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SPECIAL REPORT

"LITHIUM RESEARCH & INSIGHTS"

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COMMODITY INSIGHTS DIGEST

February 2025 Special Report on Lithium

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Long-Run Availability of Mineral Resources: The Dynamic Case of Lithium **3**
By Sangita Gayatri Kannan, Department of Economics and Business, Colorado School of Mines, U.S.A.; Maxwell Fleming, Department of Economics and Business, Colorado School of Mines, U.S.A.; and Roderick Eggert, Ph.D., Department of Economics and Business, Colorado School of Mines, U.S.A.

Lithium requirements will increase substantially in the energy transition - raising concerns about adequacy and affordability of lithium over the long term. A cumulative availability curve (CAC) helps assess these concerns. A CAC summarizes estimates of quantities, costs and locations of resources, which are key characteristics of future resource availability. With estimates of *in situ* resources and production costs for 150 conventional and unconventional lithium deposits, the CAC developed in this study shows that: *in situ* resources doubled between 2009 and 2023 to 726 million metric tonnes lithium carbonate equivalent (LCE), illustrating the dynamic nature of our knowledge of resources; cost estimates suggest an incentive price of US$12,500-$15,000 per metric tonne LCE, well below the peak price in 2023 but above the average price from 2011 to 2020; and resources are more geographically dispersed than current production. Production is not constrained by physical availability but by investment to convert resources into reserves, and further into operating mines and processing facilities, in ways that are environmentally and socially responsible.

Investing in the Batteries and Vehicles of the Future: A View Through the Stock Market **14**
By Michael Plante, Ph.D., Principal Research Economist, Federal Reserve Bank of Dallas, U.S.A.

This study uses high-frequency stock price data to uncover the factors that drive the returns of companies operating in the electric vehicle and battery supply chain. The study's statistical approach separates out the influence of systematic risk factors and factors unique to the supply chain. EV and battery stock returns are found to be exposed to a market and a tech factor. There is also evidence for an EV factor, unrelated to the broader market, that generates common variation among these returns. Lithium companies are found to be exposed to their own unique risk factor.

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Lithium Price Volatility and the Road to Market Maturity **19**
By Ahmed Mehdi, Managing Director, Renaissance Energy, U.K.

With the lithium-ion battery sector entering the terawatt era (Twh) – driven by demand from the Electric Vehicle (EV) and Battery Energy Storage Sector (BESS) – there remains little doubt over lithium's central importance to the energy transition. But how has lithium pricing evolved in the market? The recent slump in lithium prices has triggered a range of questions in the market: how sustainable are current spot
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prices? Has lithium's marginal cost of production become more dynamic compared to previous years? What next for lithium prices and pricing? This paper sheds light on some key features of lithium's evolving pricing landscape; the drivers of volatility in the market; and the implications ahead as lithium's journey to market maturity continues apace.

More Reporting Clarity Can Help Fund U.S. Lithium Growth **27**
By Reese Epper, Graduate Research Assistant at the Payne Institute for Public Policy, Colorado School of Mines, U.S.A.; Brad Handler, Program Manager, Sustainable Finance Lab, Payne Institute for Public Policy, Colorado School of Mines, U.S.A.; and Ian Lange, Ph.D., Director, Mineral and Energy Economics Program, Colorado School of Mines, U.S.A.

Just as a regulated reserve reporting update helped spur investors to U.S. oil and gas production nearly 15 years ago, recent regulatory changes to resource and property disclosures in the mining sector could similarly catalyze investment in lithium extraction today.

Critical Mineral Futures Markets: A Brief Introduction **31**
By Gabriel Collins, Researcher, Payne Institute for Public Policy, Colorado School of Mines, U.S.A.

The stepwise shift in demand for critical minerals in the upcoming decades necessitates an equal supply response. For the investors and companies to effectively allocate capital towards increasing the supply of minerals, the market must improve pricing efficiency. Deepening critical mineral futures markets will be an important step in the path to the renewable energy transition.

The Rise of the Lithium Futures Market **36**
By Przemek Koralewski, Global Head of Market Development, Fastmarkets, U.K.

The global shift towards net zero emissions has significantly increased demand for traditional commodities and created new markets, particularly within the battery supply chain supporting electric vehicles and energy storage systems. This paper explores the performance and trajectory of the lithium futures market, which emerged to manage price volatility in the booming lithium industry.

Hedging Battery-Material Price Risk: The Case of Lithium Compounds **43**
By Hilary Till, Managing Co-Editor, Commodity Insights Digest; Honorary Senior Visiting Fellow, Bayes Business School - City, University of London, U.K.; and Principal, Chicago-based Premia Research LLC, U.S.A.

Amongst other factors, the success of the clean-energy transition currently relies on lithium. With their distinctive properties, lithium compounds are a crucial component in lithium-ion batteries, electric vehicles (EVs), and energy storage systems. There are currently no foreseeable alternatives to lithium's use in modern battery technology. But, lithium-compound prices have been on a rollercoaster. Can this price risk be hedged by industrial consumers, thereby facilitating the scaled-up use of one of the essential materials in the energy transition? This article briefly examines this question solely from a U.S. perspective, and the answer is promising.

Long-Run Availability of Mineral Resources: The Dynamic Case of Lithium

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Lithium requirements will increase substantially in the energy transition - raising concerns about adequacy and affordability of lithium over the long term. A cumulative availability curve (CAC) helps assess these concerns. A CAC summarizes estimates of quantities, costs and locations of resources, which are key characteristics of future resource availability. With estimates of in situ resources and production costs for 150 conventional and unconventional lithium deposits, the CAC developed in this study shows that: in situ resources doubled between 2009 and 2023 to 726 million metric tonnes lithium carbonate equivalent (LCE), illustrating the dynamic nature of our knowledge of resources; cost estimates suggest an incentive price of US$12,500-$15,000 per metric tonne LCE, well below the peak price in 2023 but above the average price from 2011 to 2020; and resources are more geographically dispersed than current production. Production is not constrained by physical availability but by investment to convert resources into reserves, and further into operating mines and processing facilities, in ways that are environmentally and socially responsible.

Introduction

Lithium-based batteries and the rise of electric vehicles are central to the global energy transition. Recognized as a critical mineral, lithium faces potential supply disruptions and market volatility throughout its supply chain (U.S. Federal Register, 2022; U.S. Department of Energy, 2023). Projections suggest that lithium demand could surge by 13 to 51 times current levels by 2040 (International Energy Agency, 2021; Hund *et al*., 2020), reflecting evolving battery chemistries and commercialization challenges (Frith *et al*., 2023). This anticipated demand spike raises crucial questions about lithium availability: where will production occur, and at what cost? To assess long-term availability, we employ the cumulative availability curve (CAC), which integrates the physical and economic dimensions of resource quantities and production costs. Unlike industry cost curves that focus on operating mines within capacity constraints over limited periods (Tilton and Guzman, 2016; Tilton *et al*., 2018), the CAC offers a comprehensive view of resource availability.

Since the first lithium CAC constructed by Yaksic and Tilton (2009), the lithium industry has undergone significant evolution. Our updated 2022 CAC traces the changes in lithium availability and resource knowledge between 2009 and 2023. Over this period, global *in situ* lithium resources have more than doubled, increasing from approximately 325 million metric tonnes (MMT) lithium carbonate equivalent (LCE) to 726 MMT LCE. This substantial growth reflects new discoveries, advancements in extraction technologies, and a deeper geological understanding of existing deposits.

The 2022 CAC illustrates that (a) resource quantities have increased, (b) are composed of different types of deposits, and (c) are more geographically dispersed. In 2009, brine deposits predominantly constituted known resources. Since then, hard-rock deposits have gained prominence, comprising larger shares of total resources. The increased identification and development of hard-rock lithium deposits, especially in countries like Australia and Canada, have diversified supply sources. Additionally, unconventional sources such as clay and geothermal brines are being explored and show promise due to recent technological advancements, though they have not yet gained prominence in production. These potential deposits could further expand the resource base and potentially lower production costs as technologies mature. At the 2022 production level of 737,000 MT LCE (Australian Government | Department of Industry, Science and Resources, 2023), resources could last over 450 years. However, increased production aligned with demand projections (International Energy Agency, 2021; Hund *et al*., 2020) suggests potential depletion in 36 to 64 years. This tension between resource growth and consumption underscores the ambiguous nature of depletion.

Findings indicate that all resources are feasible to produce below US$12,500 per metric tonne (MT) LCE, significantly lower than the 2023 average price of US$46,000 (U.S. Geological Survey, 2024). We suggest an incentive price range of US$12,500 to US$15,000 per MT LCE, acknowledging that our cost estimates exclude environmental, social, and governance (ESG) considerations and taxes. Availability is unlikely to be constrained on the physical dimension. Rather, the ability to increase production will depend on substantial investment in converting resources into reserves, and further into operating deposits and processing facilities. Profitable investment and successful growth of supply chains is inextricable from effectively managing environmental costs and obtaining a social license to operate in impacted communities.

Relevance of the Research Question

Lithium requirements are projected to increase substantially as the world transitions to more renewable energy – raising concerns about the adequacy and affordability of lithium over the longer term. This paper asks: how much lithium is available? What will it cost to produce? Where will it come from? A CAC sheds light on these questions. The CAC includes estimates of *in situ* resources and operating and capital costs for 150 lithium deposits, both conventional and unconventional.

While concentrations of lithium in the earth's crust are determined by historical geological processes, quantifying resources depends on our knowledge of them. Market signals such as elevated prices encourage exploration to locate and develop resources within the resource base. Continued development and investment convert resources to reserves, which are the working inventory of mineral production. Technological advancement can increase recovery rates and render low grade deposits more feasible for production. These processes drive the dynamic nature of resources. The evolution of the CAC for lithium since 2009 highlights the dynamic nature of our knowledge of resources and emphasizes the importance of continuous investment in exploration, technology, and sustainable practices to meet future demand. Our updated CAC provides critical insights into the long-term availability of lithium, helping stakeholders make informed decisions in the rapidly evolving energy landscape.

Data and Methods

The CAC for lithium is constructed using *in situ* resource quantities of known lithium deposits (X-axis) and the estimated production costs associated with those deposits (Y-axis). While lithium-based battery producers use either lithium hydroxide or lithium carbonate, we chose to maintain an apples-to-apples comparison by standardizing all deposits to produce lithium carbonate expressed in LCE.

The horizontal axis of the CAC represents global *in situ* resource quantities of known lithium deposits, expressed in MMT LCE. *In situ* resource quantities are compiled into a database using a deposit-specific approach. Total resource estimates include measured, indicated and inferred resources based on the availability of data for each deposit. The type of lithium deposits covered include brine, hard-rock (including spodumene, petalite, lepidolite) and unconventional deposits (including geothermal brine, oilfield brine, hectorite clay, jadarite clay, greisen, tin tailings, boron tailings, volcanic rock, zinnwaldite). Sources for the resource quantity estimates include national and regional geological reports, National Instrument (NI 43-101) documentation, feasibility and pre-feasibility reports, company information such as investor presentations, and academic papers. The CAC includes resource estimates of 150 deposits in total, of which less than 25 deposits are currently in operation, while others are in various stages of the project analysis pipeline.

We obtain operating cost information from technical reports, consultant reports, investor presentations and academic sources. Where cost data is unavailable, we construct an ordinary least squares (OLS) estimation model to estimate operating costs based on deposit type, grade, region, evaporation rates, and magnesium:lithium ratios. While this model abbreviates many factors influencing operating costs and does not provide investment-grade estimates for individual mines, it provides a high-level industry-wide snapshot of operating costs. While operating costs constitute the majority of long-run production costs, capital costs are substantial and influence investment decisions. We model capital expenditure and amortization with regionally characterized costs of capital, assuming constant returns to scale as capital costs are a relatively small portion of total production costs.

Results and Discussion

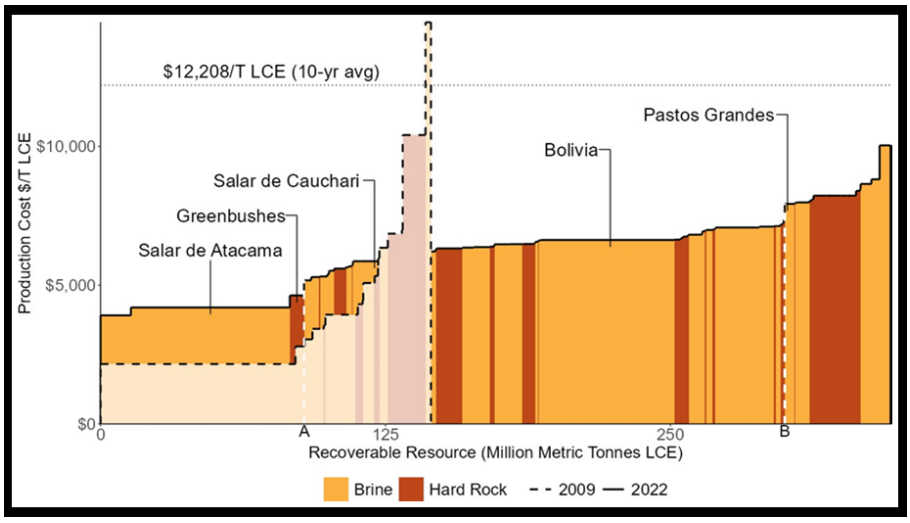
This analysis catalogs 150 lithium deposits including *in situ* resource estimates of 726 MMT LCE. It includes 649 MMT LCE of conventional resources and 41 MMT LCE of unconventional resources. Brine deposits account for 540 MMT LCE while hard-rock accounts for 110 MMT LCE. Our CAC illustrates total quantities of lithium resources across all known deposits with estimated production costs given current technology and market conditions. It helps us think about three determinants of the future availability of lithium. First, the shape of the curve is determined by geologic characteristics of known deposits and how these characteristics influence the relationship between quantities and costs. Second, the speed at which society moves up this curve will be determined by future demand growth that is not met by recycling. Third, shifts in the curve over time will be determined by the combined effect of production-cost reductions derived from technological innovation (such as direct lithium extraction) and the discovery and development of previously unknown resources (Tilton and Guzman, 2016).

Conventional Resources and Their Evolution Between 2009 and 2023

A conventional resource, for purposes of this study, is any type of lithium resource that has been produced in significant commercial quantities to date, producing lithium for the most part from surface brine and hard-rock. Surface brine production is concentrated in the "Lithium Triangle" of Argentina, Chile, and Bolivia. Conventional production from these deposits involves concentration in solar evaporation ponds and chemical processing to yield lithium carbonate which may be processed further into lithium hydroxide. Hard-rock operations are primarily located in granite pegmatite deposits containing lithium-bearing spodumene. Processing consists of crushing, flotation, roasting, and acid treatment to yield lithium concentrate (Warren, 2021). At this stage, concentrate may be processed into either lithium carbonate or lithium hydroxide.

The first CAC for lithium was constructed in 2009 (Yaksic and Tilton, 2009). Figure 1 shows the 2022 CAC for lithium superimposed on the 2009 curve (Yaksic and Tilton, 2009) to highlight the evolution over the 14 years between 2009 and 2023. The 2022 CAC in Figure 1 includes 124 conventional deposits (51 brine and 73 hard-rock) containing 649 MMT LCE *in situ* resources. Recovery rates of 50% for brine (Sociedad Química y Minera de Chile S.A., 2021) and 70% for hard-rock (AMG Advanced Metallurgical Group N.V, 2017; Galaxy Resources, 2017; Critical Elements Lithium Corporation, 2021) were used for converting i*n situ* resources to recoverable resources. We find that there is significant availability of lithium at a variety of production costs. Several portions of the curve indicate large quantities available from either a single large deposit or multiple deposits with similar costs. There are several discontinuous cost increases along the curve, where relatively significant increases in cost are required to continue production.

