TECHNICAL ASSISTANCE ON BRAZIL MINERAL RESOURCES

Lithium – Market Analysis and Competitiveness Report

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Acronyms

ANM	Agência Nacional de Mineração
BMI	Benchmark Minerals Intelligence
BPA	Blanket Purchase Agreement
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CBL	Cia Brasileira de Lítio
CPRM	Geological Survey of Brazil
DERA	German Mineral Resources Agency
DLE	Direct Lithium Extraction
DMS	Dense Media Separation
DOS	Department of State
DRC	Democratic Republic of the Congo
EMGP	Energy and Mineral Governance Program
ENR	Bureau of Energy Resources
ESG	Environment, Social, and Governance
ESS	Energy Storage Systems
EV	Electric Vehicles
FID	Final Investment Decision
IRR	Internal Rate of Return
LCE	Lithium Carbonate Equivalent
LCT	Lithium-Cesium-Tantalum
LFP	Lithium-Iron-Phosphate
LME	London Metal Exchange
LOM	Life of Mine
M&A	Mergers and Acquisitions
MME	Ministry of Mines and Energy
NCA	Nickel-Cobalt-Aluminum
NCM	Nickel-Cobalt-Manganese
NPV	Net Present Value
OEM	Original Equipment Manufacturer
PEA	Preliminary Economic Assessment
PNM	National Plan for the Brazilian Mineral Sector
REE	Rare Earth Elements
SQM	Sociedad Química y Minera de Chile
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 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 is focused on lithium, one of the four minerals selected by the Government of Brazil for a deep-dive market analysis.

Key Findings

- **Brazil does not have significant lithium resources and reserves**. Based on current estimates, Brazil has a relatively low level of lithium reserves and resources, and accounts for just 0.5 percent of global total (see Table 1). According to the U.S. Geological Survey (USGS), Brazil has lithium reserves of 95 kt Li and resources of 470 kt Li in 2020. Brine deposits are the main source of lithium resources in South America, but Brazil has predominantly hard-rock ('Mineral') deposits. This has limited economic implications, but each require a different extraction and processing method. A report published by CPRM in 2020 found that Brazil had 92 lithium occurrences, deposits, or mines, with 59 percent occurring in Minas Gerais State and 25 percent in Ceará State. Brazil currently has about 315 mineral rights for lithium issued covering almost 400 kha[1].

[1] One thousand hectares (kha) is equivalent to 2,471 acres.

- **Brazil is a relatively small, but low-cost producer of lithium.** Brazil currently has two mines producing lithium, Mina da Cachoeira (operated by Cia Brasileira de Lítio) and Mibra (operated by AMG Brazil), which account for about 1.5 percent of global output. The country also has one project (Grota do Cirilo operated by Sigma Lithium Resources) at an advanced stage of development.[2] Domestic industries, such as the aluminum industry are the main consumers of the existing lithium production (although the new Grota do Cirilo project will export its spodumene concentrate to South Korea for lithium chemical production). The country's lithium production is relatively low cost. Mibra produces lithium as a by-product, while Mina da Cachoeira[3] sits at the bottom of the cost curve for Mineral producers (see Figure 23) giving it a higher operating margin than its peers.
- **Producers are looking to expand production in Brazil.** The two lithium mines Mina da Cachoeira and Mibra, and the Grota do Cirilo project are all planning to expand mining capacity but have not provided a specific timeframe. If these expansions occur, this will double Brazil's output from these three operations from approximately 50 kt/y LCE to 100 kt/y LCE. In the meantime, global capacity is growing at approximately 6-7 times over the same period. As a result, Brazil will remain a relatively small producer of lithium over the next decade. Brazil currently has three recognized lithium exploration projects, but these remain in a very early stage of development. While current production of lithium in Brazil is low, the government lists lithium as a strategic mineral under their Pro-Strategic Minerals policy, which will allow for an acceleration of development procedures to reach lithium/critical mineral production, mainly by easing the licensing process of newly listed strategic mineral projects[4,5]. Brazil is taking the steps required to expand lithium potential in the country.

Key Recommendations

The lithium market is expected to be in deficit over the next decade and, if prices continue their upward trajectory, the lithium market could offer robust returns to both miners and host countries. Brazil should therefore look to maximize its lithium output over the next few years and further develop its resources. Brazil's production at the two operating lithium mines (Mina da Cachoeira and Mibra) are slated to expand, and a third mine at Grota do Cirilo is anticipated to begin production. The exact timeline for these increases is not yet fully clear. Brazil should therefore look to accelerate the growth of its lithium industry over the longer term by:

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[2] Sigma Lithium Resources are the developers of Grota do Cirilo. They also are expected to bring a new mine into production in 2022 for lithium exportation

[3] Li carbonate, an hydroxide produced by CBL are not of battery grade

[4] Through the Pro-Strategic Minerals policy, the Government of Brazil has issued a list of specific critical minerals it aims to boost production of, and that are deemed of special interest to the country. Resolution No. 2 of June 18, 2021 defines the list of strategic minerals for the country. https://www.in.gov.br/web/dou/-/resolucao-n-2-de-18-de-junho-de-2021-327352416

[5] Through the Pro-Strategic Minerals policy, the Government of Brazil is focusing on easing the licensing process by facilitating, for example, the dialogue between the environmental agency responsible for conducting the environmental licensing process and authorities such as the managing bodies of Conservation Units, the National Indian Foundation (Funai), the National Institute for Colonization and Agrarian Reform (Incra) and the National Institute of Historic and Artistic Heritage (Iphan).

- **Encouraging its existing lithium producers to pursue faster and larger expansions.** Brazil should have discussions with existing lithium mine operators (CBL and AMG Brazil) about the timing and scale of their planned expansions, with the aim of accelerating timelines and increasing production levels. Any expansion would need to be done on an economically sustainable basis, but the Government of Brazil could assist by implementing measures, such as credit guarantees, higher capital allowances, and tax reductions, as required and appropriate.
- **Pursuing higher production levels for Phase 1 of the Grota do Cirilo project.** This development project is currently planning for a capacity of 220 kt/y of spodumene concentrate in Phase 1, with 440 kt/y planned for Phase 2 at some stage in the future. As outlined in the competitiveness analysis in Section 10 of this Report, Grota do Cirilo's has a high (43%) Internal Rate of Return and relatively low capital intensity, (Net Present Value [NPV]/Capital Expenditure [CAPEX]). As such, Brazil should prioritize discussions with Sigma Lithium Resources, the developers of Grota do Cirilo, to start / accelerate the project to Phase 2 production levels as soon as possible. As noted above, any expansion would need to be done on an economically sustainable basis, but the Government of Brazil could assist by implementing measures, such as credit guarantees, higher capital allowances, and tax reductions as required and appropriate.
- **Streamline access to, and circulation of, up-to-date domestic lithium resource data to domestic and international exploration companies to encourage exploitation and to promote lithium development in Brazil.** This may require gathering and distributing more extensive information for the regions considered to have significant lithium potential. Legacy CPRM geological data, reports, and studies should be more broadly published online and in a range of languages. Brazil should also 'market' these documents to expand their circulation, use, and impact. These materials should highlight the announcement of the Decree No. 11,120 of July 5, 2022, which allows for unrestricted foreign trade operations of lithium minerals, ores, and their derivatives. According to this decree, Brazilian lithium imports and exports will no longer require preliminary authorization from government entities. This measure is expected to attract lithium investments.[6]
- **Developing downstream processing facilities to capture more of the lithium value chain.** Currently, most downstream lithium processing takes place in China. Nevertheless, Brazil could become a midstream processor of lithium chemicals as part of a greater strategy to develop a downstream lithium-ion battery industry. Brazil could achieve this by constructing a facility to process the spodumene ore produced by Sigma Lithium Resources into lithium carbonate and/or lithium hydroxide (Brazil currently plans to export this ore unprocessed). This type of venture may also help to encourage the construction of cathode-manufacturing facilities and lithium-ion battery manufacturing. Discussions with existing global lithium-ion battery companies about investment in Brazilian initiatives, such as 'Colossus Cluster Minas Gerais', which aims to build a 35 GWh battery Gigafactory, may help to accelerate the business case for commercial lithium processing.

[6] The Decree No. 11,120, of July 5, 2022, allows for foreign trade operations of lithium minerals, ores. and their derivatives. The measure promotes the opening and dynamization of the Brazilian lithium market, with the objective of positioning Brazil in a competitive way in the global chain and attracting investments for research and mineral production, and for the advancement of production capacity in the stages of processing and production of components and batteries.

In addition, Brazil does not necessarily need to wait for new domestic mines to come in line for it to achieve scale in lithium processing; the country could choose to import primary resources from neighboring producers.

- **Undertaking a comparative review of Brazil's exploration and mining policies/initiatives versus other lithium-producing countries.** Such a review, taking approximately 12 to 18 months, would analyze and prioritize how Brazil's government could encourage and accelerate lithium exploration and mine development through potential legal, regulatory, and Environmental, Social, and Governance (ESG) improvements. Such improvements could include simpler licensing and permitting processes, lower royalties, preferential tax rates, and a coordinated approach to environmental policy.

1. INTRODUCTION

1.1. Purpose of this Report

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

1.2. Organization of this Report

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

- **Section 1: Introduction** – Presents the purpose of this Report, background and context on lithium, and a summary of market trends and outlook for lithium.
- **Section 2: Lithium Physical Characteristics** – Provides information on lithium uses and applications, and different lithium types.
- **Section 3: Lithium Resources** – Provides information on global lithium resources and reserves, as well as more detailed data on the countries with the largest recognized reserves (Argentina, Bolivia, and Chile).
- **Section 4: Lithium Supply** – Gives an overview of the global production of lithium ores and lithium chemicals and recent supply trends.
- **Section 5: Lithium Demand** – Explains global lithium demand trends based on end-user markets.
- **Section 6: Lithium Trade and Prices** – Provides information on main features of global lithium trade and presents historical pricing data for lithium products.
- **Section 7: Outlook for Lithium Demand** – Outlines expectations for future changes in global lithium demand, given growing consumption trends in relevant end-use industries, particularly lithium-ion batteries.
- **Section 8: Outlook for Lithium Supply** – Presents how the global lithium supply should increase to meet rising demand and consumption trends. This section also examines potential production increases from existing producers and other mining projects that could potentially come on stream by 2030.
- **Section 9: Market Balance and Price Outlook** – Explains how the lithium market is expected to balance out to 2030 and provides insights on price forecasts for trade in the future.
- **Section 10: Economic Competitiveness** – Summarizes production and cost information of existing mines and 42 mining projects to benchmark and assess the economic competitiveness of the sector and other mines and exploration projects in Brazil.
- **Section 11: Conclusions and Key Recommendations** – Summarizes the Deloitte's team analysis of the lithium 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 lithium industry.

- **Annex 1** – Provides a description of lithium mining and benefits.
- **Annex 2** – Provides a description of lithium uses.
- **Annex 3** – Provides a table of lithium conversion factors.
- **Annex 4** – Provides information on recent mergers and acquisitions (M&A) in the industry.
- **Annex 5** – Provides a list of lithium feasibility projects.

1.3. Background and Context

The shift from high-carbon fossil fuels to low-carbon energy sources is crucial for meeting climate change goals (this will include shifting towards wind, solar, hydrogen, and battery technologies). Lithium is a key component of batteries, which are particularly important for developing hybrid and electric vehicles (EVs). Lithium-ion batteries are the preferred technology for almost all EVs on the market today and will continue to be for the foreseeable future.

Brazil has some of the largest and most diverse mineral deposits in the world, yet most of its mining sector activities and revenues focus on 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 lithium and other critical minerals and metals found in Brazil.

However, Brazil currently produces just 1.5 percent of the world's lithium and has just 0.5 percent of the world's defined global resources. Brazil is a relatively small (but low-cost) producer of lithium, of which domestic industries are the principal consumer. The two producers of lithium in Brazil (CBL and AMG Brazil) already have plans to expand capacity in the next few years. Sigma Lithium Resources [TSXV: GSML] also expects to bring a new mine, Grota do Cirilo, into production in 2022 for lithium exportation. While these developments are positive, they will not be significant in scale on a global basis. As a result, Brazil will remain a relatively small producer of lithium, albeit a relatively low-cost one.

Brazil's identified lithium resources could hold further potential for new developments in the longer term, but Brazil's currently identified resources are relatively small on a global scale. This suggests that Brazil is unlikely to become a significant producer of lithium in the future, even though lithium is a strategic mineral under the Brazil's Pro-Strategic Minerals policy (which streamlines approvals and permitting procedures to accelerate production of critical minerals).

1.4. Summary of Market Trends and Outlook for Lithium

1.4.1. Lithium Resources

Although global lithium resources are substantial, only a few types of lithium deposits are economically worthwhile to process – 'Mineral' (hard-rock) spodumene deposits and brine deposits. In addition to these two types, oilfield brines, geothermal brines, and clays also contain lithium. However, commercial production from these sources has not yet occurred, although projects are now at various stages of development.

South America's lithium reserves and resources account for 58 percent of the world's total. Argentina, Bolivia, and Chile have the largest amounts, predominantly of brine deposits (see Table 1). Bolivia has yet to exploit its lithium resources and currently holds 20 percent of world resources in brine deposits. Brazil has a relatively low level of global lithium reserves and resources, especially when compared to other South American countries.

Outside of South America, Australia holds 10.4 percent of global reserves and resources (primarily Mineral pegmatite deposits), the United States holds 8.1 percent (Mineral, brine, and clay), and China holds 6.2 percent (brine and Mineral).

1.4.2. Lithium Supply and Demand

The USGS reports that lithium produced from Mineral and brine operations totaled about 446 kt of Lithium Carbonate Equivalent (LCE) in 2020. Just four countries (15 mining operations) accounted for 95 percent of that output (see Figure 5). These included five active Mineral operations in Australia, two brine operations each in Argentina and Chile, and four brine and two Mineral operations in China (see Table 3).

Brine operations produce a final chemical of lithium carbonate, while Mineral operations produce an intermediate ore (spodumene) concentrate. Brazil is a relatively small producer of lithium and produced 5.3 kt LCE of spodumene concentrate in 2019 from two mines - Mina da Cachoeira and Mibra (domestic industries consume this production). China currently processes the majority of intermediate ore to produce final lithium chemicals. China accounts for 58 percent of chemical production capacity, processing its own as well as imported ores.

Global lithium demand totaled about 330 kt of LCE in 2020 (resulting in a supply surplus). According to Benchmark Minerals Intelligence (BMI), the battery sector consumed about 57 percent of this demand, and the remaining balance was used in other industrial sectors. Glass and ceramics were the second largest applications of lithium and consumed 15 percent of demand, followed by lubricating grease at 8 percent. The top three applications account for 80 percent of demand. The rechargeable batteries market has been the foundation of lithium demand growth and is expected to drive future demand, strongly influenced by the growth rate of EV fleet sizes.

1.4.3. Lithium Trade and Prices

Despite its rapid growth profile in recent years, the lithium market remains a modestly sized specialty chemical market, and lithium pricing remains relatively opaque. The majority of lithium material is bought and sold under long-term contractual agreements and each industry has unique requirements in terms of desired chemical composition, particle size, and tolerable values of impurities.

The lithium market moved into oversupply in 2019 and lithium prices gradually deteriorated. This was due to a rapid increase in new supply coming on stream, as well as a marked slowdown in global EV demand during the first half of 2020 due to the COVID-19 pandemic. Lithium spot prices started to recover towards the end of 2020 and have moved up notably during 2021 due to strong recovery in EV demand in 2021 (particularly in China). The market is currently in a supply deficit.

1.4.4. Future Market Outlook

The consensus view and the data suggest that it will be challenging for lithium supply to keep up with demand growth over the next decade. Current forecasts all suggest that the lithium market will remain in deficit, even with timely financing and the development of new capacity. Attempts to accelerate demand are becoming visible with some planned mining projects and new chemical plants increasing in size. Consequently, the market will need to develop new types of lithium sources such as clays and evaporites to meet demand.

Shortages of spodumene concentrate, lithium carbonate, and lithium hydroxide are expected to impact all end-use markets including ceramics, glass, and construction applications. However, the largest expected deficit is in the battery specification lithium market. A growing supply deficit would likely result in demand destruction and substitution or thrifting of lithium from key end-use markets. It could result in the delay of capacity build-out of lithium-ion batteries and reduce forecasted demand for EVs due to unavailability of materials. It may also stimulate the development of other battery technologies, based on materials other than lithium.

1.4.5. Economic Competitiveness

Deloitte has evaluated data from 42 companies (see Table 6, Table 7, and Table 10) that have produced recent feasibility, pre-feasibility, and scoping study reports for the market (this is typically done as part of the process of developing projects). Deloitte found that the cost curve for Mineral operations is relatively steep, highlighting the large variability in production costs across this sector of the lithium industry. Brazil's Cachoeira mine is a small, low-cost producer located at the bottom end of the cost curve. Brazil does not produce brine lithium, but the cost curve for brine operations is much flatter.

Using this data, Deloitte also calculated average costs for different types of final lithium products. The weighted average mine operating cost is $1,998/t LCE for spodumene concentrate, $4,020/t LCE for integrated Mineral projects producing lithium carbonate, $4,819/t LCE for integrated Mineral projects producing lithium hydroxide, $3,668/t LCE for brine projects producing lithium carbonate, and $3,888/t LCE for brine projects producing lithium hydroxide. These costs are significantly below current prices and in line with forecast long-term prices.

Deloitte's analysis also indicated that Brazil's only significant project, Grota do Cirilo, would be a low-cost spodumene producer. The project has a relatively low capital intensity, a high IRR at 43 percent, and a relatively favorable capital intensity or NPV/CAPEX. The median IRR of the group of projects was 28 percent which suggests generally good returns (although the average is distorted by a few high values).

2. LITHIUM PHYSICAL CHARACTERISTICS

Lithium is a soft, silvery-white alkali metal with a metallic luster that is extremely soluble. It is the lightest metal and has excellent electrical conductivity. Its physical and chemical properties make it useful in chemical and metallurgical applications, including ceramics and glass, lubrication greases, aluminum production, and, most importantly, lithium-ion batteries.

Lithium is a relatively abundant and widely distributed metallic element, usually found as a trace element in various mineral compounds and salts in the earth's crust and in seawater. Lithium does not naturally occur in its elemental form due to its reactivity but occurs in 145 different mineral compounds. The following sections provide more information about lithium production as well as key lithium products.

2.1. Lithium Production

Most of the world's known lithium resources are in Bolivia (20 percent), Argentina (20 percent), Chile (17 percent), Australia (10 percent), United States (8 percent), and China (6 percent), and around 95 percent of total lithium production originates in Australia, Chile, China, and Argentina. Economically viable deposits of lithium are relatively rare and fall into two broad categories: 'Mineral' or hard-rock (mostly pegmatite granites) deposits and brines (aquifers containing mineral-rich dissolved solids). Other sources of lithium exist, such as clays and geothermal brines, but these are yet to be exploited on a commercial scale.

To exploit brine deposits, producers pump saline brines with high lithium content from beneath the surface. Producers then concentrate the lithium via evaporation ponds before sending the brine to processing facilities to produce lithium carbonate. In some cases, producers process lithium carbonate further to create lithium hydroxide. Chile, Argentina, and China are the main brine-producing countries.

To exploit Mineral deposits, producers extract ore using conventional mining techniques before producing a concentrate by crushing the ore or using dense media separation or flotation. The primary lithium-bearing mineral in this ore is typically spodumene and most mines produce spodumene concentrate as the final product (Australia is main producer of spodumene concentrate). Producers then usually sell lithium-bearing concentrate to conversion plants, mostly located in Asia (primarily in China). The plants then convert the concentrate to various lithium salts.

Historically, five companies have dominated global lithium mine production: Albemarle – United States domicile, Sociedad Química y Minera de Chile (SQM) – Chile, Jiangxi Ganfeng Lithium - China, Tianqi Lithium - China, and Livent – United States. These same five companies also dominate global lithium chemical processing, with some 58 percent of the processing taking place in China and 26 percent occurring in Chile. However, new producers are starting to challenge these companies in terms of production, and many new Mineral mine projects are being planned as integrated producers of lithium chemicals.

2.2. Key Lithium Products

Lithium salts are important lithium products that are used as building blocks for other lithium derivatives. A large number of lithium salts exist in market applications, but the three main chemicals in the production chain are lithium carbonate (Li_2CO_3), lithium hydroxide (LiOH), and lithium chloride (LiCl). These chemicals can be used for the following:

- Lithium carbonate: The main building block for other lithium derivatives and used in a large variety of applications, including lithium-ion batteries, the ceramic and enamel industries, heat resistant glass, aluminum production, and pharmaceuticals.

- Lithium hydroxide: Its main use is as a reagent in high-performance lithium greases, dyes, and also in lithium-ion batteries.
- Lithium chloride: As a very hygroscopic salt (absorbs moisture from the air), it is used in fluxes, humidity control, and zeolites. It is also a raw material required for the electrolysis of lithium metal.

Each industry has unique requirements in terms of desired chemical composition, particle size, and tolerable levels of impurities with regard to lithium chemicals. For instance, lithium is a key component across the structure of the battery – it is present both in the cathode and the electrolyte, allowing charge to flow between the anode and cathode. Companies can use both lithium hydroxide and lithium carbonate to produce lithium-ion batteries, but companies usually report LCE.[7]

Figure 1: Lithium Concentrate from Brine Evaporation Ponds

Source: SQM Sustainability Report 2020.

Forecasts show that future demand for lithium-ion batteries for use in EVs and renewable energy will significantly drive demand for lithium chemicals going forward. Expansion of existing mining operations, as well as a large number of new brine and Mineral deposits progressing through to production, could meet this demand by 2030 (see Figure 1). However, the market expects there to still be insufficient supply, causing deficits in the coming years out to at least 2030.

[7] Care should be taken in studying lithium data from varying sources as it can be presented in different terms and sometimes presented in 'equivalents' for comparison. These include contained lithium metal (often abbreviated as Li), lithium oxide (LO), lithium carbonate (LC), lithium carbonate equivalent (LCE), or lithium hydroxide (LH). As the precise content of lithium chemicals differ, supply and demand are often denominated in terms of LCE. Lithium hydroxide contains less lithium than lithium carbonate and so one tonne of lithium hydroxide is converted by a factor of 0.878 when expressed in LCE terms. The grades of lithium ores and concentrates can be presented as ppm or percentages. Annex 4 – Lithium M&A Activity contains a conversion table.

3. LITHIUM RESOURCES

Lithium is not a rare metal – it has substantial global reserves and resources. South America's lithium reserves and resources make up more than half of the world's total. While Brazil does have reserves and resources at its disposal, its levels are relatively small, especially when compared to its neighbors. The following sections provide more information on sources of lithium ores, global lithium resources, and Brazilian lithium resources.

3.1. Sources of Lithium Ores

Although lithium is widely found around the world, it usually occurs in low concentrations in combination with other minerals. As a result, lithium generally only exists in suitably large economic deposits of silicate minerals and mineral-rich brines.

In the case of silicate minerals, there are only a few that are economically worthwhile to process for lithium: spodumene, petalite, and lepidolite (all found in granitic pegmatites).[8] Spodumene (aluminum silicate) is the most commonly available economic lithium-bearing mineral, followed by petalite. Spodumene has a maximum theoretical percentage of lithium oxide (Li_2O) of 8.03 percent (3.7 percent lithium), petalite has a maximum percentage of lithium oxide of 4.88 percent (2.2 percent lithium), and lepidolite has a maximum percentage of lithium oxide of 7.70 percent (3.6 percent lithium). Typically, a mineralized rock contains approximately 12 percent to 20 percent spodumene, or about 1.5 to 4 percent lithium oxide (0.7 to 1.9 percent lithium).[9]

Commercial quantities of lithium also exist in brines (a high concentration salt solution containing mineral-rich dissolved solids). The main type of brine deposit mined for lithium exists in interior saline desert basins. These basins in the past contained water before the rate of evaporation exceeded the rate of recharge, leaving behind a dry lakebed. The chemistry of saline brines is unique to each site and can change dramatically even within the same salar. The typical grade of an economic brine deposit is around 0.04-0.15 percent lithium (400-1,500 ppm).[2] The salars of Chile and Argentina have the highest lithium concentration of brines.

