DYNAMIC SUSTAINABILITY LAB™
AT SYRACUSE UNIVERSITY

CRITICAL MINERALS & THE ELECTRIC VEHICLE TRANSTION

www.DynamicsLab.org
Researching the Risks and Opportunities of the Global Sustainability Transition

Bulletin No. 20220102

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INTRODUCTION

The transportation sector is the greatest source of greenhouse gas emissions in the United States, responsible for 29% of emissions.[4] The transportation sector also contributes $1.1 trillion annually to the US economy.[5] As such, electric vehicle production and sales have the potential to significantly benefit both the domestic economy and environment.

However, the electric vehicle supply chain carries significant risks for domestic producers. In order to produce electric vehicles, automakers need access to critical minerals for batteries. The US is heavily reliant on imports for critical minerals.

THE FIVE CRITICAL MINERALS

Production of a typical lithium-ion battery requires the following five minerals dubbed "critical minerals" by the US Department of the Interior: lithium, nickel, cobalt, manganese, and graphite.[6]

These "critical minerals" are defined as:
essential to the economic or national security of the United States;
with a supply chain vulnerable to disruption;
which serve an essential function in the manufacturing of a product. In this case, EV batteries manufacturing.

SUPPLY CHAIN DISRUPTIONS

The EV mineral supply chain includes unique challenges for each of the critical minerals. These bottlenecks create vulnerabilities that, if left unaddressed, could undermine EV production and impact the EV transition. For example, lithium is extracted from an arid region in South America using environmentally impactful techniques. Cobalt is mined in the DRC, which is mired in human rights abuses and corruption. Graphite, along with all critical minerals used for Li-ion batteries, is dominated by Chinese production and refining. Nickel and Manganese, while still subject to supply chain disruptions, are less at-risk than the other minerals.

A PATH FORWARD

The US should take the following three steps to improve the EV mineral supply chain:
1. Increase domestic production of critical minerals (following appropriate permitting, environmental standards, and community involvement protocols, especially regarding indigenous communities).
2. Invest significantly in battery recycling infrastructure to improve circular economy and alleviate bottlenecks.
3. Research alternative battery chemistries less reliant on critical minerals.

FAST FACTS

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10X

Projected growth of the EV industry in the United States from 300K to 3M by 2030[1]

1

Number of domestic mines in the United States producing lithium minerals[2]

2030

Date for US and partners to establish a secure battery materials and technology supply chain[3]

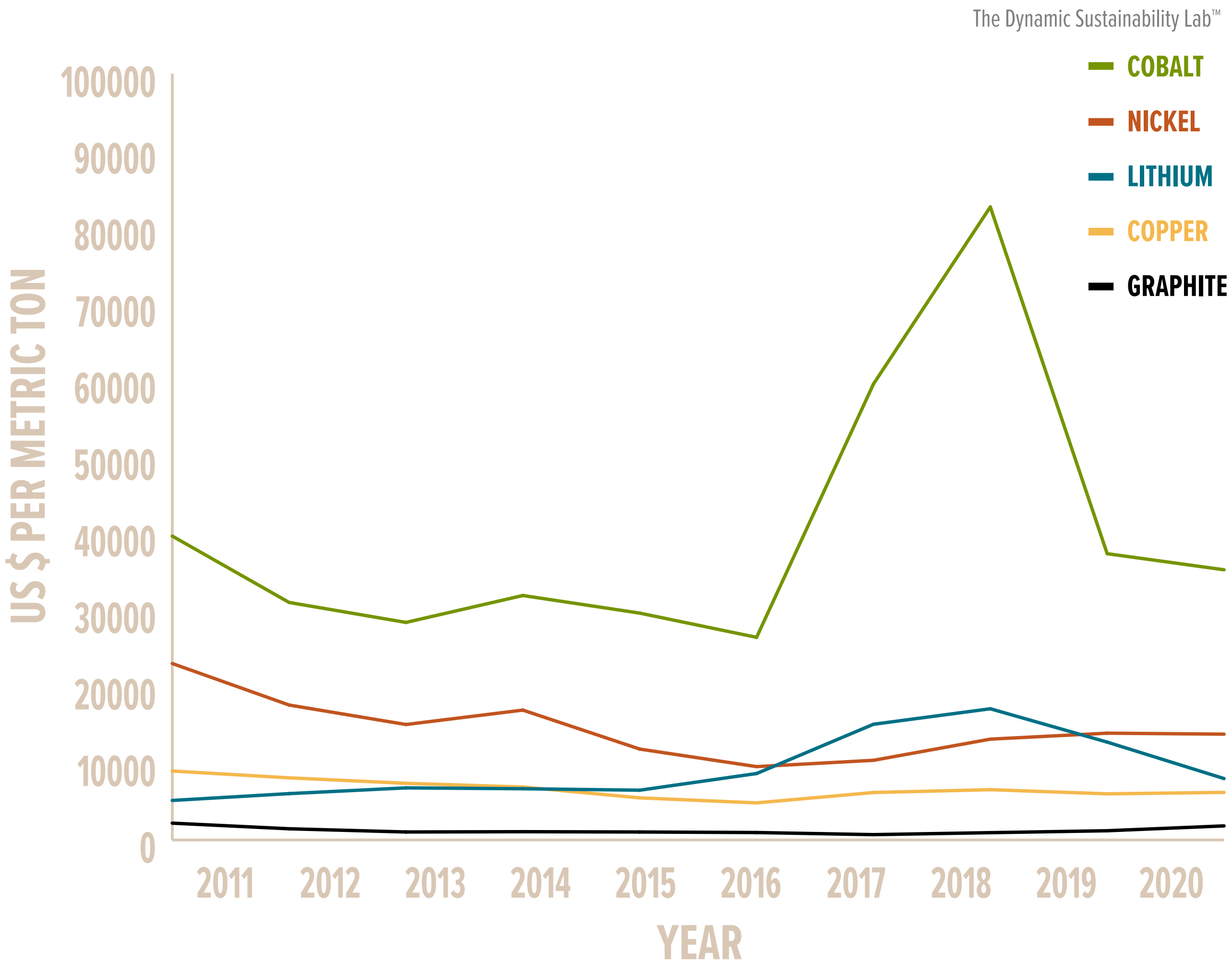
75.2%

US net import reliance on the five critical minerals[2]

6X

Amount of critical minerals required per EV compared to conventional vehicles (207.5 kg per EV, 33.9 kg per conventional)[1]

CRITICAL MINERAL PRICES OVER TIME

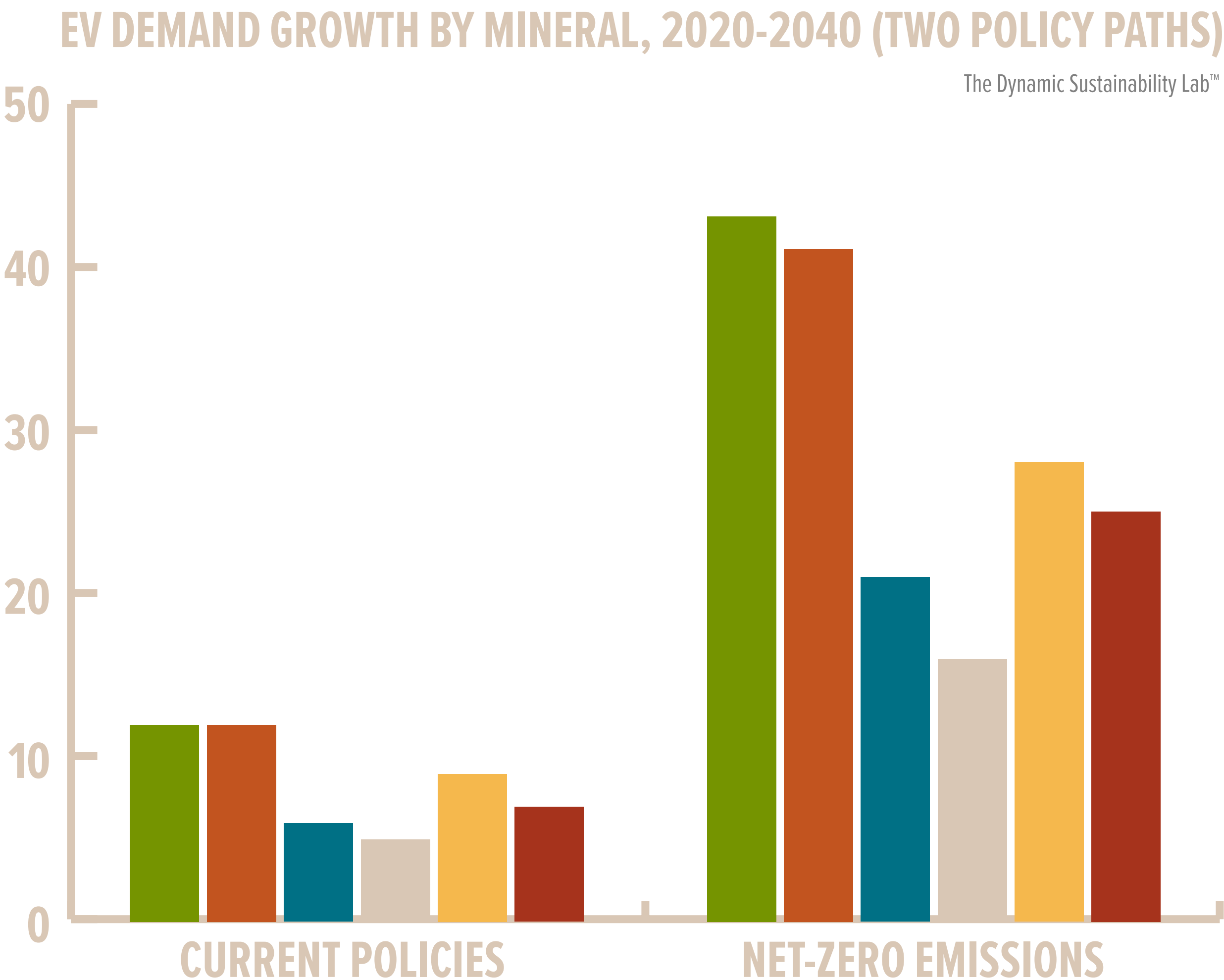


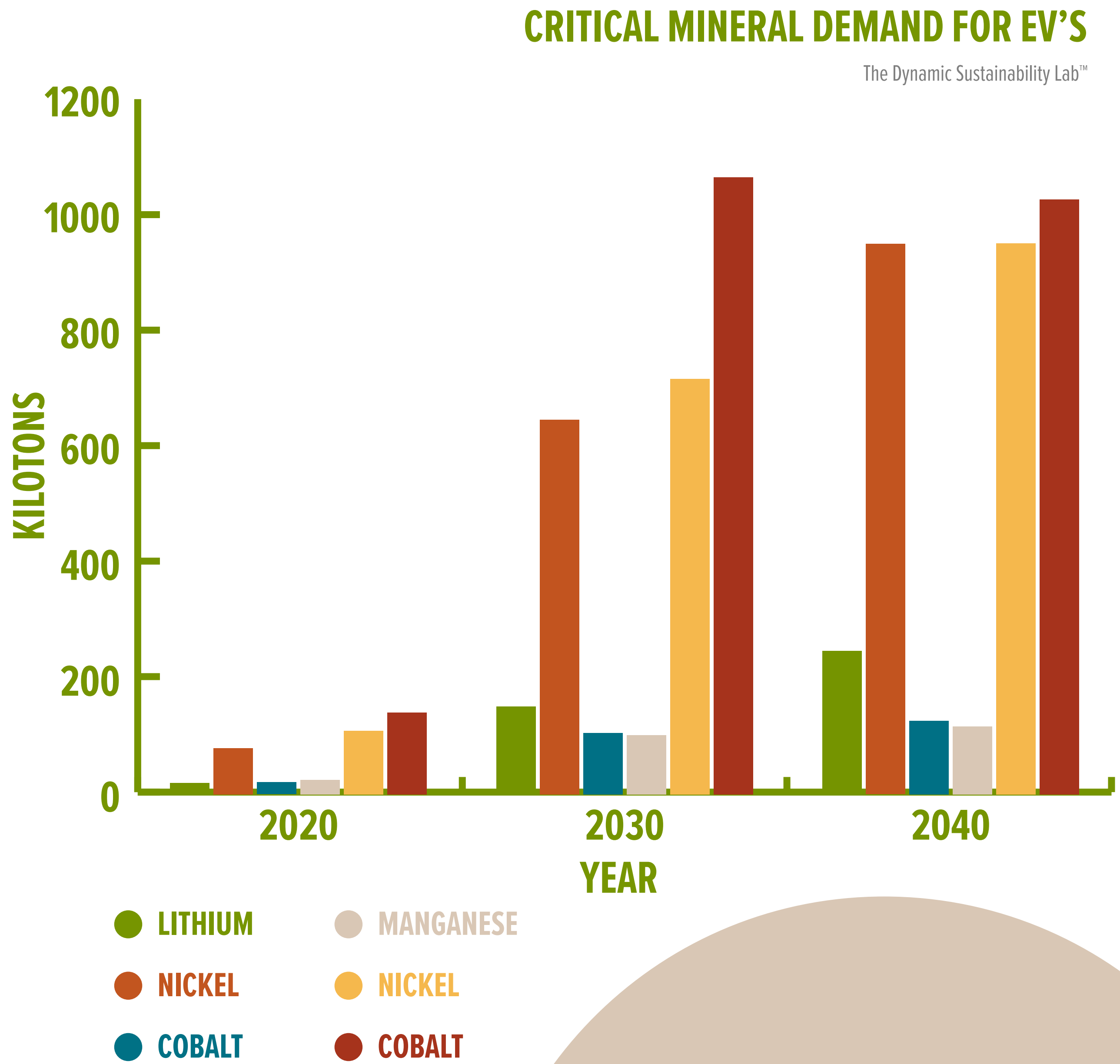
& DEMAND VOLATILITY

Mineral prices over the last decade have been volatile, with supply outstripping demand in the short term.

