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

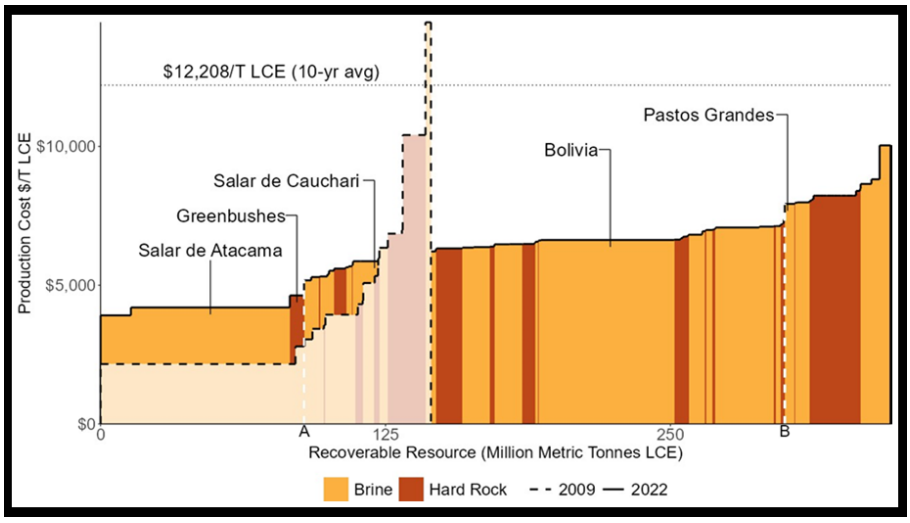
This analysis catalogs 150 lithium deposits including *in situ* resource estimates of 726 MMT LCE. It includes 649 MMT LCE of conventional resources and 41 MMT LCE of unconventional resources. Brine deposits account for 540 MMT LCE while hard-rock accounts for 110 MMT LCE. Our CAC illustrates total quantities 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.

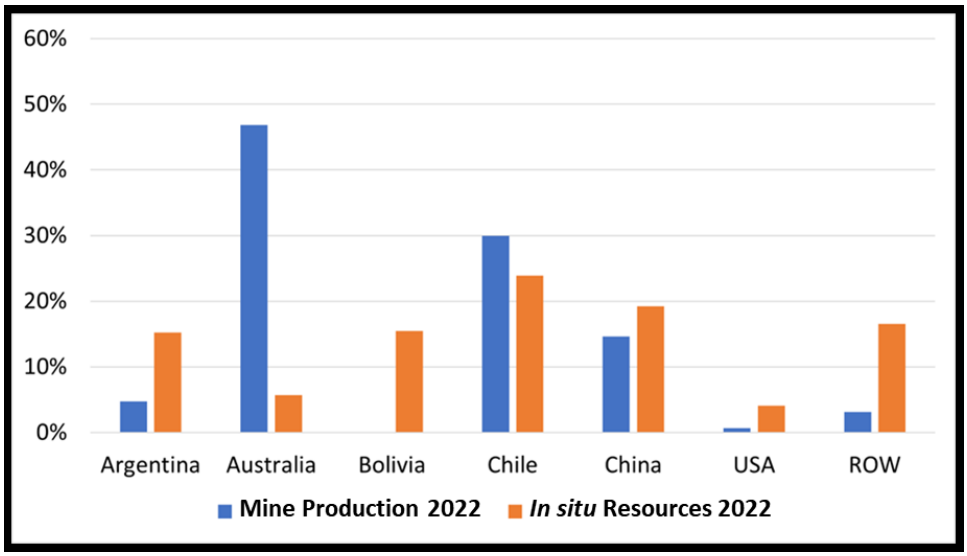
We can also observe that costs increased significantly between 2009 and 2023. Cost increases may be explained by elevated input prices, inefficiencies associated with rapid capacity expansion, and a lack of pressure to control costs (Tilton and Guzman, 2016). Inflation played a relatively minor role 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