In addition to silicate minerals and mineral-rich brines, lithium also exists in oilfield brines, geothermal brines, and clays, but there has been no commercial production yet from these sources (although projects are at various stages of development). Lithium clays (mainly containing hectorite) typically grade 0.24-0.53 percent lithium.[10] There is also a small but growing contribution from recycled sources of lithium compounds.

3.2. Lithium Resources

Although estimates for global lithium reserves and resources are substantial, sources vary (and often contradict) on regional estimates. Table 1 presents the USGS' estimates for lithium reserves (that is, the amount of lithium 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 lithium in or on the earth's crust that could *potentially* be economically extracted based on geological evidence, but have a lower level of exploration).[11]

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[8] Pegmatites are common throughout the earth's crust; however, lithium-bearing pegmatites make up only one percent of the world's pegmatite resources.
[9] British Geological Survey.
[10] Deutsche Rohstoffagentur (DERA).
[11] 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 Lithium Reserves and Resources Based on Reported Data

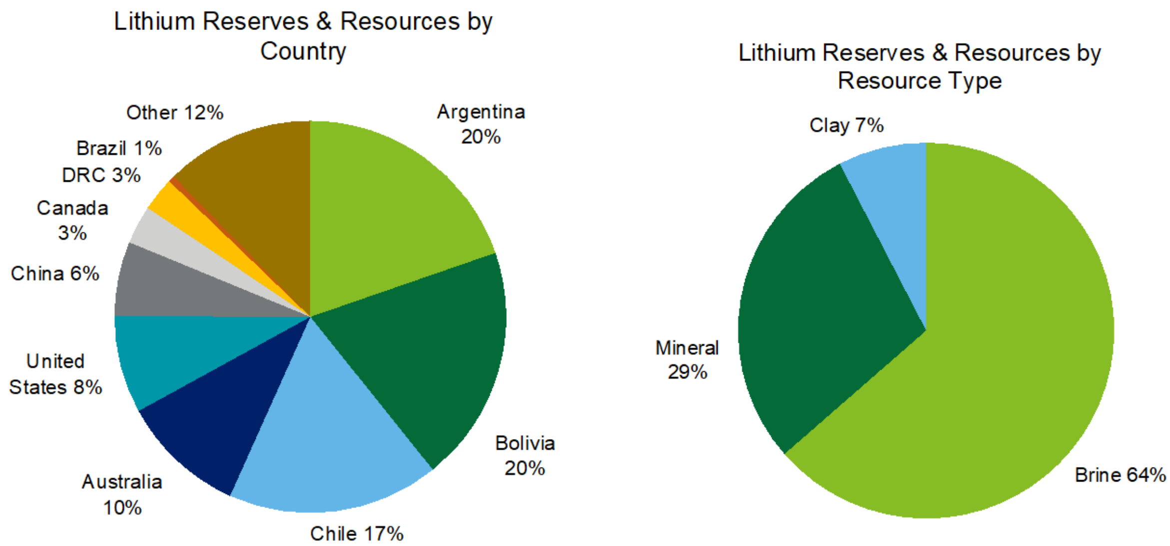
Country	USGS Reserves Mt cont. Li	USGS Resource Mt cont. Li	USGS Resvs & Rescs Mt cont. Li	USGS Resvs & Rescs Mt cont. LCE
Argentina	1.90	19.30	21.20	112.83
Bolivia	-	21.00	21.00	111.76
Chile	9.20	9.60	18.80	100.05
Australia	4.70	6.40	11.10	59.07
United States	0.75	7.90	8.65	46.04
China	1.50	5.10	6.60	35.13
Canada	0.53	2.90	3.43	18.25
DRC	-	3.00	3.00	15.97
Germany	-	2.70	2.70	14.37
Mexico	-	1.70	1.70	9.05
Czechia	-	1.30	1.30	6.92
Serbia	-	1.20	1.20	6.39
Peru	-	0.88	0.88	4.68
Zimbabwe	0.22	0.50	0.72	3.83
Mail		0.70	0.70	3.73
Brazil	0.10	0.47	0.57	3.03
Portugal	0.06	0.27	0.33	1.76
Spain	-	0.30	0.30	1.60
Other	2.10	0.29	2.39	12.72
				-
Total	**21.00**	**86.00**	**107.00**	**569.45**

Source: USGS.

Brine resources account for about 64 percent of available reserves and resources, as estimated and reported in relevant company data, while Mineral deposits account for about 29 percent, and clay deposits for about 7 percent (see the chart on the right-hand side of Figure 2).

South America's lithium reserves and resources account for 58 percent of the world's total. Argentina, Bolivia, and Chile have the largest amounts, predominantly of brine deposits. The Salar de Uyuni in southwest Bolivia has by far the largest reserve base in the world, with up to 9.0 Mt of lithium. Bolivia has yet to exploit its lithium resources and currently holds an estimated 20 percent of world resources in brine deposits. Brazil has a relatively low level of global lithium reserves and resources (0.5 percent), particularly when compared to other South American countries (see the chart on the left-hand side of Figure 2).

Figure 2: Global Reserves and Resources of Lithium

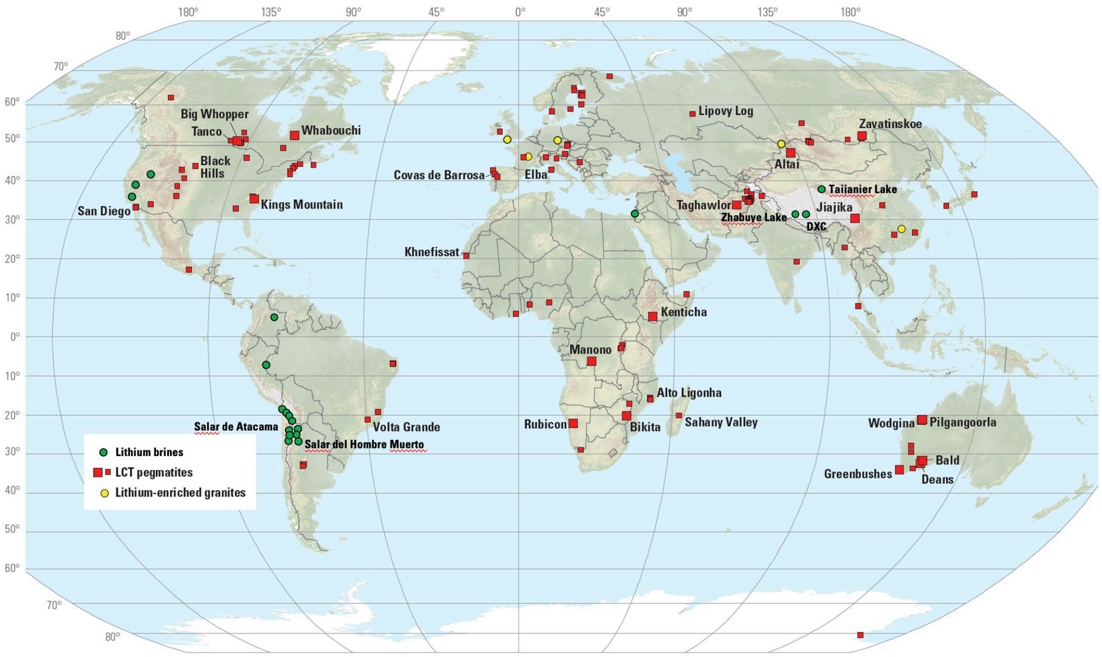


Source: USGS, Roskill based on company data of operations & projects.

In terms of other brine resources, China has numerous brine deposits in areas like the Qaidam basin (comprised of more than 30 lakes) and the Tibetan plateau (comprised of more than 300 lakes). These deposits include the Taijinaier Salt Lake (Qinghai Province) and Lake Zabuye (Shigatse Prefecture). The Qaidam Basin, where Lake Taijinaier is located, is the largest salt-bed lithium reserve in China. There are also numerous smaller brine deposits around the world in countries like Canada, China, India, Israel, Afghanistan, and the United States.

Australia also has large amount of lithium, holding approximately 10.4 percent of global reserves and resources (primarily Mineral pegmatite deposits). The United States holds 8.1 percent (Mineral, Brine, and Clay) and China holds 6.2 percent (brine and Mineral). In China, Mineral reserves and resources are mainly comprised of lepidolite ore from Yichun, in the Jiangxi province, although China's domestic Mineral lithium deposits are comparatively low quality. Canada, Zimbabwe, and Brazil are among other countries with Mineral reserves (see Figure 3).

Figure 3: Lithium-cesium-tantalum (LCT) pegmatites, lithium granites, and lithium brines.



Source: Deloitte – Original USGS map amended with other USGS data.

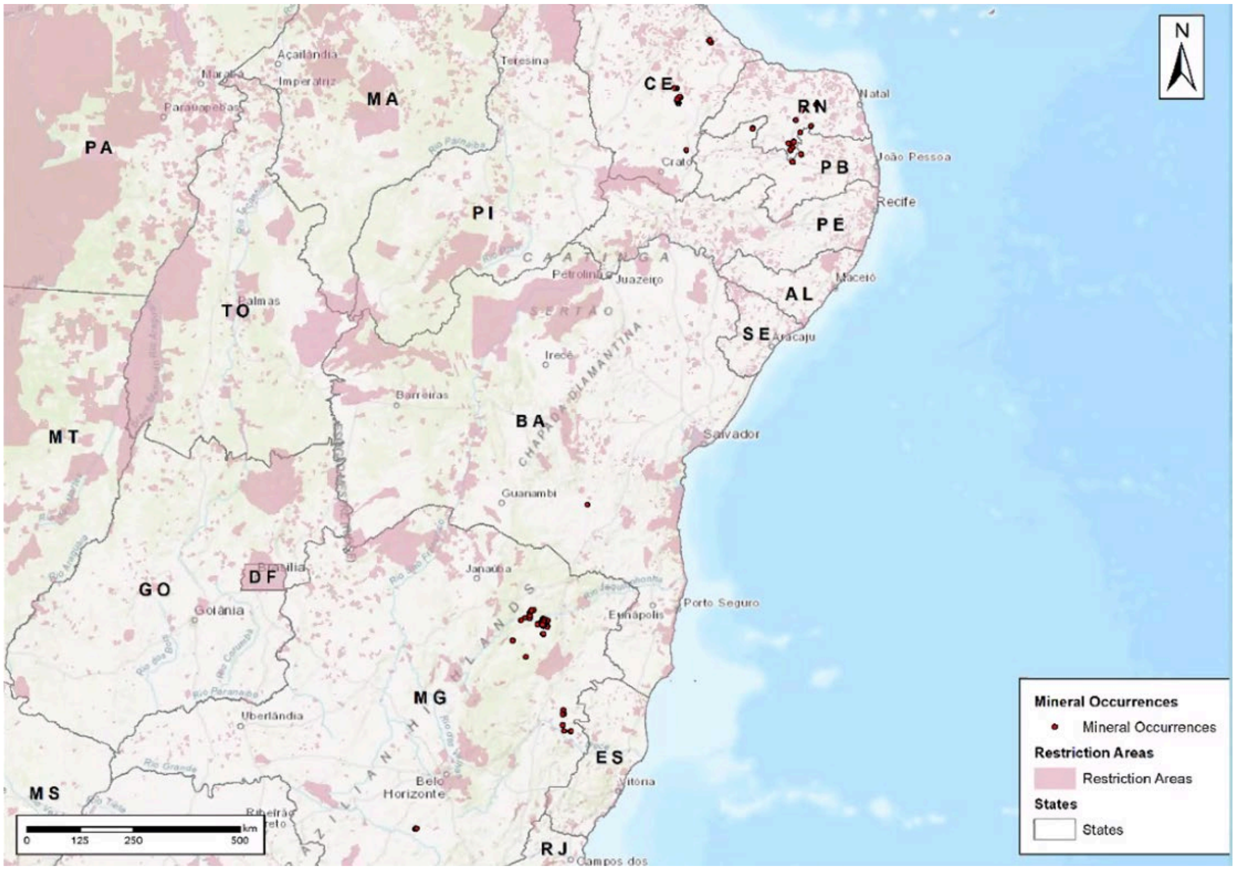
3.3. Brazilian Lithium Resources

According to the USGS, Brazil had lithium reserves of 95 kt Li and resources of 470 kt Li in 2020. The Agência Nacional de Mineração (ANM) reported resources (measured, indicated, and inferred) of 488 kt of lithium oxide (227 kt Li), with an average grade of 1.30 percent lithium oxide in Minas Gerais in 2020.

In 2016, CPRM published an evaluation report (‘Avaliação Do Potencial Do Lítio No Brasil: Área Do Médio Rio Jequitinhonha, Nordeste De Minas Gerais’) to improve the information and understanding of lithium pegmatite deposits in Brazil. The report’s main focus was the midstream area of the Jequitinhonha River, in northeastern Minas Gerais, an area of existing lithium mine production and project development. Other regions studied included the Borborema Province and Solenopoles Sub-province located in the northeast region of Brazil. Figure 4 displays these lithium occurrences.

The report showed that these areas contained widespread LCT type pegmatites. The report also noted that there is potential for a considerable expansion of the lithium reserves in the mid Jequitinhonha River area. Some 92 occurrences, deposits, or mines existed in 2020; of which, 59 percent were in Minas Gerais State and 25 percent in Ceará State. There are currently some 315 mineral rights issued covering almost 400 kha.

Figure 4: Lithium Mineral Occurrences in Brazil

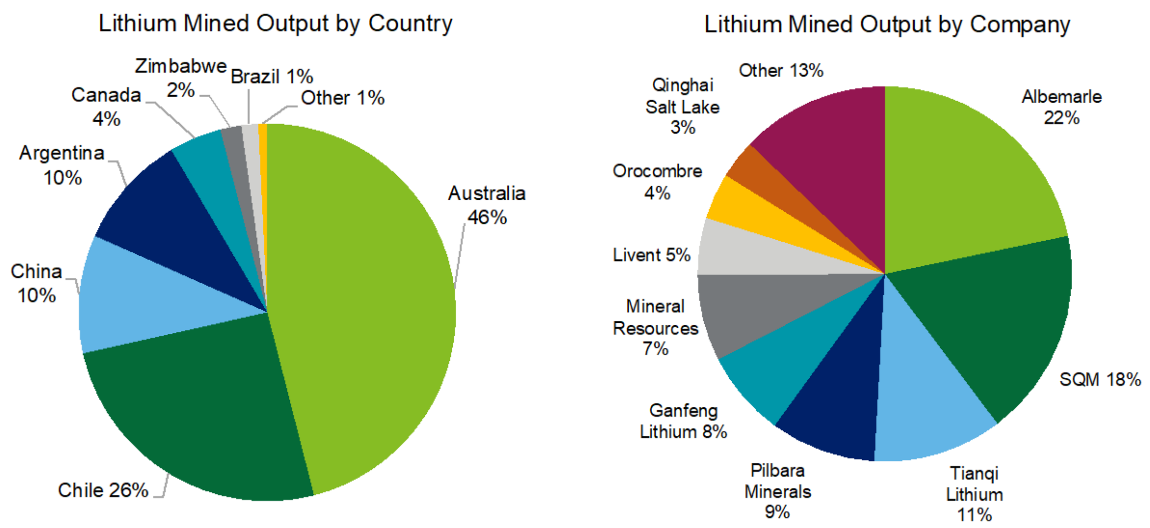


Source: CPRM.

4. LITHIUM SUPPLY

The data for lithium production varies between sources, partly because some producers do not report data. The USGS reported that lithium produced from Mineral and brine operations totaled about 84 kt of lithium (446 kt LCE) in 2020. Just four countries (11 mining operations) accounted for 95 percent of that output. These comprised just four active Mineral operations in Australia, two brine operations each in Argentina and Chile, and two brine and one Mineral operations in China. Figure 5 shows a breakdown of lithium production by country.

Figure 5: Global Mine Production of Lithium 2020



Source: S&P Global, company data.

Relatively few companies dominate mine production, with just seven companies accounting for 75 percent of output in 2020 as shown in Figure 5. The sections that follow provide more information about lithium mining, downstream lithium processing, and current lithium production in Brazil.

4.1. Mining of Lithium

The main sources of lithium for commercial extraction are Mineral (mostly pegmatite granites) and brines (aquifers containing mineral-rich dissolved solids). However, other sources of lithium, including geothermal brines, oilfield brines and hectorite clays, are also under evaluation for future exploitation.

4.1.1 Mineral Lithium Production

In 2020, lithium Mineral sources accounted for 53 percent of lithium feedstock around the globe. To produce lithium from Mineral sources, the material typically undergoes an initial process of concentration at a mine site. In the case of spodumene (the most common and economic Mineral source), producers typically concentrate the material to 6 percent lithium-oxide content. This material can then be processed into a chemical product (either lithium carbonate or lithium hydroxide) or sold as spodumene concentrate. Australia is the predominant supplier of spodumene concentrate and third parties in China undertake most of the chemical processing. The competitiveness of these assets is derived from the quality of the deposits, together with the geography, and long-standing expertise in large-scale mining in Australia.

To secure supply and market share, some Chinese lithium chemical processors (Tianqi and Ganfeng) have purchased interests in Australian mines. Other South American brine producers (Albemarle and SQM) have also purchased interests in Australian mines and projects to diversify and grow their production base. Table 2 shows how Australia dominates lithium production.

Table 2: Global Lithium Mine Production by Country (Li & LCE content)

Country	2016	2017	2018	2019	2020	2020
	Li tonnes	Li tonnes	Li tonnes	Li tonnes	Li tonnes	LCE tonnes
Australia	14,000	40,000	58,800	45,000	40,000	172,880
Chile	14,300	14,200	17,000	19,300	18,000	95,796
China	2,300	6,800	7,100	10,800	14,000	74,508
Argentina	5,800	5,700	6,400	6,300	6,200	32,996
Zimbabwe	1,000	800	1,600	1,200	1,200	6,386
Brazil	200	200	300	2,400	1,900	10,112
Portugal	400	800	800	900	900	4,790
USA	900	900	950	950	450	2,395
Canada	-	-	2,400	200	-	
Other	20	20	20	500	1,200	6,386
Total	38,920	69,420	95,370	87,550	83,850	446,250

Source: USGS 2021, Deloitte estimates for US production (not given by USGS).

Table 3 provides more information on global lithium mine operations in 2020. The largest pegmatite operation was Greenbushes mine in Australia, owned by Albemarle (49 percent) and Tianqi (26 percent), followed by Mount Marion, owned by Mineral Resources and Ganfeng.

Table 3: Top 11 Lithium Mine Operations (95 Percent of Capacity)

	Mine	Mine	Owner	Ore	2020 Prodn
	Name	Location		Type	LCE kt
1	Greenbushes	Australia	Albemarle/Tianqi Lithium	Pegmatite	88,000
2	Salar de Atacama	Chile	SQM	Brine	72,200
3	Mount Marion	Australia	Mineral Res./Ganfeng	Pegmatite	59,827
4	Salar de Atacama	Chile	Albemarle	Brine	42,000
5	Pilgangoora ops	Australia	Pilbara Minerals	Pegmatite	36,668
6	Salar del Hombre Muerto	Argentina	Livent	Brine	19,801
7	Mt Cattlin	Australia	Orocobre	Pegmatite	15,988
8	Chaerhan Lake	China	Qinghai Salt Lake Industry	Brine	13,502

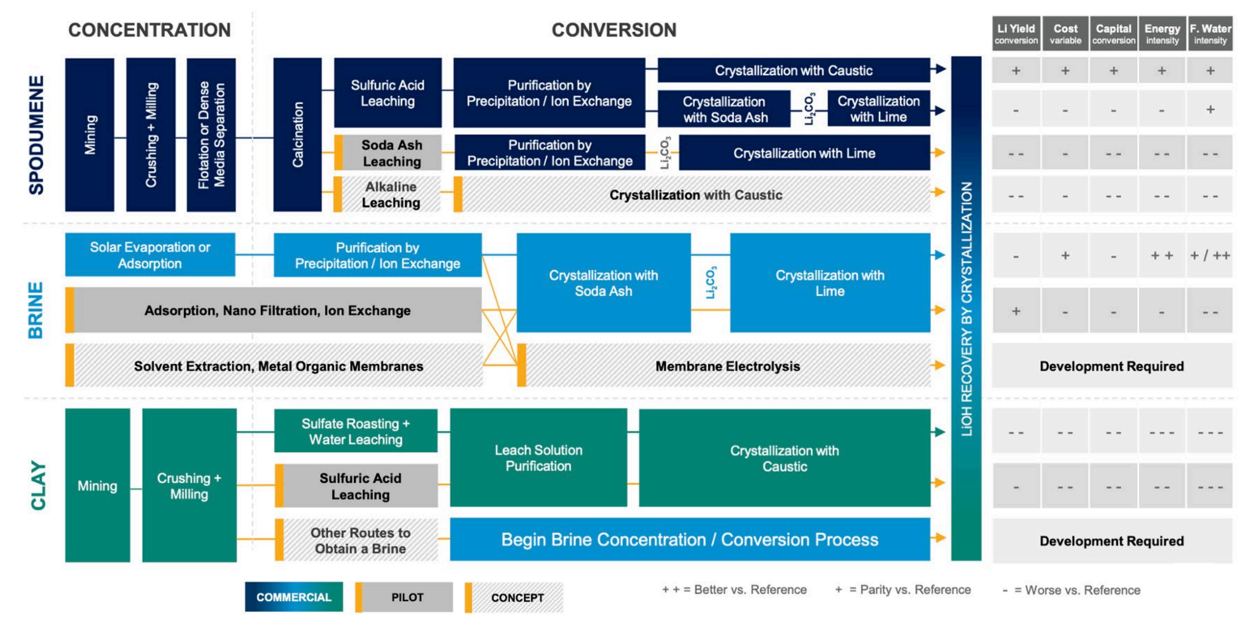
	Mine	Mine	Owner	Ore	2020 Prodn
	Name	Location		Type	LCE kt
9	Salar de Olaroz	Argentina	Orocobre	Brine	11,922
10	Yichun	China	Yichun Tantalum	Granite	9,787
11	East Taijinair	China	Western Mining Group	Brine	9,454

Source: S&P Global Intelligence, Company data.

China also produces ore from domestic Mineral lithium deposits, the largest being lepidolite from Yichun, in the Jiangxi province. Other sources are reported to be comparatively low-quality and potentially uncompetitive as sources for conversion to lithium chemicals. As a result, China has been, and is forecasted to remain, mainly dependent on imported feedstock for conversion into lithium chemicals according to BMI.

Figure 6 provides an overview of how lithium in processed from different sources, including Mineral deposits (like spodumene), brine, and clay.

Figure 6: Key Process Routes to Lithium Hydroxide



Source: Albemarle.

4.1.2 Lithium Brine Production

Brine lithium sources accounted for 47 percent of lithium feedstock in 2020. Lithium from brine conventionally undergoes a process of concentration via evaporation ponds, producing a lithium carbonate salt. Lithium carbonate production from brine undergoes processing at integrated facilities away from the salar with evaporation ponds. Although lithium brine processing initially produces lithium carbonate, it can also produce lithium hydroxide if required. However, this increases costs and generally results in a more expensive route to produce lithium hydroxide.

