Jain Family Institute

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Unpacking Mineral Markets: Situating the Opportunities

By Jonah Allen and Shane Sethi

Overview

Decarbonization and development are driving up demand for critical minerals; the countries that produce these minerals have new opportunities to capture value both from mining and from more lucrative downstream activities. Yet mineral price volatility and overcapacity across the supply chain have put these ambitions to the test.

The mix and scale of transition demand now and in the future, and the expectations behind them, will shape realized growth in market volumes, while prices, which are volatile and uncertain, will determine fiscal windfalls as well as the viability of projects both upstream and downstream.

Sharper examination of mineral market dynamics, and clearer dissemination of their complexities are needed to ground more robust policy objectives aimed at lasting development outcomes.

The Promise of Electrification?

- Global electrification is expanding both the scope and scale of mineral demand.
- Renewable energy tech is more materially complex than fossil incumbents (Fig 1).
- Electricity networks need to be established, expanded, and upgraded, requiring copper, aluminum, and steel.
- Batteries for sustainable transport and grid storage demand lithium, graphite, nickel, manganese, cobalt, iron, and other materials.
- This mineral demand growth is expected to present an opportunity to producer countries, both from the mining of these minerals and the more lucrative downstream activities.

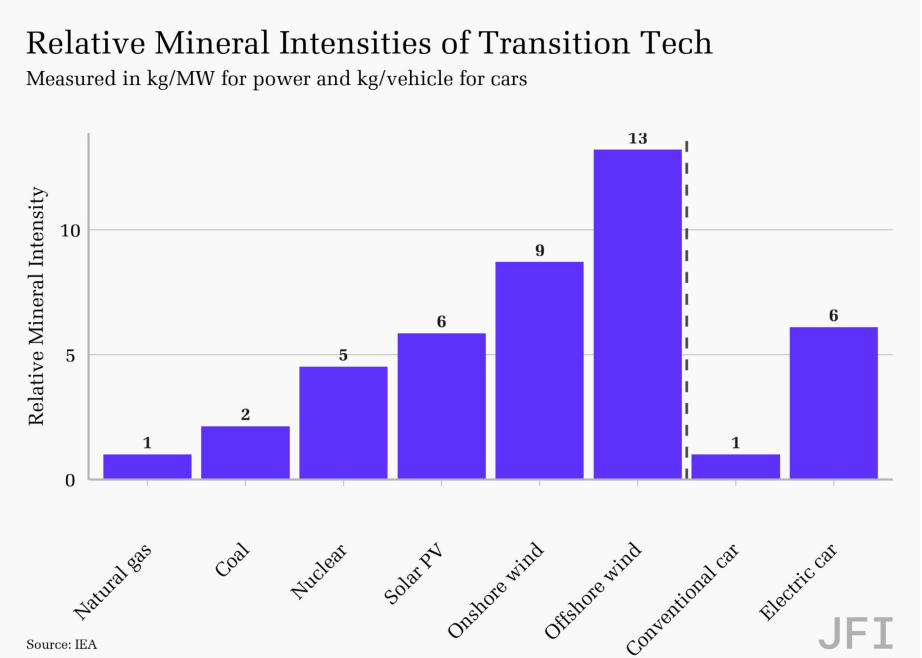

Figure 1 (above): Total mineral intensity of typical power generation and transport technologies, from IEA, 2021, benchmarked against the incumbent technology.

The Promise of Electrification?

- Market realities have put the ambitions of producer countries to the test. **Other than copper, major transition-critical mineral markets are currently experiencing supply gluts through 2030 at least.**
- The pace at which supply scaled to meet potential demand—and demand did not scale accordingly—has caught market analysts, producers, and policymakers in both producer and consumer countries by surprise.
- **The turbulence in battery mineral prices is most pronounced in the lithium market.** Lithium carbonate prices peaked in Dec 2022 at $68,366/mt and by Jul 2025 were down 87% to $9,050/mt (Fig 2).

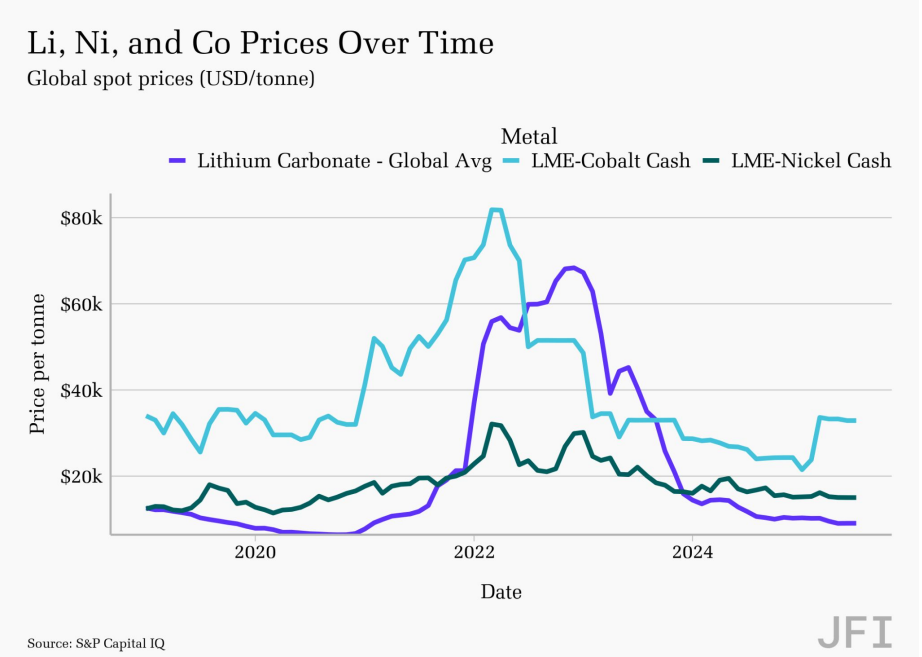

Figure 2 Lithium, nickel, and cobalt monthly prices, from S&P Cap IQ (Jan 2019 to July 2025).

The Promise of Electrification?

- Producers across the world raced to cash in on projected lithium growth, and supply has scaled rapidly, led by hard-rock mines in Australia. However, demand growth has been more modest than expected due to slower-than-anticipated adoption rates, rollbacks in EV subsidies, and broader economic headwinds.

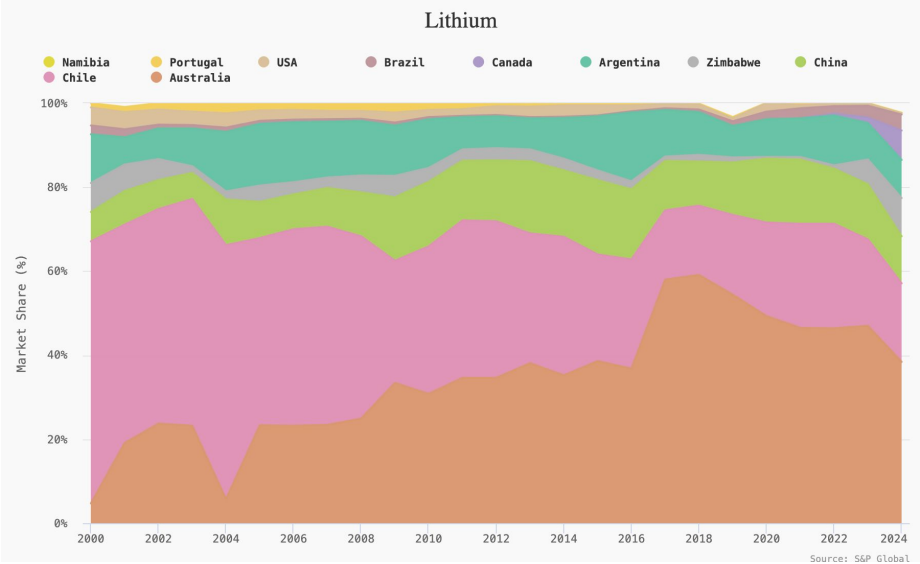

Figure 3: Historical Market Share of Production for Lithium from JFI's Mineral Market Dashboard. See the Appendix for more minerals.

The Promise of Electrification?

- Meanwhile, advances in battery technology have shifted the makeup of battery chemistries and reshaped associated demand expectations.
- Chemistries with reduced or no reliance on nickel and cobalt, such as lithium-iron-phosphate batteries, have gained traction and are significantly downgrading forecasts for long-term nickel and cobalt demand.
- Nickel and cobalt are mined globally, but their highest-quality and lowest-cost reserves are concentrated.

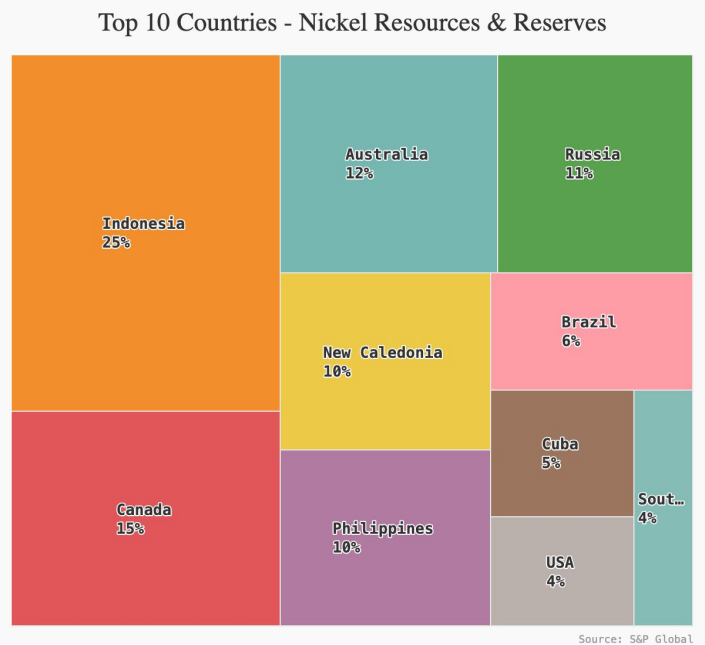

Figure 4: Share of nickel reserves among the top 10 countries with reserves, from JFI's Mineral Market Dashboard with data from S&P Global. Note that this is the relative split of the top 10 countries only, so that both the names and resource estimates of other countries are excluded. See the Appendix for more minerals.

The Promise of Electrification?

- Indonesia is the dominant producer of high-purity nickel processed into nickel pig iron and refined via energy- and carbon-intensive methods, often through Chinese-owned or -financed facilities.
- Since the export ban in 2020, the island nation has prioritized an aggressive downstreaming policy—now reaching midstream NMC battery component manufacturing—that has relied on equally aggressive expansions in supply.