However, demand is expected to increase significantly for all critical minerals. Under current policies, lithium and nickel mineral production is expected to grow by a factor of 12. Under a net-zero emission policy approach, lithium production is expected to increase by a factor of 43 and nickel by a factor of 41. Gross projected demand of graphite is expected to be highest in the short term, but may wane as anode alternatives (like silicon) come online.

&DEMAND VOLATILITY



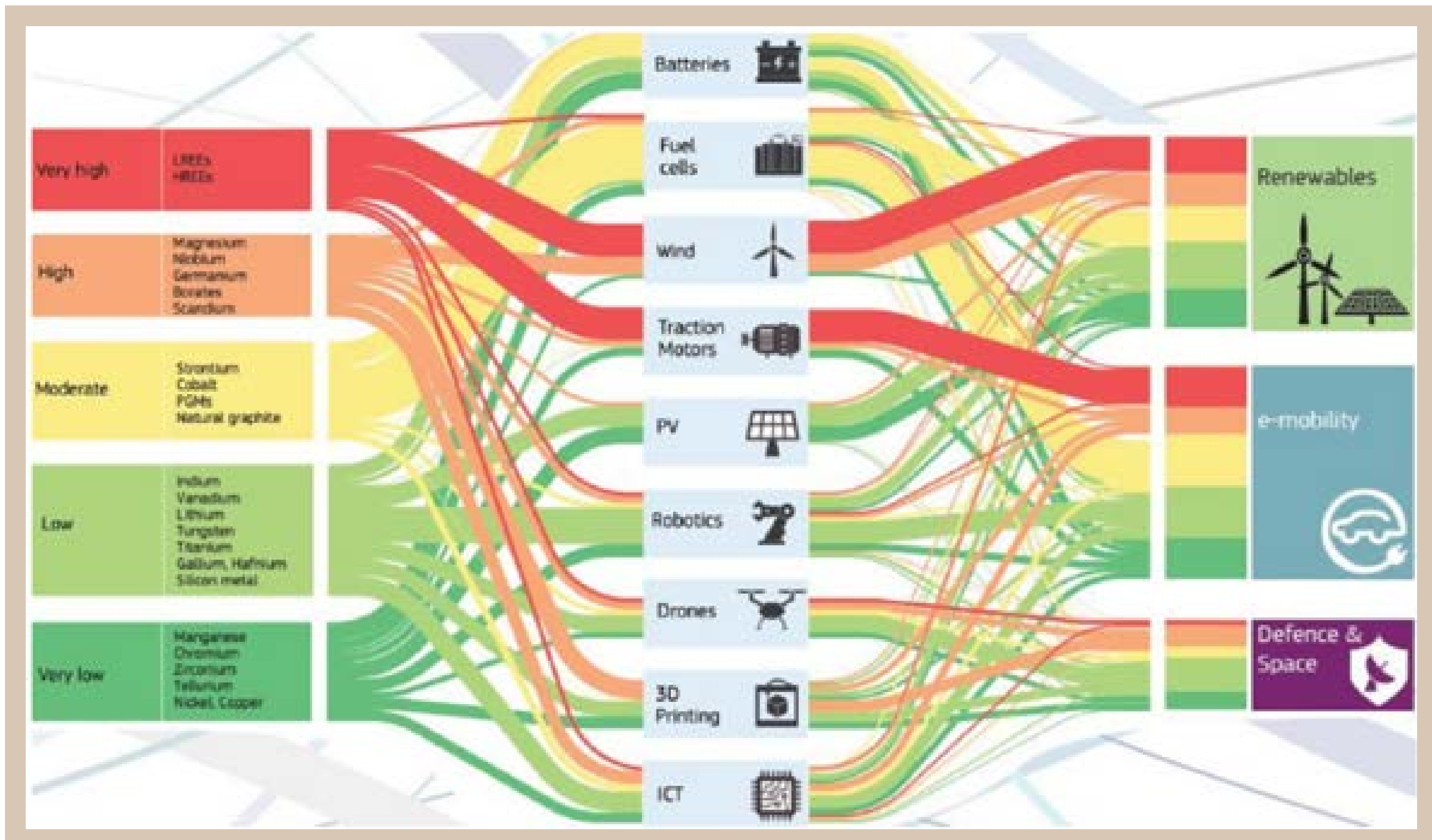


&DEMAND VOLATILITY

DEMAND IN OTHER SECTORS

Demand for critical minerals is not limited to the EV battery sector. Competition between sectors - and even within a sector, by application - makes critical mineral supply all the more tenuous.

Critical minerals are required for applications beyond electric vehicle batteries. This sankey diagram shows a ranking of critical minerals, their use by application, and their use by different sectors.



Lewicka, Ewa, Katarzyna Guzik, and Krzysztof Galos. 2021. "On the Possibilities of Critical Raw Materials Production from the EU's Primary Sources" Resources 10, no. 5: 50. https://doi.org/10.3390/resources10050050

2020 CRITICAL MINERAL PRODUCTION PERCENTAGE BY COUNTRY (TONNES)

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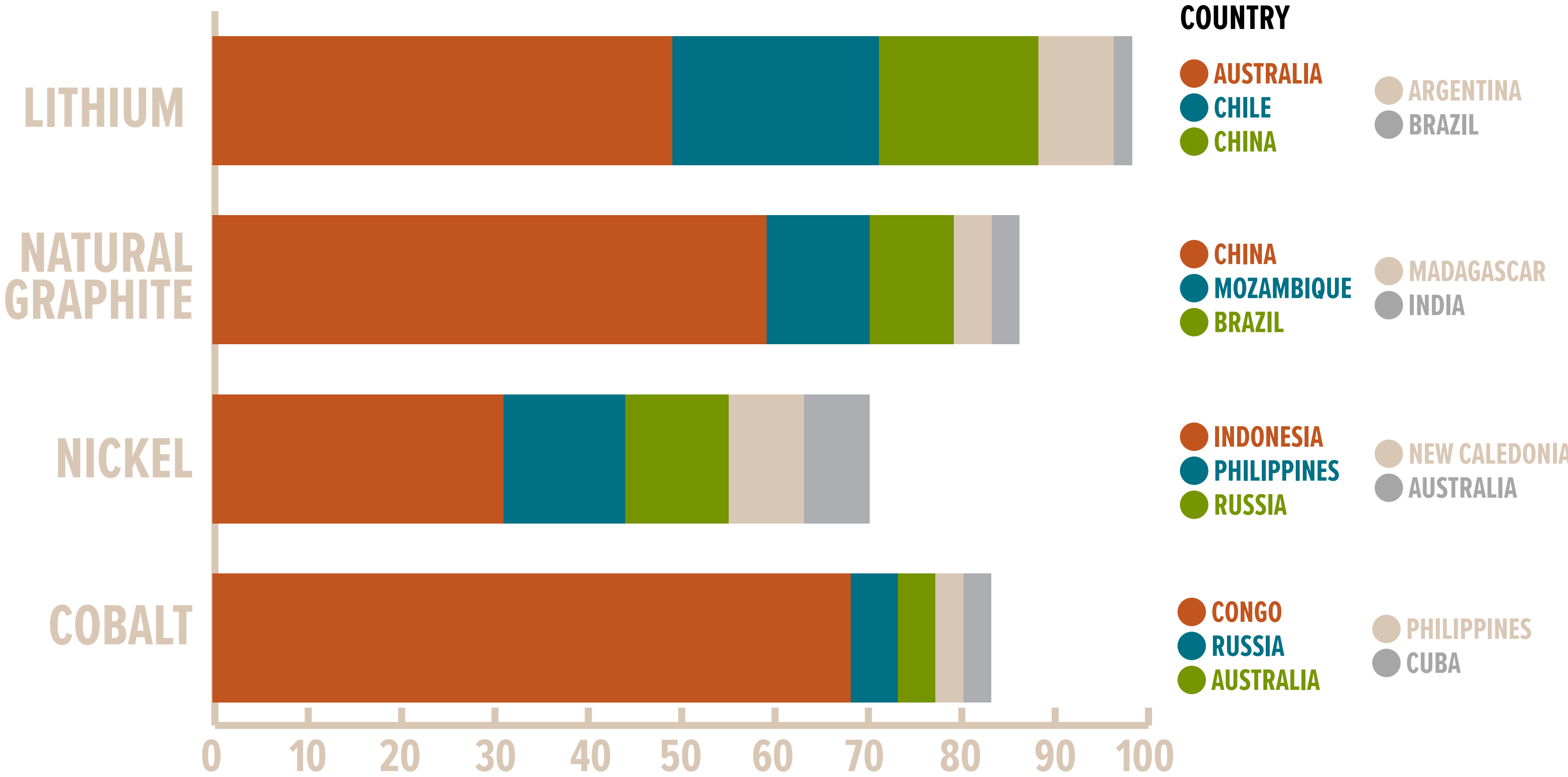

CONCENTRATED PRODUCTION

Production of critical minerals is concentrated in just a handful of countries. Cobalt is mined almost exclusively in the Democratic Republic of Congo and China dominates graphite production (both natural and artificial). China is even more dominant in the mid-stream steps of battery production, accounting for 80% of chemical refining (processing) for all critical minerals. The next slides will show how production is concentrated for each mineral.

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CONCENTRATED PRODUCTION

CHINA'S SHARE OF BATTERY PRODUCTION % IN FULL YEAR, 2019

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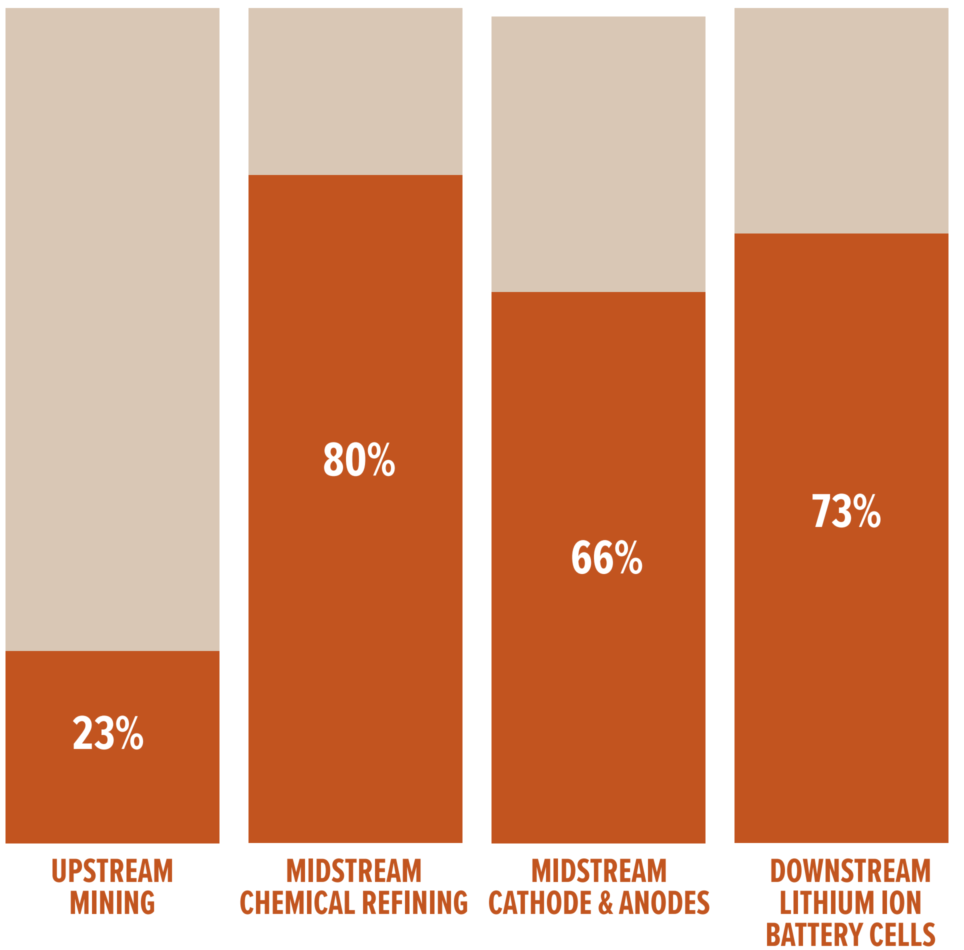

*LITHIUM, COBALT, NICKEL, GRAPHITE, MANGANESE, CATHODE, ANODE, CELLS ACCOUNTED FOR IN CALCULATIONS.

