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GEOPOLITICAL ADVISORY

RESEARCH BRIEF

Critical Materials: Geopolitics, Interdependence, and Strategic Competition



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I. Introduction: Dangers of Structural Interdependence

The current geopolitical environment is leading to a more fragmented and polarized world. The reconfiguration of supply chains is at the core of this trend as governments engage in an escalatory industrial policy race, especially in strategic technologies. The Inflation Reduction Act (IRA) and the CHIPS and Science Act in the US, Europe’s Critical Raw Materials Act, and China’s Made in China 2025 program are all examples of industrial policies focused on two objectives: (1) restore (or maintain) manufacturing advantages in strategic sectors, especially clean energy, and advanced electronics; and (2) reduce dependencies on geopolitical competitors.

Successfully achieving these goals will depend on the dynamics at play upstream in the supply chain: the exploration, mining, and processing of critical materials that serve as the building blocks of the global economy.¹ From the copper and lithium needed for the energy transition, to the rare earths used to build everyday and industrial technologies, these materials are becoming increasingly contested and vulnerable to geopolitical risk and economic fragmentation.

In this report, we unpack the geopolitical risks emerging from competition over the resources indispensable to three strategic sectors: clean energy, advanced electronics, and healthcare. We identify the geopolitical and economic disruptions that corporates could suffer given the highly concentrated nature and scarcity of some of these materials, and propose strategies to minimize disruptions. We identify potential opportunities in this environment as well.

Selected Sectors and Critical Materials

Sector	Materials	Examples Products Uses
Clean Energy	<ul style="list-style-type: none"> Lithium Cobalt Nickel Copper Graphite 	<ul style="list-style-type: none"> Electric vehicles Rechargeable batteries Solar panels Wind turbines Transmission lines
Advanced Electronics	<ul style="list-style-type: none"> Rare earths Silicon Gallium Palladium 	<ul style="list-style-type: none"> Solar panels Semiconductor wafers Aluminum alloys 5G network
Healthcare	<ul style="list-style-type: none"> Platinum metals Zinc Titanium 	<ul style="list-style-type: none"> Surgical tools Implants and medical devices Electronic measurement tools and implants Health supplements

Critical materials are an essential component of these strategic sectors. Increasingly, these represent the highest cost of these technologies. The cost of lithium-ion batteries has fallen by over 90% in under ten years, but minerals’ share of the cost of batteries (mainly lithium, iron, nickel, cobalt, and copper) has reached close to 25% from 4%, underscoring the fundamental role these minerals hold in decarbonization.^{2,3} The production of magnets, hard disks, wind turbines, and light-emitting diode (LED) screens requires rare earth metals which are extremely difficult to substitute given their chemical characteristics. As a result, China’s control of the rare earths supply chain gives it a notable strategic advantage as geopolitical tensions rise.

- Note: Reserves = proven resources that are ready to be extracted for a profit without additional exploration. Production = synonym of mining or extraction of the critical minerals. Processing or refining = downstream part of the supply chain which has the objective of modifying the minerals to be used in the production of goods and technologies.
- IEA (2022), The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris.
- Chemistry World.

As economies have progressively become more intertwined, countries are able to use economic and fiscal resources in coercive ways. Trade and financial networks have been used by several countries, including the US and China, to inflict pressure on one another or third parties.⁴ History presents several examples. The oil embargo of the 1970s is the best example of the globally consequential weaponization of a critical commodity. In 1973, the nation-members of OPEC decided to stop oil exports to the US in response to the American military support to Israel in the aftermath of the Arab-Israeli war. US reliance on fossil fuels from the Middle East at the time led to significant economic repercussions and political crisis.

Beyond oil, countries have similarly weaponized other critical commodities. In 2010, a rare-earth dispute between China and Japan resulted in a major crisis for Japan’s advanced technology manufacturing industry while also disrupting global rare earth prices.

China-Japan Rare Earths Trade Incident

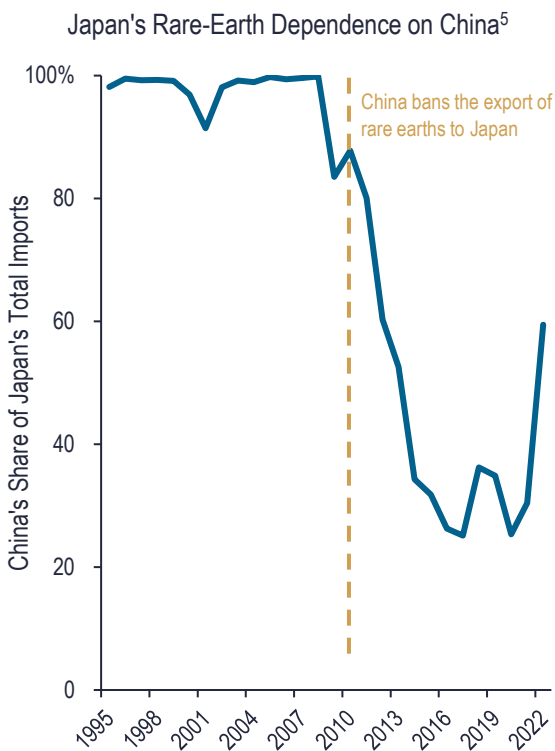
In 2010, China decided to ban exports of rare earths for a few months after the captain of a Chinese fishing vessel collided with a Japanese coast guard boat in contested waters.

Japan relied almost entirely on rare-earth imports from China to produce solar panels, car engine components, and magnets, among other technologies.

After this brief dispute, Japan began an aggressive diversification strategy to find alternative suppliers rather than China. Ten years later, Japan had successfully achieved a reduction of Chinese rare-earth imports from 90% of total to 60%. Japan also created Japan Australia Rare Earths (JARE), a special-purpose vehicle created to invest in rare earth mining, in 2011. In 2023, Japan invested \$133 million through JARE in Australian rare earth producer Lynas that would secure priority supply rights for Japan until 2038.

The recent increase in imports of Chinese rare earths by Japan is a reflection of the surge in demand of clean energy technologies, many of which use rare earths as inputs to function.

This case study underscores that supply diversification is achievable but faces long timelines and other constraints. The high concentration of rare earths production and refinement in China indicates the world’s dependence on China will endure for the foreseeable future.



This report outlines risks (summarized in the tables below) across two categories: first, the key risks that countries and companies will face in relation to critical materials supply, and second, the trajectory of global critical materials supply chain fragmentation. Importantly, this report covers how critical material supply networks might evolve given that the policies countries are creating today will be felt for years to come.

4. Henry Farrell, Abraham L. Newman, Weaponized Interdependence: How Global Economic Networks Shape State Coercion, International Security Journal 2019.
 5. UN Comtrade.

Critical Materials Key Risks

1. China's Leveraging of Critical Materials

- China's control over the processing of a vast number of critical materials, combined with the growing tensions with the West, pose meaningful risks that it might decide to geopolitically and economically leverage materials, such as rare earths, graphite, and titanium
- China has strong incentives to do so sooner rather than later, before supply chains shift

2. Copper Shortages

- Growing demand is outpacing supply for copper, the most important mineral in the electricity sector
- Political risks in top producing countries — e.g., Chile, Peru, Russia, the Democratic Republic of Congo (DRC) — as well as geopolitical tensions, lagging exploration and production investments, and declining reserve quality will likely exacerbate shortages

3. Global Supply Chain Fragmentation

- Critical materials play a crucial role in the definition of economic and diplomatic blocs such as the US, China, and EU, which could lead to supply and trade disruptions elevating costs for producers and consumers

4. Resource Nationalism & Geographies with Higher Political Risk

- Challenging domestic political dynamics could jeopardize the supply of materials from top producing countries
 - DRC: Cobalt and copper
 - Russia: Platinum, palladium, copper, and zinc
 - Southeast Asia: Nickel and bauxite
 - South Africa: Palladium

5. Buyers' & Sellers' Clubs

- Critical materials consumers and producers have growing incentives to join with peers to gain geopolitical leverage and market power
- Buyers' clubs could help Western countries gain bargaining power, although this approach likely has limitations
- Sellers' clubs are unlikely to be able to replicate the geopolitical influence of OPEC, but could create episodes of price volatility

To reach these conclusions, we analyze the most consequential factors that impact critical material supply chains:

1. The geographic locations where materials are extracted and processed
2. The policies implemented by countries that either produce and export materials or source them for the development of their industries
3. The domestic and global political dynamics influencing governments and companies as they deal with critical material supply chains

From a policy point of view, the role each country plays in the supply chain of critical materials (whether up, down, or midstream) is a strong indicator of the type of policies these countries are currently implementing or will be incentivized to pursue in the future.

Policies Vary According to Each Country’s Position in the Critical Materials Supply Chain⁶

Role in the Supply Chain	Countries	Policy
Importers of Critical Materials	<ul style="list-style-type: none"> US EU China Japan South Korea India 	<ul style="list-style-type: none"> Critical raw material reliance on allies and trading partners Incremental but slow efforts to process critical materials domestically will face significant political and social challenges due to environmental concerns Mainly focused on industrial policies to re-shore or near-shore manufacturing of strategic sectors
Developed Producers / Exporters	<ul style="list-style-type: none"> Australia Canada 	<ul style="list-style-type: none"> Aiming to become top providers of critical materials to their trade partners and allies Increase role in processing to reduce China’s dominance Mostly focused on supplying allies with materials with limited but incremental efforts to increase manufacturing in strategic sectors
Developing Producers / Exporters	<ul style="list-style-type: none"> Mozambique Nigeria Peru Philippines Russia Argentina Bolivia Chile DRC Indonesia Madagascar 	<ul style="list-style-type: none"> Growing resource nationalism <ul style="list-style-type: none"> Taxes and royalties Export bans Favoritism of state-owned companies and national champions Nationalization Some countries will attempt to move up the value chain ladder into processing raw materials, but will face significant challenges
Full Supply Chain Participation	<ul style="list-style-type: none"> China 	<ul style="list-style-type: none"> State-supported efforts to control extraction of critical minerals domestically and abroad Industrial policy targeted at refining critical materials domestically to control domestic and global supply of strategic sectors Continue efforts to expand manufacturing of strategic technologies via subsidies, fiscal and financial benefits

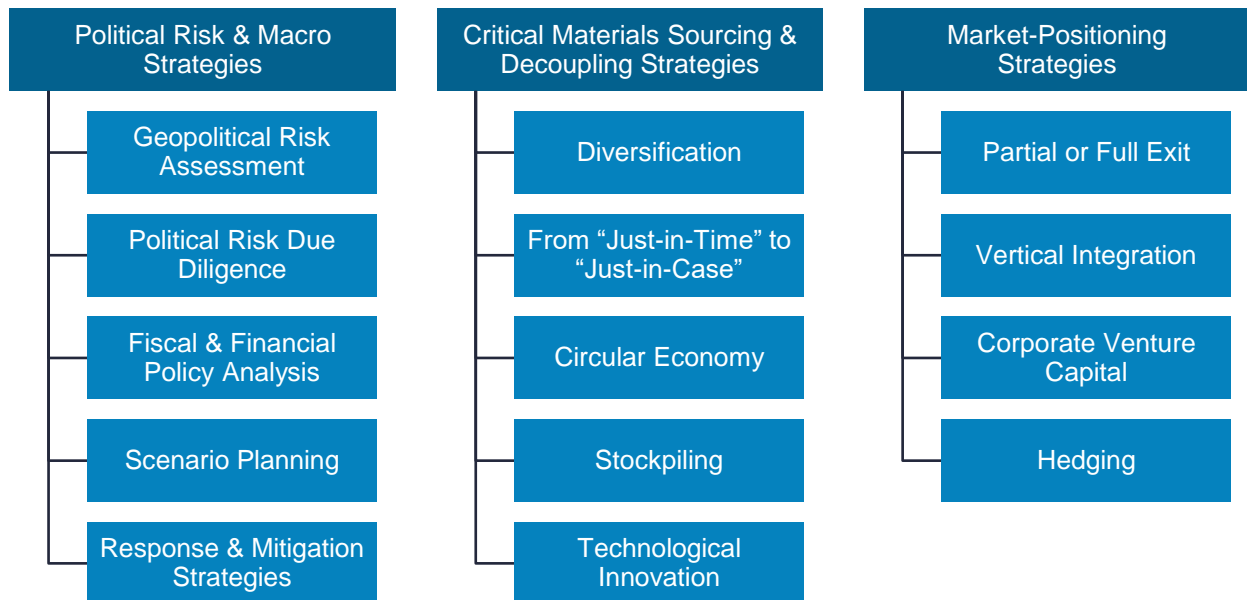
The mix of the production, policy, and geopolitical outlooks serves as a strong indicators of the way critical materials supply chains will evolve. **Current dynamics strongly indicate that the interdependencies that currently exist will not change in the coming years**, with China remaining the top player in the refining of most materials. Moreover, growing demand could create supply bottlenecks that would increase costs and therefore affect the adoption of sustainable energy technologies, with implications for global decarbonization targets. **The materials in the clean energy sector (like cobalt, nickel, graphite, and rare earths) face the most stringent policy outlook as well as the highest levels of production and processing concentration by a few countries.**

The variable that could change this is innovation. Technological changes could accelerate as the price of the materials increase and supply chains become more inefficient, delivering new technologies that end the dependence on a material and the countries that control them, e.g., hydrogen, fusion, or zinc-ion batteries, among other potentially game-changing breakthroughs.

6. Note: Countries selected given their relevance to each step of the supply chains of critical materials. This is a non-exhaustive list.

The last section of the report addresses strategies firms could implement to mitigate risks or take advantage of unfolding supply chain dynamics. Firms will have to make the decision to maintain engagements in geographies that pose significant geopolitical risks (whether via direct operations or supplier relationships) and take political concerns into consideration.

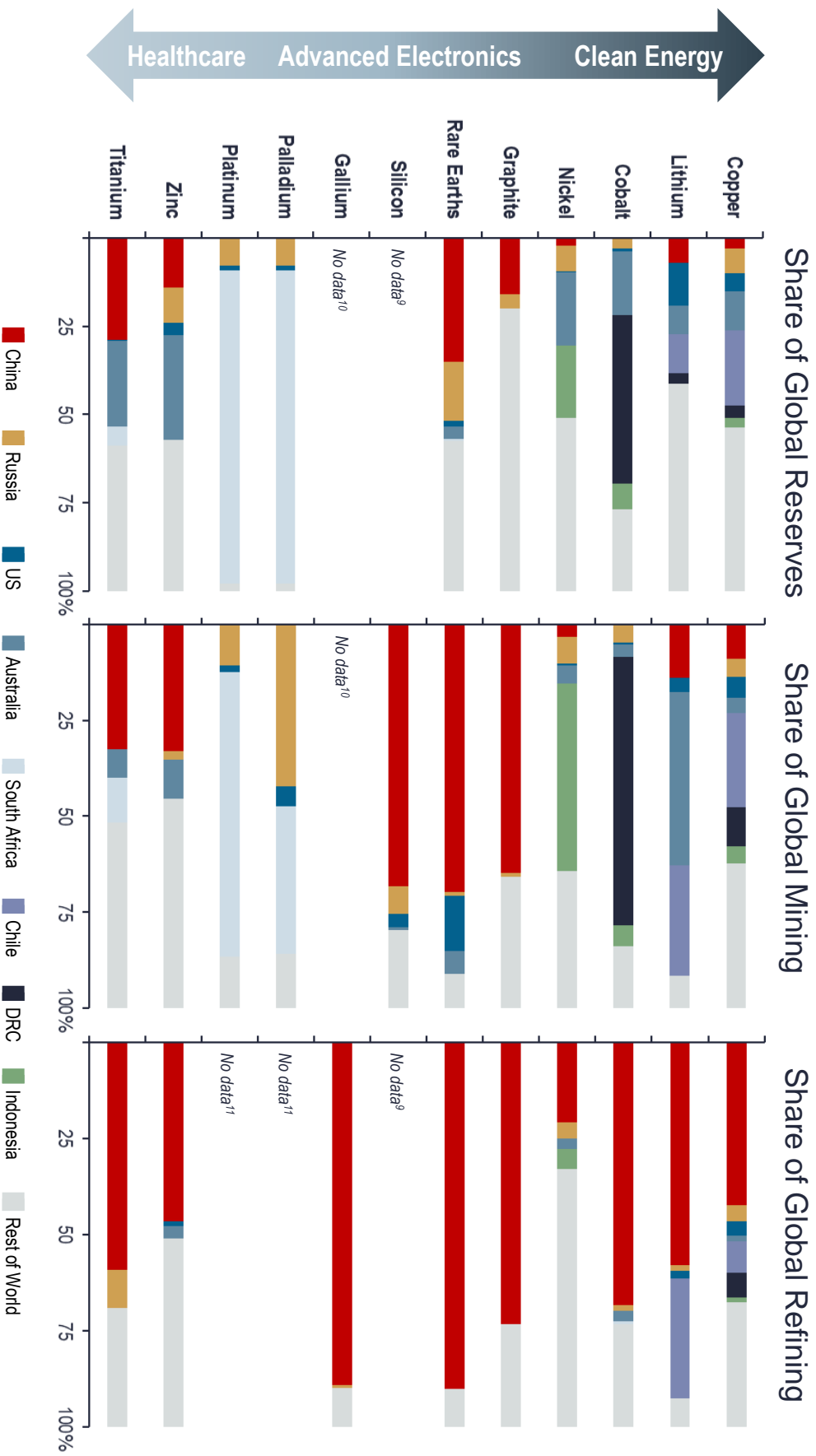
Select Critical Material Risk Mitigation Strategies



Having analyzed the geopolitical, production, and policy dynamics that are driving the competition over critical materials, below are our most important conclusions:

- ① There are political and economically significant risks hidden in the upstream supply chains of critical materials
- ② The key geopolitical risk relates to China given its dominance in processing and intensifying tensions with the West, but other producing countries could also jeopardize the supply chains of critical materials
- ③ Despite the rapidly evolving critical materials policy landscape, it will take years to significantly alter global supply chains and existing interdependencies
- ④ Unlike oil, no single critical material has the same structural implications for the global economy, making disruptions to certain sectors / products isolated but deeply impactful
- ⑤ Corporations need to prepare for a world of more contested critical materials
 - Better understand geopolitical risks and exposures hidden in their supply chains
 - Understand the policy direction and economic incentives / disincentives
 - Scenario plan for disruptions and develop contingency plans addressing the most disruptive risks
 - Adopt risk mitigation strategies such as diversifying supply chains, creating a just-in-case supply chain, engage in the circular economy, stockpile resources, and / or vertically integrate to minimize risks and maximize opportunities
 - Support innovation and incorporate supply chain security into their vertical integration and corporate venture capital strategies

The World Is Dependent on a Few Key Players for Critical Materials across the Clean Energy, Advanced Electronics, and Healthcare Sectors^{7,8}



7. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

8. Note: The order of these materials is based on their significance to the clean energy, advanced electronics, and healthcare sectors. However, most materials are used across all sectors. Rare earths, for instance, play an important role in cross-sector technologies.

