An Overview of the Lithium Supply Chain

Thomas Brady, Ph.D.
CoBank Executive Director, J.P. Morgan Center for Commodities, University of Colorado Denver Business School; and Managing Director and Editor, *Commodities Report*, Capitalight Research, Canada

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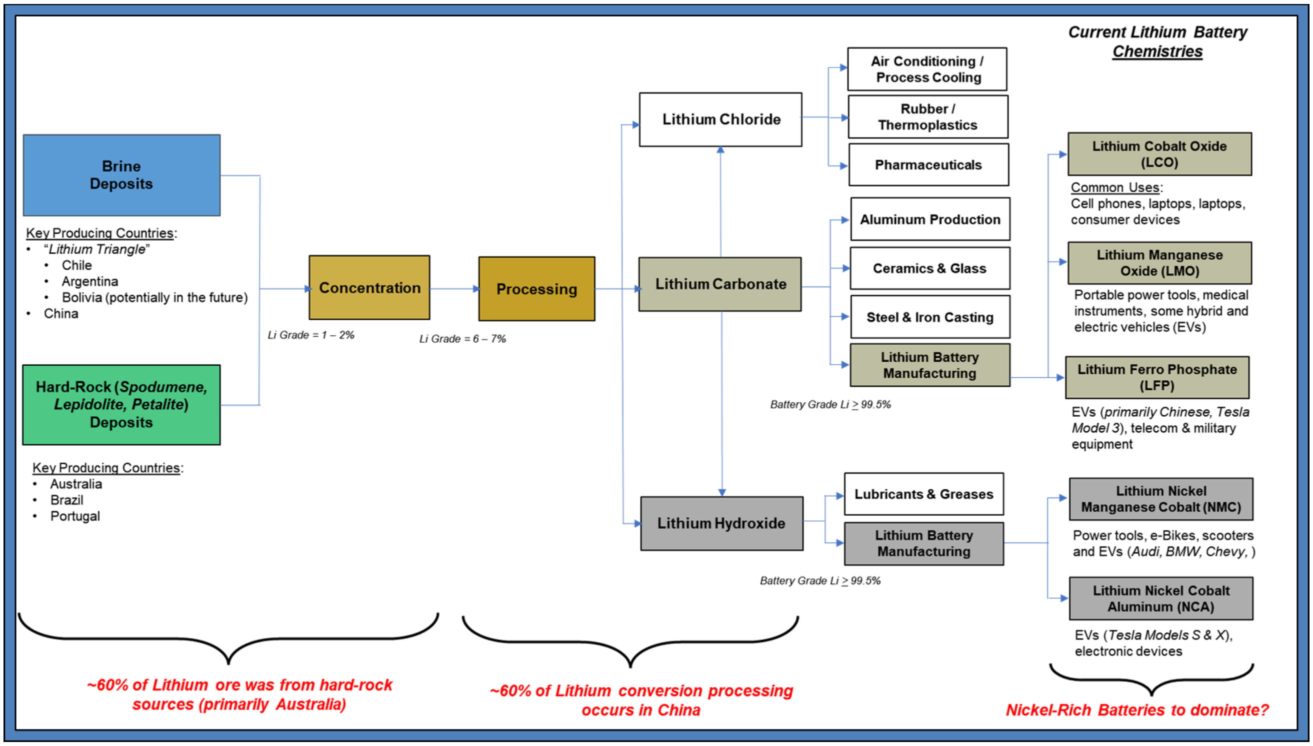
In this digest article, we provide an overview of the global lithium supply chain from the mining of ore through the processing of intermediate compounds, to the manufacture of lithium-ion batteries (Figure 1). Driven by increasing global demand for batteries, the search for new mine supply sources and processing techniques alongside the evolution of battery chemistries, this supply flow is guaranteed to change in the future.

Currently, the majority of lithium mining occurs from either brine or hard-rock deposits.[1] Brine deposits are primarily mined from areas within the "*Lithium Triangle*" (which includes Argentina, Chile and potentially, in the future, Bolivia) and is also mined in China. Actual mining from brine deposits involves the pumping of saline groundwater enriched with dissolved lithium from underground reservoirs to the surface for solar evaporation in successions of ponds. Hard-rock sources are dominated by spodumene deposits, primarily located in Australia. The Greenbushes operation, presently the world's largest lithium mine, is located in Western Australia.

