel	Indonesia	Commissioning	PT Halmahera Persada	4.6
Sunrise	Nickel	Australia	Late-Stage Dev.	Sunrise Energy Metals	4.4
Morowali-IP	Nickel	Indonesia	Construction	PT QMB New Energy	4.0
Obi Island 2	Nickel	Indonesia	Construction	PT Halmahera Persada	2.2
Idaho Cobalt	Cobalt	USA	Construction	Jervois Global	1.9
Nico	Cobalt	Canada	Late-Stage Dev.	Fortune Minerals	1.6
NorthMet	Copper	USA	Late-Stage Dev.	PolyMet Mining Corp.	0.1
SCONI	Cobalt	Australia	Late-Stage Dev.	Australian Mines	0.1
Total					**53.2**

Source: S&P Global Intelligence, company reports.

[11] High Pressure Acid Leaching

4.9.3. Cobalt Projects at Feasibility Stage

Table 8 shows the list of the main global cobalt projects that remain at feasibility stage with the potential to come onstream by 2030. This is likely not an exhaustive list as there are many copper and nickel projects that plan to produce small amounts of cobalt that remain difficult to identify. Further, there is no guarantee that all these projects will reach production, although many appear to have a reasonable probability of achieving start-up based on development progress to date. The Cameroon East project - the largest resource of any primary cobalt project - appears to be delayed due to shareholder-government disagreements.

Overall, the Deloitte team calculates that the projects listed in Table 8 have the potential for at least 29.3 kt/y of cobalt production (there is no data available for Kisanfu).

Table 8: Cobalt Feasibility Projects (kt)

Project	Primary Metal	Country	Owner	Prodn Kt Co	Resources Co kt	Grade % Co
Cameroon East	Cobalt	Cameroon	Geovic Mining	6.2	682.6	0.211
Weda Bay	Nickel	Indonesia	Eramet/BASF	5.0	N/A	N/A
Santo Domingo	Copper	Chile	Capstone Mining	4.7	132.3	0.023
Thackaringa	Cobalt	Australia	Cobalt Blue	3.5	81.1	0.069
Kabanga	Nickel	Tanzania	Kabanga Nickel	3.0	115.0	0.198
Wingellina	Nickel	Australia	NICO Resources	3.0	154.4	0.070
Mt Thirsty	Cobalt	Australia	Conico/Greenstone	1.6	31.6	0.118
Kalgoorlie	Nickel	Australia	Ardea Resources	0.9	208.8	0.037
Piaui	Nickel	Brazil	Brazilian Nickel	0.9	34.7	0.048
Dutwa	Nickel	Tanzania	Blackdown Res.	0.6	29.2	0.027
Kisanfu	Copper	DRC	China Molybdenum	N/A	N/A	N/A
Total				**29.3**		

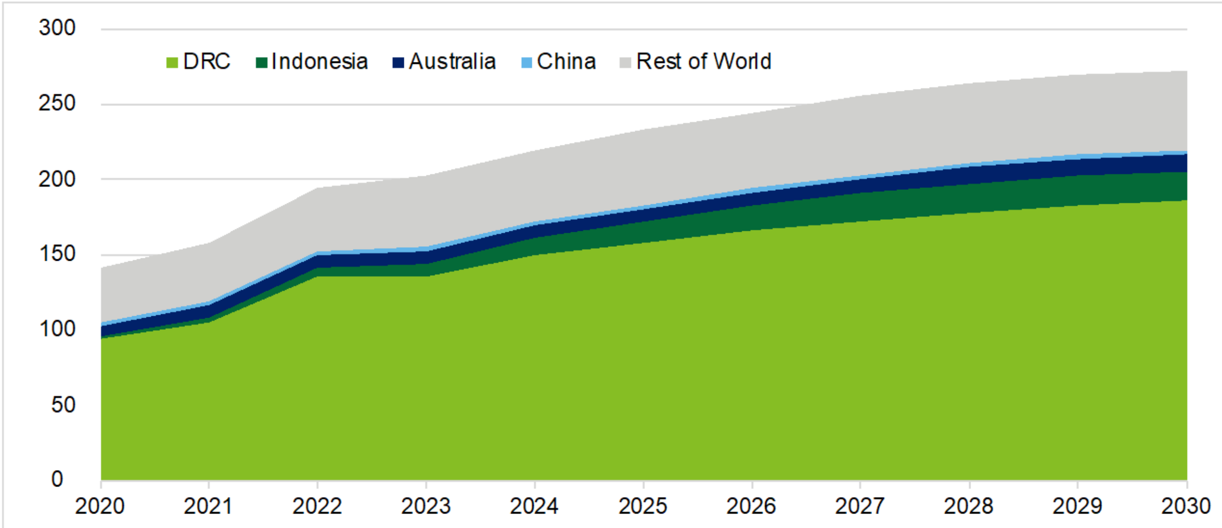
Source: S&P Global Intelligence, company reports.

4.9.4. Summary of New Mine Supply Potential

The Deloitte team calculates that expansions from the existing producers, plus new projects under construction, late-stage development projects, and 2030-targeted projects at feasibility stage, have the potential to add 145 kt/y of cobalt capacity by the start of the next decade. This estimate does not include potential growth in ASM production in the DRC.

This combination of projects has the potential to more than double cobalt mine production from 142 kt/y in 2020 to approximately 288 kt/y by 2030. The forecast from Roskill in Figure 10 implies mine production of 272 kt/y by 2030. There is no guarantee that all the projects identified by the Deloitte team will reach production, although 80 percent are planned brownfield expansions and projects under construction or at final investment decision stage. The Deloitte team also notes that there may be some potential reductions in production, or closures, of existing operations by 2030, although none were identified.

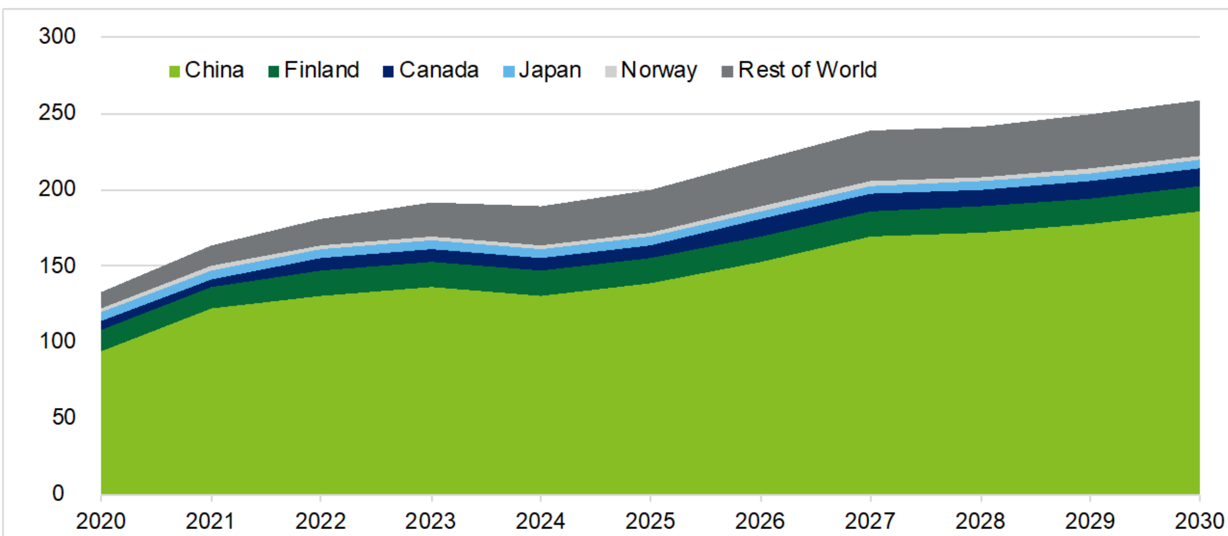
Figure 10: Forecast Mine Production of Cobalt by Country (kt)



Source: Outlook for Selected Critical Minerals, Australia 2021, Roskill 2021

Figure 11 shows the forecast refined production of cobalt by country, with most of the capacity increase from 2020 to 2030 coming from China.

Figure 11: Forecast Refined Production of Cobalt by Country (kt)



Source: Outlook for Selected Critical Minerals, Australia 2021, Roskill 2021.

4.9.5. New Brazilian Production

Based on available data, the Deloitte team has identified that Brazil has only one nickel-cobalt exploration project at a relatively advanced stage: Piauí, and two projects at pre-feasibility stage: Vermelho and Jacaré.

Brazilian Nickel operates the Piauí nickel-cobalt project in Piauí State, Brazil, applying simple heap-leach technology to treat laterite ores and produce nickel and cobalt products suited for the battery market. The company operated a demonstration plant in 2016 and 2017 and has an ongoing bankable feasibility study for full-scale commercial operation, which is envisaged to produce an average of 25 kt/y of contained nickel and an estimated 0.9 kt/y of cobalt. **TechMet** has funded the first commercial phase of project development and has signed an agreement to jointly develop nickel laterite opportunities globally.