Figure 1
Recoverable Resources Compared to Yaksic and Tilton (2009)



Notes: The solid line outlines the 2022 CAC, with estimated recovery rates applied to quantities. The dashed line outlines the CAC from 2009. Recovery rates are 45% for brine and 50% for hard-rock in 2009, and 50% (Sociedad Química y Minera de Chile S.A., 2021) for brine and 70% (AMG Advanced Metallurgical Group N.V, 2017; Galaxy Resources, 2017; Critical Elements Lithium Corporation, 2021) for hard-rock in 2022.

In Figure 1, conventional deposits are divided into three regions by vertical white dashed lines indicating discontinuous increases in costs. The first region, left of line A, consists of large, high-grade, low-cost deposits. Production costs in this region range from US$3,900 to US$4,700 MT LCE. Deposits include two zones of the Salar de Atacama in Chile, and Greenbushes in Australia. The second region, between lines A and B, consists of numerous deposits with costs between US$5,000 and US$7,500 MT LCE. Deposits in this region have a wide range of sizes and costs and are spread across numerous countries. Deposits include Salar de Cauchari in Argentina, Salar de Uyuni in Bolivia, Pilgangoora in Australia, and the Taijinar lakes in China. The third region, to the right of line B, consists primarily of deposits that have been explored less than deposits in the first two regions. This region has deposits in the high-cost range of US$7,900 to US$10,500 MT LCE. Deposits include Pastos Grandes in Argentina, James Bay in Canada and Yiliping Salt Lake in China.

Comparing the 2022 CAC with the superimposed 2009 CAC in Figure 1 shows that total recoverable resource estimates more than doubled between 2009 and 2023, increasing from 153 MMT to 401 MMT LCE in terms of recoverable resources. The increase in resource estimates can be largely attributed to increased exploration. Brine holds the major share of resources in both 2009 and 2023. The share of hard-rock marginally increased between 2009 and 2023. The share of unconventional resources has nearly tripled, reflecting new extraction methods and efforts to develop new deposit types.

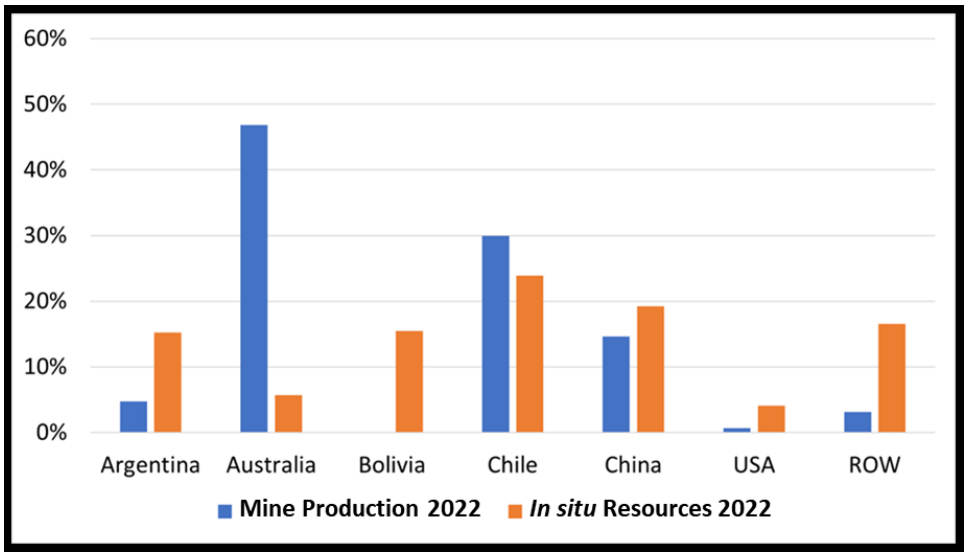
We can also observe that costs increased significantly between 2009 and 2023. Cost increases may be explained by elevated input prices, inefficiencies associated with rapid capacity expansion, and a lack of pressure to control costs (Tilton and Guzman, 2016). Inflation played a relatively minor role in cost increases prior to 2021, using the Manufactures Unit Value Index as an indicator of international inflation (World Bank, 2021). Technological advancement may have reduced necessary input quantities and opened additional deposits to production, suggesting costs might have increased further without the cost-reducing effects of technological improvements.

Geographic Distribution of Mine Production and *in situ* Resources

Geographically, lithium resources have become more dispersed. While the "Lithium Triangle" of Argentina, Bolivia, and Chile remains a key region, significant deposits have been identified in Africa, Europe, and North America. This increased geographical diversity reduces reliance on a few countries and may mitigate supply risks associated with geopolitical factors.

Figure 2 on the next page compares the geographic distribution of mine production in 2022 to *in situ* resource estimates in the same period. We find that *in situ* resources are more geographically dispersed than resource production. Resources are spread across 29 countries, but with 73% of the resources in just four countries: Chile, China, Bolivia and Australia. Bolivia with its significant resources has no current production, while Australia is the largest producing country today with only 6% of known resources. This suggests that future production could be more geographically diverse than current production.

Figure 2
Geographic Distribution of Mine Production and *In Situ* Resources, 2022



Note: ROW is Rest of the World.

Sources of Data: British Petroleum (2021) and U.S. Geological Survey (2023).

Implications for Price

A CAC provides a lens through which to view current and possible future prices. Lithium prices between 2015 and 2022 were volatile, with spot prices of lithium in 2022 exceeding US$70,000 per tonne LCE (Lucas, 2022). The incentive price is the price level that will encourage investment in new projects through covering operating and capital costs and a target return on investment (Pustov *et al.*, 2013). The costs estimated in the CAC provide a floor for the incentive price as society moves up the curve.

In Figure 1, every deposit on the CAC is feasible for development and operation at the U.S. average 2021 price of lithium carbonate of US$17,000 per tonne (U.S. Geological Survey, 2022). As prices between 2020 and 2023 were highly volatile, it is helpful to plot the 10-year average price from 2013 to 2022 of US$12,208 per MT LCE (Roskill Information Services, 2020; Mitchell, 2021) on the CAC. In Figure 1, all deposits are producible at the 10-year average price. Even if actual costs are higher by 50%, 73% of the curve is still feasible to produce below US$10,000 per MT LCE and the entire curve is feasible to produce below US$12,500 per MT LCE. Given that these cost estimates may be underestimates rather than overestimates as costs associated with ESG, taxes, etc., are not included, this study suggests a range of US$12,500 per MT LCE to US$15,000 per MT LCE as the first approximation to a likely incentive price.

Unconventional Resources

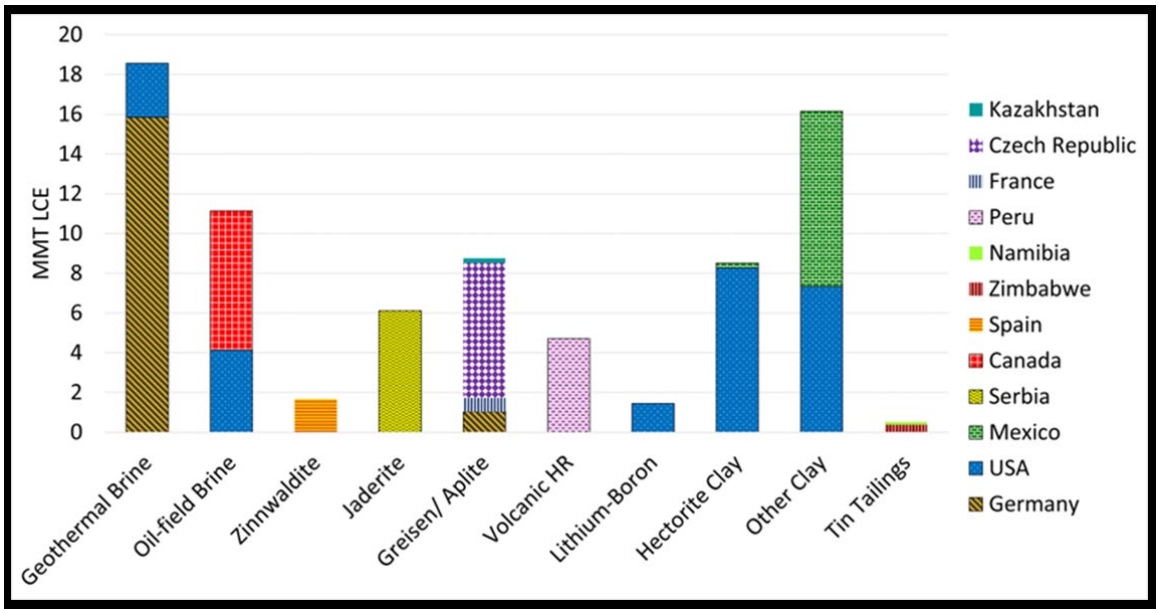
An unconventional resource, for purposes of this study, is any type of lithium resource that has not been produced in significant commercial quantities to date. This section highlights various unconventional

deposit types which have distinct characteristics affecting future production feasibility. Figure 3 on the next page plots unconventional deposits by country and deposit type. There are 26 unconventional deposits containing 78 MMT LCE. They include unconventional brine deposits (geothermal and oilfield), other rock deposits (zinnwaldite, volcanic hard-rock, greisen/aplite), tailings (boron and tin), and several clay types (jadarite, hectorite and others). Geothermal brines represent 29% of the global unconventional resources estimated in this study, followed by other clay with a share of 21%. The United States has the largest country share of the unconventional resources in this study with a share of around 30%. The deposit types that exist for unconventional resources in the United States include geothermal brine, oilfield brine, clays, and lithium-boron types of deposits. Production in unconventional deposits may be associated with potential environmental, social and governance (ESG) advantages. For example, tailings at sites originally mined for tin and boron contain lithium in concentrations that could be commercially viable in the future. Reprocessing these tailings (a) is an opportunity for greater resource efficiency (Montero Mining, 2019; Chimata Gold Corp, 2018), (b) creates the possibility of cleaning up sites damaged by past resource extraction, and (c) provides another revenue stream for companies and communities. Other unconventional resources produce lithium as a byproduct of the production of other goods - such as lithium recovered as a byproduct of geothermal energy production and from the produced waters of oil and gas drilling. Lithium production as a byproduct in geothermal and oilfield brines could create additional revenue streams for clean energy or fossil fuel production. However, failure to integrate with existing operations collaboratively or under a single operator may lead to leasing and property rights disputes (GeoEnergy for the Americas, 2020).

Technologies required to produce from different unconventional deposits, shown in Figure 3, are in various stages of development. The Sonora lithium clay project in Mexico (listed under “Other clay”) is a large unconventional deposit under development for commercial-scale operation. Most other unconventional deposits only operate at pilot scale due to low technology readiness levels. Direct lithium extraction (DLE) has potential in geothermal and oilfield brine deposits such as the Vulcan Lithium Project in Upper Rhine Valley, Germany and the Salton Sea, U.S.A. (Warren, 2021; Stringfellow and Dobson, 2021). The jadarite deposit in Serbia refers to Rio Tinto’s Jadar project that had its license cancelled by the Government of Serbia (Sekularac, 2022). The lithium-boron deposit shown in Figure 3 refers to the Rhyolite Ridge project in Nevada, U.S.A. proposed by Ioneer (Ioneer, 2020).

The decade following 2009 saw significant expansion of resources in unconventional deposits. The 2009 CAC (Yaksic and Tilton, 2009) contained 15.4 MMT LCE of unconventional resources constituting 5% of the total, which has expanded to 77.6 MMT LCE in 2022. While this is a significant increase in the span of 13 years, unconventional resources still only comprise 14% of the total. Based on costs estimated in pre-feasibility reports and other investor materials for selected unconventional deposits, we find that at least some unconventional deposits may become cost competitive relative to brine and hard-rock deposits. It would require substantial investment for many years for unconventional deposits to sway the shape of the CAC.

Figure 3
Unconventional Resources by Country and Deposit Type



Notes: These 26 prominent unconventional deposits contain 78 MMT LCE. Geothermal brine holds the largest share among deposit types. Among countries, United States holds the largest share for unconventional resources, roughly 30% - includes geothermal and oilfield brine, clay and lithium-boron.

Conclusion

A cumulative availability curve summarizes estimates of known resource quantities (on the horizontal axis) and production costs (on the vertical axis), providing insight into the future adequacy and affordability of a resource.

For lithium, recoverable resources more than doubled between 2009 and 2023, reflecting increased knowledge about previously known deposits and discovery and evaluation of previously unknown deposits. Knowledge of resources is dynamic. Unconventional resources represent a small share of total resources relative to conventional brine and hard-rock deposits. Thus, it will require substantial and sustained investment for unconventional resources to become significant in the overall stock of known resources. Resources are more geographically dispersed than current production, suggesting future production could be more diverse geographically than current production.

With respect to production costs, the entire cumulative availability curve is feasible to produce below US$12,500 per MT LCE. Given that the estimates in this study do not include costs associated with ESG considerations and taxes, we suggest the range of US$12,500 per MT LCE to US$15,000 per MT LCE as a first approximation of an incentive price – that is, the minimum price necessary to induce investment in production capacity. The incentive price range, which is well below the 2023 average price, suggests that overall operating and capital costs are unlikely to discourage majority of the investments. Physical availability is unlikely to be a limiting factor for meeting lithium demand for the energy transition. The real

challenge in meeting the anticipated demand for lithium lies in society's ability to convert resources into reserves and further into operating mines and processing facilities in a socially and environmentally responsible manner.

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Mineral depletion, Nonrenewable resources, Critical mineral supply, Cumulative availability curve, Lithium.

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Investing in the Batteries and Vehicles of the Future: A View Through the Stock Market

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This study uses high-frequency stock price data to uncover the factors that drive the returns of companies operating in the electric vehicle and battery supply chain. The study's statistical approach separates out the influence of systematic risk factors and factors unique to the supply chain. EV and battery stock returns are found to be exposed to a market and a tech factor. There is also evidence for an EV factor, unrelated to the broader market, that generates common variation among these returns. Lithium companies are found to be exposed to their own unique risk factor.

Introduction

The electric vehicle (EV) and battery supply chain includes a large number of companies that have listed in recent years on a major U.S. stock exchange. This has occurred against a backdrop of dramatic increases in the global demand for EVs, the batteries that power them, and investor interest in the industry.

This study seeks to better understand the behavior of these companies' stock returns, hereafter referred to simply as EV stock returns, and how they relate to the returns of the broader market. I use a statistical approach that can parse out the influence of systematic factors, which affect stock returns more generally speaking, and factors that may be unique to the EV and battery supply chain. This sheds light on the extent to which EV stock returns comove with other stocks and why they comove with each other.

EV stock returns are found to be affected primarily by two systematic risk factors and two factors unique to the industry. The important systematic factors include a market factor, which generates common variation among all stocks, and a factor associated with the returns of tech companies. The ability of these two factors to explain EV stock returns declined in 2023, though, coinciding with a general collapse of clean energy stock prices.

The analysis also uncovers evidence for a factor I dub the "EV" factor. It plays a key role in driving the stock returns of most EV and battery companies but is unrelated to the broader market. There is also evidence of a risk factor specifically associated with the returns of lithium companies (lithium being a key component of the batteries used in EVs).

Relevance

This work contributes to the rapidly growing literature whose goal is to understand the properties and determinants of the returns of clean energy companies. What distinguishes my work from the previous literature is its focus on the EV and battery supply chain, my interest in understanding comovement among these stocks, and the approach I use for measuring systematic risk.

Investors may also find the results of interest, as they shed light on the degree to which the returns of EV and battery companies are correlated with each other and with the broader market. The results also highlight how the returns are exposed to various risk factors, some systematic and some related specifically to the EV and battery supply chain.

Data

The main data used in the study are intradaily stock price data sourced from Polygon.io. Companies are grouped into one of two sets. The first includes companies on the S&P 500 and NASDAQ 100, from which I extract latent factors used as measures of systematic risk. The second set contains companies operating in the EV and battery supply chain.

Using a variety of sources, I identify 78 companies to include in the second set. The list spans the EV and battery supply chain and includes mining companies focused on producing critical minerals, battery companies, EV original equipment manufacturers, and EV charging companies.