The main operators of lithium brine mines are based in South America. SQM is the largest producer – it operates the Salar de Atacama in Chile. The second largest brine operation is the nearby Albemarle mine of the same name. The third largest is the Salar del Hombre Muerto in Argentina operated by Livent.

Outside of South America, China is the next largest brine producer from several salars. Its two largest primary sources of domestic brine production are in Qinghai and Tibet.

Table 4: Lithium Brine Production by Country

	Mine	Mine	Owner	Ore	2020 Prodn
	Name	Location		Type	LCE kt
2	Salar de Atacama	Chile	SQM	Brine	72,200
4	Salar de Atacama	Chile	Albemarle	Brine	42,000
6	Salar del Hombre Muerto	Argentina	Livent	Brine	19,801
8	Chaerhan Lake	China	Qinghai Salt Lake Industry	Brine	13,502
9	Salar de Olaroz	Argentina	Orocobre	Brine	11,922
10	Yichun	China	Yichun Tantalum	Granite	9,787
11	East Taijinair	China	Western Mining Group	Brine	9,454

Source: S&P Global Intelligence, Company data.

Annex 1 – Mining and Beneficiation of Lithium *covers mining and beneficiation of Mineral and brine lithium operations in more detail.*

4.1.3 Recycling and Substitution

Recycled sources are a small but growing contributor to lithium compounds; however, the supply of lithium from secondary sources and recycling does not yet play a major role.

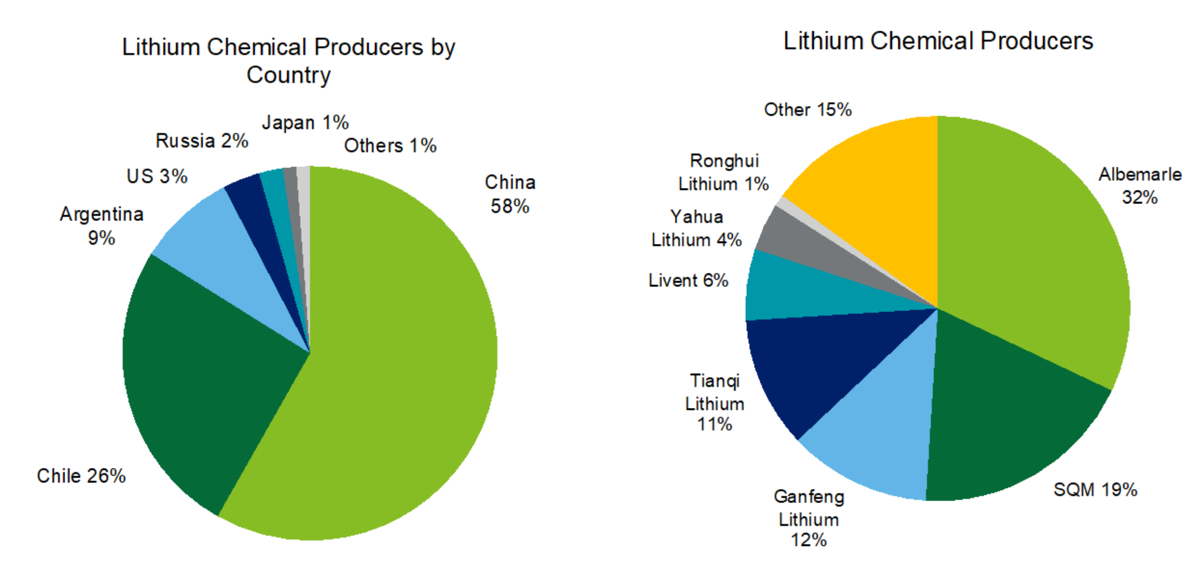
Substitution for lithium compounds is possible in many applications such as batteries, glass and ceramics, and greases. However, historically there has been little incentive to use substitutes because of lithium's relative stability of supply and proven properties. For example, in glass and ceramics, other fluxes such as sodium or potassium compounds can be used, but do not increase the thermal shock resistance to the same degree as lithium carbonate. Alternatives to lithium, such as sodium, are being investigated for portable batteries, and vanadium and zinc are being used for stationary energy storage. However, lithium remains, and is expected to remain, the dominant battery technology for the foreseeable future. A Report on the outlook for EVs and lithium-ion batteries will provide additional information on these topics.

4.2. Downstream Processing of Lithium

The full supply chain for lithium is complex and often disaggregated – it includes upstream production of brine and Mineral concentrate, through midstream chemicals, to downstream application in lithium-ion cells in EVs and stationary storage units. As with lithium mining data, the information about lithium chemical production is often unavailable, requiring estimations that cause variations between different sources. Additionally, many third-party reports often contain outdated information, which is largely irrelevant to current market conditions because of the recent rapid upturn in lithium supply and demand.

In addition, the distinction between primary lithium production at the mine and secondary processing of lithium chemicals is often blurred because brines by the nature of extraction immediately produce lithium carbonate, a lithium chemical. Consequently, brine operations are simultaneously mines as well as lithium chemical producers. Large brine producers, such as Albemarle, SQM, and Livent, traditionally regard themselves as chemical companies. Similarly, while Ganfeng owns Mineral and brine assets, it is a vertically integrated chemicals and manufacturing company that engages in lithium mining right through to lithium-ion battery producing.

Figure 7: Global Lithium Chemical Production 2020



Source: BMI, SQM, Ganfeng, other company data, and Deloitte estimates.

Figure 7 illustrates how China currently dominates lithium processing with refineries producing lithium carbonate, lithium hydroxide, and lithium chloride, much of it from Mineral concentrate sourced from Australian and other global pegmatite producers. The secondary lithium salts are chemically stable (for storage and transport), contain a high proportion of lithium, and are transformable into different lithium compounds for different uses. China dominates the market primarily due to its competitive advantage and accumulated capacity in lithium processing. The country has cheaper capital required to build conversion plants, access to low-cost reagents, and power costs that are competitive relative to the global average. Moreover, Chinese chemical processors are close to the major companies involved in the current global lithium-ion battery supply chain. As a result, China accounted for an estimated 58 percent of global lithium chemical output in 2020, despite producing only around 10 percent of the global mined lithium.

To date, only three countries ─ China, Japan, and South Korea ─ have built battery cathode plants that convert lithium chemicals into cathode-active material. According to BMI, Chinese cathode plants consumed approximately two-thirds of the lithium carbonate and lithium hydroxide used in global battery production during 2020. Japan and South Korea split the majority of the remainder, with smaller amounts going to Taiwan, North America, and Europe.

4.3. Current Lithium Production in Brazil

Brazil is a relatively small producer of lithium. According to ANM, Brazil produced 39 kt of spodumene concentrate in 2019 (about 5.3 kt LCE, 1.0 kt Li) from two mines, Mina da Cachoeira and Mibra, both in Minas Gerais. This is less than reported by USGS and below reported capacity.

Cia Brasileira de Lítio (CBL)[12] operates Mina da Cachoeira, a highly mechanized underground operation located near Araçuaí in Minas Gerais. It has a capacity of 30 kt/y of 5.5 percent spodumene concentrate (about 4.4 kt/y LCE) and has been operating since 1992.

CBL transports the concentrate to its chemical-processing plant 180 km away in Divisa Alegre, where it produces 1.5 kt/y LCE of battery-grade lithium carbonate and lithium hydroxide. The company also sells spodumene concentrate and technical-grade lithium carbonate. It has a goal to double production by 2025. In 2018 Codemge acquired a 33 percent interest in CBL.

AMG Brazil also produces lithium concentrate at the Mibra tantalum and niobium mine. The mine has been in operation for about 40 years but only started producing lithium recently. A lithium concentration facility was commissioned in May 2018 and has a capacity of 90 kt/y lithium concentrate grading 5.5 to 6.5 percent Li_2O (about 12.5 kt/y LCE). AMG Brazil has plans to build a 40 kt/y expansion.

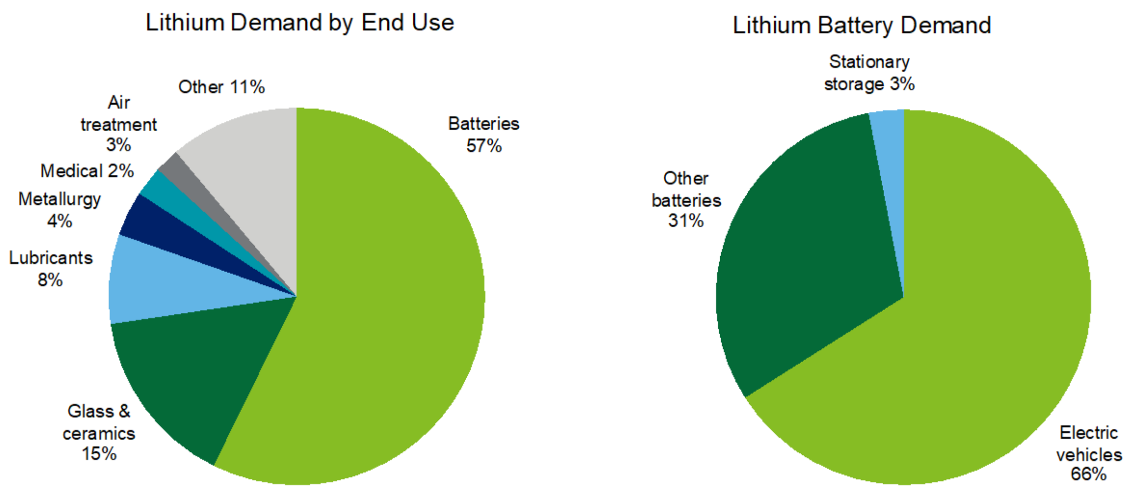
The Government of Brazil levies a Compensação Financeira pela Exploração de Recursos Minerais (CFRM) royalty on mineral production. Lithium production is subject to a 2 percent CFRM royalty, payable on the gross income from sales. Chile is advancing a bill to apply a 3 percent royalty on lithium sales, Argentina has a royalty of up to 3 percent depending on the province, and Australia has a 5 percent royalty rate for lithium concentrate feedstock, and a 3.75 percent royalty rate on lithium hydroxide and carbonate. While royalties are an important element of a country's fiscal policy, they are only one component of the tax structure for the mining industry.

[12] In 2018, Codemge acquired a 33 percent interest in CBL.

5. LITHIUM DEMAND

Global lithium demand was about 330 kt of LCE in 2020.[13] According to BMI, the battery sector consumed about 57 percent of this demand, and the remaining balance was used in other industrial sectors. Glass and ceramics were the second largest applications of lithium and consumed 15 percent of demand, followed by lubricating grease at 8 percent (see Figure 8). The top three applications account for 80 percent of demand. The use of lithium in both glass and ceramics and in batteries has grown rapidly since 2010, with growth in batteries accelerating from 2018.

Figure 8: Lithium End-Use Demand 2020



Source: BMI.

The following sections provide more detailed information on lithium uses and applications, lithium content of lithium-ion batteries, and the current Brazilian demand for lithium.

5.1. Lithium Uses and Applications

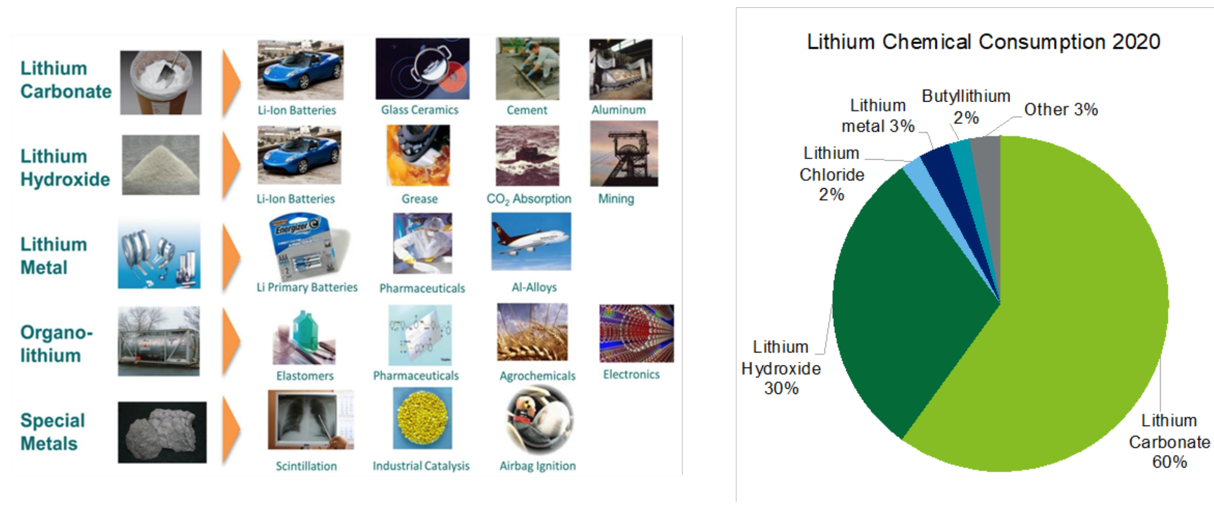
The rechargeable batteries market has been the foundation of lithium demand growth and is expected to drive future demand. In 2020, rechargeable batteries accounted for 57 percent of total lithium demand, and this is forecasted to exceed 80 percent by 2025.[14] While a wide variety of products, including hand-held power tools, portable electronics, e-bikes, and energy storage systems (ESSs) form important end-use markets for rechargeable batteries, the use of lithium-ion technologies in electric and hybrid vehicles now dominates demand growth. Electric and hybrid vehicles represented over 66 percent of lithium demand from lithium-ion battery technologies in 2020, as shown in Figure 8.

[13] DERA estimate, BMI estimate 302 kt.

[14] Roskill – Lithium Outlook to 2031.

Non-battery uses for lithium are largely comprised of end uses that consume lithium chemicals, predominantly (but not exclusively) lithium hydroxide and carbonate. However, some of the lithium consumed by the glass and ceramics sector is in the form of Mineral concentrate (spodumene or lepidolite). Material specification will tend to differ between application (see Figure 9). For example, spodumene concentrate used to manufacture ceramics is usually of lower specification than that used for processing into battery-grade lithium hydroxide (*Annex 2 – Lithium Uses provides more information on lithium-ion batteries and other lithium uses*).

Figure 9: Key Products and Applications, and Consumption of Lithium Chemicals

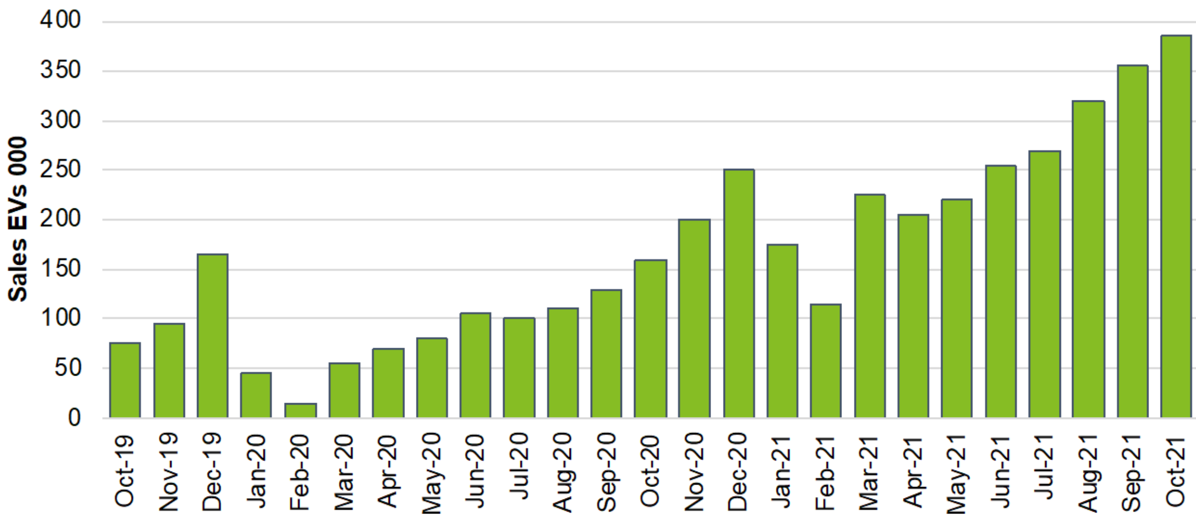


Source: Albemarle, German Mineral Resources Agency (DERA).

The growth rate of EV fleet sizes will strongly influence demand for lithium-ion batteries. This rate is difficult to forecast and there are a range of estimates made by government agencies, economists, research analysts, and industry. Historically, the market has been overly optimistic in its projection for EVs. This now appears to be changing with EVs at an inflexion point and most analysts are now projecting strong growth for EVs over the coming decade (*for more information, see Section 7 Outlook for Lithium Demand*).

Producer SQM reports that it expects market demand for lithium in 2021 to be close to 50 percent higher than 2020. This has been driven by significantly higher EV sales in 2021, particularly from demand growth in China. Figure 10 shows monthly Chinese EV sales.

Figure 10: Chinese EV sales (Oct 2019 – Oct 2021)



Source: BMI.

5.2. Lithium Content of Lithium-ion Batteries

Lithium hydroxide and lithium carbonate are both used in lithium-ion batteries. Manufacturers favor lithium hydroxide for cathode technologies and high nickel chemistry batteries such as NCM811 (nickel-cobalt-manganese or NCM), which have a higher energy density. NCM622 cathodes can use either lithium hydroxide or carbonate, while lower nickel-bearing NCM cathodes require lithium carbonate. Other lithium batteries such as lithium-iron-phosphate (LFP), which have a lower energy density but are lower cost, also use lithium carbonate. Lithium salts produced for batteries require a higher purity of product and usually designated as 'battery-grade'.

Overall, lithium currently makes a relatively small contribution to the overall cost of cell production. At 2020 price levels for example, lithium accounted for roughly 8-10 percent of the cost of an NCM811 battery cell.[15] Consequently, Original Equipment Manufacturers (OEMs) are currently not preoccupied with lithium in their efforts to reduce cell production costs, and thus lithium does not impose any medium-term substitution threat. However, lithium prices have risen significantly over the past year and lithium-ion battery prices are expected to rise in 2022 for the first time in many years.

Table 5 shows the metal content for a selection of different cathode types and shows that a typical lithium-ion battery has between 80 and 120 g/kWh of lithium. A typical EV battery has an 80-kWh battery (Tesla Model 3), meaning it has some 6.4 kg (NMC111) to 9.6 kg (LFP) of lithium content (34.1 to 51.1 kg of LCE), depending on the type of battery technology. Tesla is currently using LFP batteries.

[15] Benchmark Mineral Intelligence (2020).

Table 5: Metal Content of Different Battery Cathodes kg/kWh

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

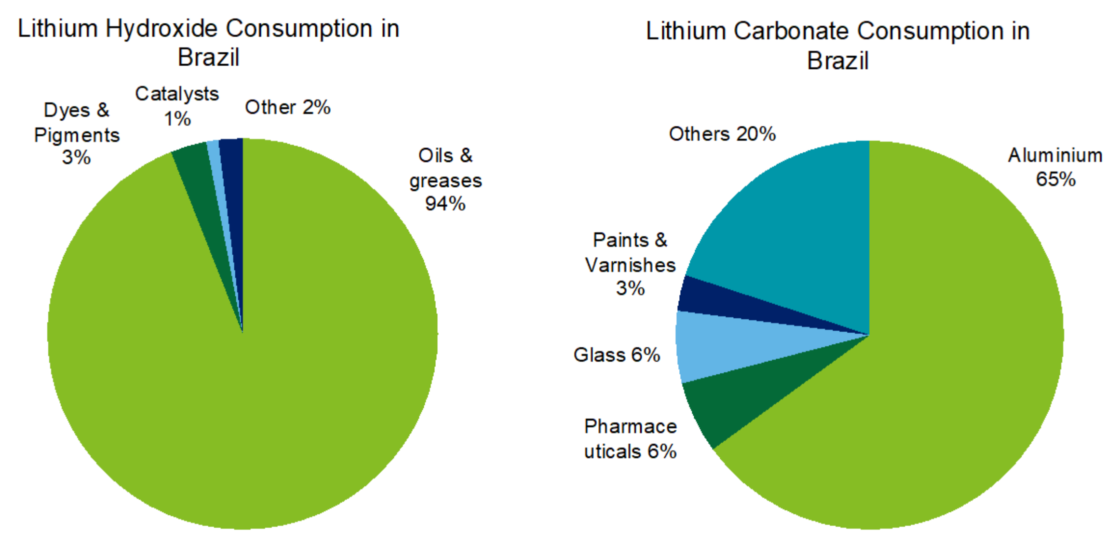
Source: Fraunhofer ISI & Fraunhofer IZM 2021 for DERA 2021.

An upcoming Report on the outlook for demand growth in EVs and lithium-ion batteries, which includes a discussion of different battery technologies, will provide additional information on these topics as they relate to all the critical minerals selected for this analysis.

5.3. Current Brazilian Demand for Lithium

Lithium production in Brazil is consumed by various domestic industries, the largest consumer being the aluminum industry (see Figure 11). Brazil's two existing mines produced about 39 kt of spodumene concentrate in 2019 (about 5.3 kt LCE, 1.0 kt Li). Sigma Lithium Resources [TSXV: GSML] is planning to bring its Grota do Cirilo mine on stream in 2022. It expects to produce 220 kt/y battery-grade spodumene for exportation for lithium chemical production (with the potential to expand production to 440 kt/y). The company has a 6-year initial contract with LG Energy Solution to supply the lithium concentrate on a take-or-pay basis. Pricing will be floating and linked to market prices for high purity lithium hydroxide.

Figure 11: Brazilian Demand for Lithium Carbonate & Lithium Hydroxide



Source: CPRM.

6. LITHIUM TRADE AND PRICES

South American brine producers mainly export lithium carbonate to Asia (China, Japan, and South Korea) for direct use or processing to lithium hydroxide or other salts. Similarly, spodumene concentrates produced in Australia currently flow to China for processing to lithium carbonate, lithium hydroxide, or other salts. The following sections provide information about the lithium trade and lithium market balance.

6.1. Lithium Trade

Trade in lithium centers around key raw materials and chemicals – spodumene concentrate, lithium carbonate, and lithium hydroxide, which vary significantly in their lithium content. The production of lithium-ion-batteries requires both lithium carbonate and lithium hydroxide, depending on the type and quality of the battery.

Despite its rapid growth profile in recent years, the lithium market remains a modestly sized specialty market and lithium pricing remains relatively opaque in comparison to the much larger (and more liquid) markets for precious and base metals and bulk commodities. The majority of lithium material is bought and sold under long-term contractual agreements with pricing formulas based on published prices. These are then adjusted for various factors including product quality and delivery/dispatch location. Each industry has unique requirements in terms of desired chemical composition, particle size, and tolerable values of impurities.

Spodumene concentrates are usually graded and priced according to their lithium-oxide content and impurity levels. Concentrates for the battery industry are rated 'chemical grade' or 'battery grade' and concentrates for the glass industry are rated 'technical grade'. The current industry standard for lithium concentrates in the battery industry is SC6, a chemical grade spodumene-concentrate that contains approximately 6 percent lithium oxide. In general, the glass industry has tighter limits on certain impurities than the battery industry due to the direct use of the concentrates in the respective product flow sheets.

In terms of lithium carbonate trade values, Chile was the largest exporter in 2019 with goods valued at $880m, followed by Argentina ($236m), China ($161m), and Belgium ($81m). The largest importers were South Korea ($419m), Japan ($292m), China ($235m), and Belgium ($124m).[16]

In terms of lithium oxide and hydroxide trade values, China was the largest exporter in 2019 with goods valued at $657m, followed by Chile ($130m), the United States ($110m), and Russia ($85m). The largest importers were Japan ($439m), South Korea ($374m), Belgium ($65m), and China ($35m).

