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TECHNICAL ASSISTANCE ON BRAZIL MINERAL RESOURCES

Graphite – Market Analysis and Competitiveness Report

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DISCLAIMER

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acronyms

BPA	Blanket Purchase Agreement
BOF	Basic Oxygen Furnace
CAPEX	Capital Expenditure
CPRM	Geological Survey of Brazil
DERA	German Mineral Resources Agency
DOS	Department of State
EAF	Electric Arc Furnace
EMGP	Energy and Mineral Governance Program
ENR	Bureau of Energy Resources
ESG	Environment, Social, and Governance
ECGA	The European Carbon and Graphite Association
EV	Electric Vehicles
FOB	Free on Board
GHG	Greenhouse Gas
HPSG	High Purity Spherical Graphite
IMF	International Monetary Fund
ICMNR	Information Center of the Chinese Ministry of Natural Resources
IRR	Internal Rate of Return
MOF	Ministry of Finance
M&A	Mergers and Acquisitions
MME	Ministry of Mines and Energy
NDC	Nationally Determined Contribution
NPV	Net Present Value
OEM	Original Equipment Manufacturer
PNM	National Plan for the Brazilian Mineral Sector
REE	Rare Earth Elements
USGS	U.S. Geological Survey

EXECUTIVE SUMMARY

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

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

Under *Task 2A: Economic Viability and Global Market Competitiveness of Specific Minerals*, the Deloitte team will develop a series of Interim Reports focused on (i) a high-level analysis of nine minerals including, graphite, lithium, nickel, cobalt, rare earth elements (REEs), titanium, vanadium, tantalum and copper; and (ii) a deep-dive analysis of four minerals identified by MME and CPRM that includes graphite, lithium, nickel, and REEs. The purpose of these Interim Reports is to provide recommendations to the Government of Brazil for where and how Brazil could compete most effectively, and inform their 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. Deloitte'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, *Interim Report # 1* is focused on graphite, one of the four minerals selected by the Government of Brazil for a deep-dive market analysis.

Key Findings

- **Brazil has significant graphite resources and reserves**. Brazil is the third largest producer of graphite in the world (following China and Turkey), and the second largest high-quality flake graphite producer outside of China. The country is home to three graphite suppliers that produced 95 kt of graphite in 2020, approximately 10 percent of total global supply. Activity is focused within five operating mines in the country's graphite belt, which runs between Bahia and Minas Gerais. The mining operations of Nacional de Grafite (one of the two companies that dominate domestic graphite production) are the highest-margin graphite operations in the world, and have significant reserves with the potential for expansion based on Deloitte's analysis (*see Section 10 for details*). According to the U.S. Geological Survey (USGS), Brazil, China, and Turkey have the largest recognized graphite reserves, which account for around 72 percent of the world's total.[1] Madagascar, Mozambique, and Tanzania also hold significant reserves, which account for 21 percent.

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[1] USGS, Mineral Commodity Summary of Graphite, January 2021.

- **When analyzing existing mines, Deloitte observed that Brazilian mining operations in Minas Gerais are among the most profitable operations in the world**. Deloitte analyzed data from 54 active graphite projects around the world to assess the economic viability and competitiveness of the market (*see Section 10 for more details*). Deloitte compared graphite basket prices, operating costs, capital expenditures and capital intensity, and planned output across the 54 projects to create a benchmark of economic competitiveness. This analysis indicates that mining assets in Brazil appear to have significant potential for expansion.
- **Brazil has opportunities and potential for graphite development**. The financial viability of green mineral mining projects, including graphite, rely on global market trends and supply/demand dynamics. These dynamics depend on technological advancements (e.g., more efficient use of minerals), policy decisions (e.g., Brazil's commitment to its Nationally Determined Contribution - NDC), and supply-chain disruptions and/or risks (e.g., the COVID-19 pandemic and/or strategic initiatives to diversify mineral supply arrangements[2]). These trends may boost, or reduce, the attractiveness of Brazil's mineral assets in the near-term. However, as summarized in the table below, in the long-run, Brazil provides attractive opportunities for graphite exploration and development, due to a rising market demand for graphite, plus the fact that Brazil is the third largest producer of graphite in the world, and the second largest producer of high-quality flake graphite used in EVs.

Opportunities and Potential for Graphite Development in Brazil

- **Green Uses of Graphite:** Required for EV battery development, and battery storage systems (electrodes and anodes) fuel cells for which demand is set to rise through 2030.
- **Market Demand for Graphite:** Forecasts suggest long-term demand for EV battery and battery storage development, with tight supply through 2030 and 2040. Graphite's use as an anode material for lithium-ion rechargeable batteries has significantly increased demand for the mineral. As countries move to decarbonize their energy and transportation sectors to meet global greenhouse gas (GHG) goals, graphite demand is expected to grow to support the increase in battery usage in transport and power storage applications. In fact, almost all incremental demand growth for graphite – beyond normal GDP growth – is expected to come from the lithium-ion battery market in the future.
- **Opportunities in Brazil:** Brazil is the third largest graphite producer, and the second largest flake graphite-producing country, in the world. Flake graphite, the most common form of natural graphite, has been identified as a critical and strategic material by the United States and Europe due to its essential applications in the aerospace and energy sectors and its role as the primary anode component in lithium-ion batteries. Graphite produced in Brazil using hydropower (which encompasses 65 percent of Brazil's power supply) has the potential to be marketed as 'green' graphite, thereby aligning it with the efforts of many auto and battery manufacturers to enhance the green credentials of their own products.

[2] China is currently the dominant global producer of graphite, and is responsible for nearly 62 percent of global production. The development of Brazil's graphite resources could help to diversify this concentrated supply.

- **There are currently limited expectations of any significant expansion of graphite production in Brazil.** The two domestic companies who dominate graphite production (Nacional de Grafite and Extrativa Metalquimica) have no known plans of growing their operations further[3]. Currently, there is only one project at an advanced exploration stage, Santa Cruz in southern Bahia owned by South Star Battery Metals, although there are other prospects in the early stages of exploration. Graphite is a strategic mineral under the Brazil's Pro-Strategic Minerals Policy, which is designed to streamline approvals and permitting procedures to accelerate production. Nevertheless, new activity has been limited despite having some 386 properties with graphite mineral rights, located mostly in Bahia, Minas Gerais, and Ceará.

Key Recommendations

Brazil has a large graphite endowment, existing low-cost graphite mines, experienced personnel, and is a globally significant graphite producer, but will have to continue to compete globally to maintain its position in the market. . Without increasing output, Brazil's share of global production is likely to decline as other countries continue to develop their resources. Brazil should therefore build on its inherent competitive advantages to support future production expansions by:

- **Increasing access to, and circulation of, up-to-date graphite resource data to domestic and international exploration companies to encourage exploitation and promote graphite development in Brazil**. In 2020, CPRM estimated that Brazil's total graphite resources were 43.8 Mt. Brazil's main graphite deposits are found in Minas Gerais, Bahia, Ceará, Rio de Janeiro, and Mato Grosso, but the government and mining industry believe that the Amazon Craton in the Sunsás Province may also have significant potential. Increasing access to up-to-date graphite resource data will require gathering and distributing more extensive information for those regions that are considered to have significant potential, and/or encouraging investment by exploration companies. Currently, legacy CPRM geological data, reports and studies are available in hardcopy; digitization of, and online access to, these records will greatly expand their impact and circulation. However measured potential (i.e., detailed resource delineation and metallurgical testing) may be unknown to the mining community until additional studies are completed. As new data becomes available and the results of additional CPRM studies are finalized (for example detailed resource delineation and metallurgical testing on individual deposits), these should also be published online as a matter of record, thereby helping to accelerate broader industry access to, and interest in, Brazil's graphite potential.
- **Considering financial incentives (e.g., lower royalties, preferential tax rates) to companies to encourage the expansion of existing graphite projects and new investment.** Without increasing output, Brazil's share of global production is likely to decline to just 3 - 4 percent by 2030 (from its current level of 9-10 percent) when other graphite mines come on stream(see Table 4). Currently, Brazil has limited plans for increasing production beyond the exploration project in Santa Cruz. The government should fast-track the progress of graphite opportunities to avoid being crowded out by other graphite mine developments around the world, and before other countries with large resources, but a low level of projects – like Turkey, Russia, and India – decide to fast-track their own opportunities. The government should also encourage both international and domestic graphite companies (e.g., Nacional de Grafite and Extrativa Metalquimica) to participate in the development of new projects through financial incentives such as lower royalties, preferential tax rates, and assistance in capital financing.

[3] CPRM

- **Undertaking a comparative review of Brazil's exploration and mining policies vs. other graphite-producing countries.** This review should analyze whether the government can encourage graphite exploration and mine development through legal, regulatory, and Environmental, Social, and Governance (ESG) improvements. Such improvements may include simpler licensing and permitting processes, lower royalties, preferential tax rates, and a continued focus on environmental policy. The ultimate objective of such improvements should be to encourage development and stability for investors looking to develop the Brazil's mineral sector as a whole, and graphite in particular.
- **Developing downstream processing facilities to capture more of the graphite value chain.** Downstream graphite processing is currently concentrated in China, but given its graphite resources of approximately 43.8 Mt, growing worldwide demand, and the natural tendency for global supply chains to seek diversification, Brazil has an opportunity to become a leading downstream player in the graphite industry.

1. INTRODUCTION

1.1. Purpose of this Report

The purpose of this Report is to provide a detailed analysis of the global graphite market and to give an informed understanding of the current and future dynamics of the industry, the potential opportunities, and the possible risks associated with graphite development. The Report analyzes global graphite resources, the supply and demand dynamics, technological and industrial drivers, current and future mineral producers and processors, and the economics of the graphite market. The Report also examines Brazil's position in the context of the current graphite market and its potential for the future. The analysis and recommendations in this Report will help the MME and CPRM to make informed decisions about future policy actions with regard to Brazil's graphite industry and resources.

1.2. Organization of this Report

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

- **Section 1: Introduction** – Presents the purpose of this Report, background and context on graphite, and a summary of market trends and outlook for graphite.
- **Section 2: Graphite Physical Characteristics –** Provides information on graphite uses and applications, different graphite types, and the relevance of value-added downstream processing.
- **Section 3: Graphite Resources** – Provides information on global graphite resources and reserves, as well as more detailed data on the countries with the largest recognized reserves (China, Brazil, and Mozambique, among others).
- **Section 4: Natural Graphite Supply** – Gives an overview of the global production of natural graphite and recent supply trends from China, Brazil, and other relevant regions.
- **Section 5: Graphite Demand** – Explains global graphite demand trends based on end-user markets.
- **Section 6: Graphite Trade and Prices** – Provides information on main players involved in global graphite trade, and presents pricing data for flake graphite from recent years.
- **Section 7: Outlook for Graphite Demand** – Outlines how global graphite demand is expected to change in the future, given growing consumption trends in relevant end-use industries, like steel and lithium-ion batteries.
- **Section 8: Outlook for Graphite Supply** – Presents how the global supply of synthetic and flake graphite must grow to meet rising demand and consumption trends. This section also examines potential production increases from existing operations in China and Mozambique and other mining projects that could potentially come on stream by 2030.
- **Section 9: Market Balance and Price Outlook** – Explains how the graphite market is balanced and provides insights on how prices are expected to fluctuate in the future.
- **Section 10: Economic Competitiveness** – Summarizes information from 54 mining projects, to benchmark and assess the economic competitiveness of the sector and examines development and exploration projects in Brazil.
- **Section 11: Conclusions and Key Recommendations** – Summarizes the Deloitte's team analysis of the graphite market, including project financing and potential global opportunities. This section also presents key recommendations for the Government of Brazil to inform their future policy actions with respect to the graphite industry.

- **Annex 1** – Provides a description of graphite types.
- **Annex 2** – Provides a description of graphite uses.
- **Annex 3** – Provides of list of graphite projects by country.
- **Annex 4** – Provides information on mining and beneficiation of graphite.

1.3. Background and Context

Brazil has some of the largest and most diverse mineral deposits in the world, yet most of its mining sector activities and revenues generated are focused on several core commodities such as iron-ore, gold, copper, and bauxite. While the production of these resources will remain valuable to global industries and markets, there is growing demand and new opportunities for other critical minerals and metals that can be found in Brazil, including graphite.

Brazil is the third largest producer of graphite in the world following China and Turkey and the second largest high-quality flake graphite producer outside of China. According to USGS, Brazil, China, and Turkey have the largest recognized graphite reserves, which account for around 72 percent of the world's total.[4] Madagascar, Mozambique, and Tanzania also hold significant reserves, which account for 21 percent.

Graphite is a strategic mineral under the Brazil's Pro-Strategic Minerals Policy, which is designed to streamline approvals and permitting procedures to accelerate production. The Government of Brazil is making efforts to advance its graphite industry and attract responsible investment, however internal (lack of infrastructure which may result in higher costs, potential improvements in the legal, regulatory, and ESG frameworks) and external challenges including geopolitical factors (e.g., China's monopolistic market dominance of the graphite market), market influences (e.g., graphite price volatility) discussed in subsequent sections of this Report could inhibit Brazil's overall market competitiveness. However, given the most recent market trends Brazil has opportunities and potential for graphite development in the medium-and long-term as outlined below.

1.4. Summary of Market Trends and Outlook for Graphite

1.4.1. Graphite Resources

The U.S. Geological Survey (USGS) estimates that global graphite reserves – that is, the amount of graphite that could be economically extracted or produced at the time of determination – are approximately 320 Mt.[5] The USGS also reports an additional 800 Mt of recoverable graphite in inferred resources – that is, the amount of graphite in or on the Earth's crust that could *potentially* be economically extracted based on geological evidence. The countries with the largest recognized reserves are Turkey, China, and Brazil accounting for some 72 percent of the total[6]. Madagascar, Mozambique, Tanzania, and Canada also hold significant resources.

East Africa has been the focus of exploration activities in recent years. This has led to a sharp increase in the reserve and resources base of flake graphite, particularly in Mozambique, Tanzania, and Madagascar.

[4] U.S. Geological Survey, Mineral Commodity Summary of Graphite, January 2021.
[5] U.S. Geological Survey, Mineral Commodity Summary of Graphite, January 2021.
[6] U.S. Geological Survey, Mineral Commodity Summary of Graphite, January 2021

In Brazil, a 2020 report by CPRM gives a graphite resource of 43.8 Mt. Of the CPRM total, 40.0 Mt is described as amorphous graphite and 3.8 Mt as flake graphite. Of this total, it is reported that 360 kt have been defined as flake graphite reserves and 3.4 Mt as flake graphite measured resources. The main deposits are found in Minas Gerais, Bahia, Ceará, Rio de Janeiro, and Mato Grosso. Flake graphite, the most common form of natural graphite, has been identified as a critical and strategic material by the Unites States and Europe due to its essential applications in the aerospace and energy sectors and its role as the primary anode component in lithium-ion batteries.

1.4.2. Graphite Supply and Demand

The global production of graphite is currently estimated at 2.5 Mt per annum.[7] About 1.0 Mt or 40 percent comes from natural graphite (primarily flake graphite), and 1.5Mt or 60 percent comes from synthetic graphite – that is, graphite that is manufactured from petrochemical precursors. Demand declined in 2020 due to the market impact of COVID-19, but has picked up as demand patterns for steel, lithium-ion batteries, and other industrial uses normalize. Currently, the largest suppliers of natural graphite are China, Mozambique, and Brazil.

China is the world's largest natural graphite supplier. According to the USGS, China produced approximately 650 kt of natural graphite in 2020, which was over 60 percent of total global supply. China also does all downstream processing for graphite, and about 80 percent of global battery anode production currently occurs in the country. However, graphite production in China has been constrained in recent years due to several domestic factors, including government-imposed permitting, excessive export duties, and tightening environmental regulations. Moreover, although there are hundreds of mining and processing companies in China, fewer than 10 reportedly have the capacity to produce more than 30 kt/y. This has reduced China's supply growth and reduced the market oversupply.

Mozambique is the second largest producer of graphite. In 2020, production reached 120 kt, the equivalent of 12 percent of total global supply. This was primarily due to the development of the Balama mine, which is considered one of the most significant changes to global graphite production in recent years. This mine has a capacity of 350 kt/y, which is close to one-third of the existing market.

Brazil is the third largest producer of graphite in the world. The country is home to three graphite suppliers that produced 95 kt of graphite in 2020, approximately 10 percent of total global supply. Activity is focused within five operating mines in the country's graphite belt, which runs between Bahia and Minas Gerais. The mining operations of Nacional de Grafite are believed to be the highest-margin graphite operations in the world and reportedly have significant reserves with the potential for expansion.

1.4.3. Graphite Trade and Prices

Global exports of natural graphite were roughly 560 kt in 2018,[8] with China being one of the largest exporters. China dominates the graphite market as the largest producer, exporter, consumer, and importer of graphite products in the world. Processing and refinery facilities outside of China are limited, so all stages of the graphite production supply chain are concentrated in China as a result. China consumes most of its domestic production (as does Brazil). However, the main export market for China's natural graphite is Japan, with large quantities also going to the United States, Germany, India, and the Republic of Korea, among others.

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[7] The European Carbon and Graphite Association (ECGA) annual report 2020
[8] German Mineral Resources Agency (DERA)

Natural graphite prices are difficult to determine because there are no standard or quoted prices or spot or futures markets. Instead, pricing is based on several factors, including flake size, carbon content, and other technical attributes. Since the technical attributes for graphite sought by end-users tend to be proprietary information, pricing is not publicly available. Pricing data that does exist is based on actual transactions in the market, which are typically direct negotiations between the buyer and seller.

Historically, the price of graphite has been well-correlated to the industrial production cycle and the steel market. The price of flake graphite peaked in 2011 (reaching over US$2,500 per tonne), but subsequently normalized. Prices began dipping in 2019 (due to several market factors, including the start-up of the Balama mine in Mozambique and COVID-19) but are now returning to historic averages of around US$1,2500 per tonne.

1.4.4. Future Market Outlook

Future demand for graphite will be determined by key end-use industries that use graphite-based products. For instance, the steel, automotive, public transportation, aluminum, and aerospace industries will be the first determinant of graphite demand going forward. The most important factor, however, will be the growth that is expected from the rapid increase in lithium-ion battery manufacturing. Lithium-ion batteries account for about 75-85 percent of graphite consumption and alkaline batteries for around 10-15 percent, with the balance used in lead-acid and other battery types. The battery sector is expected to drive the growth of future graphite demand due to the transition to electric mobility and the development of the energy storage market.

There are a range of demand forecasts for graphite from industry players – however, based on available data, Deloitte estimates that the graphite industry requires around 2.5 Mt to 2.8 Mt of additional flake graphite from mines to satisfy expected demand growth to 2030. The battery sector consumes both natural flake graphite and synthetic graphite, but flake graphite is expected to gain popularity as battery manufacturers look to optimize manufacturing costs and improve their environmental footprint (flake graphite is cheaper relative to synthetic graphite and reported to be cleaner).

The graphite market is currently perceived to be adequately supplied; however, the expected growth in the lithium-ion battery market, along with encouraging growth in steel and other key end-use industries, should drive the future supply of graphite. Pricing is not incentivizing increases in production since prices are still around historic averages; however, there is a general expectation that prices could rally over the next decade.

Chinese graphite production is a key input for forecasting global graphite supply – especially for flake graphite (the country is expected to produce an additional 185 kt to 600 kt in flake graphite by 2030). China will also continue to be the largest player in graphite processing and continue to focus strongly on downstream, higher-value products.

However, Australia, Canada, and Europe are also kicking off flake graphite projects, including developing downstream processes to increase the value-add of their projects and satisfy increasing demand from the battery market.

The market also expects further production of flake graphite from Mozambique, Tanzania, and Madagascar. The Balama mine in Mozambique was closed for most of 2020 and produced just 12 kt, but has a planned capacity of 350 kt. This is likely to absorb the market demand growth in the near term but falls short of reaching the 2.5 Mt to 2.8 Mt of additional flake graphite required by 2030. Thereafter, additional new capacity needs to be brought on stream.

Deloitte has analyzed active graphite projects around the world and identified 28 that could potentially come on stream by 2030 (this includes projects where construction had started or is planned and those where a feasibility study had been completed or is underway). If this happens, the market would either have 435 kt in surplus or 265 kt in deficit by 2030 (depending if 2.5 Mt or 2.8 Mt are needed).

Deloitte has also identified an additional 26 active projects that already have defined graphite resources and where work is under way – including the Santa Cruz project in Brazil, which is an advanced-stage exploration project. Certainly, some of these projects could be developed to close potential supply gaps before 2030, but most of them are likely to come on stream after 2030 if they are economic. There are also 80 active graphite exploration projects around the world that have not yet defined a resource, which include four projects in Brazil.

Over the next few years, a key factor in the market balance and price of graphite will be the level of output from the Balama mine in Mozambique, along with the graphite production from the number of junior projects starting up. The price path is likely to be uneven, as both supply and demand change and surge at different rates over time. The construction of new mines, downstream processing plants, and new lithium-ion battery plants tend to result in 'lumpy' changes in capacity.

Increasing awareness of environmental considerations may also impact the graphite market going forward. Production costs (including labor, environmental, and energy costs) could also influence prices. In the longer term, the outlook for graphite becomes more uncertain and graphite forecasts vary across the market.

1.4.5. Economic Competitiveness

Deloitte analyzed data from 54 active graphite projects around the world to assess the economic viability and competitiveness of the market. Deloitte compared graphite basket prices, operating costs, capital expenditures and capital intensity, and planned production across the 54 projects to create a benchmark of economic competitiveness. Deloitte found that although projects varied in terms of production capacity, potential deposit grades, flake sizes, and basket prices, the average project would generally have high returns. The average planned capacity is 77 kt/y, although this is skewed by a few very large projects and more than a third of projects around the 50 kt/y level. Deloitte also calculated an average basket price of US$966/t for mined graphite, average operating costs of US$454/t, and average capital intensity of US$121/t. Looking at the ultimate measure of economic viability – the internal rate of return (IRR) – Deloitte calculated the median IRR to be 36 percent, suggesting high returns.

