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The Opportunity in Critical Minerals

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The push toward net-zero emissions[1] has expedited the need for green energy and technology. At the forefront of this green energy boom are critical minerals, the essential inputs to all types of green technologies, especially electric vehicles ("EVs") and EV batteries. This research note provides an overview of critical minerals, their uses, current market size, as well as describes the unique opportunity that critical minerals may provide for investors.

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What are critical minerals?

In broad terms, critical minerals are minerals, elements, substances, or materials that have a high risk of supply chain disruption and serve as a raw material in one or more energy technologies.[2] Some of these minerals are widely known and used (e.g., copper, magnesium), while others are less well known, such as rare earth metals.

The US Department of Energy ("DOE") periodically assesses critical materials and minerals and publishes a report with their findings.[3] In the report, materials/minerals are placed on a criticality matrix (see Figure 1) that depicts where each stands in terms of supply chain disruption risk and importance to energy technologies (including technologies that produce, transmit, store, and conserve energy). The matrix looks at both what has happened recently and is expected to continue in the short term as well as what is expected to happen in the future (i.e., the "medium term").

[1] Net-Zero emissions refers to the goal of balancing greenhouse gasses produced with greenhouse gasses removed from the atmosphere.

[2] Note that these are also key components for defense weapons and semiconductors.

[3] The DOE has published critical mineral reports in 2011 and 2019, and going forwards plans to do so every three years.

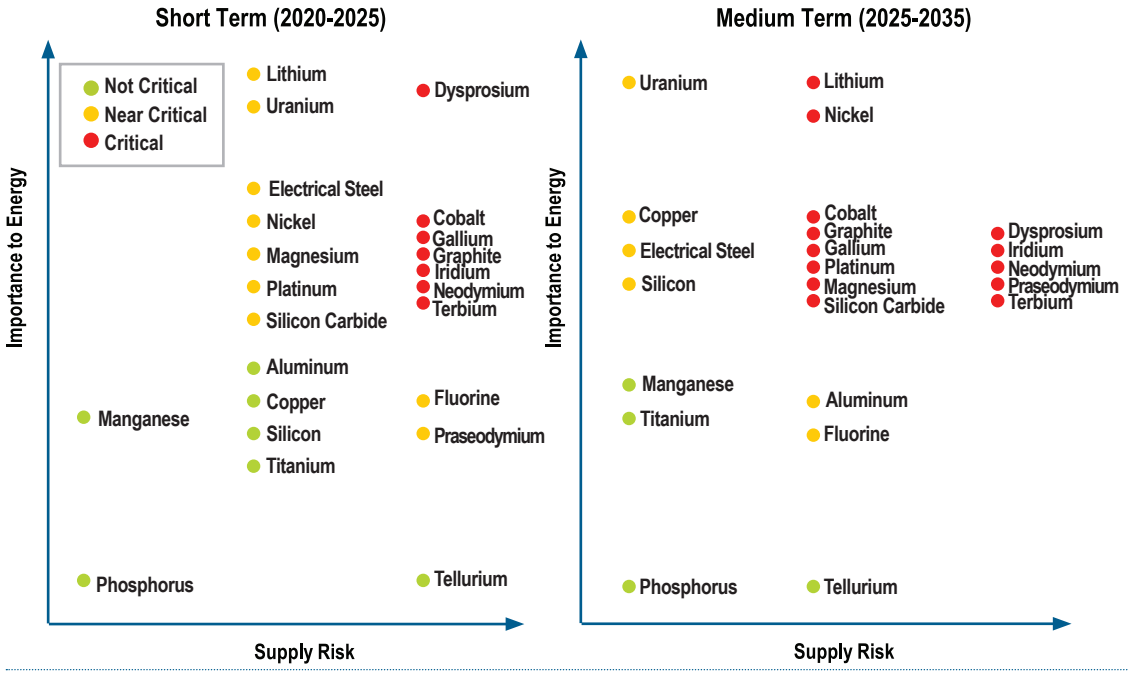

FIGURE 1
Criticality Matrix

Source: US Department of Energy, "Critical Materials Assessment 2023." The report considers 38 minerals/materials, of which 23 were evaluated for criticality after a screening process.