PROCESSING: SHARE OF TOP 3 COUNTRIES BY CRITICAL MINERALS

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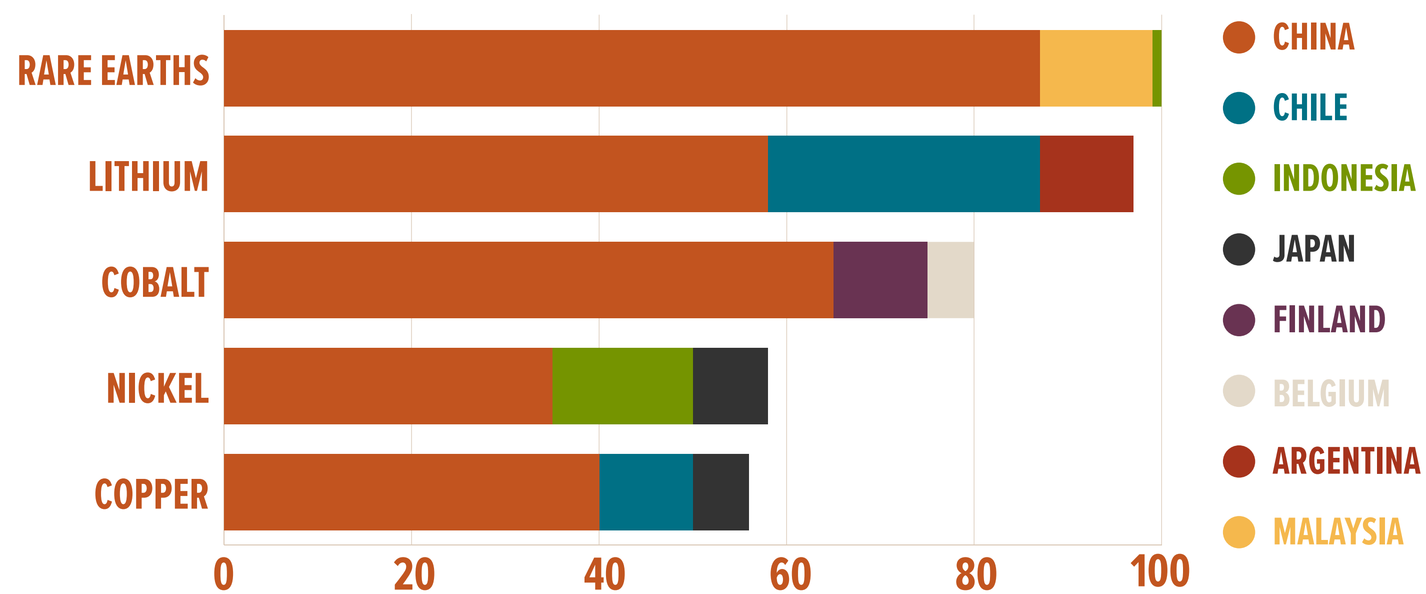

CONCENTRATED PRODUCTION

GLOBAL DISTRIBUTION OF KNOWN RESERVES AS OF 2020 & 2019 MINING PRODUCTION

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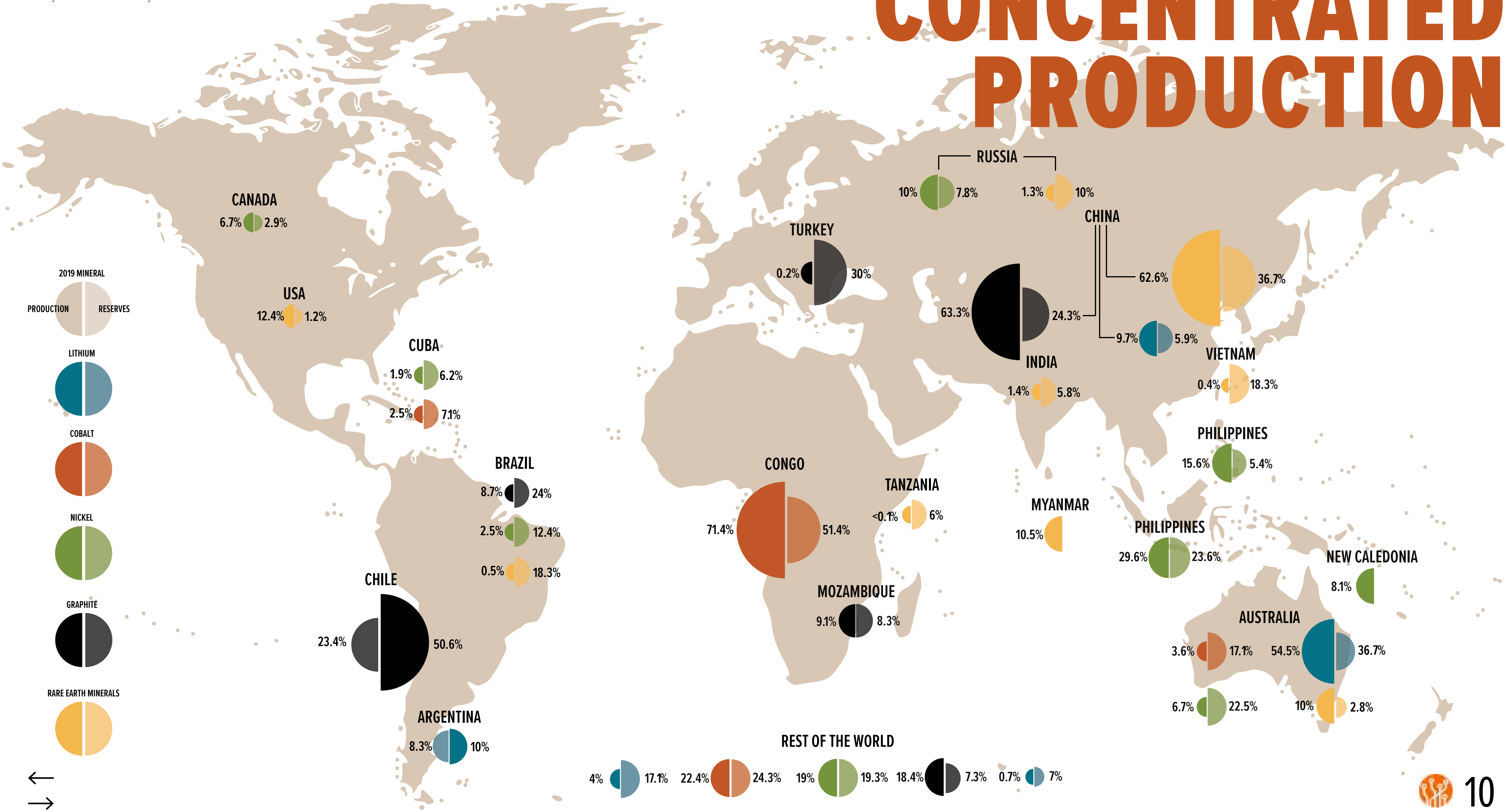

COBALT

Cobalt is a critical mineral in the cathode of most Li-ion batteries and is the most significant challenge in the supply chain. Cobalt mining is dominated by Chinese companies in Congo and nearly monopolized by Chinese refining.

ALL COUNTRIES EXPORTING COBALT TO ALL COUNTRIES IN 2019 BY VALUE (US $)

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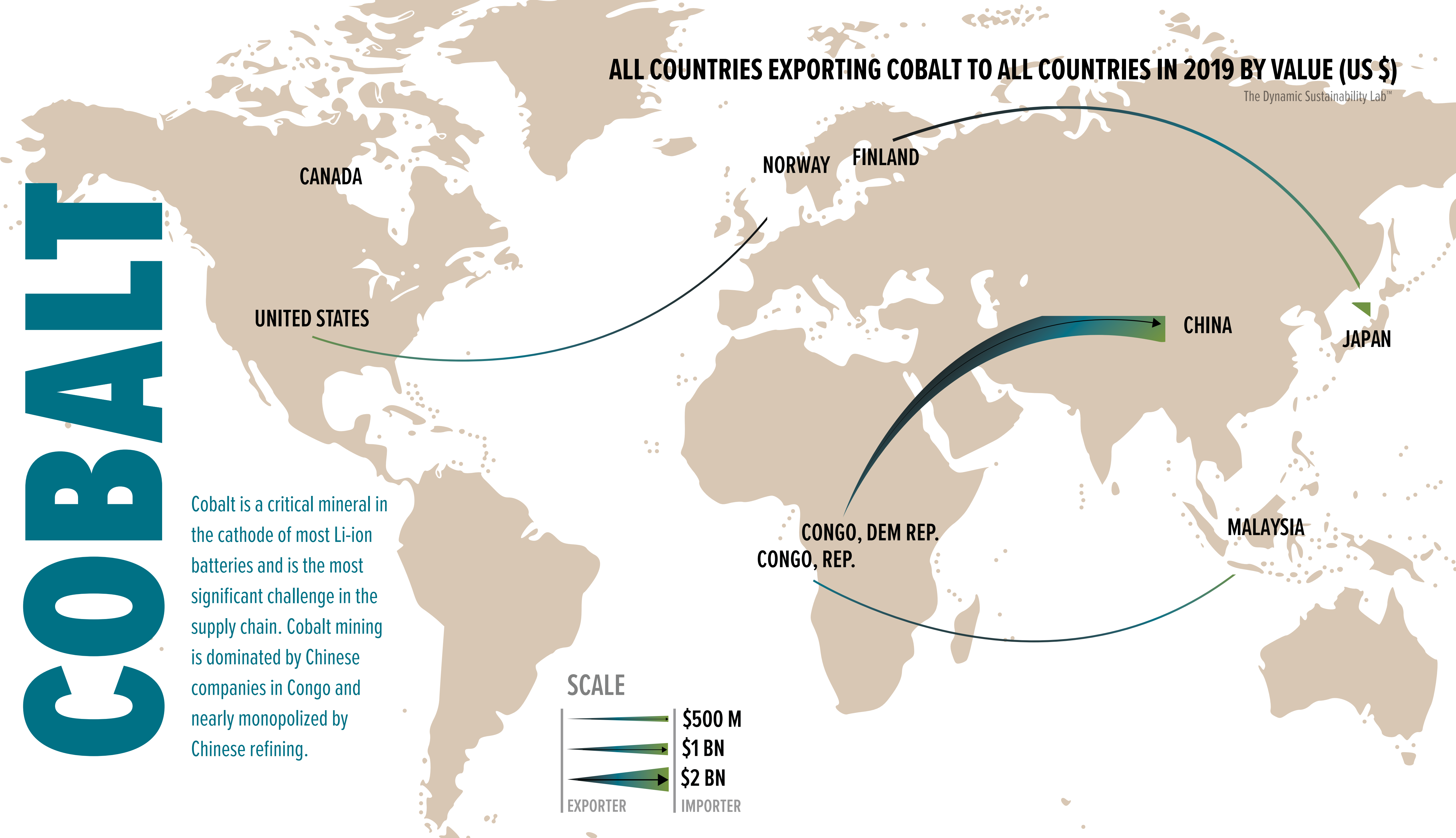

MARKET CONCENTRATION CASE-STUDY

COBALT

Not only is cobalt geographically concentrated, it also faces market concentration: 8 of the 14 large-scale mining companies in the DRC are Chinese-owned.[16] Of the cobalt produced in the DRC, chinese companies accounted for 50% of production in 2018, with their stake continuing to grow.[17]

Gecamines is the DRC state-owned mining company and is plagued by corruption and fraud.[18] Increasingly, Gecamines has sold stakes to private, foreign companies. Recently, China has consolidated power in DRC by buying up these stakes, such as the Tenke and Fungurume deposits.[19]