6.2. Lithium Pricing and Market Balance

Several providers publish prices for spodumene and a number of other lithium chemicals including lithium carbonate, lithium hydroxide and lithium chloride. These prices are available in various currencies and based on dispatch or delivery at a number of relevant locations. The premium of battery grade over technical grade has historically been about 10 percent.

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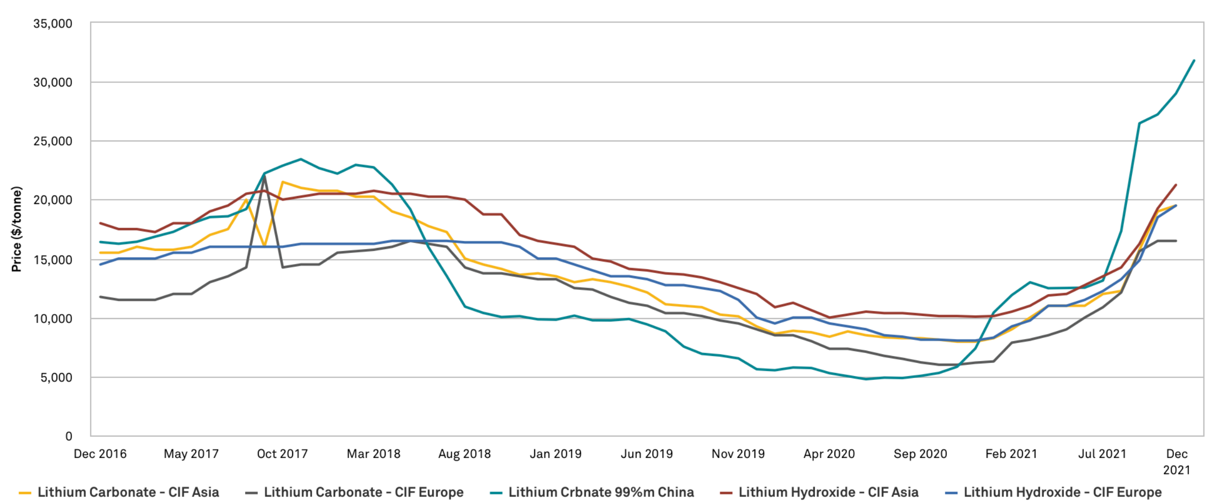
[16] Observatory of Economic Complexity (OEC).

Trade in the spot market is currently relatively minor, but this may change if the market expands significantly over the next decade as expected. In June 2021, the London Metal Exchange (LME) launched a new cash-settled futures contract for lithium hydroxide. The contract offers the industry a price risk management tool. The index name is 'Fastmarkets Lithium hydroxide monohydrate 56.5 percent LiOH.H2O min, battery grade, spot CIF China, Japan, and Korea $/kg'.

The lithium market moved into oversupply in 2019 and lithium prices gradually decreased. This was due to a rapid increase in new supply coming on stream, as well as a marked slowdown in global EV demand during the first half of 2020 due to the COVID-19 pandemic. The Chinese government's reduction in EV subsidies did not help demand, which then had a substantial impact on China's low-end EV market. The elimination of these subsidies resulted in lower demand for lithium compounds among small local EV manufacturers.

The build-up of inventory of battery-grade lithium resulted in lithium prices more than halving over a 3-year period. As a result, several established lithium operations postponed capacity expansion plans, some mining operations closed, and investment in the sector slowed. In Australia, lithium concentrate suppliers Altura (Pilgangoora) and Alita (Bald Hill) were forced into receivership and Albemarle idled its Wodinga operation. In the United States, Albemarle idled its Silver Peak lithium mine in Nevada, and the Kings Mountain brine operations and lithium hydroxide production facility in North Carolina.

Figure 12: Recent Price History for Lithium Carbonate & Lithium Hydroxide ($/t)



Source: S&P Global Intelligence.

The lithium carbonate spot prices started to recover towards the end of 2020 as demand from battery materials producers increased in response to growing EV sales and supply cutbacks in the market (see Figure 12). EV demand has been strong in 2021 and prices have continued to increase during the year to more than double those in September 2020, returning to the highs of 2017 and 2018. As global lithium chemical prices increased in 2021, spodumene contracted prices also moved up notably.

The market is currently in a supply deficit despite some disruption due to COVID-19, with the tightness in prices being compound by difficulties in supply logistics in South America. Furthermore, the delays to lithium expansion projects and development of greenfield projects in recent years is expected to cause continued market tightness.

7. OUTLOOK FOR LITHIUM DEMAND

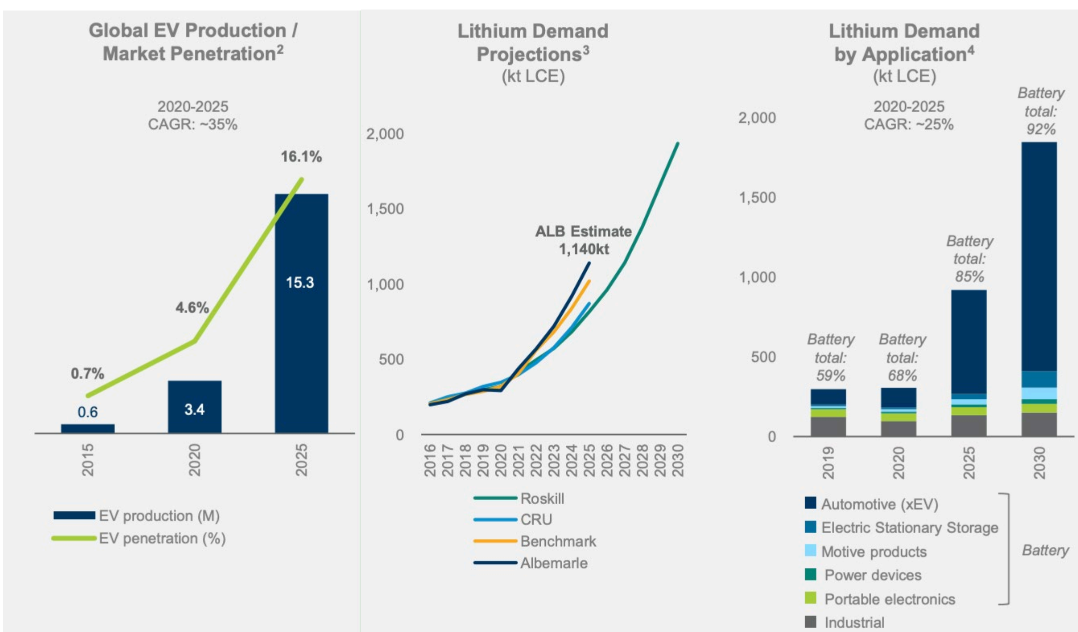
The demand growth for lithium-ion batteries for EVs is expected to drive demand in the lithium market. Automakers are currently investing some $90bn in developing 200 new electric models over the next few years. Battery cell manufacturing has attracted significant capital with investment planned globally for over 241 battery Gigafactories at end-2021, of which 142 are currently active.[17] Of those plants, some 72 percent of planned plants are for China, 8 percent for Asia (ex-China), 11 percent for Europe, and 9 percent for the US.

According to BMI, forecasts show planned global capacity at about 4,600 GWh by 2030, a significant increase over the 755 GWh of capacity currently installed. The forecasts for global capacity have risen strongly over the past few years and increased by 53 percent alone in 2021. The sections that follow provide more information on lithium demand growth for batteries and other uses.

7.1. Lithium Demand Growth for Batteries

The strong growth in the production of EVs has led to lithium demand projections of around 1.0 Mt LCE by 2025, according to a range of consultants including Roskill, CRU Group, and BloombergNEF (see Figure 13). Demand was approximately 330 kt in 2020, which signifies an overall compound annual growth rate (CAGR) of about 30 percent, with a 47 percent CAGR for battery-grade lithium for EVs.

Figure 13: Lithium Demand Projections & Demand by Application



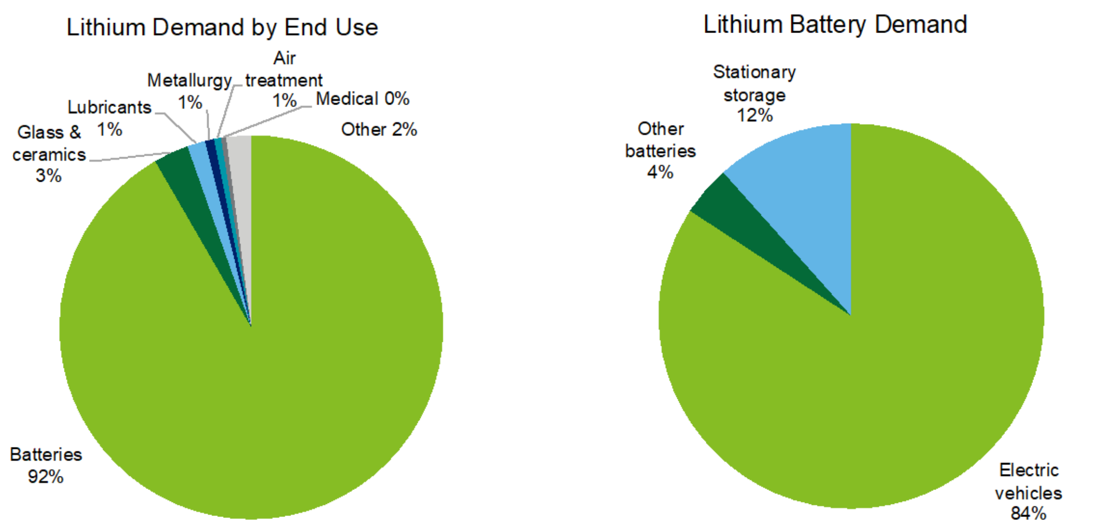
Source: Albemarle. Notes: [2] IHS Markit report as of Jan-2021. [3] Roskill projections as of Oct-2020, CRU Group projections as of Nov-2020, Benchmark projections as of Dec-2020. [4] Roskill report as of Aug-2020.

[17] BMI as at Dec 2021.

According to its latest reports, Roskill expects the demand forecast to rise to 2.28 Mt LCE by 2030 (see Figure 15), while BMI forecasts it will increase to 2.25 Mt. Of this, BMI expects batteries to account for more than 2.06 Mt LCE (93 percent) of annual consumption. As shown in Figure 14, EVs will account for 84 percent of battery use, stationary storage will account for 12 percent, and other types of batteries for 4 percent.

It is possible that LCE demand could be even higher than forecasted. Given the lithium content found in batteries (see Table 4), a 1 GWh lithium-ion Gigafactory would consume around 100 t/y lithium (532 t/y LCE) on average. Assuming that 4,600 GWh of planned battery capacity is built by 2030, EV demand alone for LCE would account for 2.45 Mt – much higher than current total global LCE demand forecasts.

Figure 14: Lithium End Use Demand Forecast 2030



Source: BMI.

7.2. Lithium Demand Growth for Other Uses

Demand in other sub-sectors of the lithium market is expected to be more modest and in line with forecast industrial growth. Albemarle forecasts industrial uses (specialty glass, lubricants, automotive) to grow at 2 to 4 percent annually, and Specialties (healthcare, pharmaceuticals, agriculture) to grow at 3 to 5 percent annually out to 2025. These sectors are expected to account for just 8 percent of demand by 2030.

7.3. Change in Lithium Chemical Demand for Batteries

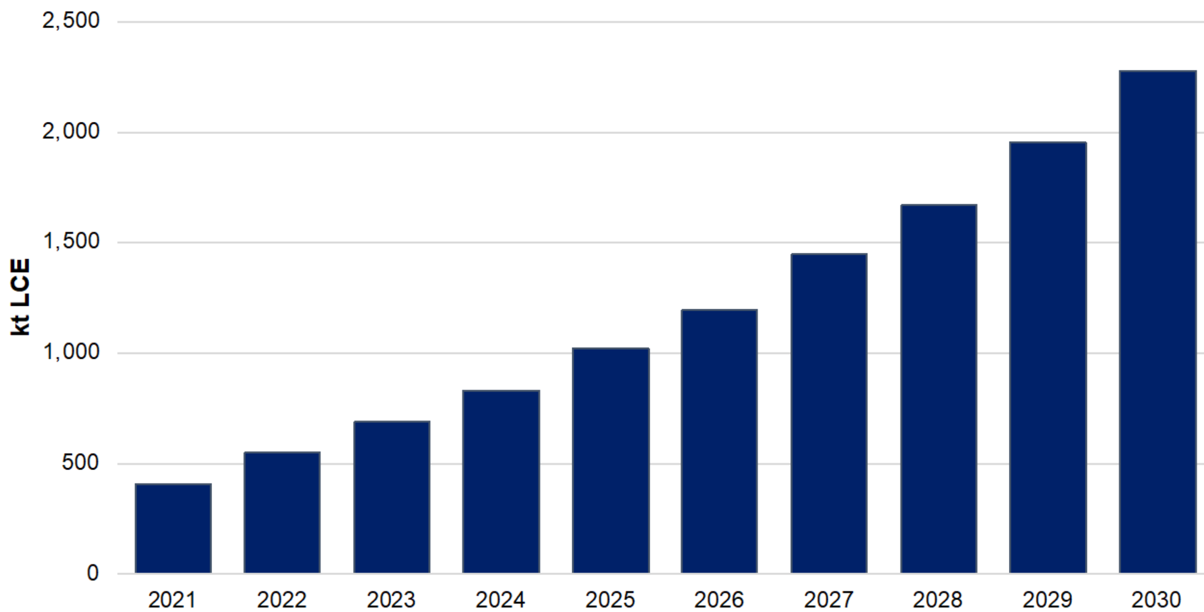
As the market for EVs expands, the demand for high-performance automotive batteries (>60 percent Ni) with high-energy densities is expected to grow given the focus on miles travelled per charge. This will result in increased demand for lithium hydroxide over lithium carbonate, with the market expected to consume more lithium hydroxide than lithium carbonate by 2030.

BMI forecasts that China will remain the largest producer of cathode material over the next decade. NCM811 or nickel-cobalt-aluminum (NCA) are expected to make up slightly less than 40 percent of China's planned cathode capacity, which will require the use of lithium hydroxide rather than lithium carbonate. NCM622 will comprise an additional 18 percent or so of this planned capacity, which can use either lithium hydroxide or carbonate.

Japan, South Korea, the United States, and Europe have plans for cathode capacity additions which will be, for the most part, NCM811 or NCA. Overall, however, Chinese plans currently overshadow plans to build cathode capacity outside of China.

BMI believes that there is a strong probability that additional cathode projects will emerge in the EU and the US, and western OEMs are advocating to bring elements of the EV supply chain closer to their domestic operational hubs. This reduces both working capital requirements and mitigates excessive reliance on Chinese-based supply. Lithium chemical consumption in the EU and US would increase at the expense of consumption in China and other Asian markets. Spodumene concentrate converters are seen as best placed to capitalize on this growth, due to their ability to produce a battery-grade hydroxide directly from concentrate.

Figure 15: Forecast Lithium Demand 2021-2030



Source: Roskill.

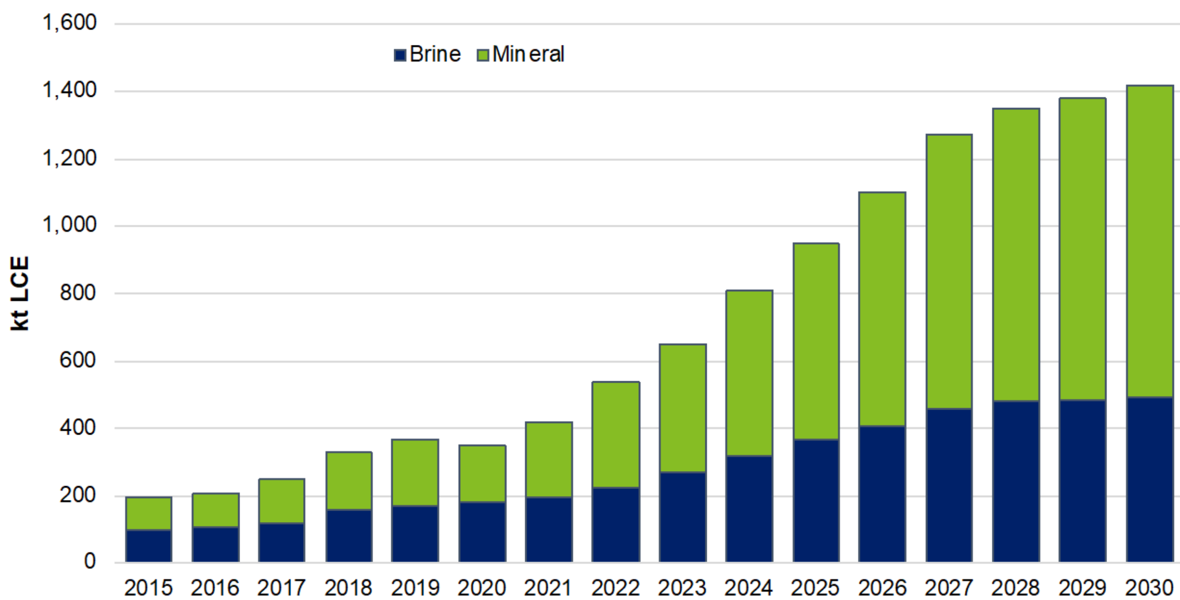
8. OUTLOOK FOR LITHIUM SUPPLY

The robust demand outlook for lithium is expected to drive a rapid expansion of mine capacity as well as the construction of new processing facilities. This section examines supply growth and its sources in more detail.

8.1. Lithium Mine Supply

A relatively small number of producers control mined lithium supply. However, forecasts indicate that this could change in coming years as new brine and Mineral deposits progress from development stage to production. Mineral (predominantly spodumene) lithium output will increasingly make up a larger share of mined lithium production in the future. Figure 16 shows actual production and forecasts for each lithium source from 2015 to 2030. BMI forecasts an increase in lithium supply from about 350 kt LCE in 2020 to some 1,420 kt/y LCE by 2030, a four-fold increase. Roskill has forecasted supply to be slightly lower – about 1,250 kt/y LCE in 2030.

Figure 16: Lithium Mine Supply Forecast 2015-2030



Source: BMI.

Mineral lithium operations offer potential cost and scale benefits relative to brine operations. In addition, producers can process Mineral lithium directly into lithium hydroxide. Producers also face fewer regulatory restrictions due to their location and the conventional mining techniques involved in development. Mineral mines are expected to contribute 65 percent of mine supply by 2030, up from 49 percent in 2020.

Deloitte expects that some of these projects located in strategic regions, such as in Europe or North America, are likely to receive preferential financial arrangements to secure their development. This is because these projects will be crucial in creating a sustainable supply chain for lithium-ion batteries for OEMs looking to diversify their supply chains away from Asia. Longer term, another important supply source will be recycling of end-of-life batteries.

8.2. Expansion of Existing Producers

In the next few years, large and established players will undertake significant investment to develop new lithium capacity. These players include Albemarle, SQM, Ganfeng Lithium, Livent and Tianqi Lithium.

8.2.1. Albemarle

Over the next year, Albemarle will commission two new plants to add 90 kt/y LCE capacity, which will more than double its nameplate capacity to 175 kt/y LCE by end-2022. Albemarle is also building out its conversion capacity in China. The company believes it can add 150 kt/y LCE capacity in the next 3 to 5 years at a cost of $1.5bn. It also has future ability to follow this with an additional 125 to 175 kt/y LCE capacity, to produce a total of 450-500 kt/y LCE potentially by the end of the decade.

Albemarle is constructing a third lithium carbonate conversion plant at its La Negra brine facilities (Salar de Atacama) in Chile and expects to commission the plant in 2022. In the United States, Albemarle is investing about $40m to double the current production at Silver Peak by 2025 and evaluating its lithium expansion potential at Kings Mountain and Magnolia.

Albemarle is also planning to restart its Wodgina spodumene operation in Australia in the second half of 2022. At Kemerton, Albemarle is constructing a high-quality spodumene conversion plant, expected to come on stream in mid-2022. When completed, the plant will covert spodumene concentrate transferred from Greenbushes and the Wodgina site (when operating) to produce 50 kt/y LCE of lithium hydroxide, with an ability to expand to 100 kt/y LCE over time.

Albemarle is also making investments in new conversion plants in China. The company already has conversion plants at Chengdu and Xinyu. However, Albemarle has an agreement to acquire Guangxi Tianyuan New Energy Materials, which is building a conversion plant in Qinzhou designed to produce 25 kt/y LCE, with the potential to expand up to 50 kt/y with commercial production expected in the first half of 2022. In addition, Albemarle has investment agreements for two sites in China at the Yangtze River Chemical Industrial Park (Zhangjiagang) and the Sichuan Pengshan Economic Development Park (Meishan). Albemarle plans to build 50 kt/y LiOH conversion plants at each site.

8.2.2. Sociedad Química y Minera de Chile (SQM)

At the Salar del Carmen in Chile, SQM is expanding conversion capacity by 50 percent from 120 kt/y LC to 180 kt/y by mid-2022. It is also expanding the capacity of its lithium hydroxide plant from 21.5 kt/y (18.9 kt/y LCE) capacity to 30 kt/y (26.3 kt/y LCE) capacity. Additionally, SQM is diversifying its operations by product and geography. In February 2021, SQM invested approximately $700m for a 50 percent share of the development costs of the Mt Holland lithium hydroxide project in Australia, a joint venture with Wesfarmers. SQM expects the venture to produce 45 kt/y lithium hydroxide (40 kt/y LCE).

8.2.3. Livent

Livent is currently increasing its lithium carbonate capacity at its Salar del Hombre Muerto brine operation in Argentina by 20 kt/y in two steps – with 10 kt/y starting production in the first quarter of 2023 and an additional 10 kt/y starting in the fourth quarter of 2023. At its Bessemer City chemical plant, Livent is increasing lithium hydroxide capacity by 5 kt/y starting in the third quarter of 2022. Livent is also planning for an additional 20 kt/y of lithium carbonate capacity and 25 kt/y of lithium hydroxide capacity.

8.2.4. Ganfeng Lithium

Over the past year, Ganfeng has been growing and acquiring interests in lithium mine operations to increase its access to offtake agreements. The company has increased its stake in Mt Marion in Australia to 50 percent, grown its interest in the Cauchari-Olaroz project (currently under construction) to 51 percent, and continued to hold 16.7 percent of Lithium Americas. Moreover, Ganfeng acquired a 25.8 percent interest in Bacanora Lithium and a direct 22.5 percent interest in Bacanora's Sonora project, as well as increased its stake in Pilbara Minerals to 6.86 percent (Pilgangoora mine).

8.2.5. Tianqi Lithium

Tianqi is constructing a battery-grade lithium carbonate project at Zhabuye Salt Lake in China. The plan includes annual output of 12 kt/y of lithium carbonate and plans to be in operation in 2023. In Australia, Tianqi is constructing a two-stage lithium processing plant in Kwinana, Western Australia. The first stage of the plant is scheduled for commissioning by the end of 2022, with a capacity of 24 kt/y of high purity, battery-grade lithium hydroxide.

8.2.6. Other Producers

Other significant expansions from existing producers include Allkem's expansion of the Salar de Olaroz brine operation (Allkem is a merger of Orocombre and Galaxy). The Olaroz stage 2 expansion will increase lithium carbonate production capacity by 25 kt/y to approximately 42.5 kt/y beginning in the first half of 2022 (scoping for stage 3 is underway). Stage 2 will produce primary-grade lithium carbonate, part of which will be used as feedstock for the Naraha lithium hydroxide plant at a cost of $330m. The product will also feed a new 10 kt/y lithium hydroxide plant being built at Naraha in Japan. Allkem is also bringing on the Sale de Vida project in Argentina.