9. Note: Silicon is the second-most abundant element in the Earth's crust, as more than 90% of the crust is composed of silicate materials. Silicon processing is intimately linked with the mining phase.

10. Note: As gallium is an element that is mostly contained in small amounts of bauxite and zinc resources, it is difficult to quantify, and its mining is not independently reported.

11. Note: The refining of platinum group metals, including palladium, is intimately linked with the mining production phase and is not reported separately.

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II. Critical Materials in the Hands of a Few

Critical materials are inherently geopolitical. For the sectors that depend upon these materials, disruptions in their supply would have meaningful macroeconomic and business implications. To understand these dynamics, this section considers:

1. Which countries have the largest reserves?
2. Who are the top producers?
3. Where are the processing capabilities of the critical materials required for clean energy technologies, advanced electronics, and healthcare technologies most concentrated?

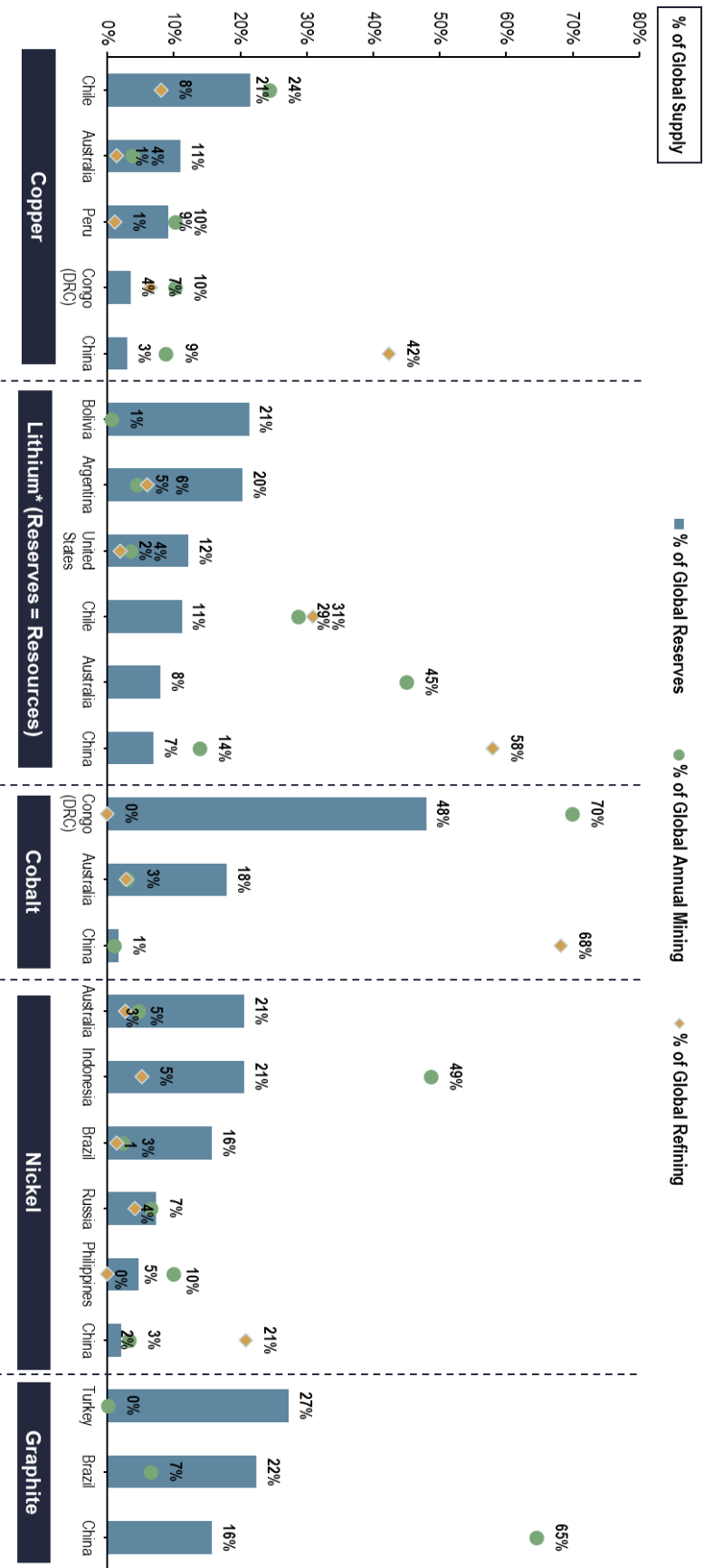
The control over production and processing of critical materials is both concentrated and sticky, which presents a strategic challenge in an environment defined by fragmentation and a growing emphasis on diversification and self-reliance. **The collision between geopolitical fragmentation, tensions, and interdependencies opens the door to episodes of price volatility and supply disruptions — which are likely to become more frequent in the decade ahead.**

Key Takeaways

1. **China dominates the refining and processing steps of the supply chain across nearly all critical materials**, including copper, lithium, cobalt, rare earths, gallium, silicon, and many others
2. **China has significant control over the critical materials in advanced electronics**. From the extraction and processing of the critical materials to the manufacturing of goods, China plays a key role in the supply chains of rare earths, gallium, and silicon, which are some of the most relevant materials for semiconductors, magnets, hard drives, and a wide range of other advanced electronics
3. **Over the next decade, existing interdependencies in the three analyzed sectors are not going to change significantly**. Three factors define this trend:
 - a. **Production challenges**: limited upstream investments, stalled capex over the past 5 years, declining quality of reserves for some materials like copper
 - b. **Long lead times**: new investments often take close to a decade to materialize
 - c. **Status quo policy**: recently implemented policies will maintain the current supply and demand balances, rather than change them
4. **For most of the critical materials in the clean energy sector, growing demand will likely outpace supply**, putting pressure on prices and generating episodes of volatility. Lead times for new production are significant, thus recent lags in investments imply lower short- to medium-term supply

Below, we analyze in more detail the reserves, production, and refining outlook of the critical materials used in the clean energy, advanced electronics, and healthcare sectors.

1. Clean Energy Critical Materials^{12,13}



12. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

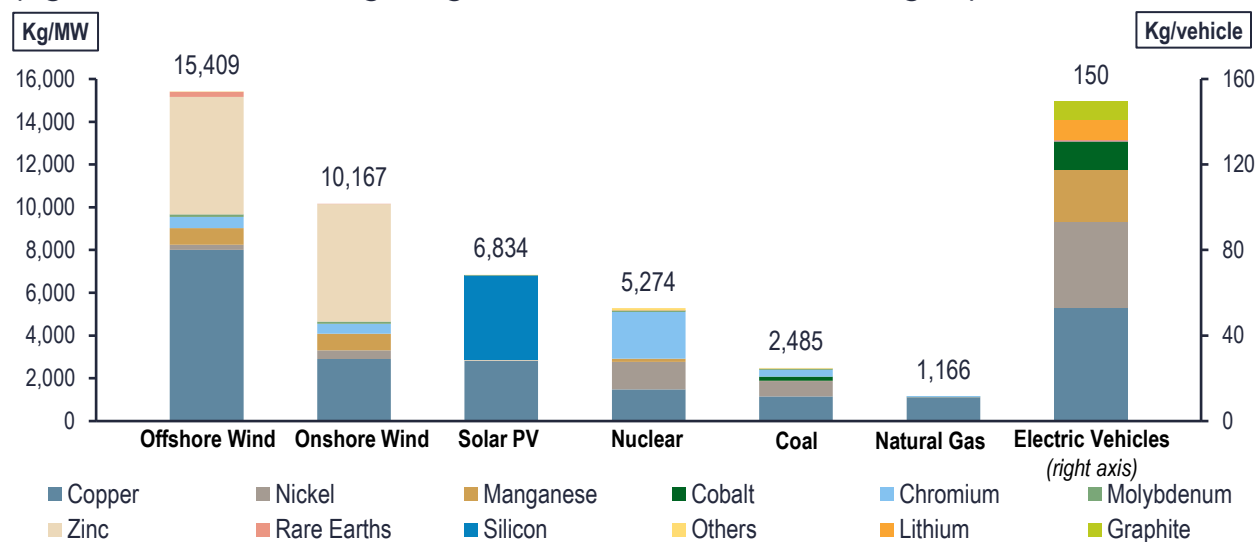
13. Note: For some materials mining is not independently reported from refining, thus it could not be reflected on the graph.

1. Clean Energy Critical Materials

The growing commitments to decarbonize the economies of the world have led to a faster adoption of renewable sources of energy. These clean energy technologies have become part of great power competition, with the US, EU, and China making the most aggressive and decisive efforts to become the leaders in their development and manufacturing.

The equipment and infrastructure used for the energy transition requires a vast number of minerals, in particular, cobalt, copper, lithium, nickel, graphite, and rare earths (to be covered further in the advanced electronics section of this report).

Critical Minerals Used by Energy Technologies (kg/vehicle for EVs, kg/megawatt for all other technologies)¹⁴



According to the International Energy Agency (IEA), the demand for critical minerals used in clean energy transition technologies will increase four-to-six times over the next 20 years.

Supply will struggle to meet demand, at least over the next decade, given the lead time of projects. For many of these materials there have not been enough investments in exploration and production, and even though this is starting to pick up, a greenfield mining project has lead times of 5 to 15 years before any output is delivered. Under these circumstances, any financial, operational, or political disruptions can lead to supply chain disruptions and price volatility.

Mining of cobalt, lithium, and nickel are significantly concentrated. This will make reducing dependencies in countries that control most mines, such as the DRC and Indonesia, hard to break. **There is no single country that dominates the reserves and production of several critical materials used for clean energy technologies, making it hard for one country or firm to control the full supply chain.**

The processing front is a different story: China has significant dominance in the processing and refining facilities for most clean energy materials. This has led to a critical dependency between China and the West. Breaking those dependencies could be less complex than it is upstream in the supply chain, as processing facilities do not have to be tied to a specific geographic location. However, it is politically challenging to build refining capabilities in western countries as these processes can be water and energy intensive and polluting.

14. IEA (2022), The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris.

Copper, the most widely used mineral in the electric sector (from transmission and distribution lines to power generation equipment), faces fewer concentration risks. Chile is the top producer, but Peru, Australia, the DRC, and other geographies have significant production capacity. **That said, growing demand, political and regulatory risks in some producing countries, underinvestment in upstream capacity, and diminishing quality of existing reserves, taken together will lead to significant supply challenges that undermine global efforts to meet electrification goals.** From 2003 to 2010, on average, 29 greenfield copper mining projects were announced per year.¹⁵ This figure fell to ten during the 2010–2020 decade and over the past three years only recovered to pre-pandemic levels, recording nine projects per year.

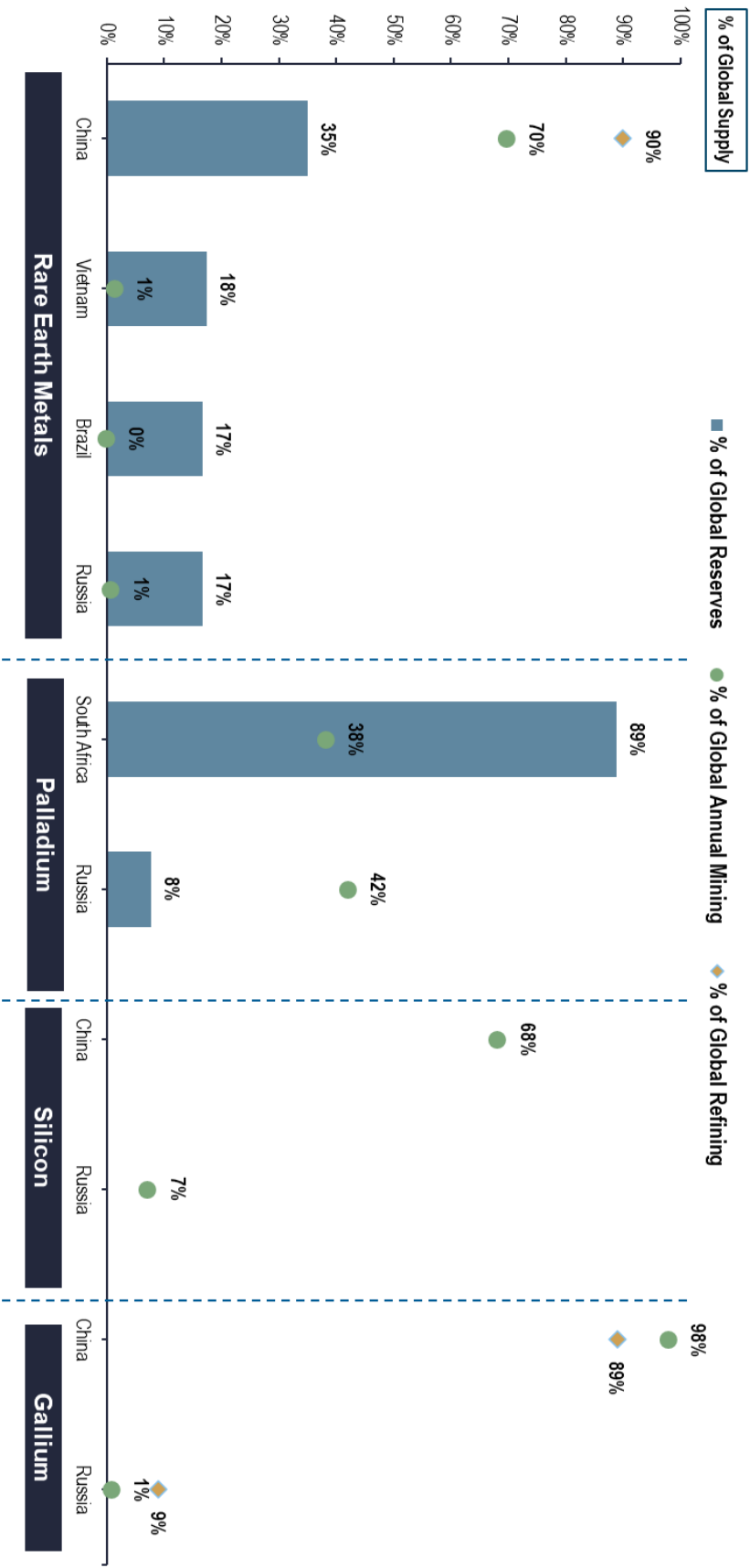
Key Takeaways for Clean Energy Critical Materials

Material	Outlook	Supply Risk ¹⁶
Copper	<ul style="list-style-type: none"> Copper does not face a significant risk of production concentration; however, it faces supply constraints due to under-investment and diminishing quality of existing reserves 	3/5
Lithium	<ul style="list-style-type: none"> Lithium is abundant globally, but most resources are not yet recoverable. The medium-term issue is supply rather than concentration, as demand is growing too fast, and output is lagging by comparison 	2/5
Cobalt	<ul style="list-style-type: none"> Probably the mineral with the highest dependency risk, as the DRC has both the largest reserves and production in the world 	4/5
Nickel	<ul style="list-style-type: none"> Indonesia will remain the world's top nickel miner, even though global reserves are relatively diversified. Over the next decade, this is unlikely to significantly change as Indonesia is leading most global production increases 	3/5
Graphite	<ul style="list-style-type: none"> Despite not having the largest graphite reserves, China is the largest producer. This creates a dependency risk for EV production. Output has been rapidly growing in Mozambique, but domestic unrest signals uncertainty of supply 	4/5

15. fDi Markets.

16. Note: Supply Risk is determined by a combination of factors: Concentration of reserves, production, and processing by few countries; expected supply surplus / deficits over the next ten years; and risks of high supply disruptions such as political, social, economic instability in top producing countries.

2. Advanced Electronics Critical Materials^{17,18,19}



17. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

18. Note: For some materials mining is not independently reported from refining, thus it could not be reflected on the graph.