The Deloitte team did not include the Vermelho nickel-cobalt laterite project in Table 8 because it is not yet at the feasibility stage. It is owned by **Horizonte Minerals** and is located in the Carajás Mining District in the Pará State, northeast Brazil. The project has a mine life of 38 years, and the pre-feasibility study released in October 2019 proposes an HPAL operation producing 24 kt/y nickel and 1.2 kt/y cobalt for the battery market. Horizonte acquired the project from Vale in 2017. A feasibility study, along with permitting, is advancing. The nickel and cobalt sulfate products are planned to be transported to the port of Vila do Conde for sale to overseas customers.

Anglo American reports that the early-stage exploration Jacaré project looks promising. Jacaré is a high-grade, large-tonnage nickel-cobalt deposit. Anglo American reports that Phase 1 of the project could deliver 35 kt/y of nickel, with Phase 2 potentially delivering a further 50 kt/y of nickel with cobalt by-products. The company has not given recent updates on this project.

These projects look prospective, although the primary commodity is nickel, and cobalt is only recovered as a by-product. Vermelho and Jacaré are not in the list of expected production by 2030 because they are in early stages; however, if all three projects do achieve production by 2030, combined they would likely produce an estimated 5-10 kt/y of cobalt per annum, equivalent to 2-3 percent of global production.

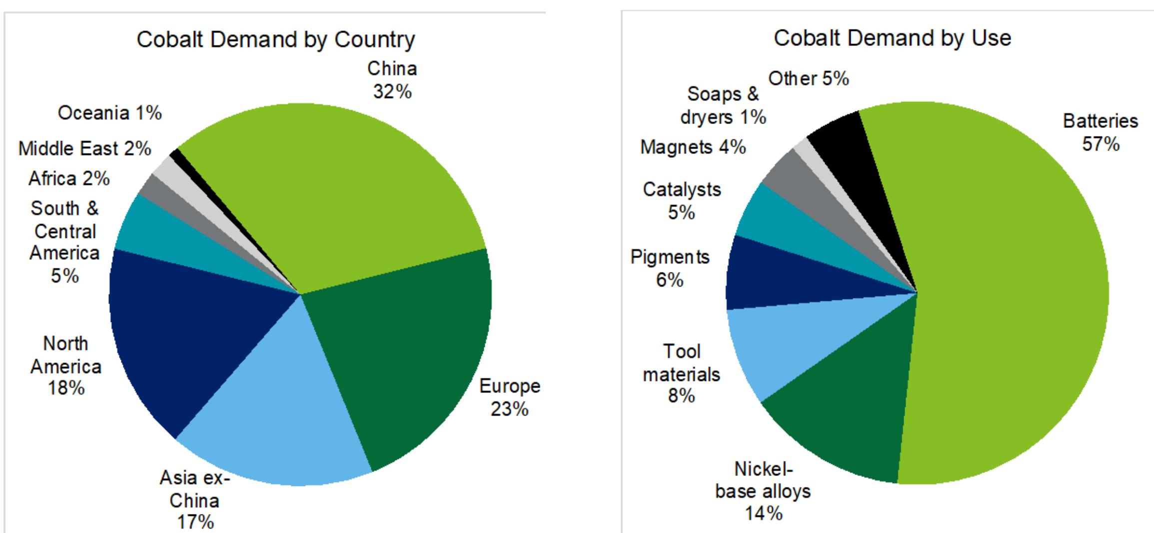
In July 2022, Jervois Mining [ASX: JRV] acquired the nickel refinery at São Miguel Paulista (SMP) which closed in 2016 with the aim of restarting the refinery. The company has completed a bankable feasibility study (BFS) and ore will be supplied from the company's Idaho Cobalt Operation in the United States. Jervois Mining is also planning to construct a pressure-oxidation autoclave in front of the existing circuit to allow the processing of sulfides in addition to the hydroxide and carbonate feeds the refinery can already accommodate. This will allow the refinery to also process material from recycled lithium-ion batteries. Jervois Mining expects start-up to take place in 2024 with capacity of 25 kt/y nickel and 2.0 kt/y cobalt. This is secondary refined cobalt production and not derived from Brazil.

5. COBALT DEMAND

Global cobalt consumption in 2020 was approximately 135 kt, according to the Cobalt Institute. Cobalt is primarily used in manufacturing batteries, which in 2020 accounted for 57 percent of global cobalt consumption. Other significant uses include nickel-base alloys mainly used in turbine engine components (14 percent of global consumption), and hard materials used in carbides for cutting tools (8 percent). Other uses include pigments used in coloring glass and ceramics and in paints (8 percent), catalysts for petroleum refining and plastics manufacturing (5 percent), magnets used in electric motors and loudspeakers (4 percent), soaps and paint dryers (1 percent). Several other minor end-uses, including foodstuffs, biotechnology, medicine, electroplating, and electronics, make up the remaining 5 percent of consumption.

China was the largest consumer of cobalt in 2020, accounting for approximately 32 percent of demand. Cobalt use in China is driven by the country's substantial battery industry, with secondary uses including magnets, tool materials, and pigments. The rest of Asia accounted for a further 17 percent of cobalt demand. Europe accounted for 23 percent and North America accounted for 18 percent of global cobalt consumption in 2020. These regions primarily use cobalt for strengthening nickel-base alloys and tool materials. Central and South America, Africa, the Middle East, and Oceania accounted for the remaining 10 percent of global cobalt consumption. Figure 12 shows global cobalt consumption by application and by region.

Figure 12: Global Cobalt Demand by Country and by Use 2020



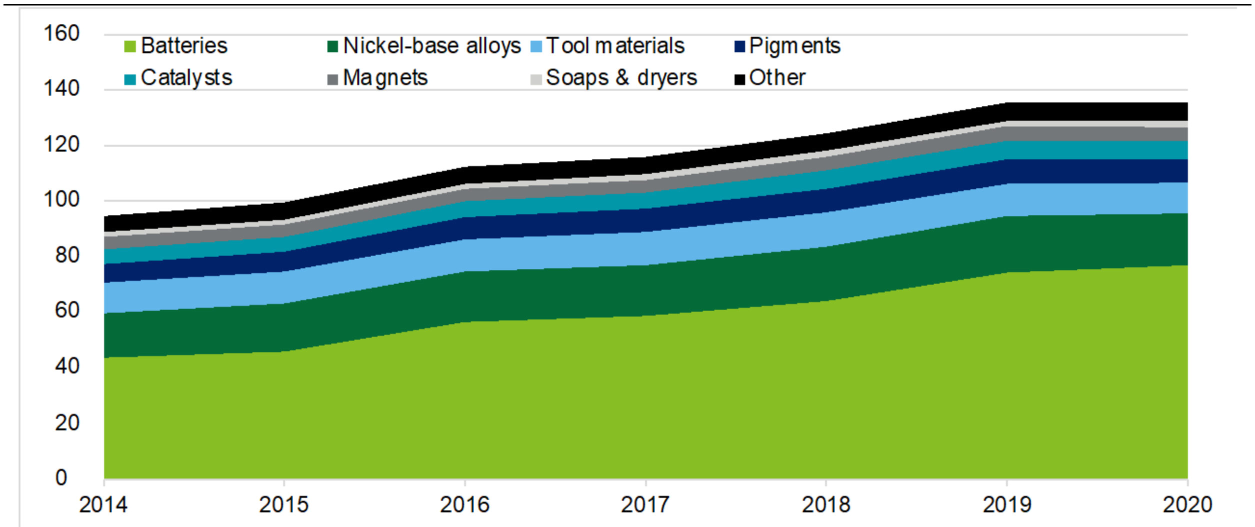
Source: Cobalt Institute, Roskill.

Figure 13 shows the breakdown of the end uses of cobalt by application from 2014 to 2020. Overall cobalt consumption has grown at a CAGR of 6.1 percent with strongest growth coming from the use in lithium-ion batteries with a CAGR of 9.9 percent over this period. Pigments had a CAGR of 4.5 percent, catalysts 3.8 percent and magnets 2.3 percent. Demand for soaps and dryers, and tool materials was flat.

Different industries use different forms of cobalt. Nickel-base alloys, magnets, and tool materials are exclusively reliant on the metallic forms of cobalt such as cathodes and powders. Consequently, there was a sharp drop in demand for cobalt metal in 2020 because of the challenging conditions in the aerospace and industrial sectors.

Lithium-ion batteries, together with catalysts, pigments, and soaps and dryers, consume mainly cobalt chemicals. Demand for chemicals was comparatively more robust in 2020.

Figure 13: Consumption of cobalt, by application, 2014-2020 (kt)



Source: Cobalt Institute, Roskill.

5.1. Cobalt Applications

The following section provides a brief description of cobalt consumption. *Annex 3 – Cobalt Uses* provides more detailed information on cobalt applications.