When analyzing existing mines, Deloitte found that Brazilian mining operations in Pedro Azul, Itapecerica, and Salto Da Divisa currently sit at the top of the margin curve, which indicates that they are among the most profitable operations in the world. Mining assets in Brazil reportedly have significant potential for expansion; however, the two companies who dominate graphite production in Brazil have no known plans of growing their operations further. The high margin and large reserve base are ideal attributes for expansion in Brazilian graphite capacity ahead of other graphite mines and projects.

Graphite is a strategic mineral under the Brazil's Pro-Strategic Minerals Policy, which allows an acceleration of procedures to achieve production. Nevertheless, new activity has been limited despite having some 386 properties with graphite mineral rights, located mostly in Bahia, Minas Gerais, and Ceará, mainly due to the very early stage of any exploration on these properties. Only one project, located Santa Cruz in southern Bahia, is at an advanced stage.

2. GRAPHITE PHYSICAL CHARACTERISTICS

Graphite is a versatile, carbon-based mineral that is used in many different metallurgical and manufacturing industries due to its unique properties, including its resistance to outstanding thermal and electric conductivity and high resistance to oxidation, cyclic temperature stress, high pressure, and most chemical agents.

2.1. Graphite Uses and Applications

Graphite has a wide range of applications, including in the following:

- **Electrodes** – Mainly in electric arc furnace steel production.
- **Refractories** – Ceramic materials designed to withstand very high temperatures in blast furnaces and manufacturing.
- **Batteries** – Used principally as an anode in lithium-ion batteries. It is also used to dissipate heat in consumer electronics.
- **Foundries** – Used as a mold wash prior to casting to protect the mold and product.
- **Lubricants** – Used as a dry lubricant or mixed with lubricating oils.
- **Other** – Smaller-use areas including carbon shapes and brushes, bearing, seals, fire retardants, building insulation, as well as in the petrochemical, aerospace and defense, aluminum, chemical, photovoltaics, and glass industries.

The increased use of lithium-ion batteries is expected to drive almost all incremental demand growth for graphite in anodes (*see Annex 2 – Graphite Uses for more information on lithium-ion batteries and other graphite uses*).

2.2. Types of Graphite

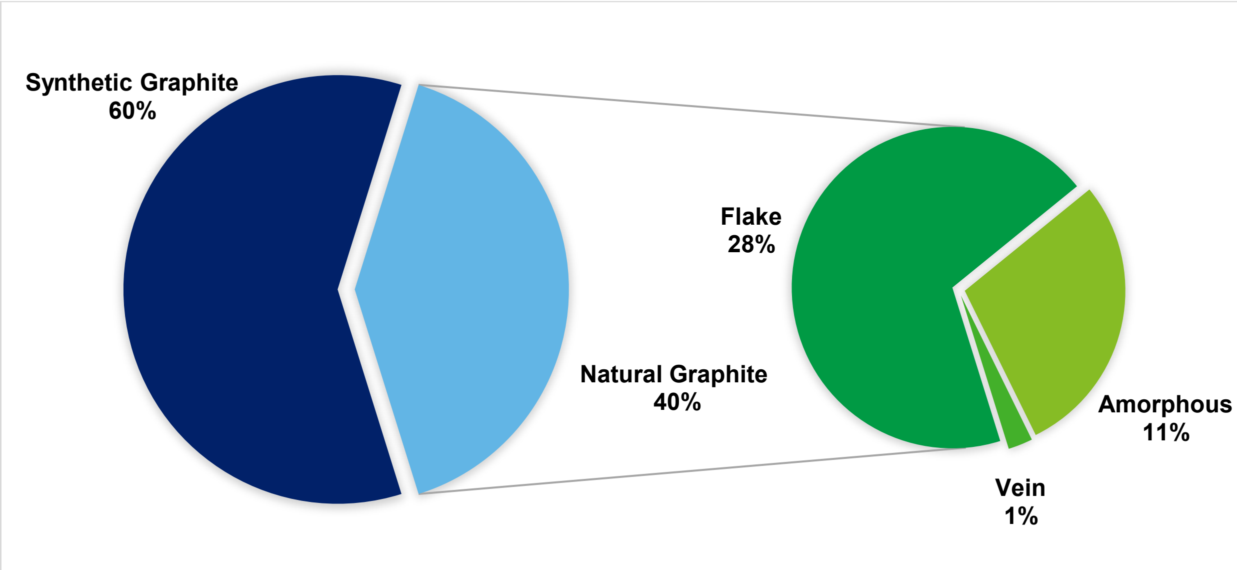
There are four main types of graphite – flake, amorphous, vein, and synthetic. While synthetic graphite is manufactured and accounts for most of the world's supply, the other three graphite types are widely found in nature, including in many types of metamorphic rock and some sedimentary and igneous rocks (although most natural occurrences have no economic importance). The graphite market consists of two main subsectors: natural graphite and synthetic graphite. Natural graphite, formed through metamorphic processes and organic matter present in rocks, sells on the market in three ways: as amorphous graphite (fine-grained), flake graphite, or vein (also called lump)[9]

Flake graphite is the most common. It has small, crystalline graphite flakes that occur as isolated, flat, plate-like particles. Amorphous graphite, on the other hand, has very fine flakes and is associated with lower-grade metamorphism. Vein graphite is the rarest. It tends to be hydrothermal in origin with crystalline aggregates (*see Annex 1 – Graphite Description and Types for more information on the different types of graphite*).

Synthetic graphite currently supplies 60 percent of the world's required demand, while natural graphite supplies around 40 percent. Of the natural graphite that is mined, some 70 percent is flake, around 29 percent is amorphous, and only a small amount of it is vein graphite. Figure 1 provides more detail on this breakdown.

[9] USGS, Graphite, 2017

Figure 1: Types of Graphite Produced and Used by the Market



Source: Various.

Flake graphite, the most common form of natural graphite, has been identified as a critical and strategic material by the Unites States and Europe due to its essential applications in the aerospace and energy sectors and its role as the primary anode component in lithium-ion batteries. Flake graphite has free electrons that can move without restrictions through its structural layers, empowering the graphite to absorb light and become a conductor of electricity and heat. Flake graphite that is naturally extracted is classified by the carbon content and the flake size (larger flakes will typically receive a higher price).

Amorphous graphite has limited use in high-purity applications like batteries due to its microcrystalline structure, fine flake size, and low purity percentage (amorphous graphite has lowest purity of all graphite types). Instead, amorphous graphite is used extensively in foundry and refractory applications, as a source of carbon in steelmaking, in pencil industries, and in other applications where graphite additions improve the manufacturing process. Amorphous graphite also tends to be less expensive than flake graphite.

Vein graphite is one of the rarer forms of naturally occurring graphite, although it has the highest carbon content. Production of vein graphite currently only comes from Sri Lankan deposits. Due to its purity and crystallinity, many of the highest quality electrical motor brushes and other current-carrying carbon products use vein graphite.

Producers manufacture synthetic graphite by transitioning an organic precursor through a carbonization and graphitization process. Producers use high-temperature processing to transform the precursor carbon into a graphite structure and to vaporize impurities. As a result of this treatment, synthetic graphite is more than 99.9 percent graphite.

Natural and synthetic graphite each have their own applications, but compete for market share in a limited number of areas. In these cases, customers will typically choose the mineral based on required specifications, availability, and cost. Synthetic graphite has slightly higher porosity, lower density, lower electrical conductivity, and a much higher price than natural flake graphite.

In lithium-ion battery applications, natural graphite currently competes with synthetic graphite for market share, and a mix of both materials in battery applications is common. Synthetic graphite has several advantages for use in batteries, including better cycling stability, faster charging performance, higher quality consistency, and faster production scalability.[10] As a result, synthetic graphite has traditionally been the major anode material (comprising 55 percent of the market), with natural graphite comprising the remaining balance (45 percent). However, processed flake graphite (called spherical graphite) is starting to increase market share over synthetic graphite due to quality improvements and lower cost. Synthetic graphite is widely reported to sell for up to US$20,000 per tonne, although the actual price and cost structure remain opaque.

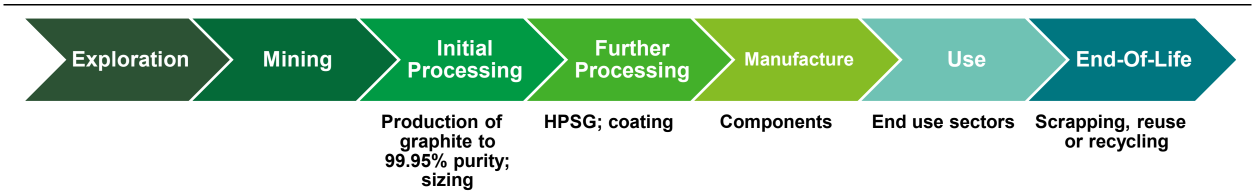
Although the United States is a significant producer of synthetic graphite, China dominates global production. Nevertheless, recent reports by Roskill suggest that strict energy-consumption control policies for high-energy industries in China could impact on-going production. In the Inner Mongolia Autonomous Region of China, for instance, new controls have already limited existing synthetic graphite production. Inner Mongolia accounts for around 46 percent of China's synthetic graphite capacity. It is an important Chinese production hub due to its relatively low electricity unit price.

2.3. Value-Added Downstream Processing

Producers often process flake graphite to create spherical graphite, a product that is deemed much more suitable for certain industries (particularly the battery industry). This downstream process first entails reducing the size of the graphite (micronization), then shaping the flakes into spheres to increase the flakes' surface area and energy density (spheronization), and lastly removing impurities and reach the required level for the industry (purification and coating).

The complete modification process results in High Purity Spherical Graphite (HPSG), a higher priced graphite product. This product is commonly bought by battery manufacturers and is currently priced at around US$2,500 to US$2,900 per tonne (Free on board (FOB) China). Figure 2 shows the complete graphite supply chain, including modification processing.

Figure 2: Graphite Supply Chain



Source: British Geological Society.

Understanding this downstream modification process is important for comprehending the relationship between the demand for flake graphite and the demand for battery anode graphite product (HPSG). Some new mining projects have plans to include further graphite processing in their developments, for instance micronization and spheronization. Although these investments can enhance the value of a project, they also can significantly increase capital costs (*see Annex 1 – Graphite Description and Types for more information on the steps within downstream processing*).

[10] SGL Carbon.

3. GRAPHITE RESOURCES

Global graphite resources are substantial, but their extent is not known with a high degree of confidence since industrial minerals are typically not fully delineated and reported far in advance. The sources and data types also vary considerably. According to USGS, the countries with the largest recognized reserves are China, Turkey, and Brazil, which account for about 72 percent of total supply.[11] Madagascar, Mozambique, Tanzania, and Canada also hold significant resources.

Table 1 below shows both graphite reserves (that is, the amount of graphite that could be economically extracted or produced at the time of determination, defined by a high level of mineral exploration) and resources (that is, the amount of graphite in or on the Earth's crust that could *potentially* be economically extracted based on geological evidence, but have a lower level of exploration) based on available data).

The table also shows the reserves as reported by the USGS and from CPRM.[12] The global totals are different, but represent different types and sources of information. For example, the S&P Global database lists reserves and resources at 508 Mt, while the USGS reports global reserves of some 320 Mt (and an additional 800 Mt of recoverable graphite in inferred resources). The CPRM data is from their 2020 Graphite Report and it calculates a global graphite resource of 1,401 Mt, derived from a variety of sources.

Most of the resources in the S&P Global figures are reported by individual mining companies and are established under the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (the JORC Code); the Canadian Institute of Mining, Metallurgy, and Petroleum; and other similar national standards. They exclude some unreported resources held by state and private enterprises and therefore vary with other sources. For instance, there is limited available company resource data for China, Turkey, and Brazil, the three largest resource countries as defined by USGS. It should also be noted that the resources reported are not necessarily economic resources as they contain measured, indicated, and inferred resources, as well as reserves. Also, resource levels can change with movements in commodity prices.[13]

Additionally, the basis for the USGS' reserves calculation is different. The USGS derives national information on reserves from a variety of sources. These sources include comprehensive evaluations, as well as national reserves estimates compiled by countries, academic articles, company reports, presentations by company representatives, and trade journal articles.

Table 1: Global Graphite Reserves and Resources Based on Reported Data

Country	S&P Reserves & Resources Mt cont. Cg	S&P Average Resource Grade %Cg	USGS Reserves Mt cont. Cg	CPRM Resource Mt cont. Cg
Mozambique	337.7	10.2	25.0	-
Tanzania	66.8	6.3	17.0	-
Canada	34.0	5.6	(a)	5.7
Australia	16.6	7.8	(a)	-
Madagascar	12.1	5.7	26.0	180.0

[11] USGS, Mineral Commodity Summary of Graphite, January 2021

[12] Projeto Avaliação do Potencial da Grafita no Brasil - Fase 1

[13] Reserves and resources defined by national codes need to be defined by a commodity price to calculate whether or not any particular part of the mineralization is economic (mineralization grades can vary across a deposit). Thus, if the commodity price rises lower grades of mineralization, previously waste, could become economic to mine and then classified as resource, and vice versa.

Country	S&P Reserves & Resources Mt cont. Cg	S&P Average Resource Grade %Cg	USGS Reserves Mt cont. Cg	CPRM Resource Mt cont. Cg
USA	11.8	4.8	(a)	-
Malawi	10.9	7.2	-	-
Sweden	10.8	15.5	-	-
Guinea	2.0	4.0	-	-
Finland	1.3	4.8	-	-
Ghana	1.0	5.2	-	-
Indonesia	1.0	12.7	-	-
Brazil	0.5	2.3	70.0	43.8
Russia-Ukraine	-	-	-	660.0
North Korea	-	-	-	33.1
Turkey	-	-	90.0	-
China	-	-	70.0	415.0
India	-	-	8.0	14.0
Uzbekistan	-	-	7.6	-
Mexico	-	-	3.1	13.4
Sri Lanka	-	-	1.5	9.3
Other	1.6	-	9.8	27.1
Total	**508.3**	8.45	**320.0**	**1,401.4**

Source: S&P Global data, USGS, CPRM, (a) included in Other.

The following sections provide more information on the graphite resources of several countries, including China, Brazil, Turkey, Russia, Ukraine, and India.

3.1. Chinese Graphite Resources

According to the latest USGS data, Chinese graphite reserves amounted to 70 Mt or 22 percent of the world's total. This compares with 537 Mt of reserves and resources in 2018 reported in official Chinese data.[14] These reserves and resources have increased by 119 percent since 2010 and suggest the potential for China to maintain existing production levels for many years and even expand output.

Since 2010, significant progress has been made in prospecting for flake graphite deposits in China. Flake reserves and resources increased by 136 percent between 2010 and 2018 to 437 Mt. Flake graphite resources in China are widely distributed, with operations in 20 provinces (autonomous regions and municipalities) and 173 mining areas as of 2018. China's main flake producing regions are concentrated in Heilongjiang and the Inner Mongolia Autonomous Region of China.

[14] Information Center of the Chinese Ministry of Natural Resources (ICMNR)

Chinese reserves and resources of amorphous graphite have increased by over 70 percent to 100 Mt between 2010 and 2018. By the end of 2018, 10 Chinese provinces and 38 mining areas had operating amorphous graphite mines. China's main producing regions for amorphous graphite are concentrated in the Inner Mongolia Autonomous Region of China and Jilin and Hunan provinces.

3.2. Brazilian Graphite Resources

According to the USGS, Brazil has graphite reserves of 70 Mt, which also constitutes 22 percent of global reserves, the same as China. Additionally, CPRM calculates Brazil's graphite resources at 43.8 Mt. CPRM estimates that 40 Mt of total resources is amorphous graphite and 3.8 Mt is flake graphite. Approximately 360 kt of this has been defined as flake graphite reserves, while 3.4 Mt as flake graphite-measured resources.

In Brazil, graphite occurs in a wide spectrum of metamorphic environments. Metamorphism is the key variable when analyzing graphite potential because it dictates the degree of crystallization and mineral purity. Overall, mineralization is concentrated in three metamorphic rock types (facies): green shale (27 percent), amphibolite (hornblende) (25 percent), and amphibolite granite (23 percent). Green shale is mainly associated with amorphous graphite while amphibolite is primarily associated with flake graphite. The main graphite deposits are found in Minas Gerais, Bahia, Ceará, Rio de Janeiro, and Mato Grosso. Additionally, the government and mining industry believe the Amazon Craton in the Sunsás Province may have significant potential. Table 2 provides more information on the graphite resources in Bahia, Ceará, and Minas Gerais.

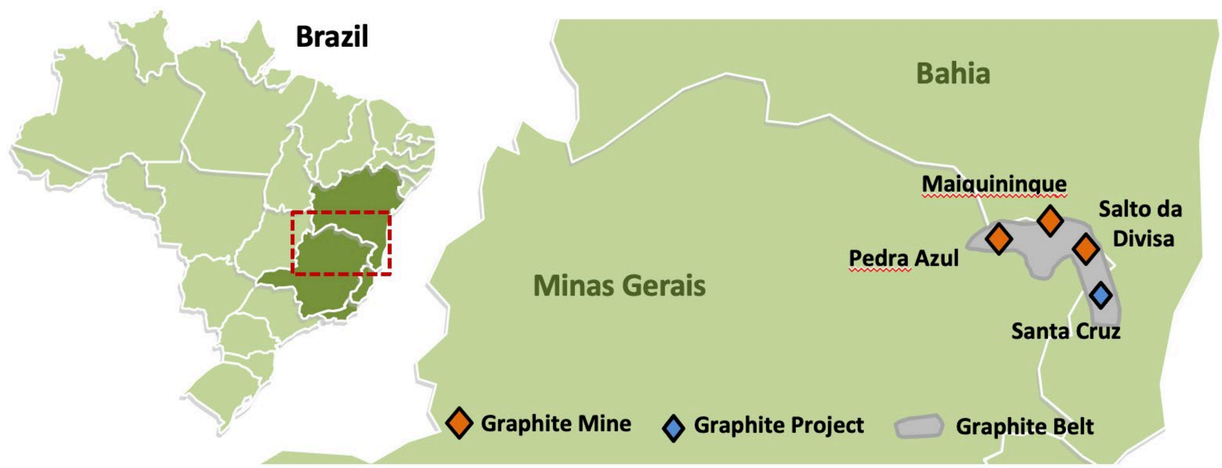
Table 2: Main Brazilian Graphite Reserves by Region (2021)

Municipality	State	Graphite MII Resource Mt
Eunapolis	Bahia	0.014
Guaratinga	Bahia	0.885
Maiquinique	Bahia	2.174
Itabela	Bahia	0
Itagimirim	Bahia	0
Baturité	Ceará	1.040
Itapiuna	Ceará	0.022
Almenara	Minas Gerais	3.667
Cachoeira de Pajeú	Minas Gerais	0.043
Corrego Fundo	Minas Gerais	0.015
Itapecerica	Minas Gerais	0.646
Jordânia	Minas Gerais	0.380
Mateus Leme	Minas Gerais	2.005
Pedra Azul	Minas Gerais	5.117
Salto da Divisa	Minas Gerais	3.439
São Francisco de Paula	Minas Gerais	1.986
Total Brazil		**21.433**

Source: CPRM.

Mining of amorphous graphite first occurred in the São Fidélis - Itaperuna Graphite Province, although this area is now inactive. Graphite is currently exploited only in flake-type deposits from mines in a large graphite belt running between Bahia and Minas Gerais (*see* Figure 3).

Figure 3: The Minas Gerais – Bahia Graphite Belt in Brazil



Source: Deloitte, various.

3.3. Other Resource Areas

Other areas with reported or potential graphite reserves and resources include Turkey, Russia, Ukraine, India, Mozambique, Tanzania, and Madagascar. For instance, graphite reserves in Turkey are deemed the world's largest at 90 Mt in 2020 according to the USGS, accounting for 28 percent of global reserves. Most deposits are amorphous graphite, which are widespread across the country. Limited information is known about the resources, and current reported graphite production is low (1.5 kt in 2020). Table 3 provides more information about graphite production in Turkey and around the world.

Table 3 also shows that Russia, Ukraine, and India are more modest graphite producers. The CPRM reports a combined resource for Russia and Ukraine of 660 Mt. Again, limited information is known about the resources, and current reported graphite production is modest. India has relatively low reported reserves and resources (14 Mt), but the country's resource base is believed to be much larger. Graphite occurrences are widespread in the country, with states of Jharkhand, Tamil Nadu, and Odisha hosting almost 100 percent of the reserves, and Arunachal Pradesh, Jammu and Kashmir, and Odisha accounting for over 80 percent of the resources.[15] Indian reserves include flake, amorphous, and vein graphite deposits.

These resource areas have the potential for clearer definition and/or an increase in graphite reserves in the future, which could lead to them being developed into graphite mines. However, Deloitte believes that this is unlikely to be within a foreseeable timeframe of 10 years. It usually takes a minimum of ten years from first discovery to mine production, and usually much longer.

[15] Indian Bureau of Mines 2018.

Table 3: Global Graphite Production 2020 by Country (Cg content)

Country	2016	2017	2018	2019	2020
					tonnes
China	780,000	625,000	693,000	700,000	650,000
Mozambique		300	104,000	107,000	120,000
Brazil	95,000	90,000	95,000	96,000	95,000
Madagascar	8,000	9,000	46,900	48,000	47,000
India	149,000	35,000	35,000	35,000	34,000
Russia	19,000	17,000	25,200	25,100	24,000
Ukraine	15,000	20,000	20,000	20,000	19,000
Norway	8,000	15,500	16,000	16,000	15,000
Pakistan	14,000	14,000	14,000	14,000	13,000
Canada	30,000	40,000	40,000	11,000	10,000
Mexico	4,000	9,000	9,000	9,000	8,000
North Korea	6,000	5,500	6,000	6,000	5,000
Vietnam	5,000	5,000	2,000	5,000	4,500
Sri Lanka	4,000	3,500	4,000	4,000	3,500
Turkey	4,000	2,300	2,000	2,000	1,500
Austria	-	-	1,000	1,000	1,000
Germany	-	-	800	800	800
Tanzania	-	-	150	150	150
Uzbekistan	-	-	5,000	100	100
Namibia	-	2,220	3,460	-	-
Other	8,000	3,480	200	200	-
Total	1,141,000	893,320	1,122,510	1,100,150	1,051,550

Source: USGS.