Table 6: Existing Producers Mine Capacity Expansions

Company	Mine Capacity Kt/y LCE			Increase
	2020	2025	2030	Kt/y LCE
Albemarle	50	190	300‡	250
SQM	120	220*	220	100
Livent	20	40	60	40
Ganfeng Lithium	122	200	350†	228
Tianqi Lithium	90	90	90	0
Other	18	54	79	50
Total	**420**	**794**	**1,099**	**679**

Source: Company data. *100% of Mt Holland production attributed. † Estimate as target of 600 kt/y is for unspecified date. ‡ Estimate as expansion target of 450-500 kt/y includes conversion capacity.

An estimated 679 kt/y of additional mine capacity from re-starts and expansions could be available by 2030 from existing producers (see Table 6). Some of the new projects are also included and estimated to account for some 71 kt/y of capacity. Estimates have also been made for production in 2030, partly to adjust for chemical capacity expansions included in the company forecasts. In addition, the forecasts are assumed to be actual expansions and not achieved through purchases of other existing projects.

8.3. Potential New Lithium Mines

8.3.1. Mines Under Construction

There are currently only five greenfield lithium mining projects under construction, three of which are being developed by existing producers (Table 7). This low level of activity partly reflects the fall in lithium prices in 2019 and 2020, which resulted in a postponement of investment, made project financing more difficult, and dented investor confidence. The total expected capacity coming on stream over the next two years from these projects is nearly 126 kt/y LCE. Table 6 lists the greenfield projects currently under construction, including Sigma Lithium Resource's Grota do Cirilo project in Brazil (see Section 8.4 for a more detailed discussion).

Table 7: Greenfield Lithium Projects Under Construction

Mine	Country	Owner	Mine Type	Prodn Kt/y LCE	Expected Start-up
Mt Holland	Australia	SQM/Wesfarmers	Pegmatite	40.0	2H 2024
Cauchari-Olaroz	Argentina	Lithium Amer./Gafeng	Brine	40.0	2Q 2022
Grota do Cirilo	Brazil	Sigma Lithium	Pegmatite	33.0	2023e
Sal de Vida	Argentina	Allkem	Brine	10.8	2023e
Rincon	Argentina	Argosy Minerals	Brine	2.0	Mid-2022
Total				**125.8**	

Source: S&P Global Intelligence, Company data, Deloitte. e = estimated

8.3.2. Projects Planning Construction

In addition to the five construction projects mentioned above, there are eight other operations identified as 'construction planned' by S&P Global Intelligence (see Table 8). These projects have completed feasibility studies but have not yet reached a final investment decision (FID) for a combination of reasons, including optimizing the feasibility study, finalizing engineering design, securing strategic partners, completing permitting, raising project finance, and negotiating offtake agreements.

Table 8: Greenfield Lithium Projects at Late-stage Development

Mine	Country	Owner	Mine Type	Prodn Kt/y LCE	Expected Start-up
Arcadia	Zimbabwe	Prospect Resources	Pegmatite	37.7	unknown
Sonora	Mexico	Bacanora Lithium	Clay	35.0	unknown
Whabouchi	Canada	Nemanska Lithium	Pegmatite	33.0	unknown
Rose	Canada	Critical Elements	Pegmatite	30.0	unknown
Finniss	Australia	Core Lithium	Pegmatite	25.1	unknown
Maricunga	Chile	Lithium Power/MSB	Brine	20.0	unknown
Authier	Canada	Sayona Mining	Pegmatite	16.9	unknown
Karibib	Namibia	Lepidico	Pegmatite	6.2	unknown
Total				**204.8**	

Source: S&P Global Intelligence, Company data, Deloitte.

While there is no guarantee that any of these projects will reach production, they appear to have a reasonable probability of achieving start-up. It is worth noting that lithium is a small industry and that the number of capable, technically trained engineers with lithium experience is limited and may hold back development of some projects. Projects can also proceed at different rates and encounter delays, thereby taking years to reach full-rated capacity. These factors further complicate the forecasting of future capacity.

8.3.3. Feasibility Stage Projects

There are an additional 22 projects where a feasibility study is complete or underway, which indicate that these projects are at a more advanced stage and have the potential to come on stream by 2030, if not sooner. These projects have a combined production potential of a further 705 kt/y LCE of capacity (*Annex 5* – List of Lithium Projects*, contains a list of these projects*).

Some of these projects may have long permitting times, further exploration requirements, high capital expenditures, high operating cost, or complex mineralogy, and so it is possible that some of these projects will not reach production.

8.3.4. Total Supply Potential from New Projects and Expansions

The combined capacity of the projects under construction, near construction, and at feasibility stage is just over 1.0Mt/y LCE. A further 658 kt/y LCE in capacity (adjusted for double counting) is possible by expanding operations by existing producers, according to Deloitte estimates. On top of existing supply, this would equate to nearly 2.0 Mt/y LCE of supply by 2030. Upside potential may also come from existing expansions or new lithium projects in China. However, there is no data available on China's potential lithium mine capacity growth.

For these estimates, Deloitte has assumed that every project will reach production and has not taken account of timing of capacity build-up. Also, a portion of capacity additions will not be of sufficient quality for use in battery applications. BMI forecasts total supply of about 1.42 Mt/y LCE by 2030.

8.4. Lithium Projects in Brazil

The only advanced lithium project in Brazil is the Grota do Cirilo project, owned by Sigma Lithium Resources. In November 2021, the company announced the mobilization of its workforce and equipment for the production plant's construction. The project is located near Araçuaí in Minas Gerais and plans to produce 220 kt/y of 6 percent Li_2O spodumene concentrate (about 32.6 kt/y LCE) under its Phase 1 plans. Since 2018, Sigma Lithium Resources has been producing low-carbon high-purity lithium concentrate at an on-site demonstration pilot plant with the objective to ship samples to potential customers for product certification and testing.

The Grota do Cirilo project has an initial capital cost of $98.4m and $15.2m in sustaining capital. The feasibility study anticipates an open pit mining operation with a strip ratio of 9.6:1 and a mine life of 9.2 years (Phase I involves mining the Xuxa deposit). Processing will be standard crushing and screening followed by dense media separation (DMS). Forecasts predict a total cost of spodumene concentrate ex-works of $238/t (equivalent to $1,604/t LCE). The project has a post-tax NPV of $249m and an IRR of 43 percent. Section 10 contains a comparison of the key parameters.

Sigma Lithium Resources completed a preliminary economic assessment (PEA) for Phase II of the Grota do Cirilo project. This phase would see capacity increase to 440 kt/y of concentrate and involve mining of the Barreiro deposit, extending the mine life by a further 12 years.

In December 2022, Sigma Lithium announced it would start commissioning the Grota do Cirilo project in Minas Gerais state, and it plans to almost triple its targeted annual output to about 100,000 tonnes of lithium carbonate equivalent (LCE) by April 2024.[18]

Brazil currently has three other reported exploration projects, but they do not yet have a quantified resource. These projects include:

- Ceara in Ceará State, operated by Infinity Lithium Corp;
- Salinas in Minas Gerais, operated by One World Lithium; and
- Manga in Goiás State, privately owned, although believed inactive.

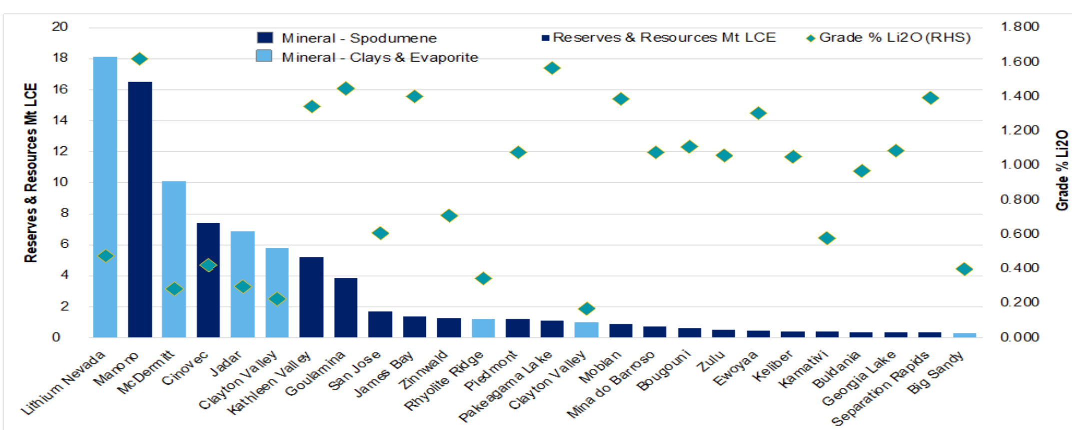
Brazil has a low number of projects in its pipeline compared with other lithium producers. This is despite lithium being a strategic mineral under the Brazilian government's Pro-Strategic Minerals policy, allowing for an acceleration of procedures to achieve production.

8.5. Other Exploration Projects

In addition to the lithium projects close to construction and under construction, and those at feasibility stage, there are 48 active projects around the world that already have a defined lithium resource and where exploration and development work is underway. These include 21 projects at the pre-feasibility/scoping stage, 22 projects undertaking reserve development, and five projects described as target outline or just exploration.[19]

These 48 exploration projects do not have an indication of potential mine size at present; however, they have a Measured, Indicated, and Inferred resource of around 41 Mt of Li_2O (102 Mt LCE). Around 46 percent of the lithium is from pegmatite/granites, 44 percent from brine, and 10 percent from clays and other (this excludes the development of large resources in Bolivia that are not yet exploited). Some of these projects could potentially undergo development before 2030, but most of them are likely to come on stream beyond 2030 if they are economic. It is also worth highlighting that some of these projects will require the development of Direct Lithium Extraction (DLE) recovery methods in order to be economic (*see Annex 1 for more information*). Companies pursuing DLE solutions include E3 Metals, Schlumberger New Energy, Vulcan Energy, and Lake Resources.

Figure 17: Early-Stage Mineral Lithium Projects with Resources (Top 26 by Resource Size)



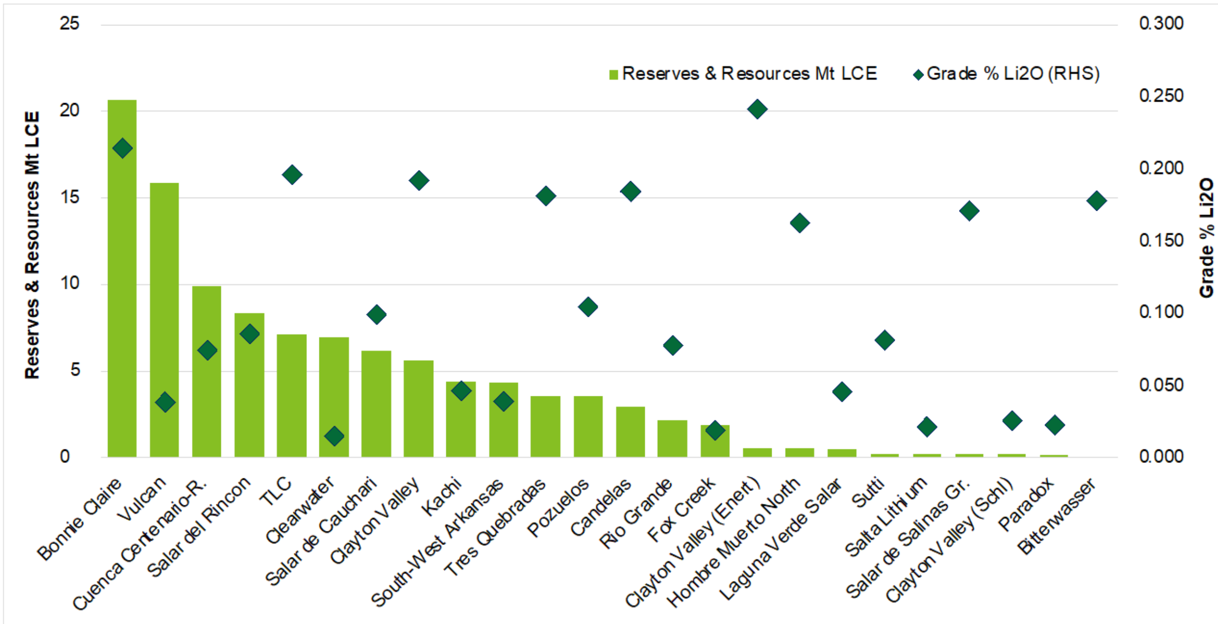
Source: Deloitte, S&P Global Intelligence.

[18] https://www.ft.com/content/82d4c6af-b426-4c92-b7dd-05845cdd1382

[19] S&P Global Intelligence.

Figure 17 and Figure 18 show the resources and grades of these projects, with Mineral and brine resources shown separately due to a large difference in grades.

Figure 18: Early-Stage Brine Lithium Projects with Resources



Source: Deloitte.

These resources by nature have the potential to expand with further exploration. Any calculations converting a lithium resource to final production of lithium chemical product should consider recovery inefficiencies throughout the production process. These inefficiencies include losses from eventual conversion of resources to reserves, mineral extraction losses at the mining stage, recovery losses in initial processing, and recovery losses in the chemical transformation stages.

SQM noted in its 2020 annual report that its proven and probable reserves do not include losses from evaporation processes and metallurgical treatment.[20] The recoveries depend on both brine composition and the process applied to produce the desired commercial products, but recoveries for lithium vary from 34 to 60 percent.

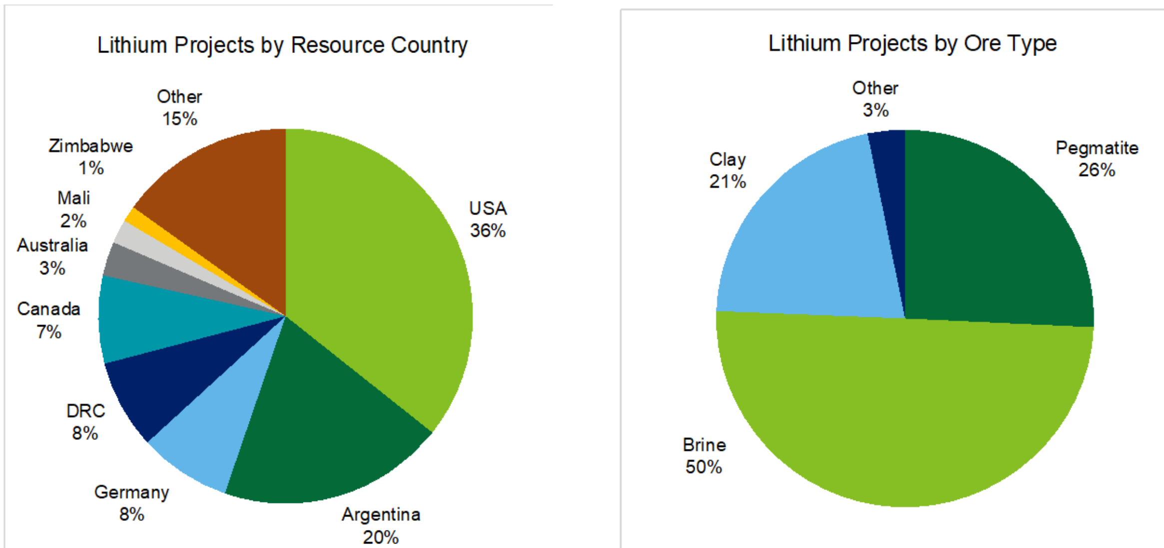
Not including the resource and mining losses, spodumene plant recoveries alone vary from 60 to 80 percent. For example, Atlantic Lithium notes an overall resource recovery of 66 percent in its feasibility study for the Ewoyaa spodumene project. For spodumene, additional losses take place in the conversion to lithium carbonate or lithium hydroxide.

8.6. Overview of Reported Lithium Project Resources

It is worth reviewing the country source and type of ore under exploration and development for these projects. For the projects assessed (48 exploration projects, 22 projects at feasibility stage, and eight projects at the planned construction stage), 50 percent had resources from brine sources, 26 percent from pegmatites, and 21 percent from clays (see Figure 19).

[20] SQM, 2020 Annual Report, page 48.

Figure 19: Resources of Potential New Lithium Mines



Source: Deloitte – includes projects with reported resources but not yet at feasibility level.

In terms of country focus, the data indicated that 36 percent of the resources are in the US. In the US, 51 percent of resources are from brine, 48 percent from clays, and 1 percent from pegmatites.

It is also notable that Australia and Chile, two of the largest lithium-producing countries with large lithium resources, have limited additional new mine projects in the pipeline. Conversely, Argentina looks to have a significant pipeline of new brine lithium projects, while Germany and the Democratic Republic of the Congo (DRC) both hold potential.

8.7. New Lithium Processing Capacity

Keeping pace with demand growth requires further additions to lithium production capacity for refined lithium products along with mine capacity. Though scheduled pipeline capacity appears sufficient to meet demand growth, challenges and setbacks in developing, financing, and commissioning lithium-refining operations are expected. Even major incumbent lithium producers are at risk of failing to meet production targets and expansion plans, highlighting the technical and financial hurdles involved with bringing sizable volumes of new chemical capacity online.

The concentration of chemical-processing capacity in Asia is encouraging US and European OEMs and battery makers to consider vertical integration and localized production in secure jurisdictions to reduce supply chain complexity and risk. Planned spodumene conversion capacity expansions will be critical to meeting demand over the next five years. While new conversion capacity is under construction in China, investment in lithium chemical-processing capacity in other geographies is also taking place.

Lithium conversion capacity for spodumene is currently under construction in Australia. Of 26 Mineral projects with feasibility studies reported (see Section 10), 14 projects plan to produce lithium chemicals directly at the mine or nearby. Of these, 11 projects plan to produce lithium hydroxide as a final product, two plan to produce lithium carbonate, and one plans to produce lithium fluoride. This requires a higher upfront capital investment and potentially makes financing more difficult, especially for junior companies. However, the NPV enhancement can be significant. Other advantages include a reduction of transportation costs and easier management of handling of waste products.

Japan, South Korea, and Europe have planned capacity additions to battery cathode plants, which convert lithium chemicals into cathode active material before use in cell making. Still, forecasts predict China will remain the largest producer of cathode material over the next decade.

In Brazil, OXIS Energy and the Minas Gerais Development Company CODEMGE announced in May 2020 that they are investing $50m in the development of a battery manufacturing site in Juiz de Fora, in the state of Minas Gerais. Phase 1 will enable the production of 5.0 m/y solid-state lithium sulfur battery cells, with the option to double cell capacity. OXIS Energy, a UK-based company, is currently administrating the project.

Other projects in Brazil include a recently formed project under the name ‘Colossus Cluster Minas Gerais’, which aims to build a 35 GWh battery Gigafactory in the Metropolitan Region of Belo Horizonte according to reports. The project will comprise a group of industries for lithium batteries, components, and EVs led by Bravo Motor Company.

8.8. Secondary Lithium Supply

The recycling of lithium-ion batteries is expected to be an important source of lithium in the longer term. Recycling of lithium-ion batteries for raw material extraction is in its infancy, and technologies have not yet reached a commercial stage. Supply from this source should begin to enter the market around 2025 at low levels. Supply will only begin to have a significant impact when the first generation of EVs begin to come off the road towards 2030.

Some country governments are encouraging recycling within the sector. For instance, the EU has targets and governmental policies to recycle lithium-ion batteries from 2030 onwards. In South Korea, the government also set collection rates of waste batteries to increase recycling rates.

9. MARKET BALANCE AND PRICE OUTLOOK

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

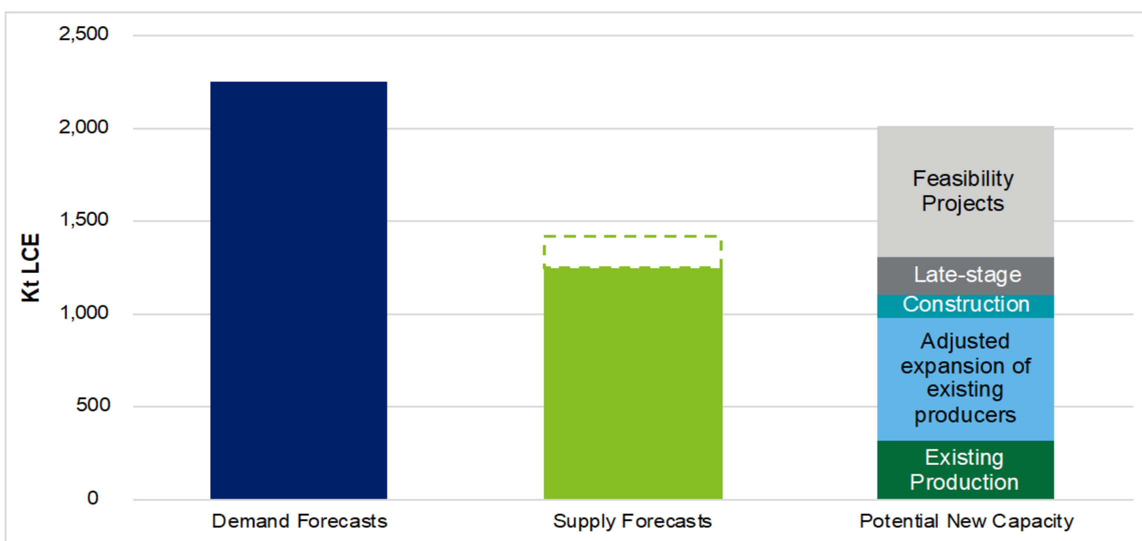
9.1. Lithium Market Balance

Rapid and sustained demand growth dominates the outlook for the lithium market, driven by the use of lithium-ion batteries in automotive and stationary applications. Meeting demand will require a significant build-out and commissioning of new mine and chemical capacity. New capacity is expected to be required at all stages of the supply chain from mine to lithium-ion battery.

The data suggests that it will be challenging for supply to keep up with demand growth over the next decade. Current forecasts also suggest that the lithium market will remain in deficit, even with timely financing and development of new capacity (see Figure 20). Roskill maintains the view that refined lithium supply will remain tight in the future, with a period of sustained supply deficit increasing to about 1.0 Mt/y LCE by 2030. BMI forecasts a growing supply deficit out to 2030 of over 800 kt/y LCE, which would require the development of unplanned capacity to match demand. Macquarie forecasts a deficit of about 400 kt/y LCE by 2030.

Attempts to accelerate supply are starting to become visible, with some planned mining projects and new chemical plants increasing in size and the market looking to develop new types of lithium sources (such as clays and evaporites). For example, in December 2021, Firefinch increased planned production from its Goulamina lithium project in Mali from 506 to 880 kt/y spodumene.

Figure 20: Forecast Lithium Market Balance in 2030

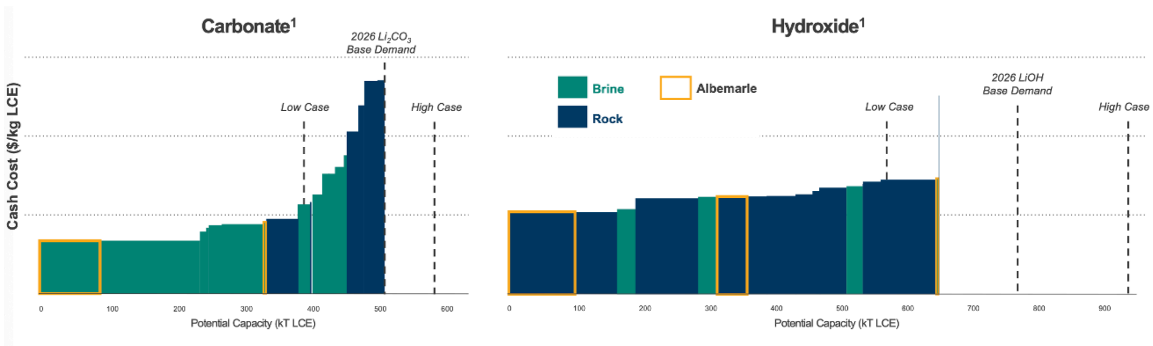


Source: Deloitte. NB The dotted line indicates the range for supply forecasts from consultants.