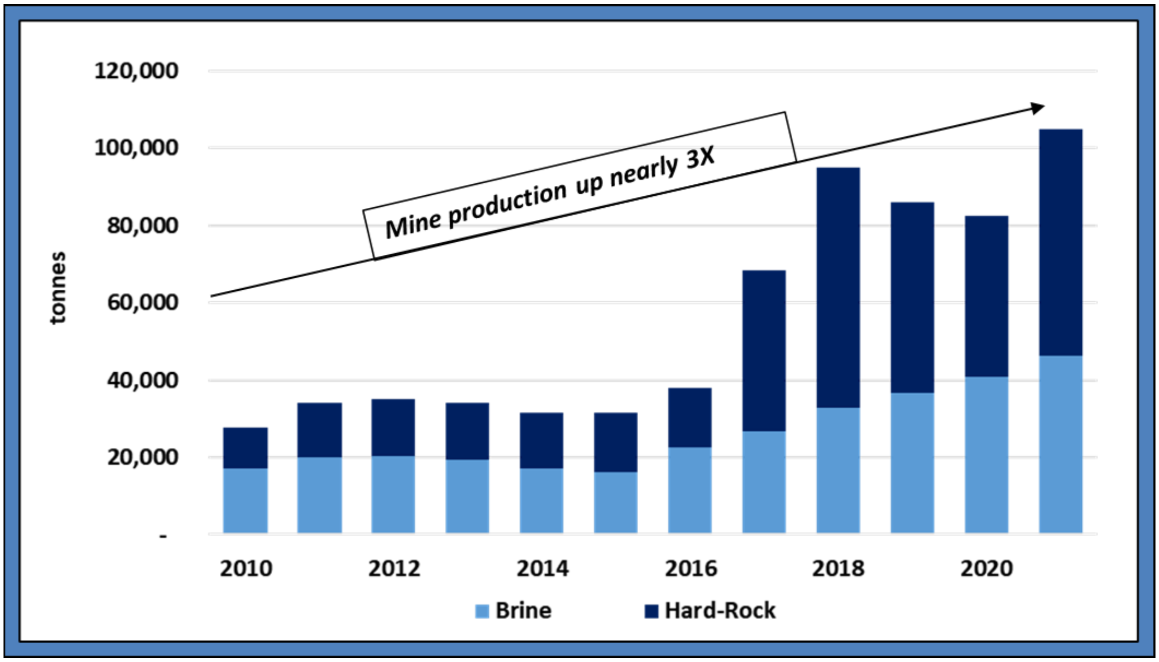
Figure 1
Global Lithium Supply Chain



Source: Capitalight, as adapted from Talens Peiró *et al*. (2013).

Figure 2 summarizes annual global lithium mine production by deposit type since 2010. As shown, global supply has increased from ~28K tonnes in 2010 to ~105K tonnes last year, a nearly 3-fold increase. Lithium mine production from brine deposits dominated annual totals until 2017. Over the last five years however, production from hard-rock sources has averaged slightly under 60% of the annual global total.

Figure 2
Global Lithium Production by Deposit Type



Sources: Capitalight and United States Geological Survey (USGS) Mineral Commodity Summaries.

As shown in Figure 1, across deposit types, mining ore grades are generally low (1% to 2%), making these uneconomic for transport. As such, ore concentration activities typically occur at the mine site. Concentration of brine mined ore occurs through solar evaporation in successions of ponds to increase the grade. At hard-rock deposits, run of mine ore is initially processed through grinding and screening to separate lithium from surrounding materials in the ore. Following concentration, lithium grades are generally in the 6% to 7% range (Bednarski, 2021).

Lithium Processing/Conversion

Following ore concentration, the next step in the lithium supply chain is processing and conversion. As shown in Figure 1, lithium carbonate is a first intermediary chemical in the lithium supply chain, which is used in various manufacturing processes (including ceramics and glass, aluminum and steel castings) as well as some electric vehicle (EV) battery types. Lithium carbonate may also be further processed to obtain lithium chloride and lithium-hydroxide, the latter of which is used in the manufacture of nickel containing (often called "nickel rich") lithium-ion batteries.