Meanwhile, East African countries have undertaken exploration activities in recent years. This has led to a sharp increase in the reserve and resources base of flake graphite, particularly in Mozambique, Tanzania, and Madagascar. In 2020, USGS estimated the region had a combined reserve base of 68 Mt, accounting for 21 percent of global reserves.

Much of the graphite resources in East Africa are owned by junior mining companies and have been quantified in accordance with reporting codes for reserves and resources. In addition, some of these resources are likely to be developed in a foreseeable timeframe of 10 years. The S&P database gives a total resource of 417 Mt for these three countries, with Mozambique being the largest (338 Mt).

4. NATURAL GRAPHITE SUPPLY

Most graphite operations are simple and use conventional mining and processing techniques. The sections that follow provide an overview of global graphite production, as well as Chinese graphite supply, Brazilian graphite production, and graphite supply from other regions. *Annex 4: Mining and Beneficiation of Graphite* gives a more detailed description of graphite mining and processing techniques.

4.1. Global Production of Natural Graphite

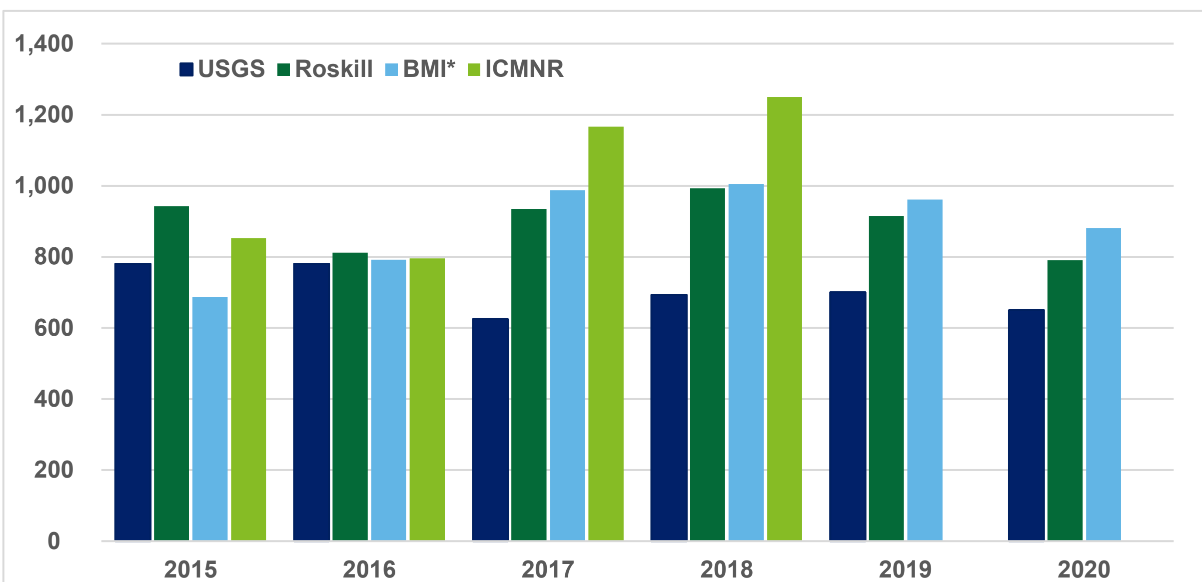
Global graphite production is currently estimated at 2.5 Mt per annum.[16] About 1.0 Mt, or 40 percent of global production, comes from natural graphite (mainly flake and amorphous). The remaining 1.5Mt, or 60 percent, comes from synthetic production. China, Brazil, and India have historically dominated natural graphite production; however, Mozambique and Madagascar have become important suppliers over the past 5-year period (*see Table 3 in the previous section*). Recent years have also seen the impact of the COVID-19 pandemic on global graphite production. In 2020, output fell by 27 percent, as producers reacted to a fall in demand caused by the global health crisis.

As with graphite resources, estimates for global graphite production vary. Nevertheless, given China's dominant supply and demand position, its future supply trends and competitive position remain key to the outlook of the graphite market as discussed further below.

4.2. Chinese Graphite Production

China is the world's largest graphite supplier. According to USGS data, China produced 650 kt of graphite in 2020, the equivalent to 62 percent of the world's supply. Figure 4 shows how Chinese graphite production has changed from 2015 onwards, according to different data sources.

Figure 4: Chinese Graphite Production Reported by Various Sources (kt)



Source: USGS, Roskill, BMI, ICNMR. * Adjusted from flake graphite data.

[16] The European Carbon and Graphite Association (ECGA) annual report 2020

Figure 4 also illustrates that, while Chinese production data is widely quoted, data can often vary significantly by source. Roskill reports that China produced 787 kt in 2020, while Benchmark Mineral Intelligence (BMI) reports that flake graphite production was about 565 kt, which corresponds to natural graphite output of about 880 Mt. To the extent that Chinese reported data can be relied upon, official graphite production data is even higher.[17] The Information Center of the Chinese Ministry of Natural Resources (ICMNR) reports that mined flake and amorphous graphite was approximately 1.25 Mt in 2018.

Jixi and Luobei in Heilongjiang province, Panshi in Jilin province, Pingdu in Shangdong province, and Xinghe in Inner Mongolia autonomous region are the centers of flake graphite mining in China. There are hundreds of graphite mining and processing companies in China, although fewer than 10 reportedly have the capacity to produce more than 30,000 t/y.

Mined graphite production declined sharply in 2012 in China and has been constrained in recent years due to several domestic factors. These include local government-imposed permits, unfavorable freight prices, excessive export duties on flake graphite, tightening mine safety procedures, tightening environmental regulations, logistical and energy constraints, plant closures, and water shortages. Some operations are believed to have shut down and some consolidation has taken place with the imposition of the stricter conditions and standards. This has disproportionately impacted the output of amorphous graphite, while flake production has been more stable. However, a new flake graphite mine is under construction in the Inner Mongolia Autonomous Region of China with capacity of 100kt/y of graphite targeting the battery and graphene markets (Roskill). This is an example of China continuing to invest in graphite and continuing to maintain its dominant position in the world.

The natural graphite sector in China is also undergoing major reforms. The largest provincial natural graphite producer in Heilongjiang, Minmetal, has embarked on a major process of consolidation around Luobei. As a result, its overall extraction grade has effectively been improved from 6 -7 percent to 11 percent, boosting production levels. According to the secretary-general of Heilongjiang Provincial Graphite Association, production of natural graphite from Luobei was 382 kt in 2020, and 349 kt in nearby Jixi. [18]

4.3. Brazilian Graphite Production

Brazil is the third largest producer of graphite in the world and home to the largest high-quality flake graphite producer outside of China. The country has a large graphite belt that runs between Bahia and Minas Gerais (*see* Figure 3). The graphite is typically shallow and the material crumbles naturally (which reduces mining and processing costs). The eastern end of the graphite belt also appears to have undergone greater metamorphism and tends to have large flake deposits as a result.

The Minas Gerais-Bahia graphite belt is one of the most active graphite provinces in the world, with over 70 years of continuous production. The rock layers and lenses of graphite gneiss have major economic importance because they include the most important deposits of flake graphite that have been explored and mined in South America, even when including current reported developments and exploration projects.

Currently, Brazil has three graphite-producing companies. In 2020, these companies had a combined annual output of approximately 95 kt from five operating mines – close to 10 percent of the world's total supply.

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[17] German Mineral Resources Agency (DERA)
[18] Source: Roskill, ICCSINO 14th Annual Anode Material

The largest company, Nacional de Grafite, is family-owned and has mining operations that are believed to be the highest profit margin graphite operations in the world, with significant reserves with the potential for expansion. Nacional de Grafite operates three mines with grades of 3-17 percent:

- Pedra Azul, Minas Gerais (about 36 kt/y);
- Salto da Divisa, Minas Gerais (about 18 kt/y); and
- Itapecerica, Southern Minas Gerais.

Extrativa Metalquimica, a non-ferrous metal alloys company, operates the Maiquininque mine in Bahia (about 30 kt/y). A small amount of amorphous production also comes from Mateus Leme. Section 9 provides more information on Brazil's current exploration and development projects.

4.4. Significant Graphite Supply from Other Regions

The most significant change in global graphite production outside of China in recent years has been the development of Balama flake graphite mine in Mozambique by Syrah Resources [ASX:SYR]. After completing its feasibility studies in May 2015, the mine started production in November 2017 with a capacity of 350 kt/y of natural graphite concentrate, the equivalent to almost one-third of the existing market. Production has been risen incrementally; however, with such large volumes entering the market, it has contributed to increased price volatility for graphite over the past few years.

Balama produced 100 kt in 2018 and 153 kt in 2019, but reduced output in September 2019 in response to a drop in flake graphite prices. Syrah then suspended production at the mine in March 2020 due to impacts of COVID-19 and weak end-user demand. Syrah then restarted production at Balama in March 2021 based on a strong improvement in market conditions and a reduction in the operating costs.

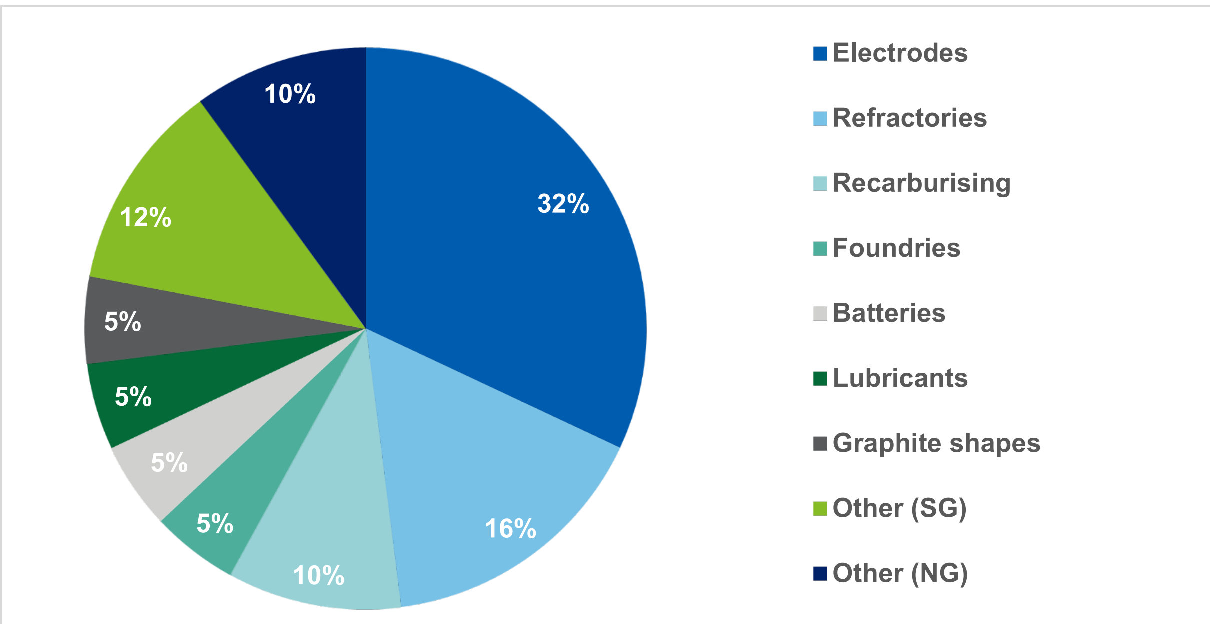
Syrah Resources is continuing to expand its production capacity. It is currently building a 10 kt/y active anode material plant in Vidalia, Louisiana in the United States, which it plans to open by 2024 and expand to 40 kt/y by 2030.

5. GRAPHITE DEMAND

Current global graphite demand of both natural and synthetic graphite in 2020 is estimated at 2.5 Mt per annum, with around 1.0 Mt supplied by the natural graphite market. Global graphite demand declined in 2020 due to COVID-19 related market impacts. Nevertheless, demand has subsequently picked up and is expected to recover further as demand patterns for steel, lithium-ion batteries, and other industrial uses normalize.

Figure 5 below shows the end-use market breakdown for natural and synthetic graphite (for more information on graphite applications by material type, *see Annex 1 –Description and Types and Annex 2 – Graphite Uses*). Electrodes represent the largest area of graphite consumption and account for 32 percent of graphite demand, all of which is from the synthetic graphite market.

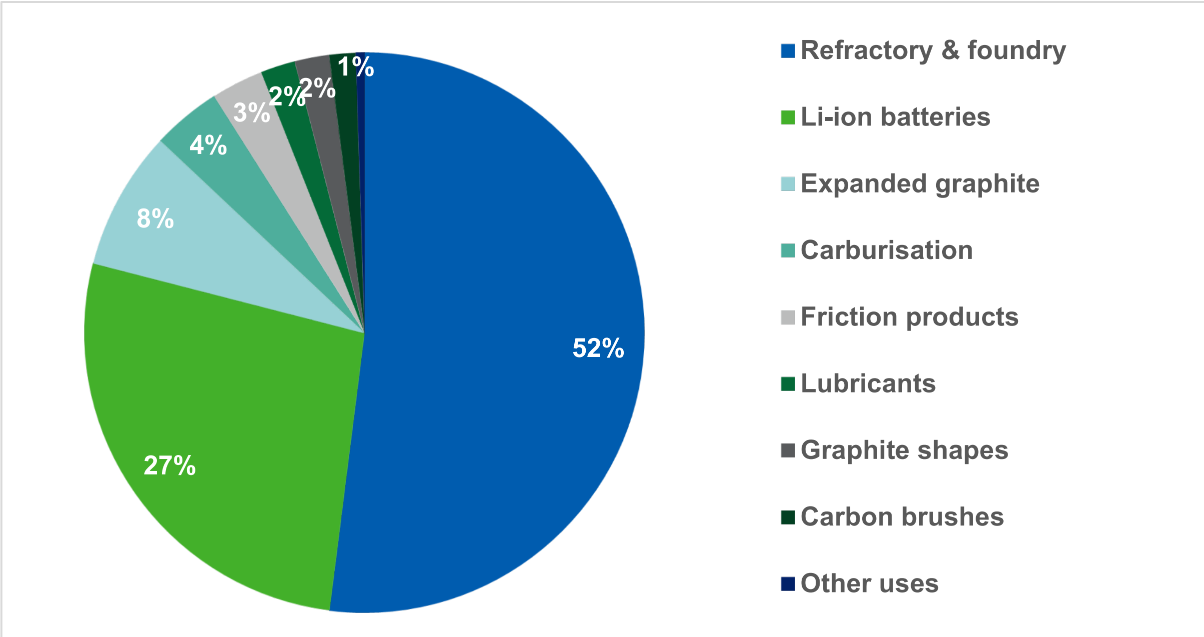
Figure 5: Total Graphite Demand by End-Use Market (Natural & Synthetic)



Source: Roskill.

Refractories are the next largest end-use market and account for 16 percent of graphite demand as shown in Figure￼. Refractory products are used in all high-temperature industrial applications. They are indispensable in a range of production processes in the steel, non-ferrous, cement, lime, and glass industries, with the steel market accounting for 70 percent of refractory demand. The refractory industry is currently the volume driver for flake graphite, with foundries and crucibles offering smaller markets for higher purity graphite products. Figure 6 shows the demand breakdown for flake graphite by end-use.

Figure 6: Flake Graphite Demand by End-Use Market 2020



Source: BMI 2021.

Around half of the world's graphite output – and about 75 percent of natural graphite – is consumed in Asia, primarily in China, followed by Japan and South Korea. This clearly illustrates the region's position as the global center of the lithium-ion battery value chain and highlights its focus on refractories and higher-value graphite products.

The anode industry associated with lithium-ion batteries manufacturing continues to be concentrated in China. This can be attributed to several factors including the availability of raw materials, the location of processing facilities, the downstream manufacturing chain, and the strong domestic market. In 2020, China produced 100 percent of the spherical graphite supply required for the battery market.

Driven mostly by demand for hand-held devices and electric vehicles, the lithium-ion battery market currently accounts for around 27 percent of flake graphite demand and is expected to be a major demand driver for graphite going forward. Deloitte will provide more information in an upcoming Interim Report specifically focused on the outlook for demand growth in electric vehicles and lithium-ion batteries as they relate to all the critical minerals selected for this analysis.

6. GRAPHITE TRADE AND PRICES

Global exports of natural graphite were roughly 560 kt in 2018,[19] with China (340 kt), Madagascar (55 kt), and Mozambique (52 kt) being the largest flake exporting countries. Although the natural graphite that is traded includes flake graphite and amorphous graphite, flake graphite accounts for most natural graphite exports. The sections that follow provide an overview of global graphite production and present overall trends associated with graphite pricing.

6.1. Trade in Natural Graphite

China is the largest producer, exporter, consumer, and importer of graphite products. Graphite production in general is concentrated in China at all stages of the supply chain. For instance, China currently produces the world's entire supply of battery-grade (spherical) graphite because processing and refinery facilities outside of China are limited. As a result, China consumes most of its domestic production. However, it exports around 350 kt of natural graphite in the form of amorphous graphite (35 percent), flake graphite (41 percent), spherical graphite (17 percent), and other powdered graphite (7 percent). The main export market for China's natural graphite is Japan, but it is also exported to the United States, Germany, India, Republic of Korea, Turkey, the Netherlands, Pakistan, Iran, and Belgium, among others.

China also imports around 110 kt of natural graphite (mainly from Madagascar, Mozambique, and Vietnam), approximately 56 percent of which is flake graphite and 41 percent is graphite powders. Imports of flake graphite started in 2017 and have risen sharply. Other importers of natural graphite for downstream processing include Japan, the United States, the Republic of Korea, and Germany.

Brazil also exports graphite (22 kt in 2018). However, Brazilian exports are substantially lower than domestic mine production, due to domestic consumption by the country's steel and refractory industries. Europe is the main export destination for Brazilian natural graphite.

6.2. Natural Graphite Prices

Graphite pricing is determined by several factors, including flake size, carbon content, and other technical attributes. Once the flake size and carbon content of a graphite product has been determined, the specific technical attributes of the flakes are defined by end-user parameters such as the expansion coefficient, thermal and electrical conductivity, and charge-discharge stability and efficiency. Larger flakes typically receive a higher price, and higher-end products with more stringent specifications can attract significant premiums over their benchmark counterparts.

Since the technical parameters that sought by end-users tend to be proprietary to their processes, pricing is not publicly available. There are no standard or quoted prices for natural graphite or spot or futures markets (in fact, there is a complete range of pricing for a wide range of products). For new producers entering the market, it typically takes 10-18 months to qualify anode materials prior to firm off-take commitments.

Pricing data that exists is based on actual transactions in the marketplace, which are typically direct negotiations between the buyer and seller. Companies such as BMI and Fastmarkets Industrial Minerals are paid subscription services that periodically survey buyers and sellers and publish pricing information, although their prices are mainly provided by large, high-volume buyers. Figure 7 shows flake graphite prices from 2007 onwards.

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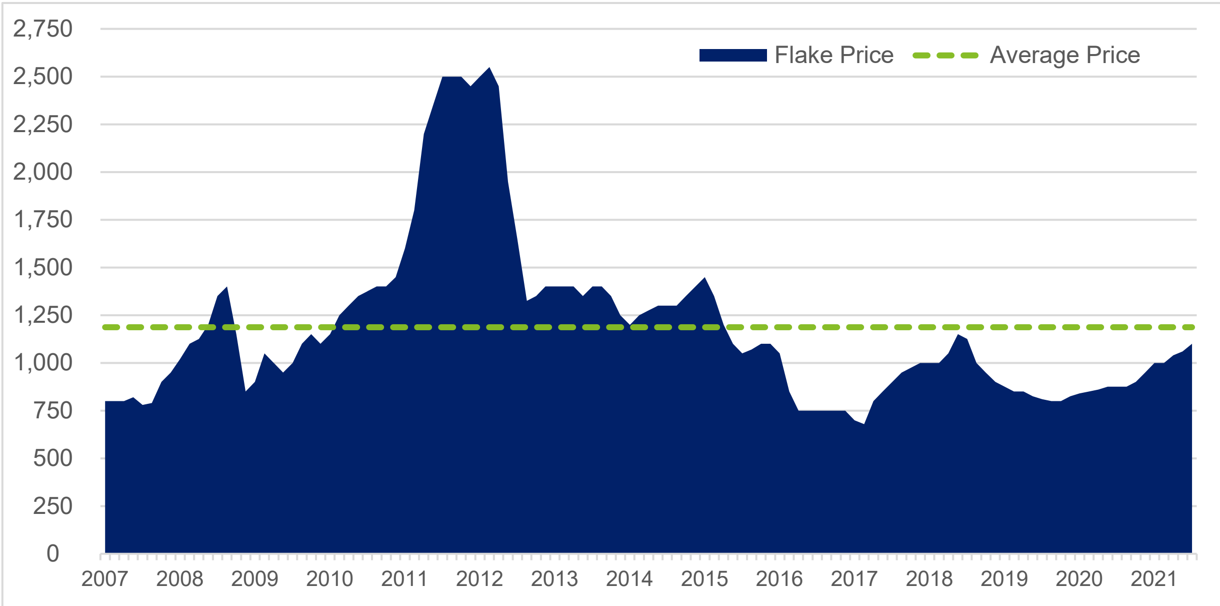
[19] German Mineral Resources Agency (DERA)

Figure 7: Flake Graphite Price (+80 mesh, 94-97% Cg, US$/t)



Source: Various.

Historically, the price of graphite has been well-correlated with the industrial production cycle and steel market. In late 2010, there was a rapid run-up in prices that peaked in 2011 (due to a strong restocking cycle and demand, post the global financial crisis, followed by oversupply from China). Prices then returned to more normalized levels but were on a downward trend and troughed in 2016 (exhibiting the same trend as many other commodity prices in 2011 through 2016).

Prices recovered from 2017 to 2019, but flake graphite supply began to outstrip market demand in 2019. The start-up of the Balama mine in Mozambique was a significant factor, along with weaker demand caused by the COVID-19 pandemic, and some disappointing data in electric vehicle demand that affected the market and softened prices. Prices began to improve in 2020 with the cut back and temporary closure of the Balama mine, along with some post-Covid recovery in market demand. This recovery has continued into 2021.