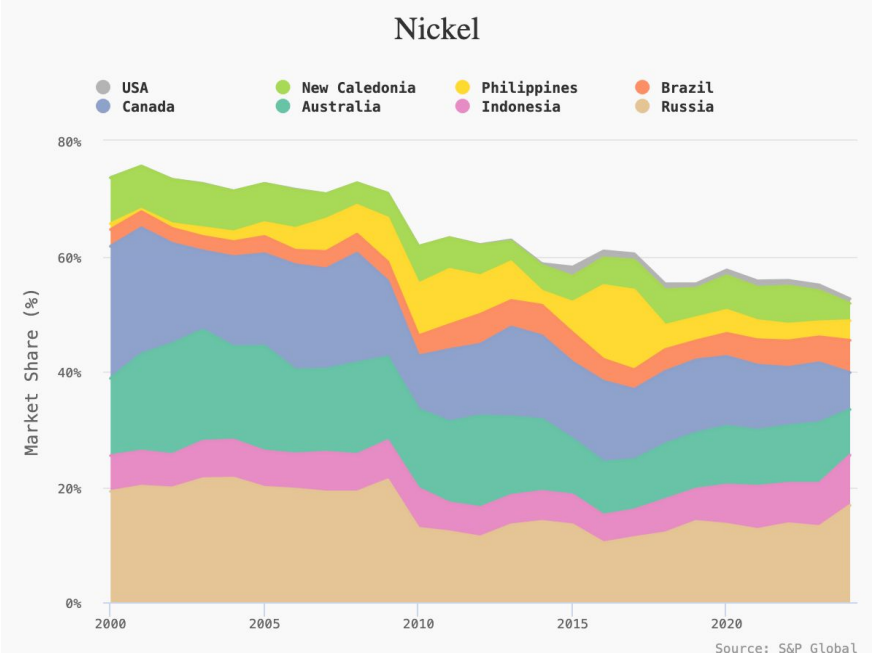

Figure 5: Historical market shares of nickel production, from JFI's Mineral Market Dashboard with data from S&P Global. See the Appendix for more minerals.

The Promise of Electrification?

- The Democratic Republic of Congo (DRC) accounts for more than 70 percent of global cobalt supply, and hosts the highest-purity deposits.
- Cobalt production in the DRC has scaled rapidly, driven in part by the expansion of artisanal mining, which often relies on child labor and exploitative working conditions.
- This surge in supply, much of it informal and poorly regulated, has flooded the market and contributed to the sharp decline in prices, while ethical and geopolitical concerns have accelerated the push to reduce or eliminate cobalt use in batteries.

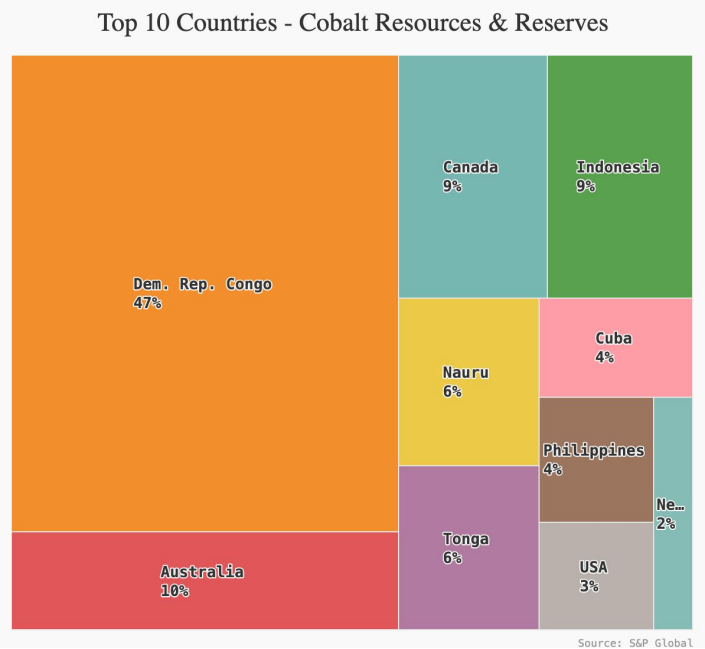

Figure 6: Share of nickel reserves among the top 10 countries with reserves, from JFI's Mineral Market Dashboard with data from S&P Global. Note that this is the relative split of the top 10 countries only, so that both the names and resource estimates of other countries are excluded. See the Appendix for more minerals.

The Promise of Electrification?

- **Recognizing their influence, both Indonesia and the DRC are attempting to rein in production growth and thereby global prices.**
- Indonesia has begun tightening annual production quotas, shortening mining licences, and increasing environmental scrutiny, while the DRC recently imposed a temporary export ban on artisanal cobalt and is beginning export quotas.
- The impact on prices depends on the effectiveness of the interventions (which is in question for both) and the broader market outlook, which is unfavorable.
- **Tariff uncertainty, growing trade barriers, and persistent global economic headwinds continue to cloud demand forecasts.**

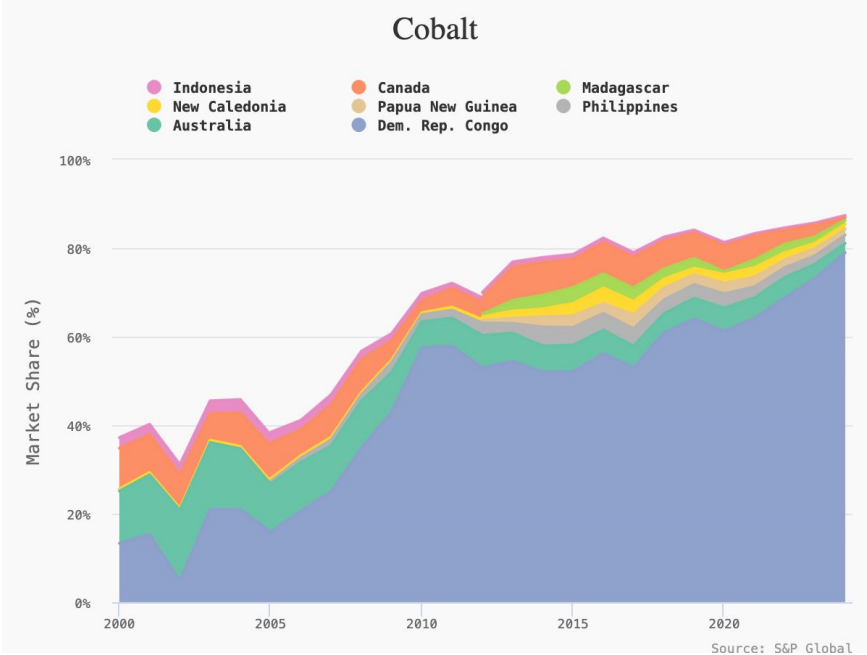

Figure 7: Historical market shares of cobalt production, from JFI's Mineral Market Dashboard with data from S&P Global. See the Appendix for more minerals.

The Promise of Electrification?

- The outlook for lithium, nickel, and cobalt will remain closely tied to **the electric vehicle market, which has continued to experience turbulence since 2021.**
- There was a wave of EV initial public offerings, particularly through special purpose acquisition company transactions, when battery mineral prices were climbing in 2020 and 2021.
- Many companies went public without generating revenue, primarily raising capital to fund the development and delivery of their first vehicle models.
- The sharp rise in interest rates in 2022 hit equity markets and debt-dependent EV companies hard; **some firms lost up to 90 percent of their equity**.

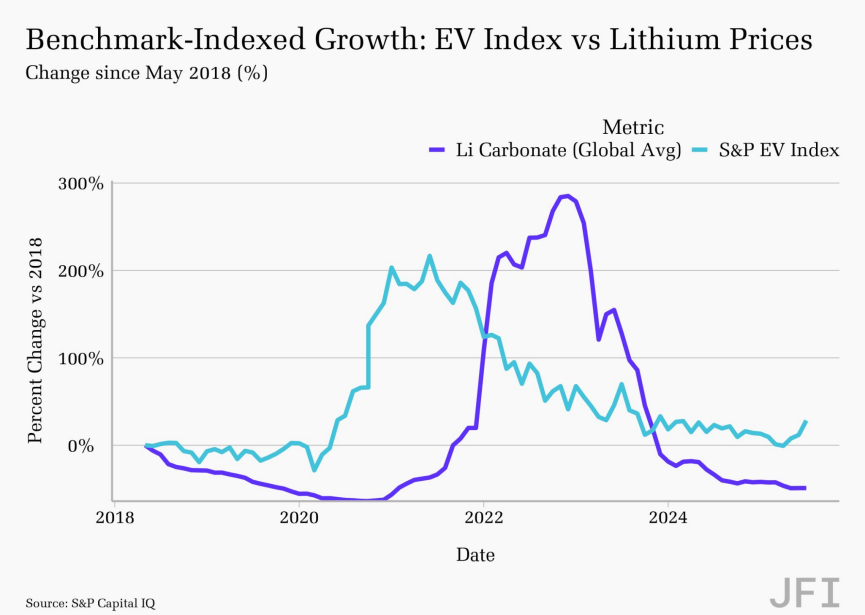

Figure 8: Kenosha Electric Vehicle Index and global average lithium carbonate prices, from S&P Global. Prices are benchmarked as a percentage movement against their starting value in May 2018 for comparability. The EV Index is designed to measure the performance of companies involved in the electric vehicle sector and the ecosystems supporting it.

The Promise of Electrification?

- Tariffs and countervailing duties to protect domestic industries in the US, Canada, and the EU have **raised consumer costs in the short term and slowed the rate** at which Western EV adoption is increasing.

- Severe EV overcapacity in China, with plant utilization averaging 50 percent and some below 5 percent, is fueling a price war between BYD and CATL – this is boosting Chinese adoption but continues to **strain battery mineral producers**.

- **Overcapacity in China extends to mineral refining and smelting;** copper treatment charges have plummeted, benefiting ore exporters but discouraging downstream investment. Gluts in zinc, aluminum, and nickel refining are eroding profitability across the sector, prompting even major Western operators to seek government support.

Transition-Critical Minerals Now and Tomorrow

In this context, transition-critical mineral markets need to be considered with more scrutiny:

- What minerals do energy transition technologies demand, and in what relative quantities?
- What is the current scale of opportunity in these markets, and how is that expected to change with the transition?
- How sensitive are these expectations, and the related potential for required minerals, to the pace of the transition and rapidly evolving technologies and material intensities?

Transition-critical minerals have a wide range of applications.

Table 1: Energy transition uses of selected commodities

Commodity	Key Energy Transition Uses
Aluminium	Solar PV, CSP, Electricity networks, EVs and Battery Storage
Chromium	CSP, Geothermal
Cobalt	EVs and Battery Storage
Copper	Solar PV, Wind, Bioenergy, Electricity networks, EVs and Battery Storage
Graphite	EVs and Battery Storage
Iron	Electricity networks, EVs
Lithium	EVs and Battery Storage
Manganese	Wind, EVs and Battery Storage
Molybdenum	Wind
Neodymium	Wind, EVs and Battery Storage
Nickel	Geothermal, EVs and Battery Storage, Hydrogen
Platinum Group Metals (PGMs)	Hydrogen
Silicon	Solar PV, EVs and Battery Storage
Silver	Solar PV
Rare Earth Elements (REEs)	Wind, EVs and Battery Storage
Zinc	Wind

CSP = Concentrated solar power
EV = Electric vehicles
PV = Photovoltaic

From Geopolitics of the energy transition: Critical materials (IRENA, 2023) and others.

Transition-Critical Minerals Now and Tomorrow

Three factors need to be considered for a given commodity to assess the scale of opportunity offered to producer countries:

1. Current market size
2. How the overall energy transition will affect demand growth (i.e., the share of transition tech demand across all its end uses)
3. How concentrated its future demand is expected to be in particular transition-relevant technologies (i.e., the diversity of transition use).