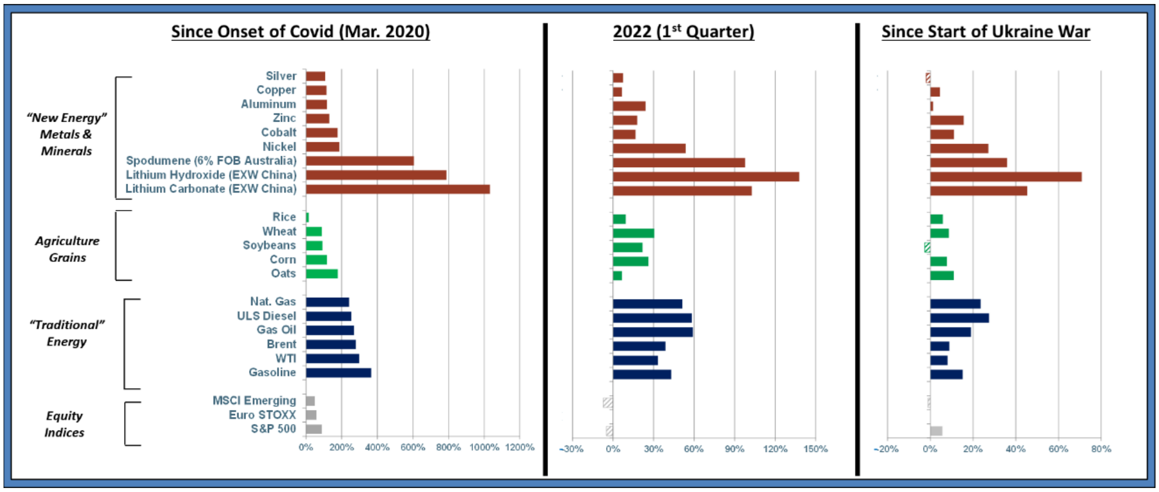
As depicted with the multiple arrows under the processing steps in Figure 1, the conversion of hard-rock (spodumene) lithium concentrate is more flexible in terms of production processes. It allows for a streamlined production of lithium-hydroxide while the processing of lithium from brine concentrates produces lithium carbonate, which must then be further processed to obtain lithium hydroxide (*Innovation News Network*, 2021).

The processing of lithium ore is difficult and becomes more so as the mineral moves through the supply chain to the eventual material used in battery cathodes. Further, battery chemistries are fragile which means that processing facilities must be able to produce consistent lithium intermediate products such as lithium-carbonate and lithium-hydroxide. Critical to this processing is the control of the many impurities that may coexist with lithium in concentrated ore such as magnesium, sodium and potassium that negatively impact battery cathode performance further down the supply chain (Bednarski, 2021).

Through the conversion steps, whether in the form of lithium carbonate or lithium hydroxide for eventual use in EVs or batteries for other electronic devices, the purity of lithium is increased to >99.5%. In terms of geopolitical risks within the lithium supply chain, currently over 60% of the facilities that convert lithium ore into the intermediate products of lithium carbonate and lithium hydroxide are located in China (Tarry and Martinez-Smith, 2020).

Figure 3 displays price returns for representative commodities and equity indices (a) since the onset of the COVID-19 Pandemic, (b) over the 1st quarter of 2022, and (c) since Russia invaded Ukraine in late February 2022. While not as widely reported as price increases in traditional energy (including West Texas Intermediate (WTI) and Brent crude oil, natural gas and gasoline), metals and minerals associated with the energy transition (labeled "New Energy" on the figure) have experienced significant gains over the three identified periods. As shown in the figure, price increases in lithium hard-rock (spodumene) ore and the lithium carbonate and hydroxide intermediate compounds have each far exceeded traditional energy and agricultural grains. These sharp increases, along with the price climbs in cobalt and nickel are sure to drive higher battery prices (and overall EV prices) over the coming months.

