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GOVERNMENT OF BRAZIL MINING SECTOR TECHNICAL SUPPORT AND COOPERATION

Copper – Market Analysis and Competitiveness Report

Prepared for:
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DISCLAIMER

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Acronyms

BGS	British Geological Society
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
IRR	Internal Rate of Return
LME	London Metal Exchange
LOM	Life of Mine
MME	Ministry of Mines and Energy
NPV	Net Present Value
PNM	National Plan for the Brazilian Mineral Sector
PV	Photovoltaic
SDS	Sustainable Development Scenario
SX-EW	Solvent Extraction Electrowinning
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. This will assist Brazil 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 the growing market and accelerating demand for critical minerals, which are essential to the development of innovative technologies to advance the global clean energy transition (electric vehicles [EVs]), batteries, and battery storage systems, etc.); and
- Streamline the structure of Brazil's nickel-cobalt data inventory, so the country 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 on 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 to inform its long-term strategic planning for mineral commercialization 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 (PNM 2050) and future policy actions for the Government of Brazil. This report focuses on copper.

Key Findings

- **Brazil's copper reserves[1] and resources[2] are relatively small, and the country is not a major copper producer.** Global growth in copper mine supply in recent years has primarily come from South America. Chile is currently the largest producer, accounting for 27 percent of global production in 2021, followed by Peru (11 percent), China (nine percent), the Democratic Republic of Congo (DRC) (nine percent), and the United States (six percent). Brazil has 0.6 percent of global copper reserves and resources, and produces 1.6 percent of the world's mined copper[3] and 0.7 percent of global refined copper.[4] Brazil has eight operating copper mines (Salobo, Sossego, Chapada, MCSA Mining Complex, Pedra Branca, Antas, Celestra, and Serrote – see Table 6), which produced approximately 350 thousand tonnes (kt) of copper in 2021.

[1] The amount of copper that could be economically extracted or produced at the time of determination, defined by a high level of exploration.

[2] The amount of copper that could potentially be economically extracted based on geological evidence but has a lower level of mineral exploration.

[3] U.S. Geological Survey (USGS) 2021.

[4] British Geological Survey 2019 (BGS)

Production is dominated by two mines, Salobo (145 kt/y) and Sossogo (82 kt/y), accounting for 65 percent of Brazil's 2021 production. The other mines are considered to be mid-to-small-scale. Brazil also has one active copper project at late-stage development (Boa Esperanza), and one project at prefeasibility stage (Alemao), although both are relatively small copper projects, compared with other global projects. Brazil does not have currently-identified large-scale copper resources (at least 100 kt/y potential – see Figure 7) that could be developed to support a new world class copper mine.

- **The copper market is forecast to be in deficit in 2030 (excluding the impacts of Russia's invasion of Ukraine).** The Deloitte team's analysis of the supply and demand outlook shows that new copper mine production and increases in scrap supply are unlikely to meet increases in refined copper demand from 2030. Supply in 2030 is forecast at 31.5 million tonnes (Mt) and demand is forecast at 34.1 Mt, suggesting a supply deficit of 2.6 Mt. This further suggests that more investment is required in greenfield and brownfield production, which will in turn likely require high copper prices (relative to history). Consensus currently expects copper prices to remain in a long-term range of $8,400/t to $8,900/t ($3.80/lb to 4.00/lb), compared with an average of $6,704/t ($3.04/lb) from 2010 to 2020. The industry currently faces cost pressures, particularly from higher energy prices, but at these price levels the copper industry would still be expected to make above average returns. The copper market could also be affected by the potential for continued restrictions on Russian exports, as a result of that country's invasion of Ukraine. Russia is the eighth largest producer of copper, accounting for 4 percent of global production in 2021.
- **The decarbonization of energy will play an important role in the future demand for copper.** Copper plays a central role in the ongoing decarbonization movement within energy markets. Copper enables renewable energy generation technologies, the implementation of EV battery technologies, and the construction of/interconnection with grid infrastructure. Geographically, China is likely to continue to be a major driver of global copper consumption, given that China's demand accounted for 59 percent of global copper consumption in 2021.
- **Brazil is mainly an exporter of copper concentrate and importer of refined copper.** In 2020, Brazil exported $2.4 billion (3.9 percent of global trade) of copper concentrate and imported $1.25 billion (1.8 percent) of refined copper. Comparatively, it exported $126 million (0.2 percent) of refined copper and imported $480 million (0.8 percent) of copper concentrate. If Brazil further develops its downstream manufacturing capabilities for items such as renewable energy equipment and auto batteries, it may prove necessary to import additional refined copper or expand existing smelting and refining facilities to process more of its domestic copper concentrate to cathode copper.

Key Recommendations

The Government of Brazil should continue to further develop its resources to meet global demand and encourage investment in the longer term by:

- **Streamlining access to, and circulation of, up-to-date domestic copper resource data to domestic and international exploration companies to encourage exploration and to promote copper development in Brazil.** This may require gathering and distributing more extensive information for those regions considered to have significant copper potential, including the Carajás district in the state of Pará. 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.

- **Ensuring copper producers (currently 15 mines and projects) utilize Brazil's low-cost and low-emissions hydroelectric power or other renewables.** In 2020, 66 percent of Brazil's electricity generation came from hydropower, although most of the capacity is located in the north. Brazil has abundant wind resources, and wind capacity is increasing in the south, and solar is increasing rapidly from a low base. Access to low-cost and low-emissions hydroelectricity or other renewables in Brazil would give copper producers a competitive advantage in their operating costs and carbon footprint. The copper market is increasingly focused on the carbon footprint of copper producers.
- **Ensuring Brazilian copper projects achieve timely production by 2030 to capture potential higher returns of the forecast market deficit in 2030.** The Deloitte team anticipates that two development projects (Boa Esperanza and Alemao) could come into production by 2030. If this is the case, these projects will likely benefit from the forecast copper market deficit and higher prices noted above that are expected to occur by that date. These projects have already applied and received acceptance for assistance under the *Policy for Supporting the Environmental Licensing of Investment Projects for the Production of Strategic Minerals* (Decree No. 10,657 of March 24, 2021).[5] The Government of Brazil has already selected Boa Esperanza and Alemao, plus the early-stage Pantera exploration project owned by Avanco Resources[6], and a dozen other mining projects to receive accelerated environmental licensing support.
- **Developing downstream processing facilities to capture more of the copper value chain domestically.** A portion of Brazil's copper concentrate production could be refocused from direct exports towards the downstream development of facilities to produce more domestically refined copper. Proactive marketing by the Government of Brazil with existing global mining, smelting, and refining companies (including Vale S.A.) could then lead to the development of further copper cathode facilities in Brazil. Preferred access to clean hydropower has the potential to make such facilities, and the cathode copper they produce, particularly attractive to end users in the renewables industry.

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[5] The Pro-Strategic Minerals Policy has been qualified under the Investment Partnerships Program (PPI), which is a government entity dedicated to expanding and accelerating the implementation of projects with the participation of the private sector in Brazil. Accordingly, if it meets specific criteria, the company that has a project of a mineral deemed strategic, may request that their project be qualified as a PPI project.

[6] https://www.gov.br/mme/pt-br/assuntos/secretarias/geologia-mineracao-e-transformacao-mineral/ctapme

1. INTRODUCTION

1.1. Purpose of this Report

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

2.1. Organization of this Report

This Report is organized into 11 main sections and three annexes:

- **Section 1: Introduction** – Presents the purpose of this Report, background and context on copper, and a summary of market trends and outlook for copper.
- **Section 2: Copper Characteristics** – Provides background information on copper's physical characteristics and applications.
- **Section 3: Copper Resources** – Provides information on global copper resources and reserves.
- **Section 4: Copper Supply** – Gives an overview of the global production of copper ores and copper products and recent supply trends.
- **Section 5: Copper Demand** – Explains global copper demand trends based on end-user markets.
- **Section 6: Copper Trade and Prices** – Provides information on the main features of global copper trade and presents historical pricing data.
- **Section 7: Copper for Copper Demand** – Outlines expectations for future changes in global copper demand.
- **Section 8: Outlook for Copper Supply** – Presents how the global copper supply should increase to meet rising demand and consumption trends. This section also examines potential production increases from existing producers and mining projects that could potentially come on stream by 2030.
- **Section 9: Market Balance and Price Outlook** – Examines whether there is sufficient copper supply to match scenarios for future copper demand by 2030 and provides insights on price forecasts for trade in the future.
- **Section 10: Economic Competitiveness** – Summarizes production and cost information of existing mines and 33 copper mining projects to benchmark and assess the economic competitiveness of the sector and other mines and exploration projects in Brazil.
- **Section 11: Conclusions** – Summarizes the Deloitte team's analysis of the copper market.
- **Annex 1** – Provides a description of copper ores and resources.
- **Annex 2** – Provides a description of mining and processing of copper ores.
- **Annex 3** – Provides a list of copper projects.

1.2. Background and Context

Brazil has some of the largest and most diverse mineral deposits in the world and is a market leader in the extraction and processing of core commodities such as iron ore, gold, copper, and bauxite. Brazil, however, remains a relatively small producer of copper, accounting for 1.6 percent of global production and 0.6 percent of global copper reserves and resources.

Brazil has eight producing copper mines, although production is dominated by two mines, Salobo (producing 145 kt/y) and Sossogo (82 kt/y). These two operations accounted for 65 percent of Brazil's copper production in 2021. The other six mines are considered to be mid-to-small-scale. Two additional copper projects expected to come onstream in the period up to 2030 − Bao Esperanza (27 kt/y) and Alemao (60 kt/y) − are also small-to-mid sized operations. The scale of Brazil's copper production is partly a product of the local dominance of iron ore copper gold (IOCG) resources, which tend to be smaller in scale than the porphyry copper deposits that are found in abundance elsewhere in South America and in other regions globally.

The Deloitte team drafted this Report following the Russian invasion of Ukraine. Russia accounted for four percent of global production in 2021. The scale and scope of possible sanctions against this output are not yet fully clear, but the threat of such action nonetheless has the potential to create additional market insecurity and supply disruptions.[7]

1.3. Summary of Market Trends and Outlook for Copper

1.3.1. Copper Resources

Chile holds approximately 34 percent of global copper reserves and resources as reported by S&P Global Intelligence. The United States (11 percent), Peru (eight percent), and Australia (six percent) also hold significant reserves and resources. Brazil holds 0.6 percent. Copper is extracted from a number of mineral deposit types, with the most significant being porphyry copper deposits, which account for 69 percent of reserves and resources. Sediment hosted deposits (eight percent), and IOCG deposits (six percent) are the next most important. Porphyry copper deposits are large-tonnage, low-grade deposits that are typically mined in large open pits. Large porphyry copper deposits are mined in the Andes of South America, the Rocky Mountains in the Unites States and Canada, the Philippine archipelago, Indonesia, and Papua New Guinea.

1.3.2. Copper Supply and Demand

The U.S. Geological Survey (USGS) estimates that global production of mined copper totaled 21.0 Mt in 2021. Chile is currently the largest producer accounting for 27 percent of production in 2021, followed by Peru (11 percent), China (nine percent), DRC (nine percent), and the United States (six percent); Brazil accounted for 1.6 percent. Globally, production is split approximately 80 percent to producers of copper concentrate and 20 percent to copper producers using Solvent Extraction Electrowinning (SX-EW) extraction methods[8].

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[7] In developing this Report, the Deloitte team extracted data from publicly available sources including: (i) company reports (ii) industry sources such as Wood Mackenzie (iii) government and other public institutions, including the USGS, British Geological Survey (BGS), International Copper Study Group (ICSG), Copper Development Association (CDA), and International Wrought Copper Council (IWCC), and the European Union (EU); and (iv) industry conferences and webinars.

[8] SX-EW = Solvent extraction-electrowinning - SX-EW technology involves the leaching (the process of dissolving ore minerals with a solution) in atmospheric conditions of copper oxide ore heaped on pads by means of diluted sulphuric acid. Copper cathode is then produced from the recovered solution.

The copper industry is relatively competitive, with a large number of companies operating mines in a wide range of countries around the world. Brazil currently has eight operating copper mines (Salobo, Sossego, Chapada, MCSA Mining Complex, Pedra Branca, Antas, Santa Rica, and Serrote – see Table 6), which produced over 349 kt of copper in 2021. Production is dominated by two mines, Salobo (producing 145 kt/y) and Sossogo (82 kt/y), accounting for 65 percent of Brazil's production in 2021. The other mines are considered to be mid- to small-scale.

Refined copper supply includes copper produced from mining as well as secondary, or scrap copper. The copper concentrates produced from mining need to be smelted[9] to produce blister or anode copper and then refined[10] to produce cathode copper. These processes also use copper scrap as feed. The final refined copper cathode (and the cathode copper produced from SX-EW operations) is the final product consumed by manufacturing industries and other consumers.

Refined copper consumption totaled 24.7 Mt in 2020 and was dominated by China, which accounted for 14.5 Mt, equivalent to 59 percent of demand. The next largest consumers were the United States (seven percent), Germany (four percent), and Japan (four percent). Copper is used widely in a broad range of industries due to its high electrical and thermal conductivity, ductility, and corrosion resistance. Key copper-consuming industries include construction, electrical and electronic equipment manufacturing, the power industry, transport, mechanical engineering, and various equipment and consumer goods production. Copper is an essential element for almost all electricity-related technologies, and over 60 percent of refined copper is used in electrical conductors, including various types of cable and wire.

1.3.3. Copper Trade and Prices

Copper metal is an exchange-traded commodity that is traded in futures and options contracts and products across the international value chain. Major copper product categories traded internationally include copper concentrates, blister and anode, cathode and ingots, scrap, and copper semis (semi-fabricated products).

The copper price hit a recent low of $4,625/t ($2.10/lb) in March 2020. Since that time, it steadily increased until reaching $10,702/t ($4.85/lb) in March 2022, followed by a modest decline. This decline reflected concerns about a resurgence of coronavirus cases in China curbing activity in the domestic economy, as well as the foreshadowing influence of rising U.S. interest rates.

1.3.4. Market Outlook

The Deloitte team's analysis shows that refined copper demand is forecast to increase from 24.7 Mt in 2020 to 34.1 Mt in 2030, an increase of 9.3 Mt and a compound annual growth rate (CAGR) of 3.2 percent. In general, demand for copper reflects the rate of underlying world economic growth, particularly in industrial production and construction. Such growth, particularly from emerging markets and China, will continue to be a major determinant of overall global copper consumption. In addition, an area of significant demand growth for copper over the next decade will be the decarbonization of power markets and the ongoing energy transition. Copper will play a central role in this transition by enabling renewable energy generation technologies, the implementation of EV battery technologies, and the development and interconnection of grid infrastructure. Renewable power generation sources and cleaner transportation vehicles are more copper intensive than conventional counterparts. While these trends suggest continuing and positive increases in copper demand, the actual rate of renewable energy uptake, and EV adoption, remains uncertain, as is the potential for substitution, principally by aluminum.

[9] Smelting - extracting metals from an ore by a process involving heating and melting.

[10] Refining - removing impurities or unwanted elements from a substance (metal).

Reflecting anticipated demand, new mine supply from brownfield and greenfield copper projects, and from increased copper scrap recycling, is expected to increase refined copper supply out to 2030. The copper mining industry, however, faces a range of challenges over the next decade including grade decline and the depletion of reserves, climate change impacts, environmental, social and governance (ESG) pressures, and political and regulatory issues. These challenges increase the risk of delays, or of projects failing to achieve full production.

The Deloitte team's analysis of the supply and demand outlook shows that new copper mine production and increases in scrap supply are unlikely to meet increases in refined copper demand from 2030. Supply in 2030 is forecast at 31.5 million tonnes (Mt) and demand is forecast at 34.1 Mt, suggesting a supply deficit of 2.6 Mt. This further suggests that more investment is required in greenfield and brownfield production, which will in turn likely require high copper prices (relative to history). Consensus currently expects copper prices to remain in a long-term range of $8,400/t to $8,900/t ($3.80/lb to 4.00/lb), compared with an average of $6,704/t ($3.04/lb) from 2010 to 2020.

1.3.5. Economic Competitiveness

The Deloitte team has evaluated data from 33 recent copper feasibility, pre-feasibility, and scoping studies (such reports are typically created as part of the project development process) This analysis has, in turn, enabled the Deloitte team to benchmark a select number of current and proposed Brazilian projects against global competitors.

Brazil does not currently have large-scale copper resources that could be developed to support a significant scale copper mine (at least 100 kt/y – see Figure 7) before 2030. As such the Deloitte team's benchmarking analysis includes three smaller Brazilian operations, Boa Esperanza (commissioning stage), Pedra Branca (a new producer), and Primavera (prefeasibility stage). Data for the other Brazilian projects is not available.

All three projects have a relatively small resource, although both Boa Esperanza (0.85 percent) and Pedra Branca (1.58 percent) have above average grades (group average 0.39 percent). Similarly, the three projects are relatively small in production size and have smaller-scale capital expenditure requirements (CAPEX). The operating cash costs are average within the peer group and show no indications of any particular competitive advantage. The returns of the three Brazilian projects are higher than average, with particularly strong returns for Primavera (internal rate of return [IRR] of 43.5 percent) and Boa Esperanza (41.8 percent). Both of these projects have a relatively favorable capital efficiency (net present value [NPV]/CAPEX).

2. COPPER CHARACTERISTICS

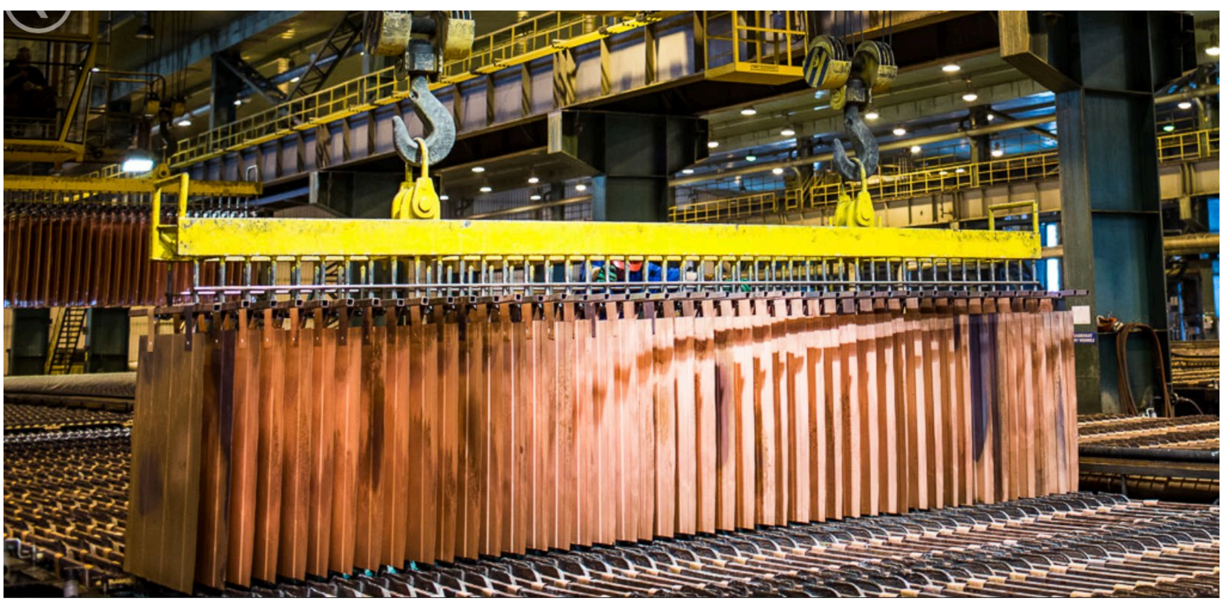
Copper is a malleable and ductile metallic element that is an excellent conductor of heat and electricity; it is also corrosion resistant and antimicrobial. This combination of properties make copper one of the most widely used industrial metals in the world, ranking third after iron and aluminum in terms of quantities consumed.

Copper occurs naturally in the earth's crust in a variety of forms. Copper metal has a characteristic reddish-brown color, with a metallic luster on fresh surfaces. Copper combines with a number of elements and more than 150 copper minerals have been identified, although only a small number of these can be exploited economically. Copper can be found in sulfide deposits (as chalcopyrite, bornite, chalcocite, covellite), in carbonate deposits (as azurite and malachite), in silicate deposits (as chrysycolla and dioptase) and as pure native copper. Copper sulfide deposits dominate global copper production. Estimates suggest at least 80 percent of copper is derived from sulfide deposits[11]. Of the sulfide minerals, chalcopyrite is by far the most widely mined, accounting for approximately 50 percent of all copper production.

Copper deposits are found worldwide in a variety of geological environments. Porphyry copper deposits are the most significant type of economic deposit, accounting for 69 percent of existing reserves and resources. Numerous other types of mineral deposits contain copper in variable amounts; however, these are of lesser economic importance.

Copper metal is generally produced from a multistage process, beginning with the mining and concentrating of low-grade ores containing copper sulfide minerals and followed by smelting and electrolytic refining to produce a pure copper cathode (Figure 1). An increasing share of copper is produced from acid leaching of oxidized ores and electrowinning copper cathode (SX-EW); this currently accounts for approximately 20 percent of global production.

Figure 1: Copper Cathode Production



Source: KGHM.

[11] British Geological Society (BGS)

In general, demand for copper reflects the rate of underlying world economic growth, particularly in industrial production and construction. The physical and chemical qualities of copper make it the material of choice for a variety of industrial and high-technology applications. Copper is used in electronic product manufacturing (32 percent), building construction (28 percent), power generation and transmission (16 percent), transport (12 percent) and the production of industrial machinery (12 percent). Copper wiring and plumbing are integral to appliances, heating, and cooling systems, and electrical and telecommunications links used every day in homes and businesses. Copper will continue to be essential in these basic uses as well as contribute significantly to new technologies for clean energy, communications, and public health.

Copper is one of the most recycled of all metals. Recycled copper (also known as secondary or scrap copper) is an important part of the overall copper supply chain (approximately 13 percent of refined production).

Annex 1 contains more detail on copper ores, and Annex 2 contains more detail on copper mining and processing.