These speak to not just the total future market size, but also its robustness against different technological pathways and the potential routes for downstream value capture. **Each factor varies considerably across transition minerals.**

Transition-Critical Minerals Now and Tomorrow

Transition-critical commodity markets are a fraction of the size of primary fossil fuel markets:

- Mineral fuels, oils, and products generated a global trade value of $3.16 trillion in 2023 and represented 14 percent of world trade, while ***all*** ores, slags, and ash products combined represent only 1.5 percent of world trade, generating $348 billion in value—**about 10 percent of fossil fuels' value**.
- **Iron ore** alone accounts for 47 percent of this value, **and copper ore** accounts for another 27 percent—together these essential infrastructure products **represent about three-quarters of global primary mineral markets.**

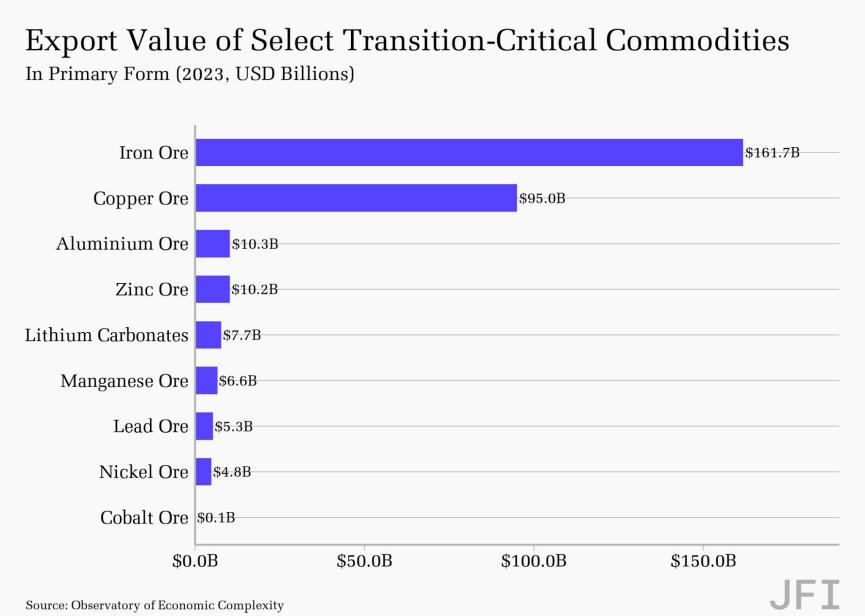

Figure 9: Global trade value of selected transition minerals in 2023 according to the Observatory of Economic Complexity. These figures correspond to the primary forms of the commodity—cobalt ores only generated $0.10 billion in trade value in 2023, but refined forms of cobalt generated $5.27 billion.

Transition-Critical Minerals Now and Tomorrow

- However, while fossil fuel supply chains are relatively short (94 percent of fossil fuels are burned for energy consumption), mineral value chains are longer and more complex, accumulating value along the way, to be manufactured into products that last 10–30 years, with potential for recycling and reuse.

- The motivation to develop even initial processing (and recycling) is clear: higher-complexity metal products had a global trade value of $1.54 trillion in 2023, **more than four times the value of their primary products**.

- For some commodities, the comparison is even more stark. Finished aluminum products (including scrap) generated $232 billion in global trade value, compared to $10.3 billion for aluminum ore (bauxite). In the case of cobalt, refined forms and scrap generated more than 50 times as much trade value compared to trade in its primary form.

Transition-Critical Minerals Now and Tomorrow

- Transition minerals have varying dependence on—and sensitivity to—transition technology requirements.
- Nickel prices have been less impacted by EV market uncertainty partly because batteries represent a smaller share of its demand (nickel is primarily used in stainless steel), whereas the majority of lithium demand is already linked to the energy transition and is expected to grow significantly in that context.

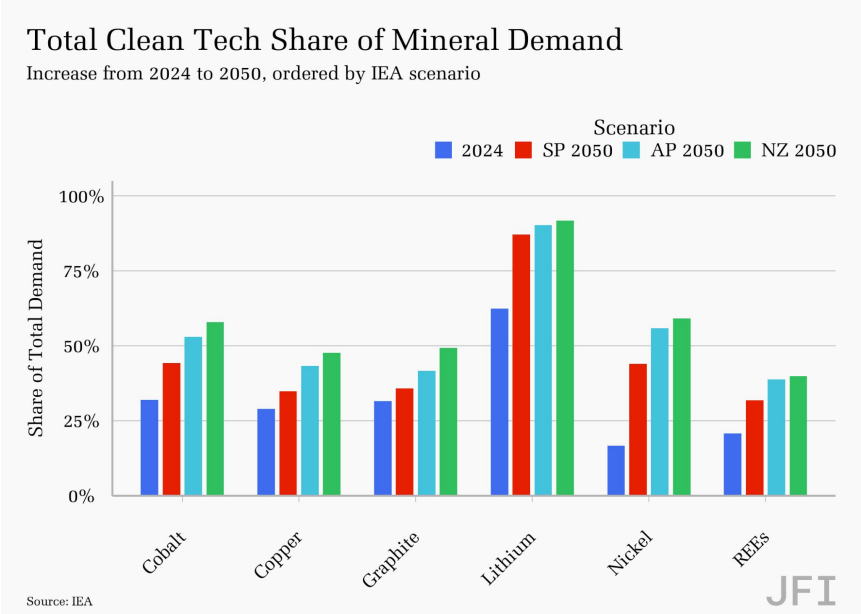

Figure 10: The current share of total transition demand for selected minerals now and in 2050 according to IEA's three scenarios: Stated Policies (SP), Announced Pledges (AP), and Net Zero (NZ).

Transition-Critical Minerals Now and Tomorrow

- Growth expectations are driven not only by assumptions of the pace of the transition, but also by the mix of technologies adopted and the material intensity of these products.
- Nickel demand growth assumes continued dominance of nickel-based cathode technologies in batteries, which are currently being challenged by lower-cost lithium-iron phosphate batteries, especially for passenger vehicles.
- Contrast this with copper, which has more moderate growth expectations across scenarios, but far more diverse end uses, and a much larger global market.

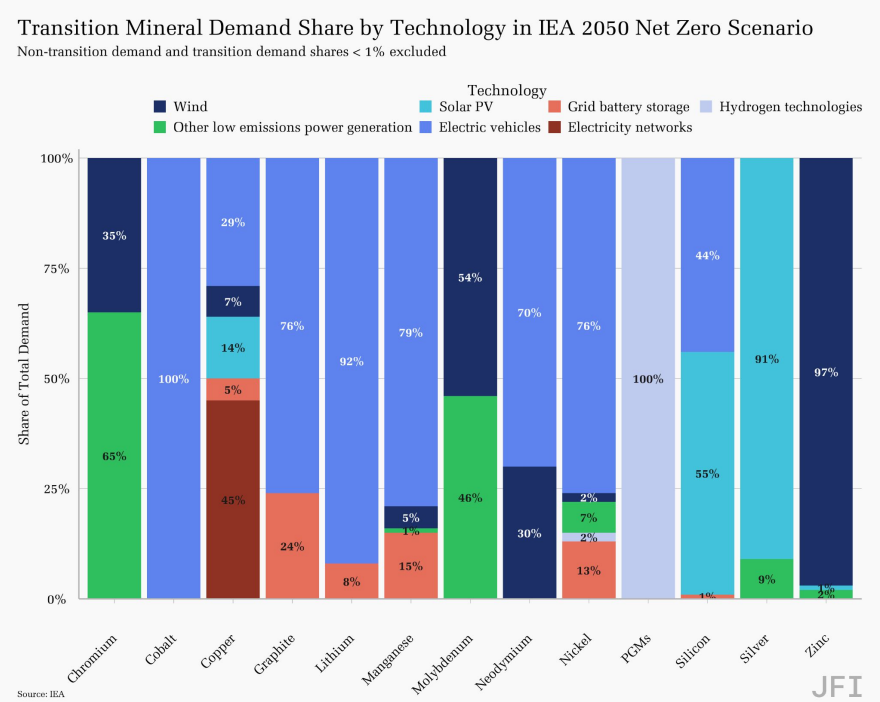

Figure 11: The mix of transition end uses by mineral in the IEA Net Zero 2050 Scenario. Demand shares that represent less than 1 percent are dropped from the figure for legibility. Non-transition demand is excluded.

Transition-Critical Minerals Now and Tomorrow

- The future opportunity that mineral markets present to producers depends on the interaction of two key factors: market volume (quantity) and value (price).
- Scenario-modeling-driven expectations for demand growth and supply forecasts are often disjointed; feedback between these two layers, which is usually signaled through market prices, is not usually accounted for.
- For example, average silver intensity per installed solar module has halved over the past decade due to silver's high cost: though it makes up less than 0.1 percent of module weight, it accounts for around 10 percent of manufacturing cost.
- New battery technologies, meanwhile, seek to innovate away entirely from high-cost or high-risk minerals, like cobalt.

Transition-Critical Minerals Now and Tomorrow

- The assumptions that scenario models make—both macro-level and technology-level—determine their outcomes.
- Our analysis shows that projections from leading expert groups, including IEA, BNEF, and S&P, vary considerably across groups and within scenarios, **demonstrating both how sensitive projections are to their assumptions and how uncertain the future market volumes pathways are**:

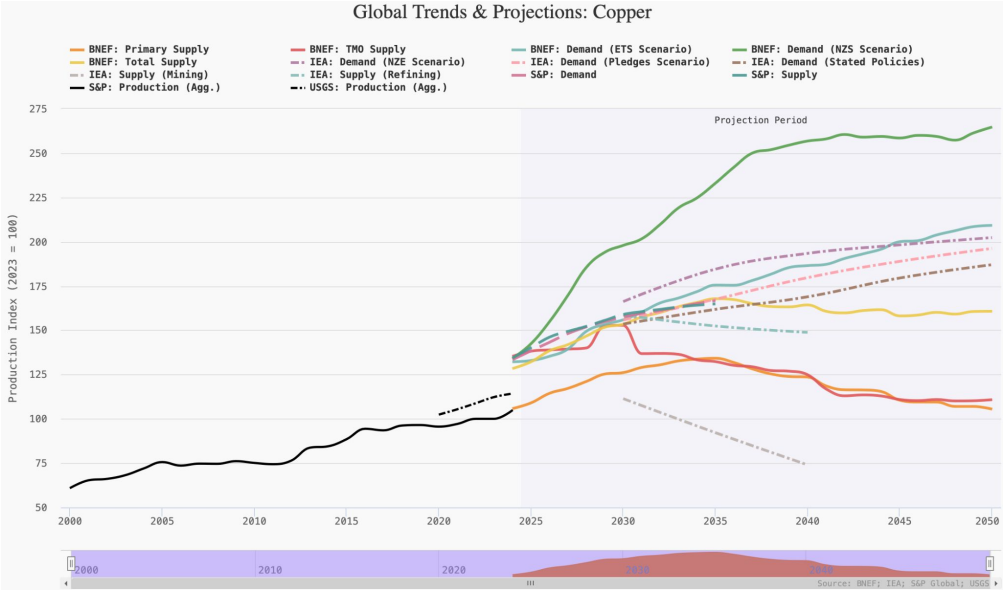

Figure 12: Varying projections of copper market growth across demand and supply scenarios, benchmarked to S&P's estimation of aggregate market volume in 2024. From JFI's Mineral Market Dashboard with data from S&P Global, BloombergNEF, and the IEA. See the Appendix for other mineral market comparisons.

Transition-Critical Minerals Now and Tomorrow

- Market value is even more challenging to account for. **The scale of opportunity is measured in potential revenues, not volume, and revenues depend on commodity price movements.**
- For example, Sigma Lithium's Grota Do Cirilo mine has consistently hit production targets presented in its January 2023 feasibility study, but due to suppressed lithium prices, the project has likely been achieving gross revenues at just 35 percent of projections in year one and 14 percent of expectations in year two, with harsh implications for local royalty revenues.
- This extreme example highlights the broader truth: **commodity prices are volatile, cyclical, and uncertain.** They are sensitive to a suite of risks and uncertainties from nature and geology, project-level constraints, and domestic and international policies, and other factors.