Figure 3
Lithium Compounds & Select Commodities Price Performance



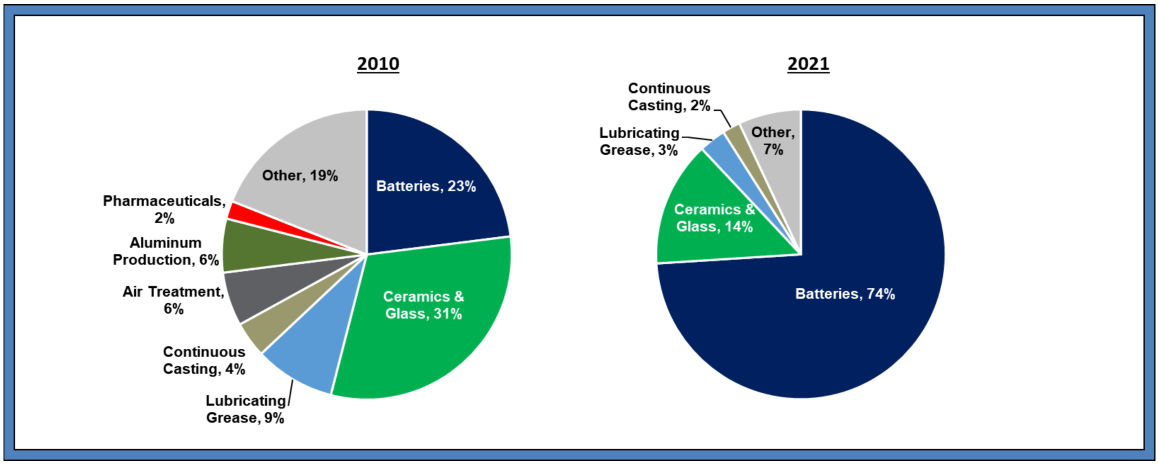
Sources: Capitalight and Bloomberg.

Lithium Demand

Progressing further through the supply chain (as illustrated in Figure 1), following the conversion to the aforementioned intermediate products, are various manufacturing and end-use applications. These include air conditioning and industrial process cooling, thermoplastics, pharmaceuticals (for bipolar and depression), as an alloy in aluminum production to add strength and corrosion resistance. In the manufacture of glass and ceramics, lithium carbonate allows for lower processing temperatures and thus lower energy input. Other uses include steel casting applications and finally in the manufacturing of lithium-ion batteries.

Figure 4 displays how the demand for lithium has evolved over the last ~10 years. In 2010, ceramics and glass demand dominated global demand, accounting for nearly one third of the total, followed by battery applications required nearly 25% of the total.[2] Spring forward to 2021, reflecting the huge increase in demand needs for EVs and other consumer electronics, batteries now amount to ~75% of annual global demand.

Figure 4
Global Lithium Demand



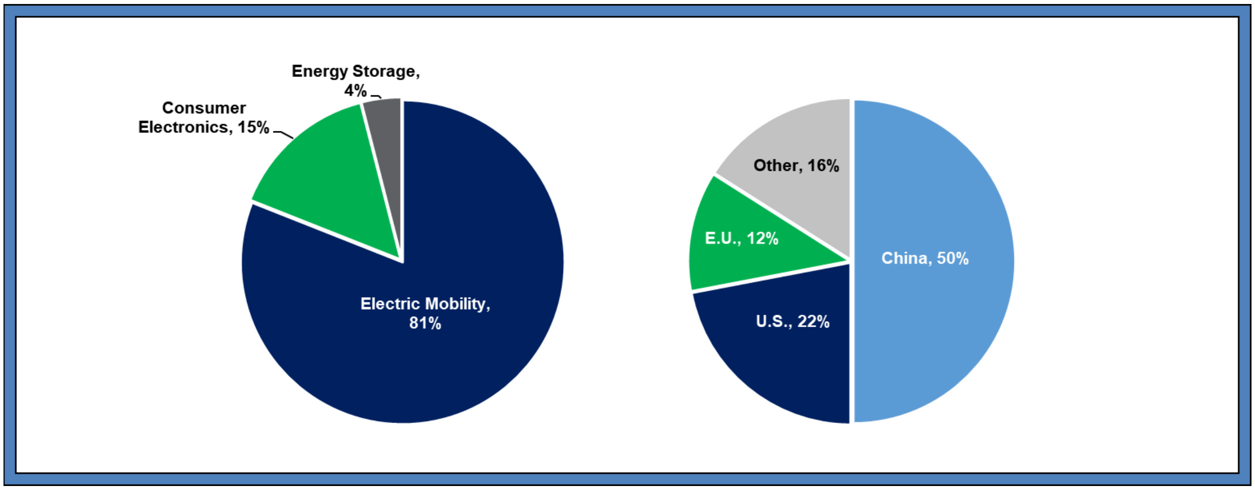
Sources: Capitalight and USGS Mineral Commodity Summaries.