3. COPPER RESERVES AND RESOURCES

Copper is one of the most abundant of the metallic elements in the earth's crust. Estimates for global copper reserves and resources are significant and have a broad geographic spread. Table 1 presents the USGS' estimates of global copper reserves in 2021,

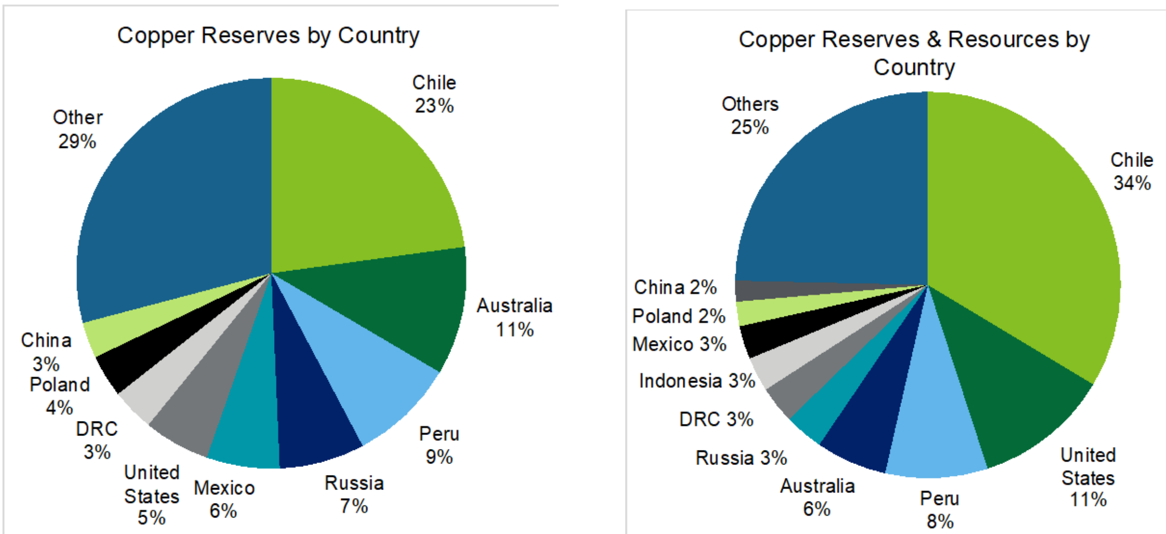
Standard & Poor's (S&P's) Global Intelligence database (sourced from company reports) contains 628 active primary copper mines and exploration and development projects. Table 1 also shows the stated reserves and resources of these mines and projects, totaling some 2.0 billion tonnes of copper. The reported reserves and resources of Brazil are included in Table 1 for reference. Figure 2 shows the reserves and resources by country and Figure 3 shows these reserves and resources broken down by deposit type.

Table 1: Global Copper Reserves, 2021 (kt copper)

Country	USGS Reserves kt Cu	% of Total	S&P Reserves & Resources kt Cu	% of Total
Chile	200,000	22.8	671,768	33.6
Australia	93,000	10.6	118,864	5.9
Peru	77,000	8.8	171,777	8.6
Russia	62,000	7.1	65,301	3.3
Mexico	53,000	6.1	55,529	2.8
United States	48,000	5.5	227,319	11.4
DRC	31,000	3.5	62,186	3.1
Poland	31,000	3.5	41,007	2.1
China	26,000	3.0	34,987	1.8
Indonesia	24,000	2.7	57,887	2.9
Zambia	21,000	2.4	42,293	2.1
Kazakhstan	20,000	2.3	47,481	2.4
Canada	9,800	1.1	55,629	2.8
Philippines	*		30,944	3.4
Argentina	*		62,270	2.9
Mongolia	*		58,654	2.8
Brazil	*		14,270	0.6
Others	180,000	20.6%	181,002	9.1
Total	**875,800**	**100%**	**1,999,168**	**100**

Source: USGS 2022, S&P Global Intelligence. * Included in Others.

Figure 2: Global Copper Reserves and Resources by Country

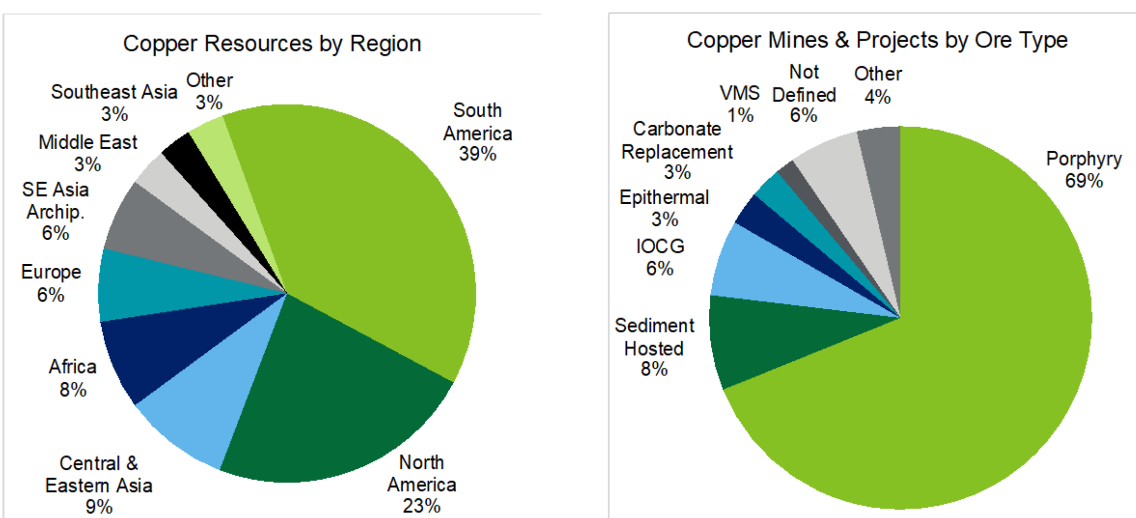


Source: USGS 2022, S&P Global Intelligence.

Table 1 shows that Chile holds by far the largest level of reserves and resources as reported by S&P Global Intelligence. The United States, Peru, and Australia also hold significant reserves and have a high level of reported resources.

Figure 3 shows that copper is extracted, or is being explored for, across multiple deposit types, with the most significant being porphyry copper occurrences (69 percent of reserves and resources). Sediment hosted deposits (eight percent), and IOCG deposits (six percent) are the next most important. Each deposit type has characteristic ore tonnages, copper grades, and associated minerology. Porphyry copper deposits are large-tonnage, low-grade deposits that are typically mined in large open pits. Porphyry copper grades typically are less than 1.0 percent and are often supplemented by molybdenum, gold, silver, and other elements.

Figure 3: Global Copper Reserves and Reserves by Region and Ore Type



Source: USGS 2015, S&P Global Intelligence.

Sediment-hosted stratabound deposits are mined by using both open-pit and underground methods, depending on deposit depth and geometry. The deposits are typically smaller than typical porphyry copper deposits and copper grades are typically about 1 to 3 percent. These copper deposits are also important sources of lead, zinc, silver, and cobalt.

Iron ore copper gold deposits include a variety of diverse mineralization systems that combine abundant iron mineralization (magnetite and/or hematite) with copper (and sometimes gold) via hydrothermal ore styles and strong structural controls. This type of deposit is particularly prevalent in Brazil.

Copper resources have also been identified in polymetallic nodules and crusts on the floor of the Atlantic, Indian, and Pacific Oceans. Mining such nodules is not yet economic, and many environmental issues remain to be resolved, but the development of deep-sea mining technologies is expected to facilitate access to these resources at some point in the future.

Annex 1 contains more detail on copper ores.

3.1. Brazilian Copper Resources

Brazil has eight operating copper mines, two projects at late-stage development, and five copper exploration projects with reported reserves and resources. Table 2 shows company-reported reserves and resources for each of these projects. Reserves and resources total 16.4 Mt across all 15 sites, at an average grade of 0.49 percent copper, of which most are in Pará State. Copper is also present in a number of other Brazilian primary gold, nickel, zinc, and lead deposits.

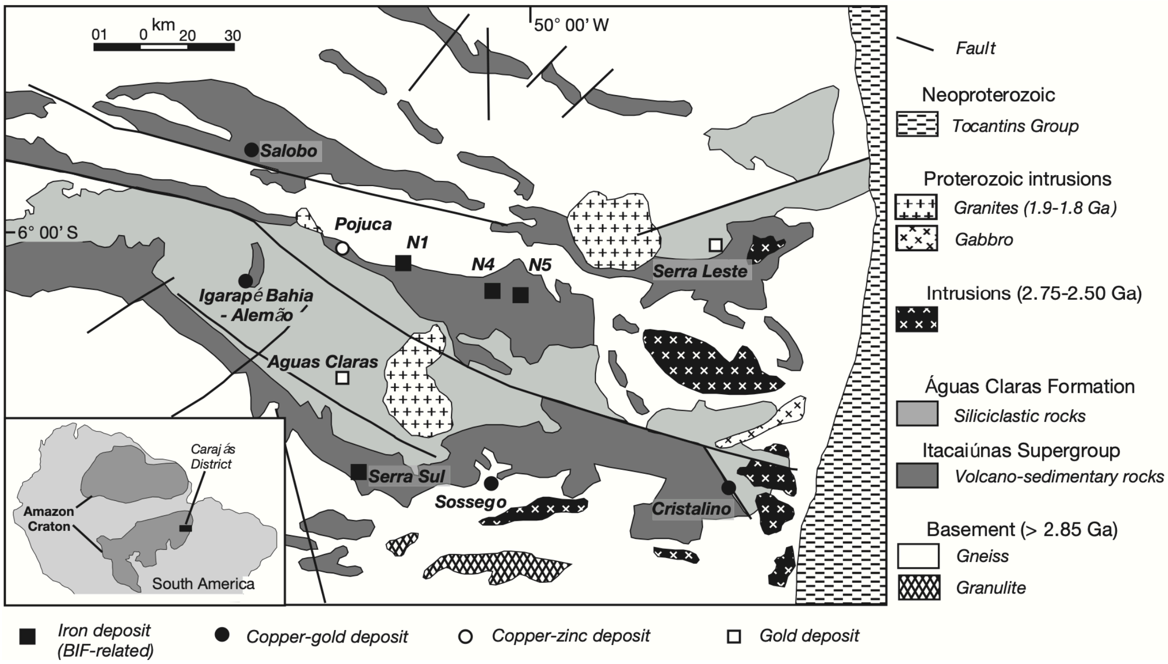
Table 2: Active Brazilian Copper Projects with Reported Reserves and Resources

Mine/Project	State	Owner	Development Stage	Grade Cu %	Cu Reserve /Resource(T)
Salobo	Pará	Vale SA	Operating	0.59	6,839,100
Chapada	Goiás	Lundin Mining Corp.	Operating	0.21	3,200,000
MCSA Complex	Bahia	Ero Copper Corp.	Operating	1.14	1,694,600
Sossego	Pará	Vale SA	Operating	0.70	683,300
Celestra	Pará	Tessarema Resources	Operating	4.04	101,934
Antas	Pará	OZ Minerals	Operating	0.45	7,200
Pedra Branca	Pará	OZ Minerals	Operating	1.58	300,000
Serrote	Alagoas	Appian Capital Advisory	Operating	0.59	309,000
Boa Esperanza	Pará	Ero Copper Corp.	Late-stage Dev.	0.85	503,840
Alemao	Pará	Vale SA	Late-stage Dev.	1.30	2,093,000
Primavera	RG do Sul	Aguia Resources Ltd.	Prefeas/Scoping	0.09	94,713
Cacapava do Sul	RG do Sul	Nexa Resources SA	Prefeas/Scoping	0.43	22,500
Pantera	Pará	OZ Minerals	Exploration	1.68	350,000
Santa Lucia	Pará	OZ Minerals	Exploration	2.07	120,000
Palma	Tocantins	Alvo Minerals	Exploration	0.96	44,000
Total				**0.49**	**16,393,187**

Source: S&P Global Intelligence.

The Carajás district in the state of Pará, Brazil and is regarded as the world's outstanding IOCG locality for copper deposits, due to the presence of several large IOCG resources**.** The region lies in Amazonia in the southeastern part of the Amazon craton. Figure 4 shows a map of copper mineral occurrences in Carajás**,** Brazil.

Figure 4: Geology and Major Ore Deposits of the Carajás Mineral District



Source: Iron Oxide Copper-Gold Deposits, Williams et al 2005.

The largest resource outside of the state of Pará is the copper-gold deposit at Chapada mine in the state of Goiás. Copper is principally present in this copper-gold porphyry system as chalcopyrite with minor amounts of bornite. Fine grained gold is also closely associated with the sulfide mineralization.

With the exception of the Alemao project, all of the copper projects in Brazil that are close to production or at the exploration stage have significantly lower reserves and resources than those mines already operating in the country. While new opportunities may be revealed by ongoing exploration, currently Brazil does not have any large-scale copper resources that could be developed to support a significant scale copper mine (at least 100 kt/y – see Figure 7).

4. COPPER SUPPLY

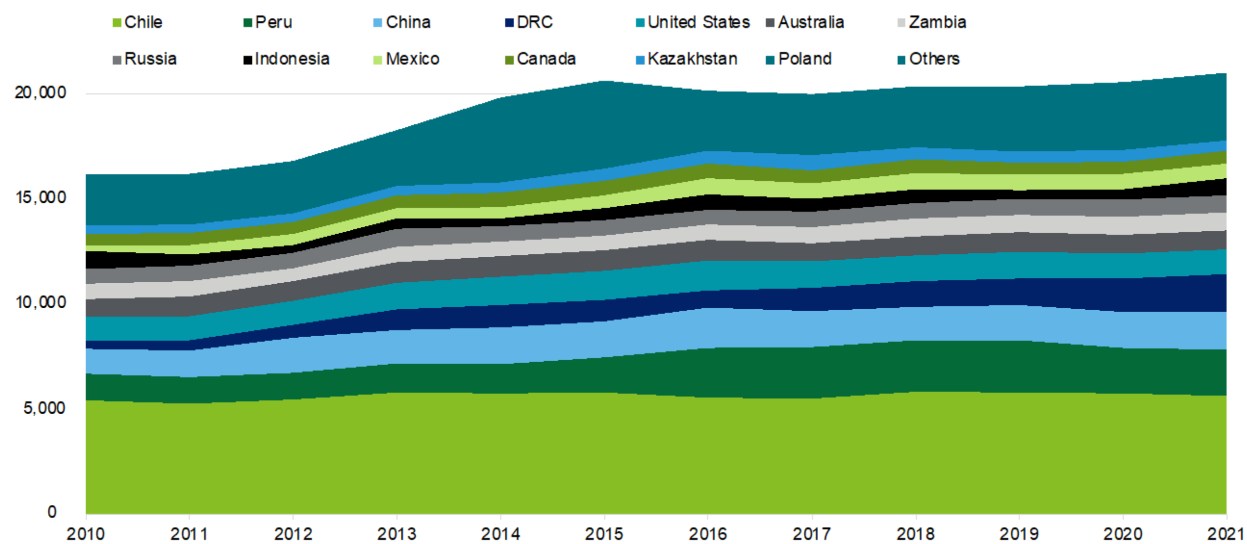
This section outlines the global supply of copper. It details the mine supply by country, company, and lists the largest mines. It also discusses the supply of copper scrap and how this is integrated into the smelting and refining of copper commodities.

4.1. Mined Copper Supply

In 2021, global production of mined copper totaled 21.0 Mt, according to the USGS. Chile is currently the largest producer accounting for 27 percent of production in 2021, followed by Peru (11 percent), China (nine percent), the DRC (nine percent), and the United States (six percent). This production was sourced from producers of copper concentrate (approximately 80 percent) and producers of copper using SX-EW extraction methods (20 percent).[12]

Figure 5 shows mined copper production growth from 2010 to 2020 by country. The overall CAGR for copper mine production from 2010 to 2020 was 2.4 percent. The CAGR has slowed in recent years, and since 2015 mine production CAGR has been 1.4 percent. This relative decline in the growth rate is often attributed to continued price declines from 2011 to 2016, which led to lower investment in copper exploration and project development. Other factors at play in copper's slower growth trajectory include increasingly stringent ESG requirements, a shortage of new high quality large-scale copper projects available to be developed, and a range of social, political, and regulatory issues in several large copper-producing countries.

Figure 5: Copper Mine Production by Country 2010-2020

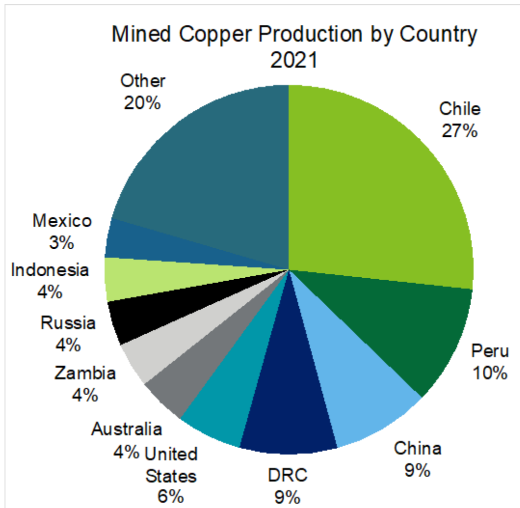


Source: World Bank, Oct 2021.

[12] SX-EW = Solvent extraction-electrowinning - SX-EW technology involves the leaching (the process of dissolving ore minerals with a solution) in atmospheric conditions of copper oxide ore heaped on pads by means of diluted sulphuric acid. Copper cathode is then produced from the recovered solution.

Figure 6 and Table 3 show the largest copper producers by country. Brazil is included within the 20 percent “other” production in Figure 6; in Table 3, Brazil’s 2021 copper production equates to 1.6 percent of that year’s global mine production.

Figure 6: 2021 Global Copper Mine Production by Country



Source: USGS 2022.

Table 3: Global Copper Mine Production by Country (t)

Country	2016	2017	2018	2019	2020	2021e
Chile	5,550	5,500	5,830	5,790	5,730	5,600
Peru	2,350	2,450	2,440	2,460	2,150	2,200
China	1,900	1,710	1,590	1,680	1,720	1,800
DRC	846	1,090	1,230	1,290	1,600	1,800
United States	1,430	1,260	1,200	1,260	1,200	1,200
Australia	948	860	920	934	885	900
Zambia	763	794	854	797	853	830
Russia	702	705	751	801	810	820
Indonesia	727	622	651	400	505	810
Mexico	752	752	751	715	733	720
Canada	708	597	648	573	585	590
Kazakhstan	600	745	603	562	552	520
Poland	424	419	401	399	393	390
Brazil	N/A	N/A	385	364	355	344
Others	2,434	2,489	2,106	2,336	2,473	2,451
Total	**20,134**	**19,993**	**20,360**	**20,361**	**20,556**	**20,980**

Source: USGS 2022, World Bank, Brazil = Deloitte estimates

4.2. Copper Mining Companies

Globally, there were approximately 309 identified individual companies or groups producing copper in 2020.[13] The top 100 companies produced approximately 85 percent of production. Table 4 lists the 20 largest copper producing companies, which cumulatively accounted for 58 percent of global output.

Table 4: Top 20 Copper Mining Companies Attributable Production (t copper)

	Company	Domicile	2018	2019	2020
1	CODELCO	Chile	1,806,446	1,706,075	1,727,457
2	Glencore	United Kingdom	1,405,357	1,247,372	1,315,547
3	BHP Group	Australia	1,256,651	1,288,769	1,221,476
4	Freeport-McMoRan	United States	1,389,526	1,169,757	1,176,543
5	Southern Copper Corp.	Peru	875,663	985,393	992,987
6	First Quantum Minerals	Canada	582,217	655,007	731,364
7	KGHM	Poland	533,395	534,800	541,500
8	Rio Tinto Group	United Kingdom	574,340	543,530	497,210
9	Antofagasta	United Kingdom	485,994	516,060	489,101
10	Anglo American	United Kingdom	489,005	464,022	462,276
11	Norilsk Mining	Russia	448,967	467,850	455,954
12	Zijin Mining Group	China	263,048	299,765	381,017
13	Vale S.A.	Brazil	384,100	373,600	355,500
14	KAZ Minerals	Kazakhstan	302,300	318,700	311,100
15	National Iranian Copper	Iran	273,959	273,446	275,341
16	MMG	Australia	321,988	308,519	267,932
17	Teck Resources	Canada	284,603	283,473	264,658
18	Sumitomo Metal Mining	Japan	245,063	258,995	247,899
19	Mitsubishi Corp.	Japan	250,669	240,673	230,013
20	Barrick Gold Corp.	Canada	173,726	210,875	223,786
	Total		**12,347,015**	**12,146,681**	**12,168,659**

Source: S&P Global Intelligence, company reports.

- CODELCO, the Chilean state-owned copper mining company, is the world's largest producer of copper. The company is currently undertaking a major brownfield CAPEX development program to replace depleted reserves at existing operations. This will allow the company to maintain current production levels out to at least 2040. It has a ten-year CAPEX program of $32 billion (2019-2028).

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[13] S&P Global Intelligence

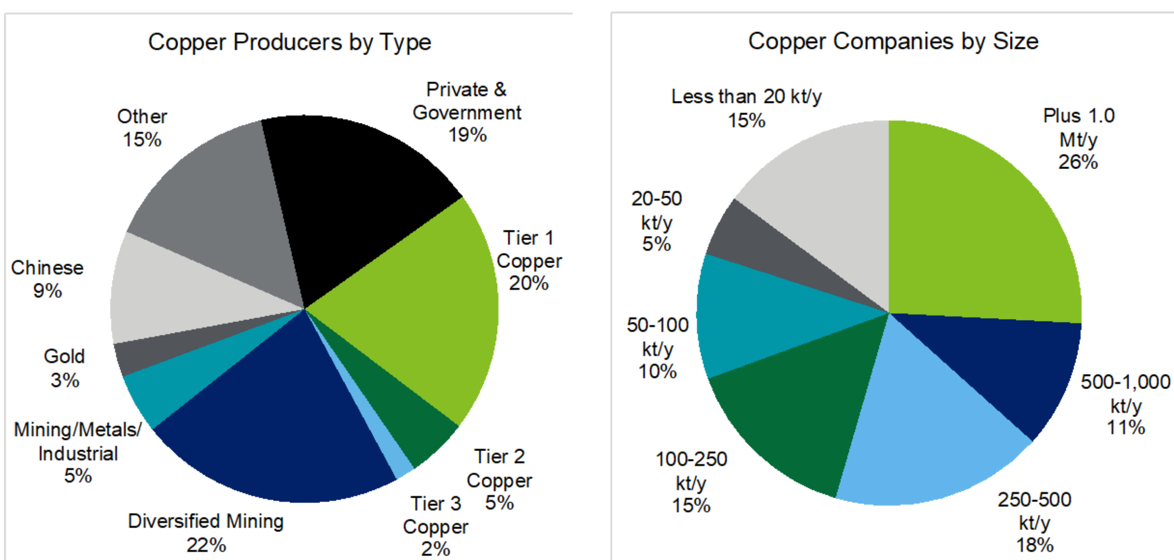
- Glencore [LSE: GLEN], the second largest producer, is a major diversified mining company based in the United Kingdom and has copper mines, smelters, and refineries in Africa, Australia, and South America.
- BHP [ASX: BHP], the third largest producer, is also a major diversified mining company based in Australia, with copper assets in Australia, Chile, the United States, and Peru.
- Freeport-McMoRan [NYSE: FCX], a copper mining company based in the United States, is the fourth largest producer, with assets in North America, South America, and Indonesia.