COBALT PRODUCTION IN DRC BY CONTROLLING COMPANY & HOME COMPANY

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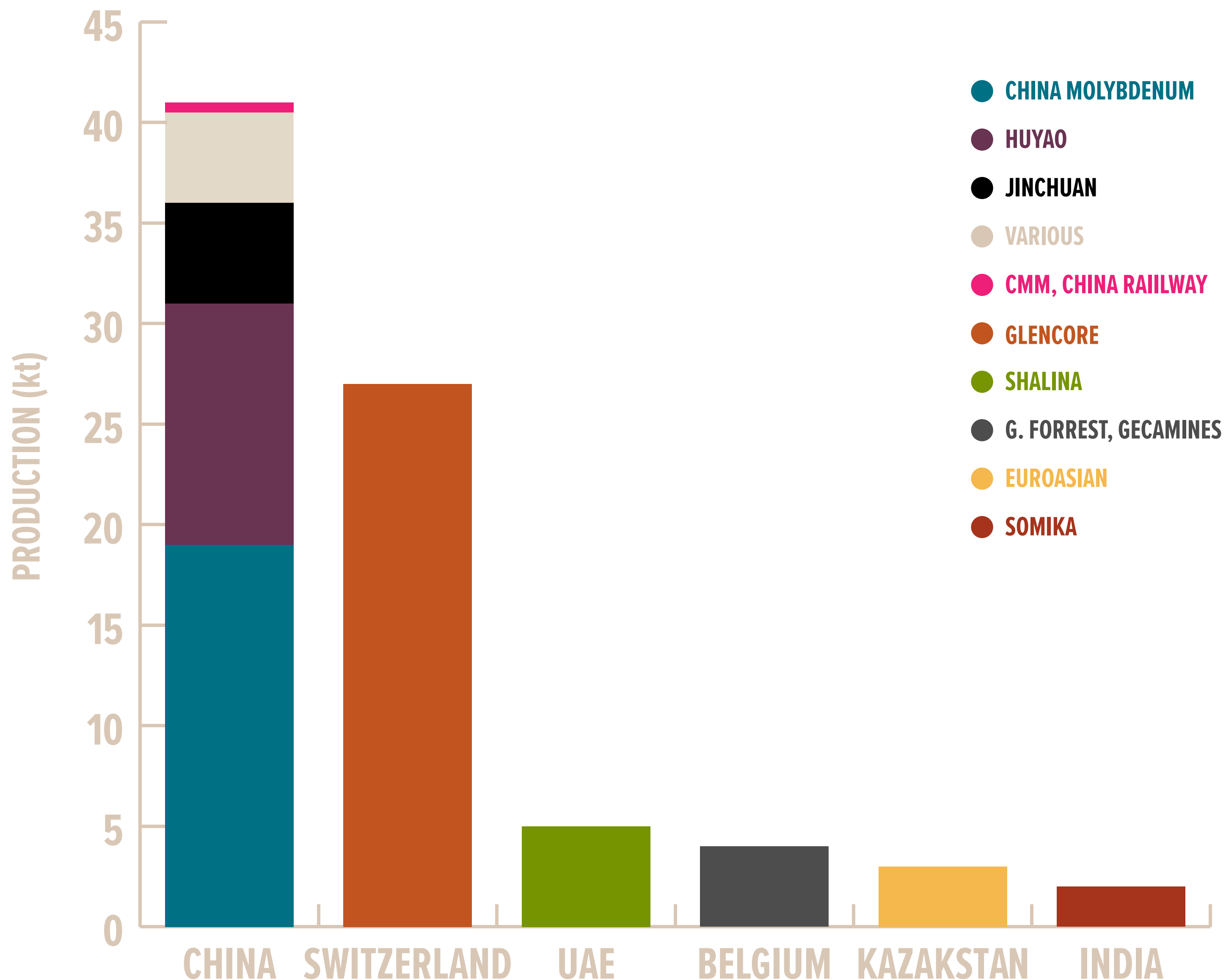


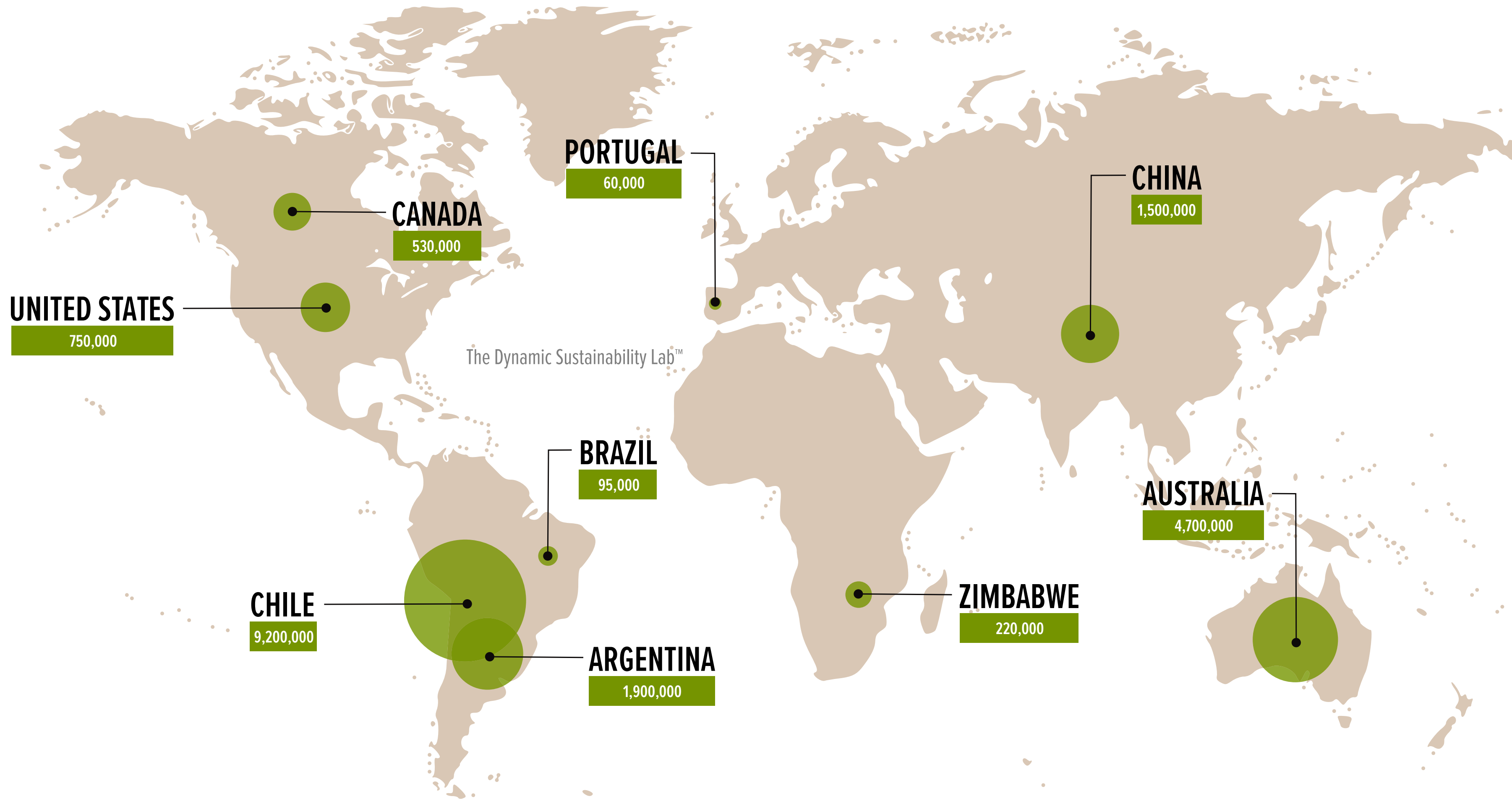
LITHIUM

Lithium is an essential element in the cathode of an EV battery. During the discharge cycle, lithium ions travel from the anode to the cathode through the electrolyte. Due to their small size, lithium ions are capable of having a very high voltage and charge storage per unit mass and per unit volume.

Lithium carbonate, the precursor material to the lithium found in batteries, can be produced from brines or ore. Australia is responsible for most of the world's ore-based lithium production, which comes from a rock called spodumene. Until recently, Australia had no lithium processing facilities and has relied on exporting lithium ore to China for processing.

The vast majority of the world's lithium brine production is from the salt flats of Chile, Argentina, and Bolivia, also known as the "lithium triangle."

Refining and processing of lithium is dominated by China.



LITHIUM RESERVES BY COUNTRY (tonnes)

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CONCENTRATION CASE-STUDY

LITHIUM

Lithium production is more geographically dispersed than cobalt, but industry and market concentration is high. The visual on the following page shows lithium companies by country and market capitalization. Many companies are vertically integrated and own mines as well as processing facilities.

The Chinese company TIanqi Lithium owns a 25.9% stake in SQM, the Chilean company that produces the second largest amount of lithium in the world after US-based Albemarle.[21]

Chinese companies also planned to infiltrate the emergent lithium market in Bolivia. Before his ouster and resignation, Bolivian President Evo Morales signed a deal with a Chinese company, Xinjiang TBEA, to hold a 49% stake with Bolivia's state lithium company YLB.[22] However, protests by indigenous groups led to the cancellation of a similar contract with a German company and may have had a role to play in Morales' resignation.[23,24]

In 2017, Ganfeng LIthium purchased a 20% stake in Lithium Americas, a Canadian company with lithium operations in the lithium triangle and the United States (Thacker Pass, NV). In turn, Lithium Americas acquired Millennial Lithium for $400M in November 2021, which has an operational lithium brine operation in Argentina.[25]

Albemarle, a US-based company, announced in October that it plans to build two lithium refining facilities in China, each of which will produce 50,000 metric tons of lithium hydroxide a year.[26]

CONCENTRATION CASE-STUDY
LITHIUM

LITHIUM COMPANIES & MARKET CAP

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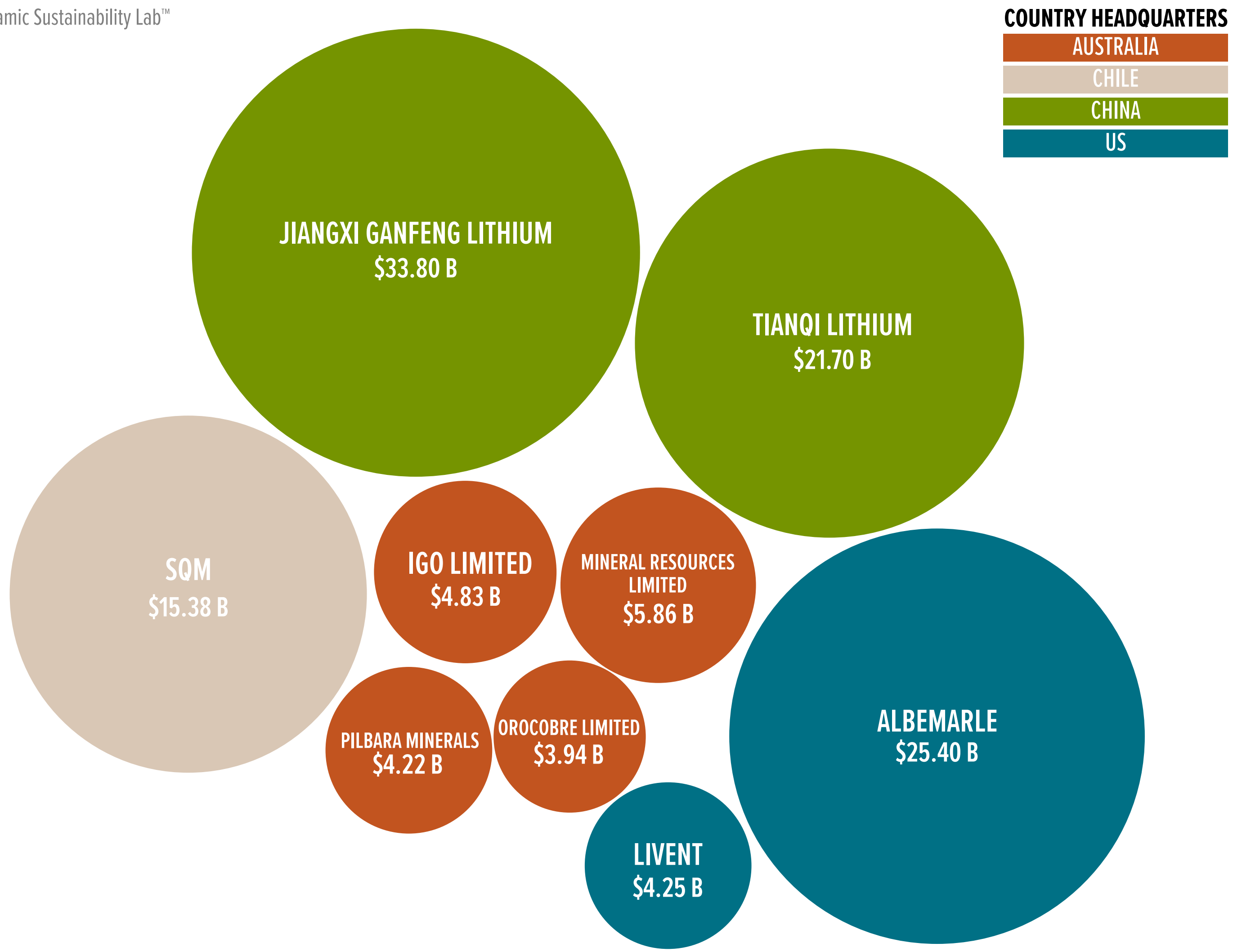