Lithium-Ion Battery Manufacturing and Demand

Continuing down the lithium supply chain, Figure 1 also displays the major types of current lithium-ion batteries that have come to dominate the portable electronics, energy storage and EV markets. Key to lithium batteries are the relatively higher energy densities (higher power and lower weight) compared to non-lithium ion battery types. For EVs, higher energy density translates into more power and higher mileage ranges. As shown on Figure 1, at present there are five general types of lithium-ion battery chemistries including lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium ferro (or iron) phosphate (LFP), lithium nickel manganese cobalt (NMC), and lithium nickel cobalt aluminum (NCA).[3] While some of these common battery types may or may not include cobalt (a topic for a future article), all contain lithium. Actual manufacturing of lithium-ion batteries occurs primarily in China, Japan, and South Korea.

Figure 5 displays demand for lithium-ion batteries by end-use and by country for 2020. As shown, electronic mobility (primarily EVs but also includes e-bikes, and scooters) dominates demand at over 80%. Consumer electronics (laptops, medical devices, cell phones to name a few) accounts for 15%, followed by energy storage (4%). China by far leads in the global demand for lithium-ion batteries with over half, followed by the U.S. (22%) and the EU at 12%.

Figure 5
Lithium-Ion Battery Demand by Use and Country (2020)



Sources: Capitalight and Liu *et al.* (2022).

Lithium-Ion Battery Types & Pros and Cons

Specifically, the following summarizes the benefits and challenges associated with current five general chemistries utilized in the cathode of lithium-ion batteries.[4]

Lithium-Cobalt Oxide (LCO) – These batteries are most commonly used in smaller, portable electronics including mobile phones, tablets, laptops, and cameras. A key attribute of this battery type is the ability to deliver power over long periods for low power-requirement applications. Negatively, these batteries suffer from relatively short lifespans, losing effectiveness after 500 to 1,000 life cycles (or charging periods.) These batteries also have poor thermal stability: there are many reported incidents of batteries overheating due to overcharging and/or poor performance in extremely hot or cold environments.

Lithium-Manganese Oxide (LMO) – In comparison with LCO batteries, this chemistry offers improved thermal stability. LMO batteries are commonly used in power tools and medical instruments. Early EVs such as the Nissan Leaf used LMO batteries which suffer from relatively short driving ranges of 80 to 100 miles. LMO batteries have shorter life cycles in the 300 – 700 charging cycles range.

Lithium-Ferro-Phosphate (LFP) – Along with LMO batteries, LFP chemistries have the benefit that these do not contain cobalt (another mineral critical to the "New Energy Future" whose prices have also climbed, as shown in Figure 3.) In addition, cobalt brings significant geopolitical risk as >80% of world supply is from the Democratic Republic of Congo. LFP batteries offer a relatively longer life span (1,000 to 2,000 charge cycles.) These batteries are known to be relatively safe, however performance can suffer in low temperatures. In addition to not using cobalt, LFP batteries use iron rather than more costly nickel. Average costs are currently lower than nickel-rich chemistries. At present, the current trend appears to be heading toward LFP batteries. Nearly 60% of EVs produced in China during 2021 use LFP batteries (Pressman, 2022). Also, Tesla recently migrated its entry-level Model 3 to use LFP.

Lithium-Nickel-Cobalt-Manganese (NCM) – Within the cathodes of NCM batteries, manganese is added to nickel to provide additional thermal stability. These batteries are known for having relatively long life spans (similar to LFPs). NCM batteries are widely used in power tools, e-bikes, and scooters. Higher end Chinese EVs such as the BYD Qin Pro use NCMs as does the VW ID.4 and Chevy Bolt.

Lithium-Nickel-Cobalt-Aluminum (NCA) – NCA batteries are widely used in the EV marketplace as they perform well under high-load applications and offer long battery life. NCA batteries can offer ~30% more energy density (more energy per unit of weight) compared to LFPs. Tesla's higher-end models (the S, X and Y) use NCA battery types.