4.2.1. Copper Mining Industry Structure

Figure 7 gives a breakdown of copper producing companies by type and copper output. The categories are somewhat arbitrary, but Tier 1 covers pure copper companies[14] with an annual copper production of more than 300 kt/y, Tier 2 producers 70 to 300 kt/y, and Tier 3 20 to 70 kt/y. The largest category is Diversified Mining where copper is produced by companies such as Rio Tinto, BHP, Anglo American, and Glencore. The category 'Other' accounts for producers of less than 20 kt/y, with much of this output the by-product of other types of mining operations. Data from the 'Other,' 'Chinese' and 'Private and Government'[15] categories remain somewhat opaque, but output from these sources was estimated by the Deloitte team to account for 43 percent of 2020 production.

A full analysis of the largest copper companies shows that just 36 organizations produced more than 100 kt/y and accounted for 70 percent of annual production. In terms of individual mines, there were 49 mines that produced more 100 kt/y in 2020.

Figure 7: Structure of the Global Copper Mining Industry



Source: Deloitte

[14] Companies that only produce copper

[15] These two categories are combined as information is opaque

Table 5 shows the top 15 copper mines which accounted for 32 percent of global copper output in 2020. The largest mine by production is Escondida in Chile, owned by BHP and Rio Tinto [LSE: RIO]. Escondida produced nearly 1.2 Mt of copper in 2020, equivalent to 5.7 percent of annual mined copper production. Six of the world's largest copper mines are located in Chile and three are in Peru, thereby emphasizing the high concentration of copper production in South America.

Table 5: Largest Copper Mine Operations

	Mine	Country	Owner	Source	Prodn 2020 t Cu
1	Escondida	Chile	BHP/Rio Tinto	Conc. & SX-EW	1,190,700
2	Collahuasi	Chile	Glencore/Anglo American	Conc. & SX-EW	629,100
3	Morenci	United States	Freeport-McMoRan	Conc. & SX-EW	445,400
4	El Teniente	Chile	CODELCO	Conc. & SX-EW	443,220
5	Buenavista	Mexico	Southern Copper	Conc. & SX-EW	431,774
6	Chuquicamata	Chile	CODELCO	Conc. & SX-EW	400,720
7	Lubin	Poland	KGHM	Concentrates	392,700
8	Antamina	Peru	Glencore/BHP/Teck	Concentrates	380,700
9	Cerro Verde	Peru	Freeport-McMoRan/Others	Concentrates	371,945
10	Grasberg	Indonesia	Freeport-McMoRan	Concentrates	366,956
11	Los Pelambres	Chile	Antofagasta	Concentrates	359,600
12	Polar Division	Russia	Norilsk Nickel	Concentrates	351,413
13	Los Bronces	Chile	Anglo American	Conc. & SX-EW	342,700
14	Las Bambas	Peru	MMG	Concentrates	311,020
15	Kamoto	DRC	Glencore/ Gécamines	SX-EW	270,700

Source: S&P Global Intelligence, company data.

4.2.2. Copper Mine Production in Brazil

Brazil currently has eight operating copper mines that produced 349 kt of copper in 2020. The two largest (Salobo and Sossego) are both owned by Brazilian company Vale S.A. [BVMF: VALE3]. Salobo is the only copper mine producing more 100 kt/y in Brazil; it is also expanding run-of-mine capacity by an additional 35 kt/y. Despite this expansion, Salobo would be regarded as a mid-size operation in global terms. Sossego is also expected to be expanded by 35 kt/y by 2025, via the development of satellite deposits. Brazil's third largest deposit, Chapada (in the State of Goiás) is operated by Lundin Mining [TSE: LUN]. The other four mines listed in Table 6 that produce less than 10 kt/y would be regarded as small copper operations in global terms.

Table 6: Brazilian Copper Mine Production

Mine	Owner	Prodn 2019 t Cu	Prodn 2020 t Cu	Prodn 2021t Cu
Salobo	Vale S.A.	189,400	172,700	144,600
Sossego	Vale S.A.	65,500	87,700	81,800
Chapada	Lundin Mining Corp.	59,738	50,038	52,019
MCSA Mining Complex	Ero Copper Corp.	42,318	42,814	45,511
Pedra Branca	OZ Minerals	0	2,000	8,000
Antas	OZ Minerals	6,810	8,613	7,298
Celestra	Tessarema Resources	0	N/A	N/A
Serrote	Appian Capital Advisory	0	0	4,750
Total*		**363,766**	**355,252**	**343,978**

Source: S&P Global Intelligence, company data. *Santa Rita nickel mine is excluded, but also produces copper.

4.3. Refined Copper Production

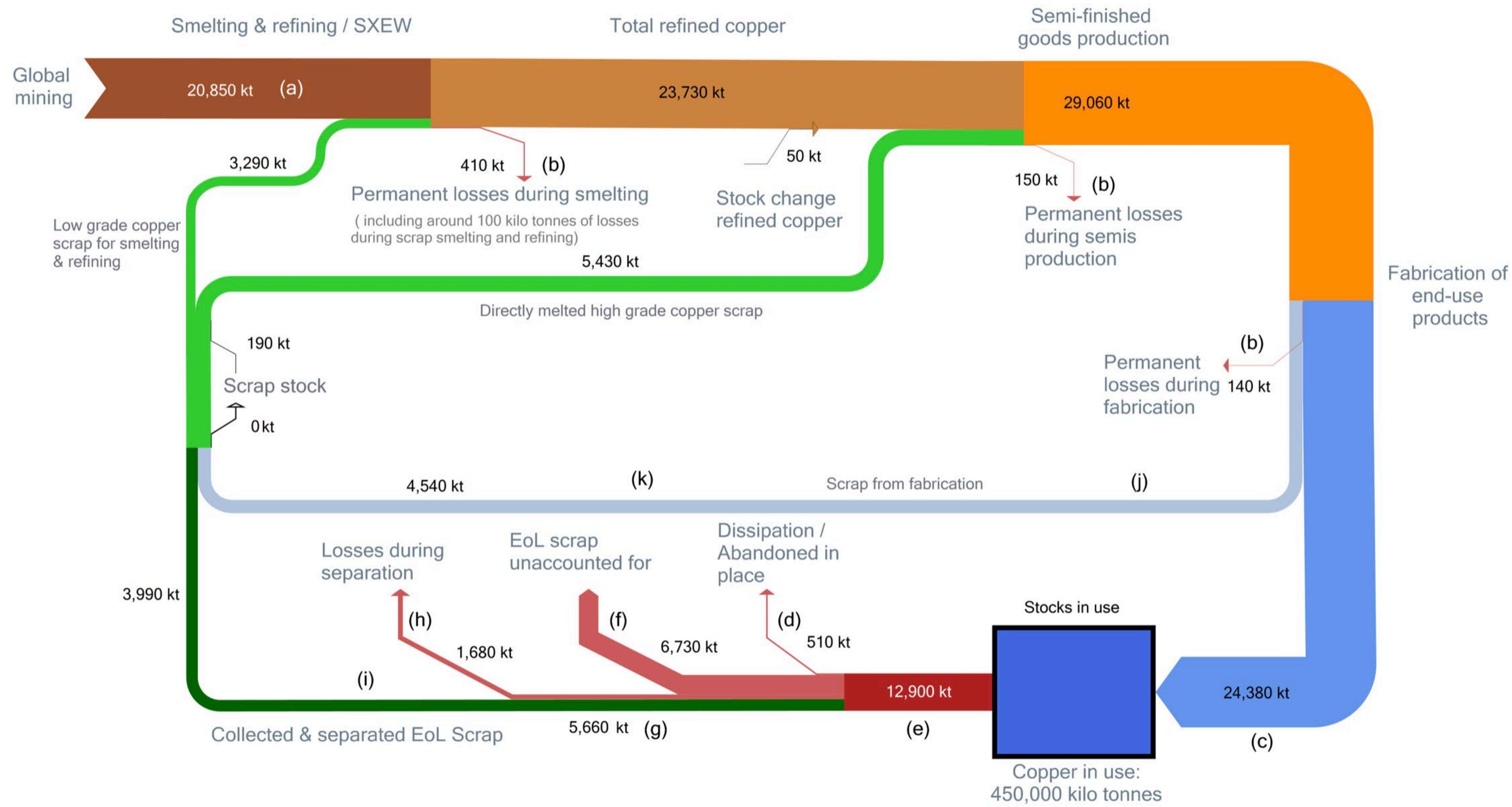
The copper concentrates produced from mining need to be smelted[16], to produce blister or anode copper, and then refined[17] to produce cathode copper. These processes often also involve the inclusion of old copper scrap as a feedstock. The final refined copper cathode, as well as the cathode copper produced from SX-EW operations, is the product consumed by end-users, such as manufacturing industries. Figure 8 shows the material flows of copper from mining through to refined production, semi-finished production, and fabrication, including the internal and external flows of copper scrap.

Annex 2 contains more detail on copper mining and processing.

[16] Smelting - extracting metals from an ore by a process involving heating and melting.

[17] Refining - removing impurities or unwanted elements from a substance (metal).

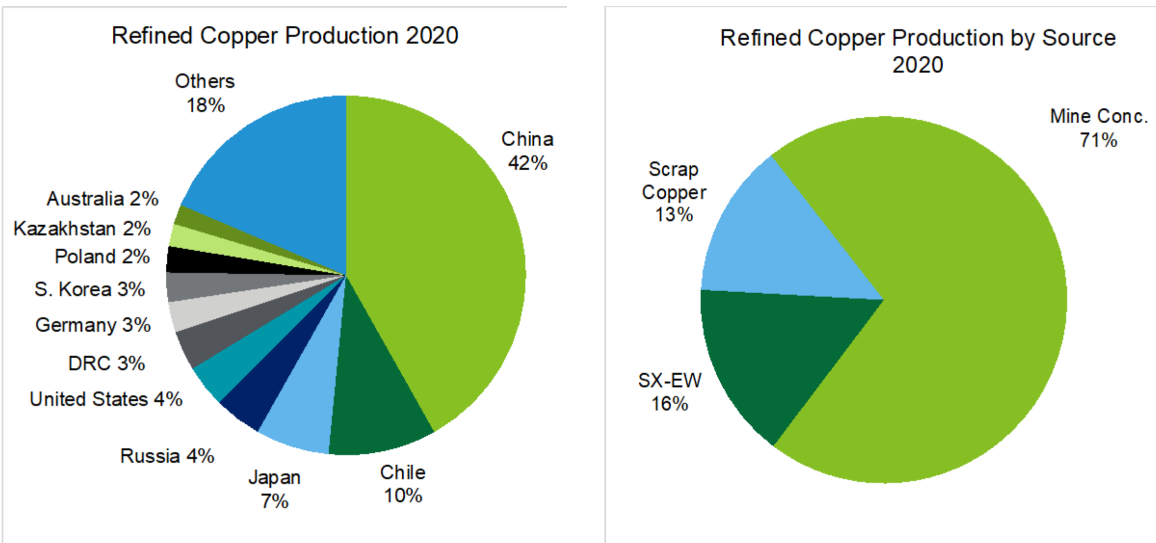
Figure 8: Copper Stocks and Industry Flows of Material and Scrap (2018)



Source: International Copper Association Jan 2020.

In 2020, refined copper production totaled 24.3 Mt[18] (excluding stock movements), increasing at a CAGR of 2.6 percent from 2010 to 2020, slightly lower than the growth in copper mine production. Figure 9 shows the largest producers of refined copper by country, according to data from the USGS. In 2020 China was the largest producer of refined copper, accounting for 42 percent of output, followed by Chile (10 percent), Japan (seven percent), Russia (four percent), and the United States (four percent). In 2019, Brazil produced 174 kt of refined copper equivalent to 0.7 percent of global production.

Figure 9: Refined Copper Production by Source



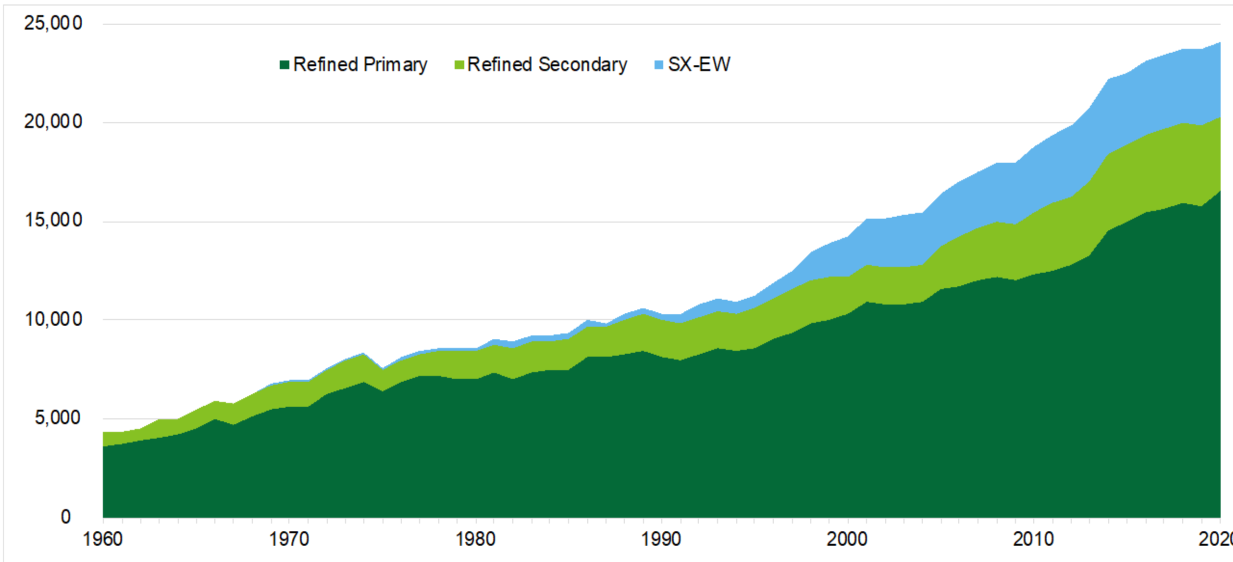
Source: World Bank, Deloitte

Copper is shipped to fabricators mainly as cathode, wire rod, billet, cake (slab) or ingot. Through extrusion, drawing, rolling, forging, melting, electrolysis, or atomization, fabricators form wire, rod, tube, sheet, plate, strip, castings, powder, and other shapes. The fabricators of these shapes are called the "first users."

Figure 10 shows refined copper production from 1960 to 2020, showing refined mine copper, refined scrap material and SX-EW production.

[18] S&P Global Intelligence, International Copper Study Group, and World Bureau of Metal Statistics.

Figure 10: Refined Copper Production 1960-2020



Source: International Copper Study Group.

4.4. Scrap Recycling

Copper scrap, or secondary copper, contributes significantly to the copper market supply and plays an important role in balancing the copper market. Consequently, it needs to be considered in the supply equation. Copper scrap is generally divided into two categories: old and new scrap.

4.4.1. Old Copper Scrap

Old scrap generally refers to post-consumer products and includes copper wire, copper tubing, roofing copper, and copper pipe and is usually converted to refined metal and alloys. Old copper scrap used in smelting, and refining totaled 3.3 Mt in 2020, or 13.4 percent of total refined supply. Over the past 10 years it has accounted for 12.6 to 15.8 percent of refined supply. Growth in industrial production increases copper demand as well as increasing the pool of available old scrap. In addition, higher prices encourage more scrap to flow into the market. Figure 8 shows the flows of old copper scrap in the global copper market.

4.4.2. New Copper Scrap

New scrap is copper metal discarded in fabrication and manufacturing processes and is typically considered higher-grade material than old scrap. The majority of this new scrap material is recycled and used directly in semi-finished goods production. Approximately five to six Mt of new copper scrap (about 20 percent of refined copper production) is used directly in semi-finished goods production. In 2020, new copper scrap totaled 5.1 Mt, equivalent to 17.9 percent of refined copper production.

This new copper scrap largely remains in an internal loop within the manufacturing process (Figure 8). This source of scrap only grows with fabrication levels and is relatively insensitive to copper prices. The volume of scrap produced from copper products fabrication is slightly lower than the volume of scrap required for semi-finished good production and so overall the market usually requires an additional 0.5 to 1.0 Mt of new copper scrap from other sources. The data for semi-finished goods fabrication and for the fabrication of end-use products is somewhat opaque and difficult to analyze, and because new copper scrap largely remains in an internal loop, market analysis principally focuses on refined copper consumption.

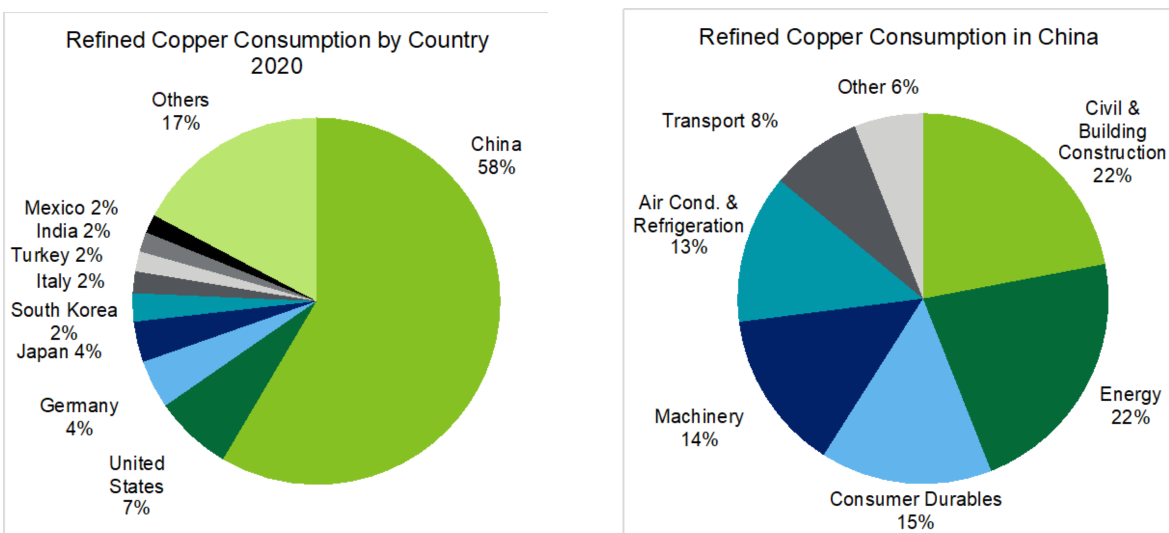
5. COPPER DEMAND

The World Bank reports that refined copper consumption totaled 24.7 Mt in 2020. Chinese demand dominated the market, accounting for 14.5 Mt - equivalent to 59 percent of total consumption. The next largest consumers were the United States (7 percent), Germany (4 percent), and Japan (4 percent). Figure 11 shows the top refined copper consumers by country in 2020 and refined copper consumption in China by end-use in 2021.

Copper is used widely in a broad range of industries due to its high electrical and thermal conductivity, ductility, and corrosion resistance. Copper is shipped to fabricators mainly as cathode, wire rod, billet, cake (slab) or ingot. Through extrusion, drawing, rolling, forging, melting, electrolysis or atomization, fabricators form wire, rod, tube, sheet, plate, strip, castings, powder, and other shapes.

Key copper-consuming industries include construction, electrical and electronic equipment manufacturing, power industry, transport, mechanical engineering, and various equipment and consumer goods production. Copper is an essential element for almost all electricity-related technologies and over 60 percent of refined copper produced globally is used in electrical conductors, including various types of cable and wire.

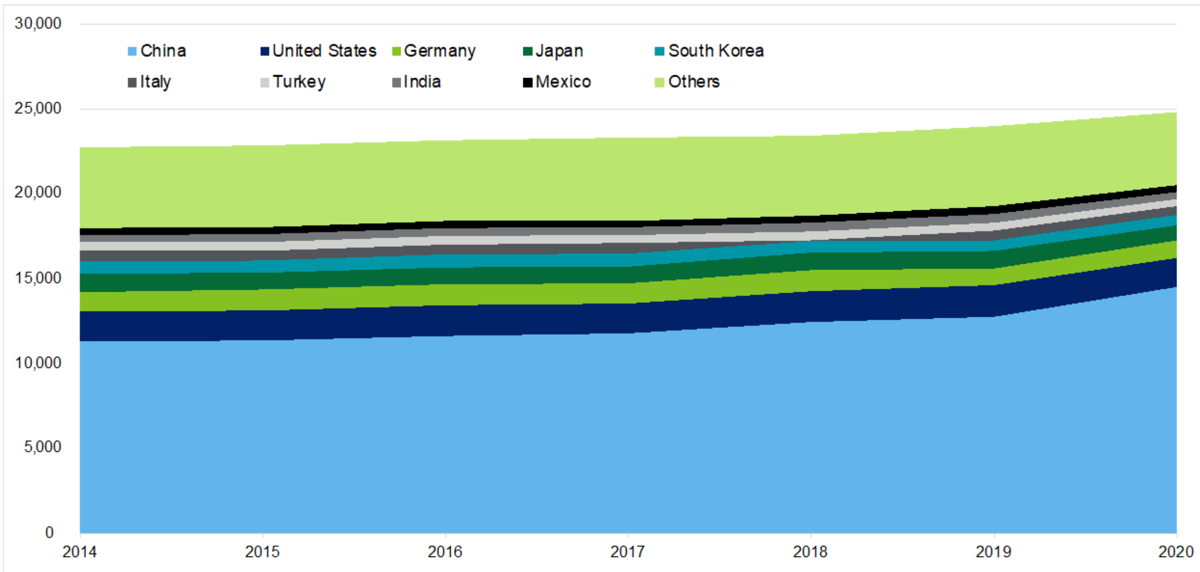
Figure 11: Global Copper Demand by Country and by Use in China



Source: Commodity Markets Outlook (World Bank) Oct 21. CRU.