5.1.1. Cobalt in Lithium-ion Batteries

The first lithium-ion batteries were developed in the mid-1990s, many of which contained formulations of NCM. The major advantage of using nickel in batteries is that it helps to deliver higher energy density and greater storage capacity, and as a result, with the development of EVs, lithium-ion battery cathodes have increasingly shifted more towards NCM formulations.

Cobalt is used in NCM battery cell formulations because it boosts charge rates and has a stabilizing effect. These uses help to extend battery life and prevent cathode corrosion, a characteristic that is important in mitigating the potential for batteries to explode or catch fire.

NCM cell formulations started off with equal proportions of the three metals (NCM111) but because of concerns regarding the cobalt supply chain, and due to the requirement to increase energy density (for improved mileage per charge), battery manufacturers have moved towards higher nickel and lower cobalt formulations. NCM523 and NCM811 (the numbers relate to the ratio of each commodity in the battery) are currently the two most-common formulations of NCM batteries. NCM811 is currently the highest-growth ternary cell chemistry and is expected to dominate market share going forward. The other important cobalt cathode battery is Nickel-Cobalt-Aluminum (NCA).

5.1.2. Cobalt in Nickel-base Alloys

Nickel-base alloys accounted for 14 percent of total cobalt demand in 2020. Demand in this sector was impacted by a sharp fall in demand in the aerospace industry because of the impacts of COVID-19. After a near total shutdown in air travel, most airlines around the world scaled back or cancelled orders.

The suspension of flights significantly diminished the need for aircraft maintenance and thus demand for cobalt in turbine blades. As a result, demand for cobalt fell by seven percent in 2020 following a period of strong growth. While a recovery is now underway, the commercial aerospace sector is expected to recover slowly, as travel demand is not expected to return to pre-COVID-19 levels before 2024[12]. This, coupled with the scaling back of orders, could have longer term impacts on cobalt demand.

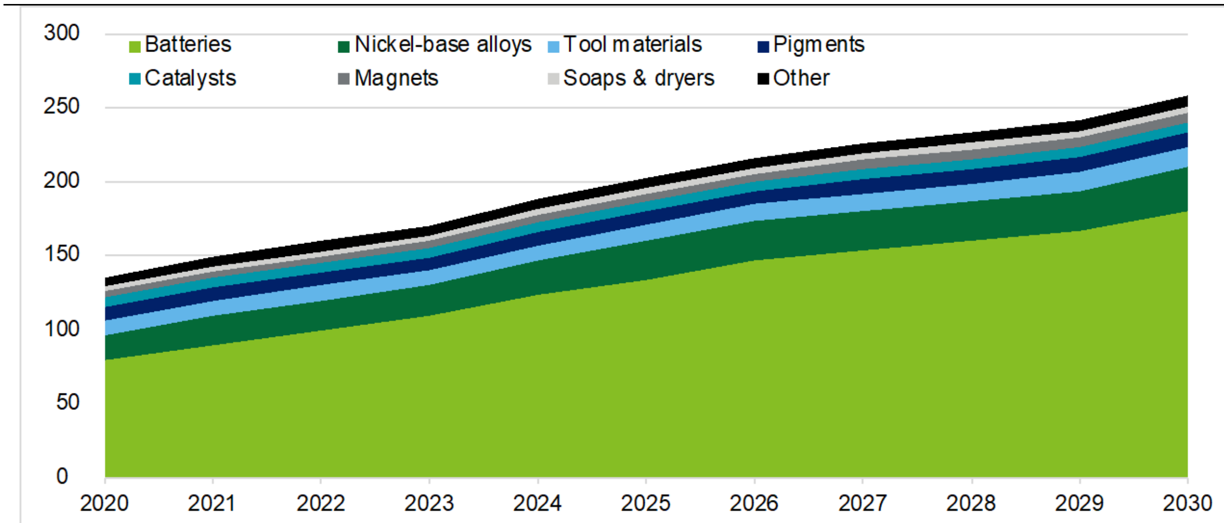
5.1.3. Cobalt in Tool Materials

The third-largest end use market for cobalt is tool materials. Demand for cobalt from this segment fell 6 percent in 2020, owing to a slump in cemented carbide demand caused by the sharp drop-off in global industrial production.

5.2. Cobalt Demand Outlook

Demand for cobalt is expected to increase from 135 kt/y in 2020 to 258 kt/y by 2030, as indicated by Roskill in Figure 14, equivalent to a CAGR of 6.7 percent per annum from 2020 levels. This compares with a CAGR of 6.1 percent from 2014 to 2020. Jinchuan Group forecasts cobalt demand to increase at a CAGR of 9.4 percent out to 2025[13].

Figure 14: Projected Cobalt Consumption by End Use (kt)



Source: Outlook for Selected Critical Minerals, Australia 2021, Roskill 2021

Figure 14 shows that this growth is expected to be largely driven by increased demand from lithium-ion batteries, principally from increased demand for EVs. This is expected to result in cobalt use in lithium-ion batteries increasing at a CAGR of 8.4 percent out to 2030 even though advances in battery composition are expected to lead to lower cobalt requirements per unit[14]. Nickel-base alloys are also expected to grow strongly with a CAGR of 6.1 percent over the period.

[12] International Air Transport Association (IATA)

[13] http://www.jinchuan-intl.com/uploaded_files/investor/813/jci%20roadshow%202021_eng.pdf

[14] Roskill 2021

6. COBALT PRICES AND TRADE

Cobalt is traded in the form of mineral concentrates, intermediate compounds, high-purity metal, and salts and is a relatively small and illiquid market. Cobalt metal trades on the LME, Chicago Mercantile Exchange via pricing from Fastmarkets, and the Shanghai Metals Exchange (SMM).

Historically, the price of cobalt has had periods of extreme volatility, including in 1992, 1994, 2004, 2007 and 2017 spiking to over $60,000/t. Figure 15 shows that cobalt prices traded in a range of $22,000/t to 42,000/t from 2010 to 2016 but surged in 2017 to 2018 due to a strong increase in battery demand for EVs in China, followed by a steep price decline due to increased cobalt production. Similarly, in 2020, strong increases in battery demand for EVs combined with COVID-19 supply disruptions, as well as news that China's State Reserve Bureau (SRB) was planning a new round of cobalt stockpiling, led to a surge in cobalt prices that has continued into 2022.

Figure 15: LME Cobalt Price ($/t) 2010-2022

Source: LME

In 2020, global trade of cobalt ores and concentrates totaled $138 million. The largest importers were China (66 percent), Morocco (19 percent), and Finland (5 percent). The largest exporter was the DRC (89 percent), according to trade data from The Observatory of Economic Complexity (OEC)

Global trade of cobalt oxide and hydroxide totaled $3.53 billion in 2020. The largest importers were China (34 percent), South Africa (21 percent), and Mozambique (14 percent). The largest exporters were the DRC (84 percent) and China (4 percent).

Global trade of cobalt metal totaled $4.96 billion in 2020. The largest importers were China (52 percent), United States (8 percent), and Japan (7 percent). The largest exporters were the DRC (48 percent), Canada (6 percent), and the United States (5 percent).

Brazil's trade in cobalt products is very small. Brazil has imports of $9.1 million of cobalt oxides and hydroxides and has $3.0 million of exports. It also has imports of $25.6 million of cobalt metal and has $1.1 million of exports.

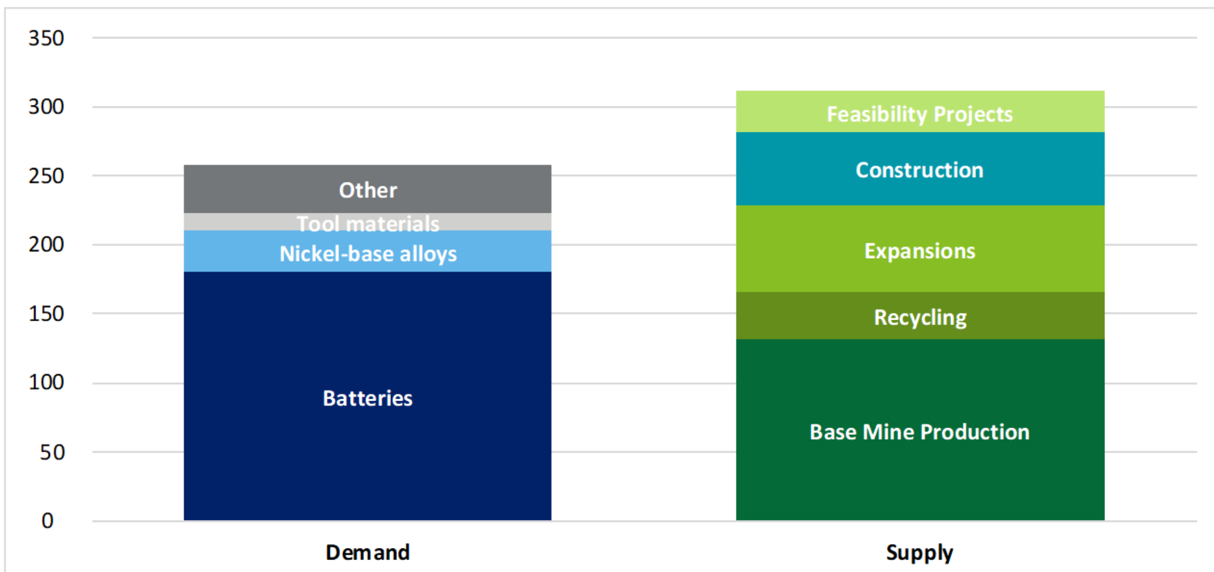
7. MARKET BALANCE AND PRICE OUTLOOK

This section analyzes the possible cobalt market balance given the demand and supply forecasts discussed in the previous sections. It also gives the current consensus price forecast for cobalt.