19. Note: Gallium is not mined as it is a byproduct from the refining of other minerals. For the same reason, there are no reserves data

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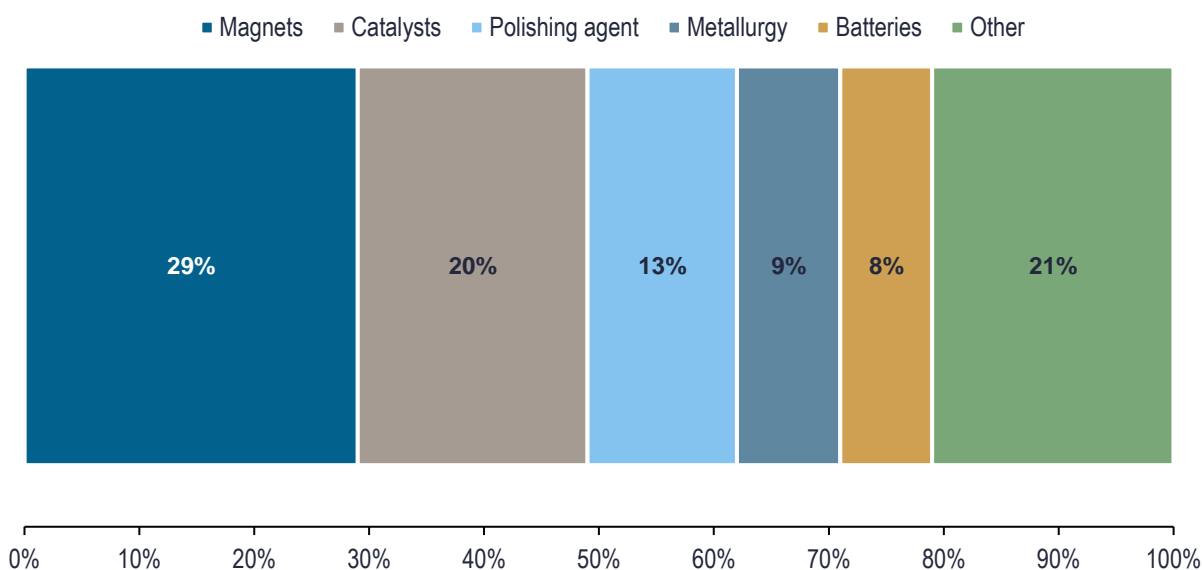
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2. Advanced Electronics Critical Materials

Advanced electronics, in particular semiconductors, have recently become a cornerstone of industrial policy initiatives and national security measures. Advanced electronics are cross cutting — they are critical to nearly every sector, often at every stage of the value chain.

Compared to other sectors, the critical materials used for the development of advanced electronics are the most concentrated in the hands of one country: China. China controls a dominant share of the supply chains for all these materials besides palladium. For instance, about 70% of global rare earths production and nearly 100% of global gallium production is controlled by China. This raises the specter of single points of failure, choke points, or targeted export controls that could rapidly cripple both economic and military national capabilities.

Rare Earth Demand by End-Use Sectors²⁰



Rare earth metals reserves are not as concentrated as the production of the mineral would indicate, signaling that breaking dependence on China is possible. However, this will take time as most resources outside of China are either at the exploration stage or production projects that have only started recently.

China is the top producer of silicon too, which is crucial to semiconductors and solar panel production. Other countries are trying to build-up domestic production capacity. However, doing so takes time. New investments in greenfield mining projects take ten years on average to deliver output. Despite abundance globally, the energy and water intensiveness of its processing, as well as the upfront investments for building processing facilities, have historically discouraged the construction of new plants and solidified dependence on China. For instance, the US' only hyper-pure polysilicon producer, Hemlock Semiconductor, is the single largest electricity consumer in the state of Michigan and on occasion is obliged to reduce production.²¹ Energy infrastructure that allows reliable access to energy and consistent operational continuity will be an important factor in establishing competitive polysilicon production outside of China.

An additional sourcing problem that could emerge in this sector is concerns over China's human rights abuses in the Xinjiang region, where most of their advanced electronics capacity is located. The US is imposing stronger restrictions through the Uyghur Forced Labor Prevention Act, which could create additional supply challenges for the sector.

20. Irena.

21. Mlive.

Other risks to the advanced electronics critical materials supply chain include:

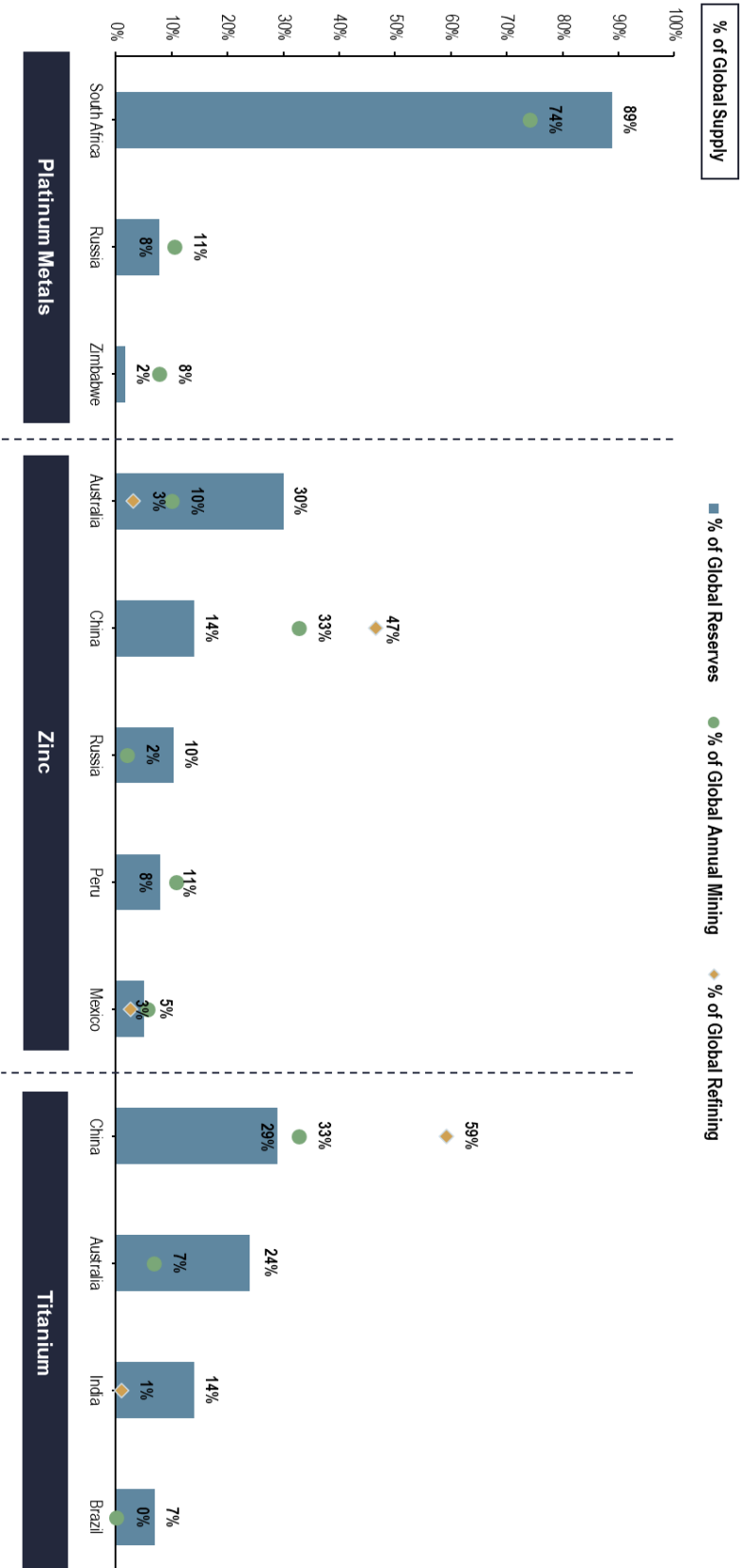
- Additional Western sanctions or export controls on Russian and / or Chinese industrial sectors, mining operations, or technologies
- US-China tensions put the supply chains of advanced electronics at risk of disruption, primarily via the use of export controls or the deliberate withholding of exports, such as rare earths
- Growing demand for goods and materials from Vietnam continue to face logistics-related bottlenecks despite government efforts to build and improve infrastructure. A sharp increase in demand for goods from Vietnam would magnify these bottlenecks, as would disruptions to vulnerable seaborne shipping lanes in the South China Sea

Key Takeaways for Advanced Electronics Critical Materials

Material	Outlook	Supply Risk ²²
Rare Earth Metals	<ul style="list-style-type: none"> • The demand for a range of rare earths is expected to triple from 2022 to 2035 because of electrification and digitization. China's sophisticated industrial complex for rare earths will likely enable the country to continue leading the production and refining of the materials for years to come 	4/5
Silicon	<ul style="list-style-type: none"> • Silicon refining is energy intensive and costly, adding price pressures already exacerbated by elevated energy prices stemming from the war in Ukraine, especially for Europe. The most significant disruption risk stems from China's nearly 70% dominance over silicon production 	4/5
Gallium	<ul style="list-style-type: none"> • Gallium is found in small amounts with multiple other minerals, which should ease the diversification of its processing away from China. However, like with other critical materials, China has invested in gallium production for decades and controls most production capacity, generating a dependency that will be hard to break soon 	5/5
Palladium	<ul style="list-style-type: none"> • As the West and its allies seek to diversify away from Russian palladium, South Africa will likely be the key supply source. However, its power sector challenges and complex mining regulations will continue to pose production challenges 	3/5

22. Note: Supply Risk is determined by a combination of factors: Concentration of reserves, production, and processing by few countries; expected supply surplus / deficits over the next ten years; and risks of high supply disruptions such as political, social, economic instability in top producing countries.

3. Healthcare Critical Materials^{23,24}



23. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

24. Note: For some materials mining is not independently reported from refining, thus it could not be reflected on the graph.

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3. Healthcare Critical Materials

From basic medical supplies to advanced surgical tools and implants, the healthcare sector relies on a wide range of critical materials, including platinum, zinc, and titanium. Notable healthcare items reliant on these materials include pacemakers, defibrillators, cancer treatment drugs, portable oxygen devices, and surgical implants.

The supply chains — from reserves to production and refining — of platinum, zinc, and titanium are primarily dominated by just three countries: South Africa, Australia, and China. Platinum has the most concentrated supply chain, with South Africa controlling around 90% of reserves and about 75% of global production.

Among platinum producers, South Africa is one of the most open to trade and with the least protectionist tendencies, making dependencies on the country less acute. However, two risks emerge from these dependencies: unintentional disruptions creating single points of failure that could cripple supply chains, and intentional export controls and other measures used to target specific healthcare systems and nations.

As in the other sectors analyzed in this report, China is an important player in the critical materials used in healthcare. That said, most of the materials it produces are used for domestic consumption.

Russia also plays an important role, especially in the extraction of zinc and platinum. Despite not being the top global producer, the disruptions caused by the war in Ukraine led to an acute price reaction.

Numerous national actors within the healthcare supply chain present distinct risks, including but not limited to:

- Utilities and labor disruptions in South Africa
- Western economic sanctions against Russia
- Economic and / or political instability in South Africa, Zimbabwe, Peru, India, and Brazil
- Elevated production and refining costs from higher fossil fuel and electricity prices stemming from global inflationary pressures and conflict-driven supply disruptions

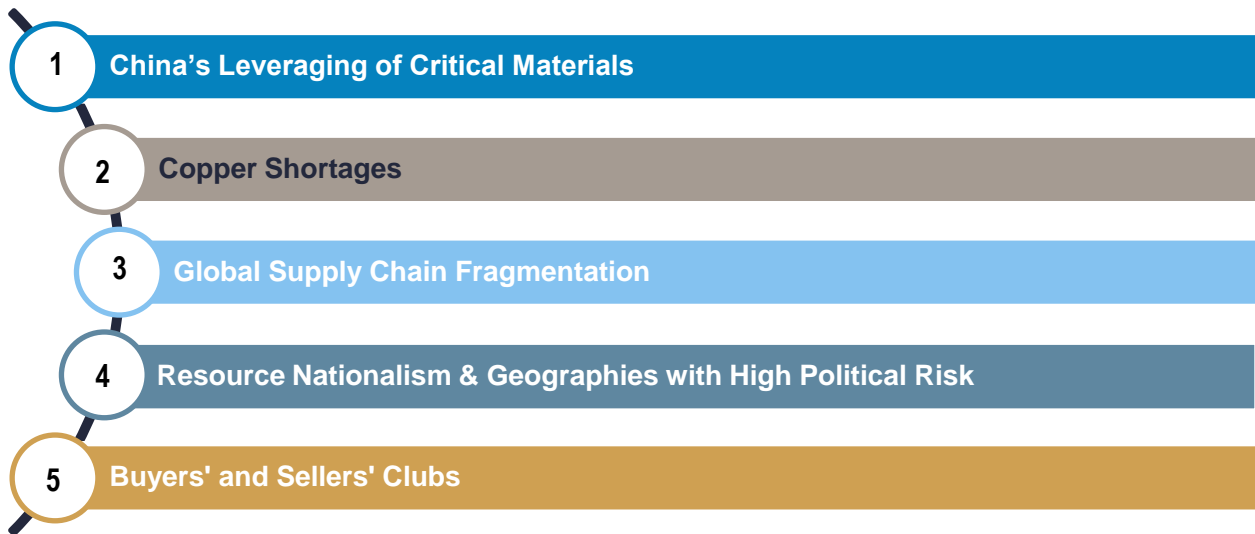
Key Takeaways for Healthcare Critical Materials

Material	Outlook	Supply Risk ²⁵
Platinum Metals	<ul style="list-style-type: none"> • Platinum supply chains are highly concentrated and thus face a higher risk of single points of failure. However, supply bottlenecks stemming from the conflict in Ukraine have moderated in recent months 	4/5
Zinc	<ul style="list-style-type: none"> • Zinc faces significant pressures from elevated demand in both the healthcare and industrials sectors, while at the same time being constrained by high energy prices. Despite relative reserve diversification, China continues to grow its dominance over production and refining 	3/5
Titanium	<ul style="list-style-type: none"> • Titanium is relatively more diversified across the value chain. However, it is a primary input not only for the healthcare sector, but also for military and non-military industrial uses. Given its importance to defense technologies, it faces higher risks of export controls and national industrial policies 	3/5

25. Note: Supply Risk is determined by a combination of factors: Concentration of reserves, production, and processing by few countries; expected supply surplus / deficits over the next ten years; and risks of high supply disruptions such as political, social, economic instability in top producing countries.

III. Critical Materials Key Risks

As critical materials become a more significant point of concern for national security, economic growth, and corporate strategy, the following are the top five risks that could disrupt companies' supply of critical materials in the years ahead.



1. China's Leveraging of Critical Materials

China and critical materials intersect at a vulnerable juncture: the growing tensions with the West, and the control it has over the critical materials needed for strategic sectors. China's efforts to develop and control these technologies does not come from an interest in improving the environment, but as a way of reducing its energy vulnerabilities as it is a net importer of coal, oil, and gas.

This point of leverage for China makes it likely that it may resort to using its critical materials dominance as a tool of economic coercion. Increasing diplomatic, trade, or economic pressures from the West may increase China's willingness to selectively cut off access to strategically important critical materials.

Geopolitical leveraging could take several forms. **The most common, and relatively less disruptive, is dumping**, which refers to selling a product below production cost, giving the exporting entity an unfair advantage over producers in the importing country.²⁶ Companies attempting to become significant players in the targeted critical materials will be most at risk if China pursues a dumping strategy.

A more aggressive way of leveraging a product or trade in general is by one country "starving" another country of a product they rely upon. China has used this strategy multiple times in the past like with Japan, Norway, and Lithuania.

China has incentives to use its supply chain advantage sooner rather than later. It is unlikely the West will be able to fully decouple from China's critical materials supply within the next 5–15 years, but the West dependency will likely go down over time, making it more effective to leverage its dominance over the materials in the short-term to obtain strategic gains.