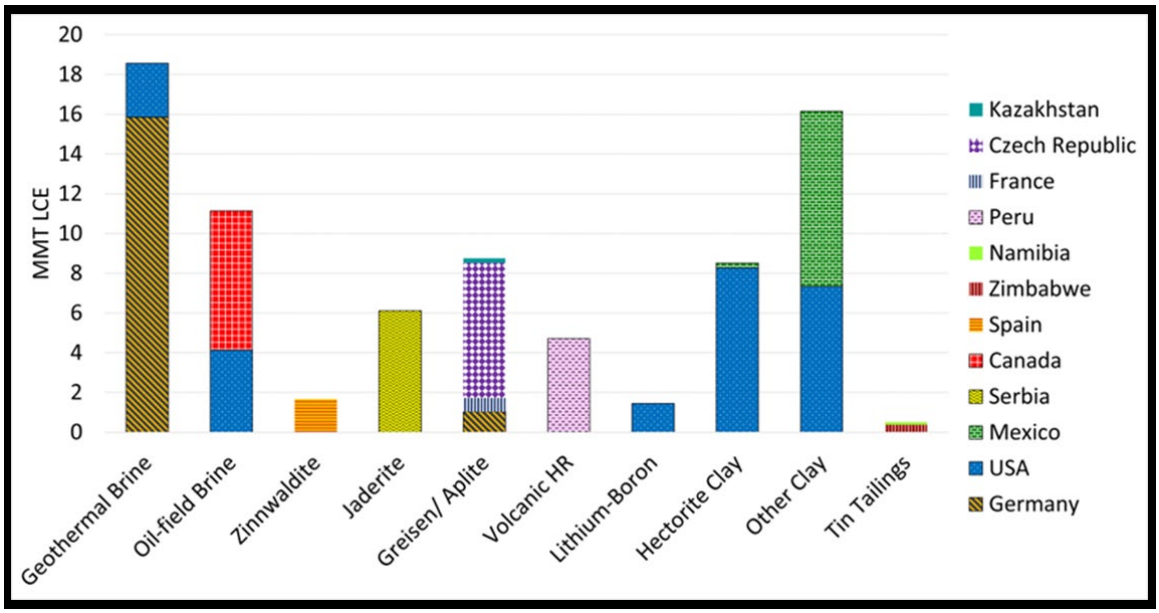
An unconventional resource, for purposes of this study, is any type of lithium resource that has not been produced in significant commercial quantities to date. This section highlights various unconventional

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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References

AMG Advanced Metallurgical Group N.V., 2017, "AMG Advanced Metallurgical Group N.V. Announces Increased Lithium and Tantalum Mineral Resources at Mibra Mine," AMG Press Release, April 3. Accessed via website: https://amg-nv.com/investors/press-release/amg-advanced-metallurgical-group-n-v-announces-increased-lithium-and-tantalum-mineral-resources-at-mibra-mine/#%3A~%3Atext%3DThe%20Technical%20Report%20on%20Mineral%2C%2C%20tantalum%2C%20niobium%20and%20tin on January 4, 2025.

Australian Government | Department of Industry, Science and Resources, 2023, *Resources and Energy Quarterly*, Technical Report by the Office of the Chief Economist, March. Accessed via website: https://www.industry.gov.au/sites/default/files/2023-04/resources-and-energy-quarterly-march-2023.pdf on January 4, 2025.

British Petroleum, 2021, "Statistical Review of World Energy." Accessed via website: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf on January 4, 2025.

Chimata Gold Corp, 2018, "Chimata Releases NI 43-101 Technical Report on the Kamativi Tailings Lithium Project," Press Release, November 7. Accessed via website: https://webfiles.thecse.com/2018.11.07_Chimata_-_Press_Release_Kamativi_43-101.pdf?DLILPHMDxO5JDbGCvRI8GxxcCaXIG6uv on January 4, 2025.

Critical Elements Lithium Corporation, 2021, Investor Presentation.

Frith, J. T., Lacey, M. J. and U. Ulissi, 2023, "A Non-Academic Perspective on the Future of Lithium-Based Batteries," *Nature Communications*, Vol. 14, No. 420, January 26. Accessed via website: https://www.nature.com/articles/s41467-023-35933-2 on January 4, 2025.

Galaxy Resources, 2017, "James Bay Resource Update."

GeoEnergy for the Americas, 2020, "GeoEnergy for the Americas - 2020 – Proceedings."

Hund, K., La Porta, D., Fabregas, T. P., Laing, T. and J. Drexhage, 2020, "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition," Technical Report, World Bank. Accessed via website: https://pubdocs.worldbank.org/en/961711588875536384/minerals-for-climate-action-the-mineral-intensity-of-the-clean-energy-transition.pdf on January 4, 2025.

International Energy Agency (IEA), 2021, "The Role of Critical Minerals in Clean Energy Transitions," Technical Report, May. Accessed via website: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions on January 4, 2025.

Ioneer, 2020, "Rhyolite Ridge Definitive Feasibility Study Summary," April.
Accessed via website: https://www.ioneer.com/investors/dfs-summary/ on January 4, 2025.