7.1. Cobalt Market Balance

The Deloitte team's analysis shows that cobalt supply from mine production and recycling could increase to 311 kt/y by 2030, an increase of 169 kt from supply of 142 kt in 2020. This compares with a demand forecast of approximately 258 kt/y from Roskill. This implies a significant potential surplus of 53 kt/y by 2030. Figure 16 shows the make-up of the projected supply and demand numbers.

Figure 16: Supply and Demand Forecast 2030 from 2020 Base (kt)



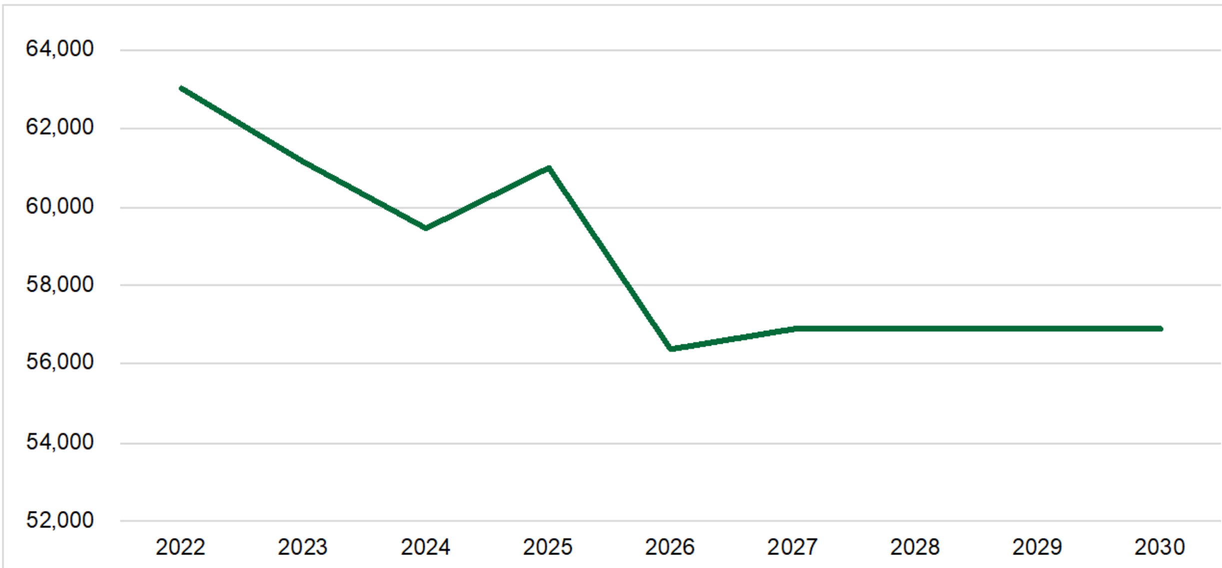
Source: Deloitte, Roskill

As previously stated, although there will likely be delays to some projects and others may not achieve production, it appears that the market is likely to be in deficit by 2030. Furthermore, producers may adjust capacity slowly to this potential surplus because nearly all mine production is produced as a by-product of other metals. Most of the new cobalt capacity coming on stream is from planned copper and nickel project expansions, nickel and copper projects that are new, already under construction, or at late-stage development.

7.2. Price Forecast

While prices are partly a function of supply and demand and inventory levels, costs also impact prices, and nickel and copper operations are currently being impacted by the rising cost of energy, as production of these metals is energy intensive. Higher sulfur costs for sulfur used in nickel-cobalt processing, are also adding to cost pressures.

Figure 17: Consensus Price Forecast for Cobalt (US$/t)



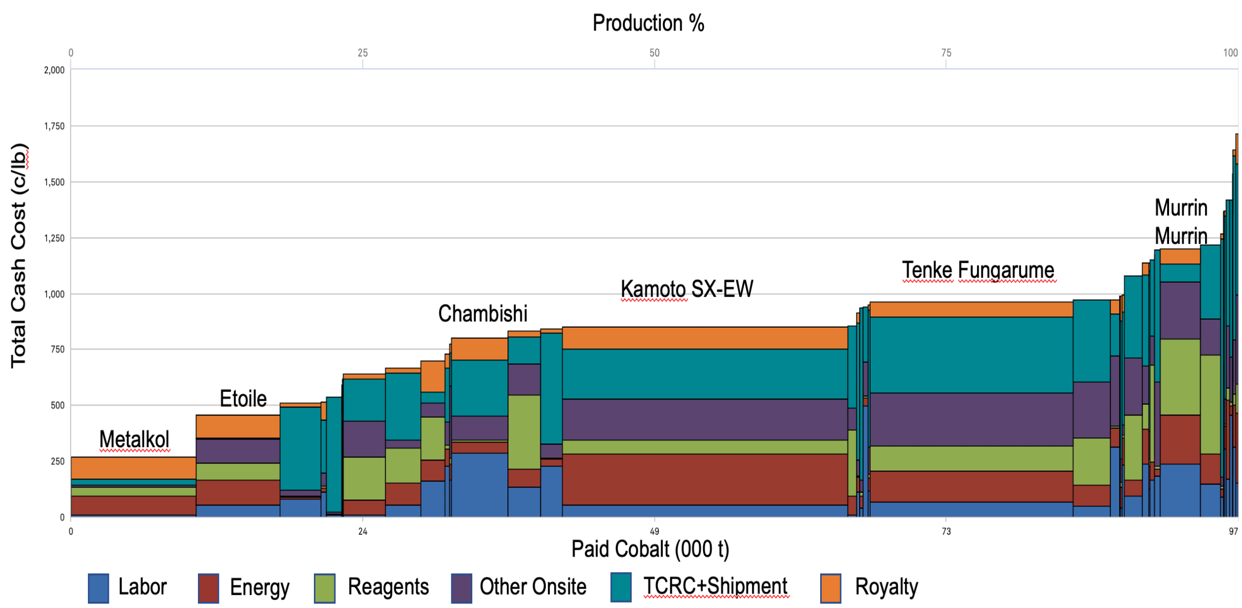
Source: Consensus Economics.

Figure 17 shows the consensus price forecasts for cobalt to 2030 as at January 2022 in nominal terms. The outlook is for prices to decline from the current high levels but still to remain at around $57,000/t which is high compared to historical prices. The cobalt price has averaged $39,400/t since 2010, including the 2017-2018 spike and the current rise in prices.

8. ECONOMIC COMPETITIVENESS

Benchmarking cobalt production is difficult because cobalt is produced principally as a by-product. Figure 18 shows cobalt production ranked on total cash cost. The data from S&P Global Intelligence covers 67 percent of 2021 global recovered cobalt production.