Where are critical minerals used?

Critical minerals are utilized substantially more in the construction of green energy power generation assets than in traditional (i.e., fossil-fuel based) power generation. For example, an onshore wind plant typically requires 9x more mineral resources to build than a gas-fired power plant. Figure 2 below shows the difference in minerals required for green power sources compared to traditional sources. Notably, clean energy requires substantially larger quantities of copper, zinc, silicon, chromium, and manganese.

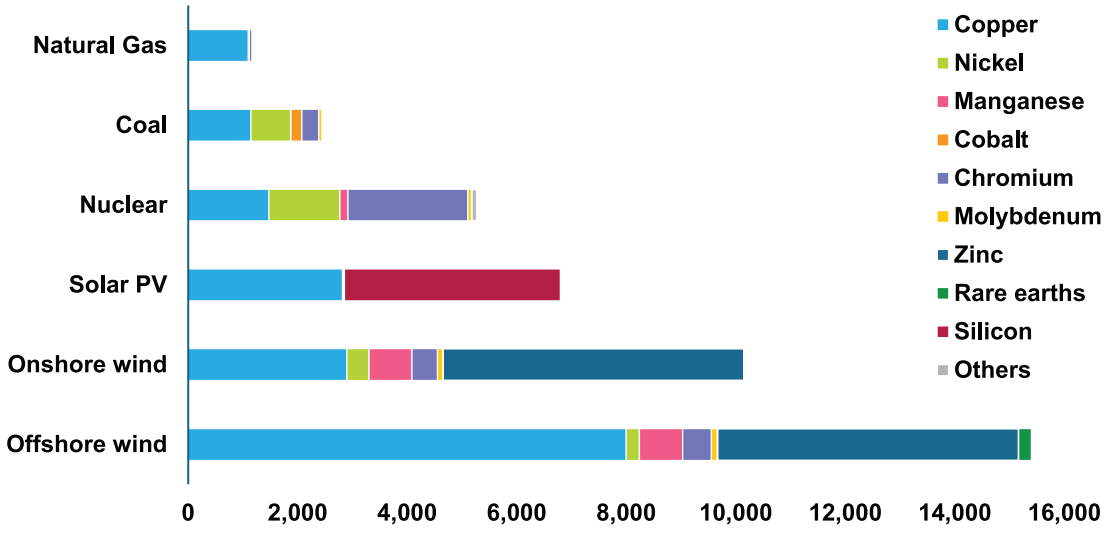

FIGURE 2
Minerals used in Clean Energy versus Other Power Sources (kg per MW)

Source: IEA, "The Role of Critical Minerals in Clean Energy Transitions," as of May 2021.

Importance to EVs and EV batteries

Electric vehicles and EV batteries are one of the largest categories of green energy technology and one of the largest consumers of critical minerals. Globally, EVs jumped from less than 5% of all new vehicles sold in 2020 to 14% in 2022.[4] While the majority of EVs purchased were in China, EVs made up 8% of cars purchased in the US in 2022. This percentage is projected to increase in the US due to the EV incentives in the 2022 Inflation Reduction Act (discussed in the sections below) and several state laws that will prohibit the purchase of new gas-powered vehicles beginning in 2035.

[4] Source: IEA, "Global EV Outlook 2023."

A typical electric vehicle requires 6x the mineral inputs of a traditional gas-powered car to assemble. In addition to the copper and manganese used in gas-powered cars, EVs require the critical materials graphite and cobalt, as well as two near critical materials projected to turn critical, nickel and lithium (see Figure 3). Future EV demand is a driving factor for why nickel and lithium are expected to move from near critical in the short term to critical in the medium term, shown previously in Figure 1.