Shortages of spodumene concentrate, lithium carbonate, and lithium hydroxide are expected to impact end-use markets including ceramics, glass, and construction applications. However, the largest deficit is expected in the battery-specification lithium market. A growing supply deficit would likely result in demand destruction and substitution or lithium thrifting from key end-use markets. It could also result in the delay of capacity build-out of lithium-ion batteries and reduce forecasted demand of EVs due to unavailability of materials.

Albemarle, the largest lithium producer in the market, expects a market deficit in 2026. The company also expects for this deficit to be particularly evident in the lithium hydroxide market where demand is expected to be strongest for lithium-ion batteries, as shown in Figure 21.

Figure 21: Forecast Lithium Carbonate and Lithium Hydroxide Market Balance in 2026



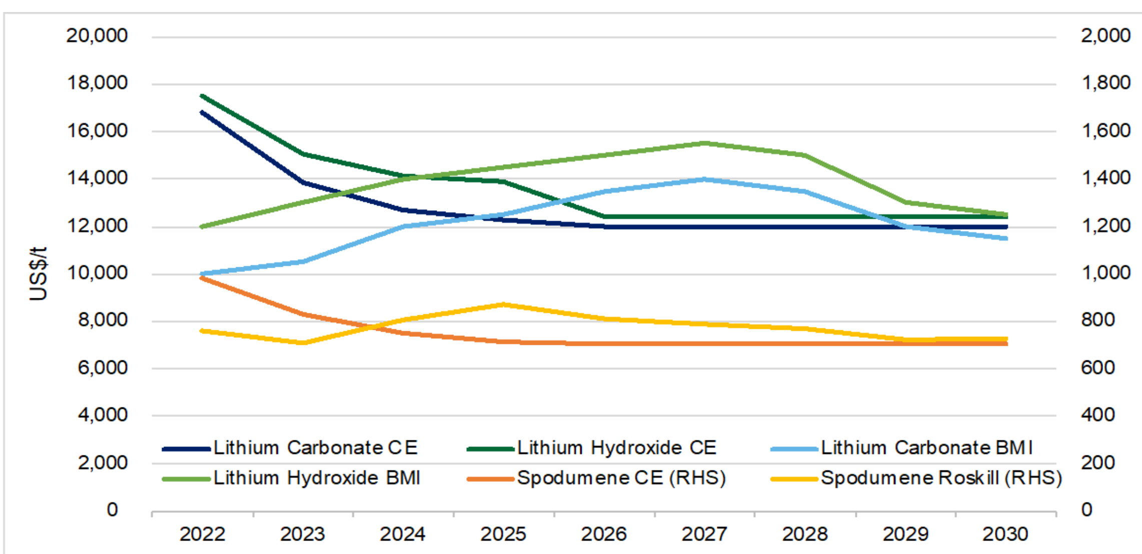
Source: Albemarle.

Further, in order to attract investment and incentivize the development of the lithium resources, lithium prices will need to be at high levels over the period to 2030.

9.2. Forecast Lithium Prices

The price path for lithium 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 tends to result in 'lumpy' changes in capacity. Figure 22 shows recent price forecasts for the main lithium commodities.

Figure 22: Forecast Lithium Carbonate, Lithium Hydroxide, and Spodumene Prices ($/t)



Source: BMI = Benchmark Minerals Intelligence, CE = Consensus Economics (Brokers data), Roskill.

Historically, the price of lithium hydroxide has tended to trade at a premium to lithium carbonate. Nevertheless, according to BMI, it is expected that they trade closer to parity with each other as an increasing amount of lithium hydroxide capacity gets built relative to lithium carbonate.

9.3. Lithium Prices to Push Up Battery Costs

BMI's Chinese battery-grade lithium carbonate prices have risen by 346 percent this year, as sales of EVs in China have almost doubled from a year earlier. This rise is expected to increase production costs of LFP battery cells by at least 16 percent in 2022. Forecasts predict NCM battery cell prices will increase by 10 to 20 percent in 2022. This will be the first rise in lithium-ion cell prices after many years of decline.

10. ECONOMIC COMPETITIVENESS

Albemarle, the world's leading lithium producer, has stated that in its experience the primary determinants of project success are resource grade, resource scale, and chemistry. These have a large impact on project cost and the ultimate economics. The lithium resource type may also have large impacts (each lithium resource is unique and complex considerations make it challenging to evaluate the ultimate success of a project).

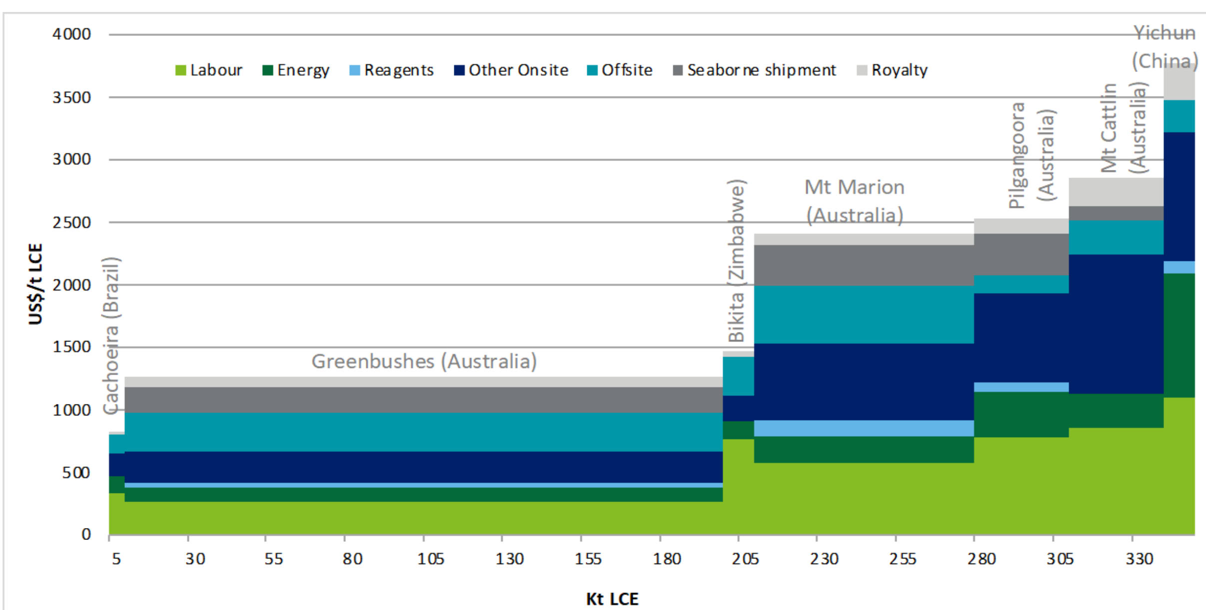
Companies, investors, finance providers, and governments may find it useful to examine the existing mine and project data as a means to benchmark potential lithium projects. However, they should take caution to distinguish between lithium resource types, since there are considerable differences between brine and Mineral deposits and direct comparisons are not wholly valid. In particular, the resource grades of brines are significantly lower than Mineral deposits, and brines produce an initial product of lithium carbonate while current Mineral operations produce an intermediate spodumene concentrate. As integrated Mineral projects come onstream, they will produce either lithium carbonate or lithium hydroxide as a final product and have their own cost structure. The following sections provide more comparative information on current lithium mining operations and project feasibility studies.

10.1. Comparison of Current Lithium Mining Operations

Mineral producers of spodumene concentrate only create an intermediate product. By their nature, they are lower cost producers ($/t contained LCE) than those with brine operations. However, Mineral producers also receive a significantly lower price for their end product. This limits the usefulness of comparing full-industry cost curves.

Figure 23 shows the cost curve for the existing Mineral spodumene producers based on current capacity (see also Table 4). The curve is relatively steep, indicating the large variability in production costs across this sector of the lithium industry. Brazil's Cachoeira mine is a small and low-cost producer, which can be found at the bottom end of the cost curve.

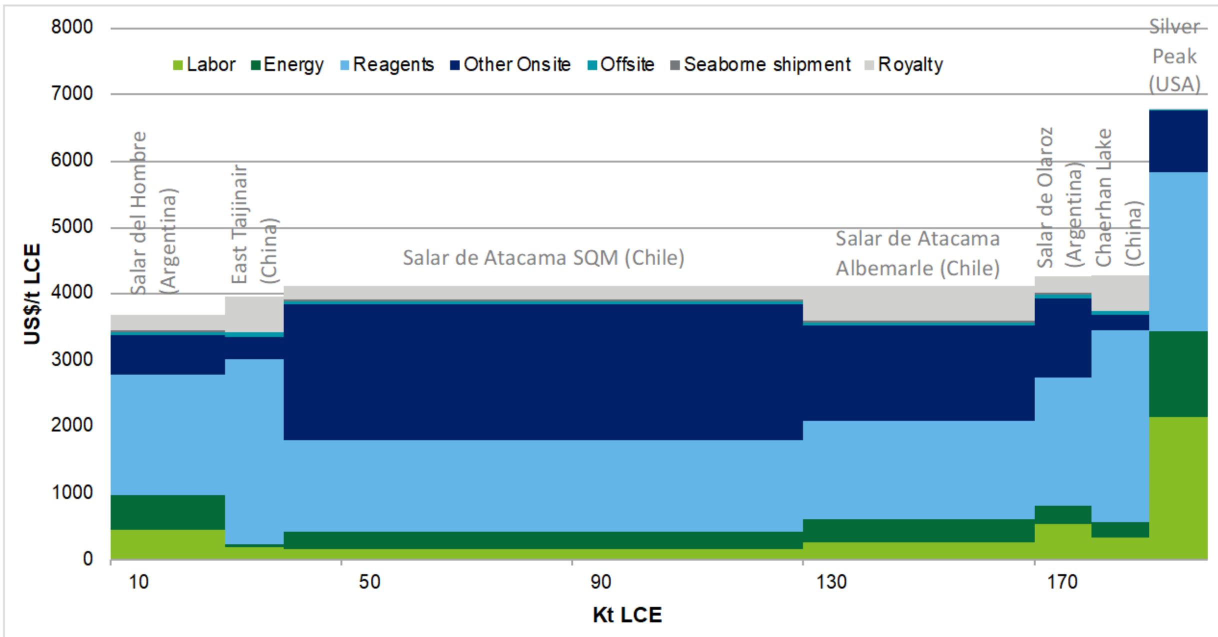
Figure 23: Cost Curve for Current Lithium Mineral Producers 2020 $/t LCE



Source: Deloitte, S&P Global Intelligence.

Figure 24 shows the cost curve for most of the existing brine lithium producers. The chart shows a very flat cost curve. Brazil does not produce brine lithium.

Figure 24: Cost Curve for Current Lithium Brine Producers 2020 $/t LCE



Source: Deloitte, S&P Global Intelligence.

Figure 23 and Figure 24 show that the Mineral spodumene operations generally have higher labor costs due to the mining extraction method (open-pit mining), and higher energy costs because aluminosilicate minerals are hard and abrasive and require significant comminution. Brine operations by their nature of extraction (evaporation ponds) have significant reagent costs rather than labor costs, which account for around a third of the overall costs. These reagents are primarily sodium carbonate and lime, which remove contaminants and precipitate lithium carbonate out of solution.

Royalty rates are also notably higher at brine operations. In September 2018, Chile's government proposed a new 3 percent royalty on the total value of production for lithium. This new legislation (Mining Royalties Law) has not yet passed, but a controversial amendment includes further royalties on a sliding scale (5 to 14 percent) on sales exceeding 50,000 t/y of lithium. The future of the bill currently remains uncertain, but if implemented could have a negative impact on current lithium producers and potentially inhibit future development. In 2020, the Argentine government also significantly raised the levy on export duties to a fixed percentage of 4.5 percent, compared with the previous fixed charge of ARS$3 per US$1 of export sales.

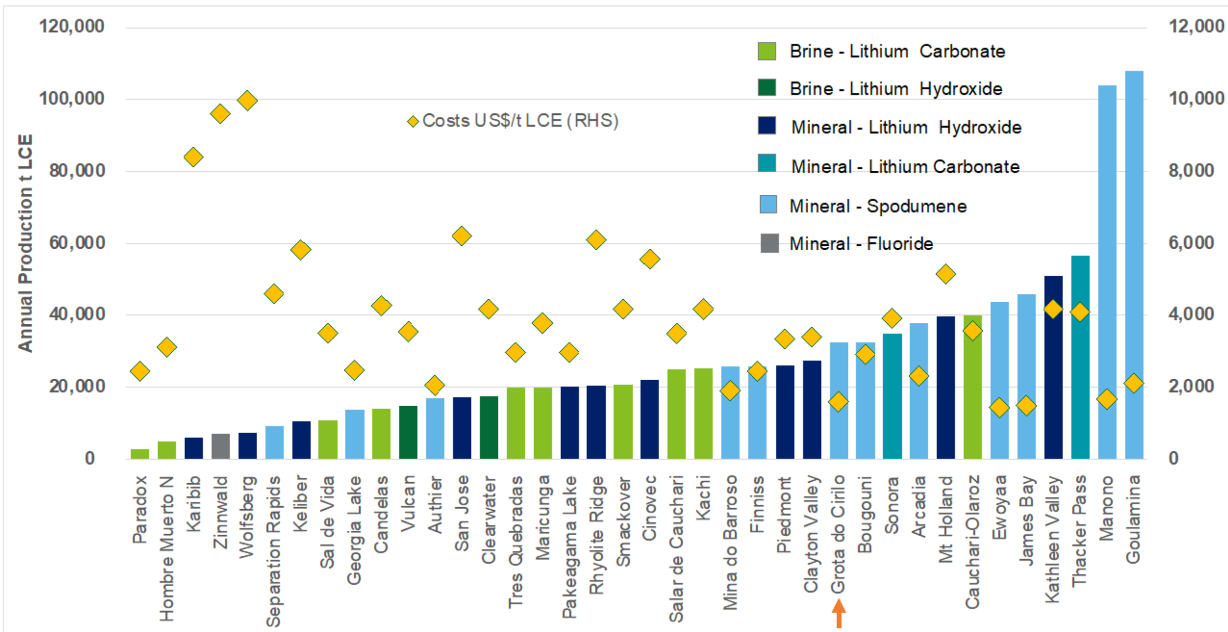
10.2. Comparison of Project Feasibility Studies

Deloitte has evaluated data from 42 companies that have produced recent feasibility, pre-feasibility, and scoping study reports for the market (this is typically done as part of the process of developing projects). This includes data from 16 brine projects, 24 pegmatite Mineral projects, and four clay Mineral projects. However, the publication dates for the reports span the past four years and have different price assumptions and are therefore not wholly comparable. Figure 17 and Figure 18 in Section 8.5 show the reserves and resources of the largest of these projects.

Figure 25 shows the projected production capacities and operating costs of these projects in LCE terms. Ideally, cost comparisons should include transportation to the port or other point of sale, but this data is not often available. The figure highlights the range of intermediate spodumene and final chemical products planned for production. Many of the Mineral producers are building integrated facilities: two projects plan to produce lithium carbonate, one project plans to produce lithium fluoride, and 11 projects plan to produce lithium hydroxide.

Deloitte calculated average costs for the different types of final products. The weighted average mine operating cost is $1,998/t LCE for spodumene concentrate, $4,020/t LCE for integrated Mineral projects producing lithium carbonate, $4,819/t LCE for integrated Mineral projects producing lithium hydroxide, $3,668/t LCE for brine projects producing lithium carbonate, and $3,888/t LCE for brine projects producing lithium hydroxide.

Figure 25: 42 Lithium Projects: Production Capacity (t/y) and Operating Costs ($/t) LCE

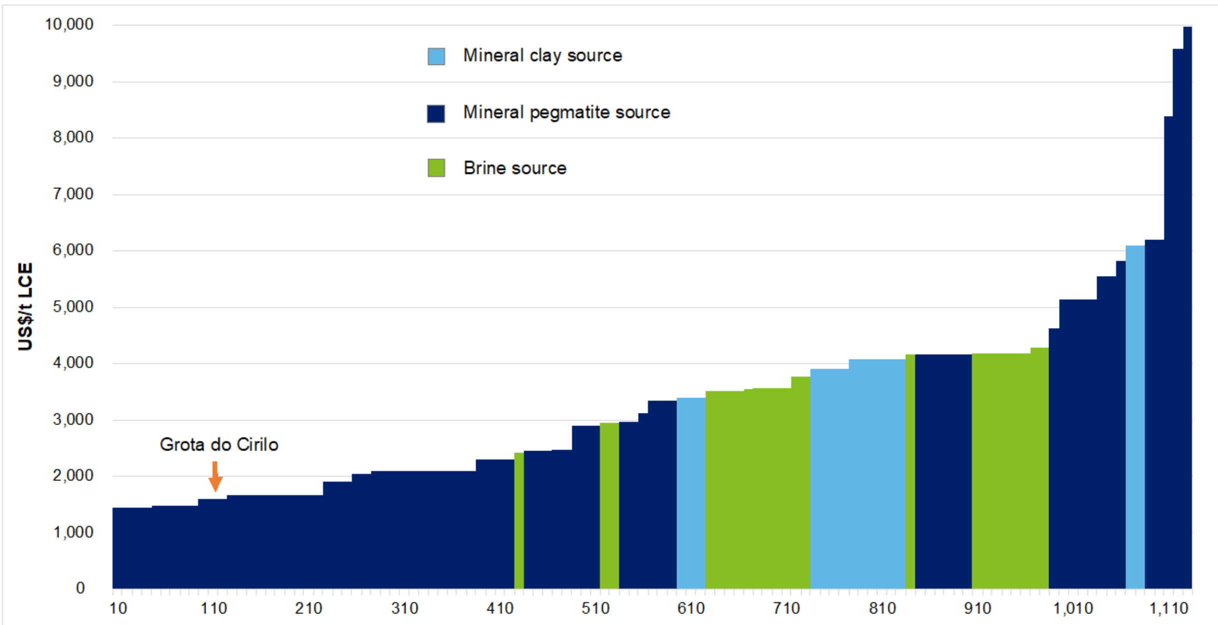


Source: Company data, Deloitte.

There is no clear pattern in size or production cost, except for the trend to increased lithium hydroxide capacity, particularly in the integrated Mineral producers. The Grota do Cirilo project in Brazil (highlighted in the figure by Deloitte), is an above-average sized project with low costs, even when compared to other spodumene producers. Figure 26 shows the projected cost curve of these projects and displays the Grota do Cirilo's position as a low-cost spodumene producer.

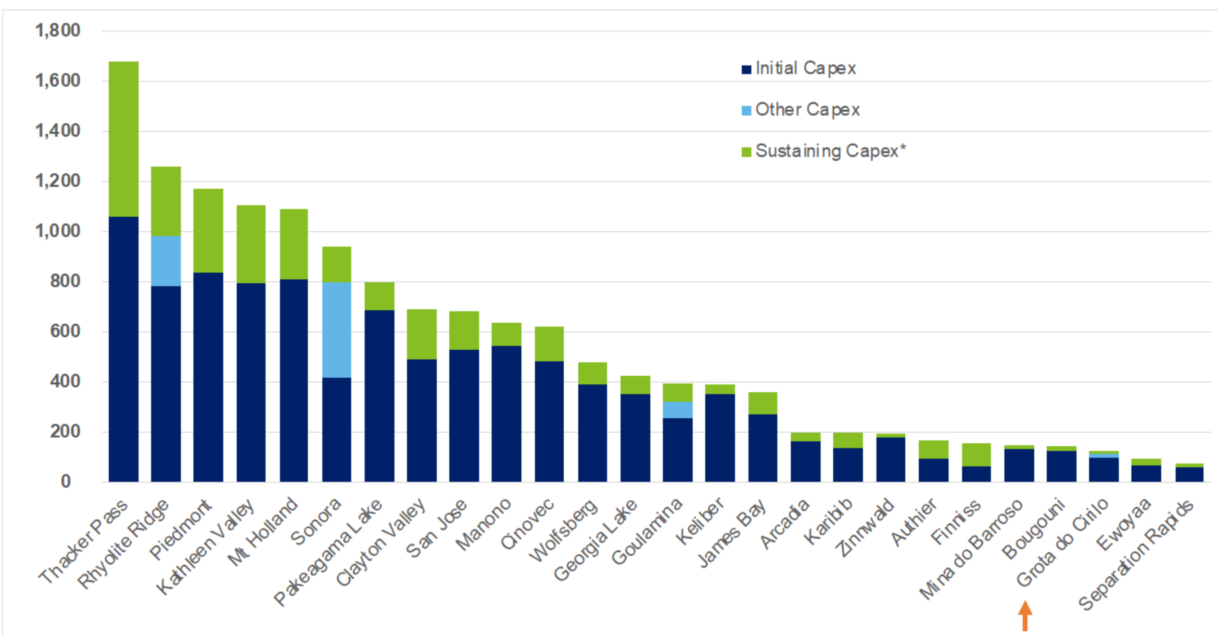
Figure 26 also shows that projects have a relatively steep cost curve. It broadly shows the spodumene producers at the lower end of the curve (along with Grota do Cirilo) and the integrated producers at the upper end of the cost curve.

Figure 26: 42 Lithium Projects: Operating Cost Curve ($/t) LCE



Source: Company data, Deloitte.

Figure 27: Mineral Lithium Projects: Life of Mine (LOM) Capital Expenditure

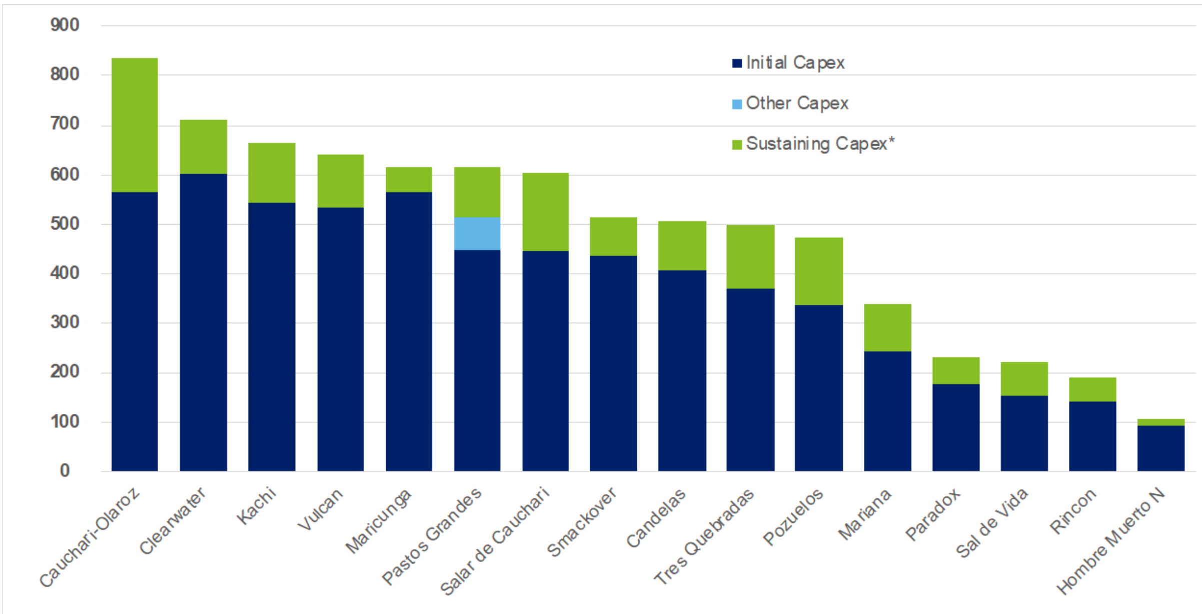


Source: Company data, Deloitte, *includes estimates.