The overall CAGR for refined copper consumption from 1970 to 2020 was 2.5 percent, a period that includes a significant increase in consumption from China due to the expansion of its economy. Figure 12 shows refined copper consumption by country from 2014-2020.

Figure 12: Refined Copper Consumption by Country 2014-2020



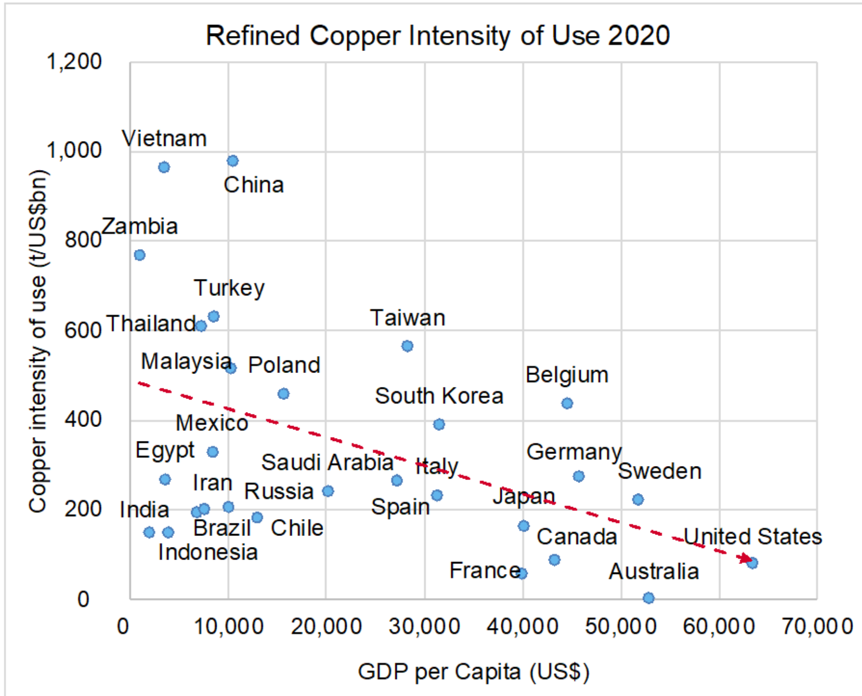
Source: World Bank Oct 21.

Copper consumption in China rose by a CAGR of 7.0 percent from 2010 to 2020. Copper consumption also increased in some other developing countries such as Mexico (4.0 percent CAGR) and Turkey (1.7 percent), however, copper consumption in most other major economies has been falling (Figure 13 and Figure 14). Over the period 2010 to 2020, consumption in the United States declined by a CAGR of 0.3 percent, Germany by 2.1 percent, Japan by 1.7 percent and South Korea by 3.2 percent - a decline of copper intensity relative to economic activity that has been apparent for decades.

Copper consumption has been declining in mature economies mainly due to declining investment in infrastructure, reduced intensity of use, and substitution. Other factors include manufacturing offshoring (to China), a slowing in real estate construction, and trends of dematerialization[19].

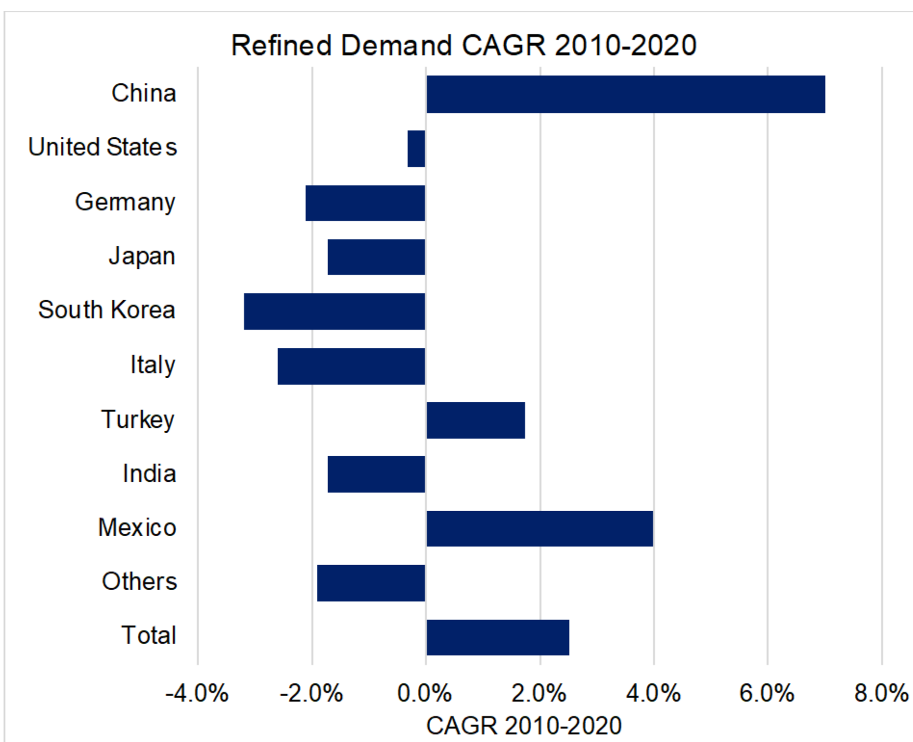
[19] Describes the process of making goods with less material and miniaturization trends.

Figure 13: Refined Copper Demand - Intensity of Use



Source: International Copper Study Group, IMF.

Figure 14:Refined Copper Demand CAGR 2010-2020



Source: World Bank Oct 21.

A recent copper demand forecast[20] for the United States concluded that domestic copper demand would gradually decrease from the baseline level of 240 kg/person to a minimum value of 227 kg around 2032 before peaking at 243 kg in 2070, due to copper's growth in some end-use sectors and shrinkage in others. This one percent increase from 2015 to 2070 is small compared to an expected per capita gross domestic product (GDP) growth of about 100 percent during the same period. The intensity of refined copper use per U.S. dollar of GDP (Figure 13) illustrates how intensity of use declines as economies mature (increased GDP per capita).

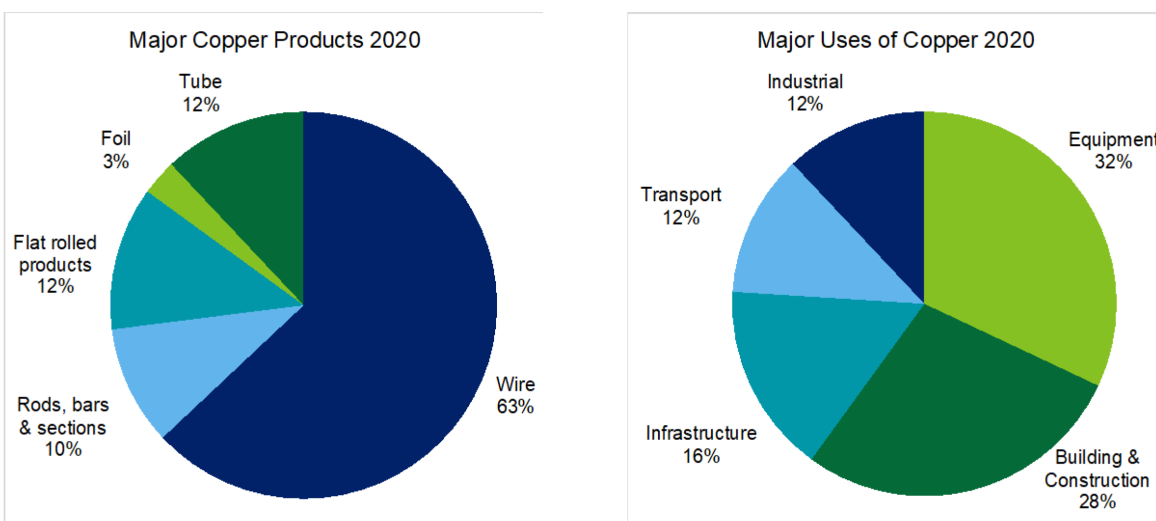
5.1.1. Copper Substitution

Substitution is a relatively significant issue in terms of reducing overall consumption of any commodity, including copper. In 2021 substitution accounted for 1.3 percent of global use, according to the latest research by the International Copper Association (ICA), with the spur to find substitutes mostly being driven by relative material cost. Most copper substitution over recent years has been centered on power cables, winding wires in transformers, and alloys, and often involves copper being substituted by aluminum. Copper will continue to experience substitution pressures, particularly as its cost increases (both absolutely and relative to aluminum).

5.2. Copper Uses

Analyzing copper and copper alloys semis consumption by use is difficult due to the lack of available data. Despite this challenge, this section provides a brief description of copper consumption and usage, with Figure 15 showing two high-level breakdowns of copper demand: by industry and by product.

Figure 15: Global Consumption of Copper by Application



Source: International Copper Study Group.

[20] Forecast of the U.S. Copper Demand: A Framework Based on Scenario Analysis and Stock Dynamics, Rui He and Mitchell J. Small, Jan 2022.

5.2.1. Copper in Electrical Applications

Copper is the best non-precious metal conductor of electricity. It is the benchmark by which other conductors are compared. Copper is widely used in power cables, either insulated or uninsulated, for high, medium, and low voltage applications. In addition, copper's exceptional ductility and resistance to creep and corrosion makes it the preferred and safest conductor for commercial and residential building wiring. The IEA estimates that some 150 Mt of copper are “locked in” the existing electricity grid.

Copper is also an essential component of energy efficient generators, motors, transformers, and renewable energy production systems. Renewable energy sources such as solar, wind, geothermal, fuel cells, and other technologies are all heavily reliant on copper due to its excellent conductivity.

5.2.2. Copper in Electronics and Communications

Copper plays a key role in worldwide information and communications technologies. HDSL (High Digital Subscriber Line) and ADSL (Asymmetrical Digital Subscriber Line) technology allows for high-speed data transmission, including internet service, through the existing copper infrastructure of ordinary telephone wire. Copper and copper alloy products are used in domestic subscriber lines, wide and local area networks, mobile phones, and personal computers.

Copper heat sinks help remove heat from transistors and keep computer processors operating at peak efficiency. Copper is also used extensively in other electronic equipment in the form of wires, transformers, connectors, and switches.

5.2.3. Copper in Construction

Copper and brass (a copper alloy) are the materials of choice for plumbing, taps, valves and fittings. Partly due to its aesthetic appeal, copper, and its alloys, such as architectural bronze, is used in a variety of settings to build facades, canopies, doors, and window frames. Unlike plastic tubing, copper does not burn, melt, or release noxious or toxic fumes in the event of a fire. Copper tubes also help protect water systems from potentially lethal bacteria such as legionella. Copper fire sprinkler systems are a valuable safety feature in buildings.

Copper roofing, in addition to being attractive, is well known for its resistance to extreme weather conditions. Major public buildings, commercial buildings, and homes use copper for their rainwater control and roofing needs.

5.2.4. Copper in Industrial Machinery and Equipment

Copper and copper alloys (such as brass, bronze, and copper-nickel) are used extensively in industrial machinery and equipment. Due to the durability, machinability, and ability to be cast with high precision and tolerances, copper alloys are ideal for making products such as gears, bearings, and turbine blades. Copper's superior heat transfer capabilities and ability to withstand extreme environments makes it an ideal choice for heat exchange equipment, pressure vessels, and vats.

The corrosion resistant properties of copper and copper alloys make them especially suitable for use in marine and other demanding environments. Vessels, tanks, and piping exposed to seawater, propellers, oil platforms, and coastal power stations, all depend on copper's corrosion resistance for protection.

5.2.5. Copper in Transportation

All major forms of transportation depend on copper to perform critical functions. Automobiles and trucks rely on copper motors, wiring, radiators, connectors, brakes, and bearings. Copper-nickel alloys are used on the hulls of boats and ships to reduce marine befouling, thereby reducing drag, and improving fuel consumption.

5.2.6. Copper in Consumer and General Products

Copper and copper-based products are used in offices, households, and workplaces. Computers, electrical appliances, cookware, brassware, and locks and keys are just some of the products that use copper. Coinage also use copper.

6. COPPER PRICES AND TRADE

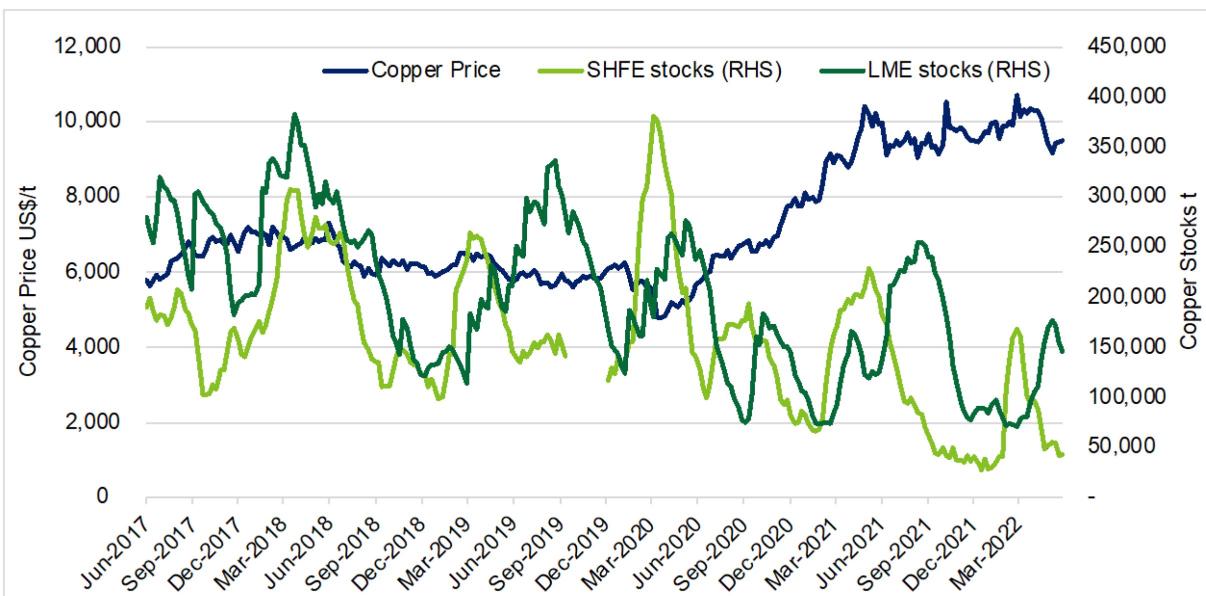
Copper metal is an exchange-traded commodity that can be traded via futures and options contracts. Copper end- and intermediary products are also internationally traded across a wide variety of value chains. Major product categories of copper traded internationally include copper concentrates, blister and anode, cathode and ingots, scrap, and copper semis (semi-fabricated products).

Copper powders and compounds are also traded globally, but typically in much smaller quantities. In addition, copper is contained in end-use products that are traded globally including automobiles, appliances, electronic equipment, and other products.

Figure 16 shows the London Metal Exchange (LME) copper price for the past five years, and LME and Shanghai Futures Exchange (SFHE) warehouse stocks. Copper prices are determined by the major metals exchanges – LME, Commodity Exchange Inc. (COMEX), and SHFE. Prices on these exchanges generally reflect the worldwide balance of copper supply and demand and can be volatile and cyclical. The LME copper price averaged $6,704/t ($3.04/lb) from 2010 to 2020.

The copper price hit a recent low of $4,625/t ($2.10/lb) in March 2020. Since that time, it steadily increased until hitting $10,702/t ($4.85/lb) in March 2022, followed by a modest decline. This decline reflected concerns about a resurgence of coronavirus cases in China curbing activity in the domestic economy, as well as the foreshadowing influence of rising U.S. interest rates.

Figure 16: LME Copper Price (US$/t) and LME & SHFE Copper Stocks (t) 2017-2022



Source: LME.

6.1.1. Copper Trade in Concentrates and Copper Cathode

In 2020, global trade in copper ores and concentrates totaled $61.8 billion. The largest importers were China (55 percent of imports), Japan (14 percent), and South Korea (seven percent). The largest exporters were Chile (35 percent), Peru (15 percent), and Australia (six percent), according to trade data from OEC.

Global trade of refined copper cathode totaled $71.8 billion in 2020. The largest importers were China (40 percent of imports), United States (six percent), and Germany (five percent). The largest exporters were the Chile (20 percent), DRC (15 percent), and Russia (seven percent).

Brazil's trade in copper is far smaller; it had exports of $2.4 billion (3.9 percent) of copper ore and $480 million (0.8 percent) of imports in 2020. It had exports of $126 million (0.2 percent) of refined copper and has $1.25 billion (1.8 percent) of imports.

7. COPPER DEMAND OUTLOOK

This section examines the demand outlook for copper. There are five key market drivers for copper demand:

- Population growth and consumer trends;
- Industrial production;
- Fiscal and monetary stimulus;
- Technology innovation and adoption; and
- Decarbonization of the global economy.

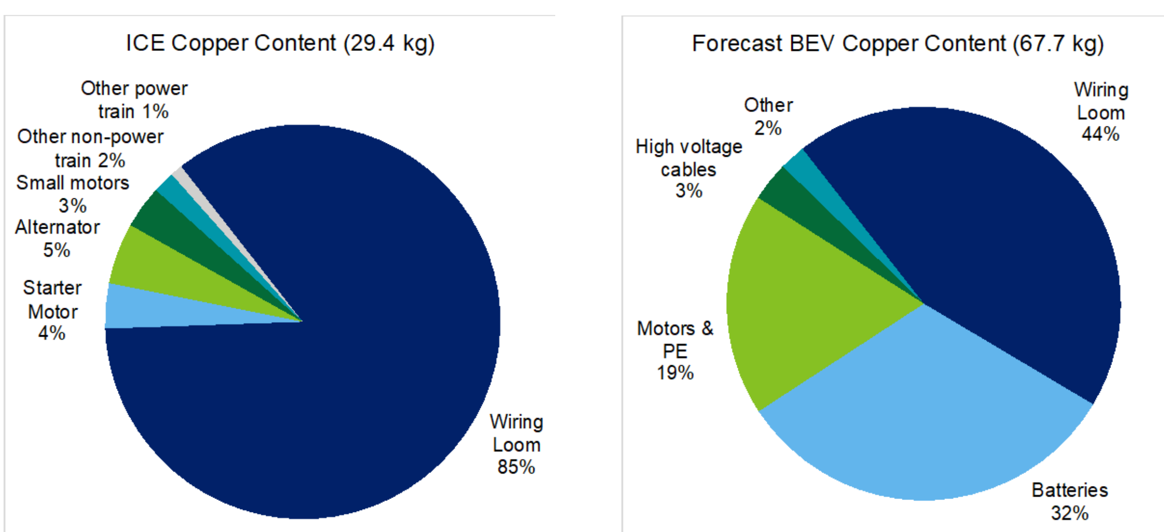
These factors will continue to drive copper demand out to 2030, as discussed in Section 6. Growth in emerging markets, in particular China, will continue to be a major determinant of overall global copper consumption. An area of significant demand growth for copper over the next decade will be increased demand for decarbonization and the energy transition. Copper will play a central role in this transition by enabling renewable energy generation technologies, the implementation of EV battery technologies, and the development and interconnection of grid infrastructure. Renewable power generation sources and cleaner transportation vehicles are more copper intensive than conventional counterparts.

7.1. Renewable Energy Copper Demand

7.1.1. Electric Vehicle Copper Consumption

A significant increase in demand for copper comes from the transportation sector, driven by the growth in use of lithium-ion batteries in EVs. In the current internal combustion engine (ICE) autos, 85 percent of the contained copper is in the wiring harness. The starter and alternator are the next largest contributors as shown in Figure 17. The standard assumption has been that a passenger battery electric vehicle (BEV) is nearly four times more copper intensive than an ICE auto. This is based on a report commissioned in 2017 by the International Copper Association (ICA) with the results shown in Table 7. Calculations of future EV copper demand have historically been based largely off this assumption.

Figure 17: Copper Consumption in Autos



Source: International Copper Study Group, IDTechEx

Table 7: Copper Used in Autos (Cu/vehicle)

Vehicle	2017 Report		2022 Report ‡	
	l	kg	l	kg
ICE autos	1	8.2-22.2	6	29.4
HEV	8	38.6	-	-
PHEV	1	59.9	-	-
BEV	1	83.0	1	67.7

Source: IDA, ICA, IDTechEx. ‡ Excludes copper for autonomous use.

In March 2022, the ICA released a new report on automotive copper demand that primarily focused on the outlook to 2040, but the conclusions should lead analysts to reduce their EV copper demand outlook.

Table 7 shows that ICE autos now have an average of 29.4 kg per vehicle, a 31 percent increase. While appearing positive for copper demand, this is now the base to use for comparison going forward and does not alter historic demand numbers. This means that the increase in copper content for a BEV is now 2.8x (using 83 kg for a BEV). The BEV copper content number, however, is also likely too high because battery and EV construction are improving and increasing the efficiency of copper use.

No figure was reported for 2030 in the March 2022 report, but a figure of 72 kg was given for 2040, although this includes 4.3 kg of copper use for autonomous systems, which are unlikely to be widely implemented before 2030. This still suggests a steady decline in copper consumption per vehicle for BEVs over the period. Using a value of 29.4 kg for an ICE in 2020 and about 68 kg for a BEV in 2030 would mean that a passenger BEV is just over twice as copper intensive than an existing ICE auto.

7.1.2. Solar Photovoltaic (PV) Copper Consumption

Installed worldwide solar PV capacity has increased by almost 20 times over the past decade, spurred by declining costs and strong policy support in key regions. The IEA reports that with sharp cost reductions over the past decade, solar PV now offers the lowest cost electricity option in many countries - cheaper, even, than coal- or gas-fired power plants. Copper is used in PV interconnectors, wiring, and inverters[21]. Distributed solar PV systems tend to have string inverters or microinverters, requiring about 40 percent more copper than utility-scale projects, which typically use central inverters. Continued growth in the construction of solar PV systems is therefore expected to result in strong demand for copper over the coming decades.

7.1.3. Wind Energy Copper Consumption

Global installed capacity of wind power has nearly quadrupled over the past decade, spurred by falling costs (which have declined by about 40 percent on average globally), and strong policy support in more than 130 countries. Wind power is expected to continue growing strongly, reflecting increased access to preferred financing, an offshore wind industry that is rapidly approaching scale, and continuing technological improvements. Particularly strong growth is anticipated in Southeast Asia, India, Latin America, and the Middle East. Copper intensity for offshore projects can be more than twice as high as onshore, with substantial copper usage in submarine collector and other cables.