Transition-Critical Minerals Now and Tomorrow

- Smooth-line scenario projections can be misleading; producer countries' abilities to capitalize on the potential that transition-mineral market growth represents will **depend on their ability to navigate volatility in practice.**
- For example, consider the 2022 and 2050 market sizes in the *Economic Transition Scenario* and *Net Zero Scenario* in BloombergNEF's 2023 Transition Metals Outlook. Interacting these volumes with prices is key to demonstrating how the relative opportunity in value terms can look very different. For example, **compare steel and copper's relative importance in volume terms on the left to value terms on the right** (next slide).

Transition-Critical Minerals Now and Tomorrow

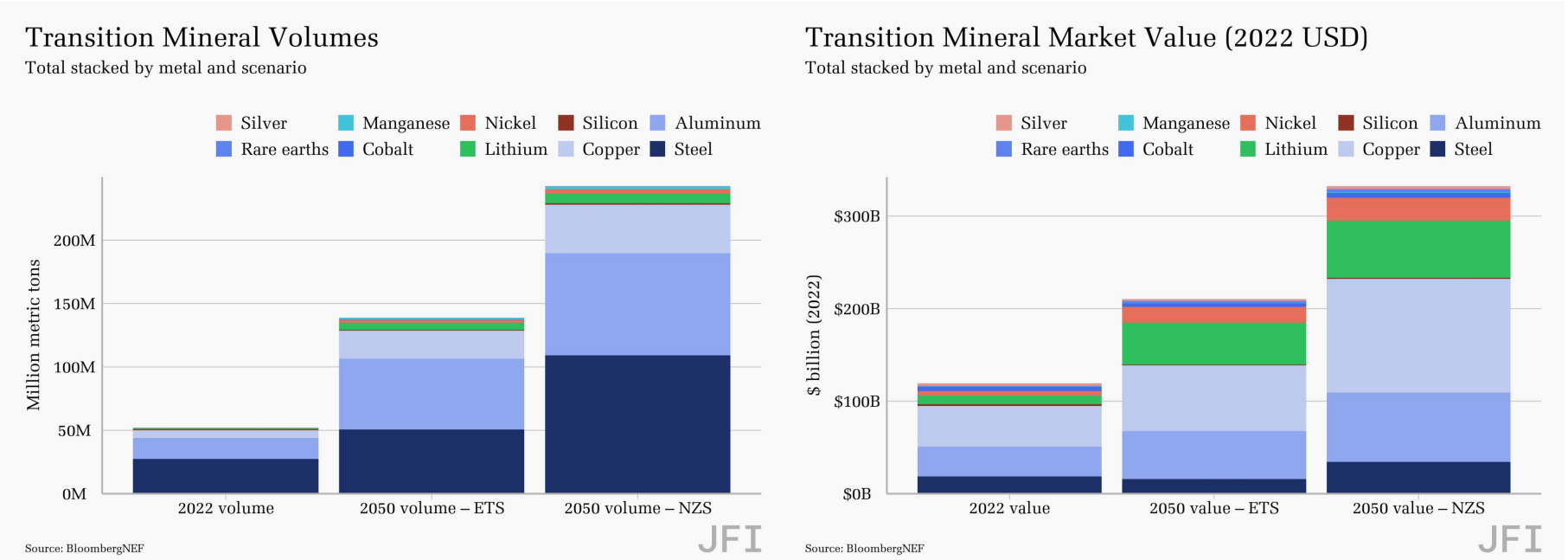

Figure 13: Transition mineral volumes vs. value in 2022 and in 2050 according to the *Economic Transition Scenario* and *Net Zero Scenario* in BloombergNEF's *2023 Transition Metals Outlook.*

Transition-Critical Minerals Now and Tomorrow

- The chart is useful for understanding the volume vs. value nuance, but **what this comparison will look like in 2050 is far less straightforward.** Utilizing market volume projections from the demand outlook scenarios, the BNEF illustration has three steps:
  1. Use (nominal) average annual prices from 2012 to 2022 to determine a historical average price,
  2. Multiply these prices by market volume in both 2050 scenarios, and
  3. Discount 2050 market values to 2022 for comparability, using a 2.75 percent annual inflation rate (which is “in line with the average rates for major economies where demand is concentrated”).

Transition-Critical Minerals Now and Tomorrow

- Illustrative forecasting methods like these **risk misleading** the broader audience about the **extreme uncertainty** these markets face.
- To highlight this uncertainty and the sensitivity of outcomes to modeling assumptions, consider instead a rolling 36-month average of five key commodities using observations from January 2009 through July 2025 (about the same period as BNEF analysis, but with more recent data).
- ***When and how* an average price is taken has key implications for analysis.** BNEF executed this analysis in 2022, the year when battery mineral prices—particularly lithium—were at peak.

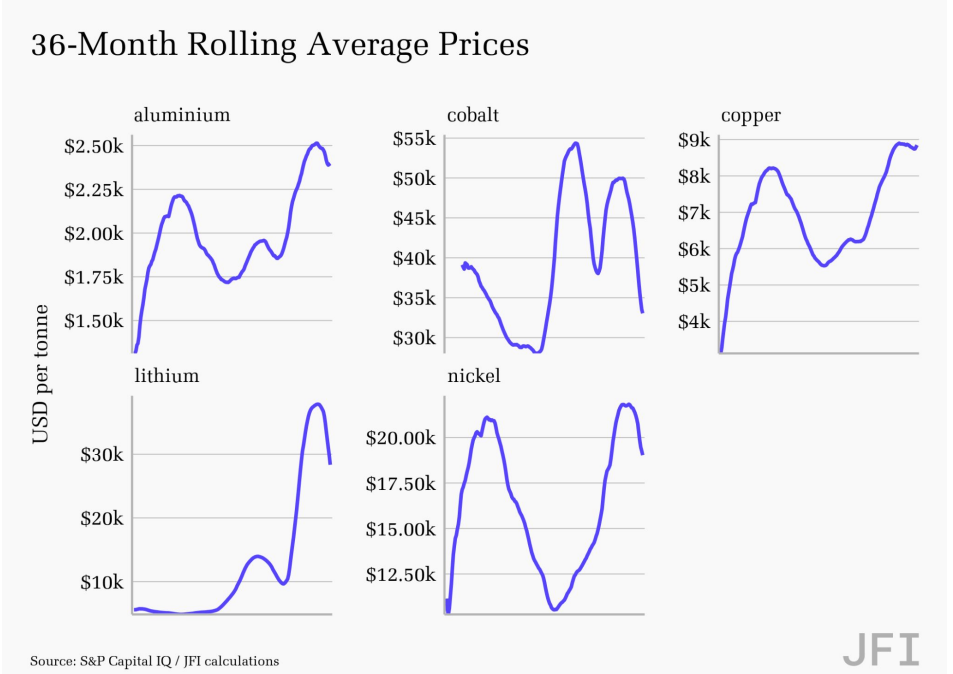

Figure 12: The rolling 36-month average price of aluminum, cobalt, copper, lithium, and nickel from January 2009 to July 2025. The second month averages across only the first and second months; the 36th month averages across all months in the data, and then the following months drop the first month of data from the average, and so on. This approach captures market volatility while also dampening the price swings.

Transition-Critical Minerals Now and Tomorrow

- **Price volatility can have an even greater impact on projections for future market size than scenario modeling results of future market volumes.**
- To illustrate, we take the highest and lowest 36-month average of these commodities and interact them with the market volume estimate in the Economic Transition Scenario (the more conservative scenario projection), similar to BNEF's approach but without the Net Zero Scenario outlook.
- We inflate the BNEF values into nominal terms using the 2.75 percent annual rate for consistency and comparability, and plot them alongside the potential "range" between the high/low price interactions.

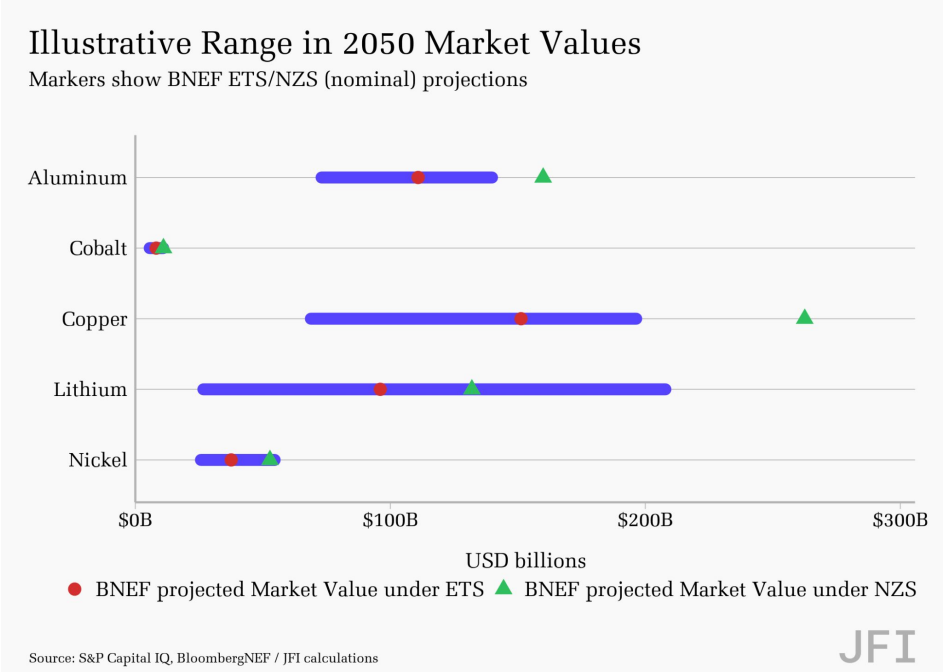

Figure 13: An illustrative range of future market values using the more conservative *Economic Transition Scenario* volumes and the highest/lowest values of the rolling 36-month average price of aluminum, cobalt, copper, lithium, and nickel from January 2009 to July 2025. The markers show BNEF's approach with the 10-year average price against the *Net Zero Transition Scenario* and the *Economic Transition Scenario*. Cobalt is a small market, so the distribution is less obvious than the other four minerals; the low-price case estimate for cobalt is $5.6 billion and the high-price case estimate is $10.9 billion, a 94 percent difference.

Transition-Critical Minerals Now and Tomorrow

- **Other than copper and aluminum (which are larger markets in volume terms), price has a greater (or equal) impact on total value estimates than the demand scenario.** On the low end, the percent difference between the two extreme values in 2050 ranges from about 46 percent for aluminum to as high as 680 percent for lithium, a difference of about $44 billion and $181 billion, respectively.
- This is about much more than back-of-the-envelope modeling decisions: **the reality that unfolds for transition-critical mineral markets has key implications for the sector and the countries that rely on it.**
- Which lithium projects are viable, and where, in the $181 billion world looks very different from the $44 billion world, as does the scale of tax revenues and economic spillovers for producer countries. A gross revenue royalty rate of 2–5 percent (which is standard) implies a difference of $2.74–$6.85 billion in overall potential royalty revenues.

Transition-Critical Minerals Now and Tomorrow

The future of mineral markets is promising but deeply uncertain, requiring grounded expectations for value capture and downstreaming within volatility.

Policymakers risk being misled by static views of 2050 and must be prepared for a range of possible outcomes.

There is an urgent need for more critical research on mineral market dynamics and their implications for producer-country development.

Research should focus on:

- How producer countries, especially LMICs, can navigate market volatility while attracting investment for development around the extractive sector.
- The role of stockpiling, strategic interventions, and trade partnerships in advancing both development and supply security objectives.
- The challenges and opportunities posed by market fragmentation arising from geopolitical tensions.
- The complexities of responding to price shifts in both primary and co-product minerals.
- When and how mineral market formalization delivers its intended development benefits.