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

Figure 27 and Figure 28 show the CAPEX of Mineral and brine projects separately. Companies usually focus on the initial CAPEX, but it is important to look at the CAPEX over the life of the mine (LOM) for project comparison. The project CAPEX can often vary due to the orebody location, depth, orientation, ore type, recovery methods, and the amount of labor and energy consumed in the process. This then has an important bearing on the economics of the project.

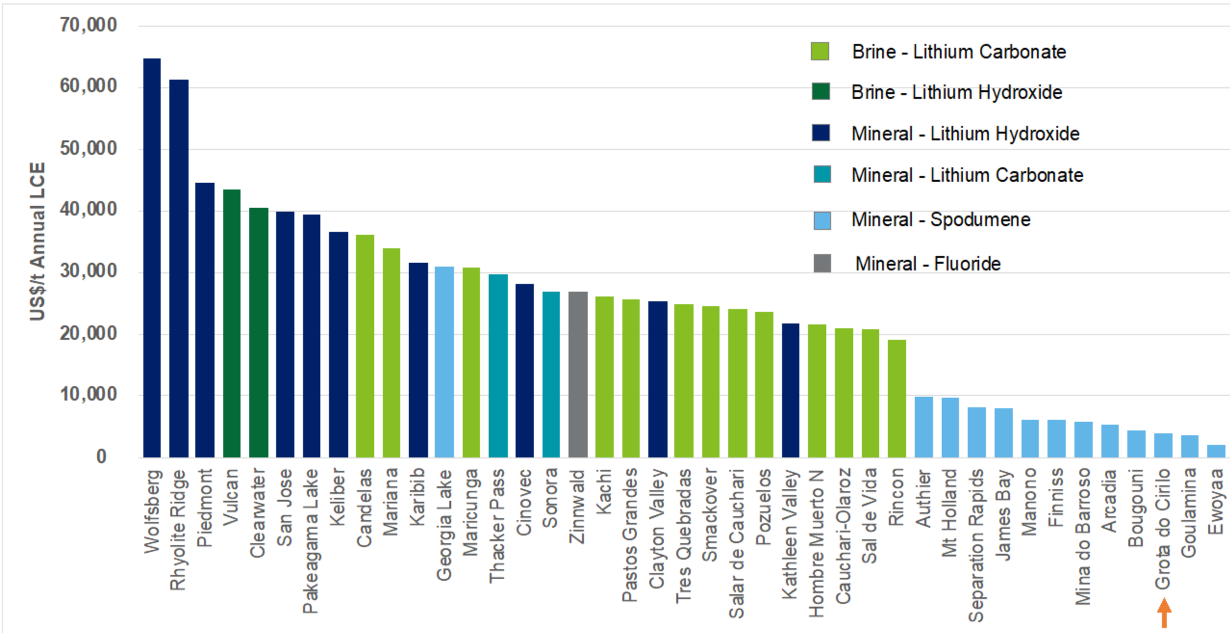
Figure 28: Brine Lithium Projects: LOM Capital Expenditure



Source: Company data, Deloitte, *includes estimates.

Capital intensity is often used to compare projects and their quality. Figure 29 shows the capital intensity of the projects based on average annual lithium production over the whole life of the project. It clearly shows the low capital intensity of the spodumene producers because they only produce an intermediate product. The integrated Mineral producers are the most capital intensive, and generally more capital intensive than the brine producers. The average for the group is $26,222/t LCE. Grota do Cirilo has a low capital intensity.

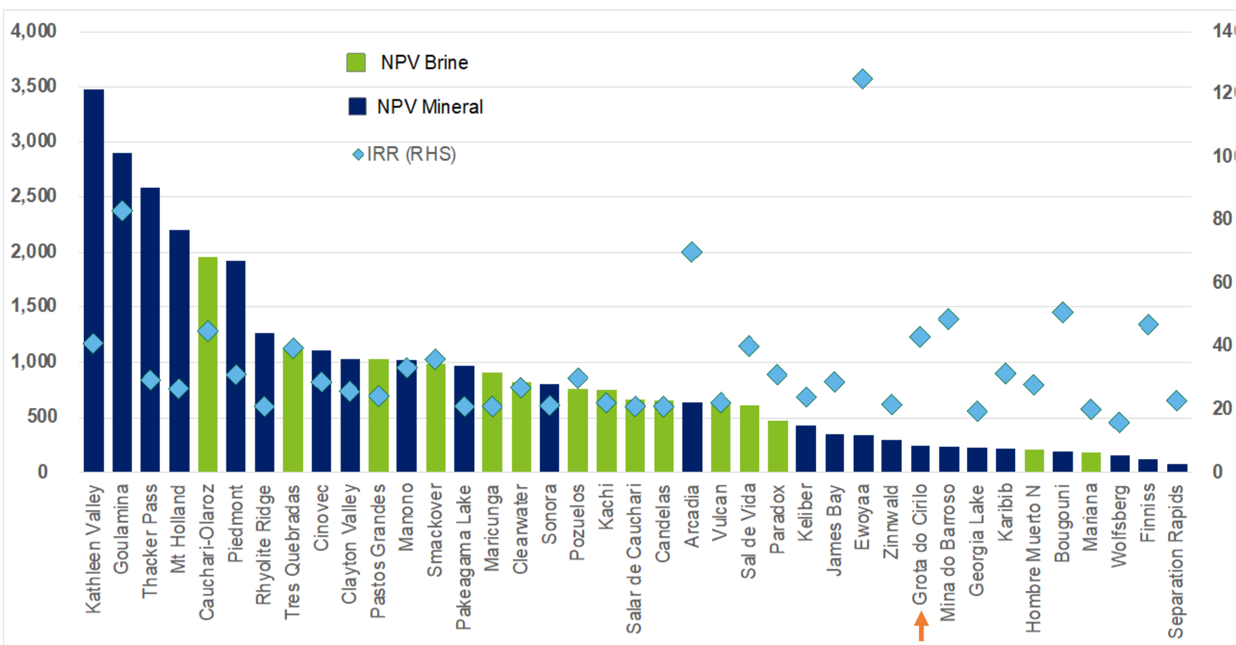
Figure 29: 42 Lithium Projects' Capital Intensity per Tonne of Annual LCE ($/t)



Source: Company data, Deloitte, includes some estimates.

Figure 30 shows post-tax values and does not include every project because some projects only reported pre-tax data. The median IRR of this group was 28 percent, which suggests generally good returns (the average is distorted by a few high values).

Figure 30: 42 Lithium Projects: NPV versus IRR

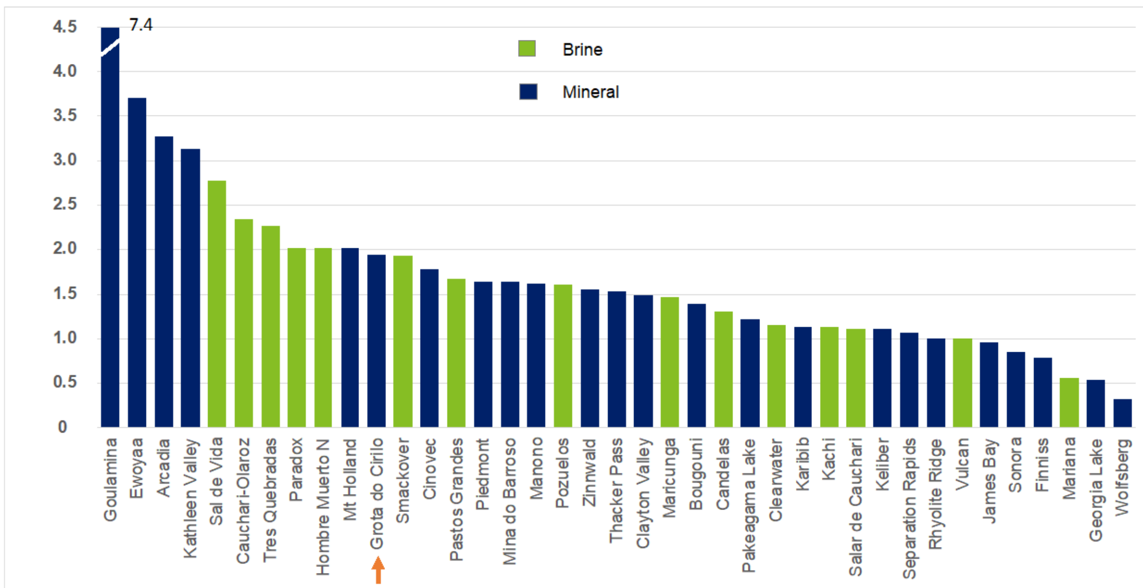


Source: Company data, Deloitte.

The ultimate measure of economic viability is the NPV and the IRR. Figure 30 shows both the NPV and IRR, which are not totally comparable because of varying assumptions used. The average input spodumene price was $715/t, the lithium carbonate price was $12,744/t, and the lithium hydroxide price was $14,433/t.

While the NPV of Grota do Cirilo is modest relative to its peers, it does have a relatively high IRR of 43 percent. Figure 31 also shows that the project has a relatively favorable capital efficiency (NPV/CAPEX).

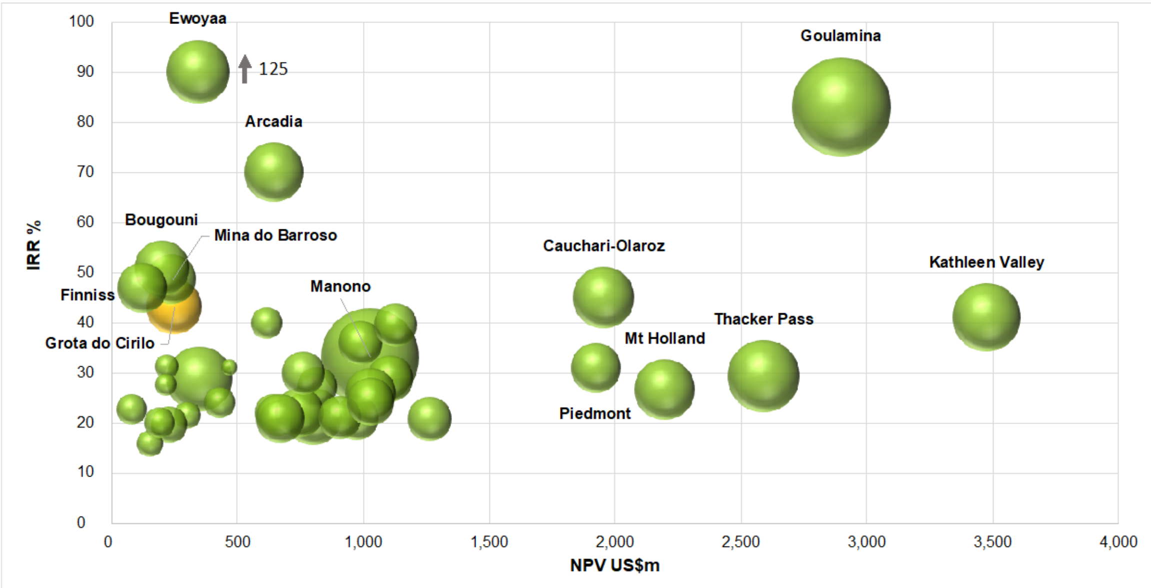
Figure 31: 42 Lithium Projects: Capital Efficiency (NPV/Capex)



Source: Company data, Deloitte, includes estimates.

Figure 32 shows the NPV and IRR data in a bubble chart where there the buddle size represents planned annual output, with many projects bunched in the bottom right-hand corner. While these projects may ultimately receive project finance, particularly with a market in deficit, the figure suggests that the grouped companies will find financing more competitive.

Figure 32: Forty-Two (42) Lithium Projects NPV versus IRR



Source: Company data, Deloitte, includes estimates.

11. CONCLUSIONS AND KEY RECOMMENDATIONS

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

11.1. Lithium Market Capacity

The demand for lithium market is set to expand dramatically over the next decade as the demand for EVs and lithium-ion batteries increases. The data suggests that it will be difficult for mine supply to keep pace with the demand. Prices of the key products have already started to rise, and this may incentivize enough additional early-stage exploration projects to fast track to production. Other companies may also decide to increase the size of their projects, possibly at the cost of a shorter life; however, this would allow them to potentially capture extraordinary returns over the next decade in addition to their normal economies of scale. An example of this is Firefinch's Goulamina project in Mali, a joint venture with Ganfeng Lithium, which is also providing Chinese debt financing.

In the event that mine supply fails to match demand, prices will rise, and thrifting and substitution will likely take place. In the extreme, it will result in shortages of downstream chemicals to supply lithium-ion batteries.

In addition to the number of planned mines for production, other assumptions are important. Assumptions made by analysts and consultants in available analyses are not all clear, and industry participants have not disclosed some technological data which remains opaque. Some assumptions that will be critical to the ultimate market balance in the future include:

- The rate of penetration of EVs in the auto markets and the number of Gigafactories constructed to meet demand.
- The amount of mid-stream chemical capacity constructed to produce and convert lithium chemicals to cathode material.
- The number of lithium chemical plants constructed to produce lithium carbonate and lithium hydroxide from mined product.
- The amount of lithium used in each different types of battery to ultimately determine demand. Deloitte has presented this data in Table 4, but this information is new and not widely available or commented upon in assumptions.
- The future growth rate of Chinese lithium mine and chemical capacity.

Finally, there are numerous projects announced that currently lack financing and teams capable of project execution. Several projects in the past few years have experienced technical problems and delays. Labor could also become a limiting factor in the development of sufficient capacity. Lithium is a small industry and the number of capable, technically trained engineers with lithium experience is very limited.

These factors may lead to increased volatility in lithium prices if too few, or too many, projects come on stream at once to meet expected demand by the end of this decade. The 'lumpy' nature of new supply and demand capacity at all levels of the supply chain will also create volatility.

11.2. Lithium Project Financing

Primary production of lithium is highly concentrated among the top five companies, which supply almost 80 percent of global production. This situation will not change significantly until about 2025 and even then, several countries are likely to remain dominant. In the meantime, it is likely that there will be company consolidations or strategic joint ventures between individual companies. There has already been a sharp increase in corporate activity in the lithium industry (*Annex 4 – Lithium M&A* Activity *lists some of the major strategic investments over the past few years*). In addition, it is possible that the downstream industry (at all stages through to OEMs) will attempt to secure lithium supply through the acquisition of primary mining assets.

China currently controls nearly 60 percent of the primary chemical processing facilities, but this is likely to decline as more spodumene processing takes place at the site of production. Forecasts show China will continue growing its processing capacity, but mines are increasingly looking to build integrated operations to include chemical-processing capacity. However, China is participating in offshore facilities as well to secure a supply of lithium chemicals to manufacture battery cathode material. The industry is currently planning to build more lithium hydroxide capacity than lithium carbonate capacity in anticipation of its increased use in lithium-ion batteries, but the ultimate balance between these chemicals is still not certain.

Timely development of both mining and chemical-processing capacity is now critical, and financing will be key. While the lead time for chemical-processing capacity is around 24 to 36 months, mine development from outlining a resource can take from 5 to 10 years. China appears prepared to continue investing and financing these projects and Western institutions and governments must match this initiative. Investor sentiment is strongly positive and financing plans must consider this sentiment.

11.3. Global Economic Opportunities

Lithium is generally not a scarce resource in the world, but the pipeline of economic projects is currently not developing fast enough to match future expected demand. This will provide plenty of opportunity over the next 10 years for lithium mines and projects to ride this wave of positive sentiment and likely higher prices. It is possible that the wave will extend beyond this period, but it is also possible that strong demand and higher prices could accelerate global exploration, and sufficient new discoveries could be available to match demand beyond this period.

It is also possible that Bolivia can start developing its very large resources at this point and overcome potential problems of high magnesium content. Another possibility is that technological developments such as direct lithium extraction (DLE) could become viable and economic and open up many more resource opportunities.

Brazil is currently a relatively small, but low-cost, producer of lithium, which is primarily consumed by its domestic industries. The two producers of lithium in Brazil already have plans to expand capacity in the next few years, although it is not clear how certain these plans are. Sigma Lithium Resources is also expected to bring the Grota do Cirilo mine into production in 2022, with favorable costs and returns, although they plan on exporting its production. These developments are positive but will not be significant in scale. As a result, Brazil will remain a relatively small producer of lithium on a global basis.

Brazil's identified resources, while still holding further potential for new developments in the longer term, are currently small and suggest that Brazil is unlikely to become a significant producer of lithium in the future.

11.4. Key Recommendations

The lithium market is expected to be in deficit over the next decade and, if prices continue their upward trajectory, the lithium market could offer robust returns to both miners and host countries. Brazil should therefore look to maximize its lithium output over the next few years and further develop its resources. Brazil production at Brazil's two operating lithium mines (Mina da Cachoeira and Mibra) are slated to expand, and a third mine at Grota do Cirilo is anticipated to begin production. The exact timeline for these increases is not yet fully clear. Brazil should therefore look to accelerate the growth of its lithium industry over the longer term by:

- **Encouraging its existing lithium producers to pursue faster and larger expansions.** Brazil should have discussions with existing lithium mine operators (CBL and AMG Brazil) about the timing and scale of their planned expansions, with the aim of accelerating timelines and increasing production levels. Any expansion would need to be done on an economically sustainable basis, but the Government of Brazil could assist by implementing measures, such as credit guarantees, higher capital allowances, and tax reductions, as required and appropriate.

- **Pursuing higher production levels for Phase 1 of the Grota do Cirilo project.** This development project is currently planning for a capacity of 220 kt/y of spodumene concentrate in Phase 1, with 440 kt/y planned for Phase 2 at some stage in the future. As outlined in the competitiveness analysis in Section 10 of this Report, Grota do Cirilo's has a high (43%) Internal Rate of Return and relatively low capital intensity, (Net Present Value [NPV]/Capital Expenditure [CAPEX]). As such, Brazil should prioritize discussions with Sigma Lithium Resources, the developers of Grota do Cirilo, to start / accelerate the project to Phase 2 production levels as soon as possible. As noted above, any expansion would need to be done on an economically sustainable basis, but the Government of Brazil could assist by implementing measures, such as credit guarantees, higher capital allowances, and tax reductions as required and appropriate.

- **Streamline access to, and circulation of, up-to-date domestic lithium resource data to domestic and international exploration companies to encourage exploitation and to promote lithium development in Brazil.** This may require gathering and distributing more extensive information for the regions considered to have significant lithium potential. Legacy CPRM geological data, reports, and studies should be more broadly published online and in a range of languages. Brazil should also 'market' these documents to expand their circulation, use, and impact. These materials should highlight the announcement of the Decree No. 11,120 of July 5, 2022, which allows for unrestricted foreign trade operations of lithium minerals, ores, and their derivatives. According to this decree, Brazilian lithium imports and exports will no longer require preliminary authorization from government entities. This measure is expected to attract lithium investments.[21]

[21] The Decree No. 11,120, of July 5, 2022, allows for foreign trade operations of lithium minerals, ores. and their derivatives. The measure promotes the opening and dynamization of the Brazilian lithium market, with the objective of positioning Brazil in a competitive way in the global chain and attracting investments for research and mineral production, and for the advancement of production capacity in the stages of processing and production of components and batteries.

- **Developing downstream processing facilities to capture more of the lithium value chain.** Currently, most downstream lithium processing takes place in China. Nevertheless, Brazil could become a midstream processor of lithium chemicals as part of a greater strategy to develop a downstream lithium-ion battery industry. Brazil could achieve this by constructing a facility to process the spodumene ore produced by Sigma Lithium Resources into lithium carbonate and/or lithium hydroxide (Brazil currently plans to export this ore unprocessed). This type of venture may also help to encourage the construction of cathode-manufacturing facilities and lithium-ion battery manufacturing. Discussions with existing global lithium-ion battery companies about investment in Brazilian initiatives, such as 'Colossus Cluster Minas Gerais', which aims to build a 35 GWh battery Gigafactory, may help to accelerate the business case for commercial lithium processing. In addition, Brazil does not necessarily need to wait for new domestic mines to come in line for it to achieve scale in lithium processing; the country could choose to import primary resources from neighboring producers.
- **Undertaking a comparative review of Brazil's exploration and mining policies/initiatives versus other lithium-producing countries.** Such a review, taking approximately 12 to 18 months, would analyze and prioritize how Brazil's government could encourage and accelerate lithium exploration and mine development through potential legal, regulatory, and Environmental, Social, and Governance (ESG) improvements. Such improvements could include simpler licensing and permitting processes, lower royalties, preferential tax rates, and a coordinated approach to environmental policy

ANNEX 1 – MINING AND BENEFICIATION OF LITHIUM

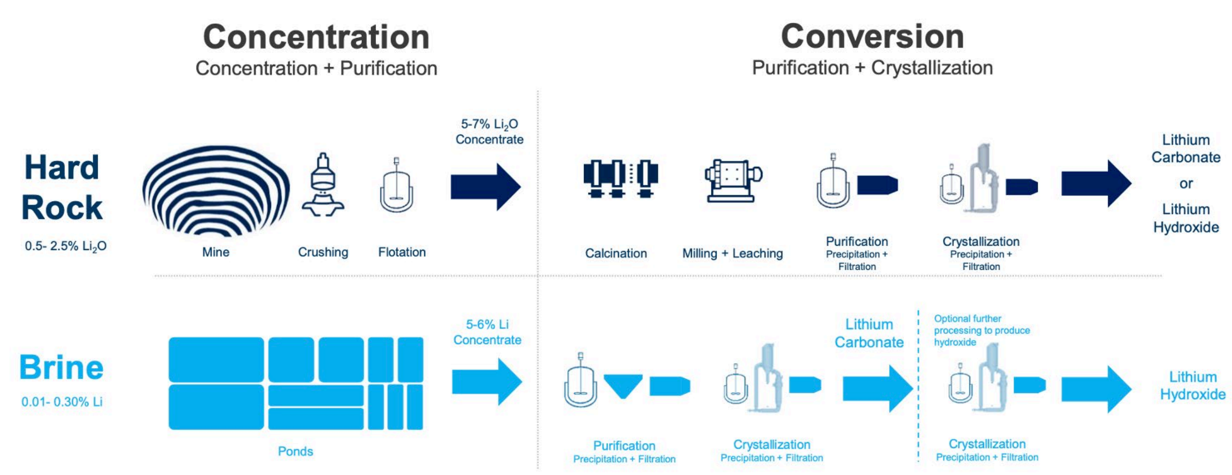
Economically viable deposits of lithium are relatively rare and fall into two broad categories: 'Mineral' or hard rock (mostly pegmatite granites) and brines (aquifers containing mineral-rich dissolved solids). Other sources of lithium exist, such as clays and geothermal brines, but these have not yet undergone exploitation on a commercial scale.

Mining Lithium

Mineral Lithium Deposits

Within the Mineral category, there are three lithium minerals commercially mined today: spodumene, petalite and lepidolite. Spodumene is by far the most important lithium mineral given its naturally higher lithium content. Extraction of lithium minerals uses both open-pit and underground mining methods. Typically, the mineralized rock contains approximately 12 to 20 percent spodumene, or approximately 1 to 1.5 percent lithium oxide. Spodumene typically occurs in pegmatites which are igneous rocks similar in mineral composition to granites but with very coarse grain sizes. With the expansion of the lithium mining industry in recent years, Mineral production has been re-established as the single largest source of lithium raw material globally.

Figure 33: Simplified Flow Sheet for Lithium Mining & Processing



Source: Albemarle.