26. Jon Stibbs, Sybil Pan, "Demand patterns may shift with EU anti-dumping duties on Chinese graphite electrodes."

Main Implications	
Price Increases and Volatility	<ul style="list-style-type: none"> During the Japan-China rare earth conflict, prices increased from three to fifteen times over several months Japan remains the country most exposed, as it is the top importer of Chinese rare earths, and second-largest importer of natural and synthetic graphite, minerals dominated by China As production of rare earths increases in other places, China will likely use dumping as a strategy, leading to lower prices
Macroeconomic Repercussions	<ul style="list-style-type: none"> After China stopped all exports to Lithuania during its political and trade spat in 2020, this resulted in an 11% total import decline Lithuania in 2021²⁷
Acceleration of Global Fragmentation	<ul style="list-style-type: none"> The weaponization of critical materials, especially those used in the clean energy and advanced electronics sectors, which have become the center of the great power competition between China and the West, will further fuel the creation of economic and diplomatic blocs

Materials China Could Leverage and Implications

Potential for use as geopolitical leverage: High Medium Low

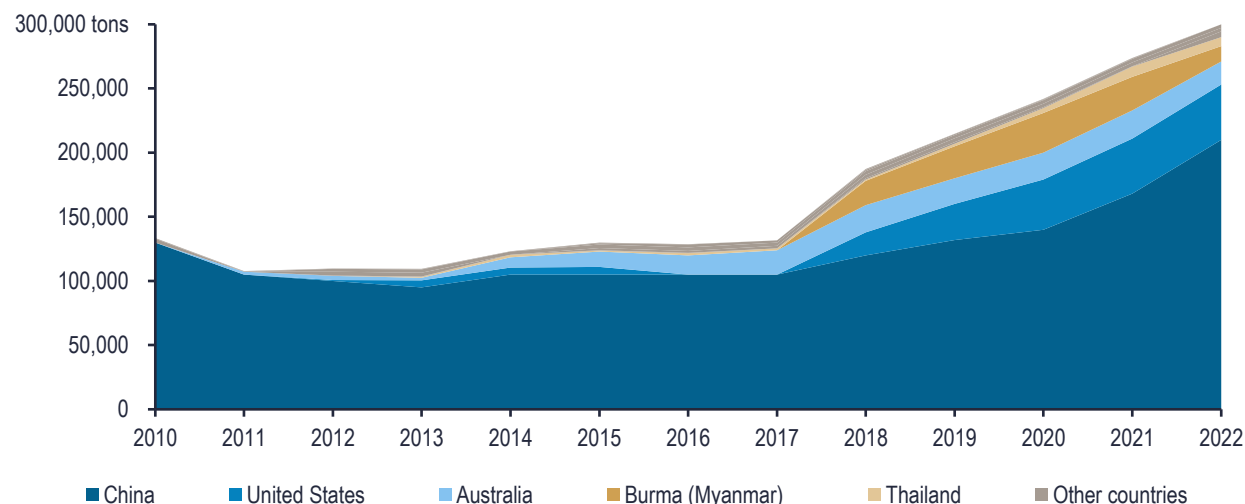
Sector	Material	Activity	Implications
Clean Energy	Lithium	Processing	<ul style="list-style-type: none"> Particularly impactful for Western countries with ambitious targets to develop their EV industry as cost of automobiles would become less attractive Companies that have decided to leave China and focus mainly on expanding battery production in the US and Europe would be most impacted
	Cobalt	Processing	<ul style="list-style-type: none"> Similar effects to that of lithium
	Graphite	Production & Processing	<ul style="list-style-type: none"> Less disruptive as it can be synthetically produced and would be easier to replace This, however, would not be achievable over the short run, disrupting EV prices
Advanced Electronics	Rare Earths	Production & Processing	<ul style="list-style-type: none"> Disruptions to strategic technologies such as wind power plants, cellphones, hard disks, and magnets China's dominance of this material makes it one of the most likely to be leveraged for geopolitical purposes
	Silicon	Production & Processing	<ul style="list-style-type: none"> Raw silicon disruptions would be less negative as it is widely available globally Processed silicon, however, would take time to be replaced, disrupting the supply chains of chips, as occurred during the COVID-19 pandemic
	Gallium	Processing	<ul style="list-style-type: none"> Like silicon, the main impact would be to semiconductors' supply chains
Healthcare	Zinc	Production & Processing	<ul style="list-style-type: none"> China consumes most of the zinc it produces and refines, reducing the odds it will be used in disputes
	Titanium	Production & Processing	<ul style="list-style-type: none"> Titanium would not only represent a risk for healthcare equipment supply chains but also for other industries, such as aeronautic

27. Bloomberg.

It is important to mention, however, that using critical materials in strategic trade confrontations can backfire, as it incentivizes other countries to search for new suppliers and for production to increase elsewhere. China remains the top rare earth producer, with 70% of total global extraction. However, in 2010, the year of the conflict with Japan, China controlled over 95% of the world's rare earth production. After this, countries invested in increasing production of rare earths and Japan took actions to reduce its reliance on China's rare earths, bringing it down from 90% to 60% of imports over ten years. Moreover, given that the rare-earth market is relatively small, increasing market share and moving capacity is easier than for other more abundantly produced and traded materials (like copper or nickel).

This highlights three things: (a) the use of an overly aggressive strategy will catalyze diversification efforts to minimize exposure, (b) it could also speed up technological innovations that reduce the reliance on China, and (c) ramping up production takes decades and only marginally reduces exposure to China's dominance. Despite some diversification, China remains the top refiner of rare earths with 85% of the global output and 92% of rare earth magnet production.

Rare Earths Global Production by Country²⁸



Given the growing competition around critical materials, China will likely continue to use these strategies as part of its geoeconomic retaliatory toolkit. Russia may pursue a similar approach. Most recently, Russia threatened to stop nickel exports to Europe, which represented close to 50% of total European nickel imports in 2021.²⁹ All of these examples indicate that heightened geopolitical tensions tend to open the door for these strategies.

An important silver lining is that there is not one single material that has the same impact as oil does, making any trade restriction less effective. The oil embargo of the 1970s that OPEC implemented against the US was extremely disruptive for the whole economy. Critical materials are highly relevant for specific sectors or targets (e.g., decarbonization), but none is as impactful to the functioning of the entire economy in the same way as oil. This minimizes the overall negative effect of leveraging critical materials for geopolitical purposes.

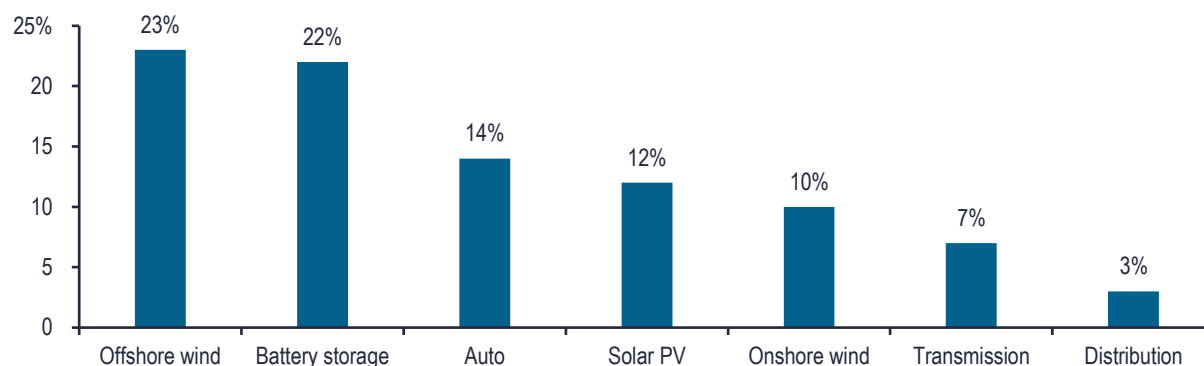
28. USGS.

29. FactSet.

2. Copper Shortages

If one critical material could be equated to the importance of oil, it would likely be copper. It is one of the most widely used metals, especially in the energy sector. Copper markets face a gloomy outlook as production is not able to keep up with demand.

Copper Demand Annual Growth 2021–2035 (% change)³⁰



Political risk, geological issues, and slowing exploration and production investments have contributed to this problem.

On the political risk front, social and political instability as well as restrictive policies in the top producing countries has led to more challenges for extraction. According to some estimates, copper shortages could last until 2030.³¹ Chile, the world’s top producer, is implementing more restrictive policies, elevating royalties and taxes, as well as increasing the regulatory requirements for the metal’s extraction. Social and environmental protests are also making investments in the sector more challenging. Similar trends can be observed in Peru, the third-largest producer in the world. In addition to significant political unrest, protests have blocked mines and transportation routes and damaged the sector. The DRC and Russia are also important copper producers with meaningful political risks, adding to metal extraction challenges.

The economic slowdown caused by the pandemic and China’s “Zero-COVID” policies has led to underinvestment and reduced production. The quality of copper reserves has also been declining, leading to higher extraction and refining costs.

The implications could be meaningful:

- **Inflationary pressures** – Given the widespread use of copper, lower production leads to higher prices which can drive inflationary pressures
- **Slowdown of decarbonization efforts** – Most, if not all, clean energy technologies use copper; higher prices and limited availability could lead to a slower adoption of these technologies
- **Headwinds for electrification in developing economies** – Higher costs of copper would impact countries that are investing in expanding their transmission and distribution lines, which would have negative macroeconomic and development implications

30. S&P Global.

31. JPMorgan, CNBC, Financial Times.

3. Global Supply Chain Fragmentation

The intensifying race to develop and control the advanced electronics and clean energy sectors has led to a battle for control over supply of critical materials. This fight for upstream materials is a critical manifestation of the emergence of economic and diplomatic blocs.

By forming “bloc”-oriented supply chains of critical materials, countries are incentivizing economically inefficient behavior that could lead to sustained inflationary pressures and risks to supply chains globally. As the competition for materials grows, behaviors like resource nationalism, industrial policy to stimulate self-reliance, and the creation of blocs (sellers’ and buyers’ clubs), among others, will further entrench these disruptions.

Critical materials are becoming an important facet of great power competition (e.g., between the US/EU and China) and is another consideration for countries to balance in a multipolar world.

The main economic and business implications include:

- **Sustained inflationary pressures** – A more fragmented world that focuses on geopolitical risk, rather than efficiency, leads to higher costs due to higher trade barriers, sanctions, and a less integrated world economy
- **Supply chain redundancies** – Firms will have to invest in redundancies in their supply chains in strategic sectors that will likely be more decoupled between the West and China and its allies
- **Higher taxes and royalties** – A more fragmented world creates incentives for zero-sum strategies that can lead to higher taxes to maximize short-term revenue

New Mining Tax Proposals by Country³²

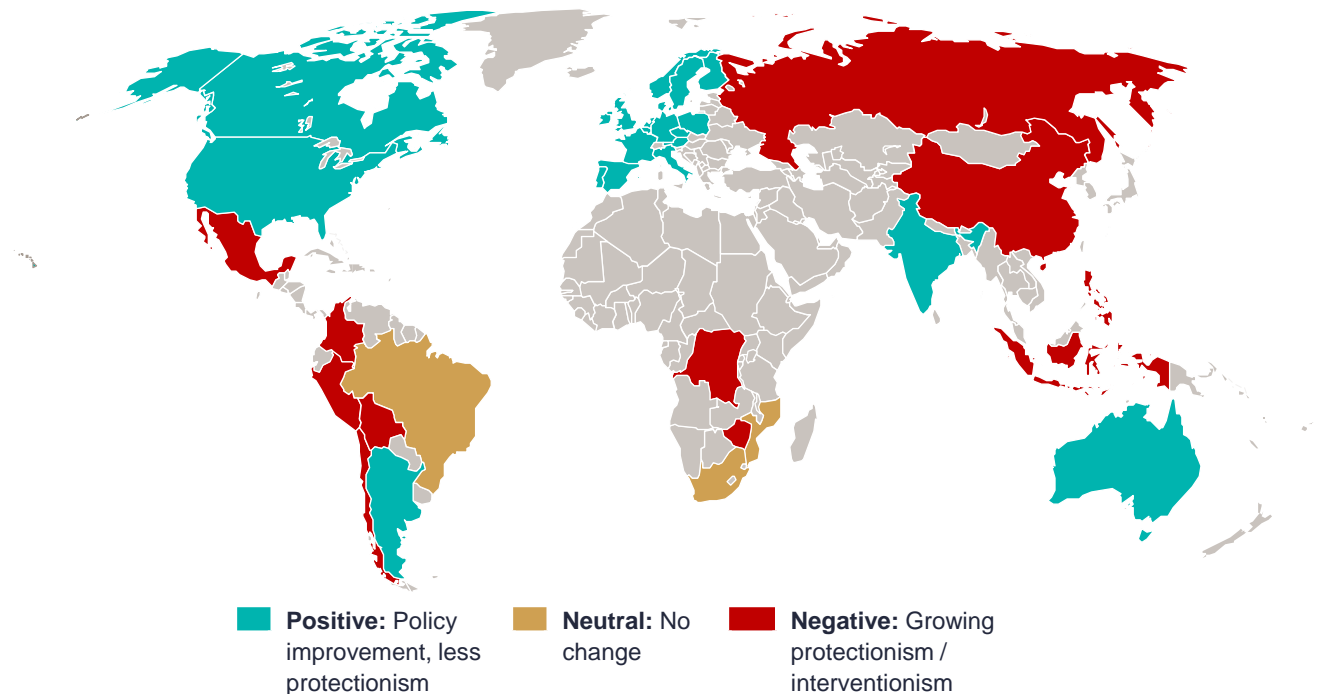


32. S&P Global.

4. Resource Nationalism & Geographies with Higher Political Risk

A series of countries essential to the production of certain critical materials have challenging domestic political dynamics that could jeopardize the supply of the materials they produce. The following are places we identified as posing the highest risk of potential disruption to critical materials supply chains and those where resource nationalist trends are also increasing.

Policy Trajectory for Critical Materials



- **The Democratic Republic of the Congo (DRC)**

The DRC — a powerhouse producer of cobalt and a major producer of copper — faces multiple political and social challenges that could risk global supplies. Artisanal and small-scale mining operations make up about 15% of the DRC’s cobalt output (it is the largest cobalt producer globally), often acting as a supply balancer when global demand fluctuates.³³ However, there are rampant labor and human rights issues in these mines that have increasingly come into focus for global consumers and businesses. Longstanding political instability and weak governance — which is likely to worsen in the run-up to the December 2023 general election — will remain structural risks.

Higher mining revenue has sharply increased the DRC’s GDP growth in recent years. At the same time, this has incentivized the government to enact ever-changing mining policies in a bid to increase revenue from mining operations. For instance, in 2018, the government introduced an up to 10% mining royalty despite significant investor pushback. **As revenue increases, so will the incentives for the government to become more resource nationalistic and for more artisanal, small-scale, or illegal mining operations to proliferate.**

33. PIIE, Building downstream capacity for critical minerals in Africa: Challenges and opportunities, 2022.

- **Russia**

As with China, there is a risk that Russia employs economic warfare strategies and restricts the export of certain materials to other countries. Critical materials exports to Europe remain significant despite the war in Ukraine. Russia is the top supplier of nickel, palladium, aluminum, copper, and silicon, among other materials, to Europe. Nickel exports increased last year despite the conflict.

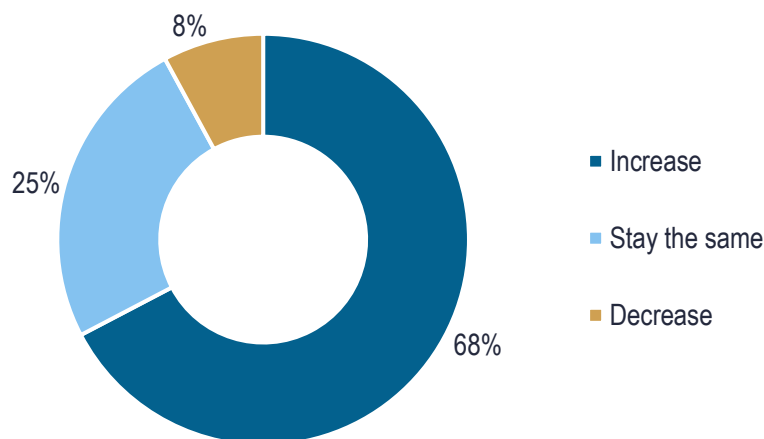
Dependency on Russian critical materials are a significant vulnerability for European economies. Especially as other countries like China, India, and the Middle East provide lifelines to the Russian economy and reduce the self-inflicted pain of cutting off critical material exports (such as copper, nickel, or zinc) to Europe. If these and other countries provide enough capacity to find sources of revenue, cutting exports to Europe could become a bigger risk.

- **Southeast Asia**

Indonesia has triggered a resource nationalism trend in Southeast Asia that seems to be spreading after the country banned exports of several metals, most notably nickel, bauxite, and tin. Indonesia is attempting to move up the value chain and develop its domestic metal processing industry. This has impacted several supply chains, particularly those reliant on nickel, as Indonesia is the top producer. Nickel is typically used in the production of batteries, turbine blades, and to prevent corrosion of equipment in harsh environments such as chemical plants, refineries, jet engines, or power generation facilities. The Southeast Asian country has also proposed the creation of a nickel cartel to control the global supply and prices, as OPEC does with oil.

Other countries in the region, such as the Philippines, have started to follow in its footsteps by increasing royalties on nickel exports. If more governments follow suit, this could have disruptive effects across multiple supply chains. For example, should Vietnam — an important source of rare earths for Western and allied countries — impose restrictive policies, this could augment the risks related to China’s rare earths dominance.

Mining Executives’ Perception of Potential Increase in Resource Nationalism in 2023³⁴



34. White & Case.

- **South Africa**

While South Africa’s mining sector was once a key driver of the country’s economy, long-standing challenges with political stability, labor disputes, and utility outages have curtailed the sector.

Investment in mining has fallen from a peak of \$170mn in 2011 to \$28mn in 2020, signaling caution among investors due to political risk.³⁵ As a primary producer of platinum, palladium, and titanium, further disruptions to mining in South Africa could strain the global supply of a wide range of electronics and healthcare tools which rely on these materials. A key concern among mining operators is frequent power outages, water disruptions, fuel distribution challenges, and the breakdown of public infrastructure. All of these have translated into higher operating costs for critical materials producers in South Africa.