One practical issue is the frequency over which to generate returns because market microstructure noise, among other issues, can contaminate high-frequency stock returns. This is of particular concern given the small size and niche lines of business of many of the companies in my study. A 15-minute return window was chosen, based on the results of several statistical tests for the presence of noise introduced in Aït-Sahalia and Xiu (2019). Stocks were removed from the analysis if the tests pointed to significant contamination from noise.

Another practical issue is the number of years to include in the sample. Going back too far in time increases the number of returns but dramatically reduces the number of firms in the analysis. High-frequency data mitigates this problem by increasing the number of observations and allowing relatively short samples. The base results use data for 2022 and 2023. Robustness checks consider other sample periods. For each case, a company is only included if it has a full set of data.

Methodology

As a first step, I use principal components to extract latent factors from the panel of stock returns for companies on the S&P 500 and Nasdaq 100. The approach follows Pelger (2020), which has shown that a small number of latent factors can explain stock returns. A statistical test found in that paper, specifically designed for use with high-frequency data, is applied and shows that the first five principal components are systematic.

Based on their loadings, each of the five factors is shown to have a clear industry interpretation. The first factor loads on all stocks and, hence, resembles a market factor. The second factor, which I refer to as a tech factor, loads positively on tech, communication and consumer discretionary and negatively on defensive sectors, such as utilities and consumer staples. The third and fourth factors are oil and gas factors, while the fifth loads on utilities and real estate.

Each EV stock return is decomposed into a systematic component and an idiosyncratic component using a simple regression model,

$$r_{it} = \alpha_i + \sum_{j=1}^{5} \beta_{ij} f_{jt} + \epsilon_{it}.$$

The systematic component is the part that can be explained by the five systematic factors, while the idiosyncratic component is given the residual. R-squared statistics are used to quantify the ability of each factor to explain the returns.

I also consider a second regression model that includes two additional factors. These are the first and second principal components of the idiosyncratic returns.

Main Results

Figure 1 on the next page shows the explanatory power of the systematic factors for each EV stock. The blue, dark orange, and yellow bars show, respectively, the explanatory power of the market, tech, and the remaining three systematic factors.

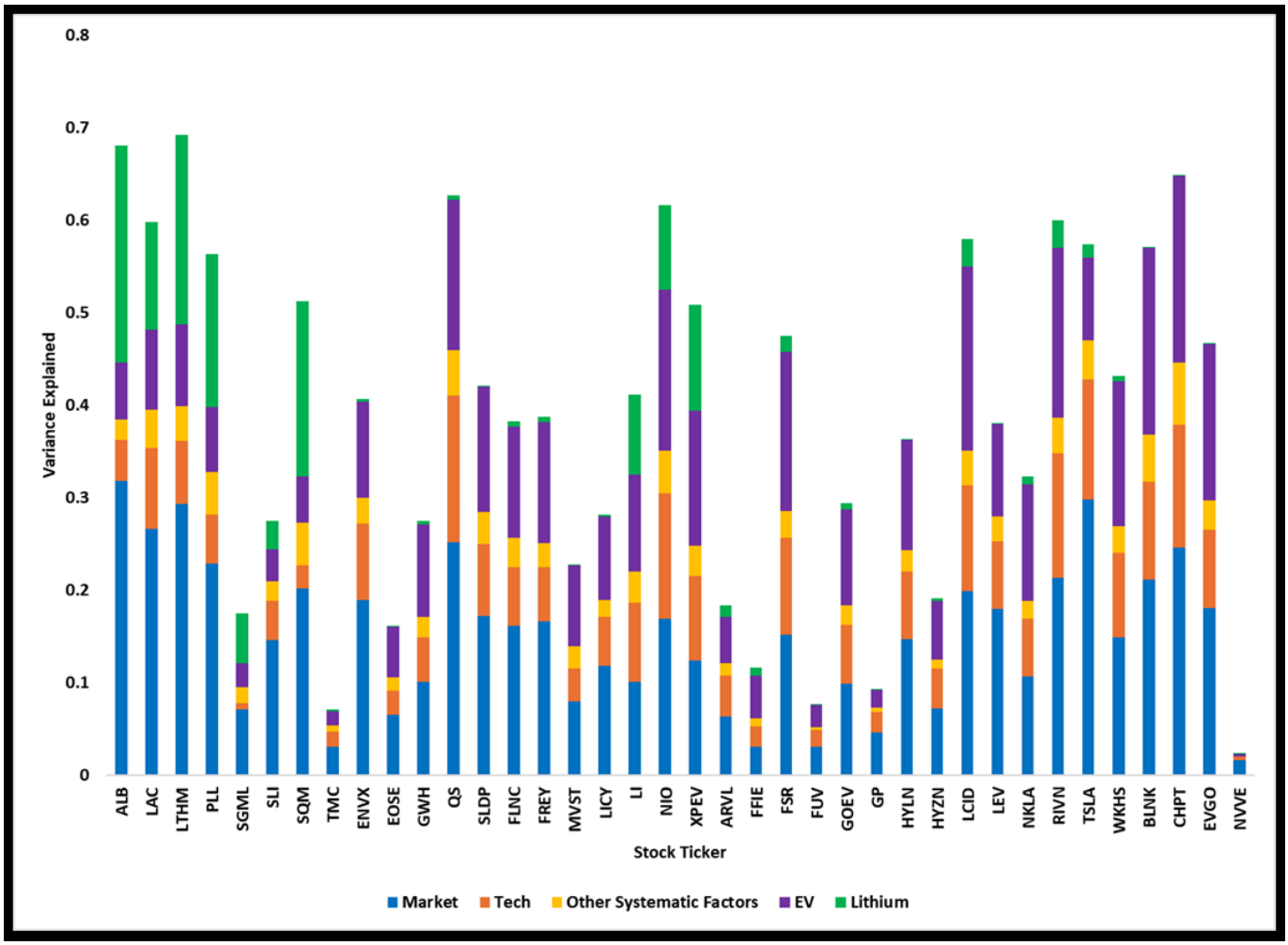
A general pattern that emerges is that both the market factor and the tech factor play an important role in explaining EV stock returns, while the remaining three factors are, more often than not, relatively unimportant. A table in the main paper shows that the explanatory power of the market factor for the typical EV stock, given by the median R-squared across all those firms, is about half that of the typical stock found on the S&P 500 and Nasdaq 100. The explanatory power of the tech factor, on the other hand, is about three times greater for EV stocks.

The tech factor is also found to load on EV stocks in the same direction as it does on tech stocks. As such, it reflects periods where both EV and tech stocks move in the same direction, and opposite to defensive sectors, such as utilities. Previous works, such as Henriques and Sadorsky (2008), have also found a connection between the returns of renewable energy companies and tech companies.

One interesting question is whether EV stock returns comove after controlling for the influence of the systematic factors. To address this question, I apply principal components to the panel of idiosyncratic returns. The first principal component is identified as an "EV" factor, as it loads on all the idiosyncratic returns. The second principal component is found to load heavily on lithium companies, pointing to a risk factor specific to those companies.

The explanatory power of these two factors can be substantial, as seen by the purple and green bars in Figure 1. The R-squared of the EV factor can rival that of the tech factor for many stocks. This points to an important source of common variation in the returns of these companies, one unrelated to the systematic factors. The lithium factor generally has substantial explanatory power for lithium companies, less so for most other companies.

Figure 1
Explanatory Power of Each Factor for Individual Stocks



Note: Mining companies go from ticker ALB to TMC; battery companies from ENVX to LICY; EV companies from LI to WKHS; EV charging companies from BLNK to NVVE. Further details about the companies can be found in the main paper.

Subsample analysis presented in the main paper shows that the explanatory power of the systematic factors declined quite a bit in 2023 for most EV stocks. On the other hand, there continued to be strong, common variation in the returns driven by the EV and lithium factors. That year saw a general reassessment of the viability of many EV and battery companies and a dramatic fall in many of their stock prices. Apparently, this has led to a weakening in the connection between the returns of these companies and the broader market.

Conclusion

Electric vehicles and batteries will be key to a successful energy transition. As demand has grown for both, there has been a proliferation of companies operating in the EV and battery supply chain. In recent years,

many have taken the next step and listed on a major U.S. exchange. My study examines the extent to which the returns of these companies can be explained by risk factors that help stock returns more broadly speaking. It also considers whether there are factors unique to the supply chain. Although these companies are often small and operate in a niche market, they do comove with the stock market more broadly speaking, due to exposure to a market factor and a tech factor. At the same time, they experience important common variation due to several factors specific to their industry.

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Keywords

Stock returns, principal components, electric vehicles, batteries, high frequency data.

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Lithium Price Volatility and the Road to Market Maturity

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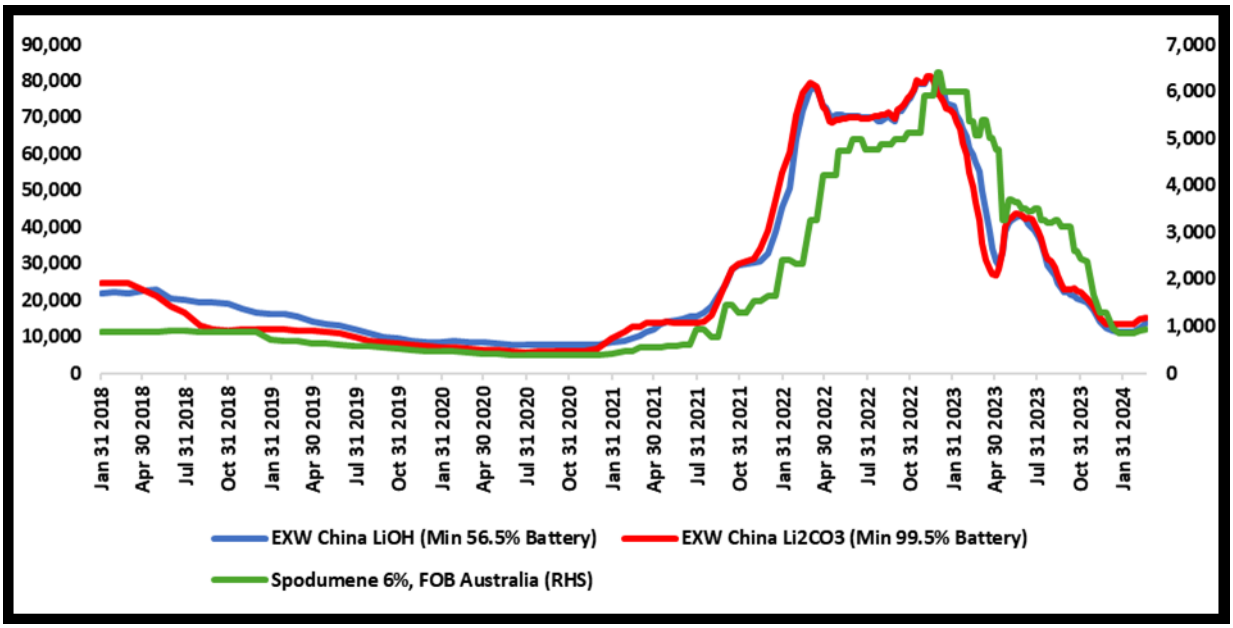
Introduction

Previously a niche speciality chemical, lithium's importance to the energy transition is undisputed. Li demand since 2015 has shown a compound annual growth rate of 23%, invariably a function of the growth in electric vehicles (EVs) and battery energy storage systems (BESS). While there has been no shortage of analyses examining the challenges of scaling Li supply to meet long-term net zero targets, less discussed has been the role of lithium's pricing mechanisms. After all, it is price signals which determine the efficient allocation of capital in any market, particularly in an immature one where China has an outsized role. Li's pricing ecosystem has also come into play over the past year as spot chemical and feedstock prices have plunged from historic highs (see Figure 1).

Figure 1
Lithium Chemical Spot Prices (LHS) and Spodumene Concentrate (RHS), US$/t



Notes: EXW = Ex Works[1], LiOH = Battery-grade Lithium Hydroxide, and Li2CO3 = Battery-grade Lithium Carbonate.

Source: Benchmark Minerals.

But how does Li pricing work? This article sheds some light on the evolution of Li pricing and the future trends to watch as Li's road to market maturity gathers pace.

Lithium Price Cycles

The Li market has been through various cycles over the past several years, key among them being:

- **Spot price collapse of 2019-20**: This was a function of excess spodumene supply from Western Australia that saw spodumene concentrate (SC6) prices fall below US$400/t.

- **COVID recovery and government stimulus cycle**: While headlines in recent months have fixated on lithium's spot collapse, the question should not be why prices fell by 80% but why prices increased to high levels in 2022 (particularly the end-2022 peak of US$80,000/t, multiples above the cost of the marginal tonne). Clearly, the COVID-led stimulus packages of governments, pent-up demand stretching order books (shown by delays) and an element of irrational exuberance in buying patterns had a role.

- **Jan 2023-present**: The price collapse witnessed in 2023 cannot be pinned on a single factor but a range of drivers, the most important being:

  - **Chinese overcapacity**: Even accounting for higher exports in 2023 on a year-over-year basis, cell inventory builds were a key feature of Chinese balances last year. The same also held for cathode inventory, which limited pressure to purchase additional material on the spot market. In many ways, early indications were apparent at the start of 2023 when CATL – the world's largest cell producer in China – began offering lower prices for its cells in exchange for fixed orders from original equipment manufacturers (OEM) customers. CATL's cell discounts, based on a discounted Li carbonate price equivalent to cash costs of its integrated supply, reinforced the company's willingness to use its scale to secure market share, which was particularly acute given the withdrawal of EV subsidies by Chinese authorities at the end of 2022. The episode highlighted a key trend which came to define China's market in 2023 (and even more so this year): dog-eat-dog competition in the Chinese value chain, where margin compression was acute and overseas expansion a priority for tier-1 players.

The Evolution of Li Pricing

Unlike other markets where the road to pricing maturity took many years (*e.g.*, the development of iron ore futures), Li's pricing journey has only just begun. Several important features distinguish the Li pricing landscape, key among them being:

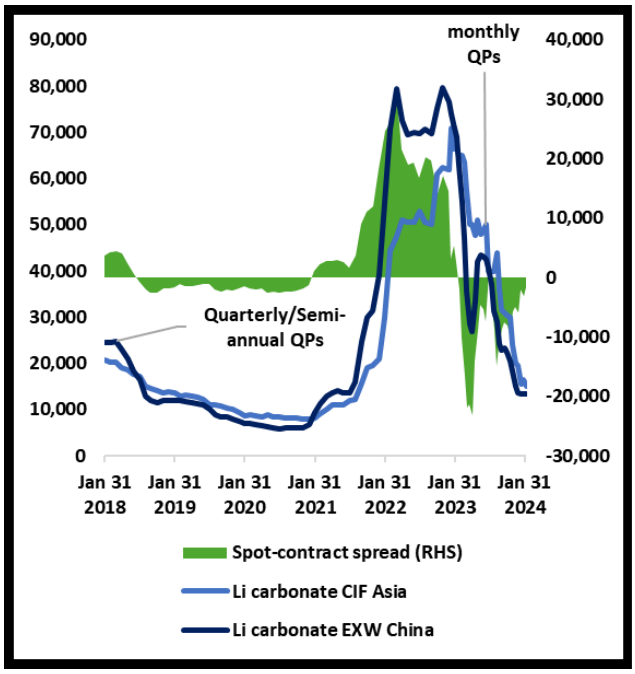
- **The role of product quality**: Li's value chain is deep and includes a range of products (*i.e.*, battery-grade carbonate and hydroxide as well as technical-grade products used in the lubricants/steel/glass industry). Lithium hydroxide - typically used by cathode manufacturers to produce high-nickel cathode active material for high-performance EVs - has typically commanded a premium over carbonate due to the cost of converting carbonate-hydroxide. Product quality also has an impact on tradability and suitability for a successful terminal market mechanism. Despite discussions around storage mechanisms or strategic stockpiling,[2] hydroxide has a limited shelf-life and unlike oil or LNG, battery-

grade products are highly specialized, making physical delivery upon contract expiry a challenge. For instance, participants may not receive material that meets their cathode specification or qualification requirements (*e.g.*, the CME Li contracts are cash-settled).