Currently the "nickel rich" batteries appear the preferred battery type in the U.S. and Europe.

Outlook

In an attempt to shore up domestic supply chains, on March 31st, the Biden administration announced plans to use the Defense Production Act to ramp up the mining and processing of key minerals used in batteries for renewable energy and electric vehicles.[5] Under the order, companies could receive funding for feasibility studies to extract lithium, nickel, cobalt, graphite, and manganese. Two initial concerns arise with this announcement. First, while companies may obtain assistance for the study of potential domestic projects, it does not appear that the U.S. government will help with actual capital expenses associated with building mining operations. Second, as highlighted in this article, the significant risks associated with the lithium supply chain lie in the processing of lithium carbonate and hydroxide intermediate compounds necessary for eventual EV battery manufacture. Sixty percent of this processing occurs in China. The Chinese have been working 10+ years on refining processes to transform lithium containing ores into the exacting and precise materials required by battery manufacturers for eventual use in EVs and other critical electrical equipment used in industry and by consumers.

In our view, many in the Western countries of the world have unrealistic expectations for the "Energy Transition." As a representative example, global automobile sales are expected to approach 125M units by 2030, a nearly 45% increase from 2021 (*Business Wire*, 2021). If the world is to build toward a "Net Zero Carbon by 2050" scenario, this will require nearly 60% of these 2030 sales to be for EVs. However, rolling back through the lithium supply chain, this would require mine supplies to be ~5-times higher than the 100K tonnes mined last year. When one contemplates the actual time required for (a) companies to explore, study and model potential resources, (b) the negotiation and finalization of national, state and local permits, (c) the extensive efforts to solidify buy-in from local communities and other stakeholders, (d) the raising of capital funds and then to (e) the actual construction of a mine, this level of expansion (all within <8 years) is extremely unlikely.[6] As the world operates today and Congress will discover, it is much easier to state proclamations such as: *"The U.S. Government will end gas-powered vehicle purchases by 2035"* than to fulfil that proclamation.

Endnotes

1 Traditionally, extracting lithium clay hosted sediments was considered too complex and uneconomic; however, a number of U.S. based projects are currently under evaluation, including Thacker Pass in Nevada, which is noted as having the largest resource in the U.S.

2 Note that in the mid-1990s only ~7% of global lithium demand was allocated to batteries. Remember the hand-held Sony Camcorder?

3 Another common battery chemistry uses lithium titanate (LTO) which replaces graphite used in the anode of the battery with lithium titanate for use in the LMO or NMC as the cathode chemistries (Dragonfly Energy, 2021).

4 This section relies heavily upon Dragonfly Energy (2021) and Liu *et al.* (2022).

5 The U.S. Defense Production Act allows the president to respond to a national emergency by requiring that companies prioritize federal contracts for whatever goods or materials it deems necessary.

6 Further, this quick calculation ignores the requirements in electronic and medical devices as well as the building requirements for the lithium needed in actual EV charging stations.

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Author Biography

THOMAS BRADY, Ph.D.
CoBank Executive Director, J.P. Morgan Center for Commodities, University of Colorado Denver Business School; and Managing Director and Editor, *Commodities Report*, Capitalight Research, Canada

Dr. Thomas Brady is a mineral and commodity sector economist and is currently the CoBank Executive Director of the J.P. Morgan Center for Commodities at the University of Colorado Denver Business School and founder of Brady Commodity Advisors, LLC. Most recently Dr. Brady was the Chief Economist at Newmont Mining Corporation responsible for generating key commodity price, foreign exchange and other financial assumptions used throughout the company. Previously at Newmont, he led the Strategic Planning function that developed and implemented portfolio modeling analytics and also held positions in Investor Relations, Treasury and Corporate Development.

Prior to rejoining Newmont, Dr. Brady was a Senior Manager at Risk Capital Management, a consultancy that advised energy and natural resource companies on financial risk, valuation and commodity hedging.

Dr. Brady holds a Ph.D. in Mineral Economics with research emphases in commodity markets from the Colorado School of Mines. In addition, he holds a Master's degree in Mathematics, also from the Colorado School of Mines.

Dr. Brady's previous articles for the *GCARD* are available here.