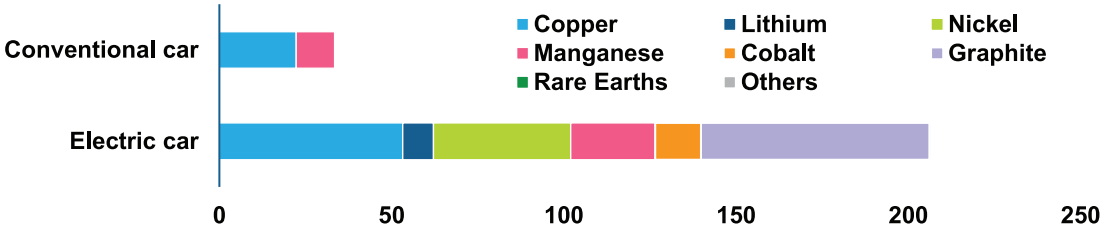

FIGURE 3
Minerals used in EVs versus Conventional Cars (kg per vehicle)

Source: IEA, "The Role of Critical Minerals in Clean Energy Transitions," as of May 2021.

Global supply and demand

Global demand for critical minerals is increasing and that demand is expected to continue to grow. Meanwhile, there are concerns regarding the future supply of these minerals. Demand has increased rapidly for some materials, particularly for those used in EVs and EV batteries. For example, from 2017 to 2022, demand for lithium tripled while demand for nickel and cobalt increased by 40% and 70%, respectively.[5] Similarly, the share of clean energy applications (out of total demand) nearly doubled for lithium and more than doubled for nickel and cobalt from five years prior (see Figure 4).

[5] Source: IEA, "Critical Minerals Market Review 2023."

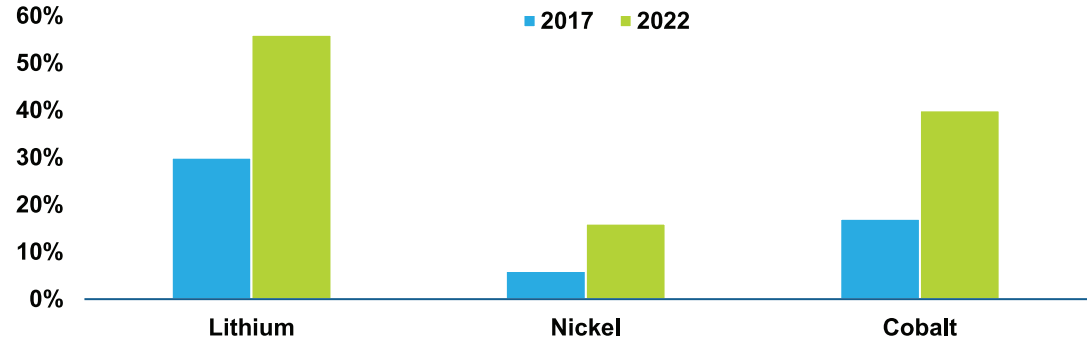

FIGURE 4
Share of Clean Energy in Total Demand

Source: IEA, "Critical Minerals Market Review 2023."

Projected demand for these critical minerals can vary depending on the modeling source and on what future scenario is considered. For example, some models consider a "Net Zero Emission by 2050" scenario where overall demand for critical minerals grows by 3.5x by 2030, primarily driven by EVs and batteries.[6] Figure 5 below depicts the International Energy Agency's ("IEA") modeled predictions for future demand and a breakdown of what the demand is used for in the "Net Zero Emission by 2050" scenario. All three of the critical minerals shown – copper, nickel, and cobalt – are heavily used in EVs, batteries, and other green energy technologies, and therefore are projected to have substantially higher demand in 2050. The IEA estimates that in 2050 there will be 1.6x the demand for copper, 2.0x the demand for nickel, and 3.0x the demand for cobalt compared to 2021 levels.

[6] Source: IEA, "Critical Minerals Market Review 2023."