[21] A type of electrical converter which converts the variable direct current (DC) output of a photovoltaic solar panel into a utility frequency alternating current (AC).

7.1.4. Other Renewable Copper Consumption

In addition, to copper demand coming from solar PV and wind, consumption is also expected to increase from other renewable-adjacent areas, including charging infrastructure, storage, and electricity grid expansions.

7.2. Renewable Energy Copper Demand Forecast

The most prominent forecast of renewables-led copper consumption was published by the IEA in May 2021 and is shown in Table 8. This is based on the Sustainable Development Scenario (SDS), which assumes a trajectory consistent with meeting the Paris Agreement goals.

Table 8: Renewable Energy Contributions to Copper Demand 2020-2030 (Mt)

Renewable Energy	Refined Copper Consumption			
	2020	2030	Change	CAGR %
EVs	0.11	1.26	1.15	27.6
Solar PV	0.34	0.93	0.59	10.6
Wind Energy	0.22	0.57	0.35	10.0
Power Grid	4.92	7.37	2.45	4.1
Storage	0.01	0.09	0.08	32.5
Renewable Demand	**5.60**	**10.22**	**4.62**	**6.2**

Source: IEA – The Role of Critical Minerals in Clean Energy Transitions (SDS scenario).

Table 8 shows renewable demand for copper of 5.60 Mt in 2020[22]. The increase in renewable energy-related copper demand from 2020 to 2030 is 4.6 Mt, equivalent to a CAGR of 6.2 percent.

7.3. Non-Renewable Energy Copper Demand Forecast

The new demand for renewable energy can be estimated from assumptions about renewable application volumes and copper intensity. The ongoing demand for non-renewable energy copper applications, after taking into account the impact of renewables, is more of a challenge to forecast.[23] Figure 18 shows a further breakdown of the copper semi-fabrication (semis) consumption shown in Figure 15. It shows the consumption for each sub-category and the CAGR from 2012 to 2019. The CAGR to 2019 was used rather than 2020 due to the negative impacts from coronavirus in 2020. Overall, the CAGR from 2012 to 2019 was 2.5 percent, in line with the longer term CAGR for copper consumption (1970 to 2020) of 2.5 percent.

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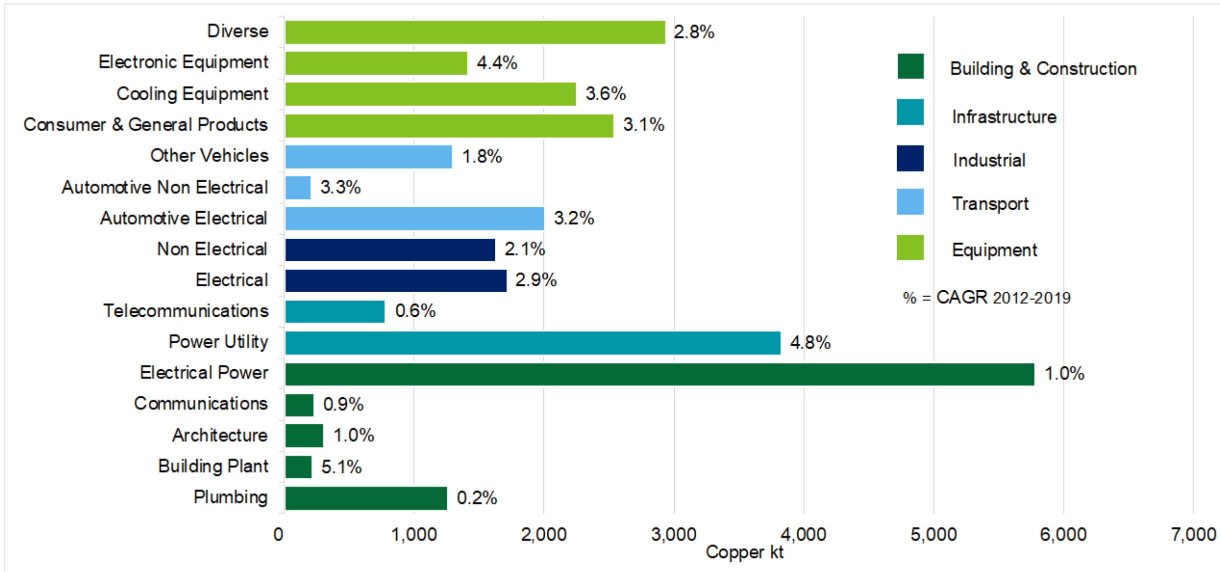
[22] ICSG

[23] To calculate the potential non-renewable energy demand increase for 2020 to 2030, the Deloitte team first excluded 'automotive electrical', as the benefits of EVs and the offsetting decline in ICE autos is already included in the renewables EV calculation. Second, the CAGR for the other sub-categories have been assumed constant, except for 'power utilities' and for 'industrial electrical applications' where the CAGR has been halved (due to existing high growth of renewables). In addition, the volume of non-renewable copper consumption in these two sub-sectors is estimated at 20 percent of the reported total. This reduction in volume in these two sub-sectors and elimination of 'automotive electrical' is equivalent to the 5.6 Mt of copper used in renewable energy in 2020 in Table 8, as calculated by the IEA.

Figure 18: Consumption of Semi-fabricated Copper by Application 2020



Source: International Wrought Copper Council (IWCC).

The result is an increase of 4.7 Mt in refined non-renewable energy-related copper consumption from 19.1 Mt in 2020 to 23.8 Mt in 2030, equivalent to a CAGR of 2.2 percent.

7.4. Total Refined Copper Demand

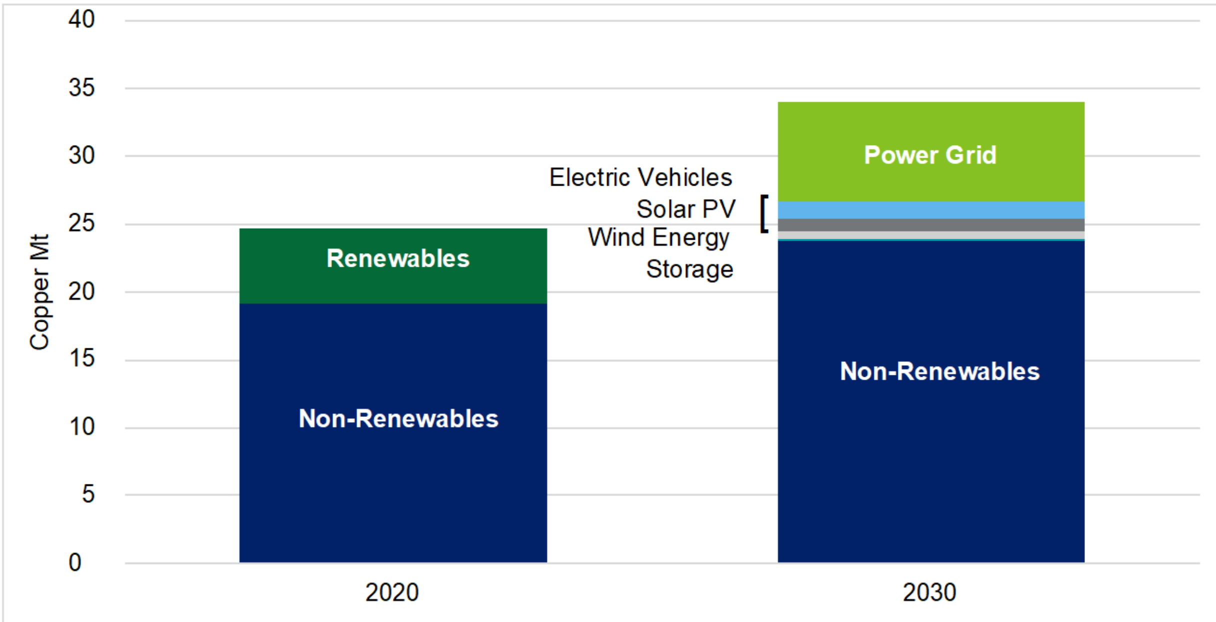
Table 9 and Figure 19 summarize the refined copper consumption forecast for 2020 to 2030 based on forecast increases in renewable demand from the IEA and increases in non-renewable demand based on historic CAGRs for the different sub-sectors of demand after removing renewable demand. Total refined copper demand is forecast to increase from 24.7 Mt in 2020 to 34.1 Mt in 2030, an increase of 9.3 Mt and a CAGR of 3.2 percent.

Table 9: Refined Copper Demand 2020-2030 (Mt)

	Refined Copper Consumption			
	2020	2030	Change	CAGR %
Total Renewable Energy Demand	5.60	10.22	4.62	6.2
Non-renewable Energy Demand	19.15	23.83	4.68	2.2
Total Demand	**24.75**	**34.05**	**9.30**	**3.2**

Source: Deloitte, IEA (SDS scenario).

Figure 19: Consumption of Semi-fabricated Copper by Application 2020



Source: Deloitte.

8. COPPER SUPPLY OUTLOOK

This section examines the main factors affecting the outlook for copper supply to 2030, including: brownfield mine expansions, new greenfield projects, potential constraints on future copper mine supply, and the consumption of recycled copper scrap.

8.1. New Copper Mine Supply

The outlook for mine copper production largely depends on:

- the longevity of existing mining operations and mine closures.
- the fall in production from grade declines over time;
- brownfield increases from capacity expansions and/or reserve extensions; and
- the number and size of new greenfield projects coming on-stream.

Understanding and forecasting each of these factors is key to estimating mine production going forward, although the copper market is very large with a large number of participants and many producers' data remains opaque. In addition, over the past decade, new environmental and other constraints on mine development/expansion have continued to increase in importance – particularly so for copper (see 8.2) – resulting in an added level of complexity when analyzing the copper supply outlook.

The Deloitte team assembled a copper project database of mines that have the potential to come onstream by 2030. This data was collected directly from company reports, technical papers, webinars, and news sources. This inclusive (albeit not comprehensive) project database contains 167 brownfield and greenfield projects that are either under construction or at various stages of development. It is likely that the database does not include some portion of projects at the smaller end of the market, and also reflects the opaqueness of the data available from Chinese, government or privately-owned mines. To address these concerns, some commodity researchers add an additional percentage to supply projections to cover 'off-radar projects.' Indeed, some estimates suggest that in the ten years of the last super-cycle, such off-radar projects accounted for 14 percent of the supply by 2014[24].

The project database is divided into three main categories: under development, probable, and possible projects. These contain both greenfield and brownfield projects, and the possible projects are further subdivided into lower- and higher-risk projects. The higher-risk possible list contains projects have higher development risks and may have a development horizon that is longer than 2030. Annex 4 contains the list of greenfield and brownfield projects under development and those in the probable and possible (low risk) categories.

8.1.1. Copper Projects Potential

Table 10 shows a summary of the copper projects incremental capacity that has the possibility to come on stream by 2030. The table suggests a total of 8.85 Mt of new copper supply becoming potentially available by that date. The table excludes additional high-risk projects that have a capacity of approximately 2.9 Mt, because they are not likely to achieve production before 2030.

Table 10 also includes mine closures over the period 2020 to 2030. An analysis of the top copper producers (accounting for 57 percent of total mined copper production) produced a forecast closure rate of 1.8 percent (of 2020 mine production) out to 2030.

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[24] Wood Mackenzie – Will a lack of supply growth come back to bite the copper industry, Mar 2021.

This appears quite low but likely reflects the quality of the orebodies held by the top producers and the brownfield expansion opportunities. The Deloitte team anticipates that this rate would be considerably higher for the remaining copper producers (accounting for 43 percent of total production) as they are likely to have a higher percentage of smaller, shorter-life orebodies. Furthermore, the brownfield expansions of this group might also be expected to carry a higher risk of not achieving financing. Consequently, an overall closure rate of three to five percent is anticipated. Table 10 shows a five percent closure rate.

Table 10: Summary of Copper Projects

Type of Projects	Incremental Cu Capacity t 2020-2030
Greenfield Under Development	1,694,050
Brownfield Under Development	2,052,272
Probable Greenfield	1,574,053
Probable Brownfield	1,339,516
Possible Lower-risk Greenfield	2,166,655
Possible Lower-risk Brownfield	1,077,150
Mine closures (5 percent)	(1,052,200)
Total	**8,851,496**

Source: Deloitte

Brownfield production estimates only reflect net new production, not the full project capacity. Illustrating this point, Annex 3: Copper Project Tables shows several brownfield projects that result in net zero incremental capacity, or even result in a net decline in production levels over the period 2020-2030, even though the mine life may be extended by the new production coming onstream. In addition, it is unlikely that all the capacity shown in Table 10 will come onstream by 2030; a risk adjusted approach to evaluating future predictions is essential and is analyzed in Section 8.3.

8.2. Constraints on Copper Supply

The copper mining industry faces a range of challenges over the next decade. There are four broad issues facing the copper industry: (i) grade decline and the depletion of reserves; (ii) climate change impacts; (iii) ESG pressures; and (iv) political and regulatory issues.

8.2.1. Grade Decline, Depletions, and Financing

In recent years, ore quality has continued to decline across all commodities as higher-grade deposits (and the elevated-grade portions within those deposits) are worked out. For example, the average copper ore grade in Chile has decreased by 30 percent over the last 15 years.[25] By increasing throughput, many existing mines can mitigate this effect to some degree and new mines can operate economically at lower grades through scale and the implementation of new technology. Extracting metal content from lower-grade ores requires more energy, however - thereby exerting upward pressure on extraction and processing costs and potentially increasing carbon dioxide (CO_2) emissions. Lower-grade ores also generate larger amounts of rock waste and tailings that require careful handling and treatment.

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[25] IEA

Ore grade declines and depletions require continued investment in new brownfield and greenfield resources. Based on industry-wide capital intensity data[26], the cost of a brownfield expansion for an existing mine and plant is about $13,600 per t/y of copper capacity; for greenfield projects investment needs are estimated to average about $18,250 per t/y of copper capacity. This suggests that around $160 billion of investment would be required for all of the capacity in Table 10 to come onstream. However, raising finance for some projects at lower grades and rates of return is likely to be difficult.

8.2.2. Climate Change

Despite the requirement for more copper to meet the world's climate change targets, it may become more challenging to produce refined metal as restrictions on industrial activity tighten. The ICSG reports that the emissions profile of copper is attractive when benchmarked against other non-ferrous metals - including its closest substitute, aluminum − and this may encourage governments to prioritize copper's development. Indeed, Brazil's recent Decree No. 11,120 to promote the development of its lithium industry is a good example of how this type of prioritization is already happening with other critical minerals.

8.2.3. Environmental, Social, and Governance

Responsible mining companies recognize that a proactive approach to ESG issues is the key to achieving an effective 'social license to operate within a country and local community. That said, ESG issues and expectations are evolving rapidly, reflecting the more complex world – and increasingly diverse stakeholder groups – that mining companies are now required to manage. Figure 20 highlights some of the ESG issues of concern to the mining industry generally, and the copper industry in particular, and how those ESG risks[27] relate to a series of countries. This analysis focuses on nine countries (including Brazil) that have witnessed significant increases in socio-environmental protests over new extractive projects in the last 15 years. The combined score reveals that eight of nine countries are classified as high risk, although conditions in Chile (the one non-high-risk country) have since deteriorated (see 8.2.4). It is also noteworthy that indigenous rights are listed as 'high' or 'extreme risk' in every jurisdiction.

[26] Southern Copper February 2022.

[27] As calculated by Verisk Maplecroft - a global risk and strategic consulting firm) vary by country.

Figure 20: Issues Central to Mining Companies' Social License to Operate

Industry	Aggregate	Corruption	Indigenous Peoples' Rights	Civil Unrest	Security Forces and Human Rights	Labour Rights	Water stress
Peru	High 4.57	High	High	High	Medium	High	Low
Argentina	High 4.41	High	High	High	High	Medium	Medium
Chile	Medium 5.66	Low	High	Medium	Medium	High	Medium
Colombia	High 4.87	High	High	High	High	High	Low
Ecuador	High 3.66	High	High	High	High	High	High
Brazil	High 4.91	High	Extreme	High	High	Medium	Low
Bolivia	High 4.41	High	High	High	High	High	Low
Venezuela	High 3.29	Extreme	High	Extreme	Extreme	High	Low
Mexico	High 3.44	Extreme	High	High	High	High	High

Legend: Extreme risk 0-2.5 High risk >2.5-5 Medium risk >5-7.5 Low risk >7.5-10

Source: Verisk Maplecroft 2019.

Water shortages are a serious problem in many countries. In recent years, a combination of more frequent drought events in major copper producing regions and higher water intensity in ore processing has highlighted the critical importance of sustainable water sourcing. This issue is particularly acute in Chile, where mines are in high water stress and arid areas, and where water shortages are already impacting copper production. Copper mines are particularly vulnerable to water stress given their high-water requirements. Some mining companies in Chile are responding to the social concerns, possible legislative change, and the reality of shrinking freshwater reserves by investing in water management technologies and alternative water sources, such as desalination.

8.2.4. Political and Regulatory

Regulatory issues are relevant to the broader mining industry, but they can also be geographically focused and/or specific to the copper industry. Table 11 shows Control Risks'[28] country ratings for major copper producing countries. All countries listed exhibit medium to high political, operational, and security ratings, except Chile. Chile's political risk was recently raised however, from low to medium, due to increasing numbers of protests throughout the country. In addition, the Government of Chile is currently promoting a bill for royalty and tax changes that could significantly increase the tax burden for copper producers.

Both Chile and Peru have recently seen significant civil unrest and labor disruptions. Ecuador and Argentina have also experienced demonstrations, creating an uncertain or unpredictable political and economic environment; there is particularly strong social opposition to mining operations in certain parts of Argentina. Over the past few years, political protests in Peru have blocked access to the shipping ports and main transportation routes and have forced the Peruvian government into contentious negotiations over indigenous land rights and environmental concerns.

[28] https://www.controlrisks.com/campaigns/mining.

Table 11: Control Risks Country Ratings

Country	Political	Operational	Security	Terrorism
Chile	Medium	Low	Low	Low
Peru	Medium	Medium	Medium	Low
Argentina	Medium	Medium	Low	Low
DRC	High	High	Medium	Low
Indonesia	Medium	Medium	Medium	Medium
Mexico	Medium	Medium	Medium	Low
Philippines	Medium	Medium	Medium	Medium
Mongolia	Medium	Medium	Medium	Nil
PNG	High	High	High	Nil

Source: S&P Global Intelligence, Control Risks.

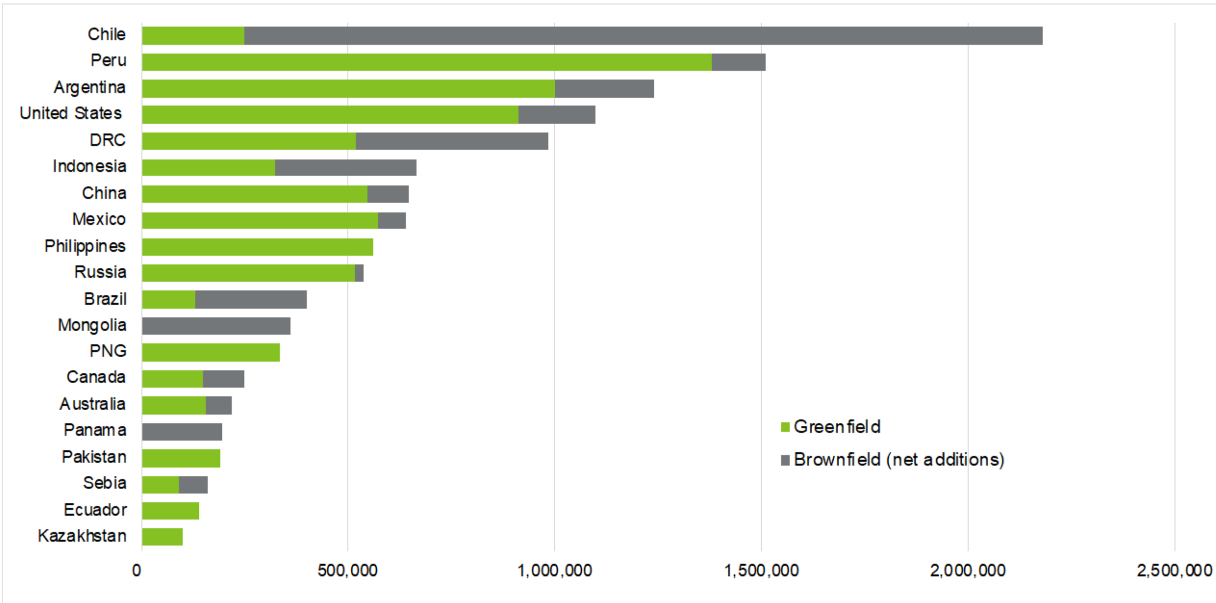
Unrest has negatively impacted copper production in multiple countries, and there have been several high-profile protests and blockades specifically targeted against copper mining and exploration projects by local communities.

Meanwhile, mining companies continue to face increasing layers of regulation and scrutiny to get key mining permits granted – such as the glacier protection legislation which recently enacted and applied in Argentina. Similar legislation is also advancing through Congress in Chile.

8.3. Summary of New Mine Supply Potential

Figure 21 shows a country breakdown of copper project capacity expansions, broken down by greenfield and brownfield capacity increases. This highlights the dominance of potential new capacity coming from South America, while the U.S. and the DRC also have a large amount of potential new production coming onstream.

Figure 21: Copper Project Capacity Expansions by Country (2020-2030)



Source: Deloitte. NB Includes Possible – high risk projects.

The mining industry has a history of project delays; it is inevitable that some projects will fall short of the timescale given in Table 10, or potentially not succeed at all. With 43 percent of new potential copper production centered in South America and increasing ESG and other issues challenging mine development in that continent (as outlined in Section 8), many news reports are now suggesting that the copper market will be in significant deficit by 2030. Research companies including Goldman Sachs[29], Wood Mackenzie, and Citigroup have also published data suggesting that the potential for a deficit in copper supply is significant.

To estimate potential copper production increases by 2030, and to understand the sensitivity of these assumptions, Table 12 applies a range of discount factors to the probable and possible copper project data previously generated in Table 6. The projects under development are all assumed to achieve production. The mine supply figures also have a five percent disruption allowance subtracted from the result. Based on this range of risk factors, copper mine supply in 2030 is estimated to range from 4.8 to 7.2 Mt; this is further discussed in Section 8.4 (below).