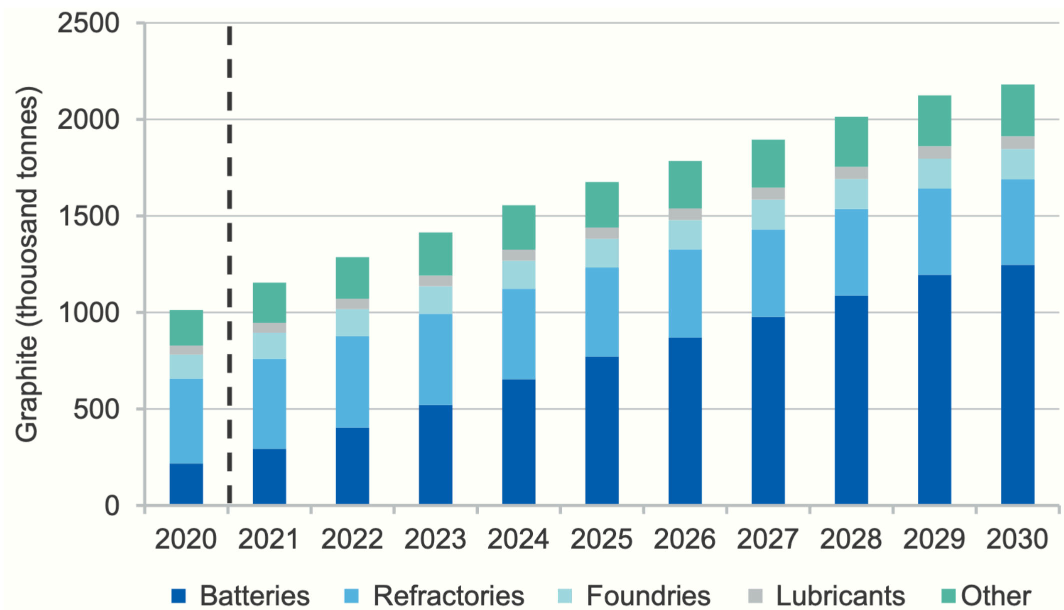
7. OUTLOOK FOR GRAPHITE DEMAND

Steel, automotive, public transport, aluminum, and aerospace are the key end-use industries of graphite-based products. The underlying structural growth of these industries, which is expected to rise at a moderate rate in line with global industrial production, will be the first determinant of graphite demand going forward. As a proxy for industrial production, the World Bank forecasts world real GDP of 5.6 percent in 2021, 4.3 percent in 2022 and 3.5 percent in 2023 (a proxy for global growth). Between 2015 and 2019 global growth averaged around 3.0 percent.

The second and most important factor will be the secular growth that is expected from the rapid increase in battery manufacturing, in particular the production of lithium-ion batteries for electric vehicles. As mentioned previously, Deloitte will provide more information on the outlook for demand growth in electric vehicles and lithium-ion batteries in an upcoming Interim Report .

Strong growth, albeit of less significance, is also expected to come from clean steel technology with hydrogen. Expanded graphite demand is also expected to grow significantly due to legislative changes and the environmental concerns around existing traditional flame retardants. Figure 8 shows how natural graphite consumption is expected to grow due to these factors.

Figure 8: Global Natural Graphite Forecast Consumption 2020-2030



Source: Roskill (2020), The Australian Government Department of Industry, Innovation and Science

There are a range of demand forecasts for graphite from consultants (e.g., Roskill and BMI, the two main independent consultants), industry, and governmental bodies. Nevertheless, the underlying message is that there will be strong demand for graphite as an anode in lithium-ion batteries for decades to come. For example, a recent report by the World Bank predicts that a rise of almost 500 percent in graphite supply would be needed by 2050 to shift to a 'low-carbon future.'

The sections that follow provide more information about potential graphite consumption in steel and battery industries.

7.1. Graphite Consumption in Steel

The global market for steel is currently estimated at 1.7 bnt and is projected to grow to 2.2 bnt by 2026 (projections assume a compound annual growth rate of 4.1 percent over the period).[20] Underlying demand growth for graphite in the steel industry is expected to grow at similar rates, although there will be areas of stronger growth.

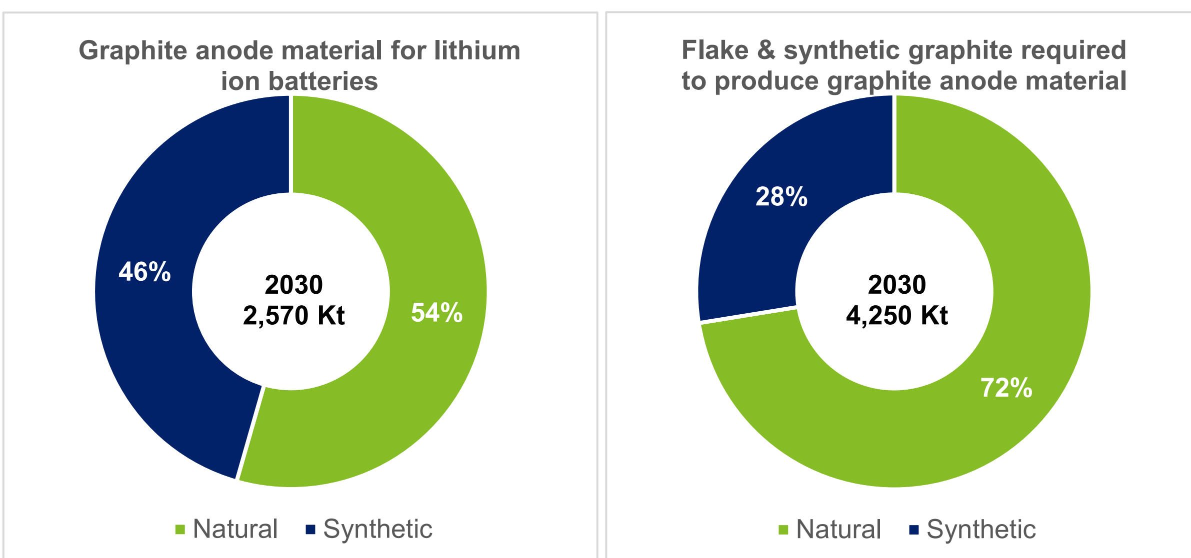
One area of growth is China's production of steel via its electric arc furnaces (EAF), which continues to grow rapidly and is increasing demand for synthetic graphite in EAF electrodes. The switch to EAF is being strongly encouraged by the Chinese government. This is also supported by the Chinese policy introduced at the beginning of 2021 which only allows high-quality steel scrap to be imported into China.

In the slightly longer term, the growth of clean steel technology with hydrogen, which requires electric arc furnaces and synthetic graphite electrodes, is also forecast to grow strongly.

7.2. Graphite Consumption in Batteries

Positive forecasts for battery manufacturing and electric vehicle sales are expected to flow through to higher graphite consumption going forward. In terms of the switch to renewable energy and the take-up of electric vehicles, the exact timing and magnitude of increases are difficult to predict. Also, the end-use demand drivers in the world remain partly dependent on government policy and subsidies. Nevertheless, this growth is expected to result in total natural graphite consumption exceeding 2.0 Mt in 2030, more than double the current levels of around 1.0 Mt (Roskill).

Figure 9: Graphite Forecast Consumption 2030 in Lithium-ion Batteries



Source: BMI data.

[20] Steel - Global Market Trajectory & Analytics

The battery sector consumes both natural flake graphite and synthetic graphite, but flake graphite is likely to outpace underlying battery growth as battery manufacturers look to optimize battery manufacturing costs by including greater amounts of natural graphite relative to more expensive synthetic graphite. Natural graphite also is reported to have a cleaner environmental footprint than some synthetic graphite production. The exact level of substitution is unknown, but forecasts anticipate the current 45 percent share of flake graphite to increase to around 60 percent by 2030.

Furthermore, to achieve the natural graphite battery anode material, some 55 percent of the mined flake graphite that is processed in the downstream treatments is unsuitable for batteries. The larger flakes and fines created by processing and are used for other graphite markets, and Deloitte assume that this material accounts for much of the growth in other flake markets.

The total anode graphite demand (synthetic and natural) for lithium-ion batteries was about 255 kt in 2020. BMI (2021) forecasts this will rise to about 1,060 kt in 2025 and 2,570 kt in 2030. Of this, natural graphite demand is expected to account for around 55-60 percent (*see* Figure 9). As a result, before processing losses, natural flake demand from mine concentrate is forecasted to rise from 225 kt in 2025 to 1,210 kt in 2025 and 3,079 kt in 2030. In addition, Roskill (2020) implied data from forecasts suggests that natural flake graphite demand for lithium-ion batteries will be 1,650 kt in 2025 and 2,750 kt in 2030.

As a result, based on available data, Deloitte estimates that the graphite industry requires around 2.5 Mt to 2.8 Mt of additional flake graphite (from mines for battery anode and other applications) to satisfy expected demand growth out to 2030.

7.3. Processing Demand

China should continue to be the main market for graphite processing, focusing strongly on downstream, higher-value products. Processing capacity for downstream products, particularly for use in the battery market, has continued to grow. Nevertheless, given the recent reductions in its own flake supply, China has become a significant importer of raw material flake graphite.

Producers in different parts of the world are planning and building new downstream processing capacity for natural graphite. This is being done to satisfy increasing demand from the battery market as well as to allow regional diversification away from China. These new initiatives include:

- Mineral Commodities is building an initial 10 kt/y active anode material plant in Norway to supply European battery plants.
- Talga Resources is building a 19 kt/y coated anode plant in Sweden.
- Elkem is building a pilot plant to produce anode materials that was scheduled for completion in early 2021.
- US-based Superior Graphite is going to adapt its Swedish operation to produce additional battery grade material.
- SGL Carbon is investing in synthetic graphite battery material.
- Leading Edge Materials is investing in Sweden’s Woxna mine with an integrated processing plant.
- Syrah Resources is looking at the feasibility of producing 10 kt/y of anode material at its plant in the US and scaling up to 40 kt/y.
- Ecograf is planning to fully integrate its Epanko graphite mine with an anode plant in Australia producing 5 kt/y and scaling up to 20 kt/y.

8. OUTLOOK FOR GRAPHITE SUPPLY

Expected growth in the lithium-ion battery market, along with encouraging growth in steel and other key end-use industries, are driving the future supply of graphite. Pricing is not currently incentivizing increases in production since prices are still around historic averages. Financial forecasts for existing graphite mine projects are largely being made based on similar averages. For 30 projects examined in detail, financial forecasts showed strong returns with a median post-tax internal rate of return (IRR) of 36 percent.[21] Nevertheless, there is a general expectation that prices could rally over the next decade, which may further incentivize more capacity in the longer term.

The sections that follow provide more information on supply forecasts for synthetic graphite and flake graphite.

8.1. Synthetic Graphite Supply

Synthetic graphite supply is forecasted to grow at up to five percent per annum, driven mostly by the increased demand in graphite electrodes. Graphite electrodes are expected to remain the largest application of synthetic graphite in the next 5-year period. The increasing use of EAF to produce steel is also expected to drive sales of large graphite electrodes, and synthetic supply is expected to rise to meet demand. The supply of synthetic graphite will also increase to meet demand created by the battery market, although this will occur at a slower pace than the expected increase in natural graphite supply for this sector.

There are several examples of increased investment in synthetic graphite from around the world. SGL Carbon, for instance, is investing in synthetic graphite battery material. Novonix in North America is also planning to increase annual production capacity of synthetic graphite for batteries. It is expecting to reach 10 kt in early 2023, with further plans to expand to 40 kt in 2025 and 150 kt in 2030.

8.2. Natural Flake Graphite Supply

About 1.0 Mt, or 40 percent of global supply, currently comes from natural graphite (mainly flake and amorphous). As discussed in Section 7.2, however, the graphite industry will require around 2.5 Mt to 2.8 Mt of additional flake graphite from mines for battery anode and other applications to satisfy expected demand growth out to 2030. This is about 1.1 Mt to 1.4 Mt of flake graphite required by 2025 and a further 1.1 Mt to 1.8 Mt required by 2030.

8.3. Natural Graphite Supply from China

Chinese graphite production is a key input for forecasting global graphite supply – especially for flake graphite and synthetic graphite. Although the supply outlook remains uncertain, and consultants have different estimates of supply growth out to 2030, data suggests that China could supply an additional 185 kt to 600 kt of flake graphite by 2030 (assuming that amorphous graphite production remains largely flat).

Roskill (2020) forecasts strong growth in natural graphite output from China (consisting mainly of flake and amorphous graphite). Chinese production is expected to more than double by 2030 to about 1,590 kt from 790 kt in 2020. This implies flake production of about 950 kt in 2030. Figure 10 illustrates how graphite production in China will increase based on Roskill forecasts.

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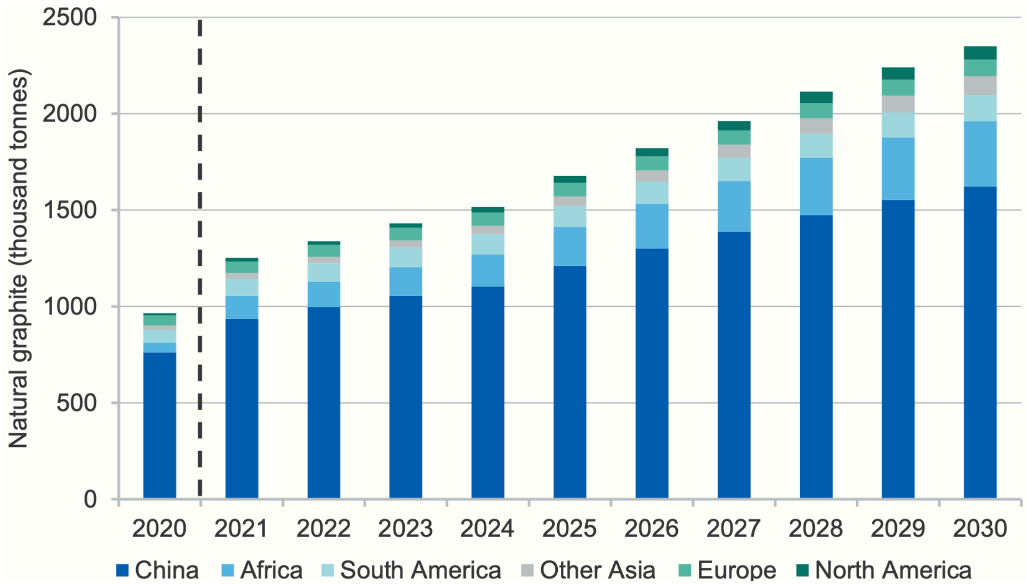
[21] Source material S&P Global, company reports.

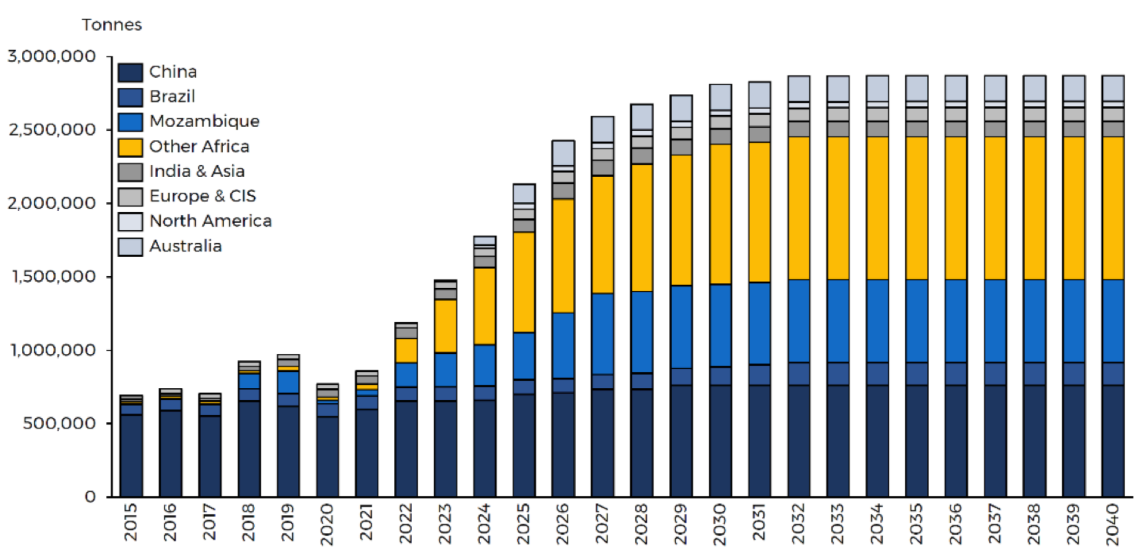
Figure 10: Roskill Global Natural Graphite Forecast Production by Region 2020-2030



Source: Roskill (2020), The Australian Government Department of Industry, Innovation and Science

BMI (2021), however, forecasts flake graphite output from China to rise only modestly. BMI estimates that production will slightly increase from about 565 kt in 2020 to 750 kt by 2030, and then remain flat thereafter (*see* Figure 11). These figures imply that total natural graphite (both flake and amorphous) output will be around 1,100 kt in 2030.

Figure 11: BMI Global Flake Graphite Forecast Production by Region 2015-2040



Source: Benchmark Mineral Intelligence, LeadingEdge Minerals

8.4. Natural Flake Graphite Supply from Other Regions

Looking at supply forecasts from other regions, the market realistically expects further production from Mozambique, Tanzania, and Madagascar (with Tanzania and Madagascar likely becoming significant suppliers of flake graphite concentrate). Australia, Canada, and Europe are also kicking off flake graphite projects, and some of the companies on the ground have planned to develop downstream processes to increase the value-add of their projects.

8.5. Potential Mine Supply of Natural Flake Graphite

New mine production capacity is required to satisfy the expected increase in flake graphite demand to 2.5-2.8 Mt by 2030. As mentioned in Section 8.3, consultants' forecasts currently suggest that some 185 kt to 600 kt additional flake graphite could be supplied from China. This means that other parts of the world would need to provide 1,900 kt to 2,600 kt of additional mined graphite supply by 2030.

It should be noted that the Balama mine in Mozambique was closed for most of 2020 and produced just 12 kt. However, this mine has a planned capacity of 350 kt, which is likely to absorb market demand growth in the near term. Thereafter, additional new capacity should be brought on stream, but this reduces the required flake graphite supply to 1,560 kt to 2,260 kt by 2030.

Deloitte has analyzed known graphite projects and identified 28 active projects of interest. Of these, 10 are projects where construction has started or is planned, and the remaining 18 are projects where a feasibility study has been completed or is underway. These are listed in Table 4 and Table 5.

Table 4: Graphite Projects where Construction has Started or is Planned

	Property Name	Country	Stage of Construction	Company Operator	Planned Capacity kt Cg	LOM Capex US$m*	Expect. Start Date
1	Nachu	Tanzania	Planned	Magnis Energy	220.0	340	unknown
2	Matawinie	Canada	Started	Nouveau Monde	100.0	277	2Q 2023
3	Ancuabe	Mozambique	Planned	Triton Minerals	60.0	147	unknown
4	Lac Gueret	Canada	Planned	Mason Graphite	51.9	275	unknown
5	Montepuez C.	Mozambique	Started	Tirupati Graphite	47.5	50	unknown
6	Molo	Madagascar	Started	NextSource Mat.	45.1	95	2Q 2022
7	Bissett Creek	Canada	Planned	Northern Graphite	44.2	179	2023
8	Siviour	Australia	Planned	Renascor Res.	28.0	271	unknown
9	Kearney	Canada	Started	Ontario Graphite	22.0	35	unknown
10	Woxna	Sweden	Planned	Leading Edge Mat.	14.7	133	unknown
	Total				**633.4**	**1,802**	

Source: S&P Global data. *Mine concentrate production only and includes some estimates.

If all projects shown in Table 4 come on stream by 2030, this adds a further 630 kt to mine supply. The additional flake supply required to satisfy demand by 2030 would then fall to 930 kt to 1,630 kt.