- **Contract vs. spot pricing***:* Historically, volumes in the Li market were dominated by long-term contracts with fixed-price components (*i.e.*, bilateral deals set to define the pricing level), largely insulating players from spot volatility. This reflected the immaturity of the industry. Fixed price deals guaranteed stable cash flows and was a means to securing financing, particularly for junior miners. Adjustments to the contract price (otherwise known as Quotation Periods, QPs) typically took place on a quarterly or semi-annual basis. In some cases, QPs could be even longer. In this sense, the average selling price (ASP) of some players during this period (2015-21) could be quite sticky and lag developments in the spot market. Typically, the contract price reference has been based on deals reported in the South Korean and Japanese markets – buyers of seaborne lithium (otherwise known as the Li carbonate CIF[3] Asia price) – upon which EU and North American CIF swap prices largely track. The spot price meanwhile has typically been determined by transactions in China, largely a function of its outsized role in the value chain. China represents around ~80% of global cathode capacity, where contracts are much shorter, allowing for greater spot liquidity and procurement channels. Given this liquidity concentration, Chinese buying of Li (above and beyond contracted volumes) has been seen as the industry bellwether for spot pricing.

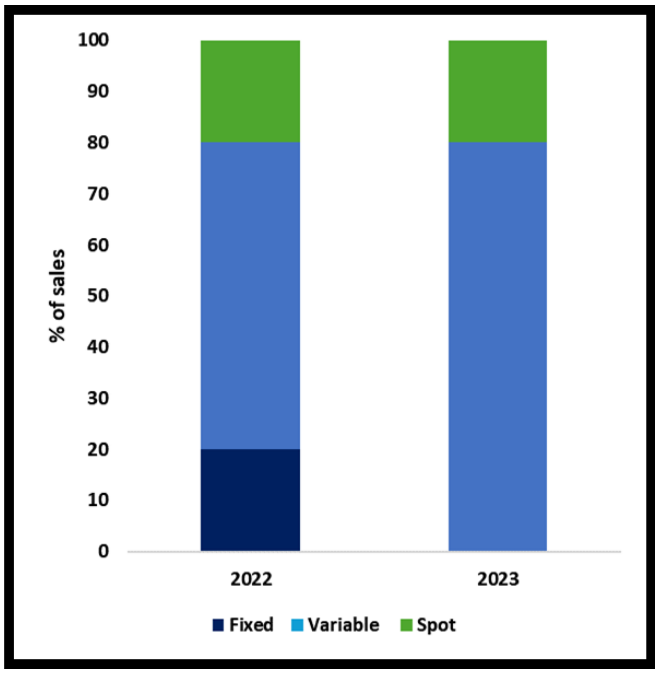
- **The emergence of dynamic pricing***:* The surge in the Li spot price in 2022 however led to a shift in mechanisms. Spreads between the Asia CIF-China EXW price blew out (see Figure 2 on the next page) and attention focused on how ASPs could capture Li's status as a seller's market, with prices being more market-led. For established players with a competitive position in the cost curve, dynamic pricing also made sense as it allowed for greater upside improving valuations and dividend streams and an ability to withstand downside pressures. As a result, QPs were shortened from quarterly to monthly and the contract price moved from a fixed to variable basis with a greater share of contracts moving to indexed-linked pricing, assessed by Price Reporting Agencies (PRAs). The development of more frequent reporting of spot prices from fortnightly to weekly to reflect greater spot volumes also helped with this trend.

Figure 2
Li Carbonate Contract vs. Spot and Spreads (RHS), US$/t



Source: Benchmark Minerals.

Figure 3
Albermarle Sales by Contract Type (2022 vs. 2023)



Source: Albermarle.

- **Role of floor and ceiling prices**: While Li pricing since 2022 has become more dynamic in the chemicals market, several factors prevent a full exposure to spot volatility, namely:

  - **price floors**: These come to the rescue of players during spot meltdowns. Price floors vary across the industry but are typically based on an understanding of long-run marginal costs/incentive prices. While some players may have floors in the range of US$12-16/kt, new project developers – particularly those in North America – would need floors in the low-mid 20s to be feasible given higher capital costs.

  - **price ceilings**: These are governed by bilateral negotiations between buyer and seller which also include discounts and other factors to dampen volatility risks.

In many ways, the lithium market's move to dynamic pricing continues to evolve and is the first chapter in the industry's road to market maturity. However, it has also exposed the value chain to greater spot volatility creating a dynamic tension with efforts to build out the value chain outside China, impacting Net Present Value (NPV) sensitivity for greenfield projects and the hurdle rate for new entrants.

Spodumene Concentrate Pricing: The Search for the Optimal Continues …

Li's pricing journey does not end with shifts in chemical pricing. As a primary feedstock for Li refiners, spodumene concentrate (SC6) pricing has a direct impact on Li refiner profitability and margins. This is

further reinforced by the industry structure of the Li value chain – split between integrated and non-integrated refiners. The latter typically sit at the top end of the Li cost curve, given their lack of integrated feedstock and sensitivity to raw material price volatility. This is similar in many ways to the oil refining cost curve, except without the ability to hedge cracks or pricing differentials.

While the Li chemicals market has coalesced on a clear path to variable pricing; the SC6 pricing landscape remains more fragmented. Currently, several pricing mechanisms exist in the SC6 market, namely:

- **Formula-based pricing**: SC6 has been priced as a formula linked to the price of chemicals tied to indexes for Li carbonate/hydroxide where there is greater liquidity, in some ways similar to the payables method used in cobalt hydroxide pricing.[4] While formulas vary in the market, a typical model would look like the following:

  SC6 formula price = (prevailing chemical price – conversion cost/processing fee + margin) ÷ recovery rate (i.e., number of tonnes of SC6 required) – freight (Aus-China)

The chemical price quotation is typically taken from a basket of PRAs, with a range of quotation periods used in the market.

Other formulas also exist in the market, including formulas which use a floor price for the miner and share of the converter's margin:

*SC6 Price = Cash cost of production + (Prevailing chemical ref. price ÷ Conversion factor - Floor SC6 Price) * SC Producer Margin Share*

- **Fixed price bilateral negotiations**

- **Link to independent SC6 price indices**

- **Spot sales and auctions**: A model was pioneered by Pilbara Minerals' platform auctions and used throughout 2022. Auctions for SC6 material can create competition for the marginal tonne and prove a useful tool for price discovery. However, the mechanism is largely limited by the volume of spot material and frequency.

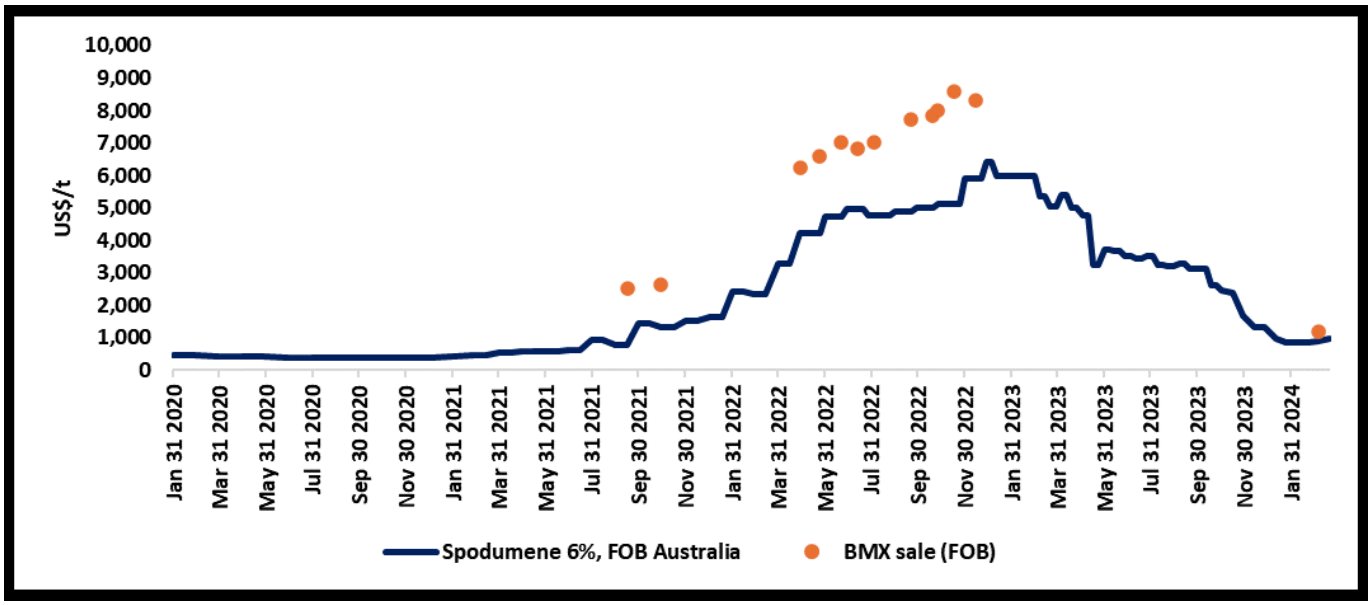
While all the above have been active components in the SC6 pricing ecosystem, 2024 has seen some key shifts take place. These include:

- **QPs used for chemical prices**: While a large percentage of formula-based pricing continues to reference an average of the chemical price from the previous month (M-1 basis), change has been afoot in the market. The volatility witnessed in 2023 has led Chinese converters to push for changes in the QP basis, moving from M-1 to M+1/M+2 basis – meaning that a converter would have greater ability to manage cash flow exposure during downcycles as the chemical price aligns more closely with

SC6 price upon delivery. The shift in QPs can be said to represent a migration in pricing power from Australian feedstock (SC6) suppliers to Chinese refiners.

- **Greater use of auctions by Li majors**: March 2024 saw the re-emergence of auctions as a tool of price discovery. Pilbara – the original pioneer of the auction system – was joined by other major Li producers in selling spot volumes via auction. These included Albermarle (the world's largest producer), Sigma and Mineral Resources. It remains to be seen if this represents a watershed moment for SC6 pricing and a potential stepping stone to something else (*e.g.*, SC6 derivatives pricing). It cannot be disputed that Australia – as the world's leading spodumene producer – has lost significant pricing power in the market, with China now able to leverage new sources of cost competitive supply (*e.g.*, African spodumene) and elastic sources (*e.g.*, Chinese lepidolite).

Figure 4
Pilbara Auction Sales vs. Spodumene Spot Price (US$/t)



Note: BMX refers to Pilbara's Battery Metals Exchange system.

Sources: Company reports and Benchmark Minerals.

How SC6 pricing evolves is not purely theoretical. Given the top-end of refining cost curve being determined by non-integrated producers, SC6 feedstock pricing can make or break converter margins – which has consequences for all players in the lithium value chain.

The Long Journey to Market Maturity

Regardless of whether the current slump in spot prices is setting the market for another round of volatility, several tools exist to manage price risk in the market, with further room for growth expected over the next decade. As noted on the next page, these include:

1) **OEM backward vertical integration:** A trend which has accelerated since 2022's price spike, OEMs are directly investing in raw material offtakes to mitigate price risk and ensure security of supply. Recent examples include GM's US$650 million investment in Li Americas, Ford's lithium offtakes (Albermarle etc.) and Tesla's plan to build a LiOH refinery in Texas.

2) **Floor prices:** OEMs may be encouraged to set a floor price with a Li producer, particularly if that player will act as a baseload source for future EV model launches. The floor price can be set at the cost of production, with prices above that floor set at a floating variable to the spot price. The OEM is encouraged to provide an adequate floor price to ensure security of supply.

3) **Growth of financial instruments to hedge price risk:** A relatively new trend has been the establishment of exchange-based venues to facilitate risk management. The CME Group, for example, has cash-settled contracts for lithium chemicals. Despite the increase of trading volume and open interest (OI) on these venues, liquidity remains relatively low and OI still a small percentage of overall ex-China OEM hedging demand. This should not overshadow the fact that OEM hedging demand is expected to increase substantially, creating significant room for trading volumes to grow and other exchanges to also establish exchange-based products (Till, 2024).

In many ways, the Li market has shown signs of moving to greater market maturity over the past several years – a greater range of players (*e.g.*, the entry of capitalized oil majors), a greater variety of feedstocks and technology routes (*e.g.*, Direct Lithium Extraction), and financing mechanisms (*e.g.*, prepayment deals). The end of fixed-term pricing also heralded a move to greater market maturity.

But that journey has only started. With no established global benchmark, a relatively small spot market and ongoing issues with the transfer of pricing risk, it remains to be seen where Li's pricing journey will move next.

Nevertheless, it is clear that new mechanisms are being sought after to ensure price discovery is not simply a function of China's control of the value chain where liquidity currently remains concentrated. While Western supply chains will never extract themselves fully from China, this does not mean that new pricing mechanisms won't develop. The biggest one to watch next could well be in the spodumene space, as more auctions are held this year. In the chemicals market, exchange-based pricing shows no signs of slowing, with liquidity and open interest gradually building. Until then, China is unlikely to want to give up its current pricing power – reinforcing the point that pricing has become a key battleground in the geopolitics of the lithium value chain.

Endnotes

1 EXW is a recognized incoterm whereby the seller must make a product available at the select location. After that, the buyer is responsible for all costs (*e.g.*, transportation). With EXW the seller is responsible for goods (and costs) until loaded "on board"; once done, liability falls to buyer.

2 It remains unclear what IEA (2022), for example, means by "strategic stockpiling" and at which point in the value chain.

3 “Cost, insurance, and freight (CIF) is an international shipping agreement, which represents the charges paid by a seller to cover the costs, insurance, and freight of a buyer's order while the cargo is in transit,” as phrased at https://www.investopedia.com/terms/c/cif.asp, which was accessed on April 29, 2024.

4 Change also appears to be afoot in the cobalt markets with growing focus on moving away from linking cobalt battery chemical pricing from metal pricing.

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More Reporting Clarity Can Help Fund U.S. Lithium Growth

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Southern Arkansas, once a hotspot for oil production in the early 1900s, is now making headlines for an energy boom of the new century. This time around it's Lithium. ExxonMobil recently announced plans to produce lithium extracted from brine-rich aquifers deep underground in what is known as the Smackover formation, aiming to capitalize on its core drilling and chemical processing capabilities (ExxonMobil, 2023). Other oil and gas giants such as Chevron and Occidental are undertaking similar initiatives. All of these are made possible by a suite of technological advancements in a process known as Direct Lithium Extraction (DLE) (Lorinc, 2023).

There is another, less heralded, parallel between the two energy booms. Just as a regulated reserve reporting update helped spur investors to U.S. oil and gas production nearly 15 years ago, recent regulatory changes to resource and property disclosures in the mining sector could similarly catalyze investment in lithium extraction today.

DLE's Potential

As a major input for Electric Vehicles (EVs), lithium demand is expected to grow by as much as 40-fold by 2040 from today; this is driving increasing interest and adoption of DLE across the industry (IEA, 2021). Auto industry giants such as General Motors and Tesla have recently announced long-term forward offtake agreements with firms involved in Direct Lithium Extraction (GM, 2021; *Reuters*, 2023). While DLE, and particularly the use of selective absorption, is not new—having been first implemented on a commercial scale in Argentina in 1998—its economic viability appears more promising due to projected growth in lithium demand and prices (Livent, 2023).

At its core, DLE uses advanced filtration techniques to separate particles of the silvery-white metal from its aqueous solution in a process both much faster and up to twice as productive as conventional solar evaporation ponds for brine-based resources (Farahbakhsh *et al*., 2024). Thus, DLE operators can also respond swiftly to fluctuations in future demands, minimizing market volatility along the way.

FastMarkets, a commodity price reporting agency, estimates DLE will contribute to 13% of the world's production by 2030, highlighting its critical role in meeting decarbonization milestones (Scheyder, 2023). Moreover, DLE enables the diversification of the global lithium supply by making known lithium

mineralizations economically viable, countering current reliance on the concentrated operations in Chile, Australia, and China.