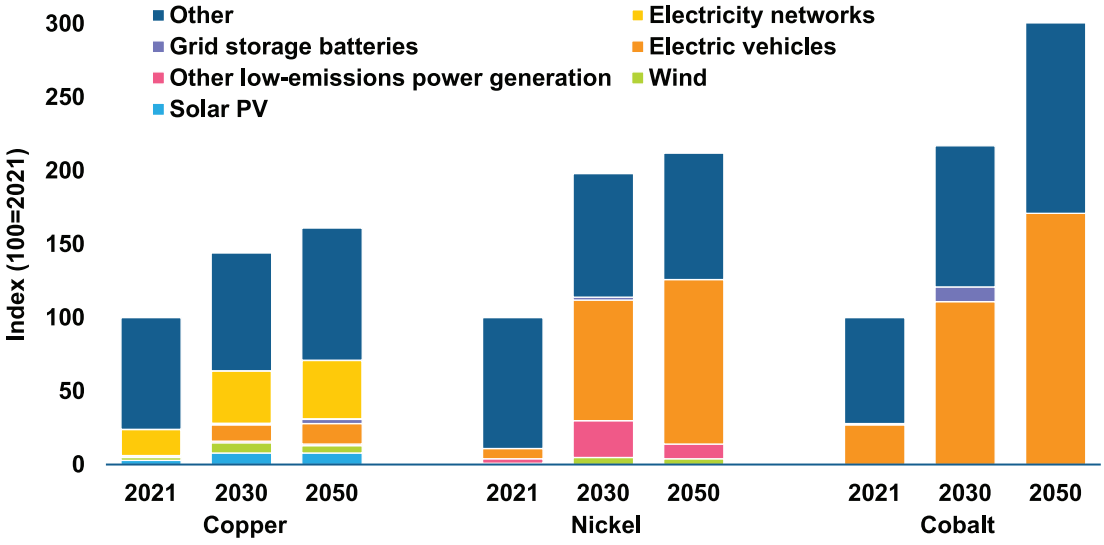

FIGURE 5
Future Total Demand by End Use in the Net Zero Emissions by 2050 Scenario

Source: IEA, "Critical Minerals Market Review 2023."

A transition of processes

As the world transitions towards renewable energy, the critical minerals universe must also transition with it. This means that in addition to transitions in the demand for the physical minerals, the mining and processing of such minerals also must undergo transitions and evolve. Currently, the minerals used in clean energy technologies are geographically concentrated, primarily outside the US, both in terms of extraction (i.e., mining) and processing.

Mining

The mining process involves removing the raw minerals from the earth. Thus, the geographic location of such minerals is a key factor that heavily influences the amount of the mineral mined, its price, the overall availability of the mineral, and more. Currently, a small number of countries control the majority of critical mineral mining. Figure 6 below shows that for all but one of the critical minerals listed, at least 47% of the mining is concentrated in a single country. As a result, these countries dominate the supply. Notably, the US makes the list of the top three mining countries for only one group of critical minerals, rare earths, at 11%.

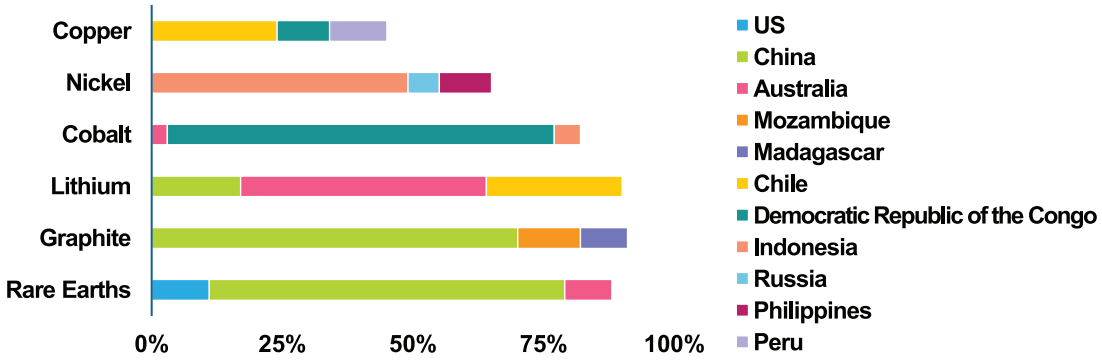

FIGURE 6
Share of Top Three Mining Countries by Mineral in 2022

Source: IEA, "Critical Minerals Market Review 2023."