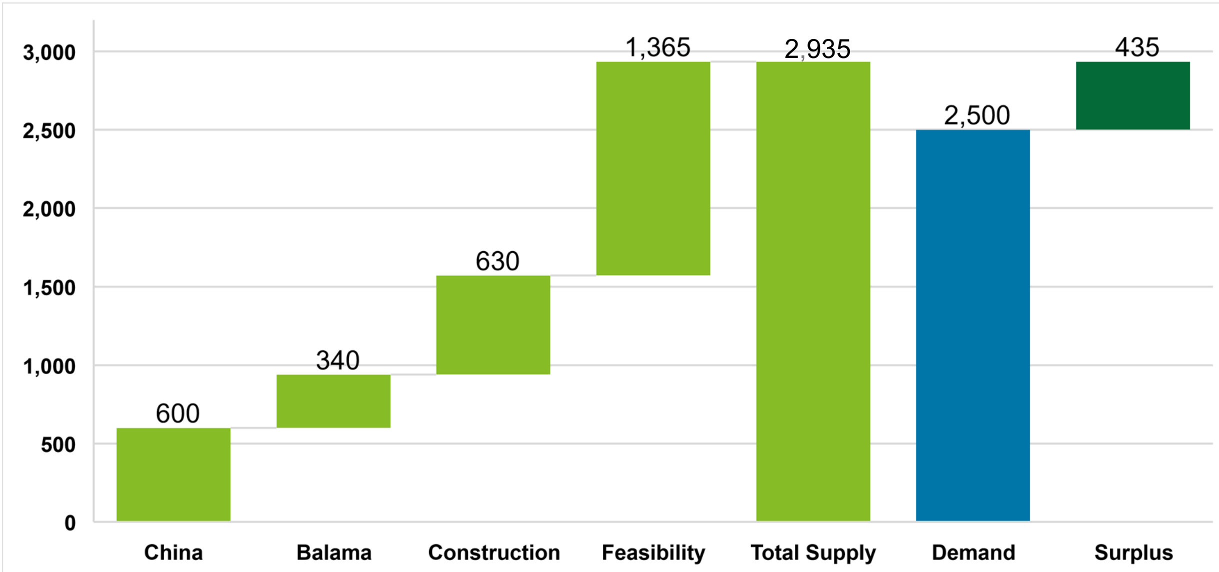
Table 5: Graphite Projects where a Feasibility Study has Started or is Complete

	Property Name	Country	Stage of Feasibility	Company Operator	Planned Capacity kt Cg	LOM Capex US$m*	Cash Cost US$/t Conc.
1	Mahenge	Tanzania	Complete	Black Rock	340.0	378	317
2	Balama North	Mozambique	Started	Triton Minerals	210.0	139	338
3	Mahenge L.	Tanzania	Complete	Armadale Capital	109.0	80	274
4	McIntosh	Australia	Started	Hexagon Energy	88.0	127	758
5	Vittangi	Sweden	Complete	Talga Group	84.7	1,296	-
6	Epanko	Tanzania	Complete	EcoGraf	60.0	101	393
7	Balama Cent.	Mozambique	Complete	Tirupati Graphite	58.0	79	337
8	Lola	Guinea	Complete	SRG Mining	54.6	135	470
9	Malingunde	Malawi	Started	Sovereign Metals	52.0	72	257
10	Munglinup	Australia	Complete	Mineral Commod.	52.0	86	474
11	Maniry	Madagascar	Started	BlackEarth Min.	51.0	87	483
12	Chilalo	Tanzania	Complete	Marvel Gold	50.0	109	662
13	Lac Knife	Canada	Complete	Focus Graphite	44.3	145	348
14	Lindi Jumbo	Tanzania	Complete	Walkabout Res.	40.0	36	282
15	Koppio-Kook.	Australia	Complete	Lincoln Minerals	35.0	52	515
16	Bunyu	Tanzania	Complete	Volt Resources	23.7	36	542
17	Coosa	USA	Started	Westwater Res.	12.7	95	822
18	Uley	Australia	Started	Quantum Graphite	-	-	-
	Total				**1,365**	**3,052**	

Source: S&P Global data. *Mine concentrate production only and includes some estimates.

The projects where a feasibility study have been completed or started are shown in Table 5. These projects suggest an additional 1,365 kt could be supplied if the projects all came on stream by 2030. This is a possibility which would then leave the market with either 435 kt in surplus or 265 kt in deficit. These conclusions are reflected in the outlook of the two main consultants (Roskill and Benchmark Minerals Intelligence) looking at graphite

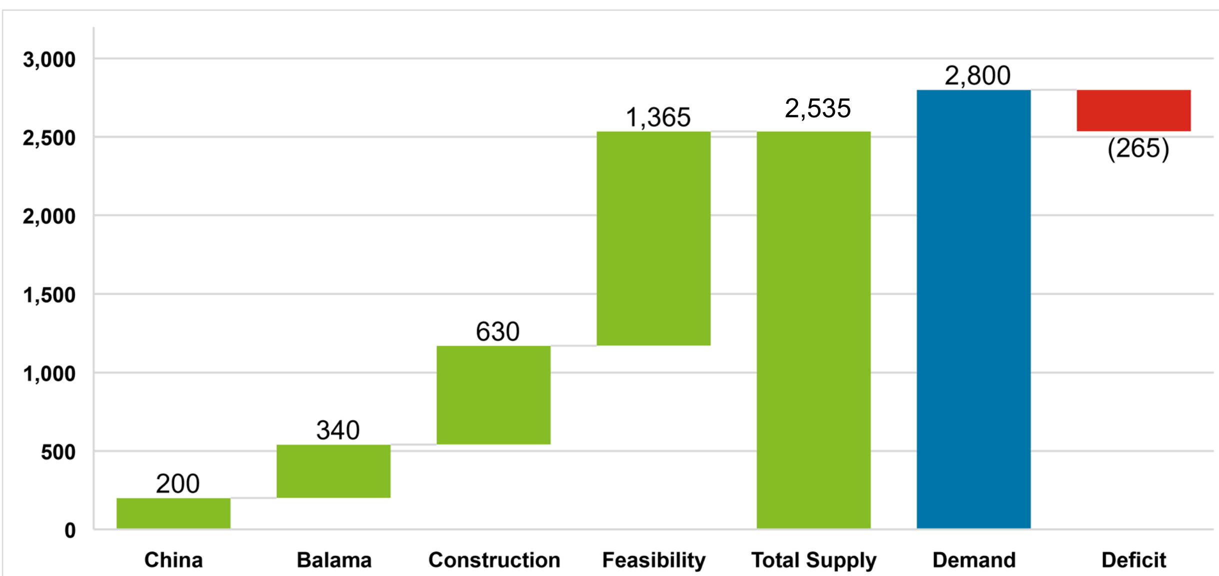
Figure 12: Bear case for Global Flake Graphite Balance 2020-2030



Source: S&P Global, Benchmark Mineral Intelligence, Roskill, Deloitte.

Figure 12 illustrates the "bear case" scenario, in which the market would end up with 435 kt surplus, while Figure 13 shows the "bull case" scenario with the 265 kt deficit.

Figure 13: Bull case for Global Flake Graphite Balance 2020-2030



Source: S&P Global, Benchmark Mineral Intelligence, Roskill, Deloitte

8.6. Other Exploration Projects

In addition to the graphite projects at the feasibility stage, there are an additional 26 active projects that already have defined graphite resources and where work is under way. These comprise 12 projects at the pre-feasibility or scoping stage, eight projects undertaking reserve development, and six projects described as being in advanced exploration.[22]

These 26 exploration projects currently have no indication of potential mine size, but have a Measured, Indicated, and Inferred resource of some 39.1 Mt with an average grade of 7.9 percent graphite. One of these projects, for example, is the Santa Cruz project in Brazil (ranked 47 out of 54 based on the amount of contained graphite resource), with 525 kt of contained graphite with an average grade of 2.3 percent. Although some of these projects could possibly be developed to close any potential supply gap before 2030, most of them are only likely to come on stream beyond 2030 if they are economic.

These resources have the potential to be expanded; however, the resources have the potential to produce approximately 985 kt/y of graphite as they currently stand. This estimate is made by applying several average factors to the resource, including a 0.7x factor for conversion of the resource to a mineable reserve, a 0.8x factor for mining losses, a 0.9x factor for mill recovery, and a 20-year mine life.

In addition to these 26 projects, there are an additional 80 active graphite projects globally that have not defined a resource yet. These include the following four active projects in Brazil:

- Santo Antonio de Padua (unknown operator);
- Sao Fidelis (unknown operator);
- Itabela (Frontera Minerals); and
- Capim Grosso (Zumbi Mineracao)

Annex 3 – List of Graphite Projects provides more information on the 54 projects discussed in this section that are close to construction, involved in a feasibility study, or involved in other pre-feasibility exploration studies.

[22] S&P Global data

9. MARKET BALANCE AND PRICE OUTLOOK

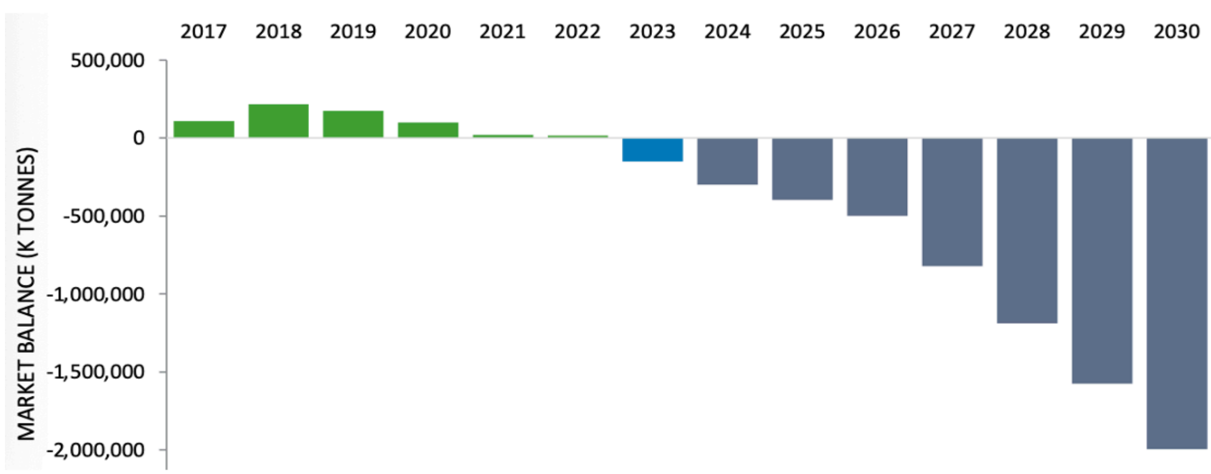
The graphite market is currently perceived to be adequately supplied. The ongoing recovery in global demand as the impacts of the COVID-19 pandemic fade, and the reduced supply from the Balama mine, are also allowing for some recovery in graphite prices. In the medium term, a stronger level of global GDP and the expected increase in demand for lithium-ion batteries is expected to support demand for graphite.

Key factors impacting the market balance and graphite pricing will be the output levels from the Balama mine, as well as the graphite production from a number of junior projects that should come on stream over the next few years. The price path is likely to be uneven, as both supply and demand change and surge at different rates over time. The construction of new mines, downstream processing plants, and new lithium-ion battery plants tend to result in 'lumpy' changes in capacity.

Increasing awareness of environmental considerations may also impact the graphite market going forward. Production costs (including labor, environmental, and energy costs) could also influence prices.

In the longer term, the outlook for graphite becomes more uncertain. The previous analysis of the graphite market has highlighted the conflicting level of data around graphite and the large number of variables that are required to complete a supply and demand analysis. As a result of this, graphite forecasts vary across the market. Nowhere is this more obvious than in the forecasted market balance from the two main consultants covering graphite – BMI and Roskill. Both consultants expect the market to remain in surplus out to 2023, followed by a broadly balanced market for a few years. However, BMI then has the market moving into deficit out to 2030 (Figure 14), while Roskill has the market in surplus over that period (Figure 15).

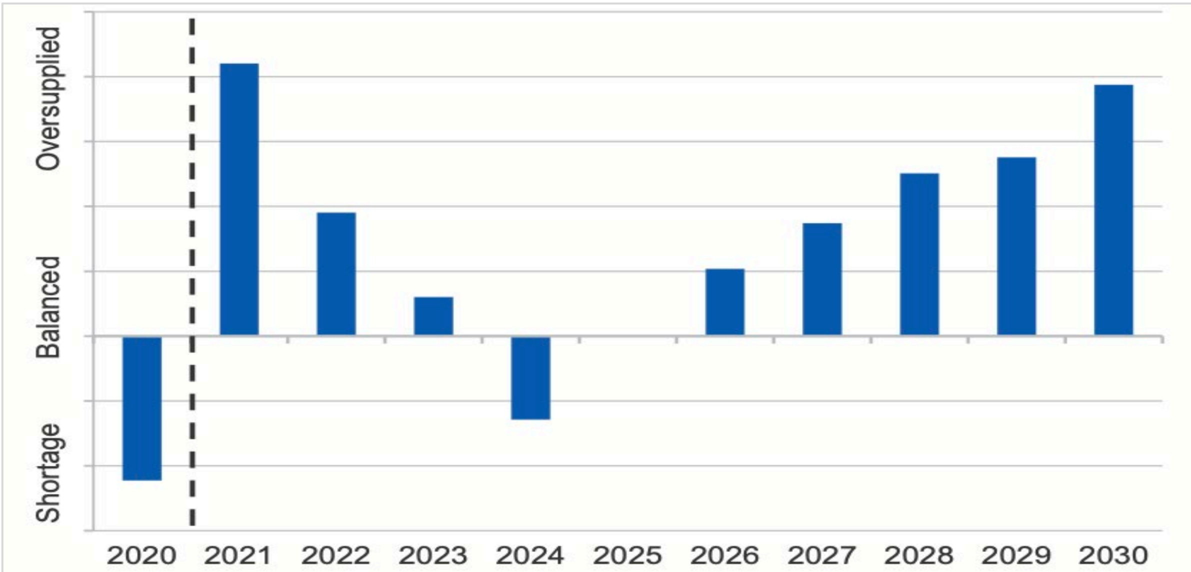
Figure 14: BMI Graphite Market Balance 2020-2030



Source: Benchmark Mineral Intelligence.

The data from BMI suggests that consumption growth associated with battery manufacturing momentum and scale increases could lead to an undersupplied market around the middle of the decade with new production unable to keep pace. In contrast, the Roskill data suggests that the pace of production and consumption adjustment will result in the graphite market being well supplied.

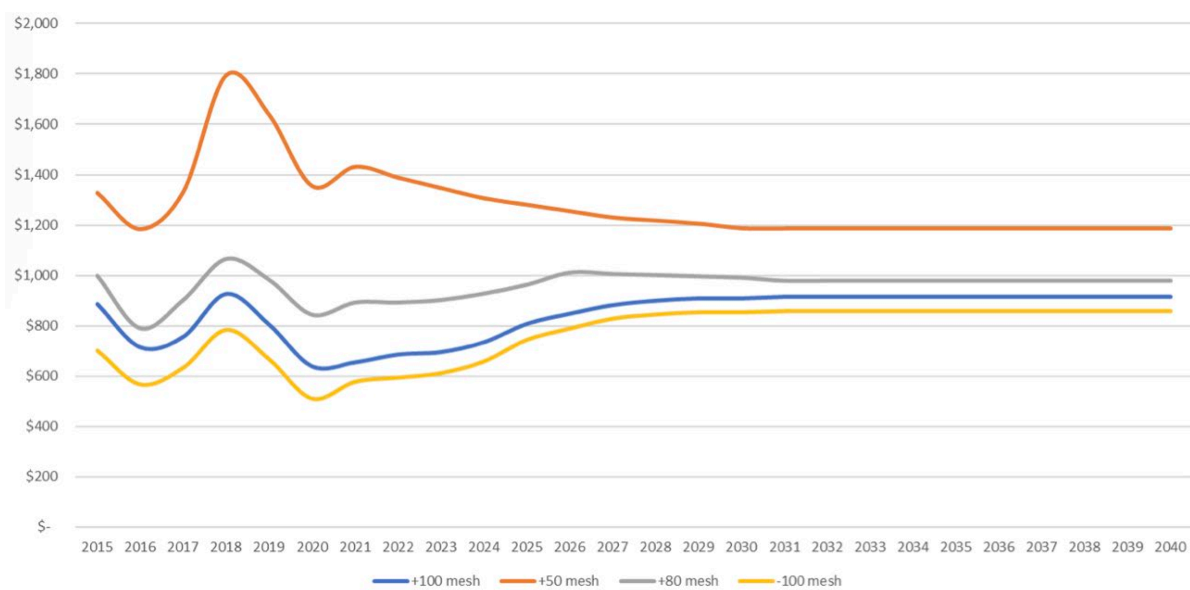
Figure 15: Roskill Graphite Market Balance 2020-2030



Source: Roskill, Australian Outlook for Selected Critical Minerals.

Despite the more positive outlook from BMI, Figure 16 shows how graphite price forecasts remain largely flat over the period.

Figure 16: Graphite Price forecast 2015-2040

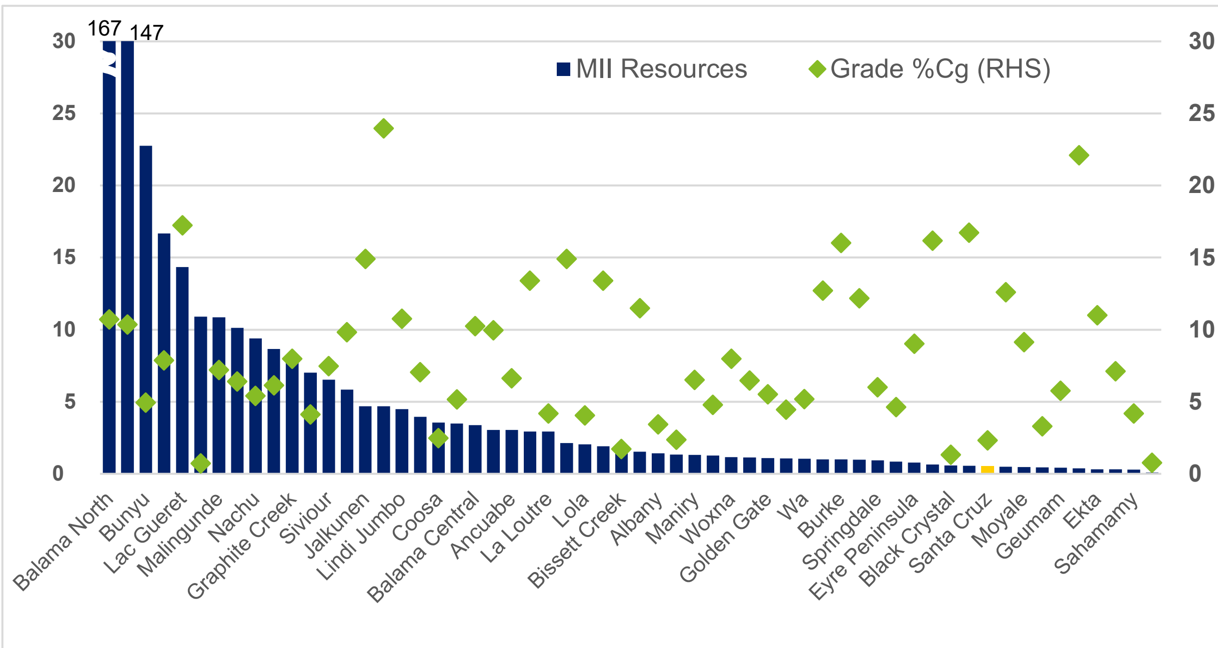


Source: BMI 2021.

10. ECONOMIC COMPETITIVENESS

Companies, investors, finance providers, and governments should examine existing mine and project data to assess and benchmark potential graphite projects. Deloitte has used S&P Global data to look at the graphite industry and identify data from 54 active projects and three operating mines (this includes information from 35 companies that have produced feasibility, pre-feasibility, and scoping study reports for the market as part of the process of developing their projects). *Annex 3 – List of Graphite Projects* shows these mines and projects in greater detail.

Figure 17: Contained Graphite Reserves and Measured, Indicated, & Inferred Resources



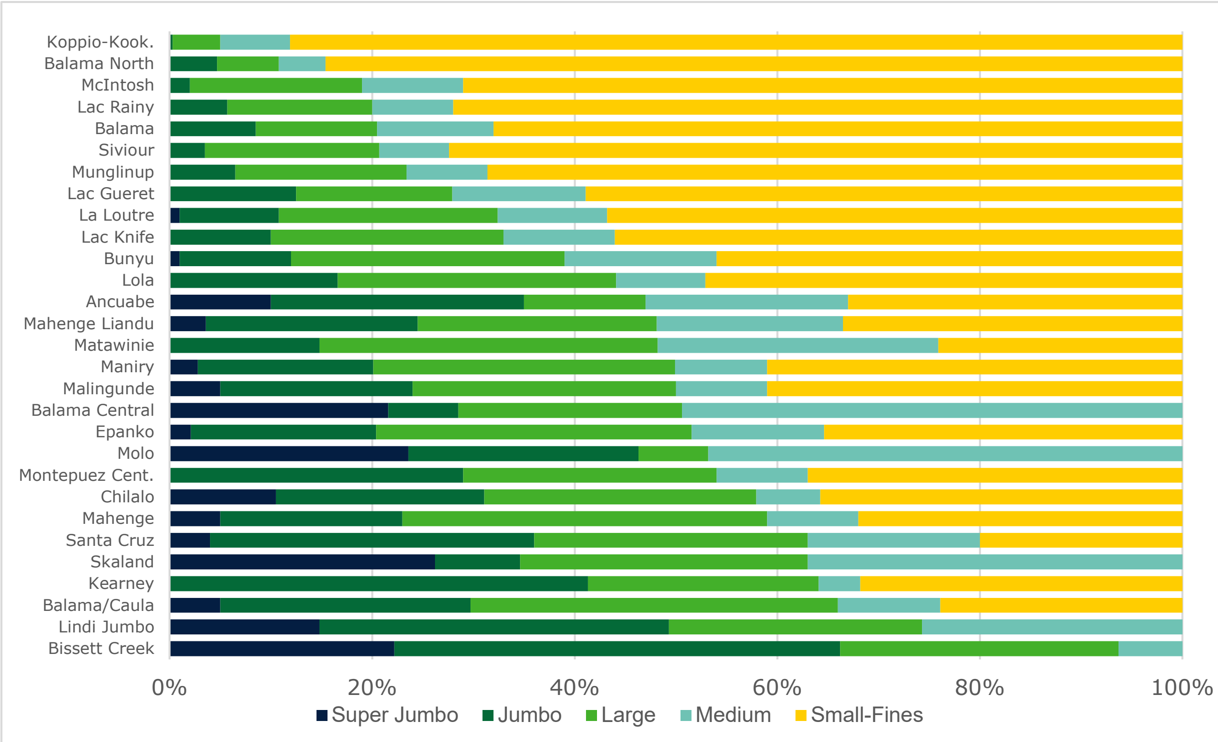
Source: S&P Global data, Deloitte

Figure 17 shows the contained graphite reserves and resources for graphite projects where data is available. The Balama mine, along with smaller operations in Skaland and Sahamamy, are the three operating mines included in Deloitte's analysis. While all other projects have the potential to come into production, not all projects will be meaningful in size. A project that can add around 5 percent to annual capacity, currently about 50 kt/y, would be considered as a meaningful sized project.

For a mine to achieve 50 kt/y in capacity, it would likely require a total resource of about 1.5 Mt. This is based on previously used recovery factors (reserves 0.7x, mining 0.8x, processing 0.9x) and assuming a 15-year mine life. Within our database, 30 graphite properties have a resource of greater than 1.5 Mt.