5. Buyers’ and Sellers’ Clubs

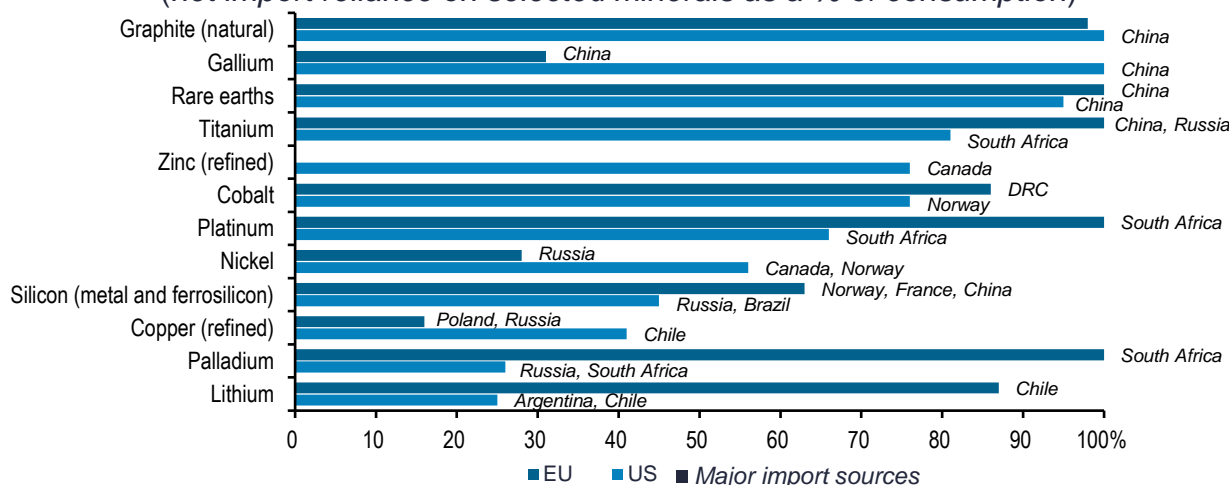
In line with the fragmentation and regionalization of supply chains, there are growing incentives and increasing proposals for the formation of critical materials clubs or cartels. This is happening among critical minerals producers and buyers.

- **Buyers’ clubs**

On the demand side, the US, EU, and G7 nations are in conversations to create a so-called “critical minerals’ buyers-club.”³⁶ The objective is to counterbalance the power that China and other producing countries have over minerals, giving them the ability to influence prices by coordinating demand.

EU and US Critical Materials Import Reliance³⁷

(net import reliance on selected minerals as a % of consumption)



The most recent agreement between the US and Japan to secure the supply chain of critical materials for EVs eliminates bilateral tariffs on EVs and allows Japanese products to benefit from the tax breaks and fiscal benefits offered by the IRA. Both the US and Japan remain extremely reliant on China for EV production, which renders the agreement marginally inconsequential over the short- to-medium term, at least in terms of their EV supply chain independence from China.

The EU is also considering creating a “buyers’ union” with the organization coordinating the purchase of critical materials for the region. During the May 2023 G7 meeting in Japan, the group underscored the growing importance of these materials – particularly to the energy transition – and signaled that strong collaboration is paramount to securing critical material supply chains. Among many measures, the group proposed analyzing ways to diversify supply chains, implement more circular economy measures like recycling, and support the development of new technologies to extract and process critical materials.

35. EIU.

36. Bloomberg.

37. USGS, European Commission, Bruegel calculations from Eurostat data.

Buyers' clubs seem to be more politically viable right now, as there is a broad alignment by developed Western economies, including Japan, to counterbalance China's influence over critical materials. **An unintended consequence of the "success" of these buyers' clubs, however, could be discouraging investment in the strategic sectors these countries actually want to develop.** By lowering prices, investments and innovation could decelerate, causing the West to remain behind China's inroads in the dominance of these sectors.

- **Sellers' clubs**

From the supply side, the creation of producers' cartels is a possibility, but not yet on the immediate horizon. It has been speculated that groups of countries that concentrate the extraction and production of certain materials could coalesce as oil producers did and create an OPEC 2.0 of sorts. For example, Bolivia and Mexico have proposed increasing coordination with Argentina and Chile regarding the extraction of lithium in the region, potentially creating a cartel. Longstanding political disagreements among the regional peers are unlikely to be resolved, complicating coordination efforts.

Indonesia proposed a similar idea for nickel. The Philippines, the second-largest nickel producer, is trying to emulate some of the policies implemented by Indonesia and could be enticed to join. However, Australia and Canada, other large producers of nickel, are highly unlikely to be part of such a group.

As previously outlined, the creation of OPEC-like blocs is unlikely to be either as successful or disruptive as it has been in the case of oil. The products reliant on critical materials are much more specialized than those that use oil and require a vast number of other materials to function. Given the lower market and geopolitical leverage this represents, this makes the sellers' cartels' creation more challenging.

IV. Implications for Businesses and the Global Economy

Many of the most important materials are also often the most rare and difficult to extract and refine, making their supply chains acutely vulnerable to disruption. However, the importance of these materials cannot be understated, and the geopolitical and geoeconomic considerations are numerous:

- 1. Economic Growth:** Critical materials play a significant role in driving economic growth, particularly in emerging industries related to advanced electronics and green technologies. As these industries are projected to rapidly grow over the coming years, the supply of critical materials will need to grow in tandem.
- 2. National Security:** Many of the most advanced defense technologies — such as missile guidance systems, communication systems, and most electronics — rely on critical materials, making the stable supply of these materials crucial for maintaining national security.
- 3. Energy Transition:** Compared to traditional hydrocarbon energy, wind farms, solar photovoltaic plants, and other sustainable energy sources often require significantly more critical materials to build and produce energy. For instance, an offshore wind plant requires about thirteen times more mineral resources than a gas-fired plant equivalent.³⁸

Critical materials and their supply chains have historically faced several disruptions with implications that range from isolated to widespread.

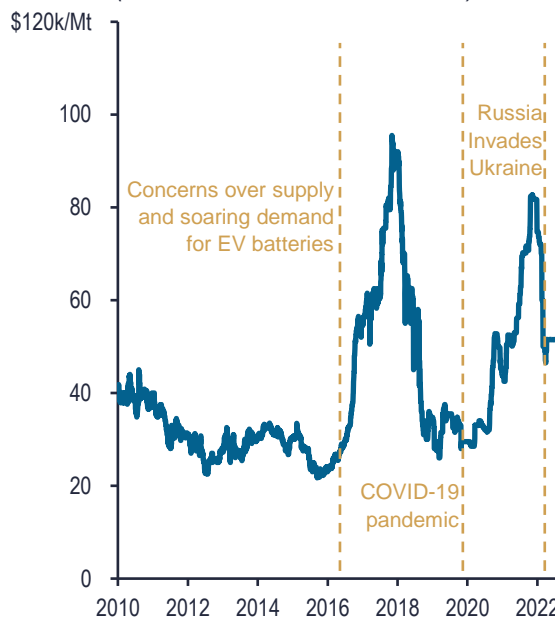
Political Instability in the DRC

In recent years, the DRC — where about two-thirds of the world's cobalt is produced — has experienced political instability that led to supply disruptions. Ongoing conflicts in various parts of the country, particularly in the eastern regions where several armed groups are vying for control over resources, have made the extraction of cobalt in the country volatile for years. There are also considerable human rights concerns related to this, including the use of child soldiers, sexual violence, and forced displacement of civilians. Growing demand for cobalt resources could exacerbate these issues and create additional reputational and regulatory pressures for corporates engaged in DRC supply chains.

Domestic instability in the DRC has made it difficult for legitimate mining operations to operate effectively, leading to a decrease in supply. This has also led to a proliferation of small-scale, often illegitimate mining operations where environmental and labor standards are often impossible to enforce.

By 2018, the price of cobalt reached a ten-year high, which, in turn, led to an increase in the prices of EVs and the lithium-ion batteries on which they rely.³⁹

The Price of Cobalt Can be Volatile
(Cobalt Cash Official LME \$/Mt)



38. IEA (2022), Critical minerals threaten a decades-long trend of cost declines for clean energy technologies, IEA, Paris.

39. FactSet as of May 1, 2023.

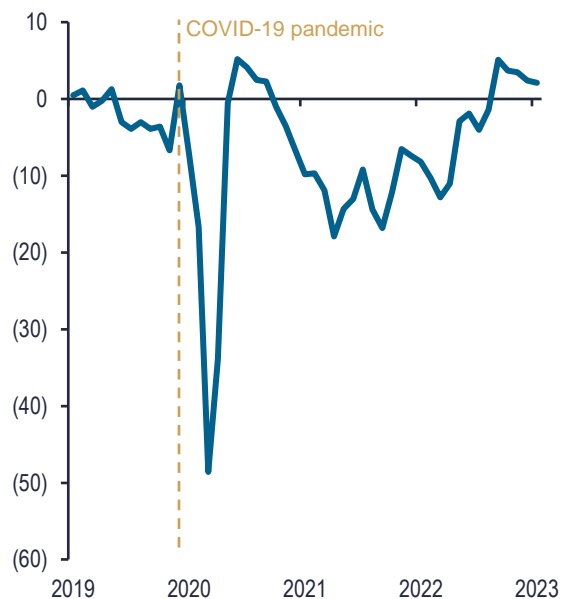
COVID-19 Supply Chain Shocks

The semiconductor industry faced a range of supply chain disruptions stemming from the COVID-19 pandemic, leading to chip shortages across the world and price shocks across numerous industries.⁴⁰ In 2021, for example, the price of graphite, which is used in the production of semiconductors, increased as mines and processing plants shut down. As the world's largest producer of graphite, China's strict pandemic policies contributed to a global shortage of graphite while global demand for the material reached new highs. Lithium, cobalt, graphite, rare earths, copper, and other materials also saw disruptions stemming from the closure of mines and production facilities due to COVID-19.

At the same time, the pandemic led to a surge in demand for personal electronic devices and remote work equipment, creating a shortage of semiconductors for other products such as automobiles. Changes in both critical materials supplies, and consumer demands forced a realignment of supply chains and brought public / policymaker scrutiny on the dependence on other countries for critical goods.

In all, the increased costs from these disruptions were passed down the value chain, resulting in increased prices for consumer electronic devices such as smartphones and other products reliant on semiconductors, such as automobiles.

US Supply Chain Disruptions
(Difference between ISM US Manufacturing PMI Supplier Deliveries and Production)



In addition to historical examples of price volatility, the share that critical materials represent of the cost of some technologies also exemplifies its relevance. According to some estimates, 40% of the cost of a lithium-ion battery comes from the commodities in the cathode, which include mainly lithium, nickel, cobalt, and manganese and over 10% from the anode, usually made of graphite.⁴¹ Meanwhile, rare earths are crucial for producing magnets which are used in computer hard drives, wind turbines, and MRI scanners among other products. According to some estimates, if China decided to stop rare earths exports for one year, this would have a multi-year impact that would lead to a 10% reduction in the production of magnets.⁴²

As geopolitical tensions rise around the world, business leaders and policymakers must be aware of the risks to critical material supply chains. However, the changing global energy landscape and subsequent growing importance of critical materials also present several economic opportunities. For instance, electricity produced from renewables continues to become cheaper than that from hydrocarbons. Electricity produced from wind and solar PV, in fact, is now the cheapest form of energy.⁴³

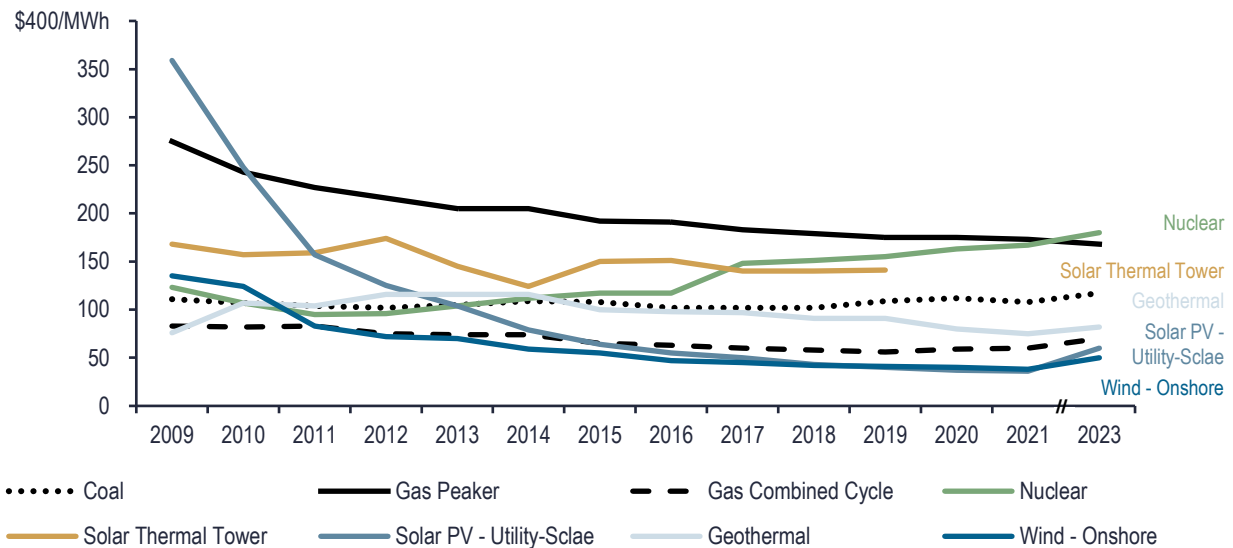
40. FactSet as of May 1, 2023.

41. IEA (2022), The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris.

42. Riddle, Matthew et al. Agent-based modeling of supply disruptions in the global rare earths market, 2021, Resources, Conservation and Recycling.

43. Lazard 2023 Levelized Cost of Energy+.

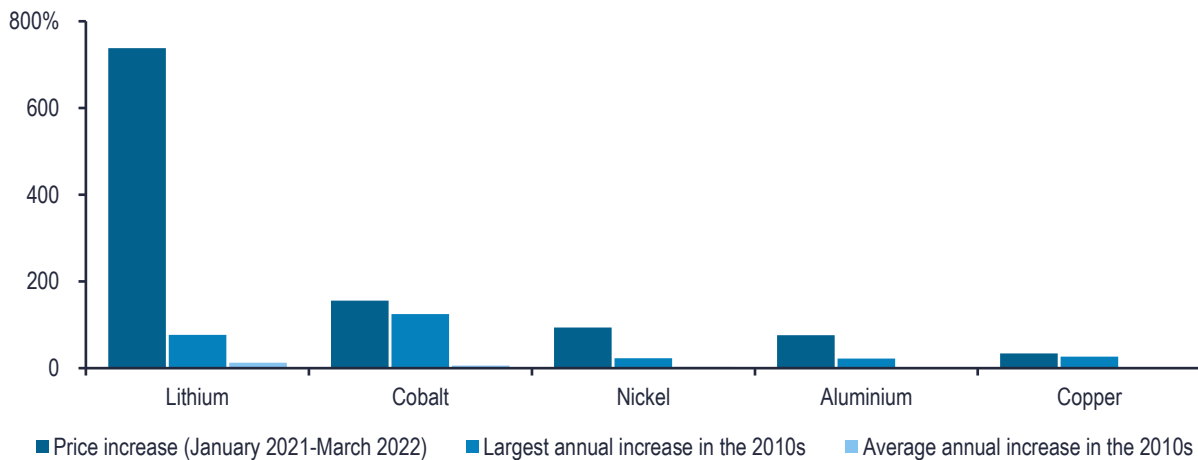
Mean Unsubsidized Levelized Cost of Energy Comparison⁴⁴



Despite increasing price competitiveness, **revenue from the production of select energy transition materials is still projected to outpace coal by 2040 under the IEA’s Sustainable Development scenario.** This highlights existing and emerging opportunities for companies and nations that produce critical materials, but also the risks of countries using critical materials for geopolitical leverage as international tensions increase.⁴⁵

The surge in demand, however, poses a risk as supply could lag behind and gives outsized influence on countries that produce the materials. According to the IEA, from just 2021 to 2022 the demand for clean energy technology materials expanded exponentially compared to the growth in demand of previous decades.

Clean Energy Critical Materials Price Increases (% change)⁴⁵



44. Lazard’s Levelized Cost of Energy Analysis—Version 16.0 reflects the average of the high and low levelized cost of energy comparison for each respective technology in each respective year. These figures reflect the minimum price energy producers must sell electricity to recover lifetime costs of a new power plant.

45. IEA (2022), The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris.

Demand may not be met with new supply over the short term, which will lead to sustained elevated energy prices and incentives for the countries that produce these materials to try to capitalize on higher revenue. This entails tax increases as well as broader protectionist measures. Suppliers will also use this as an opportunity to gain geopolitical influence — like the creation of the cartels previously mentioned.

The main implications of this newfound geoeconomic leverage could range from:

- **Higher taxes** – Producing countries could try to maximize the economic benefits from increased revenue in the mining sector
- **Trade and diplomatic disruptions** – Governments could miscalculate the leverage they have, leading to tensions and retaliations that could disrupt their economies and supply chains
- **Missing decarbonization targets** – Elevated prices of materials make clean energy technologies less economically competitive, incentivizing consumption of fossil fuel powered technologies

V. Where Are We Headed?

Having analyzed the current supply chain landscape, a picture emerges of where the world is headed regarding the control and supply of critical materials globally. The following are a series of trends that will likely impact production, policy, and the overall geopolitical landscape of critical materials.

1. Lasting Dependencies

Main Implications	
Sector-Specific Risks	<ul style="list-style-type: none"> Clean energy technologies will face the most risks as current production and refining concentration in China, as well as policy direction globally, makes them most vulnerable China will remain dominant in the refining of materials for the clean energy and advanced electronics sectors over the next decade, raising risks as strategic competition with the West intensifies
Political Risks	<ul style="list-style-type: none"> Enduring dominance of some countries amplifies the domestic risks within these countries The DRC, Indonesia, China, Russia, and Philippines face significant domestic risks that could lead to supply disruptions. Other countries, traditionally less politically risky for the mining sector, such as Chile, Peru and South Africa, have their own challenges and present a risk given their important role in the production of copper, palladium, and lithium
Acceleration of Global Fragmentation	<ul style="list-style-type: none"> The strategic use of critical materials for geopolitical competition, especially those used in the clean energy and advanced electronics sectors which have become the center of great power competition between China and the West, will further fuel the formation of economic and diplomatic blocs

The dependencies that exist today are unlikely to change significantly in the future, at least not over the next decade. This trend can be mainly explained by the following factors:

i. Limited Upstream Investments and Growing Production Challenges

Over the past few years, there has not been a significant increase in investments of most critical materials, or capacity expansion is taking place in countries that already control existing capacity.