Processing

Not only are the geographic locations of mineral mining highly concentrated, but the processing facilities are even more concentrated in a small number of countries. China dominates the processing of critical minerals,[7] representing more than half of the processing share in four of the six critical minerals shown in Figure 7. The mining and processing of critical minerals can result in pollution, which may limit production in countries with strict environmental regulations. Thus, one of the reasons for China's dominance in critical minerals is the country's overall lax environmental regulations.

[7] Note that China has a quota system for certain rare earth mining, and that it recently added export controls on some graphite products. See https://www.reuters.com/markets/commodities/chinas-rare-earths-dominance-focus-after-mineral-export-curbs-2023-07-05/

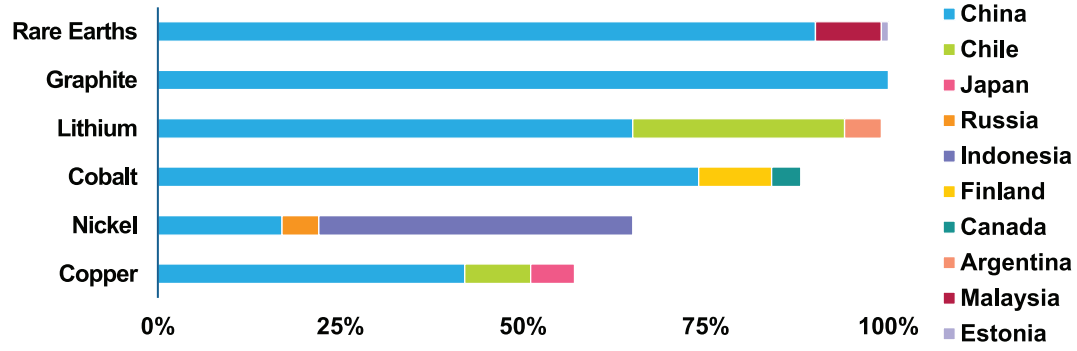

FIGURE 7
Share of Top Three Processing Countries by Mineral in 2022

Source: IEA, "Critical Minerals Market Review 2023."

Market size

The market size for the critical minerals shown in Figure 8 below has doubled in the past five years and now stands at roughly $320 billion.[8] This growth can largely be attributed to increases in demand and higher prices for minerals.

[8] Source: IEA, "Critical Minerals Market Review 2023."

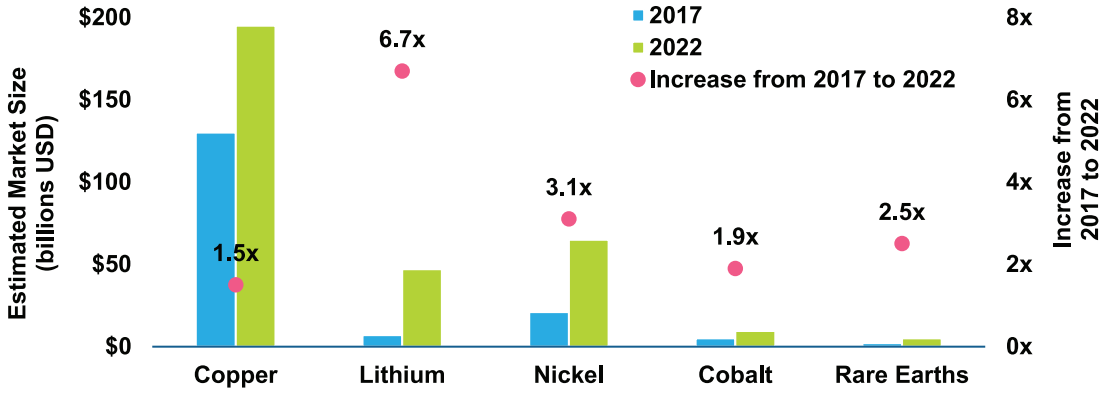

FIGURE 8
2017 and 2022 Estimated Market Size (billions USD)

Source: IEA, "Critical Minerals Market Review 2023." Market size values (billions USD) are estimates from the IEA Critical Minerals Market Review 2023 report.