These projects have a wide variation in the grades of the mines' deposits, ranging from 0.7 percent to 24 percent, and averaging 8.3 percent. Lower grade operations may have a questionable viability since higher grades are typically preferred; however, the flake-size mix of graphite operations can significantly impact revenue, so just looking at the graphite grade does not necessarily give a clear picture. Generally, the larger the flake size, the higher the price received, and so the overall revenue will depend on a basket of prices.

Figure 18: Graphite Projects: Graphite Flake Size Profile



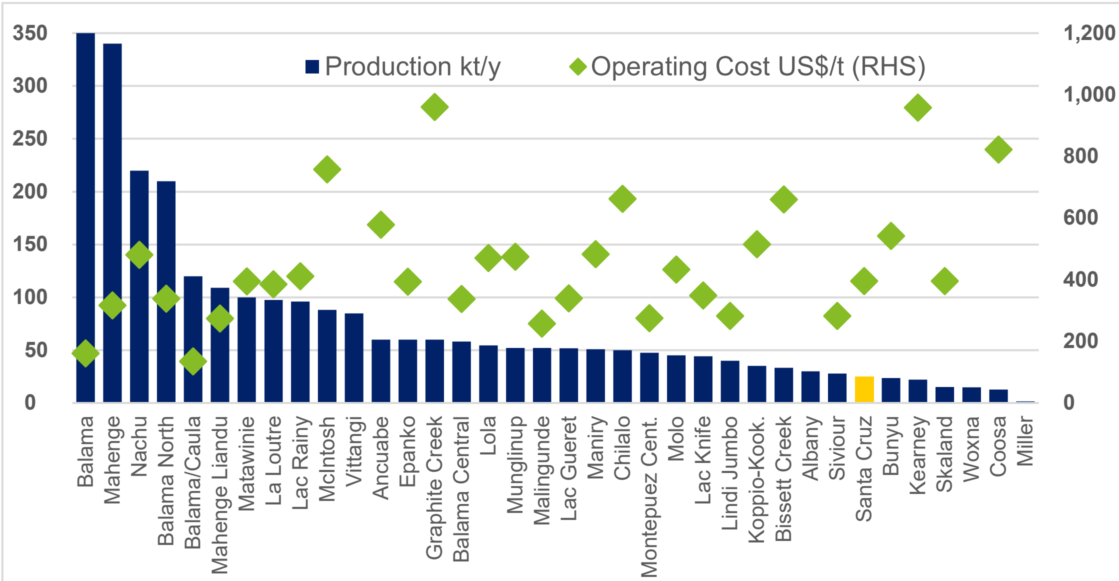
Source: Company data, Deloitte

Figure 18 shows the graphite flake size profile of the various projects that report data. The projects with largest proportion of graphite fines are likely to have the lowest basket revenue values. However, a high-grade deposit with large flake size and higher revenues will not necessarily result in the best graphite concentrate for anode material.

As mentioned previously, Deloitte used project reports from 35 companies for this assessment – however, these reports were published at different times and used different price assumptions and are therefore not wholly comparable. Nevertheless, by applying average prices to the flake size baskets, Deloitte was able to calculate an average graphite basket price of US$966/t (with a range of US$762 to $1,184/t). However, this calculation does not take into account other characteristics of the graphite than can alter the final price received.

Figure 19 shows the projected production levels and operating costs for these 35 projects. The average planned capacity is 77 kt/y, although this is skewed by a few large projects and more than a third of projects around the 50 kt/y level. The operating costs shown correspond to cash costs at the mine. Ideally, transportation costs to the port or other point of sale should be included for better cost comparisons, but this data is not often available. Based on Deloitte's assessment, the average operating cost for a mine is US$454/t. After allowing for about US$50 to US$100/t for transportation, the data suggests that most of these projects would be profitable using the average graphite basket revenue.

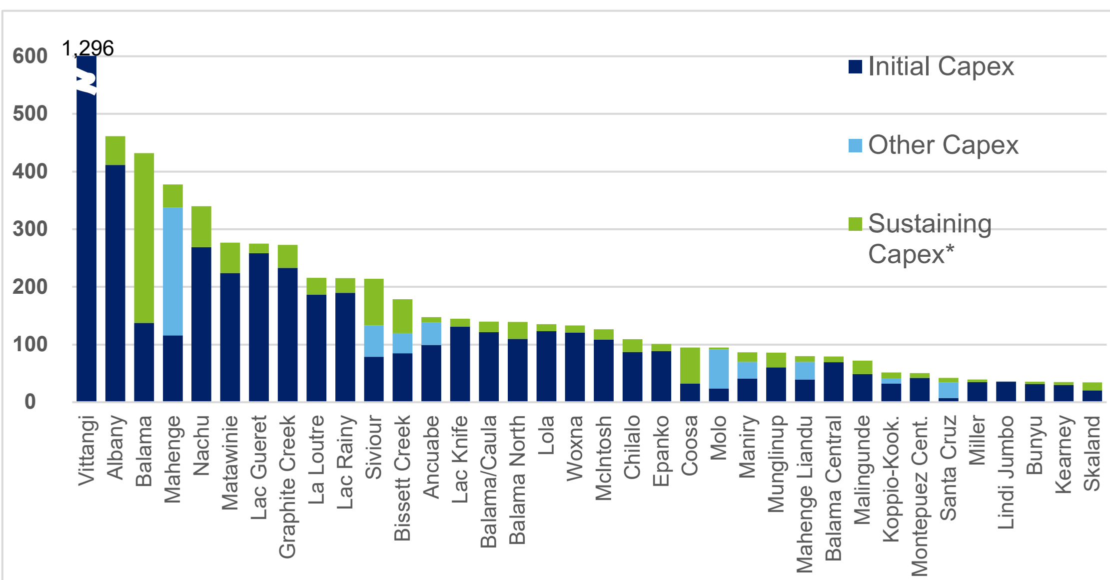
Figure 19: Graphite Projects: Projected Production Capacity (kt/y) and Operating Costs (US$/t)



Source: Company data, Deloitte

Another important factor in the economics of mining projects is the capital expenditure (capex) required to establish and operate the mine. This includes the initial capex, other capex associated with future expansions, and capex for sustaining operations (usually for the replacement of plant and machinery). These figures are shown in Figure 20. Companies usually focus on the initial capex, but it is important to look at all the capex over the mine life for an individual project for project comparison.

Figure 20: Graphite Projects: Planned LOM Capital Expenditure (US$m)

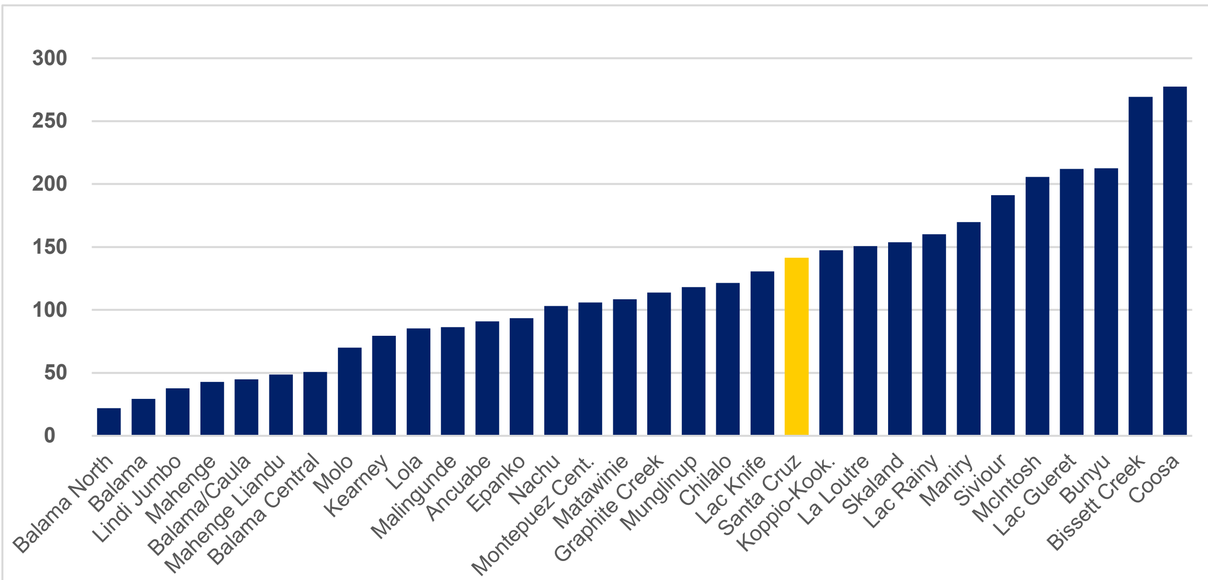


Source: Company data, Deloitte, *includes some estimates.

The project capex can often vary because of the orebody location, depth, and orientation, as well as 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.

Capital intensity is also used to compare projects and their quality. Figure 21 shows the capital intensity of relevant projects. Capital intensity is calculated based on graphite production over the whole life of the mine. The average for this group is US$121/t, which only includes capex to produce an ex-mine product since a couple projects are also planning further downstream processing.

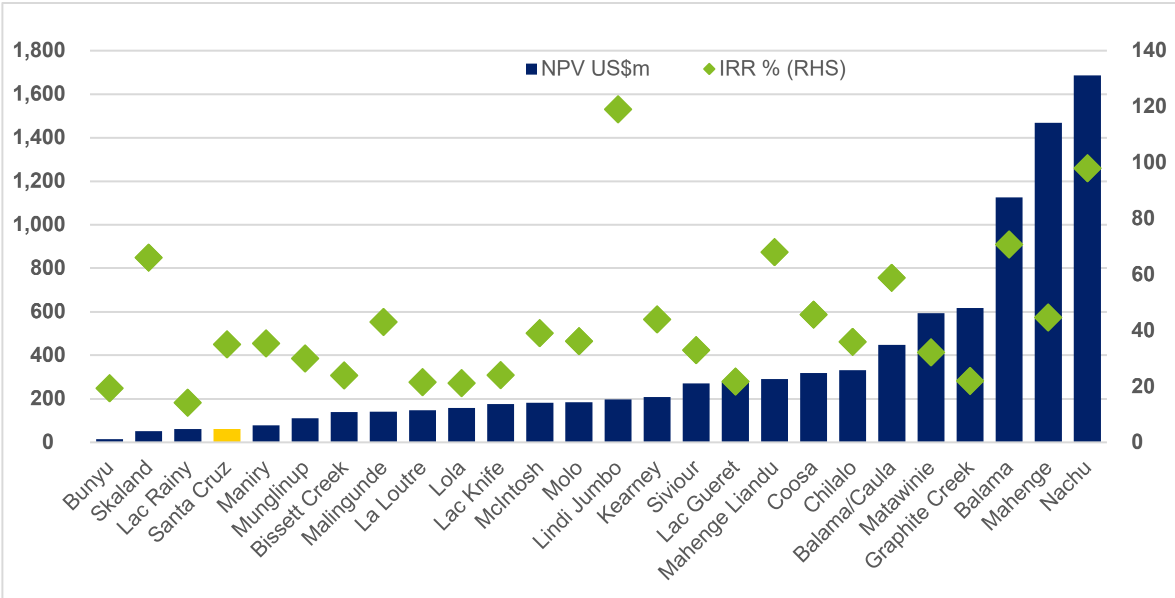
Figure 21: Graphite Projects' LOM Capital Intensity per tonne of Concentrate Produced (US$/t)



Source: Company data, Deloitte, includes some estimates.

The ultimate measure of economic viability is the net present value (NPV) and internal rate of return (IRR). Figure 22 shows the NPV and IRR for relevant projects. However, these two measures are also not totally comparable because of varying assumptions used. Additionally, not every project reported these post-tax values. The median IRR of this group was 36 percent, which suggests generally high returns (although the average is distorted by a few high values).

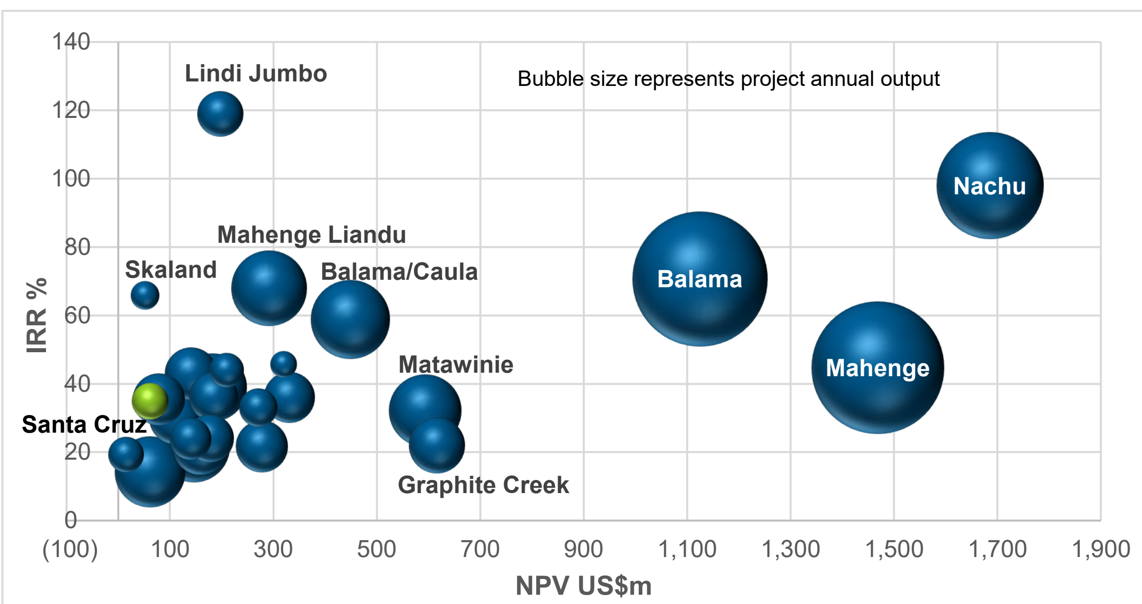
Figure 22: Graphite Projects: Net Present Value (US$m) and IRR



Source: S&P Global data, Deloitte.

Figure 23 shows the NPV and IRR data in a bubble chart where there the bubble size represents planned annual output. The figure shows a slew of projects bunched in the bottom left-hand corner. While all these projects may ultimately receive project finance, this suggests that the grouped companies will find financing much more competitive.

Figure 23: Graphite Projects: NPV versus IRR



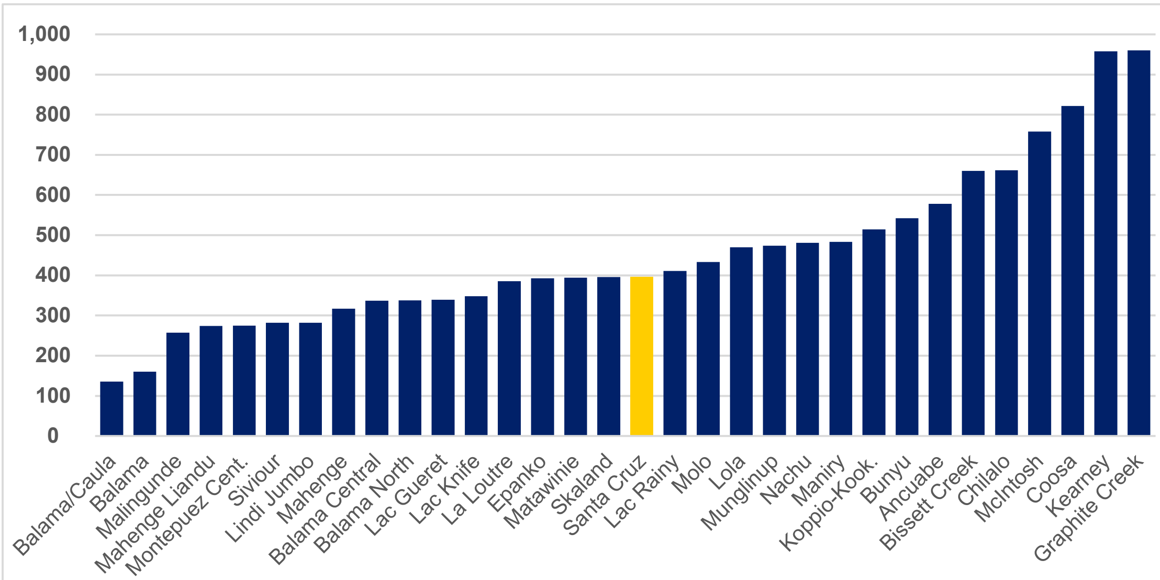
Source: Company data, Deloitte

The sections that follow present two other methods for comparing costs between projects.

10.1. Cost and Margin Curves

Figure 24 shows the operating cost curve for the selected projects. Considering planned production levels, some 50 percent of the capacity operates at US$280/t to US$480/t.

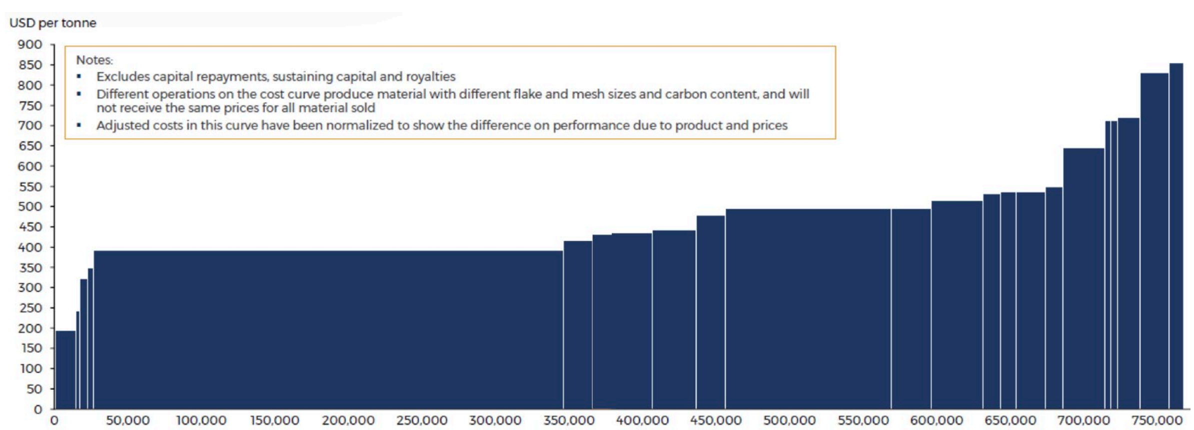
Figure 24: Graphite Projects: Mine Operating Costs US$/t



Source: Company data, Deloitte

Figure 25 shows the operating cost curve for existing mines for 2020, where 83 percent of production operates at US$450/t to US$550/t. This suggests new capacity at a lower average operating cost.

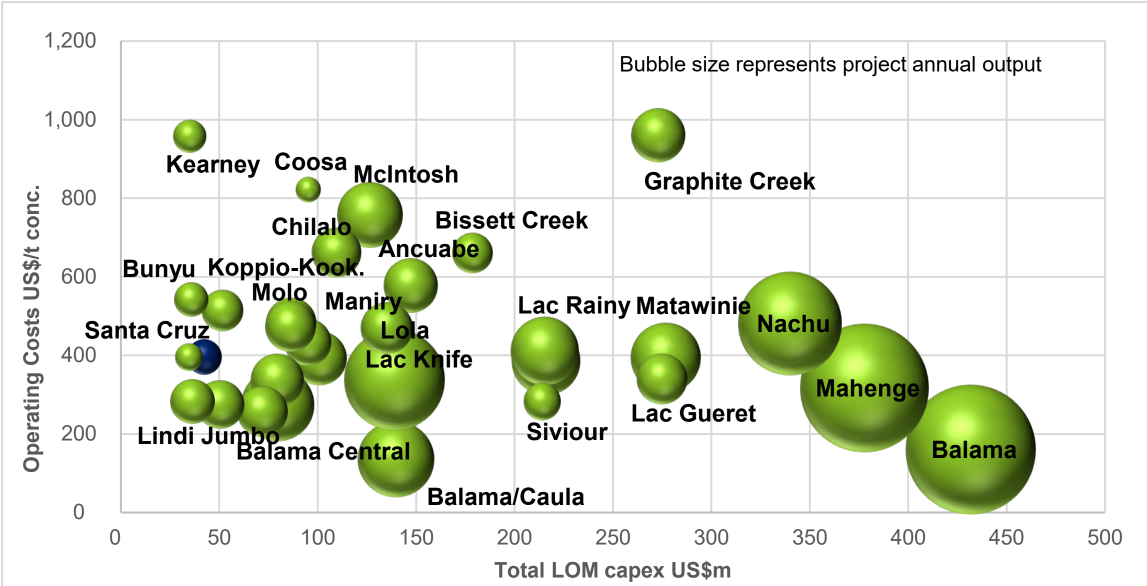
Figure 25: Flake Graphite Cost Curve for Existing Operations 2020



Source: BMI, Metals Australia

Figure 26 illustrates operating costs and the life of mine (LOM) capex to show both data points for each project. The annual output is also reflected in the bubble size to add a third important piece of data on the same chart. It highlights how several of the larger projects have higher capex but would operate at relatively low operating costs.