DLE's impact may be the most profound in North America, where brine concentrations are generally lower (Munk *et al*., 2016). Greenfield DLE project proposals across the continent have surged in recent years, leading analysts at Goldman Sachs to liken what DLE's role in the energy transition to what "shale did for oil" because of its potential to access previously uneconomical resources (Farahbakhsh *et al*., 2024). Currently, all DLE efforts in North America, such as Standard Lithium's Lanxess Project or E3 Metals' Clearwater Project, are still navigating their pilot stages.

Yet it is worth noting that the future of DLE, while promising, faces significant uncertainties, especially in the United States. Legal setbacks in the Smackover region and the recent lithium price slump are among the challenges that threaten the timeline for projects to reach production (Scheyder, 2024; *Carbon Credits*, 2024). Critics of the technology also challenge the claims of its lower environmental impact, a major selling point for DLE (Vera *et al*., 2023). As projects reach their operating phase, their ability to substantiate environmental benefits will prove critical in attracting "green" investment.

Supportive Reporting

Companies looking to develop lithium in the U.S., particularly those smaller than the oil majors, will need to attract capital to fund their investments. That task appears a little easier following the SEC's enactment of the Modernization of Property Disclosures for Mining Registrants amendment in 2021 under standard S-K 1300 (SEC, 2018). The amendment is designed to improve the transparency and detail of mineral resources and reserves disclosures. It expands the required breadth and depth of technical and economic reporting for mining properties, making it easier for investors to understand the operational specifics, geological conditions, and technological maturity of mining operations. As a result, companies are presenting a clearer picture of the full potential and risks of new mining projects, including the possibility and impact of using emerging technologies like Direct Lithium Extraction.

Prior to this amendment, U.S. reporting did not allow mineral resource disclosure, limiting early project investment. Now, declarations of resources can stimulate investment into the technologies that transform these resources into economically viable reserves. In many ways, this regulation resembles the SEC's 2009 Modernization of Oil and Gas Reporting amendment in that it allows the industry to reflect technological advancements (through how resources and reserves are evaluated and disclosed) (SEC, 2008). This amendment allowed shale, which had been previously not considered reportable, to be included in economically producible reserves. Similarly, unconventional brines, not yet declared as reserves, are now detailed extensively, which allows investor assessment of future potential, and supports investment in DLE. As the oil and gas reporting helped to usher in massive capital raise for U.S. shale development, it is hoped that so too might denoting prospects for unconventional lithium projects encourage capital to flow to these projects.

The advantage of SK-1300 — its capacity to accommodate detailed reporting — also presents a challenge as it introduces a level of inherent uncertainty that both the industry and investors must carefully navigate.

In a 2021 report, Alex Grant, co-founder of Lilac Solutions, commented that unconventional brines "are still a little bit more wild west, compared to salar type brines" traditionally used in Argentina and Chile, adding that DLE firms are proceeding with a wide range of reserve assessment methodologies "because they have to" (Jefferies University, 2021).

With that said, it is reasonable to imagine that investor sophistication in evaluating unconventional brines and extraction methods will rise as more projects progress. More project experience will also likely bring with it some standardization as the industry socializes how to present information to investors (just as shale oil development brought with it enhanced investor focus on completion techniques). In sum, the reporting can continue to lay the groundwork for fuelling much needed investment into lithium development for decades to come. What is evident is that the flexibility inherent in SK-1300 to declare reserves has not stopped viable operations in emerging unconventional places, and potential growth in U.S. firm's capabilities to produce lithium.

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Critical Mineral Futures Markets: A Brief Introduction

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Critical minerals will be an increasingly important part of the global economy (Collins *et al.*, 2024; IEA 2024; Boer *et al*., 2021). The rise in demand for critical minerals begs the question of how to develop effective market-based pricing signals that encourage new supplies. Futures markets for many critical minerals are non-existent; those that do exist like lithium and cobalt, however, remain relatively small and less liquid in the U.S. compared to other commodity markets. Thinner and illiquid markets tend to face higher levels of volatility (Redlinger and Eggert, 2016), which makes them less effective in providing pricing signals for investors to effectively allocate capital.

Efficient pricing mechanisms support long-run decisions in allocating capital through price discovery and transparency. One way for investors, companies, and traders to understand how commodity prices will behave is via the futures markets.

Current Critical Mineral Markets

There are three main exchanges in the world on which critical mineral futures trade: the Chicago Mercantile Exchange (CME), the London Metal Exchange (LME)[1], and the Guangzhou Future Exchange (GFEX) in China. Minerals such as aluminum and nickel are widely traded and well-established, but lithium and cobalt—key battery minerals—futures contracts are in their nascent stages of development.

Futures markets enable market participants to buy and sell commodities at predetermined prices and on fixed dates. In other words, market actors can engage in hedging, which is a practice to mitigate downside risk by ensuring a future price to sell or buy the mineral of interest.

Given that the majority of minerals expected to increase in use are manufactured in China—from EV batteries to solar panels—many contracts are priced relative to the cost of insurance and freight to China and delivered there. As a result of the high level of concentration in manufacturing activity, the most heavily traded critical mineral markets are in China.

A challenge for effective pricing for critical minerals comes from the nature of minerals themselves. Minerals can come in different chemical forms and grades that have different applications. Take the example of the CME's lithium hydroxide futures contract and compare it to the GFEX's lithium carbonate contract. Lithium hydroxide is broadly used for nickel-based battery cathode chemistries while carbonate is used in lithium-based cathode chemistries.[2] This difference, as we will see later, leads to arbitrage opportunities between markets (Till, 2024).

Different forms of minerals can make it difficult for the market to understand which one is most important. For example, there are different contracts for different grades and end-uses (see Table 1 on the next page). One of the key issues in hedging, for instance, is basis risk, wherein the price performance of a futures

contract can differ from the physical commodity. As a result, if a buyer of cobalt sulfate does not have a futures contract that effectively replicates the price risk of the underlying commodity, they may not be able to hedge effectively. The standardization of lithium, nickel, cobalt, manganese, and others would be a challenging yet important step towards critical mineral market future maturity.

Hedging enables buyers and sellers up and down the supply chain to manage price risk. Generally, speaking, sellers of a commodity can fix their price risk to avoid selling at a lower price. Buyers of a commodity can fix the price of a commodity to minimize their input costs. Purchasers of cobalt and lithium, for instance, could be electric vehicle battery manufacturers, while sellers are either mining companies and/or commodity traders.

Hedging activity happens through the futures market, where buyers and sellers are matched. One key feature of the futures market is the interaction of producers, speculators, and end-users. The interaction of these three broad groups is what enables efficient price discovery. Speculators are important in the provision of liquidity for both producers and consumers of commodities. For instance, a speculator can take on the other side of a producer hedging, so effectively betting that prices will rise vs. fall. This enables the producer to fix its selling price, while the speculator has the potential to earn a profit through its hedging service and if they are right about the direction of prices.

Having different forms of minerals, traded on different exchanges can open the door to potential arbitrage opportunities. As Till (2024) notes, for example, in an analysis of the lithium market, CME lithium hydroxide futures are being spread in the U.S. market versus GFEX lithium carbonate contracts.

Table 1

Selected Mineral Contracts

Mineral	Contract	Specification	Delivery Location	Pricing
Cobalt	Cobalt alloy grade	>99.8%, in warehouse Rotterdam	Europe	$/lb
	Cobalt Standard Grade	>99.8%, in warehouse Rotterdam	Europe	$/lb
	Cobalt 99.8% Co min Basis	>99.8%	China	Yuan/tonne
	Cobalt Sulfate 20.5%	Cobalt Sulfate	China	Yuan/tonne
	Cobalt tetroxide 72.6%	Cobalt tetroxide min 72.6%	China	Yuan/tonne
	Cobalt hydroxide payable indicator	Cobalt hydroxide	China	$/tonne
	Cobalt Hydroxide index	30% Co min, Cobalt hydroxide, cif	China	$/lb
Lithium	Lithium carbonate min 99%	99% LiCO3 technical & industrial grades	China	$/kg
	Lithium carbonate 99.5%	99.5% Li2CO3 min, battery grade, cif China, Japan, & Kprea	China	$/kg
	Lithium carbonate 99%	99% LiCO3 technical & industrial grades, ddp Europe & US	Europe	$/lb
	Lithium carbonate 99.5%	99.5% min, battery grade, ddp, Europe & US	Europe	$/kg
	Lithium hydroxide monhydrate min 56.5%	LiOH.H20 56.5% LiOH min, technical & industrial grades, cif,	China	$/kg
	Lithium hydroxide monhydrate min 56.5%	LiOH.H20 56.5% LiOH min, battery grade, ddp, Europe & US	Europe	$/kg
Nickel	Nickel 4x4 cathode	Nickel 4x4 cathodes	Rotterdam	$/tonne
	Nickel briquette	Nickel Briquettes, delivered Midwest US	US	$ cents/lb
	Nickel 4x4 cathode all-in price	Nickel 4x4 cathodes, Midwest US	US	$ cents/lb
	Nickel min 99.8%	>99.8% briquette, cif Shanghai	Shanghai	$/tonne
	Nickel mixed hydroxide	Mixed hydroxide precipitate, cif, China, Japan & S. Korea	East Asia	$/tonne
	Nickel mixed hydroxide	Mixed hydroxide precipitate payable indictaor %, LME, cif	East Asia	$ cent/tonne
	Nickel mixed hydroxide	Mixed hydroxide precipitate, fob, Indonesia	Indonesia	$/tonne
	Nickel Sulfate	Min 21%; max 22.5%, cobalt 10ppm max, exw, China	China	Yuan/tonne

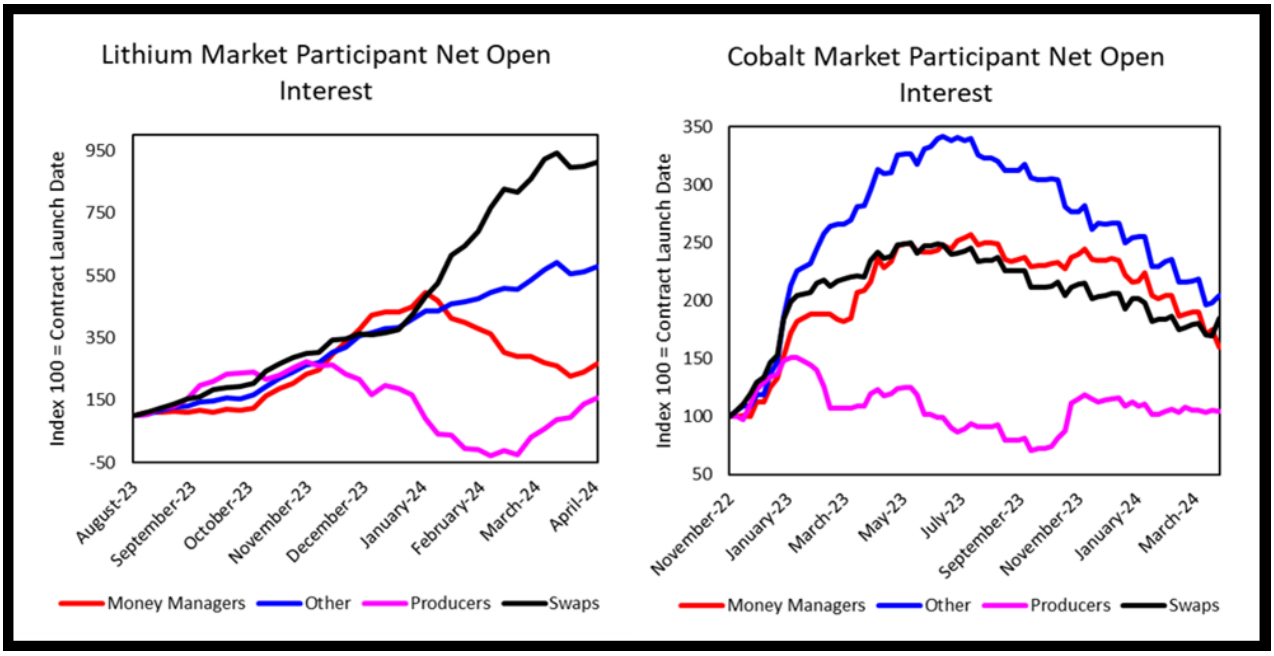
Fastmarkets

Notes: delivered = delivered duty paid
cif = cost of freight and insurance
ddp = delivered
fob = free on board

Lithium & Cobalt Futures Markets

Current cobalt and lithium futures markets at the CME remain underdeveloped relative to other critical mineral contracts such as aluminum. Data from the U.S. Commodity Futures Trading Commission (CFTC) show the recent relative changes in open interest across types of market participants for the lithium hydroxide and cobalt metal cash-settled contracts. In particular, Figure 1 illustrates the relative lack of participation by producers.

Figure 1



Sources: CFTC, Author's calculations.

Today's lithium and cobalt markets face a lack of liquidity, which restricts the ability of participants to use the futures market for improved price discovery and transparency of price movements. In contrast with aluminum futures where producers make up most of the activity, in the case of cobalt, producers make up the smallest share. This distinct lack of producer hedging in the market for cobalt is a limiting factor in the market's path to maturity and ultimately, new cobalt mines through reduced price uncertainty.

Cobalt and lithium's dearth of producer hedging limits these markets' potential for growth. In the U.S. for instance, there is over 850 GWh worth of battery cells that are either under construction or planned between 2023 and 2030—much of which will be for nickel-based cathode chemistries (Turner, 2024). As a result, there will be an increasing need for hedging up and down the supply chain to lock in investment of new producers of nickel but without an improvement in liquidity, lithium and cobalt projects could face difficulty finding investors due to concerns with the impact of low prices on project profitability.

The Path Forward

The stepwise shift in demand for critical minerals in the following decades necessitates an equal supply response. For the investors and companies to effectively allocate capital towards increasing the supply of minerals, the market must improve pricing efficiency. Deepening critical mineral futures markets will be an important step in the path to the renewable energy transition.

Furthermore, differentiating products such as lower carbon aluminum or nickel are important and necessary steps in monitoring the environmental footprint of these minerals. Shoring up critical mineral futures markets, however, remains the key issue. Developing efficient lithium, cobalt, and other critical mineral futures markets should be paramount and will be a bedrock for the energy transition.

Endnotes

1 Voyles (2024): "The London Metal Exchange, which has long served as the main venue for price discovery and risk transfer in industrial metals, has listed futures on cobalt and lithium, but so far neither has gained much of a following."

2 Nickel-based cathodes are the dominant battery chemistries in the U.S. while lithium-based cathodes are more prevalent in China.

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The Rise of the Lithium Futures Market

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The global shift towards net zero emissions has significantly increased demand for traditional commodities and created new markets, particularly within the battery supply chain supporting electric vehicles and energy storage systems. This paper explores the performance and trajectory of the lithium futures market, which emerged to manage price volatility in the booming lithium industry. Lithium futures, first launched on major global exchanges in 2021, have shown a pattern of growth akin to early iron ore futures markets. Initially, the market saw significant volatility, with spot prices fluctuating drastically. Despite this, traded volumes and open interest in lithium futures have gradually increased, peaking in mid-2024, indicating growing market adoption and liquidity. A key challenge for the lithium market is achieving a level of liquidity observed in mature commodity markets. However, for a very young market there are signs that lithium futures are on the right path to becoming a liquid futures market. Increasing participation, a more developed forward structure and multiple types of contracts available are all positive signs of a maturing market.

Introduction

The global race to net zero has boosted demand for many traditional commodities and given rise to new markets. From environmental commodities through alternative fuels to metals and minerals, we are witnessing a change that commodity markets have not seen in decades. With this shift in the physical markets comes a raft of challenges and opportunities for financial commodity markets.

A key theme of the energy transition is the exponential growth of the battery supply chain supporting the electrification of the industry, predominantly in the electric vehicle and energy storage system space.

The lithium futures market is one of the newest markets that have emerged because of the booming battery supply chain.