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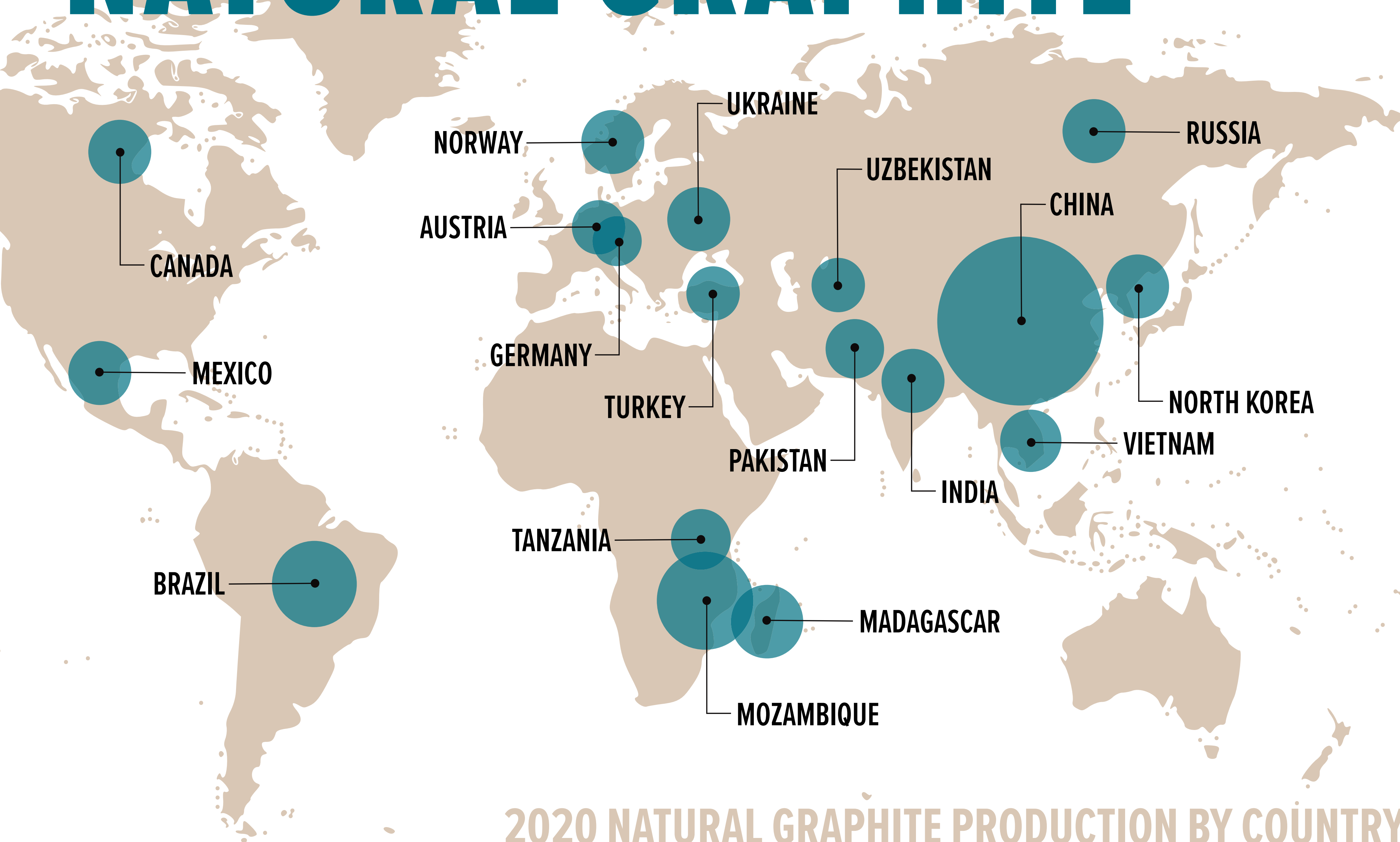
NATURAL GRAPHITE



2020 NATURAL GRAPHITE PRODUCTION BY COUNTRY (tonnes)

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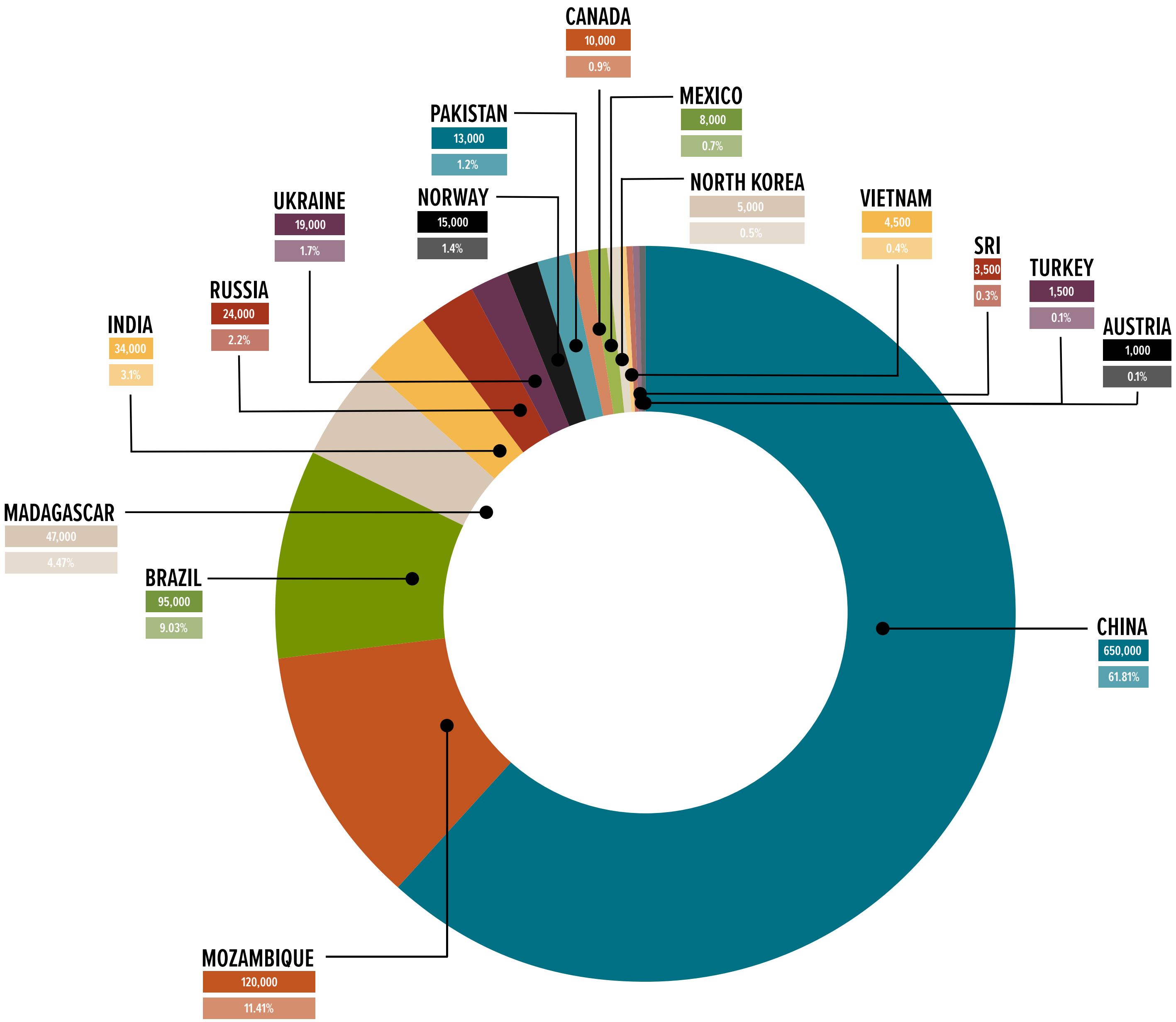
Graphite is the most commonly used mineral for the anode of electric batteries and is the most prevalent mineral in EVs by weight. For example, the Tesla Model S requires 54 kg of graphite. (Minviro)

Graphite can be mined (natural graphite), or produced by refining petroleum coke (synthetic or artificial graphite). China currently dominates both natural and artificial graphite production, while the US produces no natural graphite and is producing $31M less synthetic graphite now, than in 2010 (OEC).

NATURAL GRAPHITE



2020 NATURAL GRAPHITE PRODUCTION BY COUNTRY (tonnes)

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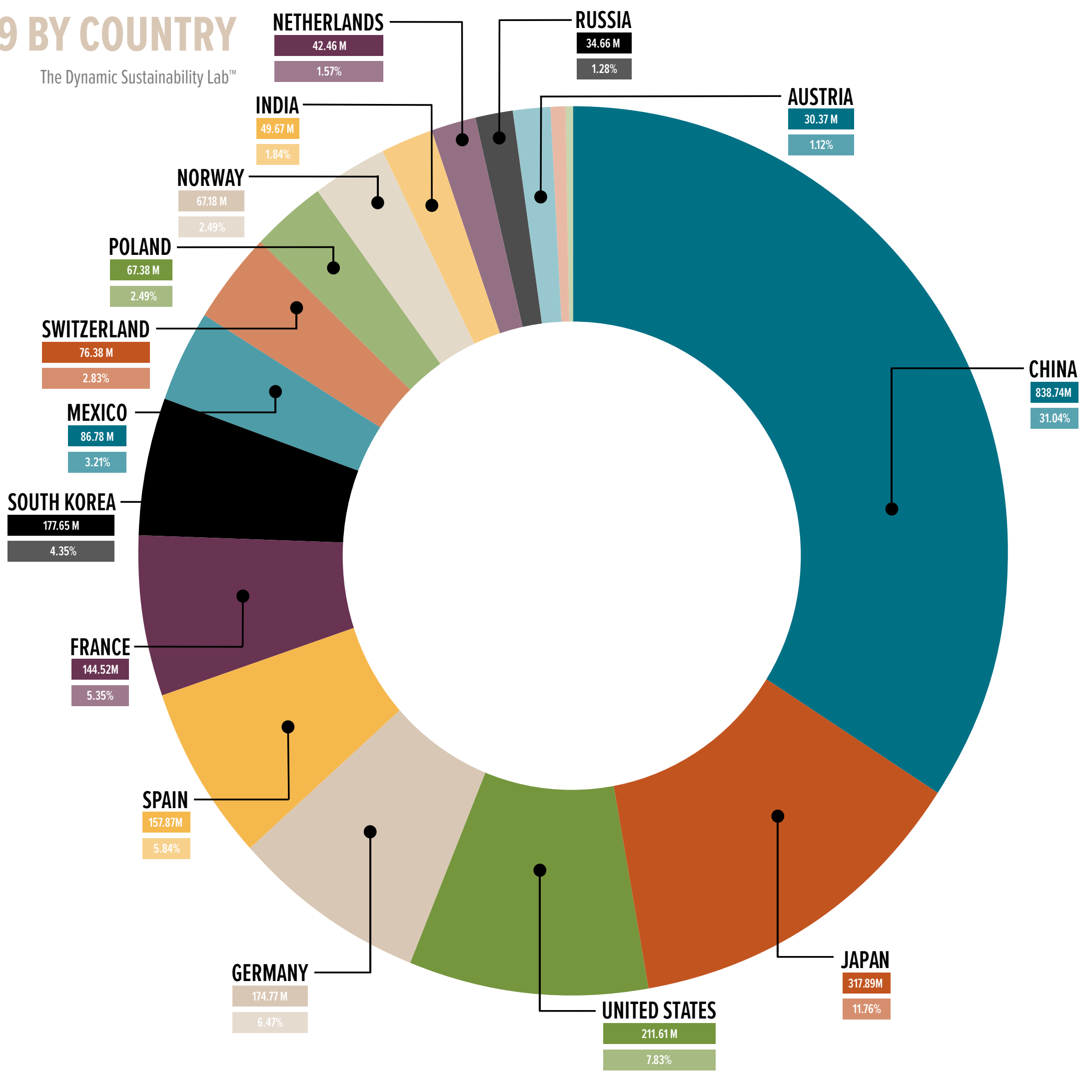
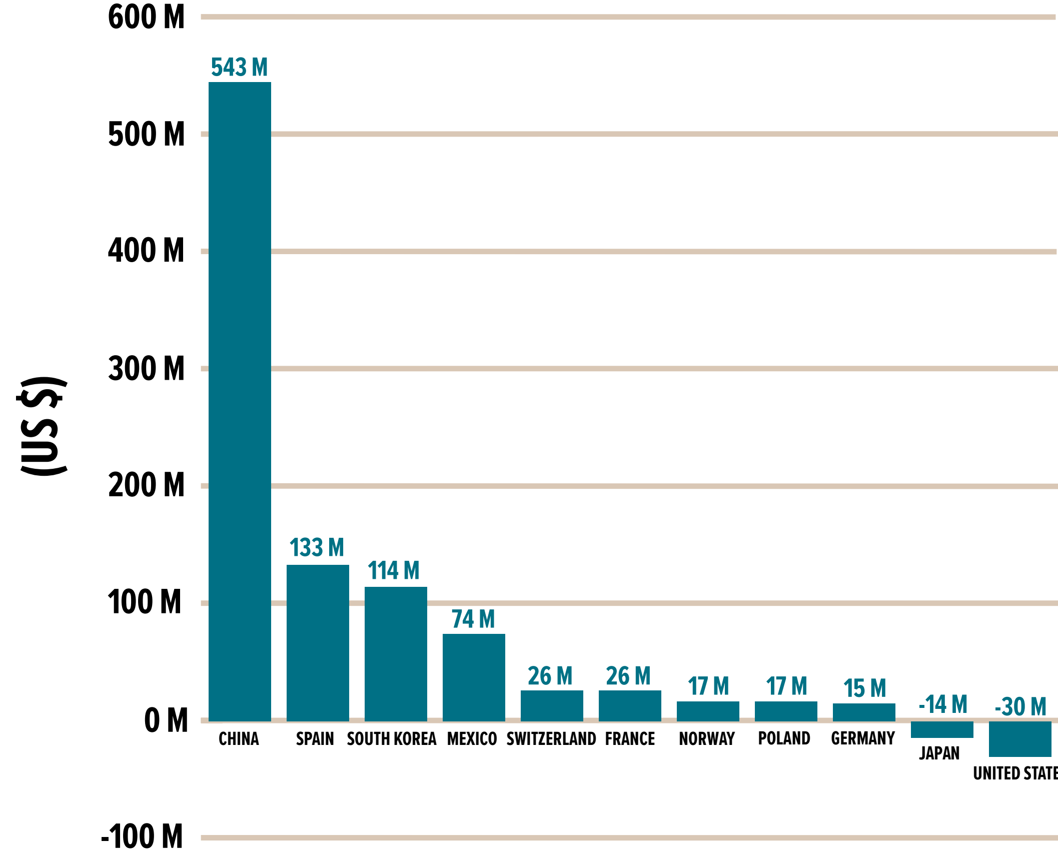
Synthetic graphite is almost twice as expensive to produce and its production relies upon feedstocks of pet coke - oil and petroleum byproducts. (LIB supply chain) But the higher purity compared to natural graphite makes it a valuable product - most companies blend natural and synthetic graphite 50/50. However, due to its higher purity, synthetic graphite is expected to make up 70 percent of battery demand by 2030. The production of synthetic graphite requires considerably more energy than does natural. While most of the carbon contained remains in the product during processing, generating a low level of CO2 emissions in production, synthetic graphite production burns off sulfur, nitrogen and ash impurities from its hydrocarbon feedstocks and is therefore a large source of NOx, SOx and particulate emissions.(GTM) Electricity mix is the highest driver of CO2 emissions for synthetic graphite.