Appendix - Accompanying Figures from JFI’s Mineral Market Dashboard

I. Scenario projections of other transition-critical minerals (excludes copper, featured above)

Note: Values are shown as an index to allow comparison across different data sources and various projection scenarios and forecasts. For all commodities except Aluminum, which references USGS 2023 Production, series are indexed relative to a common baseline derived from the values of the S&P 2023 aggregate production estimate. An index near 100 represents this approximate baseline level. This method shows relative trends and scale but prevents the calculation of precise raw data values.

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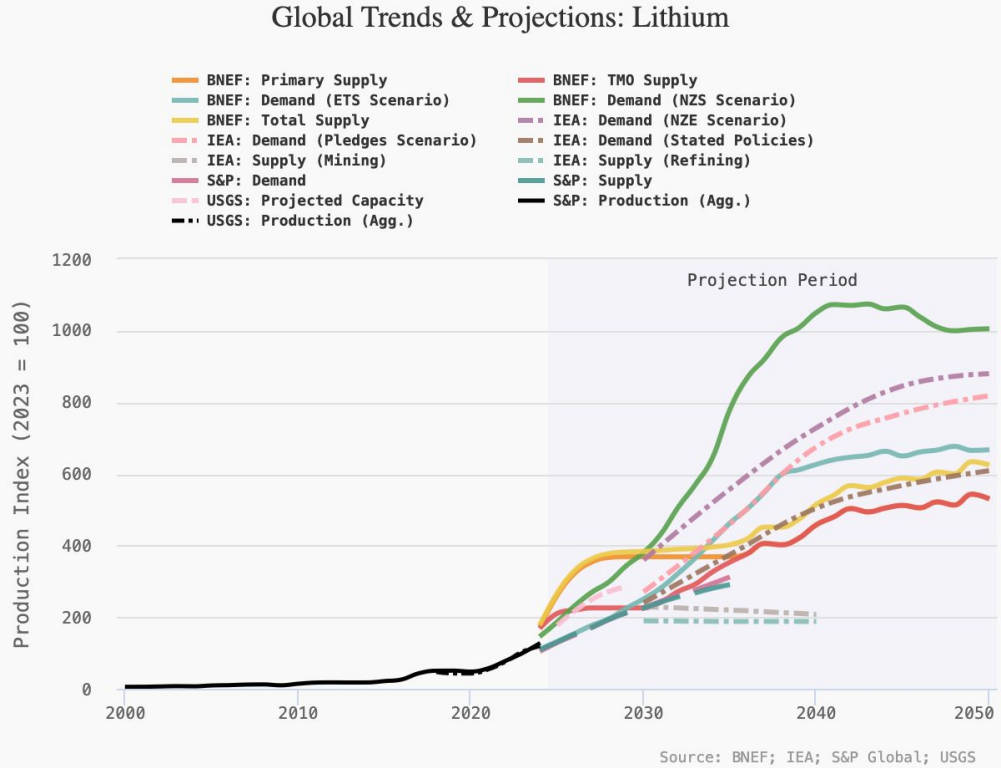

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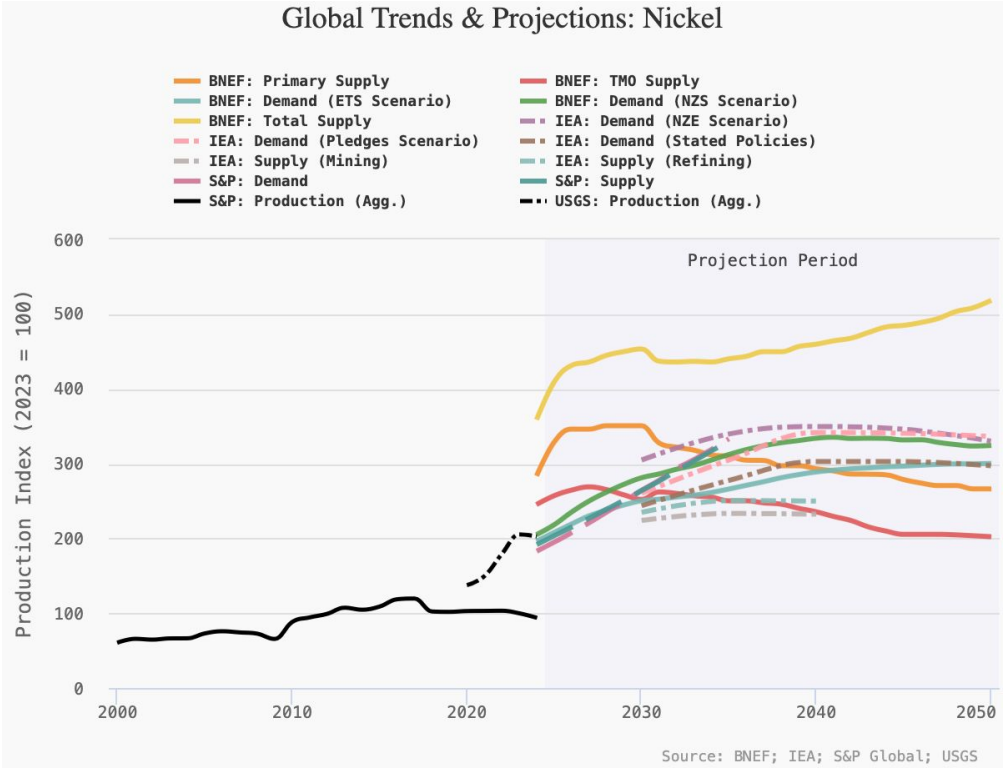

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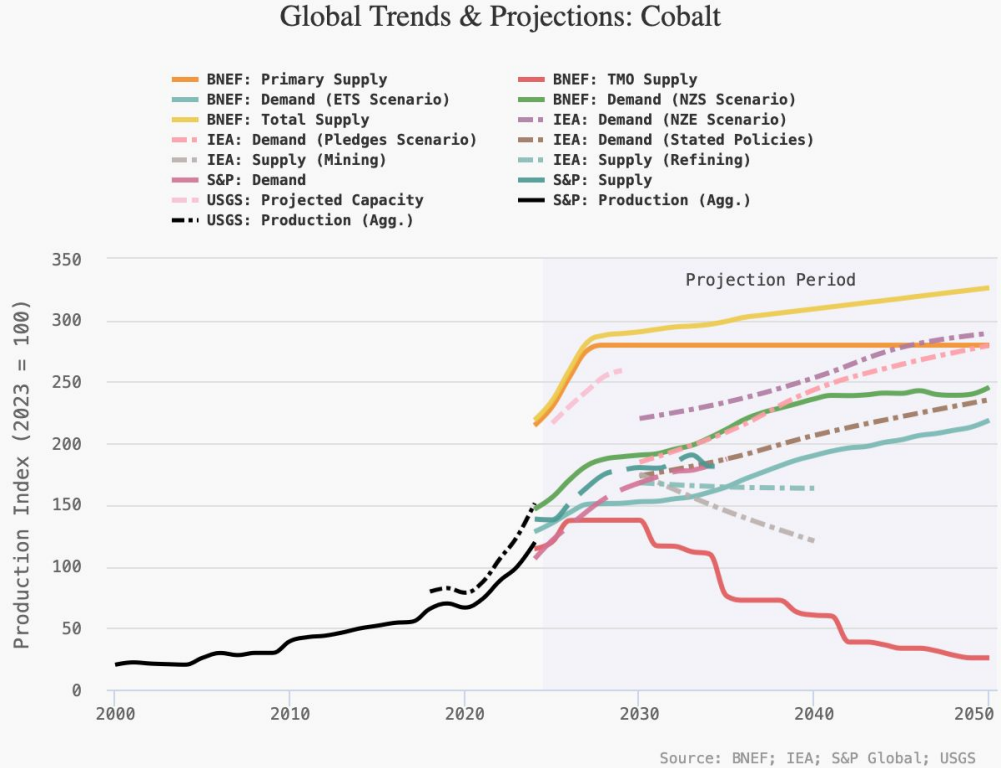

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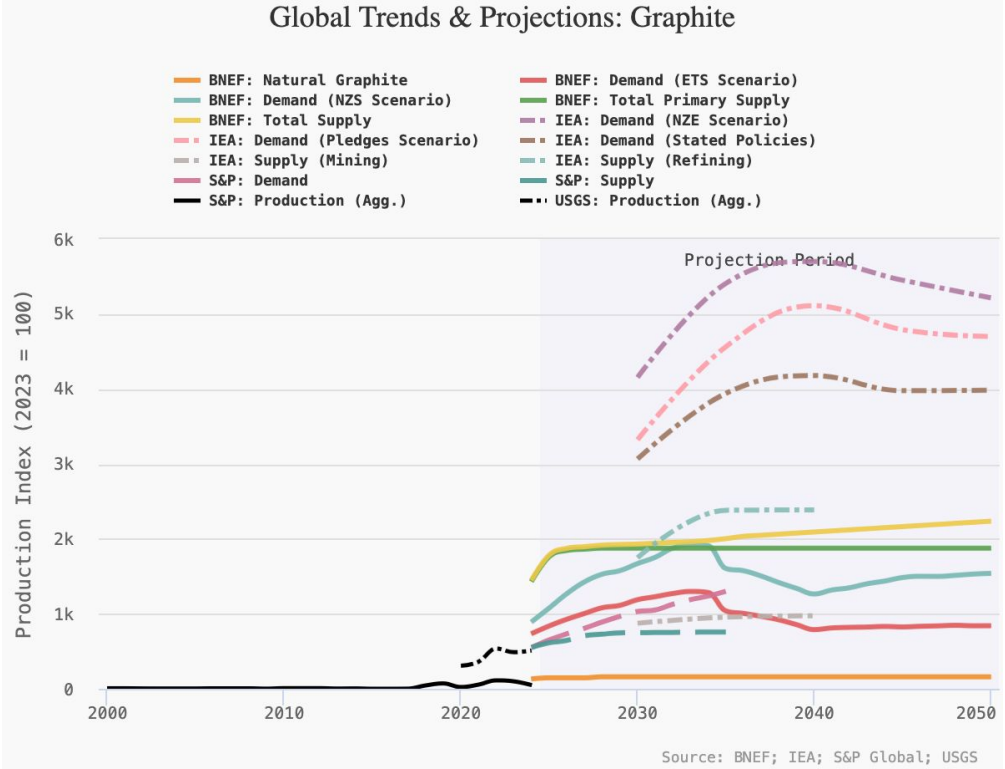