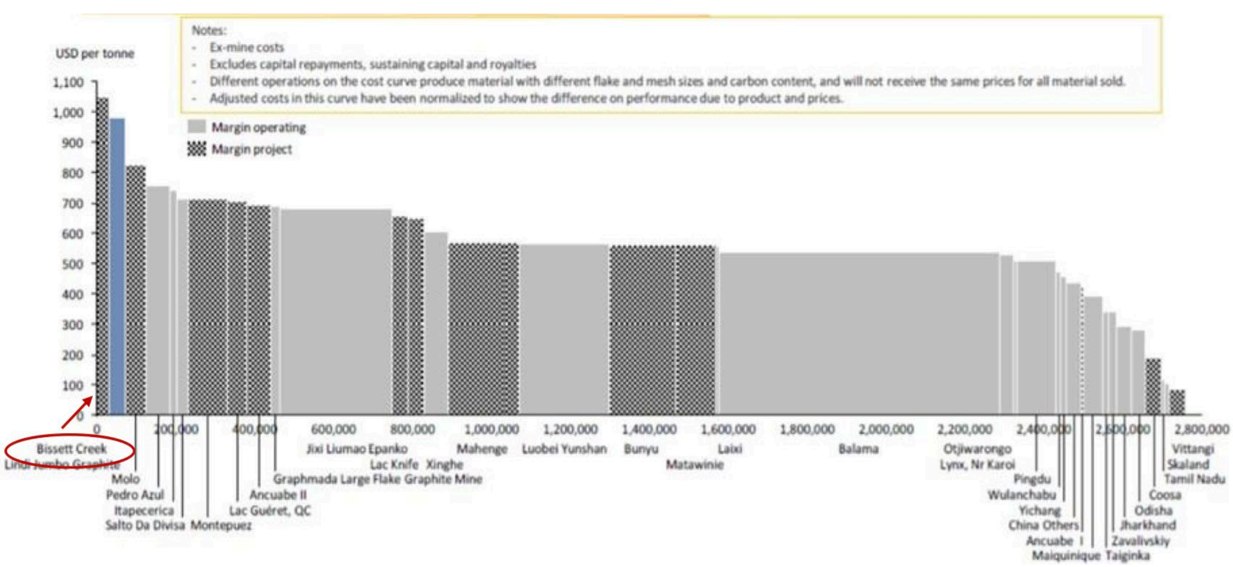
Figure 26: Graphite Projects: Operating Costs versus LOM Capex



Source: Company data, Deloitte.

However, as previously explained, because graphite is not a homogenously priced commodity and revenues are dependent on a basket price, revenue between projects can vary considerably. Consequently, for graphite it is better to look at margin curves for mines and projects. Figure 27 shows the expected 2030 margin curve from BMI and indicates that much of the new capacity sits at the higher end of the margin curve, indicating that the new projects will have above average profitability and are likely to be developed and come into production.

Figure 27: Graphite Margin Curve 2030



Source: BMI, Northern Graphite Corp.

Brazilian mining operations Pedro Azul, Itapecerica, and Salto Da Divisa currently sit at the top of the margin curve (i.e., most profitable operations globally) for currently operating assets. The section that follows discusses Brazil's development and exploration projects in detail.

10.2. Brazil's Development and Exploration Projects

As previously discussed in Section 3, Brazil has significant graphite resources. It is a major producer of flake graphite, which it produces from four high-margin operations. However, two companies currently dominate production, and while these assets reportedly have significant potential for expansion, there are no reported plans of further development. Currently, there is only one additional exploration project being considered. The rest are in early stages.

Based on S&P, Santa Cruz is the most advanced exploration project in Brazil (this project is highlighted in orange in the figures presented throughout this section). The project is located in southern Bahia and owned by South Star Battery Metals [TSXV:STS]. It has proven and probable reserves of 12.3 Mt of ore grading 2.4 percent Cg, with in-situ graphite of 295 kt. It also has at-surface mineralization in friable materials, and a large-scale pilot-plant testing (>30t) is planned. The results of the testing so far show that approximately 65 percent of Cg concentrate is +80 mesh with good recoveries and 95-99 percent Cg.

Santa Cruz is fully permitted and licensed and expected to be developed using a phased approach. Phase 1 operations for the 5 kt/y pilot plant are fully licensed and South Star plans to start construction in September 2021, with commercial production targeted for the fourth quarter of 2022. Phase 2 operations will represent a larger-scale concentration plant currently planned to produce between 25 to 30 kt/y of concentrate. The sizing of the phase 2 plant could be increased depending on the success of phase 1 operations, the ongoing development of commercial relationships, and market conditions.

Santa Cruz also has good infrastructure and logistics and is located about 1.3 km from the paved federal highway. There is a graded gravel road maintained by the municipality straight to the mine and plant. The electric substation is within 6 km of the plant site and a major natural gas line is also within 5 km. Water will be provided onsite from wells.

South Star has entered into a 5-year 20 kt/y offtake agreement with a US specialist company for graphite flake concentrate from the Santa Cruz project. It has also entered a separate contract for 4 kt/y of concentrate for 4 years with a European industrial specialist.

Frontera Minerals [private] is reportedly engaging in reserve development in Itabela, a state in Bahia. Zumbi Mineração [private] has also been outlining a graphite target in Bahia at Capim Grosso. At Capim Grosso, three preliminary drillholes and 10 shallow trenches have been completed over a 1-km part of the mineralization. Assay results of total graphitic carbon (TGC) vary between 6.8 percent TGC over 2.5 m to 21.0 percent TGC over 2.4 m in surface trenching. Drilling results of 26.5 percent TGC over 1.0 m have also been obtained.

In September 2021, Gratomic [TSXV:GRAT] announced it signed a Letter of Intent with Zumbi Mineração for the acquisition of 100 percent of Zumbi Mineração's rights and interests in the Capim Grosso property. Once Gratomic completes a pre-feasibility study, it will pay C$5.5m for the project, which includes a cash payment of C$200k, C$2m worth of Gratomic shares, and a C$3m promissory note 2 years after closing.

Buxton Mineradora is also reportedly considering the construction of downstream processing facilities to produce a spherical graphite in Brazil. No further information is available, and it is not clear if this facility is linked to a graphite mining project.

Meanwhile, there are some 386 properties with graphite mineral rights, located mostly in Bahia, Minas Gerais, and Ceará. Graphite is also a strategic mineral under the Brazilian government's Pro-Strategic Minerals Policy, allowing an acceleration of procedures to achieve production.

11. CONCLUSIONS AND KEY RECOMMENDATIONS

This chapter provides a summary of the overall market analysis for graphite, outlines some of the issues surrounding the forecast for graphite, and how they could impact the outlook for graphite supply and demand, as well as affect the future financing of the graphite industry. This section also includes potential threats and opportunities in the market and summarizes key recommendations for the graphite industry in Brazil to help the government in their long-term strategic planning and future policy action for graphite development and commercialization.

11.1. Graphite Market Capacity

The graphite market is a relatively small commodity market but feeds into many industries. It is mostly operated by small companies, many of them private and some state-owned. Around 60 percent of current mining, almost all downstream processing, and about 80 percent of battery-anode production currently takes place in China. These factors make the market very opaque, and data is often limited or unavailable. The data that is available is sometimes conflicting and there are some assumptions that will be critical to calculate the ultimate market balance in the future. These assumptions include:

- The rate of penetration of electric vehicles in the auto markets;
- The penetration of flake anode graphite material in lithium-ion batteries relative to synthetic graphite;
- The amount of flake graphite suitable for producing graphite anode material that can be extracted from a given volume of mined flake graphite;
- The availability of sufficient economic mine capacity for graphite and construction of sufficient downstream processing capacity; and
- The future growth rate of Chinese mine capacity for graphite.

Other market dynamics also hold risks – for instance, a slowdown in the steel industry, a sharp rise in graphite recycling (the recycling of graphite is not currently well developed), and battery technology changes. A final risk is the possibility that the price of flake material will be impacted by increased production. For instance, it is possible that to produce sufficient graphite material of the right size to satisfy the graphite anode material, an oversupply will occur in larger (and higher value) flake material and fines flake material, reducing the price of both. This could then reduce the overall revenue structure of the graphite basket for producers, reducing the overall profitability and returns.

It may be important for a graphite project (as with other industrial minerals) to be able to produce a balanced range of products and to supply a range of markets for it to be successful. Diversification would help ensure that all production (the basket of products) could be sold by spreading risk across different markets.

There is little doubt at this stage that large volumes of increased flake graphite concentrate are going to be required to satisfy the growth in lithium-ion battery demand. Nevertheless, the pace of electric vehicle take-up is slightly less certain, and the amount of new mine and downstream capacity that will come on stream carries even higher risk (both to the upside and the downside).

The consequence may be increased volatility in graphite prices if not enough – or too many – projects come on stream to meet the expected rapid increase in demand by the end of this decade. Volatility will also be created by the 'lumpy' nature of new supply and demand capacity.

11.2. Graphite Project Financing

At this early stage of demand growth, many graphite projects are raising exploration capital based on the positive long-term outlook of strong demand growth. Investors are looking for exposure to this high-growth market and placing bets on hopeful winners. If it becomes clearer that there will be market shortages by the end of the decade, then financing these projects will become easier, especially with the relative high returns forecast so far (median IRR of 36 percent).

However, the relative lack of freely available market information, and the perceived risks and uncertainties, have a negative impact on graphite project development because they are likely to inhibit investor interest and make financing more difficult. Certainly, the start-up of the Balama mine with such a large capacity and market overhang has resulted in an over-supplied market. It has also damaged medium-term interest in the graphite market for many investors. This could make attracting investment in Brazilian exploration projects slightly harder.

Considering future mergers and acquisition (M&A) activity, graphite is probably too small an industry to be attractive to any large mining companies. Any M&A of graphite producers is therefore only likely to come from Original Equipment Manufacturers (OEMs) if they look to build out their supply chain at any point, Chinese mining companies, private equity, and future sector consolidation. Realistically, it is highly unlikely that OEMs would be buyers in this space until there has been some consolidation. The graphite companies that are tradeable on equity markets are currently too small or have too much development risk to be attractive at this stage.

The focus is likely to be private equity and consolidators. They may, however, prefer to invest in the synthetic side of the business, which possibly has slightly lower technical development risks than natural graphite projects.

11.3. Global Economic Opportunities

Typically, investors look for high returns and low risk from an investment. Governments also look for significant returns from mine developments in the form of royalties, employment, and multiplier effects within the economy.

However, mining is rarely a low-risk business since it faces geological, technical, geopolitical, and execution risks with high capital expenditures. Usually, real cash returns only occur once a mine is in production, which can take between 10 to 25 years from first discovery. This often means that mining companies need to be offered beneficial arrangements to enhance the economics and sometimes enhance the procedures to accelerate the timescale.

Brazil has a large endowment of graphite resource but it must compete globally to maintain its position as a significant producer. Given the current list of potential new graphite mines, Brazil’s share of global graphite production will decline from its current level of 9-10 percent to just 3-4 percent by 2030 when other graphite mines come on stream.

Brazil is competing with countries that have increased exploration or have relatively large graphite resources (Madagascar, Mozambique, and Tanzania). Brazil currently has only one advanced stage exploration project (Santa Cruz), whereas several other countries are far more advanced in developing their resources. Mozambique, Tanzania, and Madagascar, for instance, have multiple projects under development. Several other countries also have relatively large graphite resources, but currently appear to have a low level of project developments. These include Turkey, Russia, Ukraine, and India.

Game theory often applies in commodity markets, including first mover advantage. This can be the case in graphite, as it is a relatively small market where a new producer can absorb the demand growth by crowding out other potential producers. A recent example of this is Syrah Resources in Mozambique, which has brought on enough graphite capacity to capture the demand growth for several years.

Game theory not only plays out in actual developments, but also in the announcement of ambitious plans for future potential developments. This is often a tactic used by large mining companies to inhibit smaller competitors, making development and financing more difficult for them.

Apart from a large resource base, Brazil also has existing, low-cost graphite mines, with experienced personnel. These assts also have large reserves that may be able to support production expansion.

11.4. Key Recommendations

Brazil has a large graphite endowment, existing low-cost graphite mines, experienced personnel, and is a globally significant graphite producer, but will have to continue to compete globally to maintain its position in the market. Without increasing output, Brazil's share of global production is likely to decline as other countries continue to develop their resources. Brazil should therefore build on its inherent competitive advantages to support future production expansions by:

- **Increasing access to, and circulation of, up-to-date graphite resource data to domestic and international exploration companies to encourage exploitation and promote graphite development in Brazil**. In 2020, CPRM estimated that Brazil's total graphite resources were 43.8 Mt. Brazil's main graphite deposits are found in Minas Gerais, Bahia, Ceará, Rio de Janeiro, and Mato Grosso, but the government and mining industry believe that the Amazon Craton in the Sunsás Province may also have significant potential. Increasing access to up-to-date graphite resource data will require gathering and distributing more extensive information for those regions that are considered to have significant potential, and/or encouraging investment by exploration companies. Currently, legacy CPRM geological data, reports and studies are available in hardcopy; digitization of, and online access to, these records will greatly expand their impact and circulation. However measured potential (i.e., detailed resource delineation and metallurgical testing) may be unknown to the mining community until additional studies are completed. As new data becomes available and the results of additional CPRM studies are finalized (for example detailed resource delineation and metallurgical testing on individual deposits), these should also be published online as a matter of record, thereby helping to accelerate broader industry access to, and interest in, Brazil's graphite potential.
- **Considering financial incentives (e.g., lower royalties, preferential tax rates) to companies to encourage the expansion of existing graphite projects and new investment.** Without increasing output, Brazil's share of global production is likely to decline to just 3 - 4 percent by 2030 (from its current level of 9-10 percent) when other graphite mines come on stream(see Table 4). Currently, Brazil has limited plans for increasing production beyond the exploration project in Santa Cruz. The government should fast-track the progress of graphite opportunities to avoid being crowded out by other graphite mine developments around the world, and before other countries with large resources, but a low level of projects – like Turkey, Russia, and India – decide to fast-track their own opportunities. The government should also encourage both international and domestic graphite companies (e.g., Nacional de Grafite and Extrativa Metalquimica) to participate in the development of new projects through financial incentives such as lower royalties, preferential tax rates, and assistance in capital financing.

- **Undertaking a comparative review of Brazil's exploration and mining policies vs. other graphite-producing countries.** This review should analyze whether the government can encourage graphite exploration and mine development through legal, regulatory, and Environmental, Social, and Governance (ESG) improvements. Such improvements may include simpler licensing and permitting processes, lower royalties, preferential tax rates, and a continued focus on environmental policy. The ultimate objective of such improvements should be to encourage development and stability for investors looking to develop the Brazil's mineral sector as a whole, and graphite in particular.
- **Developing downstream processing facilities to capture more of the graphite value chain.** Downstream graphite processing is currently concentrated in China, but given Brazil's graphite resources of approximately 43.8 Mt, growing worldwide demand, and the natural tendency for global supply chains to seek diversification, Brazil has an opportunity to become a leading downstream player in the graphite industry.

ANNEX 1 – GRAPHITE DESCRIPTION AND TYPES

Description

Graphite is a naturally occurring form of carbon that is produced when organic material originally deposited as sediment (or mixed with sediment) changes in composition due to heat, pressure, and chemically active fluids. As this process (called metamorphism) occurs, hydrogen and oxygen are driven off as water from the organic material, leaving the carbon behind to form graphite. Figure 28 shows an example of natural graphite and its typical appearance.

Figure 28: Natural Graphite

Source: Anzaplan: https://www.anzaplan.com/minerals/graphite/

On an atomic level, carbon atoms are arranged in layers. The chemical bonds across the layers are strong due to the carbon atoms' six-sided honeycomb lattice structure. However, bonding between the layers is weak, which allows layers of graphite to be easily separated and slide past each other. This gives graphite its unique properties.

Graphite is a versatile raw material used in many different metallurgical and manufacturing industries due to its unique properties. This includes:

- Graphite application in refractory and chemical materials. Graphite's high level of crystallization makes it ideal for this because it is highly resistant to oxidation, cyclic temperature stress, high pressure, and most chemical agents.
- Outstanding thermal and electric conductivity because of free electrons. The size and orderliness of graphite's crystallites is key in determining this property.
- Excellent lubrication abilities due to the large distances between layers in the graphite lattice, which are connected by weak forces.
- Graphite application in flame protection and batteries. The bonding strength between layer planes allows the intercalation – that is, the transfer of certain molecules – within the graphite lattice. This intercalation ability allows graphite to be used in flame protection and batteries.

Graphite grades can be characterized by six interrelated parameters, which can be influenced when processing the mineral. These parameters include purity, crystallinity, particle size, particle shape, surface, and porosity. By influencing these parameters, producers can achieve an optimal combination of properties for graphite's respective application and usage.

Types of Graphite

There are four main types of graphite – flake, amorphous, vein, and synthetic. While synthetic graphite is manufactured and accounts for most of the world's supply, the other three graphite types are widely found in nature, including in many types of metamorphic rock and some sedimentary and igneous rocks (although most natural occurrences have no economic importance). Significant deposits of graphite can also be found in carbonaceous sedimentary rocks that have been subjected to regional or contact metamorphism and in veins precipitated from fluids.

Graphite types that are found in nature vary widely (*see* Table 6 below for more information on their mineral characteristics). Flake graphite, for instance, refers to small, crystalline graphite flakes that occur as isolated, flat, plate-like particles. Amorphous graphite, on the other hand, has very fine flakes and is associated with lower-grade metamorphism. Vein graphite (also called lump graphite) tends to be hydrothermal in origin. It occurs in fissure veins or fractures and appears as massive platy intergrowths of fibrous or acicular crystalline aggregates.

Table 6: Natural Graphite Size Fractions

Mineral Characteristics	Flake	Amorphous	Vein
Carbon content	Low (3-25%)	Medium (50-60%)	High (>90%)
Crystallinity	Medium	Low	High
Particle size	Fine to Coarse	Very fine	Lump
Typical location depth	Open pit to 200m	Open pit	>500m
Deleterious elements	Fe, Al, Cu, Ca	NA	NA
Morphology	Plate	Plate - Needle	Granular
Density	Medium	Low	High

Source: Gratomic.

The remaining type of graphite is synthetic graphite – that is, graphite that is manufactured from petrochemical precursors. Synthetic graphite currently supplies 60 percent of the world's required demand, while natural graphite supplies around 40 percent. Of the natural graphite that is mined, some 70 percent is flake, around 29 percent is amorphous, and only a small amount of vein graphite.

Flake Graphite

Flake graphite is the most common form of natural graphite. Flake graphite is created by immense heat and pressure as carbon-rich shales and limestone material metamorphosizes. It is typically disseminated through rocks such as marble, schists, and gneisses in these metamorphic formations, often in pocket pods or distributed throughout the parent rock matrix.

Flake graphite has been identified as a critical and strategic material by the Unites States and Europe due to its essential applications in the aerospace and energy sectors and its role as the primary anode component in lithium-ion batteries. This is because flake graphite has free electrons that can move without restrictions through its structural layers, empowering the graphite to absorb light and become a conductor of electricity and heat.

Flake graphite that is naturally extracted is classified by the carbon content (or total graphitic carbon – TGC) and the flake size (super jumbo, jumbo, large, medium, small, fines). Flake graphite pricing is determined by carbon purity, flake size, as well as industry-specific technical attributes of the flakes. For instance, graphite will generally have a purity of 92 to 97 percent, with a benchmark price grade of 94 percent (this is calculated by comparing the carbon purity percentage to the impurities percentage in the concentrate that is produced when graphite is mined and processed). In addition, larger flakes will typically receive a higher price. Table 7 provides more information on the illustrative price for flake graphite based on size.

Table 7: Graphite Flake Size

Market Name of Flake Graphite	Sieve Size Microns (μm)	Mesh Size Microns (μm)	Illustrative Price US$/tonne
Super Jumbo	+500	+35	2,250
Jumbo	+300, -500	-35, +48	1,750
Large	+180, -300	-48, +80	1,050
Medium	+150, -180	-80, +120	925
Small	+75, -150	-120, +200	600
Fines	-75	-200	400

Source: Various

Graphite anodes that are needed for lithium-ion batteries are currently made by spheroidizing and treating smaller flake graphite. The preferred mesh sizing for spheroidization is most commonly -100 mesh material, but material as low as -150 mesh can be utilized. As shown in Table 6, flake graphite prices vary according to flake size and other attributes.

Since a flake graphite mine will typically produce a range of size fractions of flake graphite and each fraction will have a different yield, there is not a standard graphite price that can be applied to the production of any individual mine. As a result, a blended basket price is used, as it is necessary to know the size distribution, purity, and technical attributes of the recovered product.

Amorphous Graphite

Amorphous graphite is the result of organic anthracite coal undergoing extreme metamorphic heat and pressure conditions. This occurs when heat destroys organic molecules and dissipates other elements such as oxygen, nitrogen, and sulfur, leaving only carbon that crystallizes into fine-grained mineral graphite.

Due to its microcrystalline structure, fine flake size, and low purity percentage (amorphous graphite has lowest purity of all graphite types), amorphous graphite has limited use in high-purity applications like batteries. Instead, it is used extensively in foundry and refractory applications, as a source of carbon in steelmaking, in pencil industries, and in other applications where graphite additions improve the manufacturing process or end-products such as coatings.

Amorphous graphite is typically sold at a benchmark size of -200 mesh, with a carbon content of 80 to 85 percent. It is currently priced at about US$400 to US$450 per tonne (Free on Board, FOB, China).

Vein Graphite

Vein graphite is formed when solid graphitic carbon is transported from subterranean environments through high temperature fluids. This movement deposits the carbon into formation fractures, creating crystalline veins.

Vein graphite is one of the rarer forms of naturally occurring graphite, although it has the highest carbon content. Production of vein graphite currently only comes from Sri Lankan deposits. Due to its purity and crystallinity, many of the highest quality electrical motor brushes and other current-carrying carbon products use vein graphite.

Synthetic Graphite

Producers manufacture synthetic graphite by transitioning an organic precursor through a carbonization and graphitization process. Producers use high-temperature processing to transform the precursor carbon into a graphite structure and to vaporize impurities. As a result of this treatment, synthetic graphite is more than 99.9 percent graphite.

Natural and synthetic graphite each have their own applications but compete for market share in a limited number of applications. In these cases, customers will typically choose the mineral based on required specifications, availability, and cost. Synthetic graphite has slightly higher porosity, lower density, lower electrical conductivity, and a much higher price than natural flake graphite. Synthetic graphite is available in a wide range of particle sizes, from 2-μm powders to 2-cm pieces Its morphology also varies from flakey in fine powders to irregular grains and needles in coarser products. Table 8 illustrates which graphite type is preferred based on application (for more information on graphite applications and uses, *see Annex 2 – Graphite Uses*.