[29] Copper is the New Oil - April 2021.

Table 12: Potential Increase in Copper Mine Supply 2020-2030 (Mt)

		Risk factor applied to Probable Projects				
		50%	60%	70%	80%	90%
Risk factor applied to Possible Projects	30%	4.82	5.09	5,37	5.65	5.92
	40%	5.12	5.40	5.68	5.95	6.23
	50%	5.43	5.71	5.99	6.26	6.54
	60%	5.74	6.02	6.29	6.57	6.85
	70%	6.05	6.32	6.60	6.88	7.16

Source: Deloitte. NB Results include a 5% disruption factor.

8.4. Summary of Refined Supply Potential

Refined copper supply includes mine production supply and old copper scrap. The scrap supply in the past decade has been 14.5 to 18.7 percent of new mine production, which means that the level of scrap will also rise out to 2030, along with increases in mine production, smelter production, and refined production.

Under a bear case scenario, with additional copper mine supply of 4.82 Mt (from Table 12) and additional scrap supply of 0.44 Mt (14.5 percent), refined copper production would increase by 5.26 Mt in 2030. Under a bull case scenario, with copper mine supply of 7.17 Mt (from Table 12) and additional scrap supply of 1.97 Mt (18.7 percent), refined copper production would increase by 9.12 Mt in 2030. This gives an increase of 5.3 to 9.1 Mt equivalent to a total of 29.6 Mt to 33.5 Mt for refined copper production in 2030.

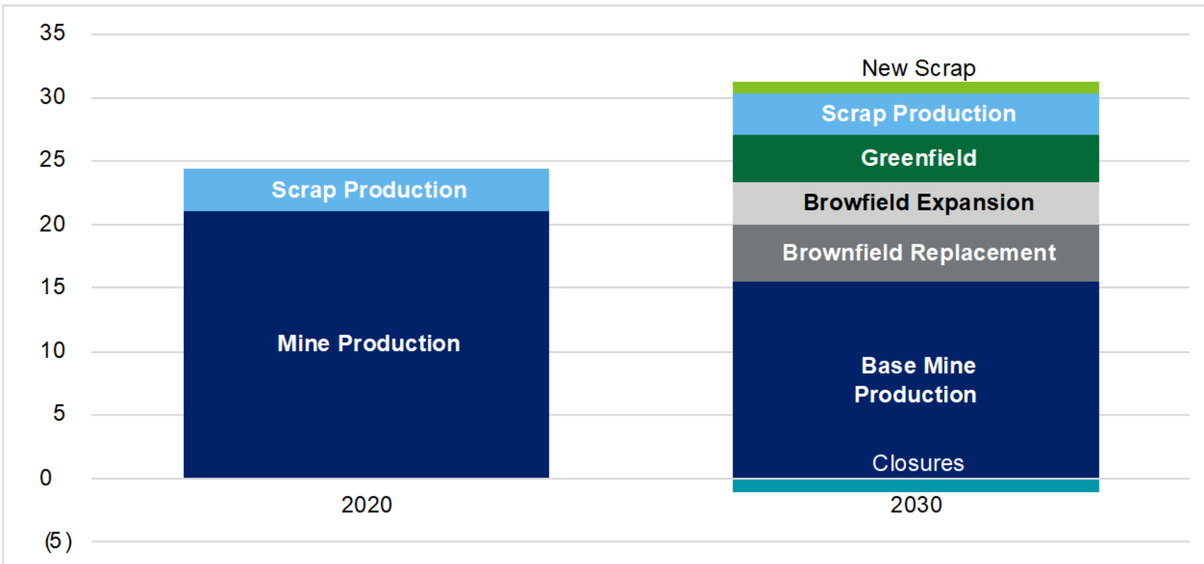
Table 13: Refined Copper Supply (Mt)

Scenario	Mine Production	Scrap Supply	Refined Production Increase	2020 Refined Production	2030 Refined Production
Bear Case	4.82	0.44	5.26	24.35	29.61
Base Case	5.99	1.18	7.17	24.35	31.52
Bull Case	7.16	1.97	9.12	24.35	33.47

Source: Deloitte.

The mid-point base case scenario assumes a 70 percent risk factor applied to probable projects, a 50 percent risk factor applied to possible projects, a five percent disruption factor and a 16.6 percent scrap supply ratio. This results in new copper mine supply of 5.99 Mt and an increase in scrap supply of 1.18 Mt to give a total increase of refined copper production of 7.17 Mt in 2030, equivalent to a total of 31.5 Mt and a CAGR of 2.6 percent. Table 13 shows the summary of the outlook for refined copper supply. Figure 22 shows the base case scenario for refined copper supply in 2030.

Figure 22: Copper Refined Supply Forecast 2020 and 2030 (Mt)



Source: Deloitte. NB Brownfield Replacement = Deloitte estimate based on analysis of top copper producers.

8.5. New Brazilian Mine Production

Salobo and Sossego are both expected to continue expanding production through development of satellite deposits and become processing hubs (see 4.2.2). In addition, based on available data, Brazil has one active copper project at late-stage development (Boa Esperanza), and one project at prefeasibility stage (Alemao) which the Deloitte team included in the project database, and expect to be operating by 2030. The Deloitte team did not include Primavera, a small copper project at prefeasibility in the database because production is anticipated beyond 2030, but is included in some of the economic competitiveness charts (see section 10).

Bao Esperanza is an IOCG-type copper deposit located in the State of Pará and is owned by Ero Copper [TSX: ERO]. The company also operates the MCSA Mining Complex producing copper in the state of Bahia. Detailed engineering design is currently underway, and early construction works were expected to commence during first half of 2022. An optimized feasibility study was completed in September 2021, which anticipates a 12-year mine life with average copper production of 27 kt/y and cash costs of $1.12/lb with an initial CAPEX of $294 million.

Alemao is also an IOCG-type copper-gold deposit located in the State of Pará and is owned by Vale S.A. It underlies the partly depleted Igarape Bahia gold mine that operated between 1991 and 2002. The mine is expected to produce an estimated 150 kt/y of copper concentrate (60 kt/y copper) and 218 koz/y gold. Alemeo is a project that has qualified under the Brazil's Pro-Strategic Minerals Policy, which is designed to streamline approvals and permitting procedures to accelerate production.

Primavera is a small copper project owned by Aguia Resources [ASX: AGR] and located in Rio Grande do Sul. The project is at pre-feasibility stage and anticipates producing 3,600 t/y of copper over a 14-year mine life. It has a low CAPEX and high capital efficiency (NPV/CAPEX).

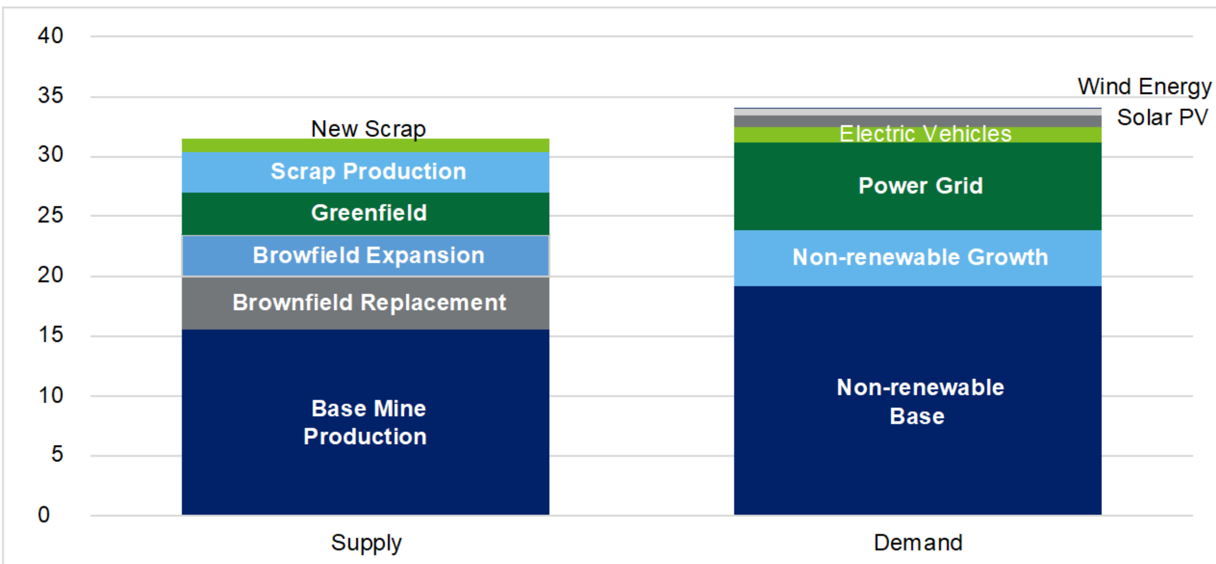
9. MARKET BALANCE AND PRICE OUTLOOK

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

9.1. Copper Market Balance

The Deloitte team's analysis shows that refined copper supply from mine production and scrap under the base case forecast could increase to 31.5 Mt while demand forecasts suggest refined copper demand could increase to 34.1 Mt in 2030, under the base case scenario. This suggests a potential deficit of 2.6 Mt. Figure 23 shows the supply and demand balance.

Figure 23: Refined Copper Supply and Demand Forecast 2030 from 2020 Base



Source: Deloitte. Uses base case supply forecast. NB Brownfield Replacement = Deloitte estimate based on analysis of top copper producers.

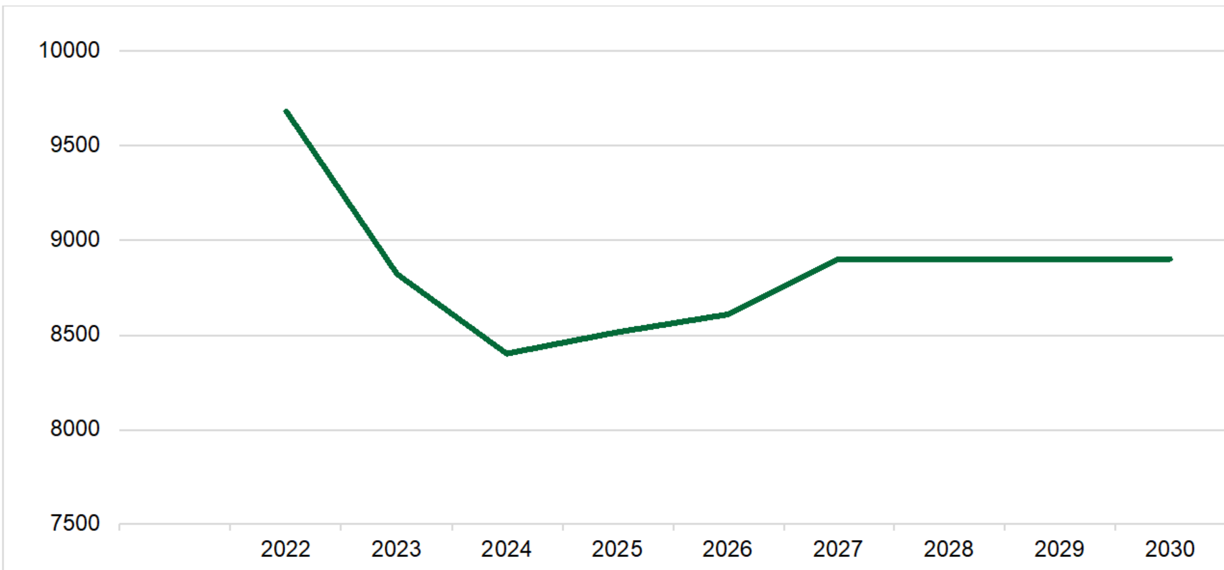
Under the supply bear case where refined copper supply totals 29.6 Mt, the supply deficit increases to 4.4 Mt. Under the supply bull case where refined copper supply totals 33.5 Mt the supply deficit decreases to 0.6 Mt. The implication is that high copper prices (relative to history) are likely to continue and will need to be high enough to encourage additional new greenfield capacity or brownfield expansions to come on stream.

In the longer term, copper will increasingly benefit from growing demand in the renewable sectors, mainly EVs, solar PV, wind turbines, as well as related grid and recharging infrastructure.

9.2. Price Forecast

Figure 24 shows the consensus price forecasts for copper out to 2030 as forecast at May 2022 and shown in nominal terms. The outlook is for the price to decline from its current levels but remain in a long-term range of \$8,400/t to \$8,900/t (\$3.80/lb to 4.00/lb)[30].

Figure 24: Consensus Price Forecast for Copper



Source: Consensus Economics.

While prices are partly a function of supply and demand and inventory levels, costs are also important and copper operations are currently being impacted by the rising cost of energy, as production of copper is energy intensive.

[30] Consensus Economics.

10. ECONOMIC COMPETITIVENESS

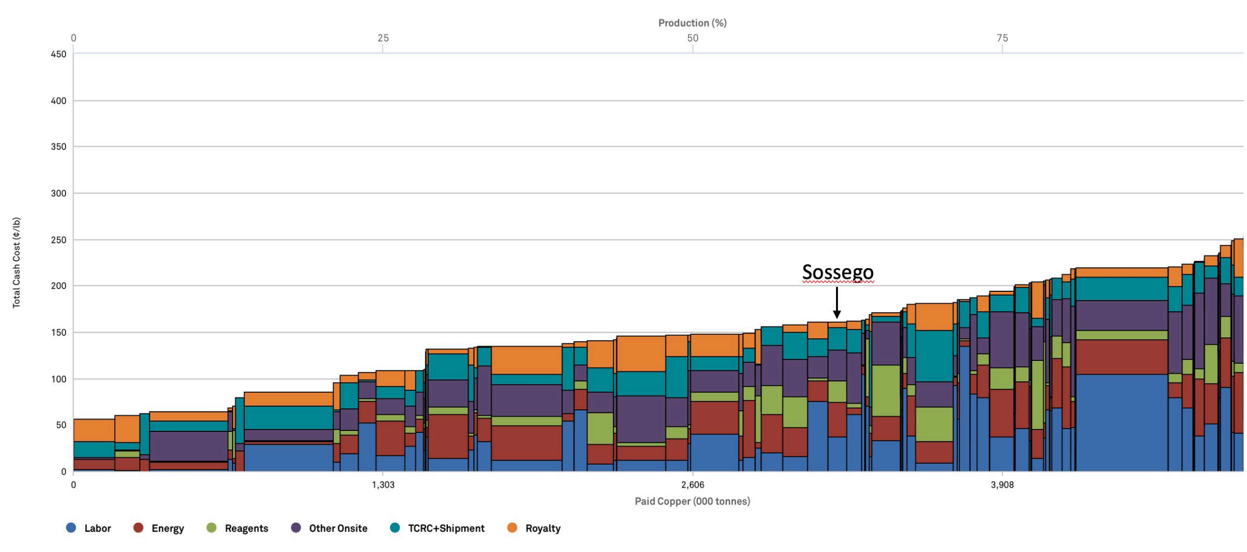
This section reviews existing mine operating costs and the economic parameters of copper projects yet to come on stream. The charts provide useful benchmarks for companies, investors, finance providers, and governments for potential new copper projects.

10.1. Brazilian Copper Production

Brazil has eight producing copper mines, although production is dominated by two mines, Salobo (producing 145 kt/y) and Sossogo (82 kt/y). Between them these two operations accounted for 65 percent of Brazil's copper production in 2021. The other six mines are considered to be mid- to small-scale. Two additional copper projects expected to come onstream in the period to 2030 - Bao Esperanza (27 kt/y) and Alemao (60 kt/y) - are also small-to-mid sized operations. The scale of Brazil's copper production is partly a product of the local dominance of IOCG resources, which tend to be smaller in scale than the porphyry copper deposits that are found in abundance elsewhere in South America and in other regions globally. As a result, Brazil only accounts for 0.6 percent of global copper reserves and resources, 1.6 percent of global production, and currently Brazil does not have any large-scale copper resources that could be developed to support a significant scale copper mine (at least 100 kt/y – see Figure 7).

Figure 25 highlights the position of Brazilian copper mine Sossego on the global total cash cost curve sourced from S&P Global Intelligence. Mine costs are identified and categorized in six items; labor, energy, reagents, other onsite, treatment and refining charges (TCRC) and shipment, and royalty. Other onsite covers other minor items, and the sum matches company disclosure.

Figure 25: Copper Production Ranked on Total Cash Cost US$/t in 2020



Source: S&P Global Intelligence.

This mine economics data, however, covers only 25 percent of 2021 global mine copper production, and data is unavailable for the seven other copper mines in production in Brazil. Sossego is at the middle of the cost curve, with average costs for each of the six categories and no particular competitive advantage in any of the cost categories.

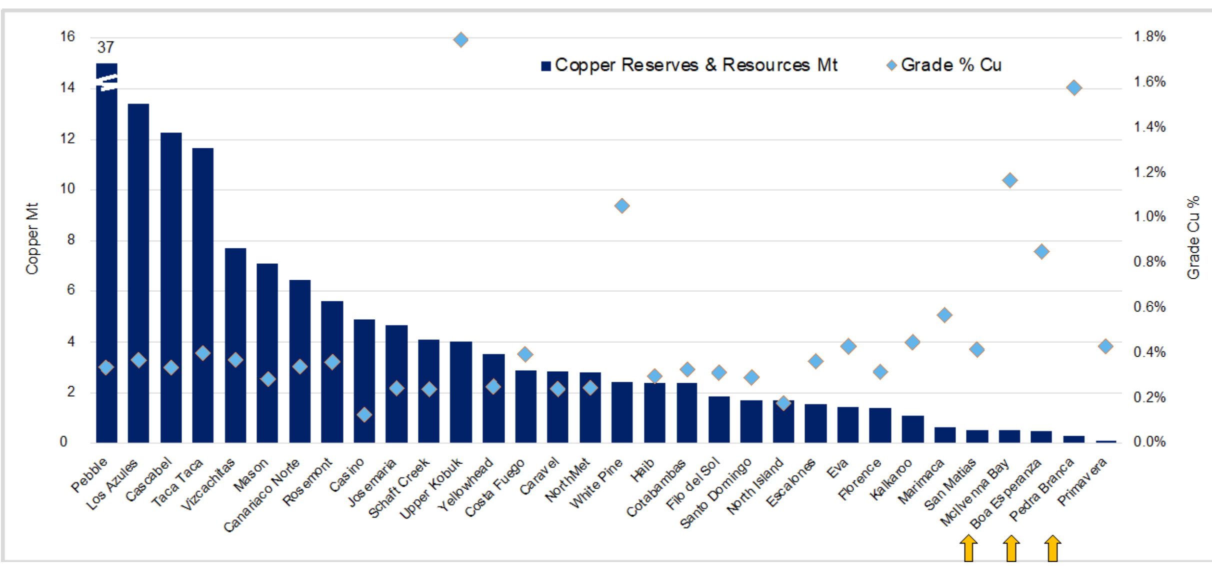
10.2. Comparison of Project Feasibility Studies

The Deloitte team has evaluated data from companies that have produced recent feasibility, pre-feasibility, and scoping study reports for the market (this is typically done as part of the process of developing projects) for 33 copper projects. The project list includes three projects in Brazil, Boa Esperanza (commissioning stage), Pedra Branca (a new producer), and Primavera (pre-feasibility stage). This allows an element of benchmarking for these three projects against global competitors. Data for other Brazilian projects is not available.

These projects contained reserves and resources of 151 Mt copper. The United States accounted for 39.8 percent of the contained copper, Argentina 20.9 percent, Canada 9.8 percent, and Chile 9.6 percent. Overall South America accounted for 45.3 percent.

Figure 26 shows the resource and grade of these 33 projects, with the three Brazilian projects highlighted. All three projects have a relatively small resource, although both Boa Esperanza (0.85 percent) and Pedra Branca (1.58 percent) have above average grades. The weighted average grade of the projects is 0.39 percent copper.

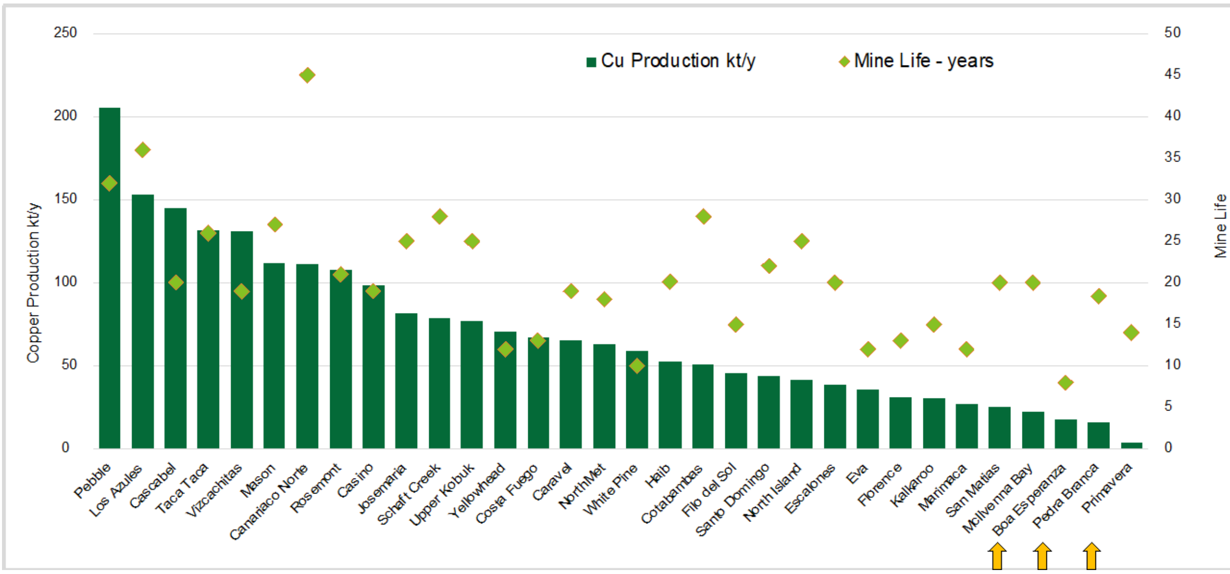
Figure 26: Copper Projects: Resources (Mt) and grade (% Cu)



Source: Company data, Deloitte.

Figure 27 shows the projects ranked by the planned production capacity and the life-of-mine in years. It highlights that the three Brazilian projects are relatively small in production size. The average mine life of the group is 20 years and the average production 68 kt/y copper.