SYNTHETIC GRAPHITE

Compared to natural graphite, synthetic graphite is almost twice as expensive to produce and its production relies upon feedstocks of pet coke - oil and petroleum byproducts. (LIB supply chain) But the higher purity compared to natural graphite makes it a valuable product - most companies blend natural and synthetic graphite 50/50. However, due to its higher purity, synthetic graphite is expected to make up 70 percent of battery demand by 2030. The production of synthetic graphite requires considerably more energy than does natural. While most of the carbon contained remains in the product during processing, generating a low level of CO2 emissions in production, synthetic graphite production burns off sulfur, nitrogen and ash impurities from its hydrocarbon feedstocks and is therefore a large source of NOx, SOx and particulate emissions.(GTM) Electricity mix is the highest driver of CO2 emissions for synthetic graphite.

TRADE VALUE 2019 BY COUNTRY (US $)





ARTIFICIAL GRAPHITE TRADE VALUE CHANGE, 2010-2019

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NICKEL IN THE MALAY ARCHIPELAGO

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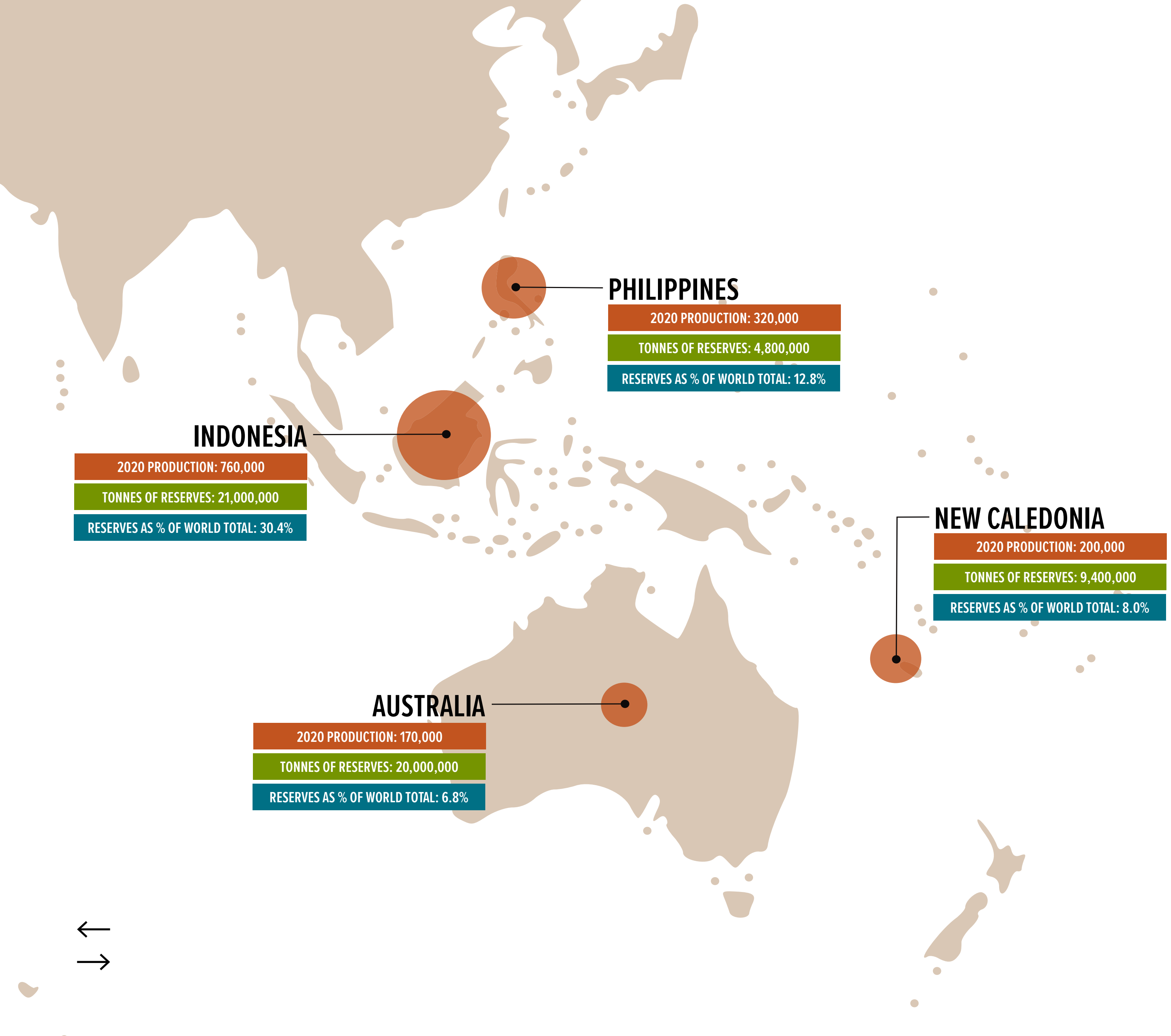

NICKEL

Global demand for nickel is expected to grow by a factor of 12 by 2040 under status quo policies, or by a factor of 42 under net-zero by 2050 policies.

Nickel is primarily produced in the Malay Archipelago, where production is far from stable. In 2014, Indonesia - the number one nickel producing state - banned nickel ore exports in an attempt to shore up domestic refining and processing sectors of the industry. They have since brought online one processing plant and have another six in the pipeline.[31]

New Caledonia, a colony of France, is the world's fourth largest producer of nickel. In 2019, after a deadly tailings collapse at an iron mine, New Caledonia was rocked by massive protests over operations at the Goro mine (the largest mine in the province), which then led to the downfall of the government. Tesla recently agreed to purchase one-third of Goro's nickel production.[32]

MINERAL DEVELOPMENT THE LIFECYCLE OF A MINERAL DISCOVERY

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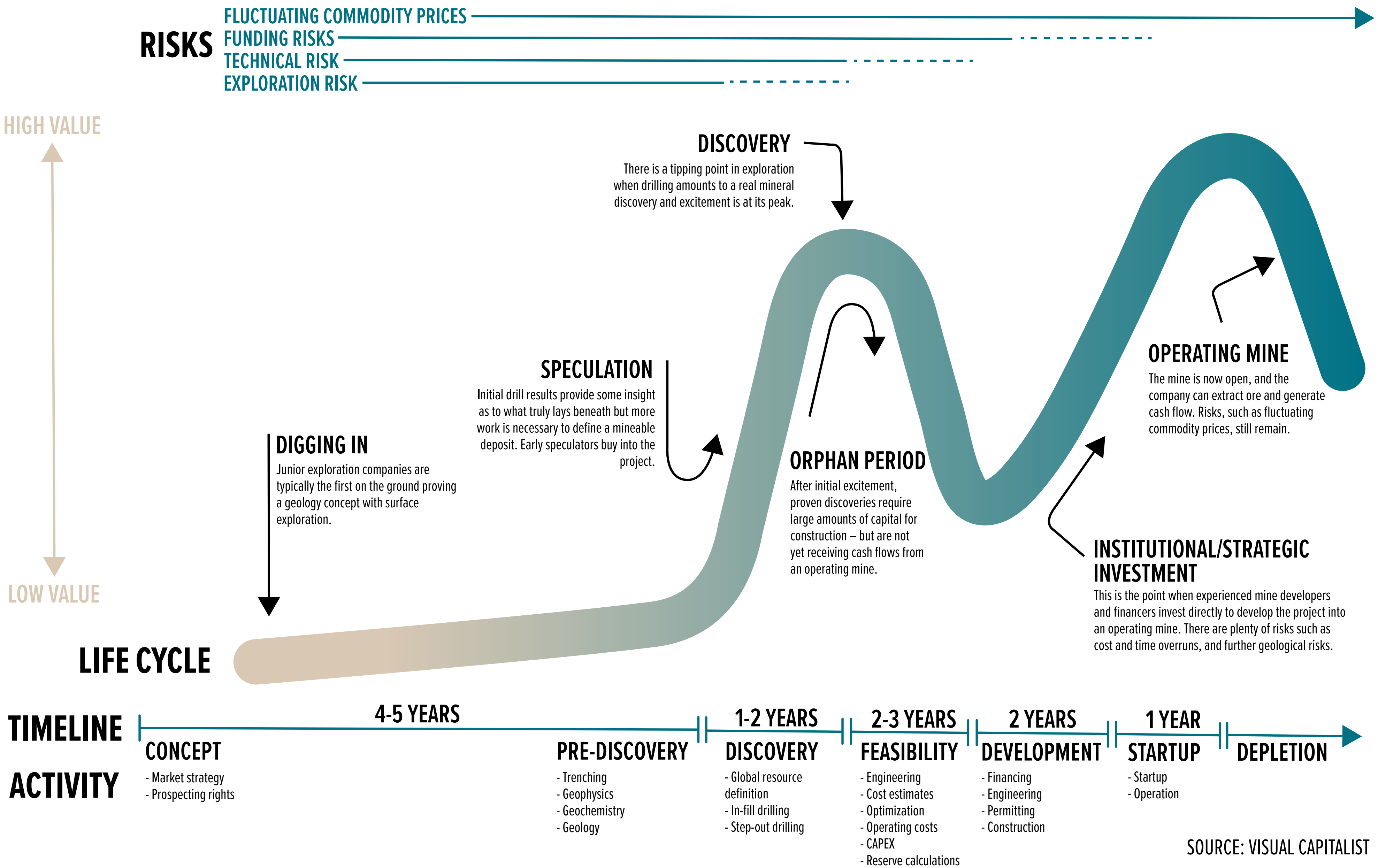


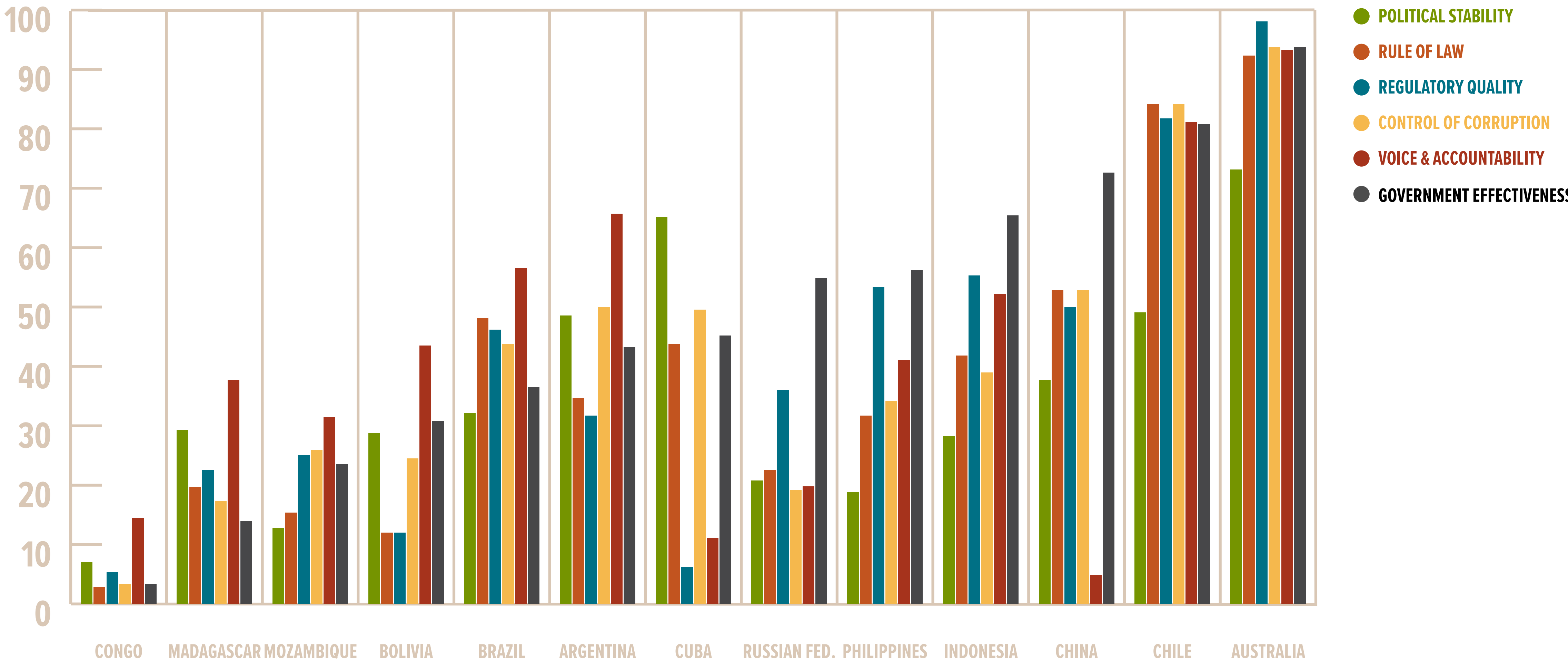
SOURCE: VISUAL CAPITALIST

Mines typically follow a trajectory called the Lassonde Curve, which tracks the timeline and activity on the x-axis and company valuation on the y-axis. However, according to the National Mining Association, in the United States it can take 7-10 years for permitting alone.[34]

Given this timeline, and the emerging pushback against further mineral development, we should assume we are limited by current mines and locations through at least 2025.