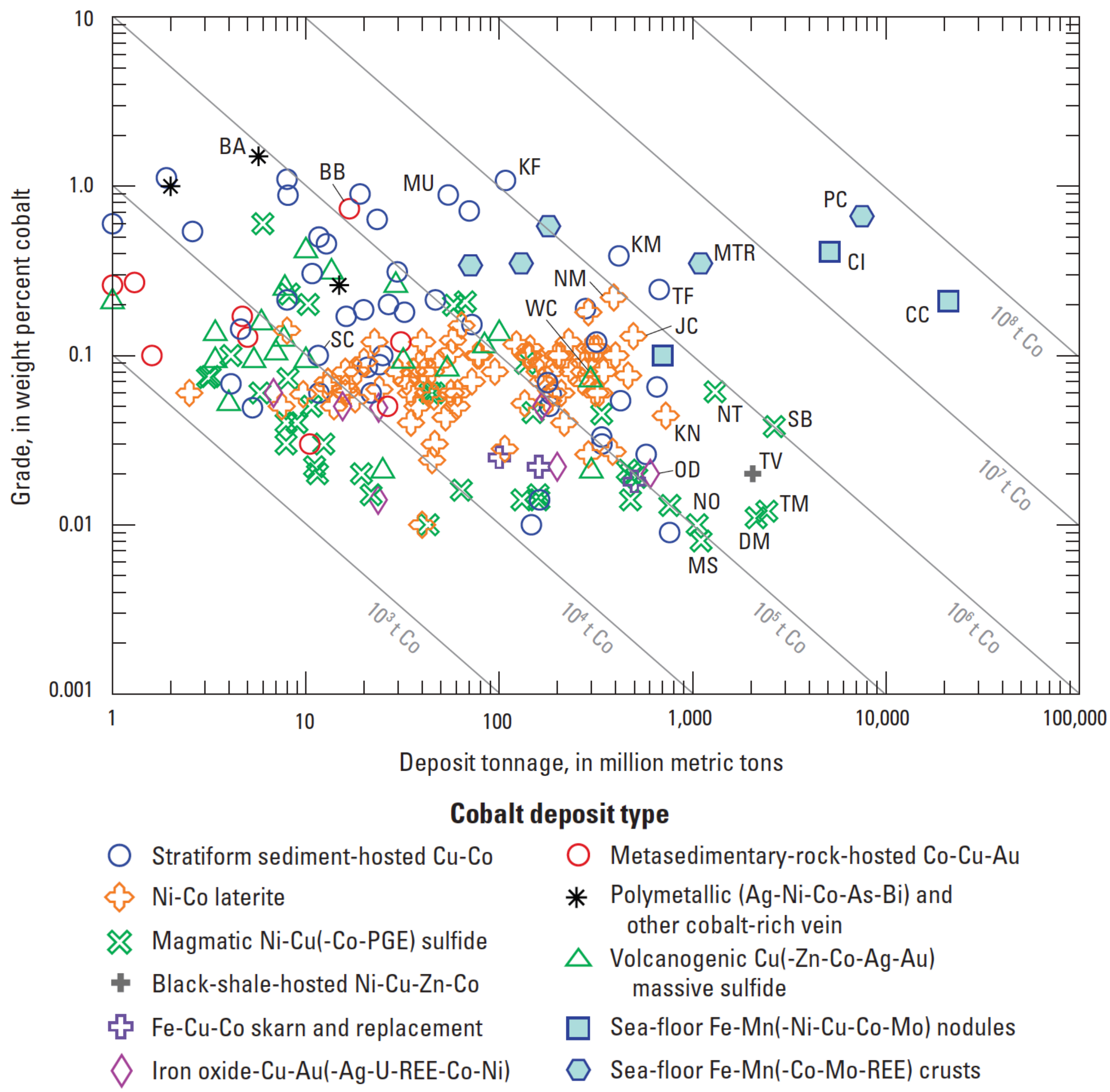
Figure 18: Cobalt Production Ranked on Total Cash Cost $/t in 2020



Source: S&P Global Intelligence.

Figure 19 is a grade tonnage chart that also differentiates between cobalt deposit types that could be used as a preliminary benchmark for potential cobalt projects.

Figure 19: Cobalt Grade Tonnage Chart for Different Deposit Types



Source: USGS – Cobalt 2017

Brazil currently produces no cobalt and data is unavailable for Brazil's one nickel-cobalt exploration project at a relatively advanced stage (Piauí), and the two nickel-cobalt projects at pre-feasibility stage (Vermelho and Jacaré).

9. CONCLUSIONS AND KEY RECOMMENDATIONS

This section provides a summary of the overall market analysis for cobalt, outlines some of the issues surrounding the forecasts, and explains how these issues could impact the outlook for cobalt supply and demand. This section also examines potential threats and opportunities in the market. It summarizes key recommendations for the cobalt industry in Brazil to help the government in their long-term strategic planning and future policy action for cobalt development and commercialization.

9.1. Cobalt Market Issues

The Deloitte team's analysis shows that current and planned new cobalt production has the potential to more than satisfy forecast demand by 2030. Markets normally self-adjust through price mechanisms, but for cobalt this may be more difficult, as producers may be slower to react to cobalt price signals because it is produced as a by-product. Consensus price forecasts are already expecting a fall in cobalt prices over the next four years, albeit to levels in the long-term that are higher than average historical prices.

ESG is an important issue for cobalt consumers given the dominance of production coming from the DRC, which has human rights and child labor issues. While the DRC has been taking steps to resolve these issues, no evidence is yet available that the problems have been eliminated. In addition, some of the new cobalt capacity coming on-stream is from nickel smelters in Indonesia where ESG issues include land clearance and habitat loss resulting from nickel mining, as well as high energy consumption required for nickel smelting. Nickel smelting in Indonesia is based on coal-fired power stations, which have a large carbon footprint. Some Indonesian smelter operators are looking to resolve this in the medium to long term through renewable energy sources. Until the DRC and Indonesia improve their ESG issues however, many battery makers and OEMs may have problems sourcing sufficient cobalt without exposing themselves to significant ESG issues.

Another risk for cobalt demand in the longer term is the continued reduction of cobalt in battery chemistries in favor of higher nickel content, as well as the use of cobalt-free batteries such as lithium-iron-phosphate (LFP) batteries. However, these trends and risks, as they are currently perceived, are taken into account in the demand forecasts to 2030 by Roskill.

Cobalt is usually produced as a by-product of copper and nickel which means that investment decisions for new project development or capacity expansion are not necessarily linked to cobalt market dynamics, but rather more susceptible to the market conditions for copper and nickel. Also, apart from a few exploration companies, there are few equity investment opportunities in cobalt. This makes it more difficult to target cobalt as a stand-alone commodity to finance or be prioritized for increased future production.

Measures to increase cobalt recovery could play an important role in maximizing future production levels, according to the IEA. Cobalt generally has high recovery efficiency, typically of 75 to 90 percent, in addition, cobalt represents an important source of refinery revenue (of approximately 15 percent on average, depending on the copper, nickel, and cobalt prices), creating strong incentives for its recovery, both at existing refineries, and for developing polymetallic deposits[15].

[15] Polymetallic deposits are mineral deposits with several commodities.

9.2. Brazilian Cobalt Opportunities

These ESG risks are potentially an opportunity for Brazil's cobalt projects, with lower carbon footprints and ESG issues. It may be easier for them to find off-take agreements for their cobalt and associated nickel products, potentially at a price premium. However, in Brazil, Piauí is the only advanced stage cobalt project and production is expected to be approximately 0.9 kt/y of cobalt. The other two cobalt projects, Vermelho and Jacaré are at an earlier stage of development but will also not be significant producers of cobalt.

9.3. The Russian War with Ukraine

The Deloitte team drafted this Report following the Russian invasion of Ukraine. Russia is a major producer of cobalt (second largest producer), accounting for 5 percent of global production in 2021, and although sanctions to this market have not yet been raised, they could result in major supply disruptions to the global supply. The war has also created uncertainty about whether automakers will accept cobalt from Norilsk Nickel, which has a deal to supply metal for EVs to German cathode-maker BASF.

9.4. Key Recommendations

The Government of Brazil could look to further develop its resources and encourage investment in the longer term by:

- **Streamlining access to, and circulation of, up-to-date domestic cobalt resource data to domestic and international exploration companies to encourage exploration and to promote cobalt development in Brazil.** This may require gathering and distributing more extensive information for those regions considered to have significant cobalt potential. Legacy CPRM geological data, reports, and studies should be broadly published online and in multiple languages. Brazil should also actively 'market' these documents to expand their circulation, use, and impact.
- **Promoting the ESG advantages of Brazilian cobalt projects to accelerate access to development finance and facilitate regional investment.** Nickel-cobalt projects in Brazil have systemic ESG advantages relative to DRC copper-cobalt and Indonesian nickel-cobalt producers. Access to low-cost, low-emissions hydroelectricity in Brazil gives nickel-cobalt producers a competitive advantage in both operating costs and carbon footprint. This advantage could potentially lead to better mine offtake terms, improved access to ESG-focused sources of development finance, and similarly enabled downstream regional investment in cathode-manufacturing facilities and lithium-ion battery manufacturing.

ANNEX 1 – COBALT ORES AND RESOURCES

Cobalt can be found in economic concentrations in three principal deposit types: stratiform sediment-hosted copper-cobalt deposits; nickel-cobalt laterite deposits; and magmatic nickel-copper-cobalt-PGM sulfide deposits.

Stratiform Sediment-Hosted Copper-Cobalt Deposits

Stratiform sediment-hosted copper-cobalt deposits are the world's second largest source of copper, after porphyry deposits, as well as the most important source of cobalt. They account for 56 percent of currently reported cobalt resources. The deposits typically comprise thin (commonly less than three meters) sulfide-bearing zones more or less consistent with the rock formations in the host sedimentary rocks (siliciclastic or dolomitic). The main copper ore minerals are chalcocite, bornite and chalcopyrite, with carrolite the most important cobalt-bearing mineral.