The market size for critical minerals is anticipated to continue to grow as the demand for clean energy technology (and its input materials) increases. Consequently, forecasts show higher mineral prices, though forecasting future mineral prices is far from an exact science. Future supply and demand are unknowable, and there exists a wide range of potential scenarios and shocks that may influence prices.

Figure 9 below depicts the average and largest price changes in the 2010's, along with a more recent price increase that occurred between January 2021 and March 2022. It shows that not only have critical mineral prices been increasing annually since the 2010's, but they also increased significantly from 2021 to 2022, higher than each mineral's largest annual increase in the 2010's.

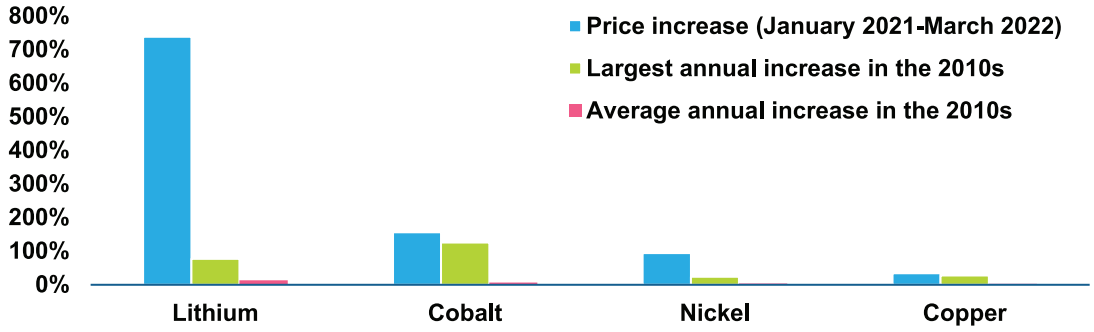

FIGURE 9
Historical Critical Mineral Price Increases

Source: IEA, "Critical Minerals Threaten a Decades Long Trend of Cost Declines for Clean Energy Tech," May 2022.

Investment opportunities

The role of critical minerals has become increasingly important to the energy sector due to a global shift toward green energy technologies. The legislation and pledges from companies, countries, and groups across all industries, such as the Paris Agreement's commitment to clean technology[9] and numerous other foreign and domestic climate-focused legislation, collectively imply that green energy technology is here to stay for the foreseeable future.

[9] UN Climate Change. The Paris Agreement is a legally binding international treaty on climate change that requires economic and social transformation, based on the best available science. The agreement was signed by 196 parties in 2016.

Not only are critical minerals becoming more important globally, but there is also an increased focus on the repatriation of critical minerals' supply and processing. For example, programs like the Inflation Reduction Act ("IRA") in the US are aimed at supplying EV production with domestic or other free trade jurisdictions' materials and processing capabilities. Thus, the US and other countries' goal to repatriate the production and supply chains of metals and minerals deemed critical and strategic from a national security perspective may provide significant incentives that could result in tailwinds for the industry.

The demand for and global price of critical minerals is increasing, while mining and production are highly geographically concentrated. Current mining (i.e., supply) levels are also a concern, one that is likely to worsen if demand growth outstrips the increase in supply. Hence, there is a need and an investment opportunity to find new, geographically diverse, supplies of critical minerals. In the venture capital sector, critical mineral startups raised a record $1.6 billion in 2022, representing a 160% year-on-year increase.[10] Globally, mineral resource exploration spending has increased in four of the past five years (with the exception of 2020), most recently growing 20% from 2021 to 2022.[11] Opportunity extends beyond strictly mining, as some of the largest mineral-consuming companies (such as EV and battery manufacturers) are looking to move up the supply chain and secure minerals directly with mining companies.[12]

Investment opportunity may also lie in the processing of critical minerals. With major manufacturers like General Motors promising to offer only EVs (for new US light duty vehicles) by 2035,[13] EV and battery production capabilities must grow in order to have the capacity to process much larger quantities of minerals. Currently, China has the largest share of global EV battery production capacity at 77%, while the US stands at just 7%.[14] The Inflation Reduction Act acknowledges this need and puts an emphasis on the domestic EV and battery supply chain. As a result, the US government has pledged billions through a combination of tax credits, loan authority, and funding to the domestic critical minerals supply chain,[15] and billions of private investments have been announced for domestic EV manufacturing.[16]