CRITICAL MINERALS & GOVERNANCE

The top producers of critical minerals tend to rank below 50 on the World Bank's Worldwide Governance Indicators, **with zero being the lowest and 100 the highest**. The Governance Indicators are based on over 30 individual data sources produced by a variety of survey institutes, think tanks, non-governmental organizations, international organizations, and private sector firms.[35]



GOVERNANCE MEASURES FOR CRITICAL MINERAL PRODUCING STATES

GOVERNANCE CASE-STUDY

CONGO

Artisanal and small-scale mining (ASM) makes up between 18-30% of the DRC's cobalt production. The rise in artisanal mining is driven by high prices of cobalt and poor governance in the region. This production is in constant flux, due to the shadow nature of artisanal mining. Additionally, large-scale mines in the DRC source materials from artisanal and small-scale mines. Children have been observed working at 1-in-4 ASM sites. Around half of children working in mines are between 15 and 17 years old, 41% are 10-14 years old, and 8% are younger than 10. There are around 200,000 informal copper and cobalt miners in the DRC. Forced labor has not been directly observed by the OECD, but in most cases, ASM miners are compelled to enter into informal financial relationships with négociants or sponsors so they can meet basic livelihood needs prior to the pits producing any minerals.[16,36]

In order to formalize ASMs, a new state-owned DRC entity named Enterprise Generale Cobalt (EGC) will begin sourcing cobalt from ASM's this year producing in the Kusulo region, operated by Congo DongFang Mining, a Chinese company. ASM production in 2020 was approximately 7,000 tonnes, but is expected to grow to 10 - 12,000 tonnes in 2021. Chinese companies are the only direct buyers of ASM cobalt to date.[37]

The DRC ranks in the bottom 10th percentile among states for several metrics related to governance and human rights, according to the World Bank's World Governance Indicators.

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TABLE 1: AVERAGE EARNINGS BY TASK

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FUNCTION	AVERAGE EARNING: MARCH 2018 PER DAY, USD LME COBALT: USD 94,500/TONNE LME COPPER: USD 6,745/TONNE	AVERAGE EARNING: AUGUST 2019 PER DAY, USD LME COBALT: USD 30,500/TONNE LME COPPER: USD 5,600/TONNE
MINER: COBALT	80-130	14-30
MINER: COPPER	80-100	25-35
TRANSPORTER	30	10
WASHER	18	3

ENVIRONMENTAL IMPACTS

The production of critical minerals has impacts on the environment, including (somewhat ironically) carbon dioxide emissions. Many of these emissions are related to electricity required to mine and process the minerals. As such, the electricity mix at the location of mining or processing plays a significant role in the carbon dioxide emissions, resulting in a range of potential emissions per mineral.

Based on the kg CO2 emissions per kg mineral, and the amount of kgs of each mineral per representative vehicle, we can estimate carbon dioxide emissions for each EV produced. On the high end, with an electricity mix powered by coal and oil, the mineral extraction and processing for a single car is 2,240.8 kg CO2. On the low end, with an electricity mix powered by renewable energy sources, the CO2 emissions equivalent is 704.8 kg, fully one-third the amount. Battery production represents 43% of embedded CO2 emissions in EVs.[39]

LOW, AVERAGE, & HIGH kg CO_2 EMISSIONS PER kg MINERAL

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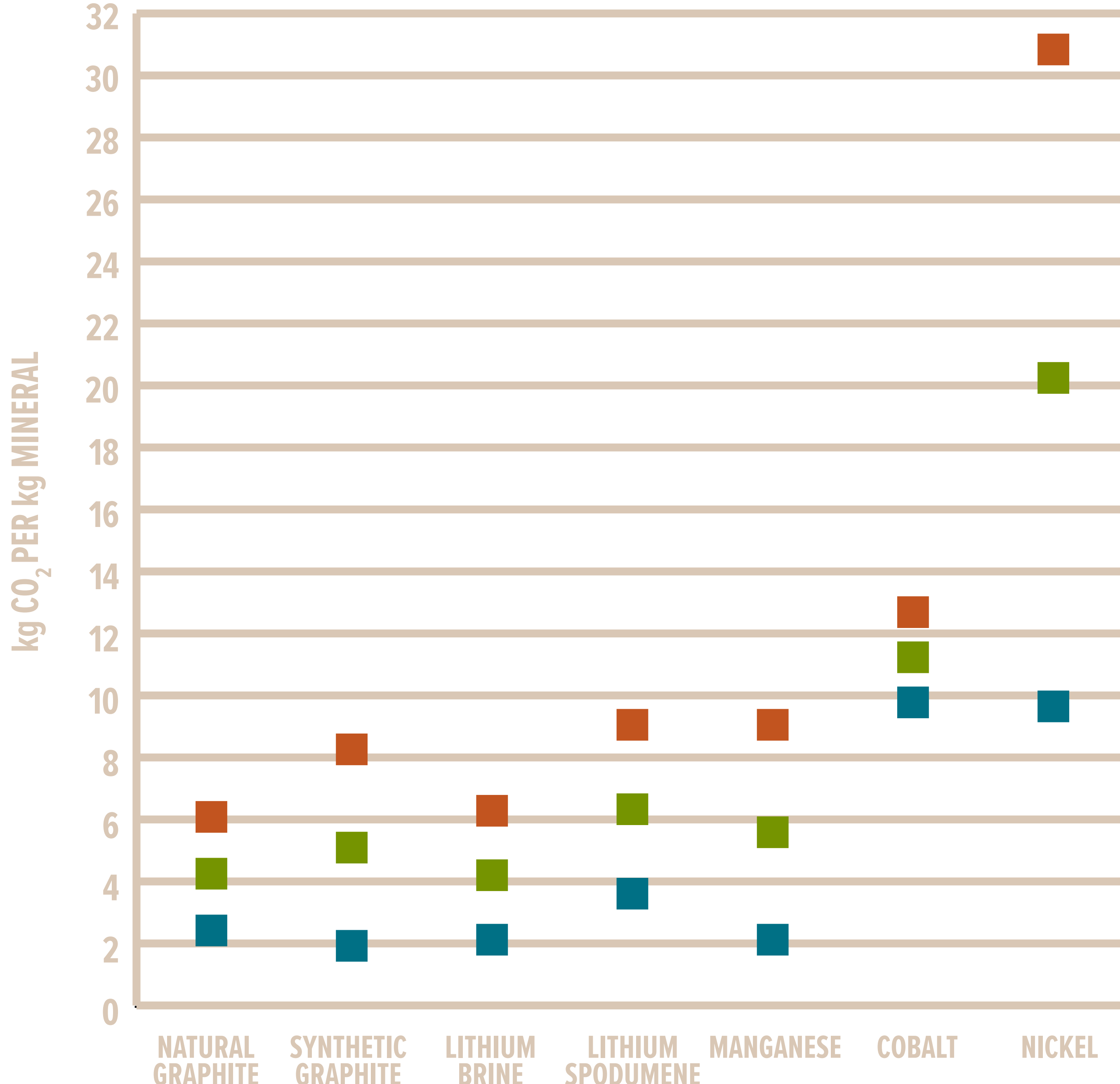
LOW kg CO2 PER kg MINERAL
AVG. kg CO2 PER kg MINERAL
HIGH kg CO2 PER kg MINERAL

ENVIRONMENTAL IMPACTS



ENVIRONMENTAL IMPACTS

MINERALS USED IN CONVENTIONAL CARS COMPARED TO ELECTRIC CARS

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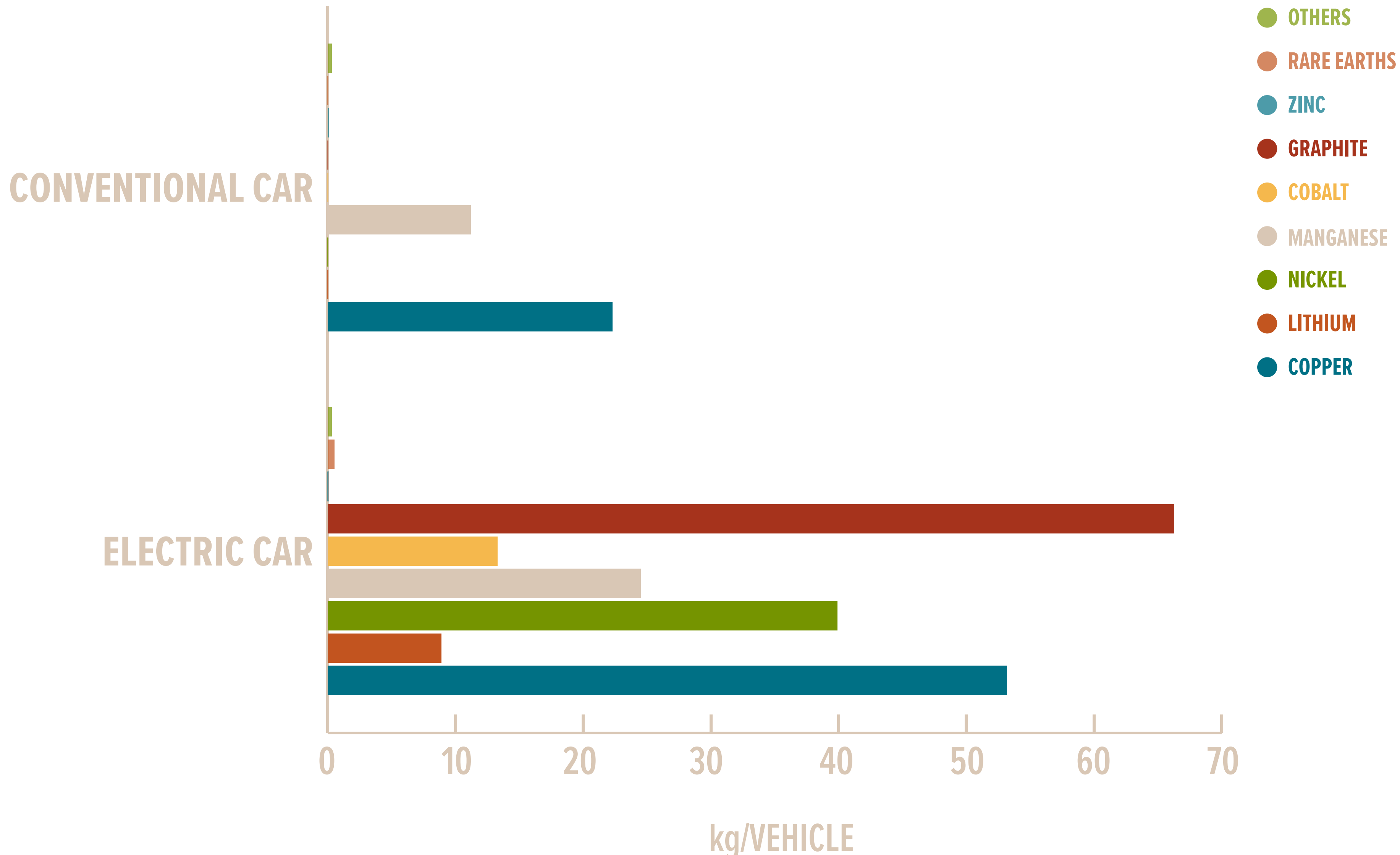


ENVIRONMENTAL IMPACTS: LITHIUM

Lithium production from ore and brines has significant impacts to the environment including: mineral waste and chemical byproducts, water use, wildlife and habitat impacts, water pollution, and greenhouse gas emissions.

Local communities are pushing back against lithium projects due to their environmental impacts, including in Chile, Bolivia, Serbia, and the United States.