Pegmatite granite extraction takes place in open-pit mines using traditional mining techniques and then mechanically crushed to reduce the rock size. The crushed ore is further milled to produce a finer product, which is more suitable for further separation in flotation cells. In these cells, the removal of various other minerals, including quartz, feldspar, and micas, takes place. Different separation processes will produce concentrate with differing levels of lithium content, which can take place in either the technical or chemical-grade markets.

Producers typically concentrate the material to 6 percent lithium oxide content, which can undergo processing to a chemical product, either lithium carbonate or lithium hydroxide, or sell as spodumene concentrate.

Most commonly, the conversion from spodumene concentrates into lithium carbonate and/or lithium hydroxide takes place in China at present although new spodumene concentrate processing facilities are being built in Australia and planned elsewhere.

Several companies are exploring the extraction of lithium from clay in Nevada, including American Lithium and Noram Ventures. The companies are testing different production methods, including sulfuric acid leaching.

Figure 34: Mt Marion Mineral Mining Operations Australia

Source: Mineral Resources

Brine Lithium Deposits

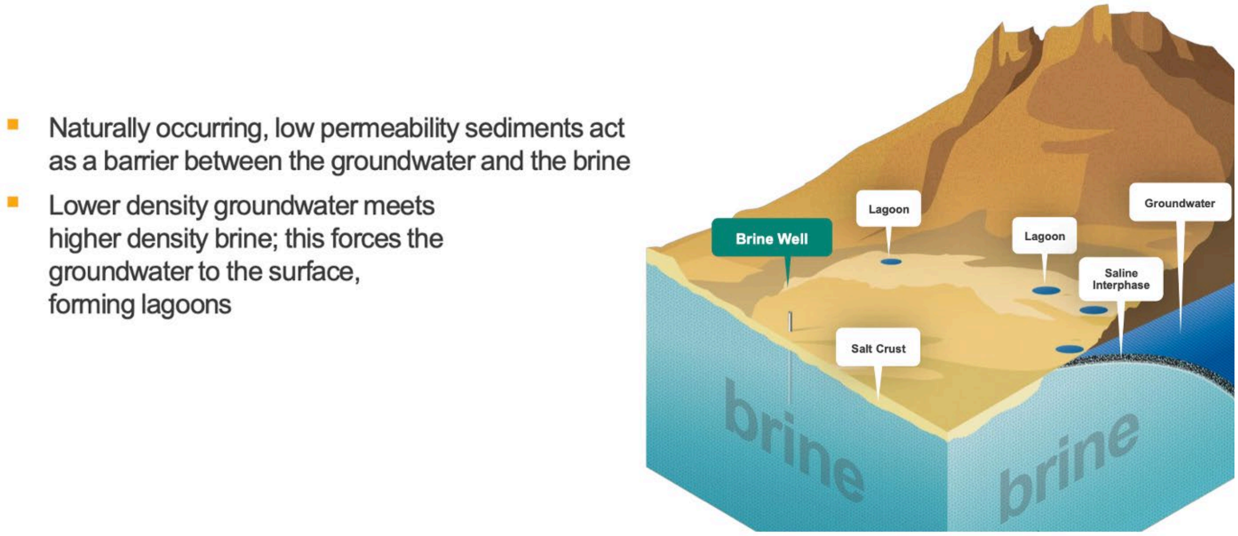
The other significant proportion of the world's lithium production comes from lithium brines. Brines form in seasonally flooded dry lakes, called salars. Volcanic and geothermal events or the eventual percolation of runoff containing high concentrations of ash created many of these brine aquifers. These events facilitate the leaching of minerals from the surrounding rock, particularly lithium chloride.

A major area of lithium brine deposits is in the Andes mountains in a region encompassing parts of Argentina, Chile and Bolivia. Brines can potentially contain economically viable concentrations of lithium and other minerals. The typical grade of a brine deposit is around 0.04-0.15 percent lithium, far lower than for a Mineral deposit although the process of producing lithium from brines is generally much lower cost than that from Mineral minerals.

In addition to lithium grade and quantity, other factors are important in determining the potential for commercial lithium production from a salar. The ratio of lithium to magnesium (Mg) and sulphate (SO_4) is equally important as it impacts brine processing; low Mg and SO4 relative to Li is a favorable characteristic.

Brine containing high concentrations of lithium is drawn from the saltwater aquifers using extraction wells. From the wellhead, the brine is diverted to an evaporation pond system. Using solar evaporation, the lithium salts are concentrated in the brine and eventually routed to the next pond in the system. This step repeats multiple times, until the lithium concentration reaches a level high enough for extraction of lithium carbonate through the use of reagents. During the evaporation process, the lithium concentration increases from about 200 ppm to up to 6 percent lithium in the final brine. The entire concentration process can take 12 to 18 months.

Figure 35: Brine Deposit Cross Section



Source: Albemarle.

Salars are exposed to different weather conditions (such as evaporation rates, precipitation rates, wind patterns, and ambient temperatures), all of which influence the ability to economically recover lithium from the salar. The process may slow down due to rain or flooding, which is a common occurrence.

Table 9: Brine Lithium Compositions

Source	Country	Li %wt	Na %wt	Mg %wt	K %wt	Ca %wt
Clayton Valley	USA	0.0163	4.69	0.019	0.40	0.045
Salton Sea	USA	0.010-0.040	5.00-7.00	0.07-0.57	1.30-2.40	2.260-3.900
Salar de Atacama	Chile	0.1570	9.10	0.965	2.36	0.045
Hombre Muerto	Argentina	0.068-0.121	9.90-10.30	0.018-0.014	0.24-0.97	0.019-0.090
Salar de Uyuni	Bolivia	0.0321	7.06	0.650	1.17	0.0306
Searles Lake	USA	0.0054	11.80	0	2.53	0.0016
Great Salt Lake	USA	0.0018	3.70-8.70	0.500-0.970	0.26-0.72	0.026-0.036
Dead Sea	Israel	0.0012	3.01	3.090	0.56	1.29
Sua Pan	India	0.0020	6.00	0	0.20	0
Bonneville	USA	0.0047	8.30	0.400	0.50	0.0057
Zabuye	China	0.0489	7.29	0.0026	1.66	0.0106
Taijinaier	China	0.0310	5.63	2.020	0.44	0.020

Source: Johnson Matthey 2018

Mineral Extraction and Processing of Lithium

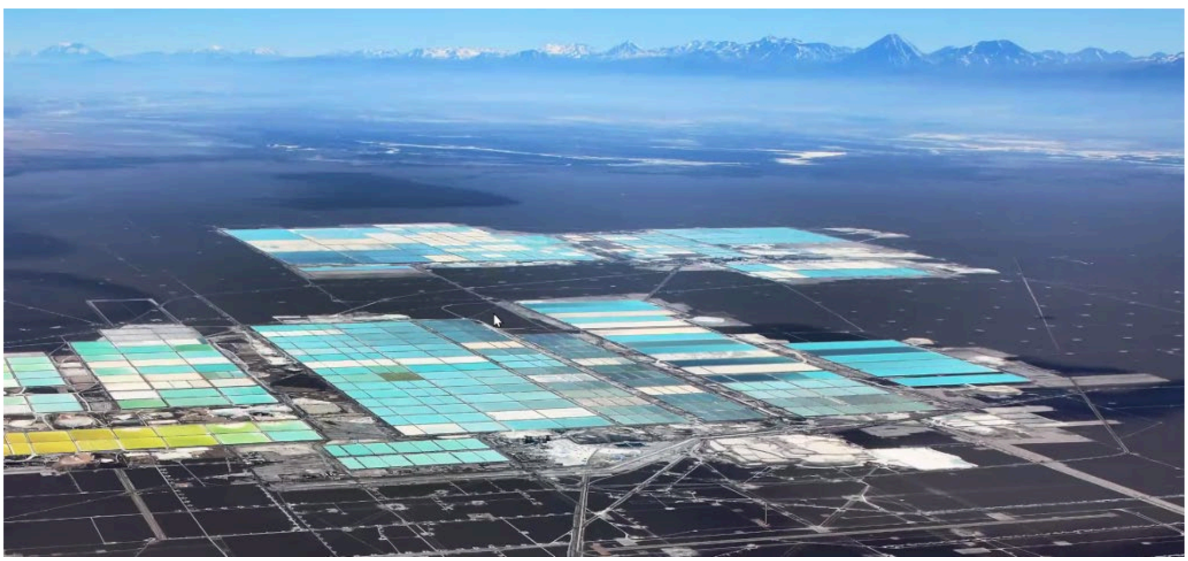
Work is also underway assessing the potential to extract lithium from brines associated with geothermally active areas and oilfields, where brines are extracted as a waste product from underground formations along with oil and gas. These deposits tend to have grades of 0.01-0.04 percent lithium. This will require the development of DLE discussed further below.

Processing plants produce a variety of lithium compounds including lithium carbonate, lithium hydroxide, lithium chloride, lithium bromide, lithium metal, and butyllithium. Lithium carbonate is the precursor of most other lithium compounds in the refining stage.

Brine Chemical Processing

In brine operations, processing methods vary considerably depending on the overall chemistry. In the basic process, the concentrated lithium-rich brine is treated with sodium carbonate to precipitate a lithium carbonate slurry. After filtering, washing, and drying, a pure lithium carbonate product is obtained. Potassium, magnesium, and boron salts may be recovered as co-products. Lithium chloride and lithium hydroxide can be produced via different processing routes. The chemical-grade mineral concentrates undergo additional processing in refining plants to produce a variety of lithium chemicals or lithium metal. The main by-products are potash, used by the fertilizer industry, and bischofite, used for road paving.

Figure 36: Brine Evaporation at Salar de Atacama, Chile



Source: SQM

Processing of Spodumene Concentrates

Different metallurgical methods exist for recovery of lithium from Mineral ores; the most common used for spodumene is the acid leaching process. Other refining processes include the autoclave carbonate leaching and the lime leaching method. The acid leaching process involves high-temperature calcination of the concentrate at about 1,100 degrees Celsius to improve the solubility of spodumene in acids, followed by acid digestion at 200-250 degrees Celsius with sulfuric acid. Lithium from spodumene forms lithium sulphate, which is soluble in water; thus, a downstream water leaching step produces a solution of lithium sulphate.

Impurities are removed by filtration, precipitation, and ion-exchange techniques. Finally, the recovery of lithium from the liquor is carried out by adding a carbonate donor like sodium carbonate (Na_2CO_3) at 80-100 degrees Celsius to precipitate insoluble lithium carbonate (carbonation step). The purity of lithium carbonate can improve through a series of re-dissolution/precipitation/ion exchange steps to achieve up to 99.9 percent grade. Industry-grade lithium carbonate generally has a purity of 98.5-99 percent, while battery-grade lithium carbonate must have a higher purity of at least 99.5 percent.

As of 2020, more than 95 percent of the conversion from spodumene-concentrates into lithium carbonate and/or lithium hydroxide took place in China. The most widely used process in the industry in China is the acid-roast process and the use of sulfuric acid. This process generates huge quantities of waste residue and is energy intensive as it requires high-temperature pre-treatment. In attempts to replace the acid-roast process, there are new technologies in development to recover lithium carbonate and lithium hydroxide directly from high quality spodumene-concentrates as well as other mineralogies.

Producing Lithium Hydroxide and Other Salts

To produce lithium hydroxide, in the typical processing route of acid leaching and before the carbonation step, the aqueous liquor after removal of impurities may undergo electrodialysis to produce a lithium hydroxide solution, and crystallization to form a high-purity lithium hydroxide product. Alternatively, lithium hydroxide is produced by a chemical reaction between lithium carbonate and calcium hydroxide.

Lithium chloride is mainly produced in brine operations, by treating lithium carbonate with hydrochloric acid. Lithium bromide is produced from lithium carbonate after treatment with hydrobromic acid. Lithium metal is obtained by electrolysis of lithium chloride and potassium chloride mixture, in the form of ingots, rods, foils, granules, and powders. Finally, butyl-lithium and other organolithium compounds are produced from lithium metal.

Lithium Extraction Methods Under Development

Technology for the direct extraction and recovery of lithium (DLE) from brines will be very important for the development of new lithium resources to meet the rising demand for lithium-dependent energy storage. Geothermal brines in particular could become a major new source of lithium around the world.

The most well-investigated and technologically advanced method for direct lithium extraction from brines is adsorption by metal oxides and hydroxides. Solvent extraction of lithium from brines using lithium-selective solvents and sorption using organic polymer sorbents, including metal-imprinted polymers, are early-stage technologies that show promise. Membrane-based processes are largely used for removing water or interfering ions, rather than for the direct extraction of lithium.

Processes based on precipitation and common ion-exchange resins can extract lithium from brines but are not specific to lithium and therefore are not practical for economical lithium extraction from geothermal brines, which have very complex chemistry[22].

It is apparent that lithium extraction and recovery from geothermal brines is becoming technically possible and 45 different DLE technology solutions are under development which may be incorporated into new lithium brine projects in development[23]. Many companies have developed their own proprietary extraction technologies.

Livent is currently using sorbent DLE to extract lithium chloride from its Catamarca brine operation in Argentina. Livent also has a development agreement with E3 Metals to cooperate on development of a DLE technology for E3's oilfield brine resource in Alberta, Canada. In China, a significant amount of experimentation is reported to have occurred across the Qinghai lithium brinefield where several different types of DLE have been tested by different groups to produce lithium chloride from waste brines of evaporative brine facilities.

However, the economics of DLE are still uncertain and challenges remain in developing economically and environmentally sustainable DLE processes for mainstream production at commercial scale.

[22] MDPI Technology for the Recovery of Lithium from Geothermal Brines 2021

[23] Jade Cove Partners

ANNEX 2 – LITHIUM USES

Lithium is a versatile metal, with a wide range of uses. Lithium's key properties include the highest electrochemical potential and a low equivalent mass. These properties are the reason why lithium has become very attractive for lithium-ion batteries.

Batteries

Lithium carbonate and lithium hydroxide are the principal lithium compounds used to produce cathode materials for batteries.

Non-rechargeable (or primary) batteries use metallic lithium for the anode. These batteries are more expensive than most of other types of disposable batteries like alkaline batteries but are superior concerning operational lifetime, size, stability, and durability. Primary lithium batteries are employed in various household applications such as calculators, cameras and watches and medical devices such as heart pacemakers. The lithium anodes can be manufactured from pure, high quality lithium metal (Na < 200 ppm), which guarantees very good processing properties. The bulk material can undergo transformation into soft foils, with thicknesses as low as 30µm.

By far the most important use of lithium is in the manufacture of rechargeable batteries. Lithium-ion batteries are high-energy-density power sources, especially important to all mobile applications. At the same time these devices are also capable of high charge discharge rates, the second important requirement for utilization in mobility applications to achieve powerful acceleration in cars and e-bikes, as well as charge acceptance for energy recuperation during braking. The most important application of lithium salts in lithium-ion battery technology is their use in cathode material production. The main sources of lithium in this application are currently lithium carbonate and lithium hydroxide.

Lithium hydroxide is favored for cathode technologies with high nickel chemistry batteries (such as NCM811) which have a higher energy density. NCM 622 cathodes use either lithium hydroxide or carbonate, while lower nickel-bearing NCM cathodes require lithium carbonate. Other lithium batteries such as LFP, which have a lower energy density but are lower cost, also use lithium carbonate.

The expectation by market consensus is that lithium hydroxide use will occur in higher quantities than use of lithium carbonate in EV markets because the market currently focuses on battery mileage (energy density) and will favor NCM cathode technologies. This is a key argument in current decision making in the construction of new lithium chemical processing facilities. However, some market commentators believe this will be less clear cut because as governments mandate petrol and diesel autos out of production, production of smaller electric cars will be required for consumers with less focus on battery mileage and will likely use the cheaper LFP technology.

Lithium salts produced for batteries require a higher purity of product and usually designated as 'battery-grade'. Overall, lithium currently makes a relatively small contribution to the overall cost of cell production. At 2020 price levels for example, lithium accounted for roughly 8-10 percent of the cost of an NCM 811 battery cell. Consequently, efforts by the OEMs to reduce cell production costs are currently not preoccupied with lithium and does not impose any medium-term substitution threat.

An upcoming Interim Report on the outlook for demand growth in EVs and lithium-ion batteries will provide additional information on these topics.

Glass and Ceramics

The second most important application of lithium is in the field of glass and ceramics which accounted for 15 percent of demand in 2020. The industries are major consumers of spodumene concentrate in combination with other lithium-bearing minerals, like amblygonite, lepidolite, and petalite. Lithium reduces the viscosity and lower the production temperatures of glass and ceramic manufacturing processes, thereby reducing costs. Due to lithium's small ionic radius, it has a low coefficient of thermal expansion.

When added to molten glass, it reduces the thermal expansion and fluidities (elasticity) of the mix. Adding 0.17 percent lithium oxide to glass lowers the melting temperature by 25 degrees Celsius and reduces energy consumption by 5 to 10 percent as well as reducing overall CO_2 emissions.

When used in ceramic production, it lowers the firing temperatures, shortens the firing time, and increases the strength of ceramic bodies. The addition of lithium provides additional durability, particularly in heatproof ceramic and glass cookware. Lithium also improves the color fastness of glazes and decreases shrinkage during production and increases resistance to corrosion.

Lubricants

Lithium is an additive to multi-purpose, high-performance lubricants. Lithium hydroxide or lithium carbonate is mixed and heated with fatty acids to produce lithium grease, a thickening agent which combines within the lubricant's final formulation to ensure that lubrication properties are maintained over a wide range of temperatures and extreme load conditions. Lithium grease is one of the most used types of lubricating grease due to its cost-efficiency, excellent water resistance and effectiveness over a wide temperature range. Lithium grease usually accounts for 6-15 percent of the final product, typically at concentrations of 0.2 to 0.3 percent lithium. An estimated 70 percent of all industrial lubricants produced globally contain lithium.

Casting Powders

The steel casting industry uses fluxes to optimize the casting process or to minimize the risk of faulty goods. The industry uses lithium in the form of spodumene or petalite, which reduces the viscosity of the melt. As a result, the flow rate and thus the productivity increases. The flux also acts as a temperature barrier between the mold and the molten steel. In addition, the surface of the continuous cast body is protected from oxidation and impurities such as Al_2O_3 are removed. In traditional casting, lithium oxide prevents the formation of defects in the finished casting. Typically, these fluxes contain up to 5 percent lithium oxide. Lithium is added to the flux as either lithium oxide or lithium carbonate. The addition of spodumene or petalite is also possible.

Polymers

The production of natural rubber compounds uses butyllithium as reagent or catalyst. Depending on the rubber compound, production requires different amounts (3-14 kg per ton of rubber compound).

Air Treatment

Different air treatment applications also use lithium. Lithium bromide solutions are used in combination with water in water-lithium-bromide absorption chillers. Absorption based air de-humidifiers use lithium chloride. This compound can absorb ten times its own weight in water. Lithium is also used in air purification. Use of lithium hydroxide can remove CO_2 from the air.

ANNEX 3 – LITHIUM CONVERSION FACTORS

Conversion Factors

Lithium is usually expressed in percentages or parts per million (ppm) of various lithium compounds but can often be expressed in one lithium compound (most often LCE), to facilitate comparisons between different types of deposits and various chemical compounds. Table 9 shows the standard lithium conversion factors. The conversion factors are calculated on the atomic weights and number of atoms of each element in the various compounds.

Table 10: Lithium Conversion Factors

Convert From		Convert to	Convert to	Convert to
		Lithium	Lithium Oxide	Lithium Carbonate
Lithium	Li	1.000	2.152	5.322
Lithium Oxide	Li_2O	0.465	1.000	2.473
Lithium Carbonate	Li_2CO_3	0.188	0.404	1.000
Lithium Hydroxide	$LiOH\ H_2O$	0.169	0.356	0.880

Source: BGS

ANNEX 4 – LITHIUM M&A ACTIVITY

There has been a considerable amount of M&A activity in recent years, this includes:

- Chengdu Tianqi purchasing a 24 percent interest in SQM in December 2018 for $4.07bn.
- PlusPetrol acquiring LSC Lithium for $111m in March 2019.
- Posco purchases northern tenements in the Sal da Vida project in Argentina from Galaxy Resources for $280m in March 2019.
- Ganfeng increased its interest in the Cauchari-Olaroz project from 37.5 to 50 percent in April 2019. Lithium Americas holds the remaining 50%
- Wesfarmers takeover of Kidman Resources for A$776m in September 2019.
- Albemarle acquiring a 60 percent interest in the Wodinga project and 40 percent of Kemerton LiOH plant for $820m in August 2019.
- Orocobre acquiring Advantage Lithium for $34m in April 2020.
- Perseus Mining acquiring Exore Resources for $44m in September 2020.
- Pilbara Minerals acquiring Altura's Pilagangoora lithium operation for $175m in December 2020.
- IGO acquiring a 49 percent interest in Tianqi Lithium Energy Australia in December 2020.
- Ganfeng agreeing to acquire Minmetals Salt Lake for $226m in March 2021.
- Ganfeng acquiring a 30 percent stake in Bacanora Minerals for $260m in May 2021.
- Orocobre acquiring Galaxy Resources for $1,405m in August 2021.
- Zijin Mining has agreed to acquire Neo Lithium for $765m in October 2021.
- Lithium America agreed to acquire Millennial Lithium for $400m in November 2021.

ANNEX 5 – LIST OF LITHIUM PROJECTS

Table 11: Lithium Projects at Feasibility by Planned Capacity.

	Property Name	Country Location	Type	Company Operator	Planned Capacity Kt/y LCE	Resv Resc Mt	Avg Grade Li2O %
1	Goulamina	Mali	Pegmatite	Firefinch	107.7	1.57	1.45
2	Manono	DRC	Pegmatite	AVZ Minerals	104.0	6.69	1.62
3	Kathleen Valley	Australia	Pegmatite	Liontown Resources	52.0	2.10	1.34
4	Salar del Rincon	Argentina	Brine	Rincon	50.0	-	-
5	James Bay	Canada	Pegmatite	Allkem	45.8	0.56	1.40
6	Moblan	Canada	Pegmatite	GUO AO Lithium	35.0	0.37	1.39
7	Bougouni	Mali	Pegmatite	Kodal Minerals	32.6	0.24	1.11
8	Lithium Nevada	USA	Clay	Lithium Americas	32.5	7.32	0.47
9	Jadar	Serbia	Evaporite	Rio Tinto	27.0	2.78	1.78
10	Piedmont	USA	Pegmatite	Piedmont Lithium	26.4	0.42	1.08
11	Mina do Barroso	Portugal	Pegmatite	Savannah Res.	26.0	0.29	1.08
12	Cinovec	Czechia	Pegmatite	CEZ Group	22.2	2.97	0.42
13	Rhyolite Ridge	USA	Clay	ioneer	20.6	0.50	0.34
14	Zulu	Zimbabwe	Pegmatite	Premier African Min.	20.6	0.21	1.06
15	Cuenca CR	Argentina	Brine	Eramet	20.0	-	-
16	Tres Quebradas	Argentina	Brine	Neo Lithium	20.0	-	
17	San Jose	Spain	Pegmatite	Infinity Lithium	14.5	0.68	0.61
18	Keliber	Finland	Pegmatite	Sibanye Stillwater	13.2	0.16	1.05
19	Mariana	Argentina	Brine	Ganfeng Lithium	10.0	-	-
20	Kachi	Argentina	Brine	Lake Resources	10.0	-	-
21	Wolfsberg	Austria	Pegmatite	European Lithium	7.4	0.09	0.74
22	Zinnwald	Germany	Granite	Zinnwald Lithium	7.3	0.51	0.71
	Total				**704.9**	**27.47**	

Source: S&P Global Intelligence

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