While sediment-hosted copper deposits are widespread, large deposits are recognized in only three basins worldwide, of which the Neoproterozoic basin of central Africa and the Permian Zechstein basin of northern Europe are most important. Significant quantities of cobalt are known to be present in the Central African Copperbelt, located in the Katanga Province of southern DRC and in north-western Zambia, hosting one of the world's greatest concentrations of copper and cobalt deposits.

Figure 20: Mutanda Copper-Cobalt Mine in the DRC

Source: BGS

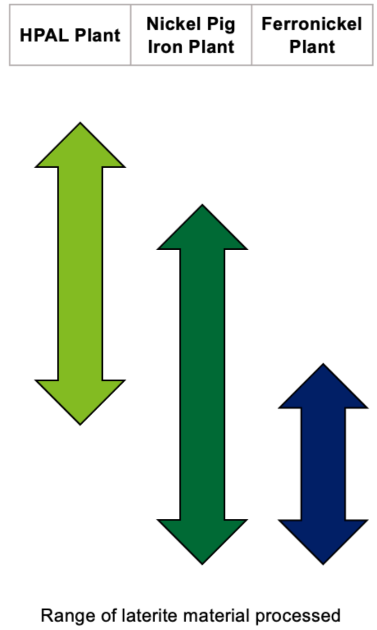
Nickel-Cobalt Laterite Deposits

Laterite orebodies are widespread, and the industry is characterized by the similarity of orebodies around the world. They account for 30 percent of currently reported cobalt resources. Typical nickel laterite ore deposits are very large tonnage, low-grade deposits located close to the surface. Nickel-bearing laterite ores are formed by tropical and sub-tropical weathering of ultramafic rocks and typically have grades of 0.8 to 3.0 percent nickel and may also contain cobalt grades of 0.025 to 0.18 percent. Mineralization is generally hosted in two horizons limonites and saprolites, with the difference being the degree of weathering which results in magnesia and silica levels being much lower and iron levels being much higher in limonites. The key factor in all laterite deposits are the proportions of iron, magnesium, and silica, as they largely determine the optimal nickel processing route.

The majority of nickel laterite deposits are confined to the equatorial belt, dominated by Indonesia, the Philippines, Cuba, and New Caledonia. Laterite resources outside this belt (Australia, Brazil, and Madagascar) are generally much older in geological terms.

Figure 21: Schematic of Nickel-Cobalt Laterite and Processing Methods

Laterite Zone	Nickel	Cobalt	Iron	MgO
Iron cap				
Red Limonite	<0.8%	<0.1%	>50%	<0.5%
Yellow Limonite	0.8 – 1.5%	0.1 – 0.2%	40 - 50%	0.5 – 5.0%
Transition Zone	1.5 – 4.0%	0.02 – 0.1%	25 – 40%	5 – 15%
Saprolite	1.8 – 3.0%	0.02 – 0.1%	10 - 25%	15 – 35%
Bedrock	0.3%	0.01%	5.0%	35 – 45%



Source: Deloitte.

In the nickel processing methods producing ferronickel and nickel pig iron (NPI) (a low-grade ferronickel), cobalt is not recovered separately but intrinsic in the ferronickel that is produced. However, HPAL plants usually recover nickel and cobalt separately.

Magmatic Ni-Cu (-Co-PGE) Sulfide Deposits

Large resources of cobalt are contained in magmatic nickel-copper-cobalt-PGM sulfide deposits. They account for 7 percent of currently reported cobalt resources. This broad class comprises two principal deposit types related to mafic and ultramafic rocks emplaced in a variety of tectonic settings: magmatic sulfide deposits (nickel-copper-cobalt-PGM), and magmatic PGM deposits in layered intrusions.

Copper, cobalt, and PGMs, mainly palladium, are important co- or by-products. In some deposits, gold, silver, chromium, sulfur, selenium, tellurium, and lead are also recovered from the ore. These deposits are formed when mantle-derived magmas become saturated in sulfide and segregate into immiscible sulfide liquid, commonly following interaction with continental crustal rocks.

Chalcophile elements such as nickel, copper, PGMs, and cobalt become relatively enriched in magmatic sulfide phases of these elements. For an economic deposit to form, sulfides precipitated from this liquid must be concentrated into a restricted physical space.

Deep-Sea Manganese Nodules

Manganese nodules contain large amounts of metals and are present over many thousands of square kilometers of the ocean floor. They contain primarily manganese, but also nickel, cobalt, and copper. Although many countries and companies are already intensively investigating their distribution, the mining of these nodules faces technical challenges and environmental issues. There is currently no commercial mining of these nodules.

Occurrences of economic interest are concentrated particularly in the Pacific and Indian Oceans, in the wide deep-sea basins at depths of 200 to 5,000 meters. The individual nodules, about the size of a potato, lie loosely on the sea floor but can sometimes be covered by a thin sediment layer. Theoretically they can be harvested relatively easily from the sea floor.

Manganese nodules occur in many marine regions. They are found in significant abundances in four regions of the ocean:

- Clarion-Clipperton Zone (CCZ) - The CCZ is located in the Pacific, extending from the west coast of Mexico to Hawaii and covers an area of around 9 million square kilometers. It is the largest and most dense area of nodule mineralization.
- Peru Basin - The Peru Basin lies about 3000 kilometers off the Peruvian coast. It is about half as large as the Clarion-Clipperton Zone.
- Penrhyn Basin – The basin is located very near the Cook Islands, a few thousand kilometers east of Australia. It has an area of around 750,000 square kilometers.
- Indian Ocean – An area comparable to that of the Penrhyn Basin has been located in the central Indian Ocean.

The CCZ is the most intensively explored area and has high grades and continuity. The nodules are precipitated on the ocean floor at the seawater interface and grow slowly from metals precipitated from the seawater. Following extensive surveys and sampling, the International Seabed Authority[16] has estimated an inferred resource of 30 billion tonnes of nodules containing 70 Mt of cobalt, 40 Mt of nickel, and 340 Mt of copper. Although the conditions for the formation of manganese nodules are the same in all four of the major regions, their metal contents vary from place to place.

The international Law of the Sea precisely regulates who can mine manganese nodules in the future. If the resources are located within the Exclusive Economic Zone (EEZ) of a country, the so-called 200 nautical mile zone, this country has the sole right to mine them or to award mining licenses to foreign companies. This is the case, for example, in a part of the Penrhyn Basin near the Cook Islands. The CCZ, the Peru Basin, and the Indian Ocean area, however, all lie far outside the Exclusive Economic Zones. Here, mining is centrally regulated by an agency of the United Nations, the International Seabed Authority (ISA). In particular, the ISA ensures that the benefits from future activities related to marine mining are shared equitably.

The potential of these resources is too large to ignore, and in March 2022, The Metals Company (TMC), announced that its subsidiary NORI had signed a non-binding term sheet with its strategic partner and shareholder Allseas, to develop and operate a commercial nodule collection system from the CCZ seafloor. The system has a targeted production capacity of 1.3 Mt/y of wet nodules and expected production readiness by Q4 2024.

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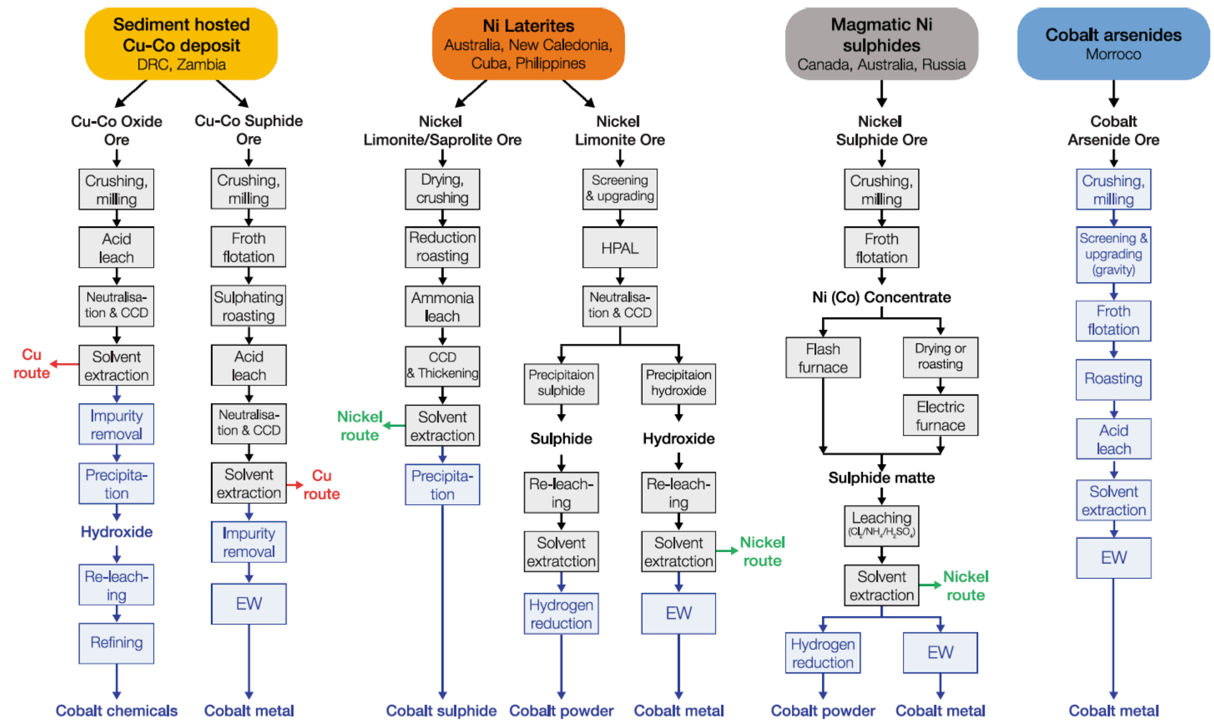
[16] https://www.isa.org.jm

ANNEX 2 –MINING AND PROCESSING OF COBALT ORES

This Annex covers in more detail the different type of mining and processing methods for different cobalt ores. Figure 22 gives a simplified view of the processing routes and products.