Recycling critical minerals

As EVs become more widespread, commercial waste and recycling of EV batteries and their materials will also become an area of increased focus. The recycling and recovery of these critical minerals may help to relieve some of the pressure on supply. As of 2021, the end-of-life-recycling rate for the minerals themselves was 0.5% for lithium, 32% for cobalt, 45% for copper, and 60% for nickel.[17] These figures refer to the share of material in waste flows that are actually recycled, but it does not necessarily mean that the recycled materials are put back into and used in the total mineral supply (i.e., the recycled input rate). Both the end-of-life and input recycling rates need to increase substantially in the future to help meet the expected increased critical mineral demand, especially for lithium and cobalt.

With the increased popularity of EVs, the EV battery recycling sector is also expected to grow over the next decade or so. The total amount of spent batteries from EV and

[10] Source: IEA, "Critical Minerals Market Review 2023."

[11] Source: IEA, "Critical Minerals Market Review 2023."

[12] Source: New York Times, "Lithium Scarcity Pushes Carmakers into the Mining Business," July 2023.

[13] Source: General Motors Newsroom.

[14] Source: IEA, "Global Supply Chains of EV Batteries," July 2022.

[15] Source: Building a Clean Energy Economy: A Guidebook to the IRA's Investments in Clean Energy and Climate Action, January 2023.

[16] Source: Environmental Defense Fund, "Report Finds Investments in U.S. Electric Vehicle Manufacturing Reach $120 Billion, Create 143,000 New Jobs," March 2023.

[17] Source: IEA, as of April 30, 2021.

storage applications was under 2 GWh as of May 2021, and projections show that it could grow to 100 GWh by 2030.[18] Currently, China accounts for nearly for 50% of global battery recycling capacity.[19] Thus, in addition to private companies and investment in EV battery recycling and technology, many countries are also focusing on their own domestic battery recycling capabilities. For example, in the US, the IRA includes a clause that incentivizes EV automakers to use US recycled battery materials.[20]

While recycling EV batteries may aid supply issues and is becoming a focus for governments and private companies alike, it is still a relatively new process. As such, it poses challenges, including the environmental impact of recycling EV batteries. Recycling may be inefficient and potentially dangerous, as batteries can be a fire hazard while both being processed and when stored. Similarly, another potential challenge is the processes used to recycle EV batteries. Currently, there are several recycling processes, each of which has its own downsides such as high energy usage and additional dismantling requirements. EV batteries are also not standardized across manufacturers, further making it difficult to dismantle and recycle them.[21]

Conclusion

Critical minerals are in high demand, given their great importance to energy technologies, while also having potentially limited supply and supply chain disruption vulnerabilities. Certain critical minerals, such as copper, cobalt, nickel, and lithium, are heavily used in green technologies, especially in electric vehicles and batteries. As expected with the heightened role of green technology and EVs, these minerals have experienced a rise in demand and prices over the past five years. Their supply, however, has not developed as quickly, and both mining and processing remains heavily concentrated in China and a handful of other countries outside the US. New mining reserves as well as further development and expansion of mineral processing facilities are needed to reach climate goals such as Net Zero Emissions by 2050.

Critical minerals play an essential role in clean energy technology. With demand, utilization, and prices projected to increase, they may present a tailwind for investors. Hence, investment opportunities may lie in both the mining and the processing of critical minerals.

[18] Source: IEA, "The Role of Critical Minerals in Clean Energy Transitions," as of May 2021.

[19] Source: IEA, "The Role of Critical Minerals in Clean Energy Transitions," as of May 2021.

[20] Source: Reuters, "Dead EV batteries turn to gold with US incentives," July 21, 2023.

[21] Source: MIT Climate Portal, "How Well can EV Batteries be Recycled," September 5, 2023.

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