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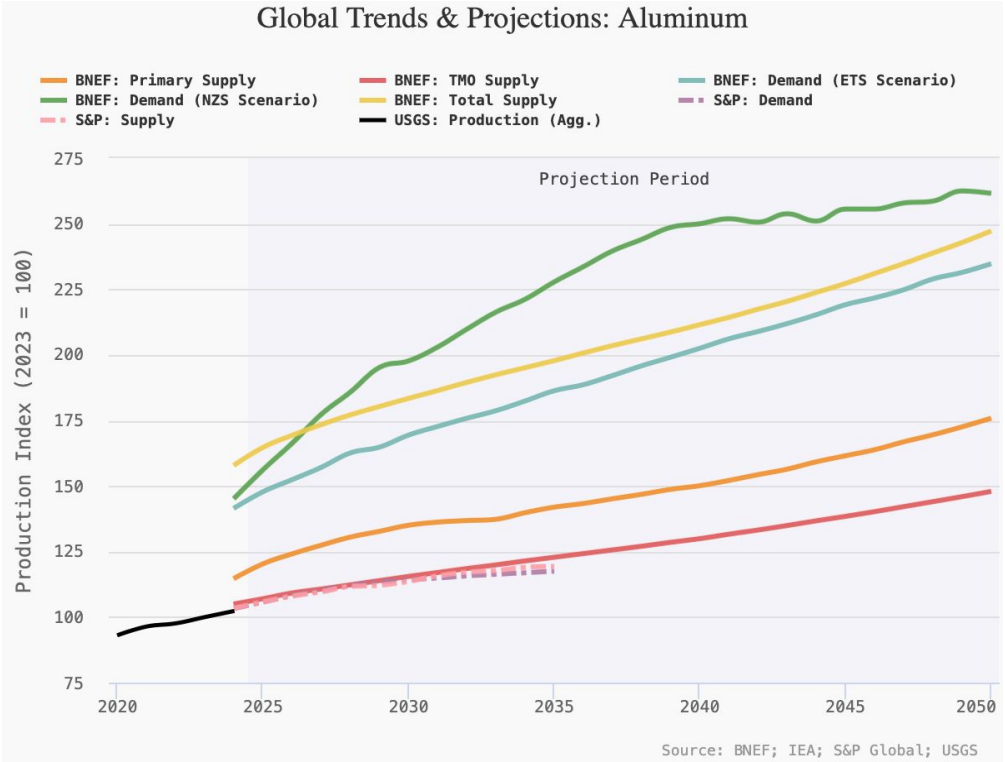

II. Leading producers of other transition-critical minerals (excludes lithium, nickel, and cobalt, featured above).

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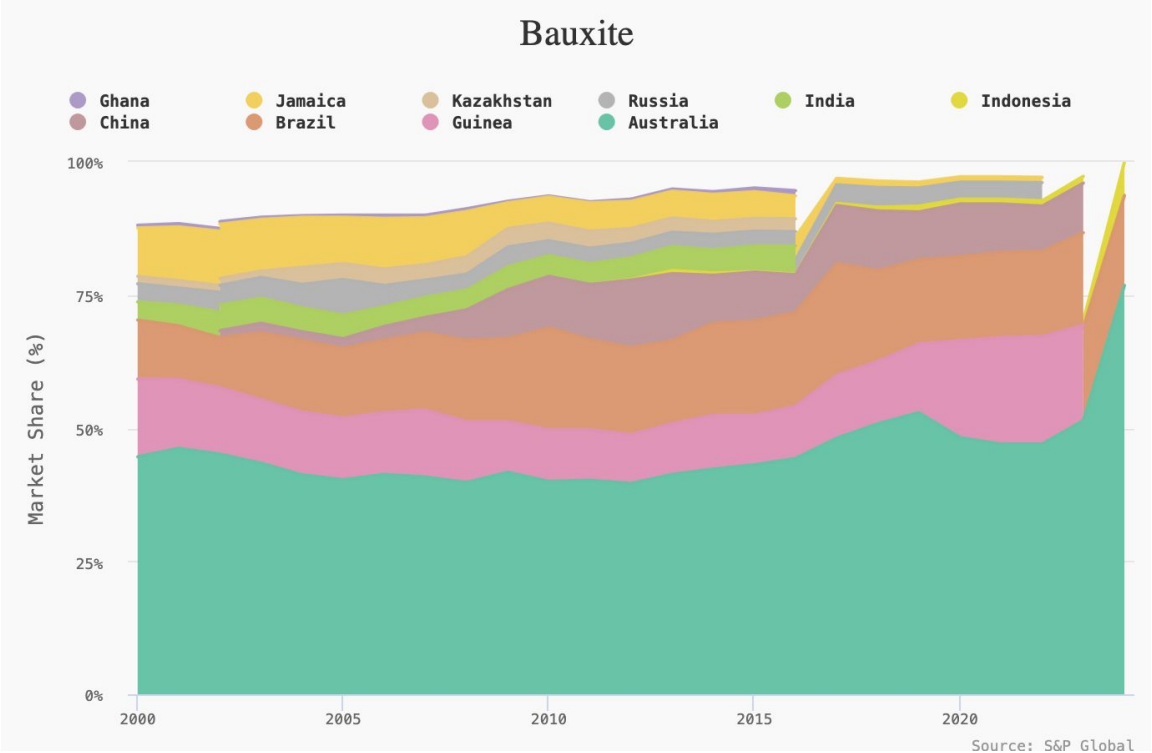

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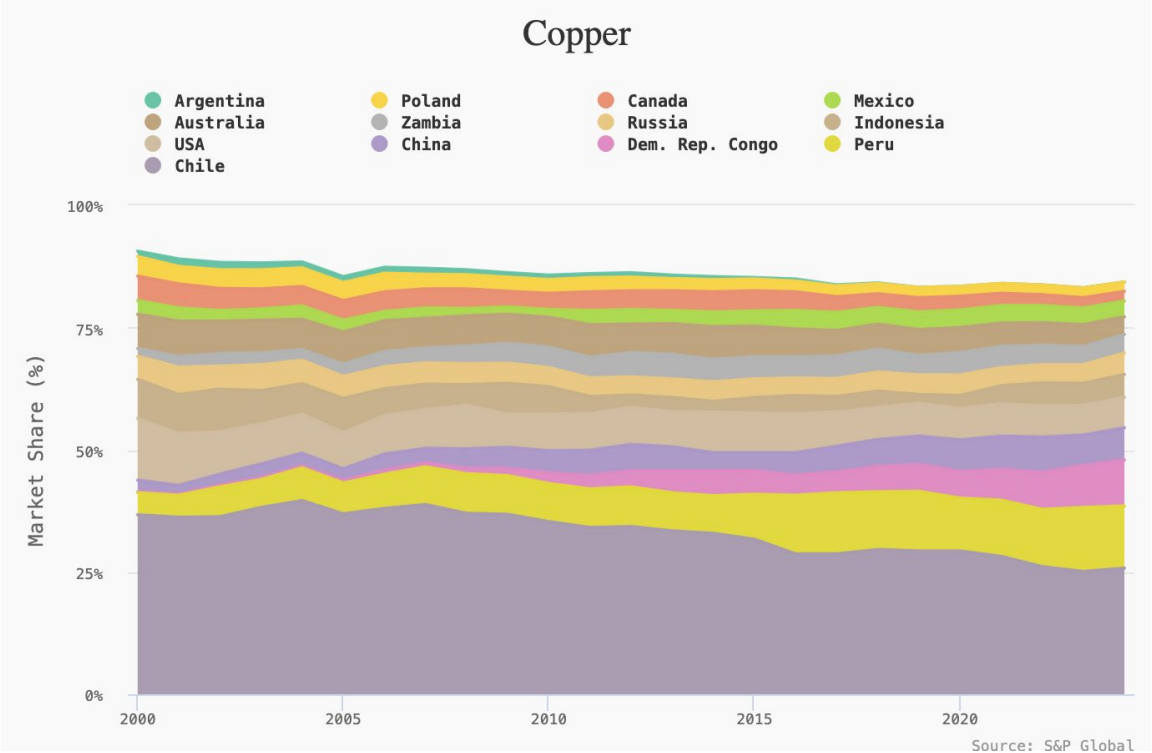

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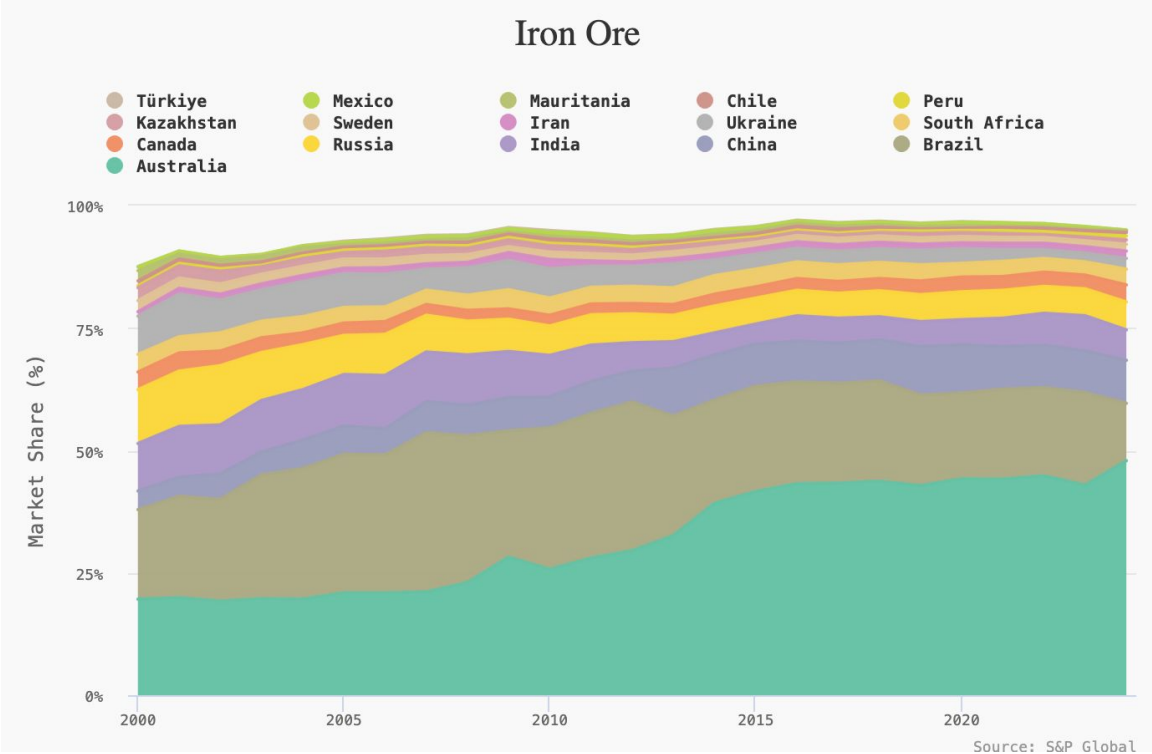

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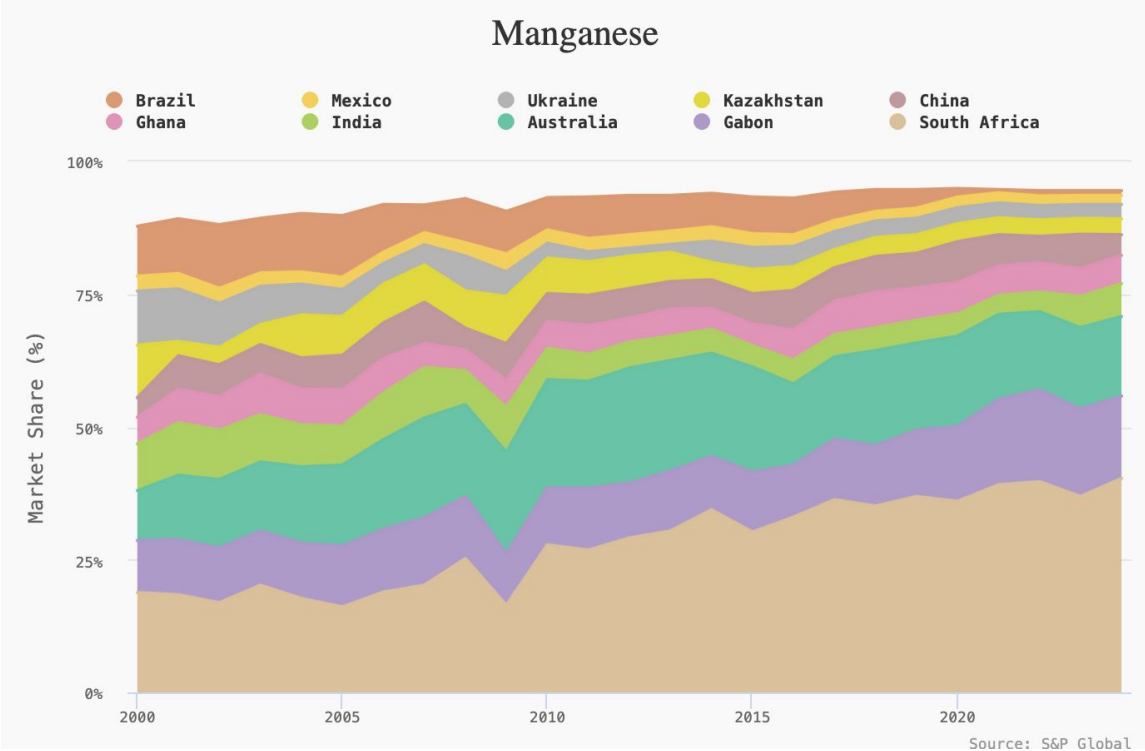