In this paper I examine the performance of lithium futures since their launch in relation to markets that have certain similarities, as well as commodity futures that can help us assess the possible trajectory lithium futures may take in the coming years.

The Birth of Lithium Futures

Lithium futures that are available for trading on exchanges outside of China are cash-settled. This means there is no physical exchange of the underlying product upon expiration. Instead, the financial profit or loss from an expiring position is calculated as the difference between the traded price of the futures and the monthly average of all spot price assessments published in the spot month by Fastmarkets, a leading commodity price reporting agency. Fastmarkets' prices are used in physical contracts guaranteeing futures convergence to the spot price at expiry.

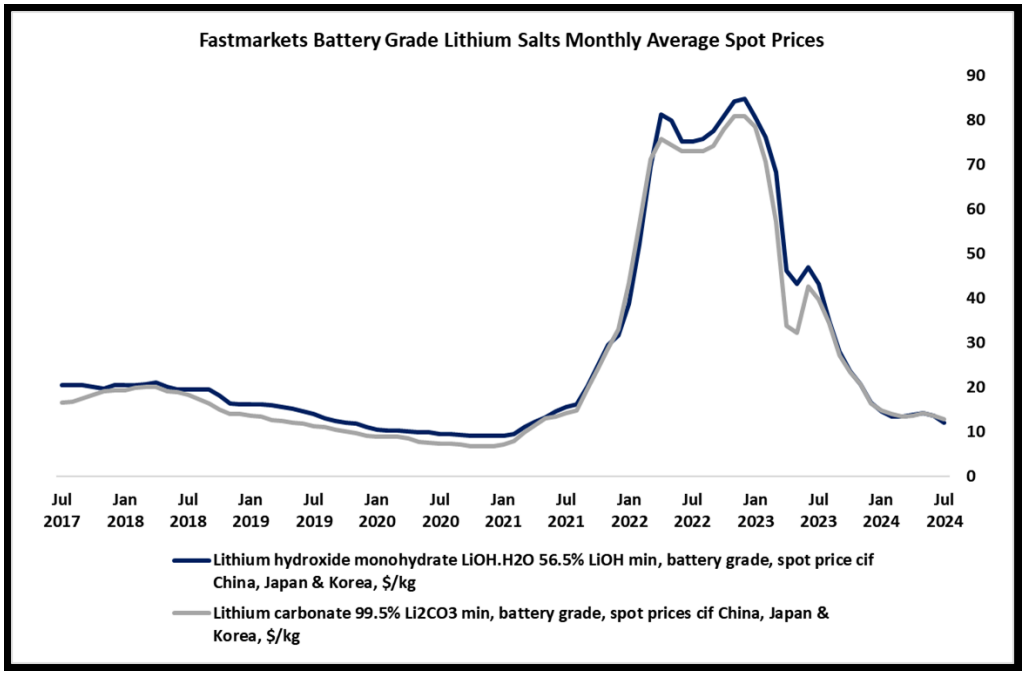
Today, cash-settled lithium derivatives encompass a suite of lithium futures and options listed on three major global exchanges. Lithium hydroxide futures are listed on the CME, the London Metal Exchange

(LME) and on the Singapore Exchange (SGX); lithium carbonate futures are traded on the CME and SGX; and additionally, lithium hydroxide options are listed on the CME.

Lithium hydroxide was first to launch on the CME on Monday, May 3, 2021, followed by LME on Monday, July 19, 2021, and SGX on Monday, September 26, 2022.

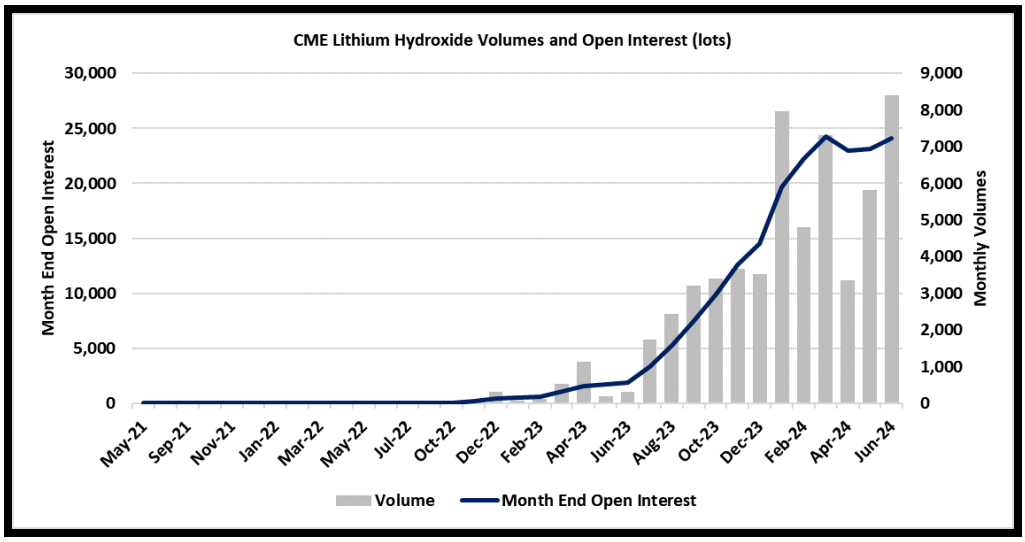
A Short History of the Lithium Futures Market

The launch of lithium futures came at a time when volatility in the spot market was picking up. The spot market popped from prices in the $10's/kg to $85/kg in just about 18 months after the launch and dropped back down to mid-$10's over the next 12 months.



Source: Fastmarkets.

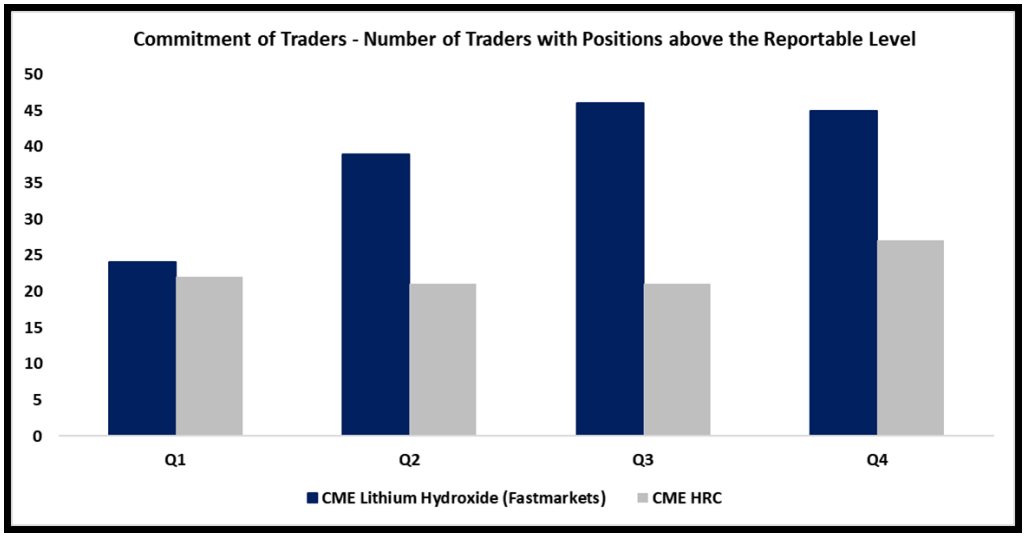
Initially, this may have been a reason to cautiously enter the market, but it was also a trigger that futures must be used to manage price volatility. Beginning in mid-2023 we started to see a gradual increase in traded volumes and open interest both of which peaked in June 2024.



Source: CME Group.

Together with the growing open interest, the U.S. Commodity Futures Trading Commission's (CFTC's) Commitment of Traders report show that the number of traders with positions above the reportable level have also been gradually increasing over the past four quarters and currently that number stands at 45 traders.

It is worth noting that another cash-settled CME futures contract, the Steel (Hot-Rolled Coil) HRC contract, did not attract as much diversification in the first four consecutive quarters it consistently appeared in the Commitment of Traders report in 2013-2014. The total number of traders with positions above the reportable level hovered around the 25-level mark. Lithium futures reached a lower level of concentration over the same time horizon. We can view this as a sign of increasing adoption and a market that is taking a positive trajectory in terms of its utility to the industry.



Source: CFTC.

Iron Ore 2.0?

We often compare the evolution of the lithium market to that of the iron ore market in the early 2010's. This is largely because the iron ore market made a shift towards spot-based, index-linked pricing mechanisms similarly to what we are seeing in the lithium supply chain today. Another similarity was the emergence of a futures market in 2010 on the Singapore Exchange, creating a reinforcement loop between the physical and financial market supporting the growth of the spot market together with trusted risk management tools. Iron ore futures are also cash-settled, yet another parallel with the lithium market.

Simultaneously to the emergence of a futures market in Singapore, the Dalian Commodity Exchange launched a domestic Chinese future. The booming Chinese futures market created a spillover effect and instead of competing for volumes it supported liquidity on the SGX. Yet again, another parallel can be drawn. A physically delivered lithium carbonate futures was launched by the Guangzhou Futures Exchange and almost overnight volumes exploded, contributing to an increase in liquidity on the CME Group's COMEX exchange.

One of the challenges and comments that are often raised is the limited liquidity in lithium markets. Indeed, a liquid futures market is critical to support the forecasted demand growth. Banks need to be able to price risk to finance projects, consumers need to lock in commodity prices to price their end products securing profit margins, producers need to manage volatility to attract financing at the right cost of capital.

However, deep liquidity in futures markets is not something that is switched on and off like a light switch. It requires time, effort and an entire ecosystem to work together to grow these markets. Both on the physical and financial side. This means, exchanges, banks, brokers, producers, consumers, traders and the price reporting agency need to work in an almost concerted effort to build up liquidity.

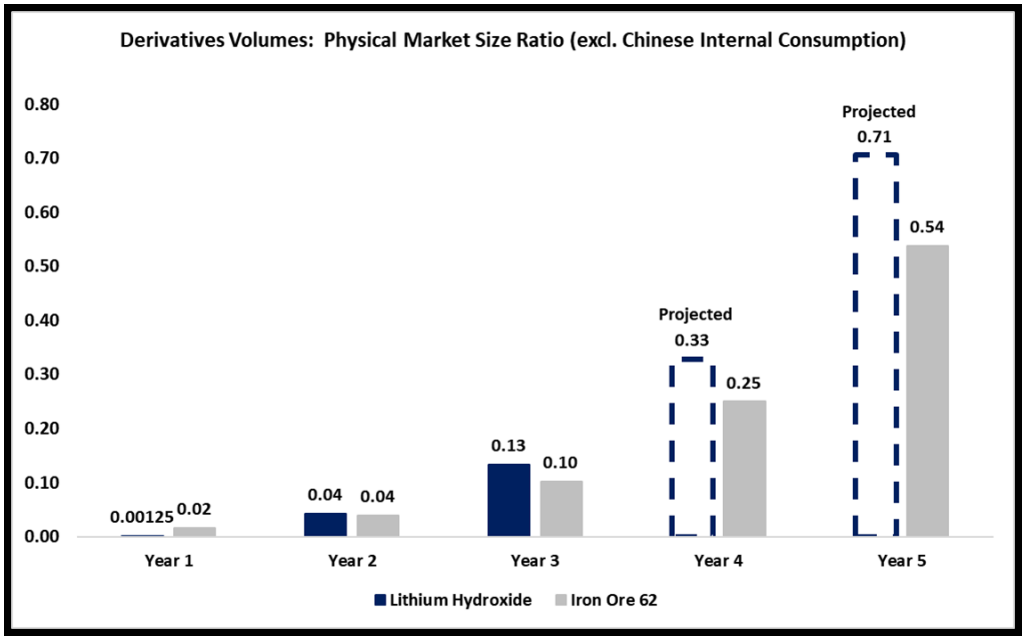
To assess the current state of the market and gain insights into what may lay ahead, we can compare the lithium market to existing contracts that have common characteristics. Unlike the base metals derivatives, which are physically-settled, and have been trading for decades in many cases, the steelmaking supply chain derivatives launched more recently and the contracts are cash-settled. Therefore, I believe they are a better comparison.

Comparing the liquidity to that of today's base metals markets such as aluminium and copper, or iron ore market will uncover lower liquidity compared to the more mature markets. But is it right to compare markets that have existed for 14+ years, and in the case of base metals, more than 40 years, to a market that is only in its fourth year? I argue that we will gain more insights when making comparisons at the same point of maturity.

When assessing the derivatives market size and maturity, a measure that can be useful is the ratio between the derivatives volumes and physical market size. Even though the lithium futures market is only in its third full year of trading, we can estimate that this ratio will reach 0.13x the physical market, excluding Chinese domestic consumption, as we are comparing the seaborne market which the Fastmarkets assessment is reflective of. Taking iron ore futures at the same point of maturity may reveal some clues

as to how lithium futures are performing and what the possible trajectory may look like in the next few years.

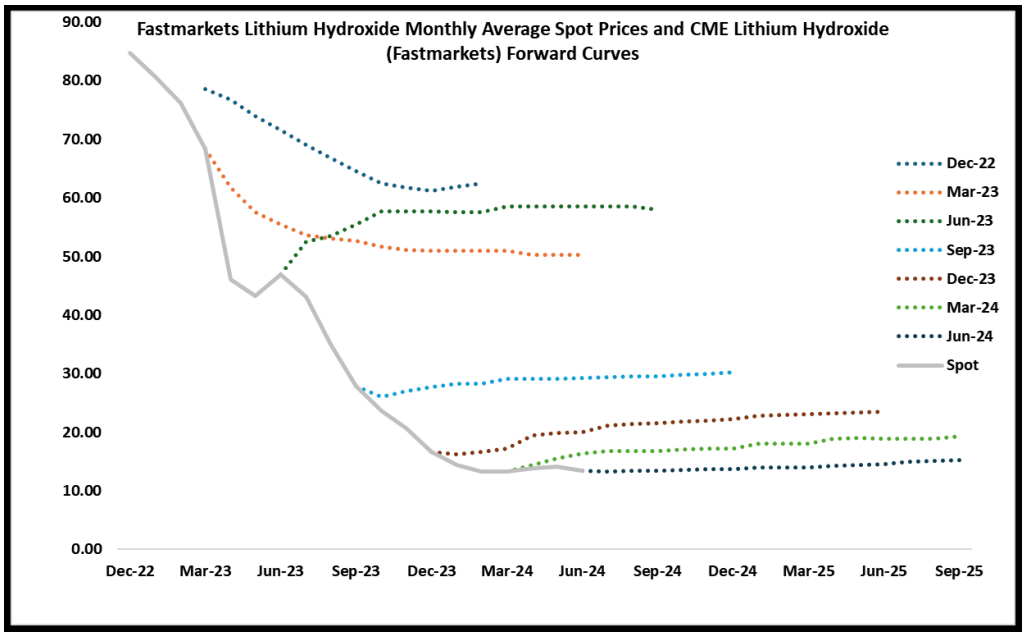
That ratio was on similar levels as can be seen on the chart, and arguably lithium is taking a steeper path. Provided lithium futures continue to track with a similar dynamic as iron ore did in its first five years, we could see derivatives volumes reach 0.33x and 0.71x the physical market in 2025 and 2026 respectively. Zooming out, today iron ore futures are trading at 3.5x the physical market and if this is any indication of the potential for lithium, we are just at the very beginning of this exciting market evolving to a mature futures market.