Nickel is a notable example. Indonesia has increased production ten times in the last seven years and almost all increases in global production in 2021–22 took place in the country, consolidating its lead as a top producer.

Copper faces different issues, as political risks in producing regions (like Peru and Chile), diminishing quality of reserves, and exploration and production under-investments have raised significant risks of shortages amid growing demand

ii. Lead Times for New Investments Take Nearly a Decade to Materialize

The lead times for new mining or processing projects take between five-to-fifteen years (depending on the type of project) to deliver new production.

The surge in demand for these materials, especially those used in clean energy technologies, is a recent phenomenon; as such, investments to meet this demand are similarly recent and will only deliver results in approximately a decade from now.

The recent discovery of rare earths in Sweden is a good example. It is estimated that there are one million tons of reserves that would cover Europe’s demand for the next decade; however, given the lead times for a mine to be fully operational, it is expected that there will be no commercial output for at least ten-to-fifteen years, and this is only if no other political or social issues emerge.

iii. Recently Implemented Policies Will Maintain the Current Supply and Demand Balance, Rather than Changing It

The policies implemented across different nations broadly align with the role these countries already play in the critical materials supply chain

- a. Critical materials importers
- b. Critical materials exporters
 - i. Developed critical materials exporters
 - ii. Developing critical materials exporters
- c. Full supply chain control

These policies are underscoring countries’ existing roles rather than leading to a change: producers will remain producers and importers of the materials will only marginally increase domestic production.

a. Critical Materials Importers

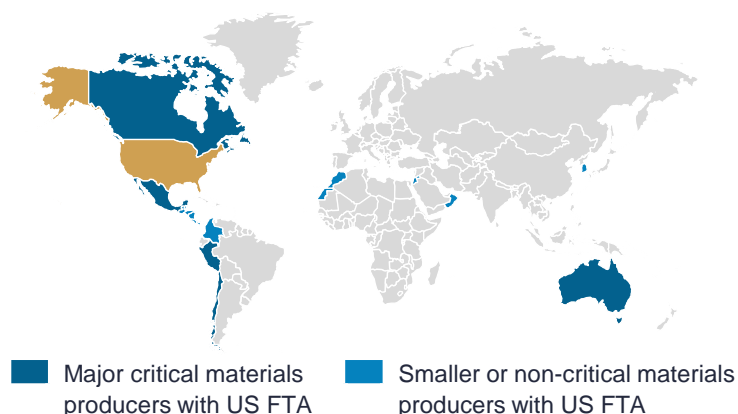
Critical Materials Importers	
Selected Countries & Regions	Policy Direction
<ul style="list-style-type: none"> • US • EU • Japan • South Korea • India 	<p>Industrial policy (near / re-shoring)</p> <ul style="list-style-type: none"> • Subsidies • Fiscal spending • R&D • Tax credits • Trade and investment barriers <p>Friend- and near-shoring</p> <ul style="list-style-type: none"> • Incentivize production of raw and processed materials in allied countries • Attract manufacturing domestically or to the country’s sphere of influence

The policies implemented by the US and EU are the best examples of what importing countries will do in the foreseeable future. **The overarching approach for these regions is a near- and friend-shoring strategy.** First, the US and EU have the ambition to focus on the latter parts of the supply chain, attracting manufacturing of the clean energy technologies and advanced electronics domestically.

For the sourcing of the critical materials, both regions will only make mild attempts to increase production domestically and will face significant challenges to do so. **As such, the main strategy to source the critical materials will be to rely more aggressively on trade partners and allies.** Australia and Canada play the most meaningful role in this strategy as both countries are developed resource-rich economies aligned with the West.

Environmental, political, and social challenges will significantly limit the development of many mining and processing projects in the US and Europe despite some efforts to promote them domestically.

Countries That Have FTAs with the US Could Benefit from IRA Incentives



Major Producers with US FTA	Key Materials
Australia	Copper, cobalt, nickel, zinc, titanium
Canada	Nickel, palladium, platinum, titanium
Chile	Copper, lithium
Mexico	Copper, zinc
Peru	Copper, zinc

b. Critical Materials Exporters

The countries with significant reserves or production are also taking action to increase their leverage. Within this category, countries can be divided between developed and developing economies, a distinction that differentiates the type of policies these are implementing.

Developed Critical Materials Exporters	
Selected Countries & Regions	Policy Direction
<ul style="list-style-type: none"> Australia Canada 	<p>Suppliers of allies</p> <ul style="list-style-type: none"> Becoming the top providers of critical materials to their trade partners and allies <p>Selective protectionism</p> <ul style="list-style-type: none"> Constraint non-allied countries (in particular China) from investing in their mining sectors

Australia and Canada best exemplify this category. **The main policy direction these nations are taking is to align with Western allies on efforts to decouple supply chains from China and expand “friend-shoring” trade initiatives.**

Other recent examples of the changing policy landscape for developed exports include Canada’s ordering three Chinese firms to divest from projects in Canada, citing national security, and the proposal of a bill that would tighten investment screening rules for foreign, state-owned entities. Australia has signaled that it may follow a similar approach. Australia is more constrained given that China is their largest trade partner. As such, Australia will try to diversify its exports, building ties with other trading partners and allies, such as the members of the Quadrilateral Security Dialogue (Quad), which includes the US, Japan, and India. This, however, is unlikely to significantly reduce its reliance on China in a meaningful way.

Developing Critical Materials Exporters		
Selected Countries & Regions		Policy Direction
<ul style="list-style-type: none"> • Argentina • Bolivia • Brazil • Chile • DRC • Indonesia 	<ul style="list-style-type: none"> • Madagascar • Mozambique • Peru • Philippines • Russia • South Africa 	<ul style="list-style-type: none"> • Resource nationalism • Taxes and royalties • Ban on exports • State-owned companies and national champions favoritism • Nationalizations • Open trade • Not all developing countries are following a protectionist path, South Africa being the best example

Developing countries that produce significant critical materials have taken a different policy direction than their developed peers. These nations tend to have two forces pulling in opposite directions. On the one hand, the materials they produce are an important source of revenue and much of their exports depend on them, incentivizing the implementation of tariffs and royalties to the sector. On the other hand, many have the aspiration to develop domestic capabilities either to process the materials or use them in manufacturing capacities. To do these, some have raised trade barriers and increasingly fallen into resource nationalism tendencies, such as Chile’s recent announcement to try to nationalize the lithium sector.

Resource nationalism is a growing trend globally, which coupled with political risks inherent to these geographies will continue to strain critical materials production and supply chains.

c. Full Supply Chain Participation

Full supply chain participation	
Selected Countries & Regions	Policy Direction
<ul style="list-style-type: none"> • China 	<p>Industrial policy</p> <ul style="list-style-type: none"> • Subsidies • Fiscal spending • R&D • Trade and investment barriers <p>Protectionism</p> <ul style="list-style-type: none"> • State-owned companies and national champions favoritism

China is probably the only country in the world with a participation in all parts of the supply chain of critical materials—from the extraction to the manufacturing of the goods that use them as inputs.

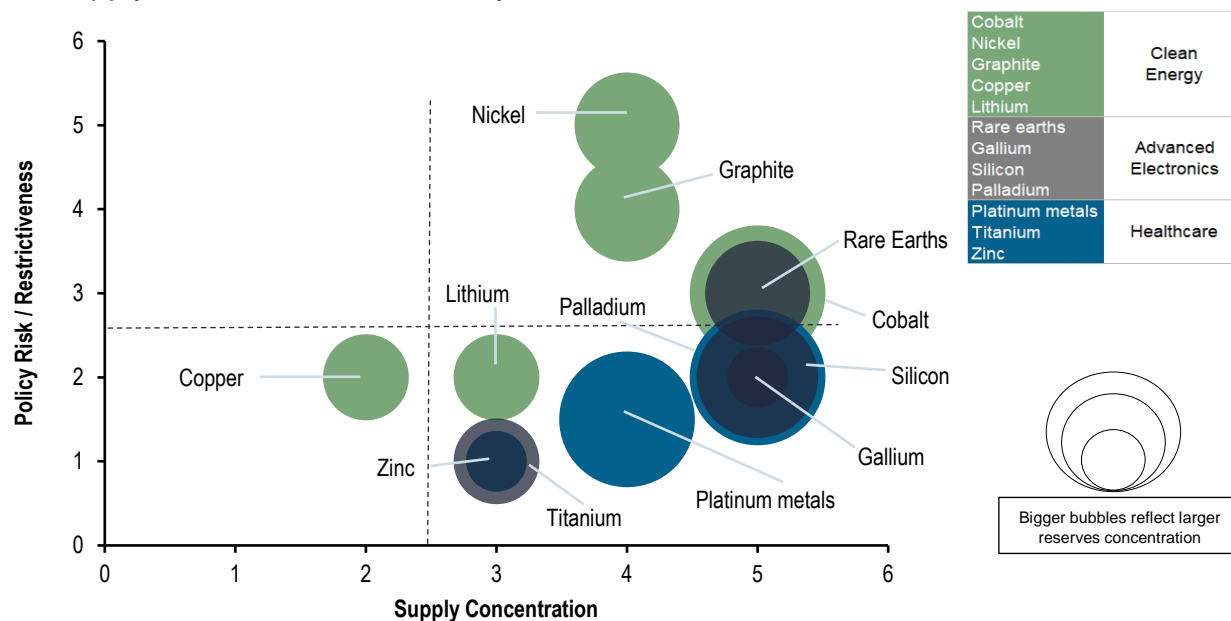
Upstream, China is investing on exploration projects to find reserves of the critical minerals it lacks and currently imports. A key component of this strategy has been to promote the consolidation of power, mostly through state-owned enterprises and firms supported by the government. In addition, the government — in collaboration with local and provincial authorities — is also issuing tax incentives and subsidies to the industry.

Like the US and Europe, China will likely try to lure diplomatic channels to build its own “friend-shoring” network. The growing Chinese influence in the Middle East, exemplified by the brokered negotiation between Iran and Saudi Arabia, is an example of the approach China is likely to take. Other resource-rich countries, such as Russia and potentially Brazil, will find it advantageous to side with China in these regards, allowing it to source the materials needed.

2. Policy and Production Risk Distribution

Given the policies and the production dynamics at play, the following graph shows which selected materials will face the greatest risks. The axes indicate how concentrated production is and how risky or protectionist the critical materials-related policies are becoming. The size of the bubbles indicate how concentrated reserves are in a limited number of countries. Finally, the color denotes the materials primary sector of use.

Supply Concentration and Policy Risk / Restrictiveness of Select Critical Materials



The materials used for clean energy technologies face the most supply and policy risks. Even though mining of some of these minerals is diversified, China controls most of the refining. This will be a challenging dependency to break despite the current policy efforts in the US, the EU, Japan, and South Korea.

High Dependency / High Policy Risk

Material	Top Producer	Sector
Nickel	Indonesia	Clean energy
Graphite	China	Clean energy
Cobalt	DRC	Clean energy
Rare earths	China	Advanced electronics and clean energy

High Dependency / Low Policy Risk

Material	Top Producer	Sector
Silicon	China	Advanced electronics
Gallium	China	Advanced electronics
Platinum metals	South Africa	Healthcare equipment
Lithium	Australia and Chile	Clean energy
Palladium	Russia and South Africa	Advanced electronics
Titanium	China, Mozambique, South Africa, and Australia	Healthcare equipment
Zinc	China, Peru, and Australia	Healthcare equipment

3. Trend Disruptors

It is important to mention that there are other ways that the existing interdependencies can break. Historically, a significant way in which supply chains change is through technological innovation. Most of the interdependencies described above are based around technologies that were not widely available until recent years (e.g., EVs, utility-scale storage, advanced semiconductors).

It is fair to assume that leaps in innovation will continue, sometimes at unpredictable paces. This is particularly true if political dynamics jeopardize entire sectors or if price dynamics affect the economic viability of legacy or new energy sources or technologies. A non-exhaustive list is provided below for examples of technologies that could alter the landscape of critical material supply chains:

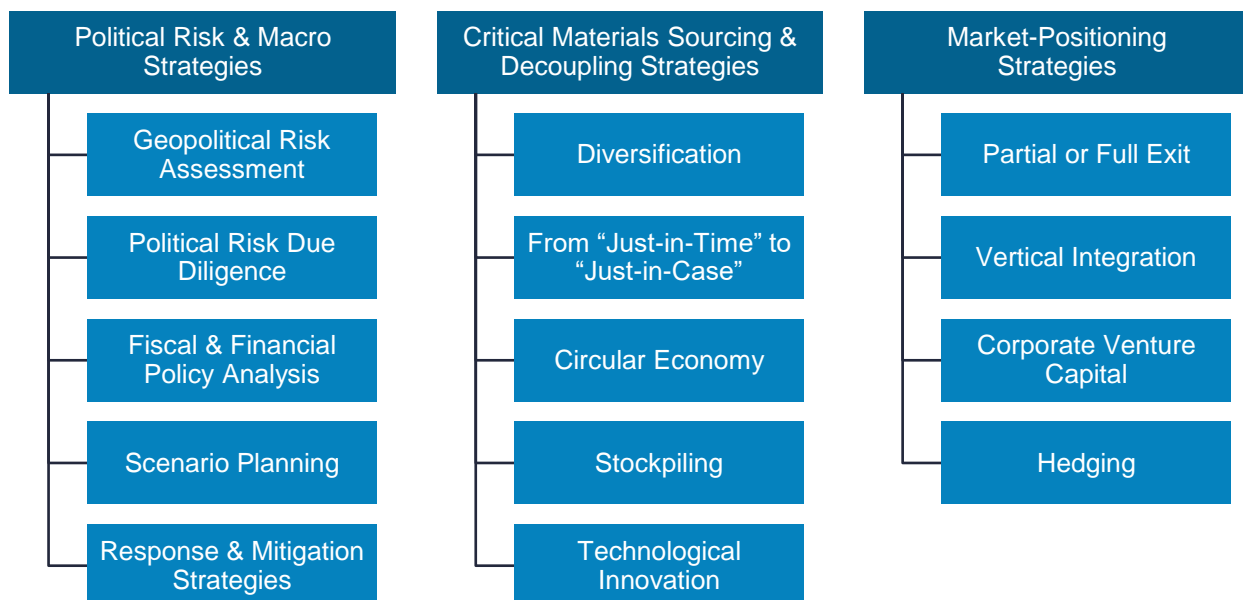
Hydrogen	<ul style="list-style-type: none"> • If made economically viable, hydrogen could change the global manufacturing and logistics landscape for industries such as steel, cement, chemicals, refining, and shipping
New Generation Technologies	<ul style="list-style-type: none"> • New geothermal or nuclear fusion • The potential power generation of these sources would dramatically shift the cost for sustainable energy resources with widespread industry and economic implications
New Storage Technologies	<ul style="list-style-type: none"> • Geo-mechanical pumped storage, zinc-ion batteries, thermal solutions, and compressed air energy storage • Direct competitors to existing materials used in current technologies such as lithium or rare earths
New Extraction Technologies	<ul style="list-style-type: none"> • Lithium brine, new recovery mechanisms, new ways to identify resources • The shale-oil revolution which allowed the US to become energy self-sufficient is an example of these types of technological innovation

VI. Navigating the Storm: Corporate Response and Strategies

To minimize the geopolitical risks inherent in critical materials — and identify potential opportunities — firms will have to consider and implement a range of strategies. These will depend on a firm’s role in the critical materials supply chains and their reliance on the countries in the crosshairs of intensifying geopolitical tension.

Companies involved in the extraction of the raw materials usually face higher competition and lower margins, with longer-term contracts, and larger-scale projects. All of this makes it extremely difficult for companies to make significant and swift adjustments to their businesses and force them to always look for the lowest cost of inputs, often regardless of the supply chain risks these might entail. As such, for these companies the radicalization of policies in the countries in which these operate (such as tariffs, sanctions, regulatory deterioration, etc.) come at the highest costs. This makes the analysis and due diligence of investing on a project extremely important.

Potential corporate responses and strategies broadly fall into three categories:



1. Political Risk and Macro Strategies⁴⁶

Analyzing the political, macroeconomic, and regulatory landscape is the first necessary step to determine risk exposure, regardless of where the company participates in the critical materials supply chain. Political risk assessments and strategies include:

Geopolitical Risk Assessment	
Description	Example
<p>Identify key underlying geopolitical, geoeconomic, and other long-term trends</p> <p>Understanding the exposure to the materials and identifying the most relevant risks</p>	<ul style="list-style-type: none"> • US-China tensions and decoupling dynamics will continue to impact the critical materials markets • This could have price, supply chain, and even reputational implications for companies that have exposure to these materials regardless of where they stand in the supply chain

Political Risk Due Diligence	
Description	Example
<p>In-depth analysis of the country and industry from which firms are exposed in their own critical material supply chain, including:</p> <ul style="list-style-type: none"> • Analysis of government’s policies and ideology • Institutional framework analysis • Policy analysis • Stakeholder analysis • Security and conflict assessments • Social dynamics 	<ul style="list-style-type: none"> • Political unrest in Peru has hurt mining production in the country • The protests that erupted after the impeachment of President Castillo in December 2022 have affected mining regions and left others unaffected, something crucial to identify for new investments • Performing a political risk due diligence of such a situation can help companies identify dynamics like: <ul style="list-style-type: none"> – How long the crisis will last – Which sectors will be mostly impacted – What regulatory changes are likely going to happen – Will there be lasting political and business uncertainty – Main stakeholders’ objectives and strategies that could impact a sector and firm

Fiscal and Financial Policy Analysis	
Description	Example
<p>Understand and take advantage of the fiscal and financial benefits that countries are increasingly offering to attract investing domestically</p>	<ul style="list-style-type: none"> • Countries are increasingly implementing industrial policies to attract investments to strategic sectors, such as clean energy technologies or semiconductors • The US IRA and the EU’s subsidies are the most recent and most aggressive examples • These represent significant opportunities and crucial elements for companies to decide where to expand or relocate production facilities

46. Company information extracted from: FactSet, Bloomberg, Factiva, Mergermarket, Capital IQ, public information, and company filings.