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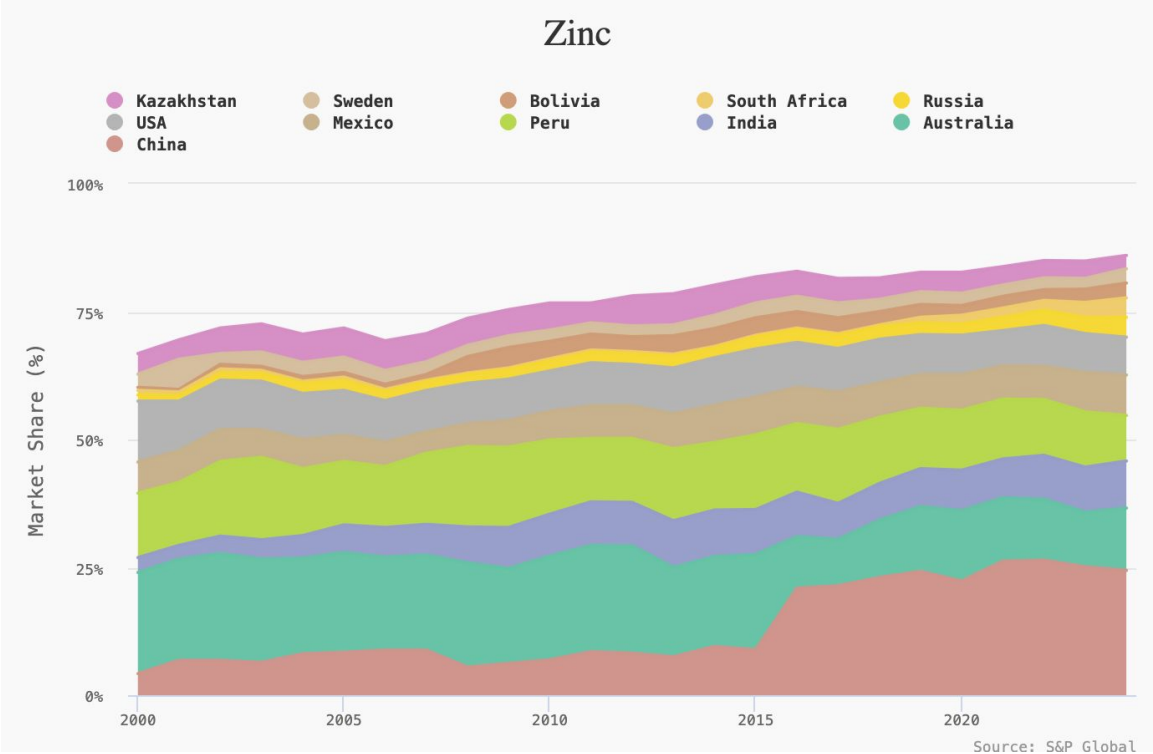
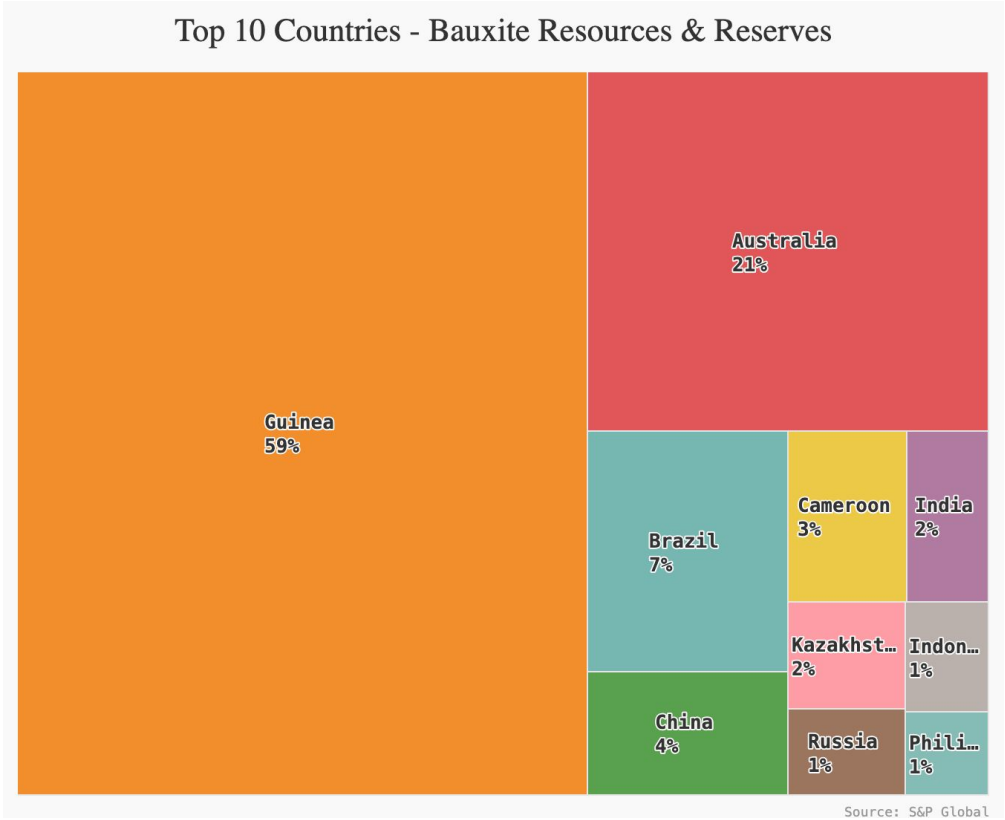


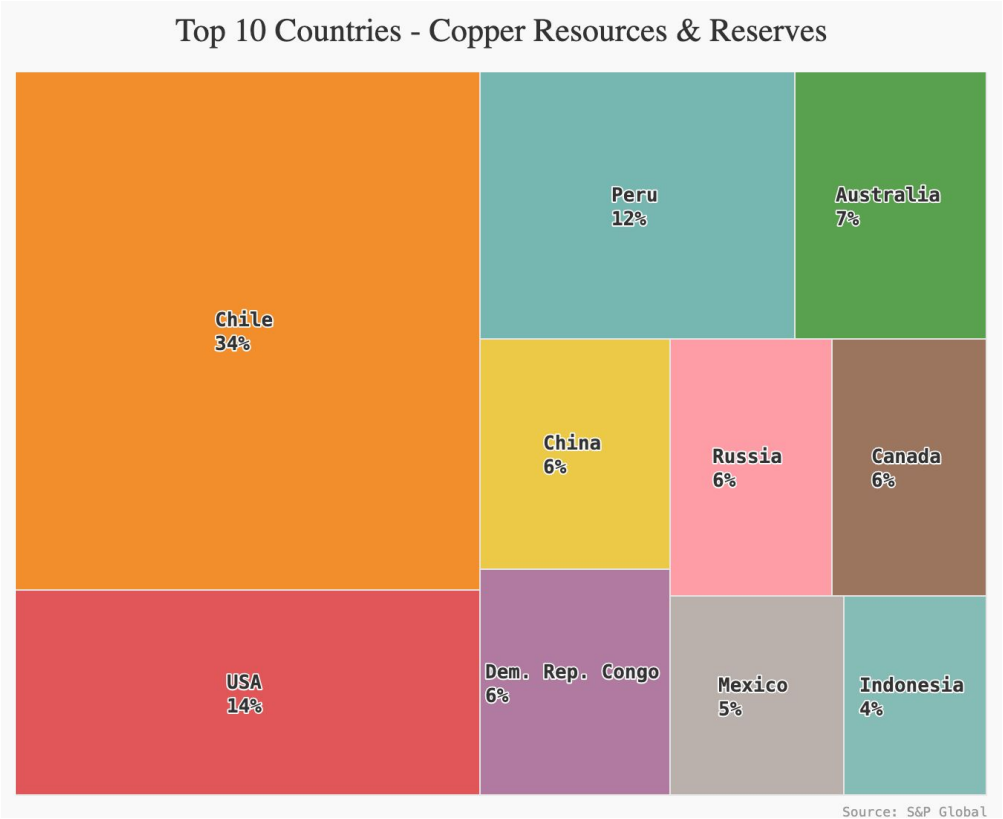
III. Countries with the largest resources and reserves of other transition minerals (excludes nickel and cobalt, featured above).

Note: These figures show the relative split of the top 10 countries only, so that both the names and resource estimates of other countries are excluded.

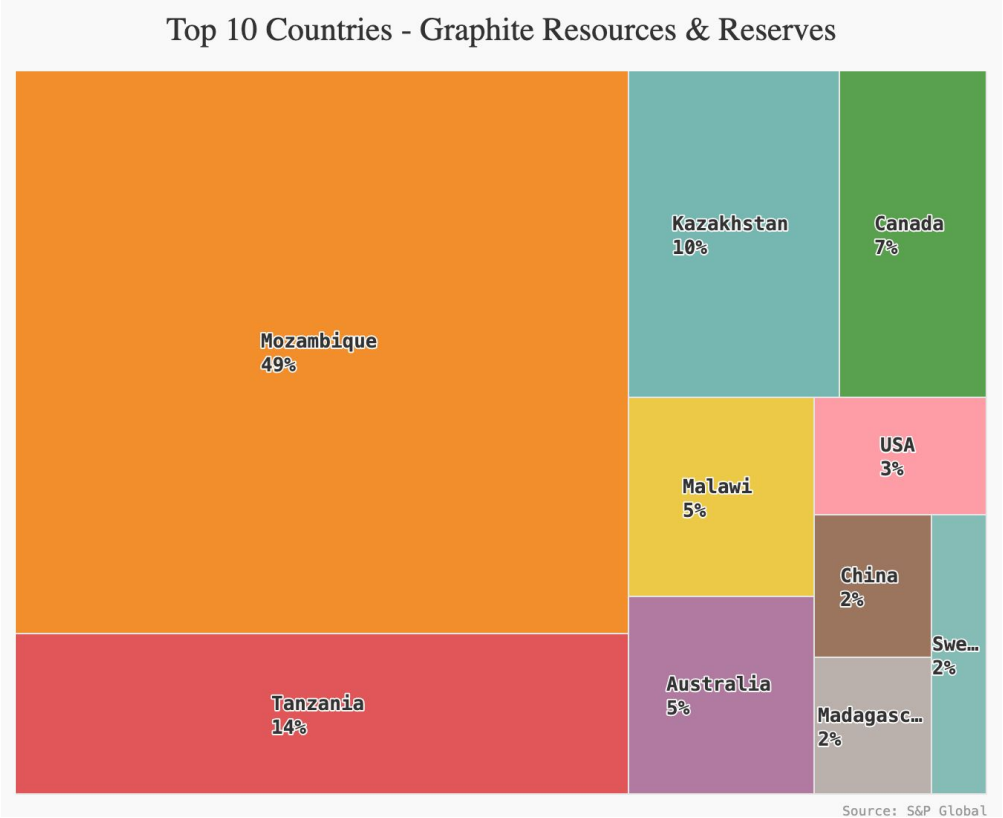
III. Countries with the largest resources and reserves of other transition minerals (excludes nickel and cobalt, featured above).