Figure 22: Simplified Flow Sheet for Cobalt Mining & Processing



Source: Dehanine Q., et.al. [2021], Geometallurgy of cobalt ores: A review; Minerals Engineering 160, p.106656.

Sulfide Mining and Ore Processing

In general, production of nickel and cobalt from sulfide ores involves either open cut or underground mining, followed by concentration through the process of flotation. Sulfide ores are firstly crushed and ground to liberate nickel minerals and then concentrated by selective flotation, sometimes in conjunction with magnetic separators. A nickel-cobalt concentrate (containing 6 to 20 percent nickel) is then produced. The enriched concentrate also contains iron sulfide, which can act as a fuel in the smelting process and reduce the energy consumption. Flash smelting and pool smelting are the main smelting processes of nickel-cobalt sulfide concentrates and produce a sulfide matte (75 percent nickel) intermediary product. The sulfide matte is then refined to produce cobalt metal and nickel products.

Nickel-Cobalt Laterite Mining and Ore Processing

Lateritic nickel deposits are generally mined from open pits by strip mining, due to the shallow depth of most deposits and their clay-type nature. The overburden is removed and generally deposited in the pit created from earlier mining. Mining is generally low cost as little, or no drilling and blasting is required. Problems can occur with high moisture content (typically 25 to 30 percent) which can cause ores to behave more like a slurry with handling and sediment control can be challenging to prevent impact on surrounding streams and rivers.

There are three principal processing methods for the treatment of laterite nickel ores: HPAL, ferronickel production, and NPI production. The processing method selected depends partly on which part of the laterite profile is to be mined, and the type of nickel product that is to be produced, depending on which part of the market it is destined (see Figure 21). Generally, the energy consumption for laterite production is significantly higher than that for sulfide smelting. One advantage of HPAL over a ferronickel or NPI plant is that cobalt can be recovered and can be an important by-product in the economics.

High Pressure Acid Leaching (HPAL)

HPAL plants typically treat low-grade limonite ores, usually with a head-grade of greater than 1.0 percent nickel. Historically, the Caron process was used but this process is no longer viewed as economic. The core process of all HPAL plants is generally the same, and is a hydrometallurgical process[17], while the back end of plants may vary depending on what products are recovered.

Limonite slurry is fed into an autoclave with sulfuric acid at an average temperature of 255°C and pressure of 4,500 kPa (45 bar, 653 psi) and nickel and cobalt are leached (selectively dissolved). The autoclaves are titanium lined to make them acid resistant. Sulfuric acid consumes the magnesium and aluminium, forming solid products, and sulfuric acid is a major operating cost. The high magnesium content of saprolite ores is the reason why they are not treated by HPAL. Laterite ores with a magnesium grade above 5 percent are generally not treated. Nickel and cobalt in the form of oxides dissolve and remain in the aqueous phase as sulfates.

Depending on the backend of the processing, a combination of MSP, MHP, nickel oxide, and nickel carbonate can be produced. The MSP and the MHP are sent to a refinery to produce pure metal or produce chemical nickel sulphate. MSP tends to have a higher-grade nickel content (56 to 58 percent) than MHP (33 to 40 percent), however the capital cost of producing MSP is higher than MHP but the operating costs are lower.

The refining of MSP and MHP takes place through the processing route of leaching and hydrogen reduction to produce refined metal. Nickel and cobalt briquettes and coarse powders are produced, and ammonium sulphate is a common by-product used as a fertilizer. HPAL plants are currently in operation in Australia, Philippines, New Caledonia, Papua New Guinea, Cuba, and Turkey.

Heap Leaching

Heap leaching is well established process used for the treatment of copper and gold and is now being used in varying degrees for nickel-cobalt laterites. The heap leach process has the potential to be the lowest capital cost and most environmentally friendly of the processes to recover nickel and cobalt from laterite ores. However, while there have been a number of pilot projects, there have been only a few fully commercial operations. This is because the heap leaching of nickel-cobalt oxides is not always straightforward and can be resistant to leaching. Heap leaching nickel-cobalt oxides produces a low (less than 50 percent) recovery, it can result in high acid consumption due to the iron content, and the fine clay morphology of the material means that acid penetration can be low.

The heap leaching of nickel-cobalt laterites is under investigation with several pilot projects underway but is not yet commercialized. Brazilian Nickel is planning to use heap leaching at the Piauí project in Brazil. The company has successfully completed large scale demonstration of the heap leaching, purification and recovery of nickel and cobalt from the Piauí ore.

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[17] Hydrometallurgy involves the use of aqueous solutions for the recovery of metals.

Three commercial height heaps have been operated, with target nickel extractions of greater than 80 percent achieved with low consumption of acid. The downstream impurity removal precipitation circuit was continuously operated for nine months. Nickel and cobalt hydroxide products were produced exported and sold.

Brazilian Nickel has begun the final phase of a bankable feasibility study (BFS) on the project. Current internal company estimates indicate that the project is expected to have a Capital Expenditure (CAPEX) requirement of $465 million for 25 kt/t of contained nickel and 900 t/y of contained cobalt, with production targeted for the end of 2024. Operating costs after refining charges and cobalt credits are expected to be less than $6,173/t of nickel.

Refining

Refined cobalt products are traded in various forms including metal and cobalt salts, oxides, and carboxylates. Cobalt metal is available in powders, granules, briquettes, cathodes, rounds, pellets, and ingots. Cobalt salts include a large range of products, such as chlorides, sulfates, nitrates, carbonates, acetates and many more. Cobalt oxides and hydroxides are produced alongside cobalt salts in chemical refineries.

The cobalt salts are derived from a variety of refining steps. For example, cobalt cathode is produced by electrowinning, but practical issues associated with solution purification requirements and plating of cobalt onto the stainless-steel cathode blanks have led to the development of alternative production methods. Cobalt rounds are an alternative to cobalt cathodes where cobalt is deposited by electrowinning on the exposed round area of stainless-steel disks and is easily stripped. Other products, such as cobalt metal in the form of briquettes and powders, are produced by hydrogen reduction in an autoclave. Cobalt sulfate is produced via steps of evaporation and crystallization; cobalt sulfide can be precipitated using sodium hydrosulfide (NaHS) or hydrogen sulfide (H2S); and cobalt hydroxide is produced through precipitation with magnesia and lime.

Factors such as the deposit type, market, supply chain, and availability of processing and refining capacity dictate the refined cobalt products made. For example, nickel-cobalt concentrate from the Glencore-owned mines in Canada is processed in the nearby Sudbury smelter, which produces a nickel-cobalt matte. This matte is refined into pure metal in Norway, in the Glencore-owned Nikkelverk refinery. Most of the African copper-cobalt sulfide concentrate is processed domestically to produce an impure cobalt hydroxide. This is then shipped to China's chemical refineries, where a range of cobalt salts including cobalt oxide and hydroxide are produced for use in multiple applications[18].