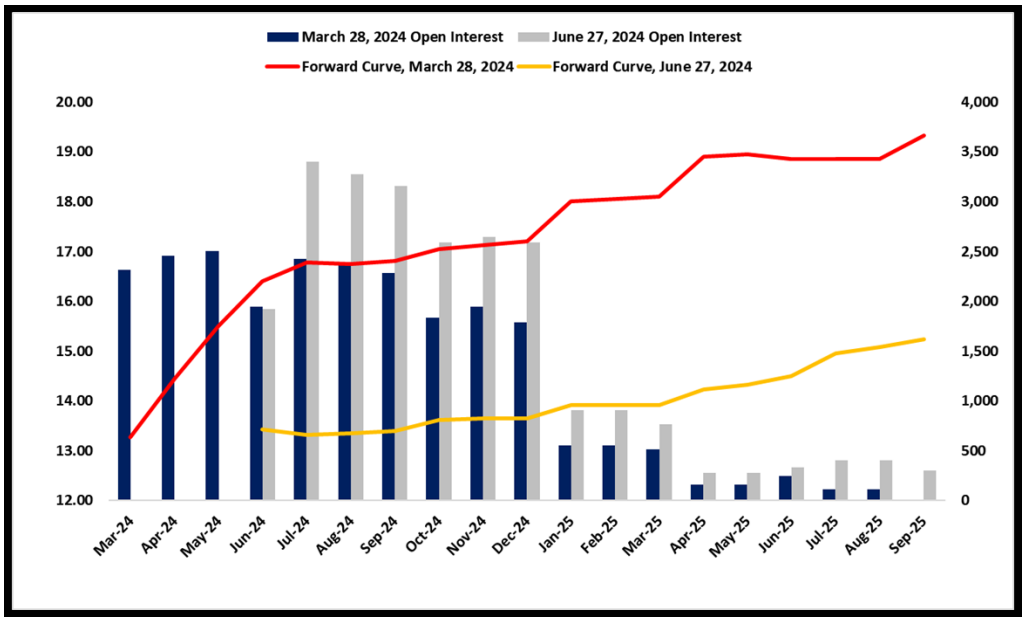
Sources: CME Group, SGX Group, and Fastmarkets.

The Forward Curve

Trust in the futures market is often associated with the forward curve. Mature markets have forward curves that are, by and large, accepted as the market value of future expirations at current market conditions. At times the forward curve can take on a shape that market participants will not view as efficient. This was the case with lithium, especially in Q1 2024. At the end of March 2024, there was a very steep contango in the market and consumers were finding it hard to justify buying forward at close to 40% premium over spot month for the March 2025 expiry. As the market continued to grow and mature in Q2 2024 the steep contango flattened and currently we are seeing a much flatter curve. Open interest in the deferred months has also increased, which can be an indication that the shape of the curve is viewed as providing opportunities for consumers to hedge. This is another positive sign as the market continues to develop.



Sources: CME Group and Fastmarkets.



Source: CME Group.

What Comes Next?

The lithium derivatives market has all the necessary ingredients to continue its path to becoming a mature, liquid market. Demand growth, financing needs, bank participation, financial counterparties, broker engagement, consumer hedging are all necessary for the market to expand. What is needed is greater producer participation. More recently there are signs that producers are beginning to embrace the futures

markets with leaders like Ganfeng Lithium indicating that they will be setting up a hedging desk. Naturally, this is another positive sign of a maturing market.

These are early days, and there are still many unanswered questions. Are all the tools available? Will new contracts emerge? Will the market structure resemble that of base metals with a single point of liquidity, like LME aluminium or copper, or will it be closer to the markets where pricing for different products in the value chain have independent futures markets, like the steelmaking chain, or energy and some agricultural markets?

While there is a case to be made for both paths, the recent drive from spodumene producers, the raw material used to produce lithium chemicals, to price spodumene independently of lithium is picking up pace. Many producers, especially in Western Australia, are openly vocal about the need for a more liquid and transparent spot pricing mechanism. This trend lends itself to the establishment of spodumene futures. I believe it is a matter of time before we see these launch on commodity exchanges attracting new participants that will be able to minimise basis risk and use tools that are more aligned with the physical products they trade.

Lithium markets are without a doubt very young markets and it is easy to say that they are illiquid compared to base metals markets or other commodity markets. However, by analyzing how far this market has gone in its short existence we can see that the growth trajectory is taking a steeper path than markets like iron ore did in the same point of their maturity. This is reassuring for the prospects of one of the most exciting commodity futures launched in recent years.

Author Biography

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Przemek Koralewski is a distinguished Commercial and People Leader with over 15 years of experience in the commodity derivatives and intelligence industry, covering markets in North America, Europe, and Asia. Currently, he serves as the Global Head of Market Development at Fastmarkets, where he leads a global team focused on spot pricing mechanisms and commodity derivatives.

Koralewski's career is marked by his innovative approach to business development and his ability to cultivate talent and drive revenue growth. His previous roles include Head of Business Development at SSY Futures Ltd. and a significant tenure at NASDAQ, where he held various leadership positions, including Head of Freight and Ferrous Derivatives and AVP, Head of Data Sales, EMEA. In these roles, he demonstrated exceptional skills in managing internal and external stakeholders, developing go-to-market strategies, and increasing market share and profitability for areas under his management.

Koralewski's expertise spans the commodity markets, commodity data and derivatives trading, with a special interest in evolving and growth markets. He holds an Executive M.B.A. from London Business School, reflecting his commitment to continuous professional development and strategic leadership.

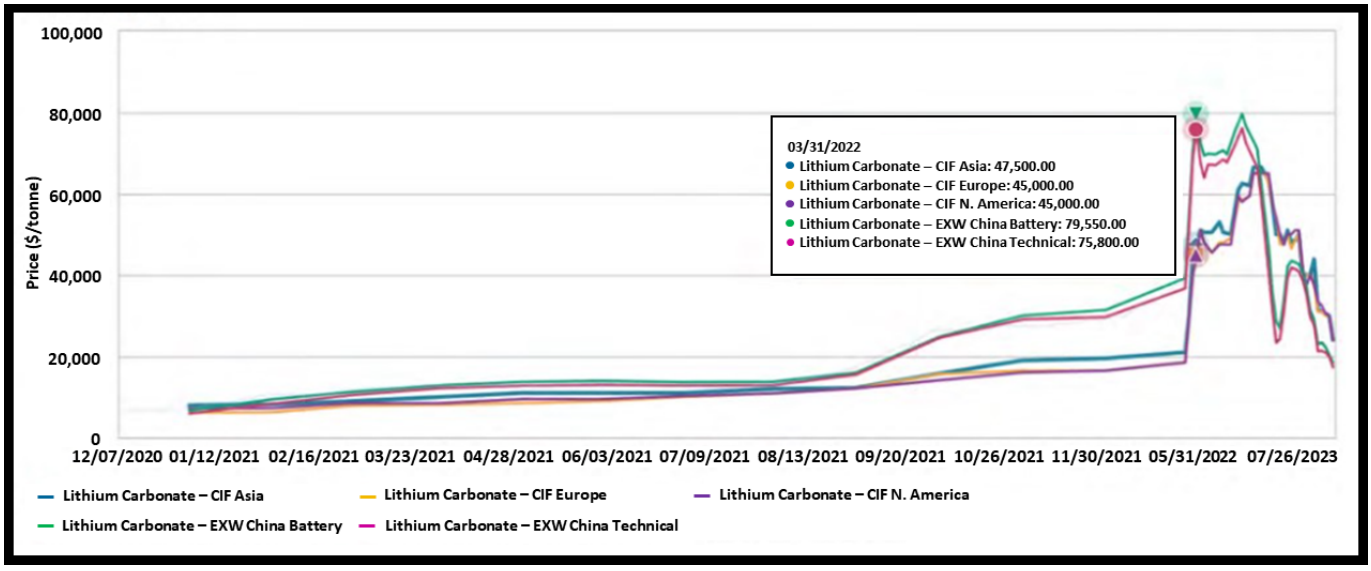
Hedging Battery-Material Price Risk: The Case of Lithium Compounds

Hilary Till
Managing Co-Editor, *Commodity Insights Digest*; Honorary Senior Visiting Fellow, Bayes Business School - City, University of London, U.K.; and Principal, Chicago-based Premia Research LLC, U.S.A.

Introduction

Amongst other factors, the success of the clean-energy transition currently relies on lithium. With their distinctive properties, lithium compounds are a crucial component in lithium-ion batteries, electric vehicles (EVs), and energy storage systems. There are currently no foreseeable alternatives to lithium's use in modern battery technology. But as shown in Figure 1, lithium-compound prices have been on a rollercoaster. And Citi Research (2024) notes that "[l]ithium price volatility is set to continue in 2024[,]" especially given that "[l]ithium is extremely sensitive to shifts in fundamentals." Can this price risk be hedged by industrial consumers, thereby facilitating the scaled-up use of one of the essential materials in the energy transition? This article will briefly examine this question solely from a U.S. perspective, and the answer is promising.

Figure 1
Lithium Spot Pricing 2020-2023



Source: Gordon (2024).

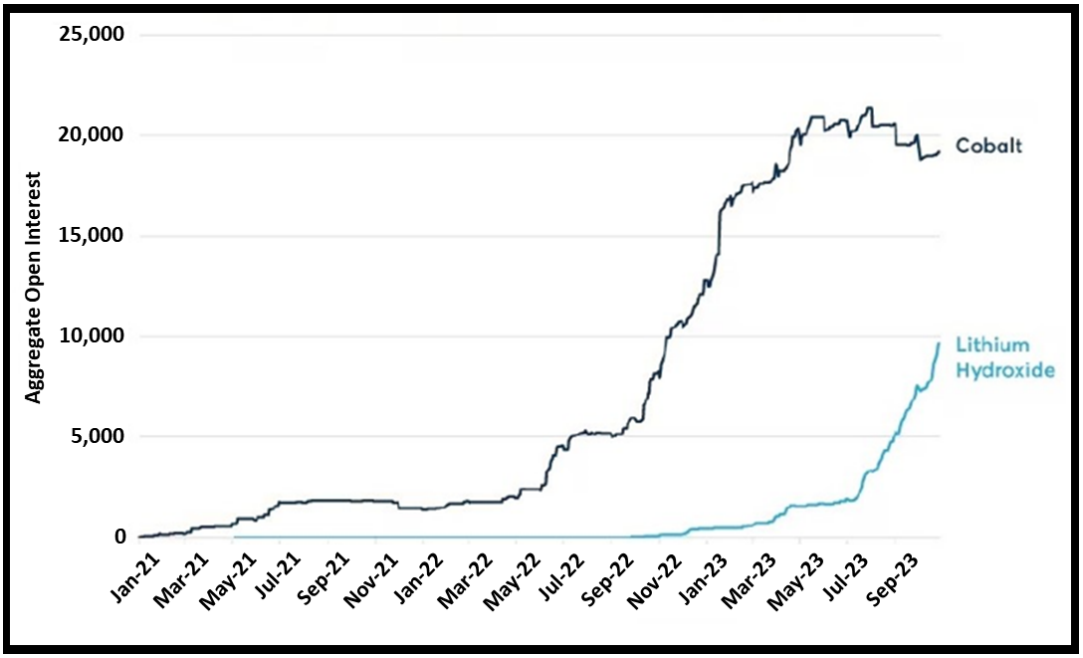
CME Group's Lithium Hydroxide Futures Contract

While the London Metal Exchange's cash-settled, battery-grade lithium-compound contract currently shows zero current activity, the CME Group's lithium hydroxide contract started gaining traction in July

2023, as seen in Figure 2. That said, the CME contract's open interest is currently at the lower end of viable contracts, as illustrated in Figure 3 in the next page.

For completeness, we note that the CME contract is "financially-settled based on the lithium hydroxide assessment published by Fastmarkets, which reflects the cost, insurance and freight (CIF) spot price in China, Japan and South Korea, where the majority of battery manufacturing capacity is concentrated," as explained by CME Group (2021).

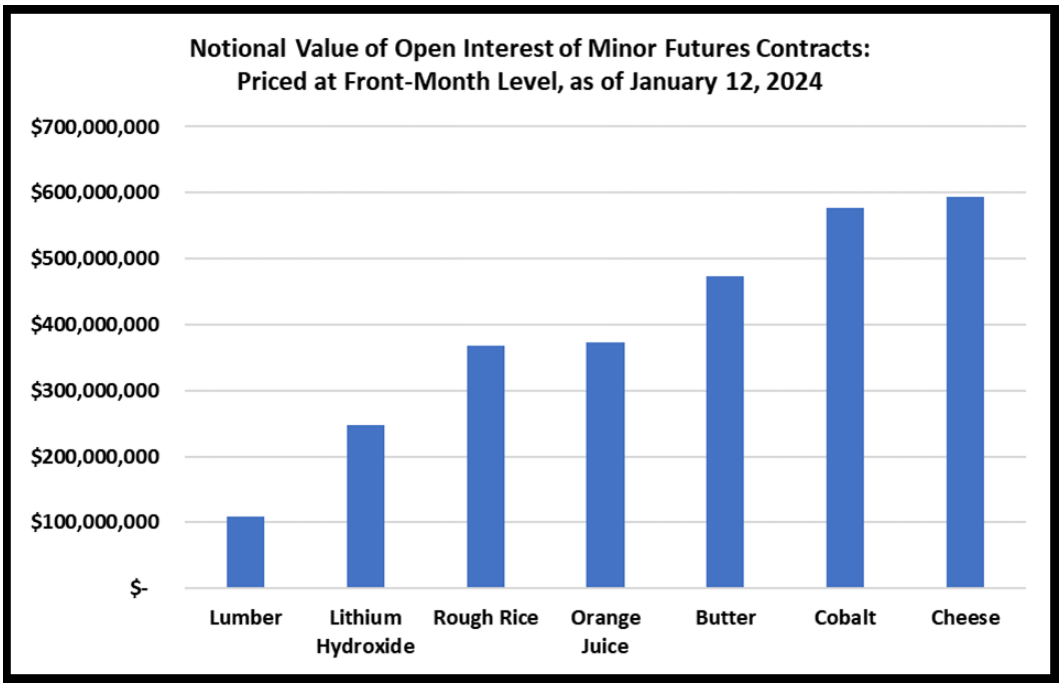
Figure 2
Cobalt and Lithium Hydroxide Aggregate Open Interest



Source: Norland (2023).

Note: As of January 12, 2024, cobalt's aggregate open interest was 19,398 contracts while lithium hydroxide's open interest was 16,604 contracts.

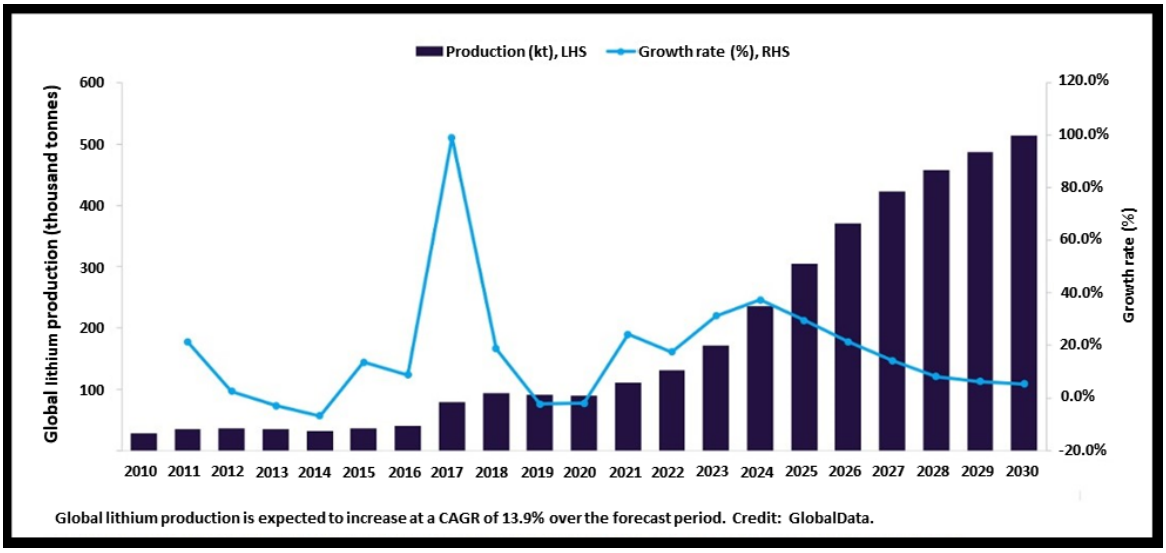
Figure 3
Notional Value of Open Interest of Minor Futures Contracts



Sources: Premia Research LLC, CME Group data.