Mitchell, J., 2021, "Soaring Demand, Rising Prices ... What Now for the Lithium Market?" *Investment Monitor*, August 23. https://www.investmentmonitor.ai/extractive-industries/lithium-price-demand-environment-supply/ on January 4, 2025.

Montero Mining, 2019, "Montero Files NI 43-101 Resource Estimate on the Uis Lithium-Tin Tailings Project in Namibia on Sedar," March 12. Accessed via website:
https://monteromining.com/montero-files-ni-43-101-resource-estimate-on-the-uis-lithium-tin-tailings-project-in-namibia-on-sedar/ on January 4, 2025.

Pustov, A., Malanichev, A. and I. Khobotilov, 2013, "Long-Term Iron Ore Price Modeling: Marginal Costs vs. Incentive Price," *Resources Policy*, Vol. 38, No. 4, December, pp. 558-567. Accessed via website:
https://www.sciencedirect.com/science/article/abs/pii/S0301420713000743 on January 4, 2025.

Roskill Information Services, 2020, "Databook for Figures - Lithium 17th ed." Technical Report.

Ruid, M., 2022, "Lithium Market Update: Elevated Prices Are Creating Favorable Dynamics for Miners," Global X, November 4. https://www.globalxetfs.com/lithium-market-update-elevated-prices-are-creating-favorable-dynamics-for-miners/ on January 4, 2025.

Sekularac, I., 2022, "Serbian Government Revokes Rio Tinto's Licenses for Lithium Project," *Reuters*, January 20. Accessed via website: https://www.reuters.com/business/retail-consumer/serbian-government-revokes-rio-tintos-licences-lithium-project-2022-01-20/ on January 4, 2025.

Sociedad Química y Minera de Chile S.A., 2021, "Memoria-anual-2021," Technical Report. Accessed via website:
https://s25.q4cdn.com/757756353/files/doc_financials/2021/ar/Memoria-Anual-2021_eng1.pdf on January 4, 2025.

Stringfellow, W. T. and P. F Dobson, 2021, "Technology for The Recovery of Lithium from Geothermal Brines," *Energies*, Vol. 14, No. 20, 6805. Accessed via website: https://www.mdpi.com/1996-1073/14/20/6805 on January 4, 2025.

Tilton, J. E. and J. I. Guzman, 2016, Mineral Economics and Policy, New York: RFF Press.

Tilton, J. E., Crowson, P. C. F., DeYoung Jr., J. H., Eggert, R.G., Ericsson, M., Guzmán, G.I., Humphreys, D., Lagos, G., Maxwell, P., Radetzki, M., Singer, D., and F.-W. Wellmer, 2018, "Public Policy and Future Mineral Supplies," *Resources Policy*, Vol. 57, August, pp. 55-60. Accessed via website: https://www.sciencedirect.com/science/article/pii/S0301420718300199 on January 4, 2025.

U.S. Department of Energy, 2023, "Critical Materials Assessment 2023," Technical Report. Accessed via website:
https://www.energy.gov/sites/default/files/2023-07/doe-critical-material-assessment_07312023.pdf on January 4, 2025.

U.S. Federal Register, 2022, "2022 Final List of Critical Minerals," U.S. Geological Survey, Vol. 87, No. 37, February 24. Accessed via website: https://www.govinfo.gov/content/pkg/FR-2022-02-24/pdf/2022-04027.pdf on January 4, 2025.

U.S. Geological Survey, 2022, "Mineral Commodity Summaries 2022." Accessed via website:
https://pubs.usgs.gov/periodicals/mcs2022/mcs2022.pdf on January 4, 2025.

U.S. Geological Survey, 2023, "Mineral Commodity Summaries – Lithium," January. Accessed via website:
https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-lithium.pdf on January 4, 2025.

U.S. Geological Survey, 2024, "Mineral Commodity Summaries - Lithium" January. Accessed via website:
https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-lithium.pdf on January 4, 2025.

Warren, I., 2021, "Techno-Economic Analysis of Lithium Extraction from Geothermal Brines," U.S. Department of Energy, Office of Scientific and Technical Information, Technical Report, May 1. Accessed via website: https://www.osti.gov/biblio/1782801 on January 4, 2025.

World Bank, 2021, "Manufacturing, Value Added (current US$) | Data."

Yaksic, A. and J. E. Tilton, 2009, "Using the Cumulative Availability Curve to Assess the Threat of Mineral Depletion: The Case of Lithium," *Resources Policy*, Vol. 34, No. 4, December, pp. 185-194. Accessed via website: https://www.sciencedirect.com/science/article/abs/pii/S0301420709000348 on January 4, 2025.

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

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