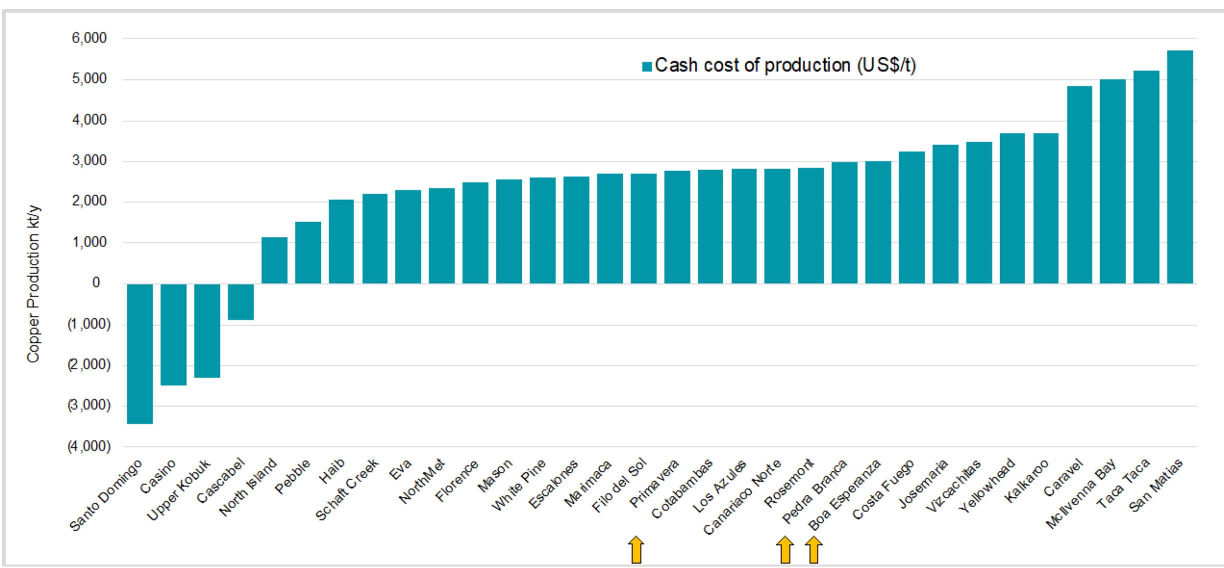
Figure 27: Copper Projects: Production Capacity (t/y) and Mine Life (years)



Source: Company data, Deloitte.

Figure 28 shows the projects ranked by projected operating costs. Operating costs include by-product credits, resulting in some projects having negative operating costs. Relative to this group, the Brazilian projects are average cash cost operations. The average weighted cost of operation of the group (including by-product credits) was $2,321/t ($1.05/lb) copper.

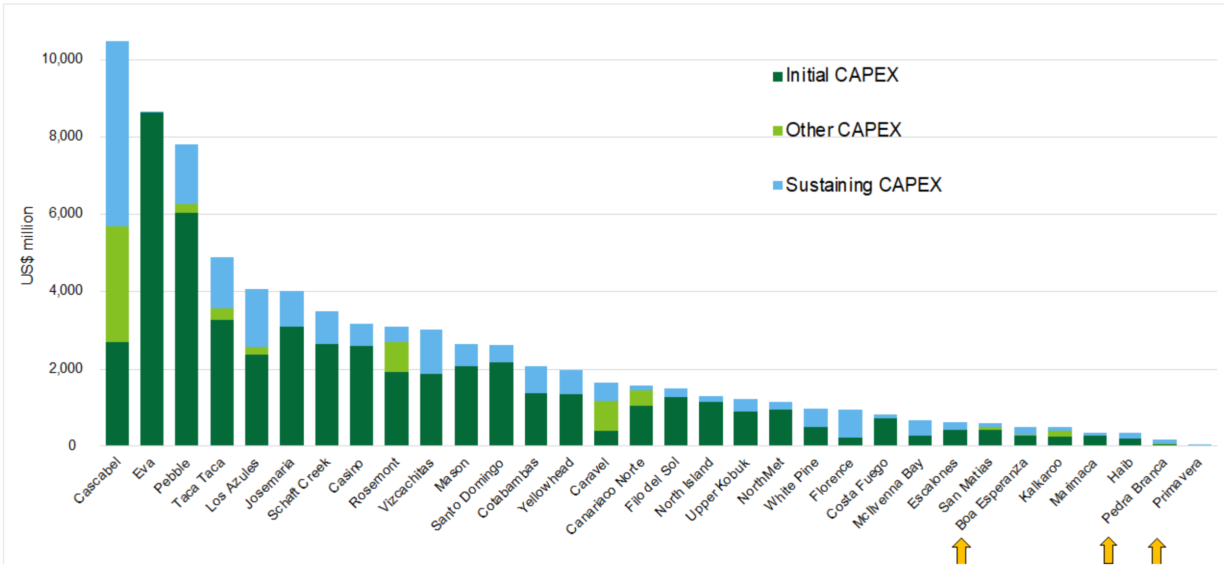
Figure 28: Copper Projects: Operating Costs ($/t)



Source: Company data, Deloitte.

Another important factor in the economics of a mining project is the CAPEX required to establish and operate the mine. This includes the initial CAPEX, other CAPEX for later expansions, and sustaining CAPEX (usually for the replacement of plant and machinery).

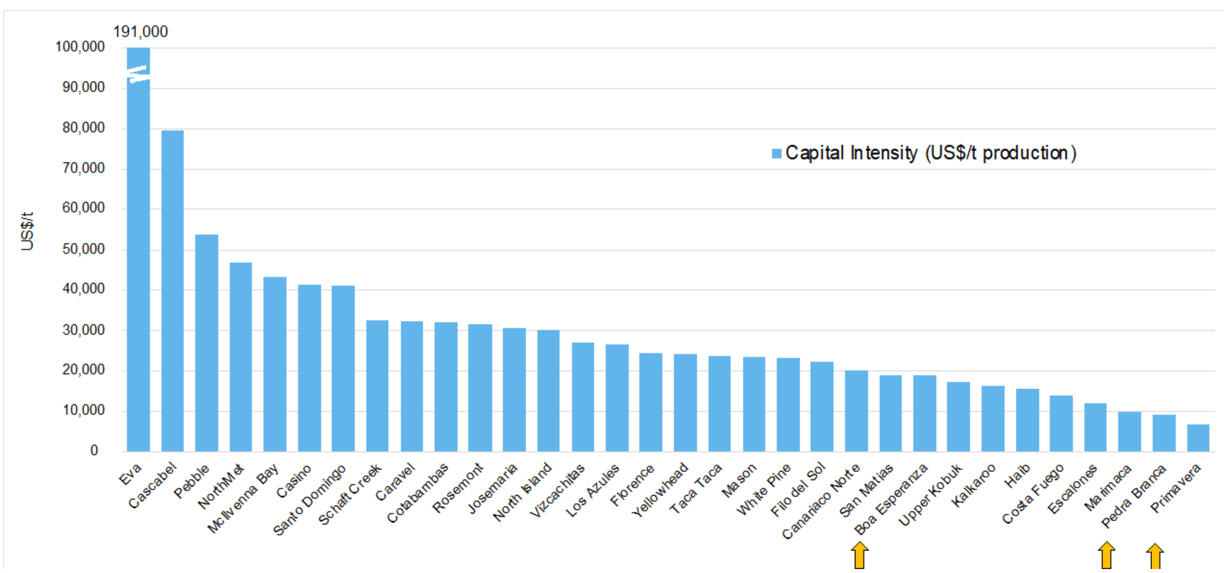
Figure 29: Copper Projects: LOM Capital Expenditure ($m)



Source: Company data, Deloitte.

Figure 29 show the CAPEX of each of the copper projects. Companies usually focus on the initial CAPEX, but it is important to consider the CAPEX over the life of the mine (LOM) for project comparison. The project CAPEX can often vary due to the orebody location, depth, orientation, ore type, recovery methods, and the amount of labor and energy consumed in the process. This then has an important bearing on the economics of the project. The three Brazilian projects have relatively low CAPEX requirements as would be expected by their comparatively smaller size.

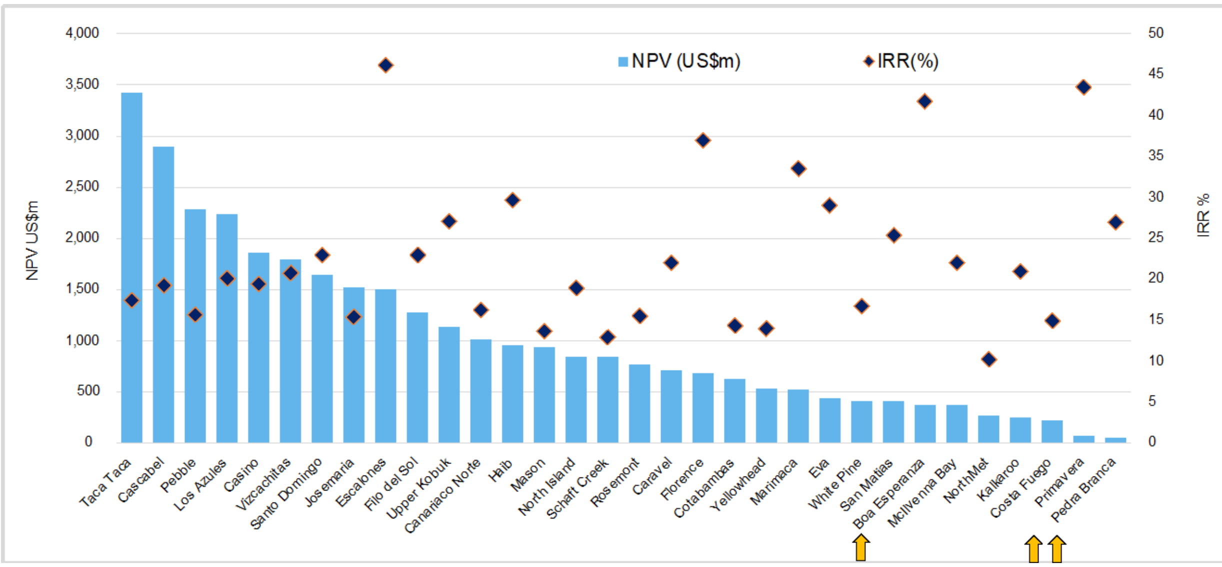
Figure 30: Copper Projects: Capital Intensity – Total Capex per Tonne Annual Production ($/t)



Source: Company data, Deloitte.

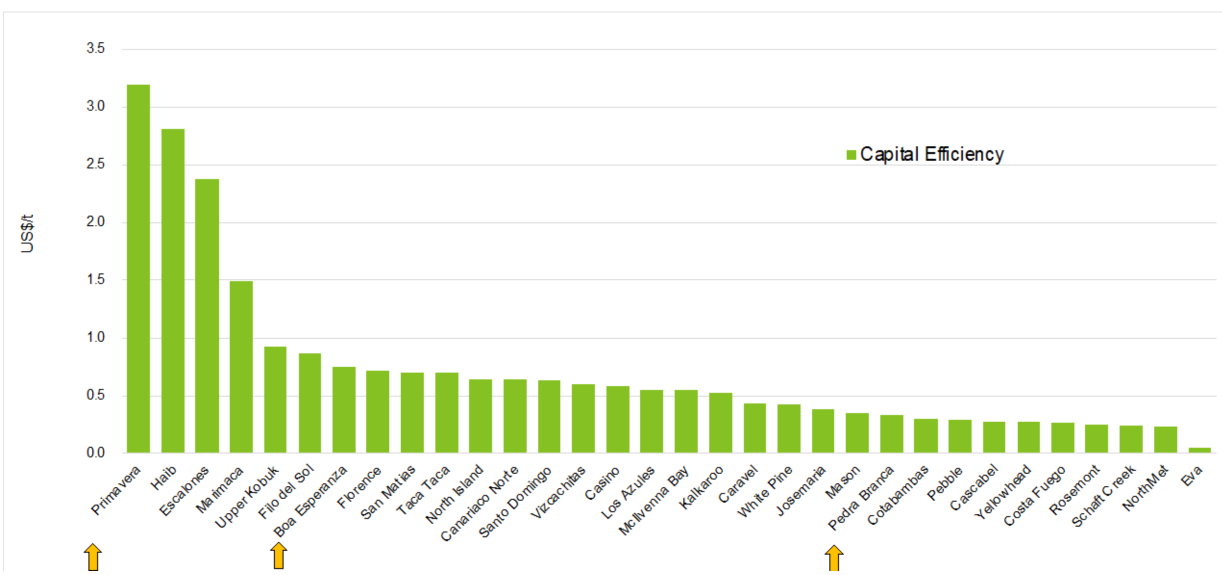
Capital intensity is often used to compare projects. Figure 30 shows the capital intensity of the projects based on average annual copper production over the whole life of the project. The three Brazilian projects have relatively low capital intensity. The weighted average for the group is $34,338/t copper.

Figure 31: Copper Projects: NPV ($m) versus IRR (%)



Source: Company data, Deloitte.

Figure 32: Copper Projects: Capital Efficiency (NPV/Capex)



Source: Company data, Deloitte.

The ultimate measure of economic viability is the NPV and the IRR. Figure 31 shows both the NPV and IRR of the projects, although they are not totally comparable because of varying assumptions used. Post-tax values are shown. The average input price was $7,175/t ($3.25/lb) copper. The median IRR of this group was 21 percent (the average is distorted by a few high values), which suggests generally good returns. The returns of the three Brazilian projects are higher than average, with particularly strong returns for Primavera (43.5 percent) and Boa Esperanza (41.8 percent). Figure 32 shows that the Primavera and Boa Esperanza also have a relatively favorable capital efficiency (NPV/CAPEX).

11. CONCLUSIONS

This section provides a summary of the overall market analysis for copper, outlines some of the issues surrounding the forecasts, and explains how these issues could impact the outlook for copper supply and demand. This section also examines potential threats and opportunities in the market.

11.1. Copper Market Issues

The copper market is large in terms of volume and broad in terms of end uses and has a large number of market participants from exploration, through mining, smelting, refining, and fabricating. While less opaque than some markets, its size makes the gathering and analysis of market data more difficult than many other commodities.

On the supply side, the copper mining industry faces a range of challenges over the next decade, including grade decline and the depletion of reserves, climate change impacts, ESG pressures, and political and regulatory issues. In addition, the copper market could also be affected by the potential for continued restrictions on Russian exports, as a result of that country's invasion of Ukraine. Russia is the eighth largest producer of copper, accounting for four percent of global production in 2021, and although the scale and scope of possible sanctions against this output are not yet fully clear, the threat of such action nonetheless has the potential to create additional market insecurity and supply disruptions

On the demand side, copper plays a central role in the ongoing decarbonization movement within energy markets. Copper enables renewable energy generation technologies, the implementation of EV battery technologies, and the construction of and interconnection with grid infrastructure. While a significant positive for copper demand, the pace of implementation and uptake of renewable energy and EVs remain uncertain. Substitution, principally by aluminum, also remains an issue and is negative for copper demand, although is partly a function of relative prices, but may continue at existing price levels. These supply and demand issues add a layer of uncertainty and risk to any forecasts made in the outlook for copper.

Considering these factors, the Deloitte team's analysis of the supply and demand outlook shows that new copper mine production and increases in scrap supply are currently unlikely to be able to meet increases in refined copper demand in 2030. Demand in 2030 is forecast at 33.5 Mt and the base case suggests a supply deficit of 2.6 Mt. Under the supply bull case, the supply deficit declines to 0.6 Mt. Under the supply bear case, the supply deficit increases to 4.4 Mt. This suggests that more investment is required in greenfield and brownfield production, which will likely require high copper prices (relative to history).

Consensus currently expects copper prices to remain in a long-term range of $8,400/t to $8,900/t ($3.80/lb to 4.00/lb), compared with an average of $6,704/t ($3.04/lb) from 2010 to 2020. Meanwhile, the industry is currently facing cost pressures, particularly from higher energy prices, but at these price levels the copper industry will make above average returns over the period. This presents opportunities for existing copper producers and new projects to capture potential higher returns of the forecast market deficit.

11.2. Key Recommendations

The Government of Brazil should continue to further develop its resources to meet global demand and encourage investment in the longer term by:

- **Streamlining access to, and circulation of, up-to-date domestic copper resource data to domestic and international exploration companies to encourage exploration and to promote copper development in Brazil.** This may require gathering and distributing more extensive information for those regions considered to have significant copper potential, including the Carajás district in the state of Pará. 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.
- **Ensuring copper producers (currently 15 mines and projects) utilize Brazil's low-cost and low-emissions hydroelectric power or other renewables.** In 2020, 66 percent of Brazil's electricity generation came from hydropower, although most of the capacity is located in the north. Brazil has abundant wind resources, and wind capacity is increasing in the south, and solar is increasing rapidly from a low base. Access to low-cost and low-emissions hydroelectricity or other renewables in Brazil would give copper producers a competitive advantage in their operating costs and carbon footprint. The copper market is increasingly focused on the carbon footprint of copper producers.
- **Ensuring Brazilian copper projects achieve timely production by 2030 to capture potential higher returns of the forecast market deficit in 2030.** The Deloitte team anticipates that two development projects (Boa Esperanza and Alemao) could come into production by 2030. If this is the case, these projects will likely benefit from the forecast copper market deficit and higher prices noted above that are expected to occur by that date. These projects have already applied and received acceptance for assistance under the *Policy for Supporting the Environmental Licensing of Investment Projects for the Production of Strategic Minerals* (Decree No. 10,657 of March 24, 2021).[31] The Government of Brazil has already selected Boa Esperanza and Alemao, plus the early-stage Pantera exploration project owned by Avanco Resources[32], and a dozen other mining projects to receive accelerated environmental licensing support.
- **Developing downstream processing facilities to capture more of the copper value chain domestically.** A portion of Brazil's copper concentrate production could be refocused from direct exports towards the downstream development of facilities to produce more domestically refined copper. Proactive marketing by the Government of Brazil with existing global mining, smelting, and refining companies (including Vale S.A.) could then lead to the development of further copper cathode facilities in Brazil. Preferred access to clean hydropower has the potential to make such facilities, and the cathode copper they produce, particularly attractive to end users in the renewables industry.

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[31] The Pro-Strategic Minerals Policy has been qualified under the Investment Partnerships Program (PPI), which is a government entity dedicated to expanding and accelerating the implementation of projects with the participation of the private sector in Brazil. Accordingly, if it meets specific criteria, the company that has a project of a mineral deemed strategic, may request that their project be qualified as a PPI project.

[32] https://www.gov.br/mme/pt-br/assuntos/secretarias/geologia-mineracao-e-transformacao-mineral/ctapme

ANNEX 1 – COPPER ORES AND RESOURCES

Copper deposits are found worldwide in a variety of geological environments and economic concentrations. The most significant deposit type is porphyry, followed by sediment hosted and IOCG deposits. Each deposit type has characteristic ore tonnages, copper grades, and associated metals with some details summarized in Table 14.

Table 14: Main Copper Deposit Types

Deposit Type	Description	Examples
Porphyry	Large relatively low grade stockwork to disseminated deposits related to intrusions	Chuquicamata and Escondida, Chile; Bingham Canyon, USA; Grasberg, Indonesia
Sediment-hosted	Strata-bound disseminations of copper minerals occurring in a range of sedimentary rocks	Nchanga, Zambia; Lubin, Poland; White Pine, USA
IOCG	Mineralization systems that have abundant iron mineralization combined with hydrothermal ore styles and strong structural controls.	Salobo, Sossego, Brazil; Olympic Dam, Ernest Henry, Australia; Manto Verde, Chile.
Red-bed	Copper mineralization occurring in oxidized zones in sedimentary and volcanic rocks	Dzhezkazgan, Kazakhstan; Mantos Blancos, Chile
Volcanic massive sulphide (VSM)	Mineralization hosted by submarine volcano-sedimentary sequences	Bathurst and Kidd Creek, Canada; Rio Tinto, Spain
Magmatic Sulphide	Sulphide concentrations associated with a variety of mafic and ultramafic magmatic rocks	Sudbury and Voisey's Bay, Canada; Norilsk, Russia; Kambalda, Australia
Sedimentary exhalative	Polymetallic sulphides deposited from hydrothermal fluids vented into sedimentary basins with no obvious volcanic source	Broken Hill and McArthur River, Australia; Red Dog, Alaska
Epithermal	Veins, stockworks, and breccias associated with high-level or near-surface volcanic related low temperature hydrothermal systems	El Indio, Chile; Lepanto, Philippines; Monywa, Burma
Copper skarns	Mineralization formed by chemical alteration associated with intrusions into carbonate rocks	Ok Tedi, PNG; Copper Canyon, USA; Rosita, Nicaragua
Vein-style	Mineralized structures often developed along fractures from a variety of sources	El Indio, Chile; Copper Hills, Australia; Butte, USA
Supergene	In-situ natural secondary enrichment of primary mineralization	Erdenet, Mongolia; Escondida, Chile; Sarcheshmeh, Iran

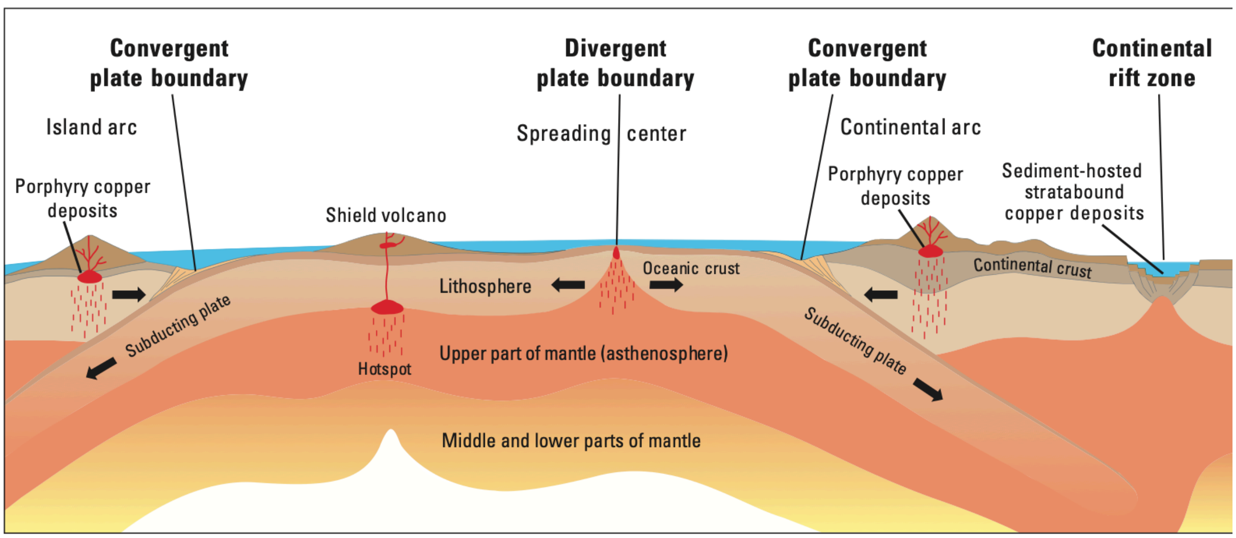
Source: BGS.