Table 8: Graphite Applications by Material Type

Application	Flake	Amor.	Vein	Synth.	Key Properties
Arc furnace anode				X	High crystallinity, high thermal & electrical conductivity, thermal shock resistance
Batteries (lithium-ion)	X			X	High thermal & electrical conductivity
Batteries (alkaline)	X		X	X	High thermal & electrical conductivity
Carbon brushes	X		X	X	High electrical resistivity, low compressibility
Conductive coatings	X		X	X	High thermal & electrical conductivity, inert
Expandable graphite	X				Expansion on heating (combined with other elements)
Fuel cells	X			X	High electrical conductivity
Lubricants	X	X	X	X	Good solid-state lubrication
Nuclear industry			X	X	Low neutron absorption, high thermal conductivity, high strength
Pencils	X	X	X		Weak inter-layer bonding, surface adherence
Plastics	X			X	High thermal conductivity, lubrication

Application	Flake	Amor.	Vein	Synth.	Key Properties
Powder metallurgy	X		X	X	Chemically inert, lubrication
Refractory uses	X	X	X		High melting point, chemically inert
Steel & iron additive	X	X			High melting point, high electrical conductivity, lubricant

Source: Battery Material Review.

In lithium-ion battery applications, natural graphite currently competes with synthetic graphite for market share, and a mix of both materials in battery applications is common. Synthetic graphite has several advantages for use in batteries, including better cycling stability, faster charging performance, higher quality consistency, and faster production scalability.[23] As a result, synthetic graphite has traditionally been the major anode material (55 percent), with natural graphite comprising the remaining balance (45 percent). However, processed flake graphite (called spherical graphite) is starting to increase market share over synthetic graphite due to quality improvements and lower cost. Synthetic graphite is widely reported to sell for up to US$20,000 per tonne, although the actual price and cost structure remains opaque.

In most metallurgical applications, synthetic graphite is preferred to natural graphite, as it performs better with very high electric currents due to its high purity and conductivity. The largest use of synthetic graphite is in electrodes that are predominately used in the electric arc furnaces for melting steel and iron and producing alloys (*see* row 1 in Table 8). Graphite electrodes are also required in electric arc furnaces that use new clean-steel technology with hydrogen.

Although the United States is a significant producer of synthetic graphite, China dominates global production. Nevertheless, recent reports by Roskill suggest that strict energy-consumption control policies for high-energy industries in China could impact on-going production. In the Inner Mongolia Autonomous Region of China, for instance, new controls have already limited existing synthetic graphite production. The Inner Mongolia Autonomous Region of China accounts for around 46 percent of China's synthetic graphite capacity. It is an important Chinese production hub due to its relatively low electricity unit price.

The global market for synthetic graphite is partially consolidated in nature, with the top five players controlling nearly 60 percent of the market. The top five players in the global synthetic graphite market are Showa Denko (including SGL Carbon), Better New Energy Material, GrafTech International, Shanshan Technology, and Imerys Graphite & Carbon.

Value-Added Downstream Processing

To create a suitable product for certain industries (particularly the battery industry), producers must modify flake graphite using energy-intensive processes. Producers first reduce the size of the graphite through micronization. Then, producers shape the flakes into spheres using spheronization, which increases the flakes' surface area and energy density. Lastly, producers use purification to remove impurities and reach the required level for the industry.

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[23] SGL Carbon.

The complete modification process results in High Purity Spherical Graphite (HPSG), a higher priced graphite product (99.95 percent carbon, 15 microns). This product is commonly bought by battery manufacturers and is currently priced at around US$2,500 to US$2,900 per tonne (FOB China).

Understanding this modification process is important for comprehending the relationship between the demand for flake graphite and the demand for battery anode graphite product HPSG. Some new mining projects have plans to include further graphite processing in their developments, for instance micronization or micronization and spheronization. Although these investments can enhance the value of a project, they also can significantly increase capital costs.

Micron size is a key component in pricing because this dictates the energy density constraints for the battery anode material. There is a premium placed on smaller micron grades (<25 micron) that can maintain their structural integrity throughout the life of application. The smaller size allows greater energy density and offsets some of the higher costs required to achieve these properties without the need of using other feedstocks. Larger micron sizes (>25 micron), on the other hand, typically prohibit use into higher value EV applications.

Micronization

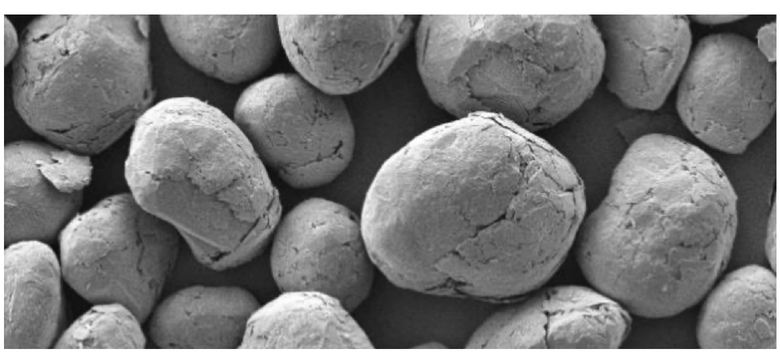
Micronization involves reducing the size of the graphite using a classifier milling system (rotary hammers) or a jet milling system (collision of the graphite grains). The mills reduce the graphite down to 10 to 25 microns. The jet mills can also generate a narrower size distribution of the particles. Nevertheless, grinding granite is difficult due to the mineral's hexagonal layered crystal structure. During grinding, most of the energy is consumed in causing slip between the graphite layers rather than fracturing the particles.

Micronized graphite has numerous applications due to its fundamental softness. In addition to being a pre-cursor to spheronization, it is also used in lubricant formulations and as an additive to structural materials and metallic alloys.

Spheronization

The spheronization process increases the surface area and allows more graphite into a smaller volume. This creates a denser, smaller, more efficient anode product for batteries. It also increases the rate at which the cell can be charged and discharged. Industrial-scale techniques are closely held by manufacturers, but during this process graphite flakes are turned into spherical shapes ranging in size from 10 to 40 microns. Figure 29 shows an example of spherical graphite and its typical appearance.

Figure 29: Spherical Natural Graphite



Source: Anzaplan: https://www.anzaplan.com/minerals/graphite/

Suitable spherical particles in flake graphite have a yield that varies between 30 percent and 70 percent; however, the yield is around 45 percent on average. The non-spherical particles, which make up around 55 percent of the original feed, are collected and sold into lower-margin markets and used in re-carburizers, pencils, and aftermarket brake pads, among others.

Purification & Coating

There are many different methodologies for purifying graphite, but the two main categories are acid purification and thermal purification. What is best depends on the impurities in the graphite, environmental restrictions and impacts, and the cost of power.

Once graphite has been purified into HPSG, it can be coated to create a homogeneous and smooth surface. The resulting coated spherical purified graphite can be used to make anode active powder, which increases the performance and longevity of the anode material. The coating used is typically a pitch or an asphalt-type substance that is baked on.

Coated spherical purified graphite material is rarely traded in the open market. Most material is consumed internally at the anode producer site using its own variable specifications, such as cell chemistry, electrolyte, cell form, quantity, and customer requirements. Contractual agreements are long term and based on highly integrated models between seller and buyer. Coated spherical purified graphite currently sells for between US$7,000 to US$10,000 per tonne.[24]

[24] Anzaplan: https://www.anzaplan.com/minerals/graphite/

ANNEX 2 – GRAPHITE USES

Electrodes

The largest single use for graphite is in electrodes, accounting for almost a third of global graphite consumption. Synthetic graphite is the only graphite used in the process since natural graphite (even when modified) is unable to provide the consistency for this high-powered application. The electrodes are principally used in electric arc furnaces (EAF) for steel production. Graphite's high thermal conductivity high resistance to heat and impact make it ideal for anodes. The world's largest electrodes measure 32 inches (80 cm) in diameter and 118 inches (3 meters) in length.

Refractories

A major market for natural graphite is in the production of refractories for the steel industry. According to Roskill, consumption of refractories is around 15 kg per tonne of crude steel worldwide . The natural graphite used in refractories is selected for its high-temperature stability and chemical inertness. Natural flake graphite with large crystals is mainly used because it increases the brick mechanical strength, although some amorphous graphite powder is also being used. Graphite flakes are used in the production of magnesia-carbon bricks which are used as a lining material in basic oxygen furnaces (BOF) and EAF, and in high-wear areas such as slag lines in ladles. These contain up to 25 percent graphite.

Foundries

In foundries (a factory for casting metal), manufacturers form shapes with metals. Natural graphite-based coatings and washings are employed as facings to protect refractory linings, troughs, and other equipment that convey molten metal, from erosion and to ease the release of cast products from molds. Furthermore, graphite is the main component in the manufacture of clay-bonded crucibles to handle molten metal.

Recarburizing

Graphite additives are used as a source of carbon to raise the carbon content of molten steel (recarburizing), as well as in grey and ductile iron in ferrous foundries. Recarburizers are used extensively during EAF steel production and for upgrading low carbon steel to higher specifications. Graphite increases the hardness properties of the steel.

There can be a wide variation in the characteristics and quality of recarburizers used, depending on the input materials, production method and the type of ferroalloy that is being produced. These products are mostly produced from natural flake graphite but are subject to competitive pricing from alternatives such as synthetic graphite powder and petroleum coke.

Graphite Shapes

Graphite can easily be machined into a variety of shapes (carbon products). Carbon brushes (used in motors and generators) are the largest application in this segment. Purified and micronized graphite is an essential additive in metal powder mixtures for the fabrication of sintered parts, mainly for automotive applications. Graphite provides internal lubrication making maximum compression possible, as well as increased mechanical strength after sintering (forming a solid mass of material by heat or pressure without melting).

Batteries

Due to its high electrical conductivity, inertness, and lithium-ion intercalation (the reversible insertion of a molecule into layered materials) of the crystal structure, flake graphite is a critical component of primary and rechargeable batteries. It is as an additive; in cathodes of alkaline batteries, in anodes as well as in cathodes of lead-acid batteries, and the main material in anodes of lithium-ion batteries. Lithium-ion batteries account for about 75-85 percent of graphite consumption and alkaline batteries for around 10-15 percent, with the balance used in lead-acid and other battery types. The battery sector is expected to drive the growth of future graphite demand due to the transition to electric mobility and the development of the energy storage market.

Lubricants

Graphite is used as a dry lubricant as well as being mixed with lubricating oil. Due to graphite's weak interlayer forces, its high thermal conductivity, thermal stability, and lubrication properties, natural graphite is a critical component as a dry lubricant in friction linings as it provides heat dissipation and effective lubrication at the friction interface. Friction applications include brake and clutch linings used by the automotive, aviation, and rail industries. The natural graphite used must be of high purity (close to 99.9 percent).

Electrical Applications

Electrical conductivity and lubricity allow natural graphite's use in electrical applications to effectively transfer electric current and minimize frictional wear. It is used in the form of carbon brushes and collector strips. Vein graphite is chosen for high-quality applications. In electronic applications, synthetic graphite is used in semiconductor technology and solar technology.

Flame Retardants

Expandable graphite has an efficient flame-retardant effect as it swells up when exposed to heat, thus isolating the fire from the material underneath or sealing a gap. Applications include the use of expandable graphite in plastics, coatings, insulation foams, textiles and firestops for buildings and constructions. Expandable graphite is manufactured by the oxidation of graphite flake in sulfuric acid and generally requires high grade, large flake graphite. Expanded graphite demand is expected to grow significantly due to legislative changes and the environmental concerns around existing traditional flame retardants.

Fuel Cells

Purified flake graphite and purified expanded flake graphite can be used as the main filler material in bipolar plates for fuel cells. Natural graphite makes up the anode and cathode material of Proton Exchange Membrane (PEM) fuel cells used in transport and stationary energy storage.

Other Uses

Natural graphite is also employed in a high number of other applications such as seals and gaskets made of graphite foil for high-temperature applications, additive in insulation foams for enhanced heat reflection, drilling mud additives, equipment to handle molten glass, heat insulation panels, additives for improving tribological and conductive characteristics of plastics. Pencils consist of a mixture of microcrystalline graphite and clay.

Due to its ability to slow down neutrons, graphite is used in many ways in the nuclear reactor industry. For example, as moderator, fuel element cladding, reflector in heavy water reactors and neutron shield in breeder reactors.

Carbon fibers are used for carbon fiber reinforced polymer composites which have high strength and low density. This is used in parts for the automotive, marine, and aerospace industries and in sport goods and bicycle frames.

Graphene has become a valuable and useful nanomaterial due to its exceptionally high tensile strength, electrical conductivity, transparency, and being the thinnest two-dimensional material in the world.

ANNEX 3 – LIST OF GRAPHITE PROJECTS

Table 9: Top 54 Graphite Project Resources by Contained Graphite Mt.

	Property Name	Country	Stage of Development	Company Operator	Meas., Inf. & Ind. Res. Mt	Average Grade %Cg
1	Balama North	Mozambique	Feasibility Started	Triton Minerals	167.16	10.7
2	Bunyu	Tanzania	Feasibility Complete	Volt Resources	22.77	4.9
3	Mahenge	Tanzania	Feasibility Complete	Black Rock Mining	16.67	7.9
4	Lac Gueret	Canada	Construction Planned	Mason Graphite	14.34	17.2
5	Malingunde	Malawi	Feasibility Started	Sovereign Metals	10.91	7.2
6	Uley	Australia	Feasibility Started	Quantum Graphite	10.86	0.7
7	Montepuez Cen.	Mozambique	Construction Started	Battery Minerals	10.12	6.4
8	Nachu	Tanzania	Construction Planned	Magnis Energy	9.38	5.4
9	Molo	Madagascar	Construction Started	NextSource Mat.	8.65	6.1
10	Graphite Creek	USA	Prefeas/Scoping	Graphite One	8.21	8.0
11	Matawinie	Canada	Construction Planned	Nouveau Monde	7.01	4.1
12	Siviour	Australia	Construction Planned	Renascor Res.	6.52	7.5
13	Mahenge Liandu	Tanzania	Feasibility Complete	Armadale Capital	5.83	9.8
14	Jalkunen	Sweden	Res. Development	Talga Group	4.69	14.9
15	Vittangi	Sweden	Feasibility Complete	Talga Group	4.68	24.0
16	Lindi Jumbo	Tanzania	Feasibility Complete	Walkabout Res.	4.50	10.8
17	Dombeya	Mozambique	Res. Development	Frontier RE	3.95	7.0
18	Coosa	USA	Feasibility Started	Westwater Res.	3.55	2.5
19	Chilalo	Tanzania	Feasibility Complete	Marvel Gold	3.48	5.2
20	Balama Central	Mozambique	Feasibility Complete	Tirupati Graphite	3.37	10.2
21	Epanko	Tanzania	Feasibility Complete	EcoGraf	3.05	9.9
22	Ancuabe	Mozambique	Construction Planned	Triton Minerals	3.05	6.6
23	Balama	Mozambique	Prefeas/Scoping	Auspicious Virtue	2.94	13.4
24	La Loutre	Canada	Prefeas/Scoping	Lomiko Metals	2.92	4.2
25	Lac Knife	Canada	Feasibility Complete	Focus Graphite	2.14	14.9

	Property Name	Country	Stage of Development	Company Operator	Meas., Inf. & Ind. Res. Mt	Average Grade %Cg
26	Lola	Guinea	Feasibility Complete	SRG Mining	2.03	4.0
27	Bissett Creek	Canada	Construction Planned	Northern Graphite	1.61	1.7
28	Lac Rainy	Canada	Prefeas/Scoping	Metals Australia	1.53	11.5
29	Albany	Canada	Prefeas/Scoping	ZEN Graphene	1.41	3.4
30	Kearney	Canada	Construction Started	Ontario Graphite	1.33	2.4
31	Maniry	Madagascar	Feasibility Started	BlackEarth Min.	1.32	6.5
32	Haapamaki	Finland	Prefeas/Scoping	Beowulf Mining	1.28	4.8
33	Woxna	Sweden	Construction Planned	Leading Edge	1.17	8.0
34	Merelani-Arusha	Tanzania	Advanced Exploration	EcoGraf	1.15	6.5
35	Golden Gate	Australia	Res. Development	Crater Gold	1.10	5.5
36	McIntosh	Australia	Feasibility Started	Hexagon Energy	1.06	4.4
37	Wa	Ghana	Res. Development	Castle Minerals	1.04	5.2
38	Balai Sebut	Indonesia	Prefeas/Scoping	PT Grafindo Nus.	1.01	12.7
39	Burke	Australia	Res. Development	Lithium Energy	1.01	16.0
40	Munglinup	Australia	Feasibility Complete	Mineral Commod.	0.97	12.2
41	Springdale	Australia	Res. Development	Comet Resources	0.94	6.0
42	Vatomina	Madagascar	Advanced Exploration	Tirupati Graphite	0.85	4.6
43	Eyre Peninsula	Australia	Prefeas/Scoping	Archer Materials	0.77	9.0
44	Yalbra	Australia	Res. Development	Buxton Resources	0.65	16.2
45	Black Crystal	Canada	Res. Development	Eagle Graphite	0.57	1.3
46	Berkwood Grp.	Canada	Res. Development	Green BM	0.55	16.7
47	Santa Cruz	Brazil	Prefeas/Scoping	South Star BM	0.53	2.3
48	Koppio-Kook.	Australia	Feasibility Complete	Lincoln Minerals	0.49	12.6
49	Moyale	Ethiopia	Advanced Exploration	Hulager General	0.46	9.1
50	Oakdale	Australia	Prefeas/Scoping	OAR Resources	0.44	3.3
51	Geumam	South Korea	Prefeas/Scoping	Battery Mineral	0.41	5.7
52	Ekta	India	Advanced Exploration	Tirupati Carbons	0.32	11.0

	Property Name	Country	Stage of Development	Company Operator	Meas., Inf. & Ind. Res. Mt	Average Grade %Cg
53	Raitajarvi	Sweden	Advanced Exploration	Talga Group	0.31	7.1
54	Miller	Canada	Prefeas/Scoping	Canada Carbon	0.09	0.8

Source: S&P Global data.

ANNEX 4 – MINING AND BENEFICIATION OF GRAPHITE

Mining Natural Graphite

Graphite deposits are mined using conventional mining methods. Flake graphite deposits are typically found near the surface and, depending on the degree of weathering, can be mined using conventional hard or soft-rock mining techniques. While flake and amorphous graphite deposits are currently mined in both underground and open pit operations, vein graphite deposits are almost exclusively mined in underground operations.

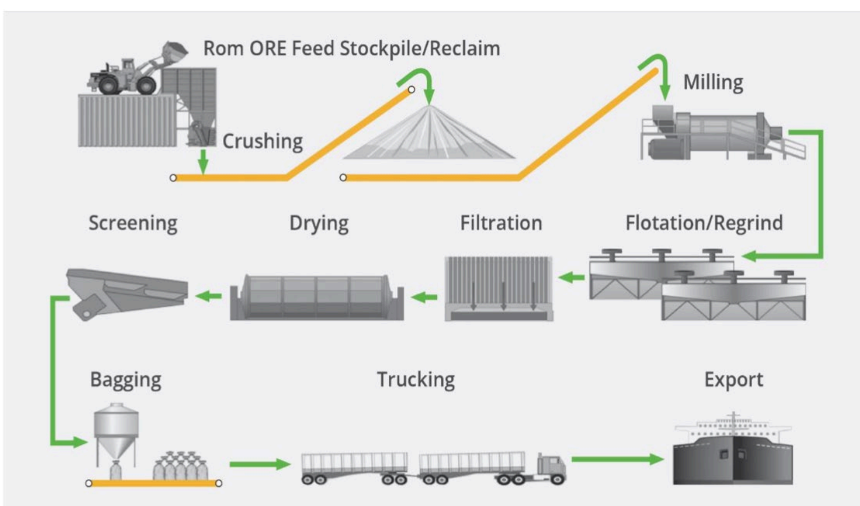
Beneficiation of Natural Graphite

In terms of mineral processing, the beneficiation of graphite is an established and relatively straightforward process. Beneficiation techniques depend on the type of deposit, flake size distribution, and the required specifications of the final concentrate such as crystallinity, texture of the flakes, ash content and level of impurities. They can be divided into comminution, beneficiation and, for flake graphite, refining stages.

Comminution processes focus on the liberation of graphite flakes from the host rock to increase recovery during the following beneficiation stages. The liberation of the graphite flakes is critical for the ultimate grade of the final product. However, as flake size and carbon content are important commercial considerations, with large and jumbo graphite flakes commanding the highest prices, processing that reduces flake size is usually kept to a minimum. Depending on the type of graphite ore, processing flowsheets for the comminution stage can vary greatly.

A combination of crushing and grinding techniques using ball mills, hammer mills, air jet mills and rod mills may be employed, with several screening stages to maximize recovery of large flakes. Attrition scrubbing processes to remove impurities while preserving crystallinity of the graphite flake may follow milling and grinding.

Figure 30: Simplified Flow Sheet for Graphite Processing Plant



Source: Battery Minerals

Following mechanical liberation of the graphite flakes from the enclosing country rock, a range of further purification techniques can be employed to remove impurities, for instance, hydrometallurgical (froth flotation, gravity separation, acid base and hydrofluoric acid methods) and pyrometallurgical methods (chlorination roasting and high-temperature methods).

As graphite is naturally hydrophobic, the most widely used graphite beneficiation technique is froth flotation. Ore slurry is fed into froth flotation cells and mixed with water and flotation agents, resulting in the flotation agents sticking to the graphite flakes. As air is injected into the cell, the graphite flakes stick to the air bubbles and float to the top of the cell where they are skimmed off. Flotation flowsheets vary depending on the ore type and may include conventional and column flotation. They typically include a rougher flotation step with several stages of cleaning.

Grades of typically 95–97 percent and up to 99 percent carbon can thus be achieved for flake and vein graphite concentrates. Amorphous graphite deposits generally have a higher ash content, with impurities attached to the graphite crystals or contained within the lattice structure. This makes flotation and other chemical-based separation techniques in these types of deposits difficult, and the concentrate grades obtained at 75–85 percent are generally substantially lower. Yield rates depend on the processing technology and efficiency and can vary greatly across the different producer countries.

Following the flotation stage, the concentrate is filtered and dried before being bagged for transport. The product may also undergo screening into different fractions.

The mining recovery of the deposits depends on the process methodology, and this can range from 80 percent to 95 percent. Plant recovery can range from 80 percent to 94 percent, giving overall recovery in the range of 64 percent to 89 percent.

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