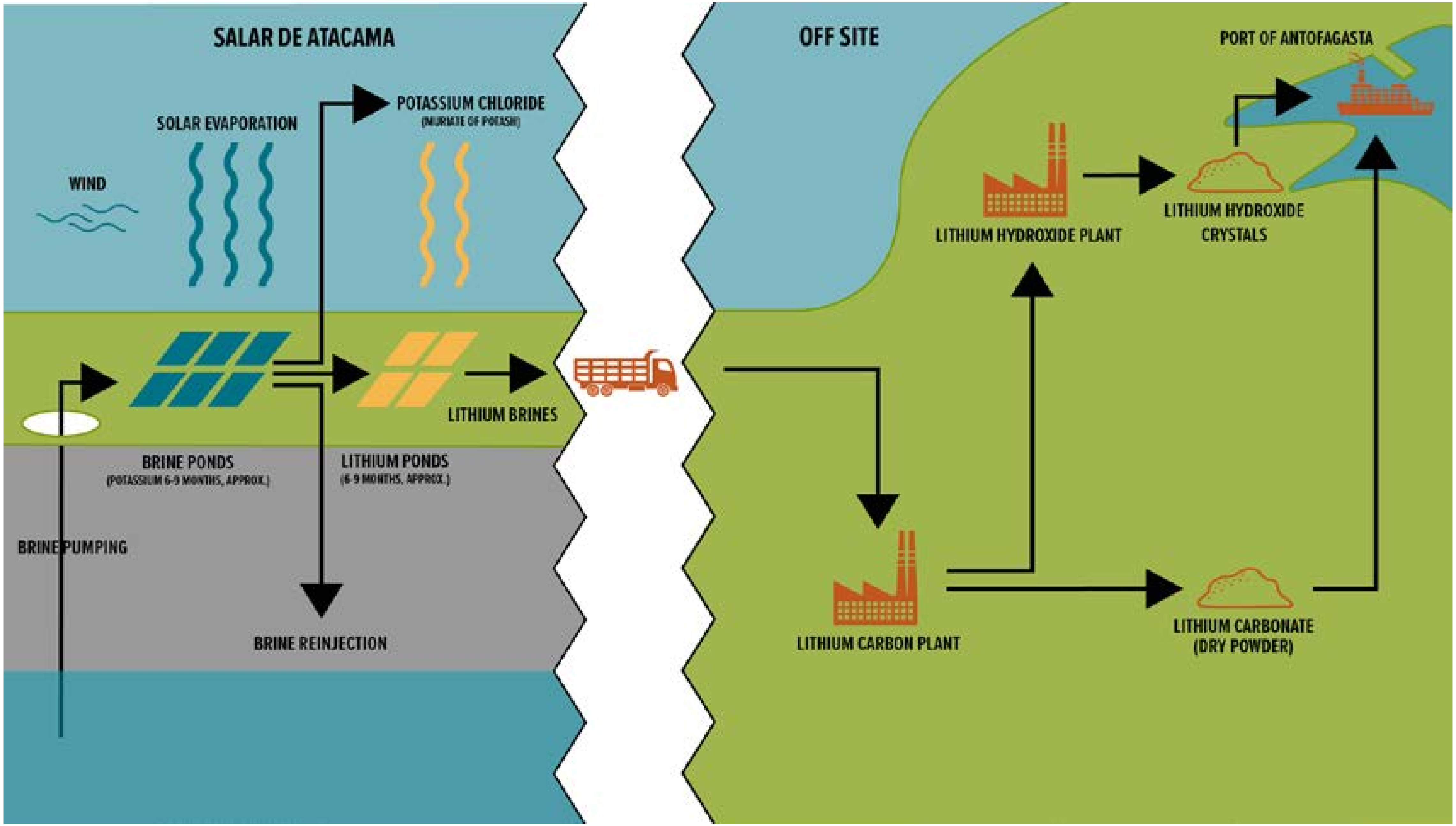
HARD ROCK EXTRACTION[40]

Water Use: 97,183 liters per tonne (Thacker Pass EIS)
CO2 Emissions: 15,000 kg CO2/ tonne Li
Waste: 317 million tons of tailings (Thacker Pass EIS)
Habitat Disturbed: 464 square meters / tonne Li
5,695 acres habitat disturbed

BRINE EXTRACTION[41, 42]

Water Use: 601,000 liters per tonne (SQM) to 2 million liters per tonne (IET).
8,842 liters per second extraction
6,810 liters per second salar recharge (IET)
CO2 Emissions: 5,000 kg CO2/ tonne
Habitat disturbed: 3,124 square meters / tonne Li

ENVIRONMENTAL IMPACTS: LITHIUM



GEOGRAPHICAL CONCENTRATION INTO THE FUTURE

Critical mineral production is highly concentrated in just a few states, and vertically integrated by powerful companies, but that is unlikely to change in the near future. Mineral projects can take decades to begin production. According to the IEA, the global average timeline for a mine to begin production is 16.9 years.[1]

GLOBAL AVERAGE LEAD TIME FROM DISCOVERY TO PRODUCTION, 2010-2019

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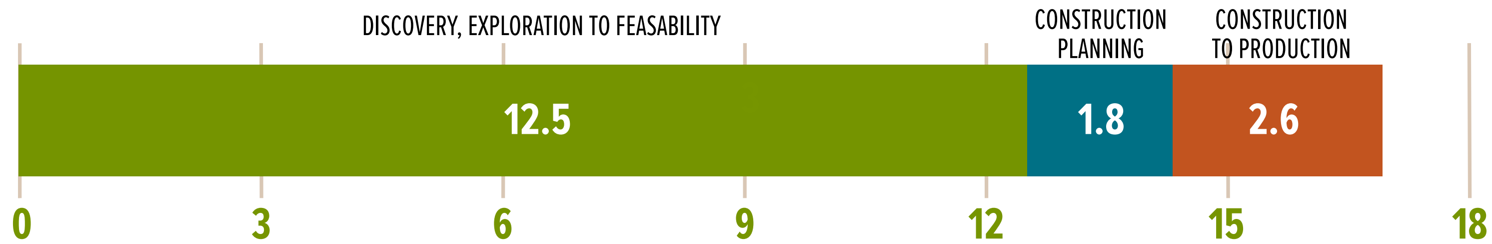

AVERAGE OBSERVED LEAD TIME FOR SELECTED MINERALS (FROM DISCOVERY TO PRODUCTION)

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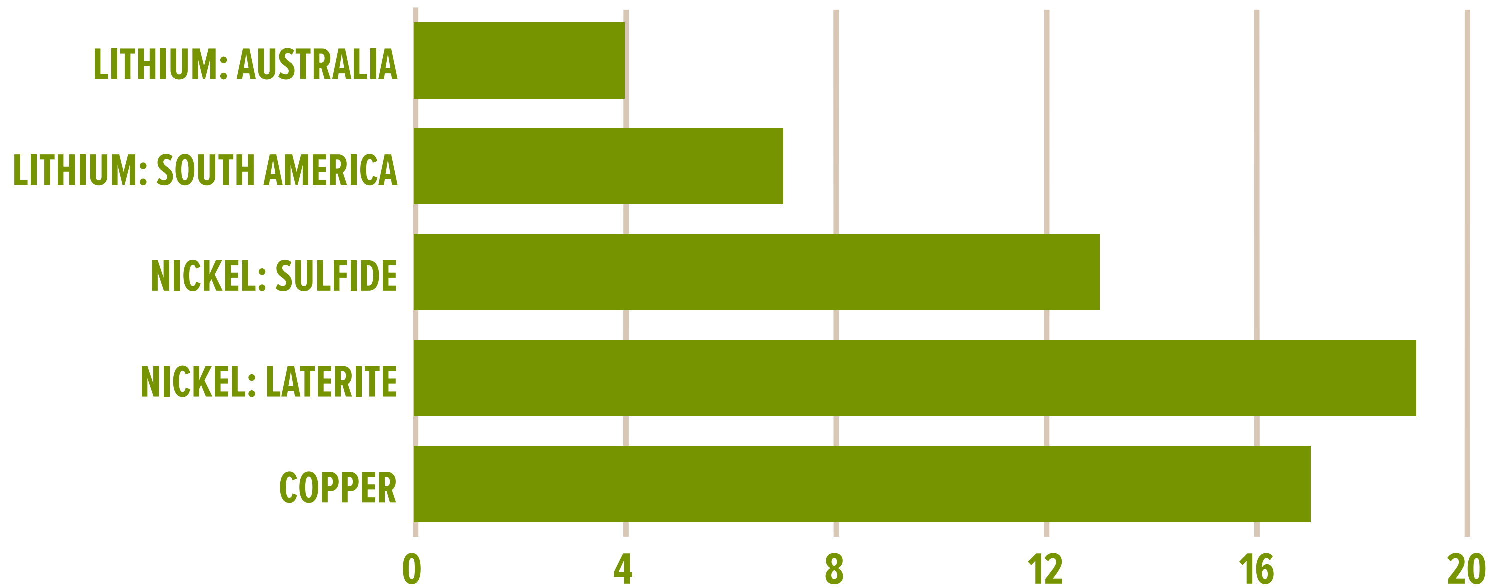

NOTE: GLOBAL AVERAGE VALUES ARE BASED ON THE TOP 35 MINING PROJECTS THAT CAME ONLINE BETWEEN 2010 AND 2019.
SOURCE: IEA ANALYSIS BASED ON S&P GLOBAL (2020), S&P GLOBAL (2019A), AND SCHODDE (2017).

GOVERNMENT POLICY NEEDS

1. STRENGTHEN THE DOMESTIC SUPPLY OF CRITICAL MINERALS AND COORDINATE WITH PARTNERS AND ALLIES TO DIVERSIFY THE GLOBAL CRITICAL MINERAL SUPPLY CHAIN

In the US, update the 1872 Federal Mining law to include environmental clean-up, royalties, and a stronger and more clear permitting pathway for mining projects on federal lands that takes into account environmental concerns, indigenous sovereignty, and the need to secure a supply chain for critical minerals for the United States

2. ENGAGE INDIGENOUS PEOPLE AND OTHER LOCAL COMMUNITIES POTENTIALLY IMPACTED BY MINING ACTIVITIES

3. INCREASE ACCOUNTABILITY FOR MINING COMPANIES THROUGH IMPROVED STATE REGULATIONS AND THIRD-PARTY CERTIFICATIONS

For example, the Initiative for Responsible Mining's "Standard for Responsible Mining"

4. IMPROVE LEGAL FRAMEWORKS REGARDING ARTISANAL AND SMALL SCALE MINING OPERATIONS (ASMS) AND FORMALIZE ASMS IN ORDER TO IMPROVE WORKING CONDITIONS, INCLUDING ELIMINATING CHILD LABOR

5. INCREASE TRANSPARENCY ACROSS THE SUPPLY CHAIN TO REDUCE BRIBERY AND CORRUPTION

Enhance traceability, accountability, audits, and other measures to allow companies to assess their supply chains

a. Extractive Industries Transparency Initiative
b. OECD Guidance

6. CONSIDER AN INTERNATIONAL MINERALS GOVERNANCE FRAMEWORK, MODELED AFTER THE IEA'S ENERGY SECURITY FRAMEWORK

7. ACROSS THE INDUSTRY, EFFORTS MUST BE MADE TO IMPROVE ENVIRONMENTAL SUSTAINABILITY OF MINING. THESE EFFORTS SHOULD INCLUDE:

a. Environmental and Social Impact Assessments (ESIAs), Environmental Management Plans (EMPS), integrated water and waste management plans to reduce water use and waste generation, dewatered tailings
b. The Energy Resource Governance Initiative Toolkit is a useful resource for both industry and governments to improve governance and environmental sustainability of mines: https://ergi.tools/#mid-steps

INDUSTRY POLICY NEEDS

1. RESEARCH AND DEVELOP ALTERNATIVES FOR CRITICAL MINERALS IN LI-ION BATTERIES, AS WELL AS ALTERNATIVE BATTERY CHEMISTRIES

i.e. silicon to replace graphite; Lithium Iron Phosphate batteries to replace cobalt and nickel-intensive batteries

2. IMPROVE MINERAL EXTRACTION TECHNOLOGIES AND ELECTRICITY MIX AT EXTRACTION LOCATIONS

i.e. geothermal lithium brine extraction pilot in Salton Sea; solar and wind generation to power mines and processors

3. INVEST IN LI-ION BATTERY RECYCLING AND THE CREATION OF A CIRCULAR ECONOMY FOR CRITICAL MINERALS

Battery recycling is an effective way to recover critical minerals, but recycling will lag production by an estimated 20 years due to lack of available end-of-life EV batteries reaching

4. DEVELOP AND IMPLEMENT ACTIONABLE ENVIRONMENTAL, SOCIAL AND GOVERNANCE GOALS

The Embedding Project hosts the Credible Goals Database and Position Database, which provides and critiques leading sustainability goals and commitments set by large companies globally. In addition, they provide a transparent goals rubric, so industry leaders can begin developing effective goals now.

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AUTHOR

Nelson Falkenburg

Graduate Student Researcher
MPA – Environmental Policy

COMMUNICATIONS TEAM

Sydney Bruno
Public Relations

Cori Dill
Public Relations & Political Science

←

ABOUT THE LAB

FOUNDED BY

Dr. Jay Golden
Pontarelli Professor of Environmental Sustainability & Finance at Syracuse University

MISSION STATEMENT

Provide support to public and private organizations on the risks, unintended consequences, and opportunities of the global sustainability transition

PRIMARY TRANSITION AREAS OF FOCUS

Technology Transitions – Energy Transitions – Biobased Transitions

COMPONENTS OF THE TRANSITION

Supply Chains – Green Finance – Critical Minerals – ESG – National Security

CONTACT

www.DynamicsLab.org – JGolde04@syr.edu