Porphyry Copper Deposits

Porphyry copper deposits consist of copper minerals in disseminations and veins that are distributed throughout large volumes of igneous rock. Copper ore minerals, typically chalcopyrite ($CuFeS_2$) or bornite (Cu_5FeS_4), were deposited from high-temperature fluids associated with magmas as they cooled. The fluids that carried copper in solution interacted with and altered rocks, forming new assemblages of alteration minerals and depositing copper. Porphyry copper deposits are large-tonnage, low-grade deposits that typically are mined in large open pits. Copper grades typically are less than 1 percent and molybdenum, gold, and silver are also recovered from many porphyry copper deposits.

Porphyry deposits are associated with subduction-related[33] felsic[34] igneous[35] intrusions. As a result, deposits mainly formed in plate boundary collision areas in island or continental magmatic arcs along active or ancient tectonic plate margins (Figure 33). The huge porphyry copper deposits in the Andes of South America, and the Rocky Mountains in the United States and Canada, formed in a continental arc setting. Deposits in the islands of the Philippine archipelago, Indonesia, and Papua New Guinea formed in an island arc setting.

Figure 33: Schematic of Porphyry and Sediment-Hosted Stratabound Copper Deposits



Source: USGS 2015

Sediment-Hosted Stratabound Copper Deposits

Sediment-hosted stratabound copper deposits are bodies of disseminated, cementing, and lesser veinlet-hosted copper minerals that are nearly conformable with their sedimentary or metasedimentary host rocks. Chalcocite (Cu_2S) and bornite (Cu_5FeS_4) are the typical ore zone minerals. The deposits contain laterally extensive (several kilometers), relatively thin orebodies (less than 50 meters) that form layers in rocks such as sandstone, shale, and dolomite in sedimentary basins (Figure 33).

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[33] Subduction is the movement of oceanic crust under continental or ocean crust.

[34] Felsick rock contains light colored silicate minerals (quartz and feldspar)

[35] Igneous rocks have a crystalline texture and appear to have consolidated from molten rock.

Sediment-hosted stratabound deposits are mined by using both open-pit and underground methods, depending on deposit depth and geometry. The deposits are typically smaller than typical porphyry copper deposits and copper grades typically are about 1 to 3 percent. Sedimentary basins in Europe and central Africa host the largest known sediment-hosted stratabound copper deposits. These copper deposits are also important sources of lead, zinc, silver, and cobalt.

The Central African Copperbelt is the world's largest province containing stratiform sediment-hosted copper mineralization. The Copperbelt is a 600 km long and 50 km wide belt extending across Zambia and the DRC.

Iron ore copper gold deposits

Iron ore copper gold (IOCG) deposits are a classification of many diverse mineralization systems that have abundant iron mineralization (magnetite and/or hematite) combined with copper and sometimes gold, with hydrothermal ore styles and strong structural controls. There are no clear spatial associations with igneous intrusions as, for example, displayed by porphyry and skarn ore deposits. Most IOCG deposits display a broad space-time association with batholithic granitoids and occur in crustal settings. Iron oxide copper gold systems are numerous and widely distributed and occur on all continents. The metal grades typically exceed those of most porphyry-style copper deposits. Gold and other by-product metals (cobalt and uranium) sometimes contribute a significant portion of revenue.

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, which makes them economically promising. 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[36] 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 the fourth quarter of 2024.

Figure 34: Bingham Canyon, USA Porphyry Copper Deposit

Source: Rio Tinto

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

ANNEX 2 – MINING AND PROCESSING OF COPPER ORES

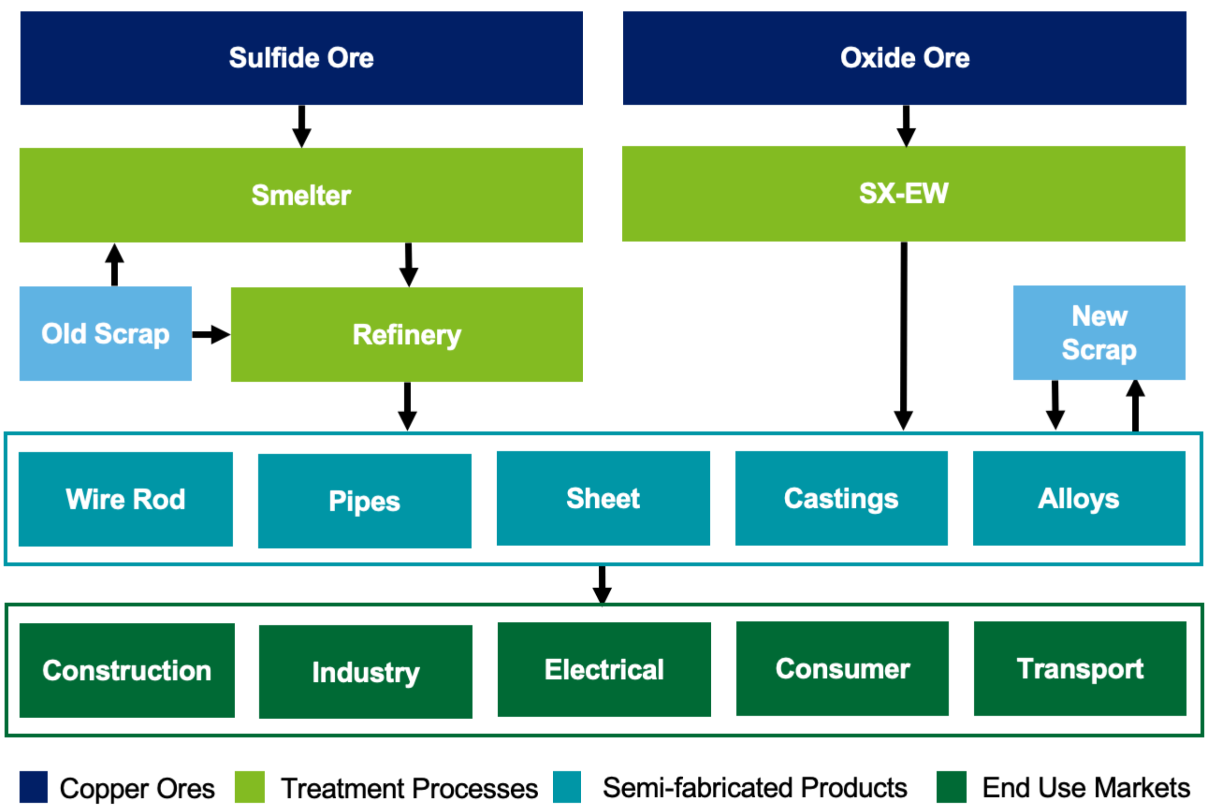
This Annex covers in more detail the different type of mining and processing methods for different copper ores. Figure 35 gives a simplified view of the processing routes and products.

Copper Mining

Primary copper production starts with the extraction of copper-bearing ores. There are two basic ways of copper mining: surface and underground mining. Open-pit mining is the predominant mining method in the world. The copper ore is drilled and blasted and delivered by haulage trucks and/or conveyors to the processing plant or heap leach pad. Waste material is delivered to waste dumps.

There are two main types of copper ore: copper sulfide (about 80 percent of production) and copper oxide (about 20 percent). Sulfide ore is processed via a pyrometallurgical process (known as smelting). Oxide ore is processed through a hydrometallurgical process known as SX-EW (solvent extraction and electrowinning).

Figure 35: Simplified Flow Sheet for Copper Processing



Source: Deloitte

Sulfide Ore Processing

Sulfide copper ores are first mechanically crushed and ground so that nearly all copper mineral particles are freed from the gangue (waste rock). Flotation by the injection of air and violent agitation is carried out with the pulverized ore held in suspension in water, to which surface-active agents have been added. The process yields concentrates containing about 30 percent copper, which are sequentially fed to a smelter.

Copper Smelting

The smelting process firstly comprises a roasting step where copper is heated and transformed into a matte[37] containing 50 to 70 percent copper. The matte is then treated in a second furnace where most of the iron and sulfur are removed. Finally, a converting furnace removes most of the remaining iron and other impurities. Depending on the type of smelting and converting furnace used, over 99 percent of the sulfur can be recovered. It is used to make sulfuric acid, which can be sold or used to leach copper using the SX-EW process (see below). The result is an impure (98+ percent) form of copper metal, which is poured into anode molds, known as blister copper (for its surface appearance) or anode copper.

Copper smelters can be classified as integrated or custom smelters. Integrated smelters, as the name suggests, process concentrates from an individual mine to anodes, and usually have an integrated refinery to produce cathodes. Custom smelters process concentrates from non-related entities (also called custom mines). However, the lines of distinction have become less clear in recent years. Smelters which were once fully integrated may now also purchase third-party concentrates. Also, many custom smelters have taken equity positions in mines, to secure a portion of feed from 'captured' sources.

Miners can also sell concentrates to traders. Traders will then generally sell the concentrates to smelters. A development since the early 2000s has been the establishment of blending facilities. A custom smelter may purchase a number of different qualities of concentrate and blend it on-site (and off-site), and traders blend concentrates at their own facilities and then sell the blended material to smelters.

Traders play an important role in the market as they add liquidity. They can also assume risk. Through the blending of concentrates, they can take complex material (with high levels of deleterious elements) and blend to a quality acceptable to smelters. Traders, from time to time, also finance mines through a variety of mechanisms ranging from debt to advance and pre-payments for copper concentrates. Traders account for approximately 45 percent of the custom/traded market.

Copper Refining

The blister copper from a smelter is next transported to a copper refinery. The first step is to refine the copper to reduce sulfur and oxygen content. The copper produced is sufficiently pure for fabrication (other than electrical). However, since the fire-refined metal may contain commercially viable concentrations of precious metals (mostly silver and gold), most of it is cast into thick sheets that are sent to the large electrolytic cells, where final refining takes place. A direct electric current, passed through the cells, dissolves the anode sheets, and deposits the copper on cathodes. The final product of the refining process is electrolytic tough pitch (ETP) copper normally containing between 99.94 and 99.96 percent copper. Cathodes are re-melted under controlled conditions and cast into forms suitable for further processing.

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[37] A crude mixture of molten sulfides formed as an intermediate product of the smelting of sulfide ores of metals.

Treatment and Refining Charges

In establishing an off-take contract, a mine must not only consider Treatment and Refining Charges (TCs/RCs) and metal payability rates, but also a myriad of other terms which will have an impact on realization costs and the Net Smelter Return (NSR)[38]. Buyers (both smelters and traders) regard all terms as sources of revenue and will trade off one factor against another. It is therefore not possible to isolate entirely each commercial term. For example, improved copper payability may lead to reduced revenue in another area. Metal recognition is expressed as a percentage of the agreed analytical value of payable metals. Smelters usually capture a bit more than the percentage they are prepared to pay. The difference can be termed as free metal. If prices rise, so does the value of the free metal to the smelter.

A TC/RC benchmark framework currently exists for copper concentrate. The benchmark is negotiated by major producers and major smelters on an annual (calendar year) basis. Since about 1990, the benchmark was set by either Escondida, Freeport Indonesia, Highland Valley, or Ok Tedi with (almost always) the Japanese smelters. However, during much of the past two decades, the benchmark has been dominated by Freeport and Antofagasta, and the benchmark is now mostly set with one of the major Chinese smelters.

Over recent years, producers both large and small have taken steps to move away from the benchmark. The rationale has been varied but it includes the fact that there are many disparities amongst concentrate qualities. Also, the benchmark applies to a full calendar year, and shorter-term pricing captures intra-year volatility.

Spot TCs/RCs are negotiated on a short-term single or multi-shipment basis. Spot sales are generally made by mines to traders and traders to smelters. Sales, typically to traders, can also be linked to the benchmark, without accepting the absolute level of the benchmark.

Other commercial terms will include penalties for deleterious elements, price references (known as quotational periods), payment terms, and shipping terms. Protocols to be applied to weight determination, sampling, and assaying must also be established. None of these terms has a zero-commercial impact but may be a zero-sum game[33].

Oxide Ore Processing

The heap-leach process method is a well-established process used for the extraction of copper from oxidized ores. SX-EW processes are usually conducted near mining sites. The oxidized ores, consisting of the silicates, carbonates, and sulfates, are heaped onto thick high density polyethylene liner and sprinklers placed on the surface spray a weak acid solution on to the ore, which dissolves the acid-soluble copper in the ore. The copper bearing solutions are collected and pumped to a solvent extraction plant where an organic extractant removes the copper from the solution. The resulting electrolyte solution is transferred to the electrowinning process where copper is plated out as a cathode. Some 20 percent of mined copper is produced through leaching using SX-EW.

[38] Copper concentrate marketing 101 - Albert de Sousa MAusIMM.

ANNEX 3 – COPPER PROJECT TABLES

This Annex covers copper projects under development, and probable and possible projects. It includes tables of both brownfield and greenfield projects under each category.

Table 15: Greenfield Copper Projects Under Development

Project	Country	Operator	Incremental Cu Capacity t 2020-2030
Quellaveco	Peru	Anglo American	300,000
Kamoa-Kakula	DRC	Ivanhoe Mines	284,000
Qulong	China	Zijin Mining Group	160,000
Udokan	Russia	Metalloinvest	135,000
Mina Justa (Marcona)	Peru	Minsur SA	92,000
Timok (Čukaru Peki)	Serbia	Zijin Mining Group	91,000
Tominskoye	Russia	Russian Copper	81,000
Khoemacau	Botswana	Cupric Canyon Capital	62,596
Gunnison	USA	Excelsior Mining	56,700
Xietongmen	China	Jinchuan Group	50,000
Pumpi	DRC	Wanboa Mining	45,000
Pumpkin Hollow	USA	Nevada Copper	40,000
Florence	USA	Taseko Mines	38,555
Pilares	Mexico	Southern Copper	35,000
Musonoi	DRC	Jinchuan Group	34,500
Dar Alou	Iran	National Iranian Copper	32,500
Aljustrel	Portugal	I'M SGPS SA	32,000
Tshukudu/Motheo	Botswana	Sandfire Resources	30,000
Kambove	DRC	China Nonferrous	28,000
Pedra Branca	Brazil	OZ Minerals	24,000
Serrote	Brazil	Appian Capital	20,000
Kombat	Namibia	Trigon Metals	14,500
Al Hadeetha	Oman	Alara Resources	7,699
Total			**1,694,050**

Source: Deloitte, company reports.

Table 16: Brownfield Copper Projects Under Development

Project	Country	Operator	Incremental Cu Capacity t 2020-2030
Oyu Tolgoi	Mongolia	Rio Tinto Group	362,200
Grasberg	Indonesia	Freeport-McMoRan	313,400
Quebrada Blanca 2	Chile	Teck Resources	302,600
Cobre Panama	Panama	First Quantum Minerals	195,000
Spence	Chile	BHP Group	185,000
Mantoverde	Chile	Mantos Copper	122,000
Collahuasi Phase 1	Chile	Anglo American/Glencore	100,000
El Abra	Chile	Freeport-McMoRan	79,400
Mutanda	DRC	Glencore	76,000
Snow Lake	Canada	Hudbay Minerals	73,000
Buenavista	Mexico	Southern Copper Corp.	68,226
Bor Basin	Serbia	Zijin Mining Group	67,793
Los Pelambres I	Chile	Antofagasta	60,000
Metalkol RTR	DRC	Eurasian Natural Res.	58,400
Constancia	Peru	Hudbay Minerals Inc.	51,000
Chino	USA	Freeport-McMoRan	49,000
Safford	USA	Freeport-McMoRan	44,400
Sierra Gorda	Chile	KGHM International	41,000
Deziwa	DRC	China Nonferrous Mining Corp.	40,000
Salobo 3	Brazil	Vale SA	35,000
Gambov	DRC	China Nonferrous Mining Corp.	28,000
Norilsk South Cluster	Russia	Norilsk Nickel	20,000
Andina Conveying	Chile	Codelco	17,000
Esperanza Sur	Chile	Antofagasta	10,000
Zaldivar	Chile	Antofagasta	10,000
Kinsevere	DRC	MMG	7,993
Mantos Blancos	Chile	Audley Capital Advisors	5,000
Aktogay II	Kazakhstan	Nova Resources	0
Deep Glogow	Poland	KGHM	0
Salvador RI	Chile	Codelco	(19,000)
El Teniente	Chile	Codelco	(33,000)
Chuquicamata	Chile	Codelco	(79,000)
Escondida	Chile	BHP/Rio Tinto	(238,140)
Total			**2,052,272**

Source: Deloitte, company reports.

Table 17: Probable Greenfield Copper Projects

Project	Country	Operator	Incremental Cu Capacity t 2020-2030
Michiquillay	Peru	Southern Copper Corp.	225,000
El Arco	Mexico	Southern Copper Corp.	190,000
Los Chancas	Peru	Southern Copper Corp.	150,000
Josemaria	Argentina	Josemaria Resources	131,000
Tia Maria	Peru	Southern Copper Corp.	120,000
Resolution	USA	Rio Tinto Group	120,000
Zafranal	Peru	Teck Resources	75,000
Upper Kobuk	USA	Trilogy Metals	70,300
Costa Fuego	Chile	Hot Chili	66,000
Santo Domingo	Chile	Capstone Mining Corp.	63,500
Alemao	Brazil	Vale SA	60,000
Eva	Australia	Copper Mountain Mining Corp.	45,000
Magistral	Peru	Nexa Resources Perú	40,500
Tizert	Morocco	Managem SA	40,000
El Pilar	Mexico	Southern Copper Corp.	35,000
Kambove	DRC	China Nonferrous Mining Corp.	28,000
NorthMet	USA	PolyMet Mining Corp.	24,853
Black Butte	USA	Sandfire Resources	23,000
Buenavista	Mexico	Southern Copper Corp.	20,000
Victoria	Canada	KGHM International	18,000
Silangan	Philippines	Philex Mining Corp.	15,000
Horne 5	Canada	Falco Resources	8,000
Platreef	South Africa	Ivanhoe Mines	5,900
Total			**1,574,053**

Source: Deloitte, company reports.

Table 18: Probable Brownfield Copper Projects

Project	Country	Operator	Incremental Cu Capacity t 2020-2030
Alumbrera MARA	Argentina	Yamana Gold	240,000
Tenke Fungurume	DRC	China Molybdenum	217,500
Centinela Sulfide	Chile	Antofagasta	150,000
Qulong Expansion	China	Zijin Mining Group	100,000
Collahuasi Phase 2	Chile	Anglo American/Glencore	100,000
Bagdad	USA	Freeport-McMoRan	90,700
Salobo North Hub	Brazil	Vale SA	85,000
Las Bambas	Peru	MMG	80,000
Kansanshi	Zambia	First Quantum Minerals	50,000
Radomiro Tomic	Chile	Codelco	50,000
Andina Division	Chile	Codelco	48,000
Sossego South Hub Exp.	Brazil	Vale SA	35,000
Salobo 4	Brazil	Vale SA	30,000
Sierra Gorda Oxides	Chile	KGHM International	30,000
Grasberg Mill	Indonesia	Freeport-McMoRan	27,216
Stockman	Australia	Washington H. Soul Pattinson	15,100
Las Cruces	Spain	First Quantum Minerals	(9,000)
Bingham Canyon UG	USA	Rio Tinto Group	0
Sossego South Hub Sat.	Brazil	Vale SA	0
Victor	Canada	Vale SA	0
Total			**1,339,516**

Source: Deloitte, company reports.

Table 19: Possible (Low Risk) Greenfield Copper Projects

Project	Country	Operator	Incremental Cu Capacity t 2020-2030
El Pachon	Argentina	Glencore PLC	400,000
Hu'u	Indonesia	Vale SA	325,000
Baimskaya	Russia	Nova Resources BV	300,000
NuevaUnion	Chile	Teck Resources Ltd.	190,000
Wafi-Golpu	PNG	Newcrest Mining Ltd.	160,000
Cascabel	Ecuador	SolGold PLC	139,000
Vizcachitas	Chile	Los Andes Copper Ltd.	111,000
Rosemont	USA	Hudbay Minerals Inc.	101,605
Casino	Canada	Western Copper & Gold Corp.	77,000
Quebradona	Colombia	AngloGold Ashanti Ltd.	61,235
Marimaca	Chile	Marimaca Copper Corp.	36,000
Hillside	Australia	Rex Minerals Ltd.	35,000
Kalongwe	DRC	Chengtun Mining Group Co. Ltd.	30,000
Viscaria	Sweden	Copperstone Resources AB	30,000
Copperwood	USA	Highland Copper Co. Inc.	28,000
Boa Esperanza	Brazil	Ero Copper Corp.	27,200
Prieska	South Africa	Orion Minerals Ltd.	22,000
Antilla	Peru	Heeney Capital Acquisition Co Inc.	20,865
Angangueo	Mexico	Southern Copper Corp.	19,500
Kisanfu	Dem. Rep.	China Molybdenum	19,000
Mabilo	Philippines	Mt Labo Exploration &	18,000
Sulphur Springs	Australia	Develop Global Ltd.	14,000
Cerro del Gallo	Mexico	Argonaut Gold Inc.	2,250
Total			**2,166,655**

Source: Deloitte, company reports.

Table 20: Possible (Low Risk) Brownfield Copper Projects

Project	Country	Operator	Incremental Cu Capacity t 2020-2030
El Abra	Chile	Freeport-McMoRan	318,000
Quebrada Blanca 3	Chile	Teck Resources	300,000
Collahuasi	Chile	Anglo American/Glencore	227,000
Salobo North Hub	Brazil	Vale SA	85,000
Carrapateena	Australia	OZ Minerals	50,000
Lonshi	DRC	JCHX Minin	37,150
Los Pelambres II	Chile	Antofagasta	35,000
Red Chris	Canada	Newcrest Mining	25,000
Antapaccay	Peru	Glencore	0
Total			**1,077,150**

Source: Deloitte, company reports.

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