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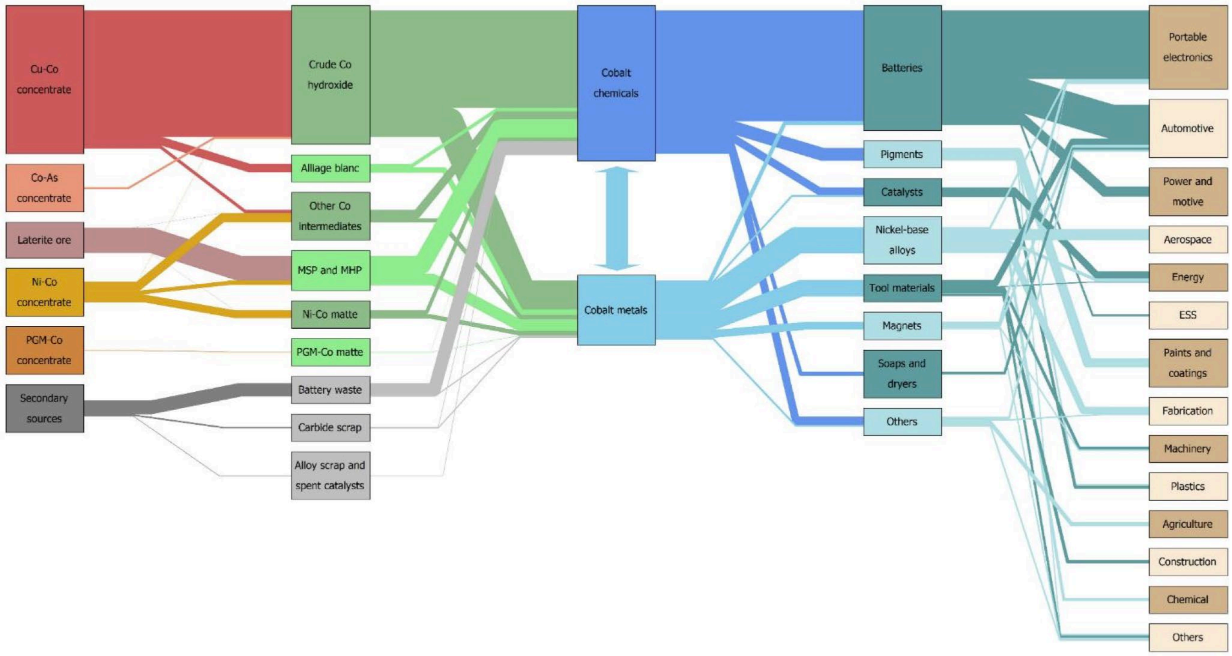
[18] BGS – Cobalt Commodity Review

ANNEX 3 – COBALT USES

Annex 3 provides greater detail on the different uses for cobalt. Figure 23 shows the flow of cobalt material from mine to end product use. Cobalt consumption can be divided into two main groups: metallurgical applications; and chemical applications.

Figure 23: Cobalt Market Flowchart 2020



Source: Cobalt Institute

Metallurgical Applications

Cobalt metal is required to produce superalloys, hardfacing alloys and high-speed steels, magnet alloys, hard materials, and special alloys.

Superalloys

Superalloys are alloys that have been developed specifically for high-temperature service, where a combination of high strength and resistance to surface degradation is required. Superalloys are employed in several critical applications such as jet engines, gas turbines, space vehicles, rockets, nuclear reactors, and power plants. Cobalt is used as the matrix or as an alloying element in superalloys because of the high melting point and superior corrosion resistance at high temperatures.

Three alloy types can be distinguished under the definition of superalloys: cobalt, nickel, or iron-based alloys. Cobalt is mainly present in cobalt-based and nickel-based alloys, which account for 6 and 80 percent respectively of the superalloy production. Cobalt-based wrought alloys contain around 30 percent of cobalt, and cobalt-based casting alloys may contain up to 65 percent cobalt. Cobalt-based superalloys provide higher melting points than nickel (or iron) alloys, superior hot corrosion resistance to gas turbine atmospheres, and excellent thermal fatigue resistance and weldability over nickel superalloys. However, as the rupture strength of cobalt-based superalloys is lower at the interval of 815 to 1,100 degrees centigrade temperatures than nickel-based alloys, they tend to be used for static (non-rotating) applications.

A high proportion of nickel-base superalloys, which have the majority share of the market, contain cobalt up to 20 percent by weight. Cobalt is not normally present in iron-based superalloys[19].

Hardfacing Alloys, High-Speed Steels, and Hard Materials

The term 'hardfacing' refers to hard alloys' deposition by a welding process on a base of softer metal to protect it from wear. Cobalt-based hardfacing alloys are selected for their excellent resistance to the broadest combination of wear types. Hardfacing alloys mainly contain cobalt, chromium, molybdenum, and nickel in various compositions. The most frequently used hardfacing cobalt alloys typically contain 40 to 60 percent cobalt.

Cobalt is also an alloying element of high-speed steels (HSS) for the manufacture of cutting tools when high strength at elevated temperature is required. Cobalt is used in both traditional tool grades as well as in powder metallurgy grades at typical compositions ranging from 8 to 13 percent cobalt.

The category 'hard materials' includes cemented carbide materials and diamond tools. Cobalt powder is employed as the binding material in the manufacture of cemented carbides to increase resistance to wear, hardness and toughness, essential qualities for cutting tools and wear-resistant components used by the metalworking, mining, oil drilling, and construction industries. The carbide is mainly produced from tungsten. Like cemented carbides, cobalt is also used together with synthetic diamond in the manufacture of diamond tools such as grinding wheels and diamond saws, as the matrix that binds the wear-resistant particles together.

Magnet Alloys

Cobalt is ferromagnetic and so is used as an alloying metal in magnetic alloys for permanent magnets used in electrical equipment. Cobalt has the highest known Curie point (the temperature at which magnetic properties are lost) than any other metal at 1,121 degrees centigrade. Cobalt is used either in the high-strength samarium-cobalt permanent magnets for electric motors or the lower-powered aluminum-nickel-cobalt magnets. Magnets containing cobalt are used in electric motors, generators, magnetic resonance imaging (MRI), microphones, loudspeakers, sensors, computer hard disk drives and many other applications. Furthermore, cobalt-bearing coatings may be applied to neodymium-iron-boron magnets for improved thermal stability and corrosion resistance.

Chemical Applications

In chemical applications, cobalt is used in the manufacture of various chemical compounds for a wide range of end-uses.

Batteries

In the mid-1990s, the first lithium-ion batteries were developed, many of which contained formulations of NCM. The major advantage of using nickel in batteries is that it helps deliver higher energy density and greater storage capacity. In conventional battery designs, cobalt boosts charge rates and has a stabilizing effect which helps to extend battery life and prevent cathode corrosion. These characteristics are important in mitigating the potential for batteries to explode or catch fire. In 2020, lithium-ion batteries accounted for 57 percent of global refined cobalt consumption[20].

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[19] Cobalt Institute.
[20] Cobalt Institute.

As a result, with the development of EVs, lithium-ion battery cathodes have increasingly shifted more towards NCM formulations. NCM cell formulations started off with equal proportions of the three metals (NCM111) but because of concerns regarding the cobalt supply chain and to increase the energy density (for improved mileage per charge), battery manufacturers have moved towards higher nickel and lower cobalt formulations. NCM523 and NCM811 are currently the two most-common formulations of NCM batteries. NCM811 is currently the highest-growth ternary cell chemistry and is expected to dominate market share going forward. Table 8 shows the cobalt content of the different types of lithium-ion batteries.

Table 9: Metal Content of Different Battery Cathodes kg/kWh

Metal	NMC111	NMC622	NMC811	NCA5	LFP
Nickel	0.333	0.525	0.653	0.725	0.000
Cobalt	0.333	0.176	0.082	0.065	0.000
Lithium	0.120	0.104	0.096	0.095	0.084
Manganese	0.312	0.164	0.076	0.000	0.000
Aluminium	0.000	0.000	0.000	0.011	0.000
Iron	0.000	0.000	0.000	0.000	0.674
Phosphate	0.000	0.000	0.000	0.000	0.374

Source: Fraunhofer ISI & Fraunhofer IZM 2021 for German Mineral Resources Agency (DERA) 2021.

Catalysts

Cobalt is multivalent and so enhances a catalytic action; therefore, cobalt salts are used as precursors for industrial catalysts in the petrochemical and plastic industries. In particular, cobalt oxides are used in desulfurization reactions in oil refining, in combination with molybdenum trioxide and aluminum oxide, which represents the highest tonnage of cobalt used in catalyst applications. Catalysts containing cobalt are also used in the production of synthetic diesel from natural gas.

Cobalt acetate is mixed with manganese bromide to be used as a catalyst in the synthesis of organic compounds, such as terepthalic acid (TPA) and di-methylterephthalate (DMT), which are precursors for the manufacture of PET. Cobalt is also used in hydroformylation reactions for the synthesis of alcohols for detergents, and aldehydes for the manufacture of plastics. Cobalt compounds used in catalysts are cobalt metal, cobalt oxide, cobalt acetate, cobalt sulphate, cobalt chloride, cobalt hydroxide, cobalt carboxylates.

Pigments and Adhesives

One of the earliest known uses for cobalt is in pigments to produce an intense blue color in glass, porcelain, ceramics, paints, inks, and enamels. A variety of cobalt compounds, including cobalt oxides and other complex forms, can be used as colorants for a variety of blue-based tints. Cobalt can also be used as a decolorizer to suppress yellowish tint glass that originates from iron contamination.

Cobalt carboxylates are used in the production of adhesives that promote the bonding of the rubber to the steel bracing in steel-belted radial tires. Cobalt carboxylates are also the principal cobalt compound used by the paint and ink industry to accelerate drying in inks, varnishes, and oil-based paints.

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