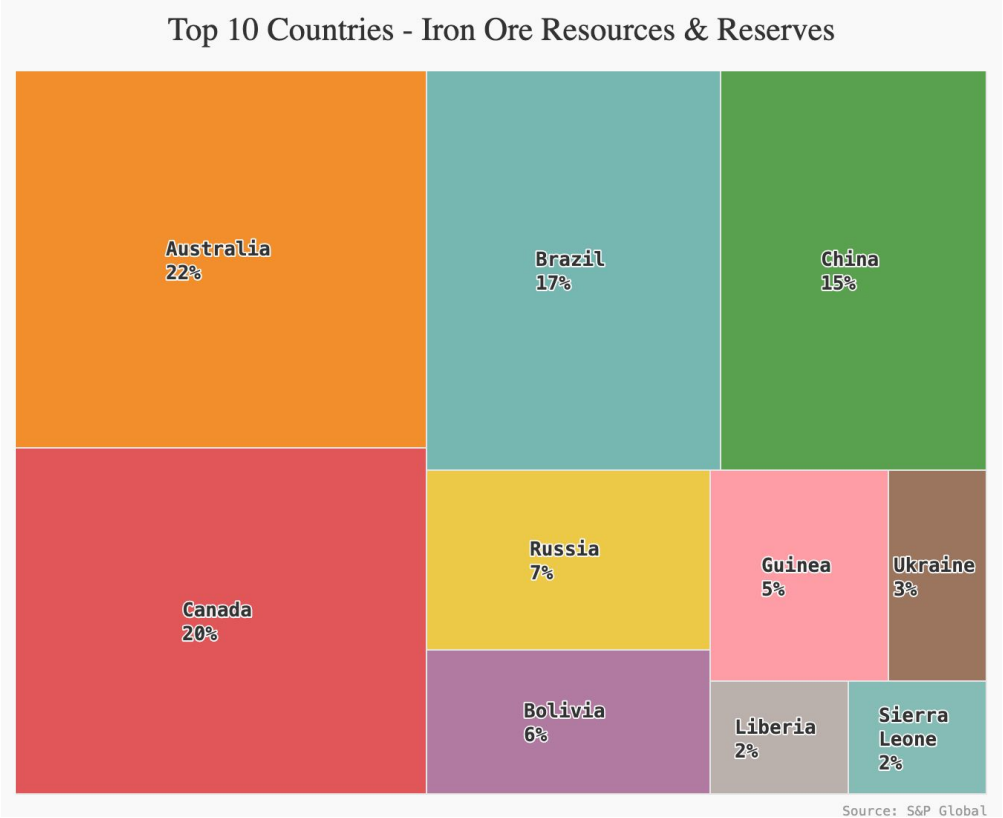
III. Countries with the largest resources and reserves of other transition minerals (excludes nickel and cobalt, featured above).



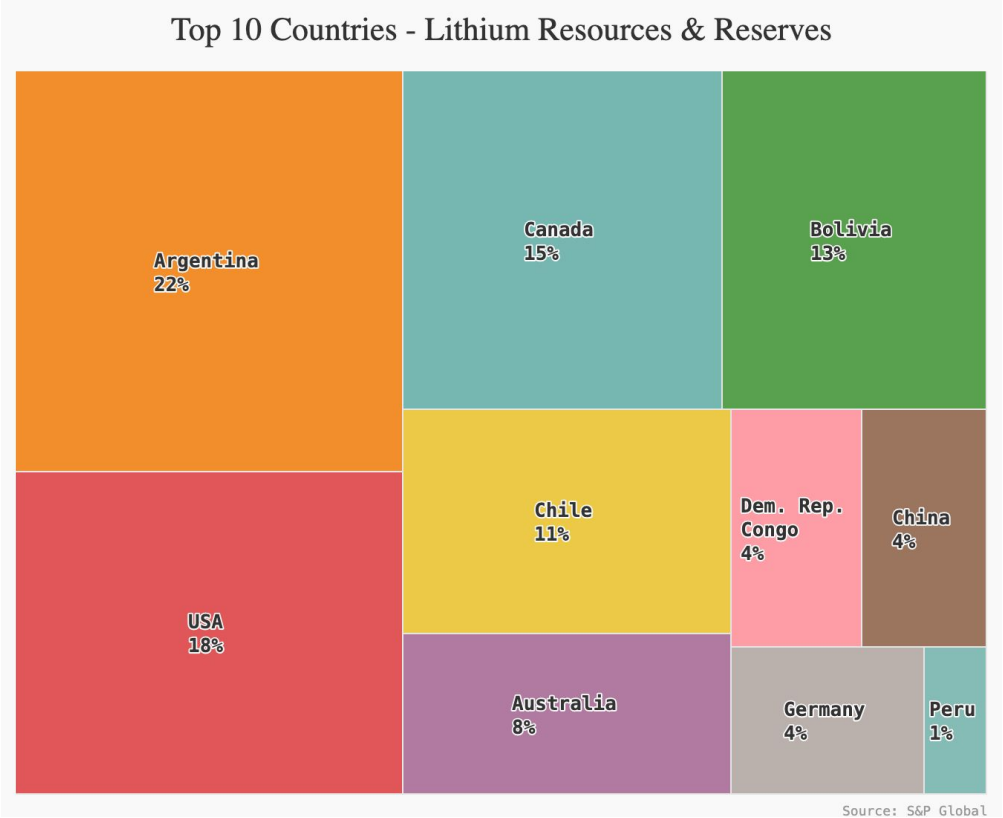
III. Countries with the largest resources and reserves of other transition minerals (excludes nickel and cobalt, featured above).



III. Countries with the largest resources and reserves of other transition minerals (excludes nickel and cobalt, featured above).



III. Countries with the largest resources and reserves of other transition minerals (excludes nickel and cobalt, featured above).



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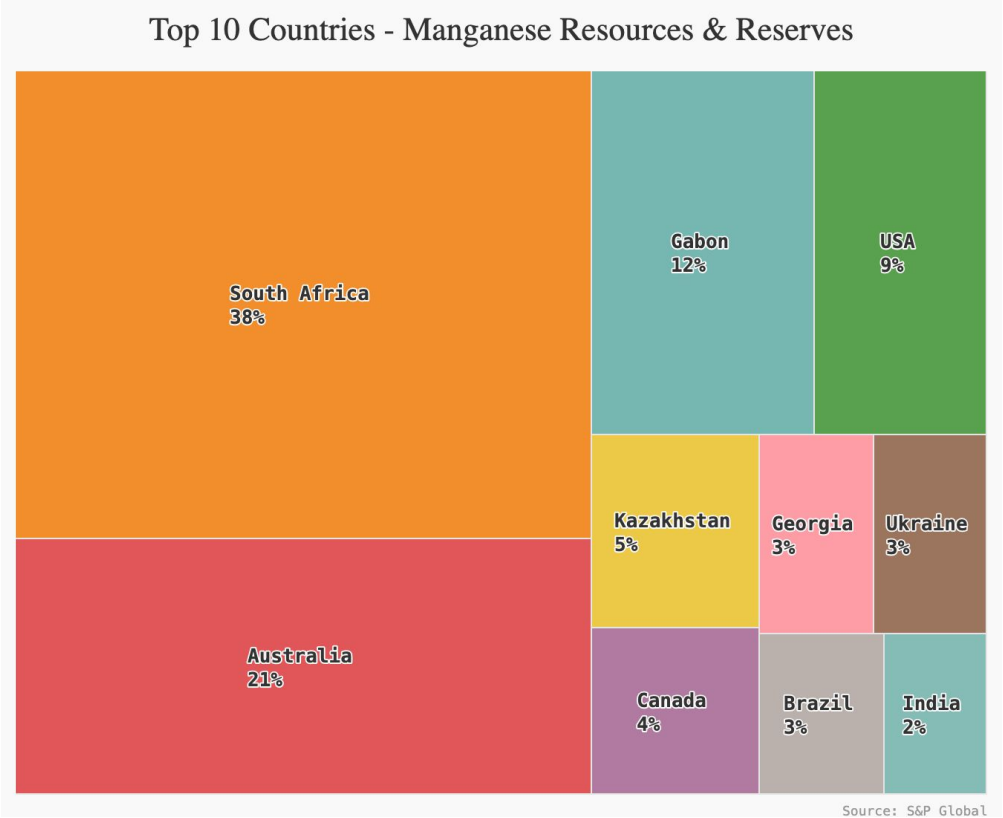
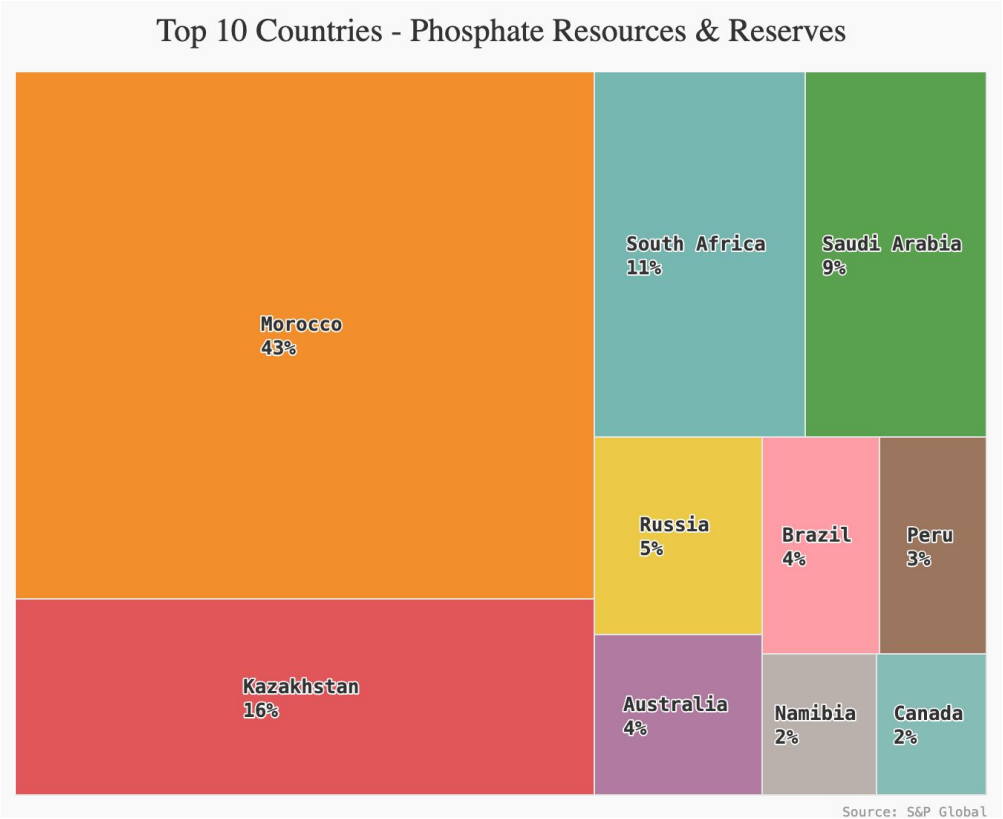


III. Countries with the largest resources and reserves of other transition minerals (excludes nickel and cobalt, featured above).



III. Countries with the largest resources and reserves of other transition minerals (excludes nickel and cobalt, featured above).