Fizaine (2018) had warned that futures contracts have not succeeded when the market size has been insufficient. In the past, the probability of success for a lithium futures contract, according to his model, was as low as 0.39% (that is, lower than 1%.) But the growth in the production of lithium, in line with its crucial role in battery technologies, has evidently made such a prediction obsolete. Figure 4 on the next page provides the historical growth in lithium production since 2010, along with plausible forecasts.

Figure 4
Global Lithium Production, Including Forecasts



Source: Mining Technology (2023).

Market Structure

A sufficient market size is not the only factor in determining whether a futures contract can be successful. There must also be a commercial need for hedging *and* a pool of speculators must be attracted to the market (Till, 2016). Regarding the former factor, Daisy Jennings-Gray at Benchmark Mineral Intelligence noted in Devitt and Liu (2024) that "[l]ithium hedging strategies are becoming increasingly important to … automaker procurement teams, given the (price) volatility … over the last few years." If there is not a natural producer short to be on the other side of long-side demand, then speculators (or non-commercials) would need to be induced to enter the market on the short side. Petzel (2001) helpfully explains how this can be achieved. For those "who might supply speculative capital, one way to minimize risks is to enter spread positions across markets. By monitoring the basis between related markets, traders are more likely to present bids and offers and supply the necessary liquidity to a new market without incurring too much risk," he wrote.

Let us examine the current market structure of the CME contract in order to understand the interplay of commercials and noncommercials. This understanding will assist us in making predictions on the current and future success of the contract.

The U.S. Commodity Futures Trading Commission (CFTC) issues the Disaggregated Commitments of Traders (DCOT) report. This report provides the breakdown of open interest between pure handlers of commodities and other market participants. Specifically, the DCOT report includes the following categories of large traders: (1) Producer/Merchant/Processor/User, (2) Swap Dealers, (3) Managed Money, and (4) Other Reportables. Let us examine a recent DCOT report that includes the CME contract. See Table 1 on the next page.

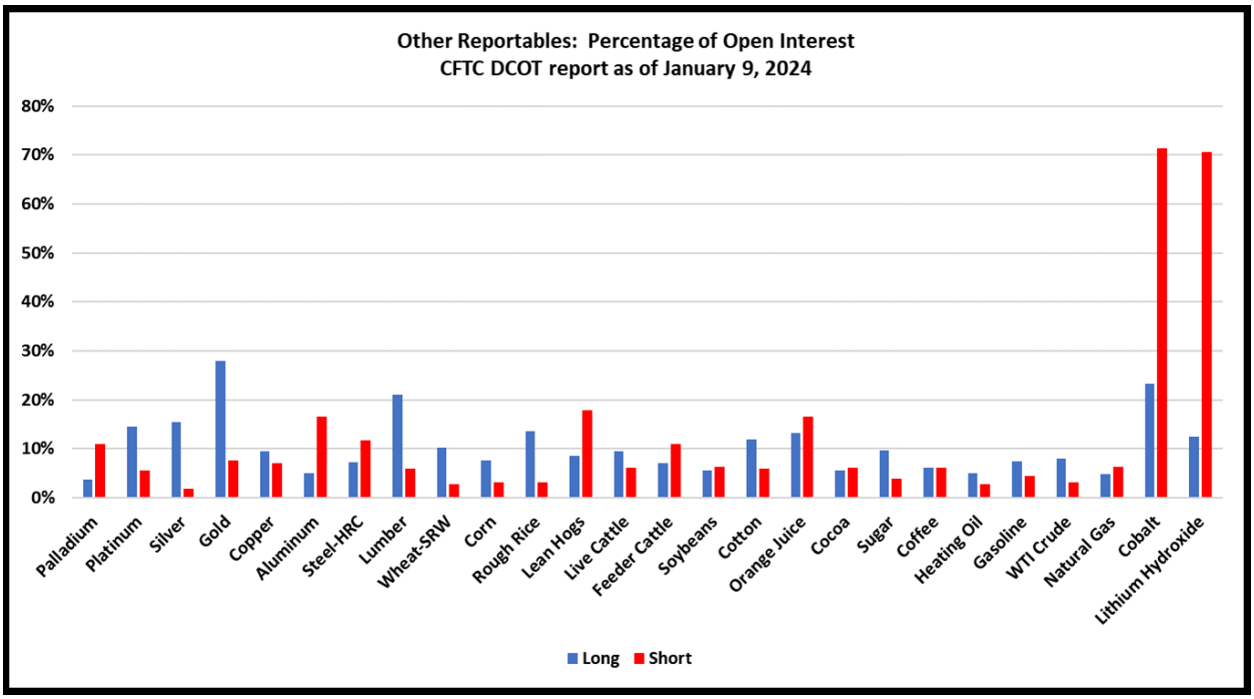
Table 1
Excerpt from the DCOT Report of January 9, 2024: the CME's Lithium Hydroxide Contract

		Producer/Merchant/ Processor/User		Swap Dealers			Managed Money			Other Reportables			Nonreportables	
	Open Interest	Long	Short	Long	Short	Spreading	Long	Short	Spreading	Long	Short	Spreading	Long	Short
Lithium	15,467	2,615	1,856	5,053	364	4	5,733	1,670	-	1,929	10,940	-	133	633

Source: CFTC (2024).

Given that lithium-compound contracts are not currently part of a commodity index strategy or Exchange Traded Fund, let us assume that the Swap Dealers' net position is due to banks hedging over-the-counter swaps that were provided to consumer clients. In that case, the DCOT report would be showing the effective commercial position as being net long. Managed Money is also net long. *Other Reportables are net short*. A noteworthy observation is that the fraction of open interest due to Other Reportables is unusually high for battery-material contracts, as compared to other exchange-traded futures contracts. This observation is illustrated in Figure 5.

Figure 5
Other Reportables



Sources: Premia Research LLC, CFTC data.

There is evidently an insufficient amount of short hedging by commercials to balance the structural longs. It would make sense that producers would be absent from the futures market because the global lithium industry is consolidated in nature (Precision Reports, 2023; Mordor Intelligence, 2024). As noted by

Kokontis (2014), concentrated industries do not welcome the visible prices that come with the launch of a new futures contract. Given that the non-commercials in the "Other Reportables" category are providing the futures contracts' structural short, how are they, in turn, hedging this exposure?

GFEX's Lithium Carbonate Futures Contract

According to industry sources, the short CME exposure is effectively being hedged via long positions in a related contract: the physically-settled Guangzhou Futures Exchange (GFEX) lithium carbonate contract in China. For example, Devitt and Liu (2024) wrote that "[h]elping the CME's contract gain traction is the … GFEX futures launched in July, which boosted arbitrage trading. … GFEX's contract is for Chinese firms only, but overseas firms can trade it via local brokers or through a China-registered entities."

By way of explanation on lithium hydroxide versus lithium carbonate, CME Group (2023) noted that "[l]ithium hydroxide and lithium carbonate are closely related but have a different chemical composition … Lithium hydroxide is often prepared by chemically treating carbonate, meaning that creating hydroxide requires an additional manufacturing step in the supply chain." Further, Fastmarkets (2023) explained that "[l]ithium hydroxide is [used in] … nickel-rich batteries such as NCMs (nickel cobalt manganese oxide), whereas lithium carbonate is used in LFP (lithium iron phosphate) batteries."

In October 2023, Li (2023) noted that the "most-active Chinese lithium carbonate contract … [was] at a level that works out to a roughly 35% discount to lithium hydroxide futures in the U.S." Continued Li (2023), "Asian funds in Hong Kong, Shanghai and Singapore have taken advantage of the price difference by buying Chinese futures and selling US ones ... [along with] … more involvement from Western traders …" Apparently, it is these funds that are the Other Reportables, and the reason for the CME contract's unusual market structure is that uniquely (at this point), the CME contract has been a relative-value trading opportunity for a much larger Chinese contract. The open interest for the Chinese lithium carbonate contract is shown in Table 2 on the next page. That the Chinese contract has become successful underscores "how China is seeking to … [gain] greater control over trading in [those] … metals [that it sees as] critical for the 21st Century," as reported by Dempsey and Lockett (2023).

Table 2
Open Interest of the GFEX Lithium Carbonate Contract

Open Interest of the GFEX Lithium Carbonate Contract
Across Contract Months as of January 19, 2024

Contract	Open Interest
lc2402	7,553
lc2403	17,277
lc2404	37,825
lc2405	11,357
lc2406	6,135
lc2407	155,078
lc2408	9,805
lc2409	7,952
lc2410	4,174
lc2411	6,732
lc2412	611
lc2501	68
Total	**264,567**

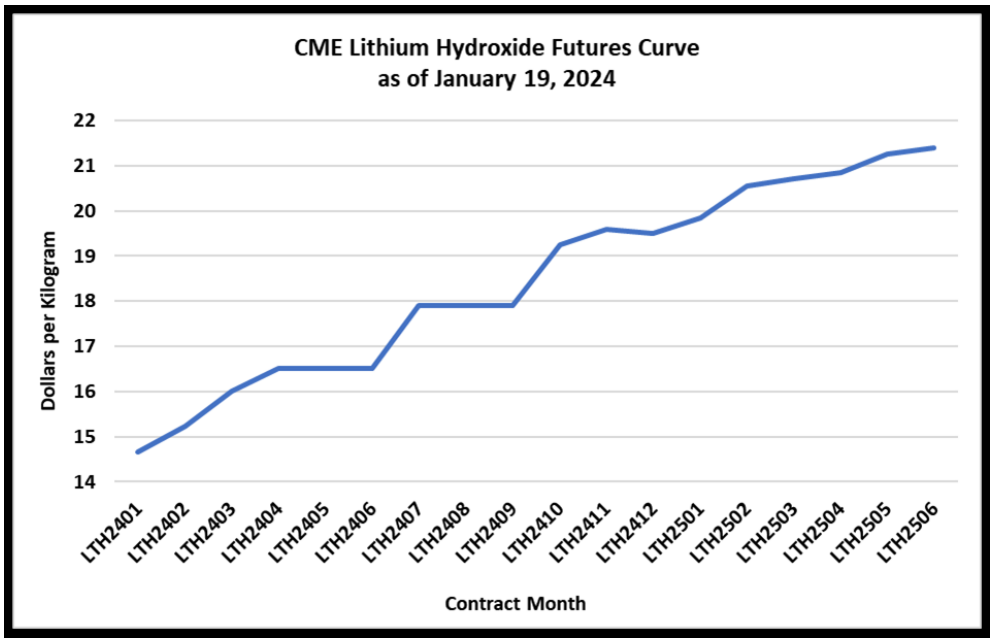
Source: GFEX (2024).

Reviewing How Spread Traders Operate

In review, if consumers desire to be structurally long CME lithium (hydroxide) exposure, then there needs to be a source of a structural short. From examining the DCOT report, producers are not playing this role. Therefore, the CME Group contract would need to be bid up to the level that funds (that are set up for such a trade) would be comfortable in going short that exposure against long positions in the GFEX lithium (carbonate) contract, presumably taking into consideration the cost of the conversion from lithium carbonate to lithium hydroxide. The spreading activity thus noted is analogous to what happens when airlines desire to go long deferred jet fuel, as covered in Till (2006). Swap dealers provide this exposure to the airlines and then hedge with long positions in deferred heating oil, a correlated proxy for jet fuel. Spread traders would then sell the swap dealers the deferred heating oil as long as the spread traders can buy deferred crude oil at levels that provide a great entry point for shorting the heating oil crack spread.

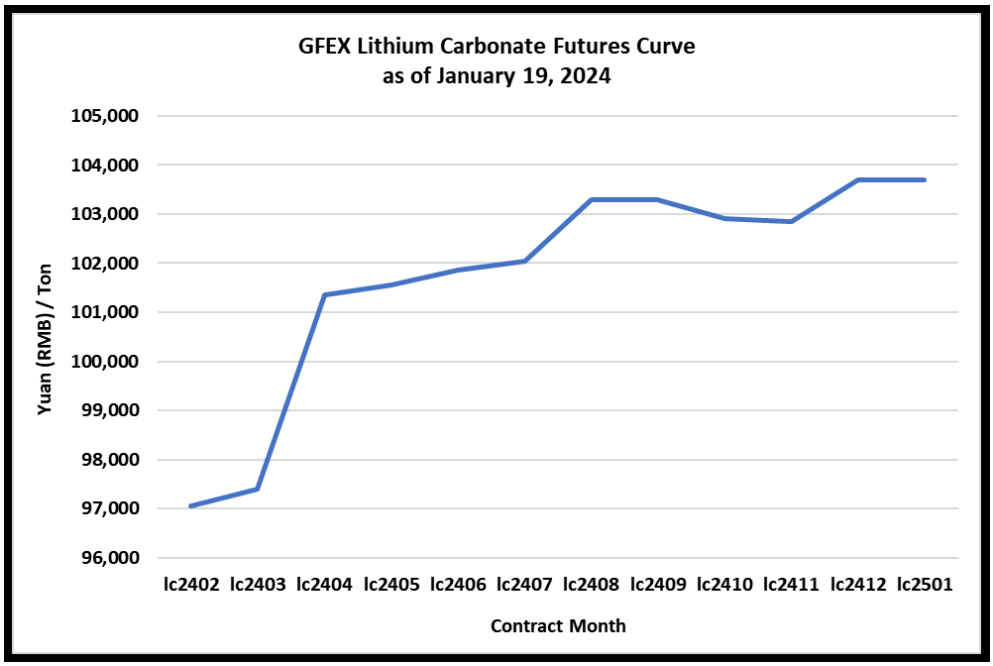
One nuance of taking a position in the GFEX vs. CME spread is to examine both contracts' term structures to find the most advantageous entry point within the limits of liquidity. See Figures 6 and 7 on the next page, which show that the CME lithium (hydroxide) futures curve is in contango from the September-2024-to-November-2024 contract months while the GFEX lithium (carbonate) futures curve is in backwardation from the September-2024-to-November contract months.

Figure 6
CME Lithium Hydroxide Futures Curve



Source: CME (2024).

Figure 7
GFEX Lithium Carbonate Futures Curve



Source: GFEX (2024).

Conclusion

The CME's lithium hydroxide contract potentially offers an effective hedging vehicle for lithium-compound consumers and their bank counterparties, who would be very familiar and comfortable with the CME Group's trading platform. The contract's open interest is in the bounds of a viable contract. But because of the apparent lack of involvement by producer shorts, the CME contract's growth may continue to rely on relative-value trading opportunities against the GFEX lithium carbonate contract whereby such traders would enter into short positions in the CME contract (vs. long positions in the GFEX contract.)

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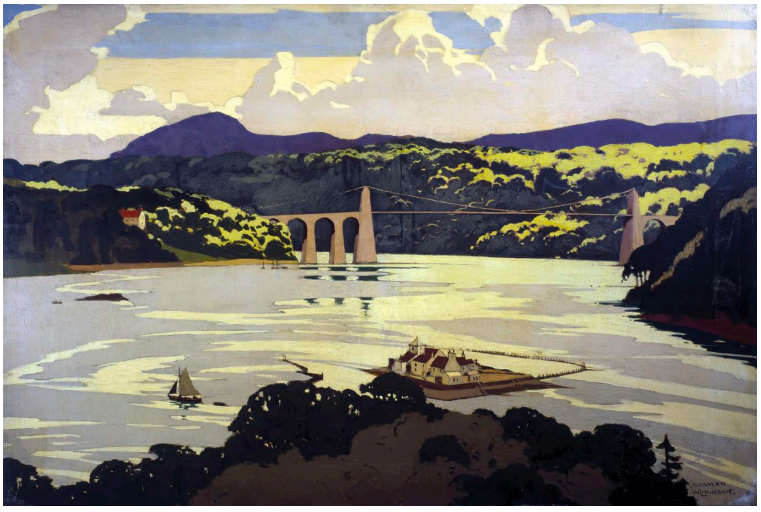

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