Scenario Planning	
Description	Example
Develop a scenario analysis, identifying the potential risks and opportunities that may emerge given the unfolding geopolitical and economic dynamics	<ul style="list-style-type: none"> • Scenario analysis on China’s rare earths strategic trade restrictions • Consider the most likely paths and duration of the different scenarios • Define the signpost and indicators

Crisis Response & Mitigation Strategies	
Description	Example
Developing proactive and reactive strategies to address exposure to potential geopolitical risks based on likely scenarios, business objectives, and operational footprint	<ul style="list-style-type: none"> • The Russia-Ukraine war was an unexpected event that disrupted critical materials prices and supply chains • Continuing to source materials from Russia requires an analysis of existing and likely sanctions and overall supply chain analysis • Finding alternative sources: recycling, new suppliers, invest in developing new production of materials

2. Critical Materials Sourcing Strategies⁴⁷

Given growing tensions between the US and China and increasingly complex dynamics in other critical material-producing countries, firms should aim to have robust and reliable materials sourcing strategies. This will become increasingly relevant as geopolitical tensions grow and new global blocs emerge, making it harder to source goods and commodities between blocs.

Diversification	
Description	Example
Seek alternative partners and geographies to source critical materials to offset potential risks (e.g., growing West-China tensions or ever-present resource nationalism policies)	<ul style="list-style-type: none"> • Tesla signed an agreement with the Syrah Resources Mozambique mine to become a main source of graphite for Tesla batteries • Japanese firms reduced their reliance in Chinese rare earths through an agreement between Japanese rare earth trader Sojitz and Australian mining company Lynas

From “Just-in-Time” to “Just-in-Case”	
Description	Example
Develop parallel supply chains to build resiliency. This is not a cost-efficient approach but one that acknowledges the growing risks to supply chains	<ul style="list-style-type: none"> • Supply chain disruptions during the Covid-19 pandemic made this strategy more important • The growing competition over critical materials may similarly necessitate duplicating supply chains for resiliency purposes

47. Company information extracted from: FactSet, Bloomberg, Factiva, Mergermarket, Capital IQ, public information, and company filings.

Circular Economy	
Description	Example
<p>Recycling and circular economy strategies that can solve short-term risks of supply disruptions</p> <p>Recycling also provides environmental benefits as materials gain a longer lifespan</p>	<ul style="list-style-type: none"> • There is a growing number of firms specializing in recycling critical materials which should help minimize the reliance on unreliable supply chains • This is a growing industry for healthcare equipment, which could reduce the use of platinum and palladium • The EU is promoting recycling in the region as a way of reducing its sourcing reliance and increasing stockpiling

Stockpiling	
Description	Example
<p>Purchase in advance and store critical materials that could face shortages due to limited supply or trade disputes (e.g., critical material export controls)</p>	<ul style="list-style-type: none"> • The EU is promoting stockpiling policies to minimize risks given the significant reliance countries in the region have on China • Corporates can follow similar strategies, stockpiling the materials closer to the manufacturing facilities or in more politically stable and reliable countries

Technological Innovation	
Description	Example
<p>Research and development of new technologies, materials, or processes to reduce reliance on a material that has become expensive or risky</p>	<ul style="list-style-type: none"> • Semiconductor manufacturer Wolfspeed plans to open a new research and development facility in the US focused on moving away supply chains from China • The firm will take advantage of the funding provided by the government's CHIPS Act • In addition to the US, Canada, Australia and the EU have included funding for research and development of critical materials in their policies to attract and develop these sectors domestically

3. Market Positioning Strategies⁴⁸

Firms will have to assess which strategy is best depending on their exposure or dependence on a certain geography. Leaving certain geographies might be beneficial as countries increasingly pursue industrial policies and offer advantages to relocate (such as the US' IRA). Sanctions and growing trade barriers could also force firms to leave places and relocate operations.

Partial or Full Exit	
Description	Example
<p>Sell a partial stake of business to potential investors, usually established domestic players, financial sponsors, or local management team</p> <p>Retain partial interest to capitalize on potential value upside from future capital market activities (e.g., HK/A-share listing)</p> <p>Full exit / carve-out of business that is underperforming, does not align with strategic direction determined by HQ and / or faces significant risks of disruption</p>	<ul style="list-style-type: none"> • Storebrand, a Norwegian private asset manager, divested from Metallurgical Corporation of China (MCC), which operates a nickel-cobalt mine in Papua New Guinea • The decision was made due to environmental concerns, as financial institutions are establishing higher ESG standards that could affect Storebrand

Vertical Integration	
Description	Example
<p>Identifying competition that covers supply chain exposures and vulnerabilities</p> <p>Vertical integration could have unintended consequences. Most critical materials have very shallow markets, and consolidating companies can lead to even thinner markets and lead to price volatility and supply issues</p>	<ul style="list-style-type: none"> • MP Materials, operators of Mountain Pass, the largest rare earth mine in the US, has a strategy to vertically integrate the full rare earths supply chains • Currently the firm extracts the minerals but is investing in refining capabilities and magnet and other goods production • In 2021, MP Materials signed an agreement with General Motors to develop its mine-to-magnet strategy

Corporate Venture Capital Strategies	
Description	Example
<p>Acquiring or investing in small firms and startups to incorporate innovative solutions to supply chain or material production processes</p>	<ul style="list-style-type: none"> • In 2021, American Resources Corp. acquired exclusive rights to innovative rare earth separation and purification technologies from the startup Hasler Ventures

Hedging	
Description	Example
<p>Use financial tools to hedge for price risks and volatility strategy, especially relevant for critical materials as these are not deep and transparent markets and where price volatility is a common issue</p>	<ul style="list-style-type: none"> • In 2022 the London Stock Exchange suspended nickel trading after prices suffered extreme volatility • Prices more than doubled in a few hours • This underscores the necessity of finding ways to protect from volatility and uncertainty

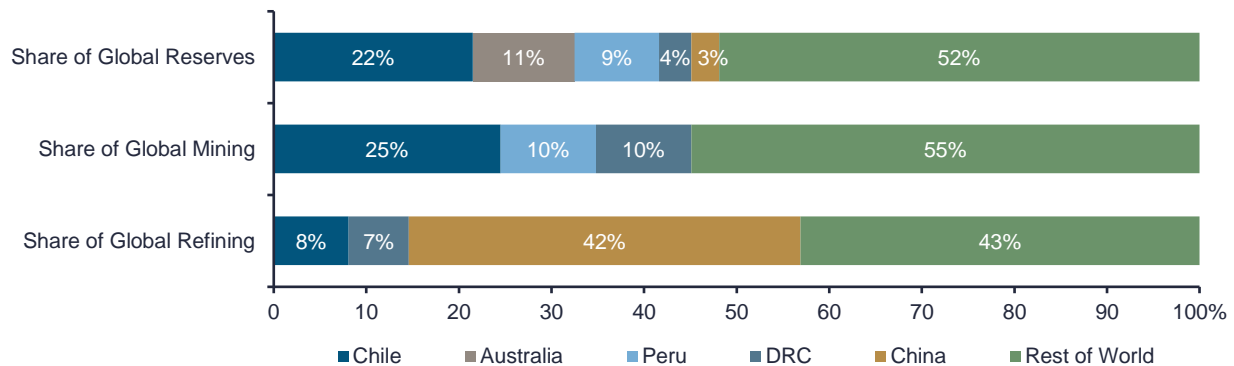
48. Company information extracted from: FactSet, Bloomberg, Factiva, Mergermarket, Capital IQ, public information, and company filings.

Appendix

1. Clean Energy Critical Materials

Copper

Five Most Significant Countries in the Copper Supply Chain⁴⁹



Given its widespread and intensive use in clean energy technologies, copper is arguably the most important mineral in the sector. Copper is used for the manufacturing of EVs, wind, solar, nuclear, and oil and gas technologies as well as in the transmission and distribution lines that constitute the power grids of every country.

Compared to other clean energy minerals, copper reserves and production are somewhat diversified. Chile has most global reserves with 22% and accounts for 25% of the total production. Australia follows with 11% of reserves. China is a smaller player in the mining of the metal but concentrates over 40% of refining, making it a crucial player in the global supply chain.

Copper demand is expected to more than double in the next twenty years, and at current investment rates production will not catch up with the demand.⁵⁰ Moreover, the quality of the production is deteriorating as higher quality ores are becoming more challenging to extract and scarcer. This increases the demand for exploration and production further. According to some estimates, there could be a 5.5% supply gap from the expected demand by 2031.⁵¹

Beyond copper mining, smelters are also reaching capacity with limited new additional supply. China has a concentration of most of the world's processing facilities, which indicates that as refined production falls short of the growing demand, China will have a more advantageous position. In addition, compared to other minerals, copper has properties that are chemically more difficult to substitute, making it more relevant and therefore dependencies stronger.⁵²

All of this indicates that copper supply will remain tight, and policies and investments in countries with the most reserves and production will be crucial for the copper markets to remain balanced and well supplied.

49. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

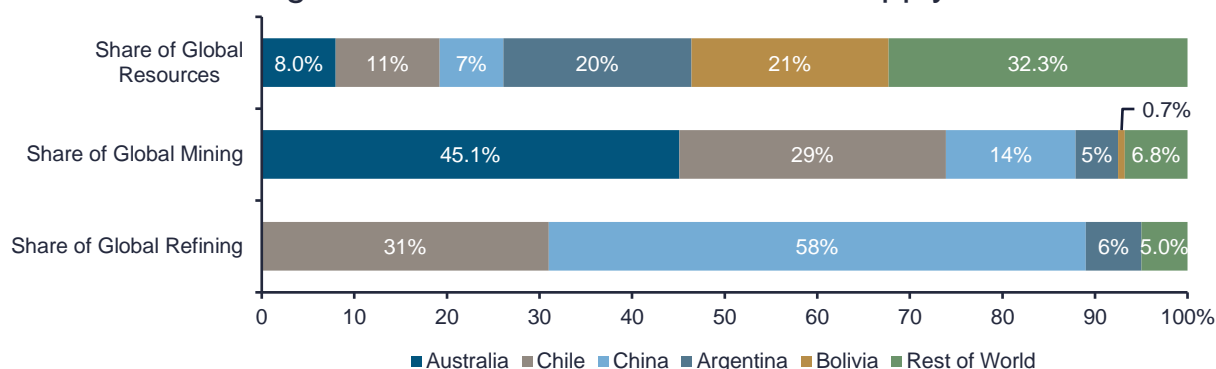
50. IEA (2022), The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris.

51. McKinsey.

52. Proceedings of the National Academy of Sciences.

Lithium

Five Most Significant Countries in the Lithium Supply Chain^{53,54}



Lithium is probably the most widely analyzed of the critical materials. Its main use is for the rechargeable batteries EVs require. They have become a crucial part of the energy industrial policies governments in the US, China, and others are implementing in clean energy.

As of now, the existing economically exploitable reserves are highly concentrated in four countries: Chile, Australia, Argentina, and China. However, lithium is abundant globally, and many regions of the world are known to have the mineral but have not done enough exploration and testing to understand the quantity and quality of their reserves. The best example is Bolivia, as it is the country with the most lithium resources with 21 of the 89 million tons of the world's known resources. Argentina follows close behind with 20 million tons, and the US is third with 12 million tons. India recently announced that they might have found over 5 million tons, but the discovery is still very preliminary and will take several years before production ramps up.

The US serves as another good example of some of the challenges the exploration and production of these materials represents. It is at the same time paradoxical and illustrative that the US has significant lithium resources and has made a strategic priority to attract the production of EVs and rechargeable batteries, which should lead to more exploration and production domestically; however, for political and policy decisions (that will be addressed in more detail in the next section), the strategy has been to focus on the manufacturing of the equipment that require the lithium, rather than producing it itself. This decision makes the US reliant on supply from other nations and as such potentially vulnerable to global trade and geopolitical disruptions.

Despite not having the largest economically viable reserves, Australia is the top producer in the world with 45% of global production, followed by Chile with 29%. On the other hand, China imports 55% of the world's lithium production, as it is the top battery producer, a position the US will challenge in the coming years.⁵⁵

According to some estimates, the demand and supply of lithium will remain mostly balanced but extremely tight over the next decade.^{56,57,58,59} Any growth in demand or problems of supply, due to political, economic, regulatory, or social shocks, could lead to price volatility and supply chain

53. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

54. Note: There is variation in lithium reserve data reporting. This report uses total resource data as a substitute for reserves.

55. La República.

56. Reuters.

57. McKinsey.

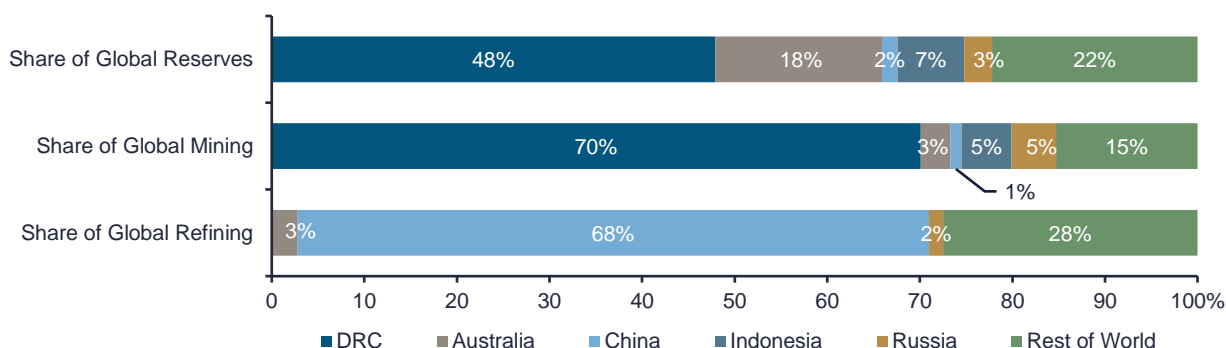
58. JP Morgan.

59. Fastmarkets NewGen.

issues. These conditions seem to indicate that over at least the next 5 years, the global lithium landscape will remain concentrated under similar hands, but this will start to change during the next decade as new players start to ramp up production.

Cobalt

Five Most Significant Countries in the Cobalt Supply Chain⁶⁰



Cobalt has been essential to the introduction of the lithium-ion battery since lithium cobalt oxide was first discovered in the 1970s as the first crystal structure that can allow for lithium ions to flow in and out of it while maintaining its structure. Since then, the development and commercialization of lithium-ion batteries and almost every cathode chemistry discovered has had some cobalt content.

Close to 50% of the global refined cobalt is used for batteries, though cobalt-based superalloys are also a notable competing end use for cobalt, especially in the United States, where they accounted for 43% of domestic cobalt consumption in 2020.

In 2022, the global reserves of cobalt are estimated at 8.3 million metric tons, with nearly 50% concentrated in the Democratic Republic of Congo (DRC), 20% in Australia, and 7% in Indonesia. Global cobalt mine production in 2022 was approximately 180,000 tons of cobalt content, of which 70% came from the DRC.⁶¹ However, over 15% of the DRC’s cobalt production is produced by small-scale mines, whose alleged mining and labor conditions garnered international condemnation in 2022. Despite international uproar, “artisanal” mining in the DRC is still critical to global cobalt supply chains, as it acts as a swing producer for global cobalt production, adapting production to changes in cobalt or copper prices much quicker than industrial mines.

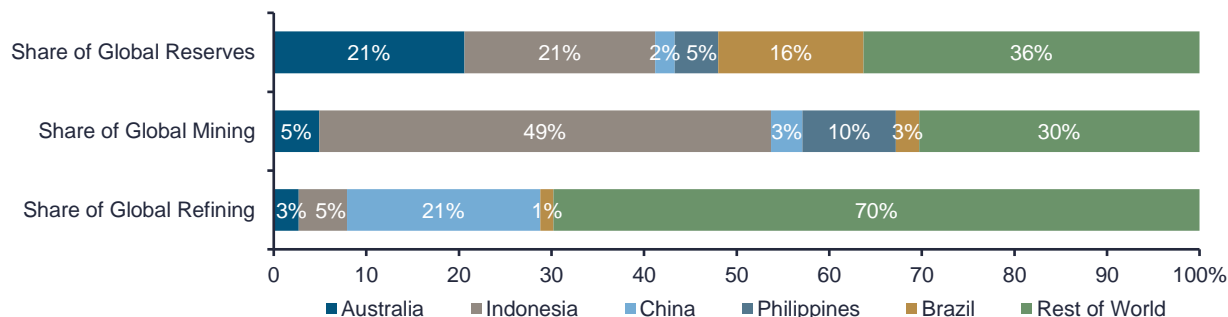
Although the DRC leads in the global mining of cobalt, 68% percent of the refining capacity is located in China. China is the DRC’s primary trading partner for cobalt with 84% of the DRC’s 2019 cobalt exports going to China.

60. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

61. USGS.

Nickel

Five Most Significant Countries in the Nickel Supply Chain⁶²



Nickel is another crucial mineral for the energy sector. The metal is mainly used to produce rechargeable batteries but is also used for wind turbines, green hydrogen, and nuclear and coal power plants. Just like the other critical materials of the energy transition, it is expected that demand will grow over 20 times in the next two decades.

Recoverable reserves are highly concentrated in Indonesia and Australia with each holding close to 22% of the global resources. Brazil is not far behind with 16%. However, Indonesia produces 49% of the world’s output and increased its production over 50% year-over-year in 2022, consolidating further its role as the most dominant player. Philippines is the second largest producer with 10% of global output.

Most of the nickel processing (69%) used to be done by China, but a decision by the Indonesian government to ban exports of the raw material has changed the downstream landscape for the mineral.⁶³ Despite this, Chinese firms have made meaningful investments to build the processing and refining capacity in Indonesia, allowing them to be a top player in the global supply chains.

Given the high concentration of the reserves and production under Indonesia, the world will remain highly dependent on the East Asian country. Moreover, a report by the White House highlighted that the supply chains of Class 1 nickel, the purest version of the mineral used to produce rechargeable batteries, could face shortages in the next six years, making Indonesian production and policies even more relevant.⁶⁴

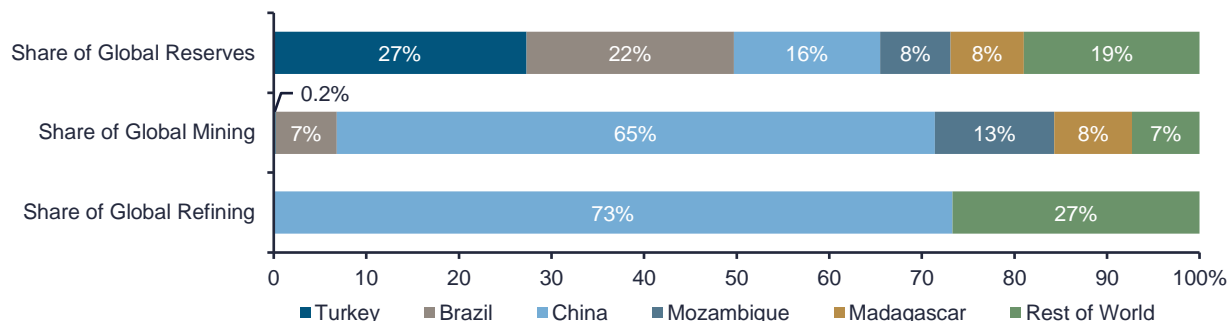
62. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

63. Silverado.

64. The White House.

Graphite

Five Most Significant Countries in the Graphite Supply Chain⁶⁵



Synthetic and natural graphite are consumed for large scale uses in products such as electrodes, lubricants, pencils, and automotive and aerospace components. Notably, the mineral is important in the production of batteries, as it is an effective conductor. About 28% of the weight of common EV batteries is made up of graphite, while nearly all battery anodes rely on the mineral.⁶⁶

China is the most significant player in the supply chain of graphite, controlling nearly 65% of mining output and 73% of global refining operations. Other major players include Mozambique, Madagascar, and Brazil. However, China's dominance in the market has led to efforts by other countries to build-up domestic graphite mining and refining capacity. China's dominance in the supply chain has also led to concerns of graphite electrode dumping practices by China, leading the EU to adopt anti-dumping measures against China for these materials in 2022.⁶⁷

The demand for graphite has increased alongside the energy transition as EV batteries and other battery storage technologies grow in importance. However, graphite is a relatively abundant mineral, and its reserves spread around the world are fairly diverse.

There are also numerous untapped reserves in alternative geographies outside of China and other currently dominant players. For instance, graphite reserves in Turkey and Brazil make up about 50% of proven global reserves, but the two countries currently account for less than 7% of global mining output and have no refined production.

Another key consideration is the environmental impact of graphite mining and refined production. Battery anodes made of natural graphite, for instance, are about 55% less carbon-intensive than synthetic alternatives.⁶⁸ This is due to the production process of synthetic graphite, where petroleum coke and other carbon-rich materials are baked at very high temperatures. However, synthetic options are typically preferred by EV battery producers for their superior charging capabilities and longevity, which adds concerns to the environmental impact of EV batteries.

65. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

66. BloombergNEF 2022, ESG of graphite: how do synthetic graphite and natural graphite compare?

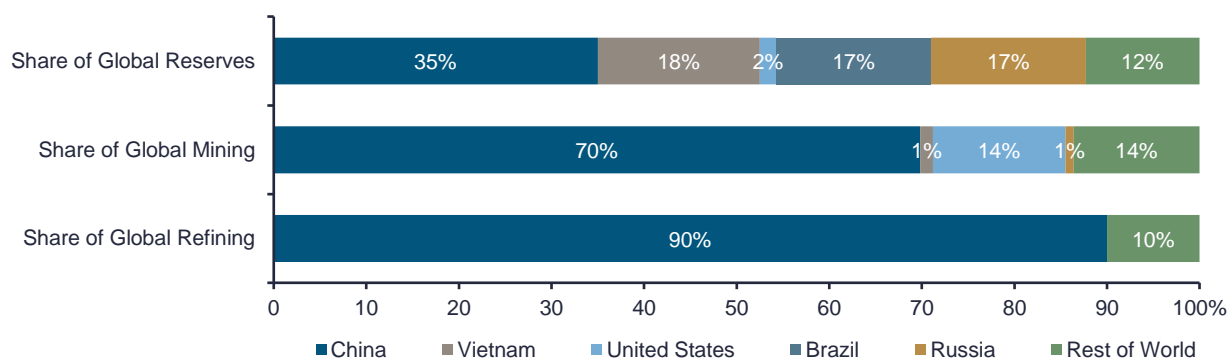
67. European Commission.

68. Benchmark Mineral Intelligence.

2. Advanced Electronics Critical Materials

Rare Earths

Five Most Significant Countries in the Rare Earths Supply Chain⁶⁹



Rare earths elements (REEs) are a set of seventeen metallic elements critical to a broad range of advanced electronics given their magnetic properties, luminescence, and strength. They are also widely used in defense applications, such as in fighter jets and drones, and clean energy technologies, including wind turbines, solar panels, and EV batteries. Many have no known substitutions. Global demand for rare earth oxides is forecasted to triple from \$15 billion in 2022 to \$46 billion in 2035 as a result of electrification and digitization requiring highly specialized rare earth magnets.

REEs are relatively abundant in the earth’s crust despite their name. However, the process of separating and refining them is complex — given that they have highly similar chemical properties — and involves environmentally hazardous chemicals. The US Defense Department has been exploring biomining as an initiative to use microbial and biomolecular engineering techniques to separate and purify rare earth mixtures, but it remains in the early phases of research.

The largest reserves of REEs were in China (35%), followed by Vietnam (17%) and Brazil (16%) with reserves half the size of China’s. The US, Australia, and Greenland also have significant deposits. Meanwhile, China dominates overall production and accounts for up to 70% of global mining. The US accounts for 14%, while Australia reaches 6% of REE production.

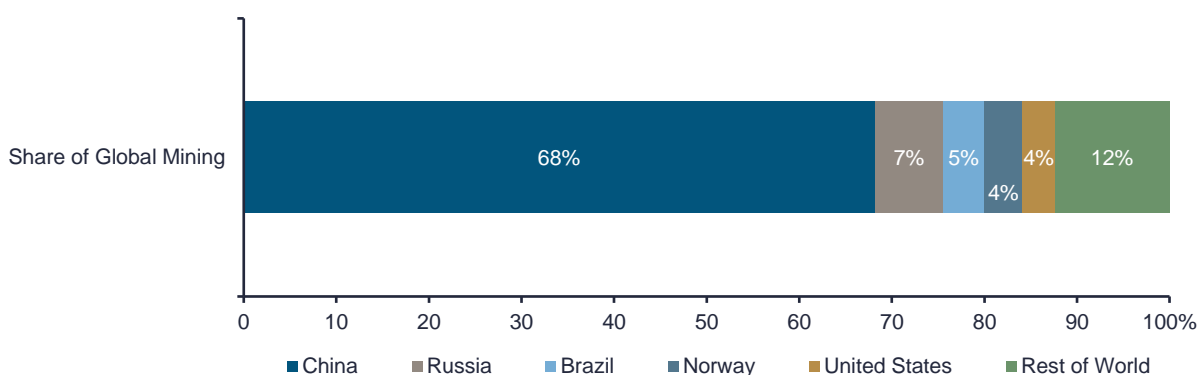
Efforts are underway to diversify the REE supply chain to reduce dependency on China. Large Australian mining company Lynas Rare Earths is spending \$345 million to expand its mine and concentration plant in Australia and increase its annual production by 50% by 2025. Lynas was also selected by the US Defense Department to build a commercial heavy rare earths separation facility in Texas. Recent explorations and investments in Africa suggest the continent may also be a new source of REEs given that historically low exploration efforts may have masked potential resources available. In 2022, a Canadian explorations firm invested \$277 million to ramp up production in its rare earths mine in Malawi, while Australian firm Bannerman Energy acquired a stake in Namibia Critical Metals to leverage its 95% ownership of the heavy rare earth mining in the country.

69. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

The main barriers to reshoring REE mining and production capacity are centered on the environmental hazards associated with the separation and concentration process. Chinese companies that enjoy laxer standards are able to remain more cost competitive compared to their western counterparts. Many rare earth mining companies are heavily indexing on sustainability efforts, including transitioning from fossil fuels to hybrid renewable power generation and investing in the development of more environmentally friendly separation processes.

Silicon

Five Most Significant Countries in the Silicon Supply Chain⁷⁰



Silicon is one of the most abundant elements found in the earth’s crust as quartz and is widely available globally — one of the reasons it is widely used in many products from semiconductor wafers and solar panels to aluminum alloy and steel production. Alternative materials and chemistries provide substitutions to silicon in advanced electronics, but silicon’s wide accessibility makes it an enduring choice for manufacturers.

Demand for silicon is driven primarily by steel production. Silicon for use in semiconductors and solar panels requires a higher purity level in much smaller volumes. Refining and producing of silicon is overwhelmingly concentrated in China (68%), followed by significantly smaller production in Russia (7%), Brazil (4.5%), and Norway (4%).

Silicon refining is energy intensive and costly. Water resources are an essential element of the silicon refining process – similarly, large volumes of water are required further down the semiconductor value chain. In 2019, TSMC consumed 63 million tons of water across all its Taiwanese facilities. Drought events can also be disruptive. A 2021 drought in Taiwan prompted the government to shut off irrigation to around a fifth of Taiwan’s irrigated land to avoid disrupting the operations of large foundries.

Chinese companies are dominant in the subsequent steps of the supply chain — in addition to polysilicon production capacity, Chinese companies make up the majority of silicon ingot and wafer production.⁷¹ In 2019, China had a 97% share of the world’s semiconductor wafer production as well as a 79% share of solar cell production and a 79% share of polysilicon production. Beijing is reportedly considering limiting exports of its advanced polysilicon production technologies to maintain its advantage in the silicon / solar sector.⁷²

70. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

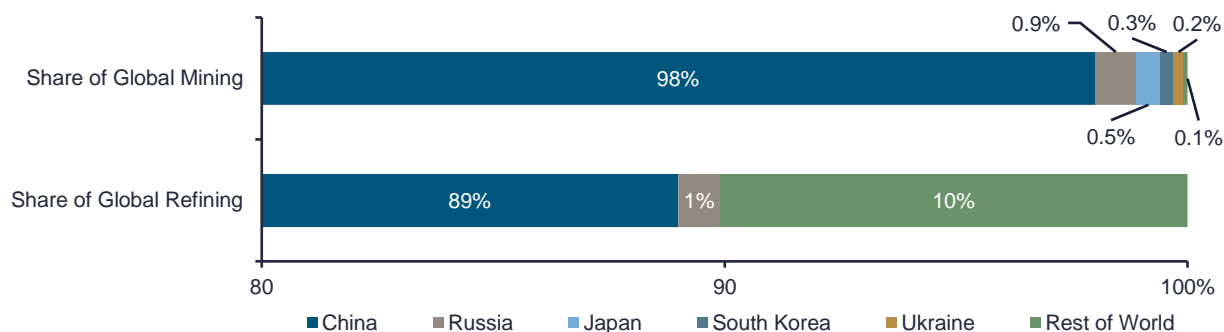
71. IEA (2022), The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris.

72. Note: Major players include Anyang Wanhua Metal Material, Dow Inc, Elkem ASA, Ferroglobe, Henan ALOY New Material, Hoshine Silicon, Liasa, Mississippi Silicon, Shin-Etsu Chemical, Rusal.

Global capacity for manufacturing wafers and cells exceeded demand by at least 100% at the end of 2021. By contrast, production of polysilicon, the key material for semiconductors and solar panels, is currently a bottleneck in an otherwise oversupplied supply chain. This has led to tight global supplies and a quadrupling of polysilicon prices over the last year. While the wide availability of silicon should facilitate onshoring of silicon production, the upfront investment and ongoing intense energy usage required for its processing requires reliable and cost-effective energy infrastructure to silicon mining and production facilities.

Gallium

Five Most Significant Countries in the Gallium Supply Chain⁷³



Gallium, when combined with arsenic to form gallium arsenide, is increasingly used as an alternative to silicon in semiconductor production. Gallium arsenide requires less power and can operate over a wider temperature range — which makes it well suited to aerospace and defense applications. The two main application fields are integrated circuits (e.g., 5G base station chipsets) and optoelectronic devices (e.g., LEDs, photovoltaic cells). Overall, silicon remains more commercially viable cost-wise, and gallium is highly toxic, requiring comprehensive precautions in the manufacturing process.

Gallium occurs in small concentrations in the ores of other metals and is typically produced as a byproduct in the extraction and processing of aluminum and zinc. Gallium reserves — contained in bauxite and other ores — are estimated to exceed 1 million tons globally, of which only 10% is recoverable. Recycled gallium is also a significant source for the market.

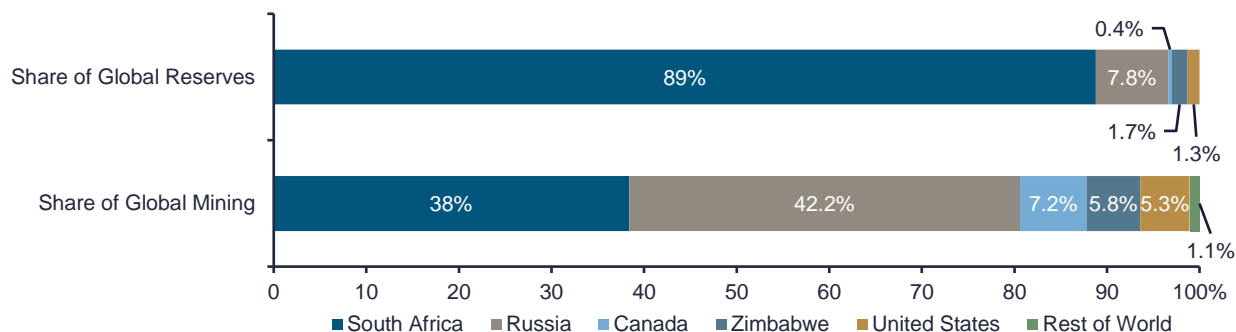
The growth of photovoltaic cell fabrication plants and semiconductors have driven demand for gallium, and the market is forecast to grow from \$1.9 billion in 2022 to \$27 billion by the end of 2032. China overwhelmingly dominates low-purity gallium production, making up 98% of global production. Russia, Japan, and Korea are the next largest producers. A 2012–17 global surplus of gallium shuttered much of global production outside China, where producers were subsidized by Beijing. Currently, the US depends on imports for the entirety of its gallium supply and on China for 53% of those imports.

Increased gallium prices have encouraged new producers to re-enter the market. The price of Chinese gallium increased from \$140 per kilogram in 2020 to \$345 in 2021 due to environmental restrictions and increased extraction costs. German producers announced their intention to restart primary gallium production by the end of 2021. Existing aluminum and zinc producers could follow a similar course to diversify supply from China.

73. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

Palladium

Five Most Significant Countries in the Palladium Supply Chain⁷⁴



Palladium is a critical input for sensor chips and certain types of computing memory and is also used in the metal connections attaching chips to circuit boards and in the junctions between the chips and other metals. Its overall predominant use is for automotive catalytic converters to control exhaust emissions.

Palladium is typically mined as a byproduct of other metals such as nickel and copper given its low concentration in accessible ores. Palladium is usually extracted as an impure concentrate and subsequently refined to higher purities — refinement to commercial grade frequently happens at separate facilities outside the country of where it is originally mined and refined.

The world’s largest platinum group metals reserves are in the Bushveld Complex in South Africa, followed by deposits in Russia, Zimbabwe, the US, and Canada. Primary global producers of palladium are South Africa, Russia, and Zimbabwe, although the White House has been encouraging the semiconductor sector to diversify their palladium supply away from Norilsk Nickel — Russia’s main palladium supplier — since the start of the war in Ukraine. Approximately 35% of US palladium is reportedly sourced from Russia.

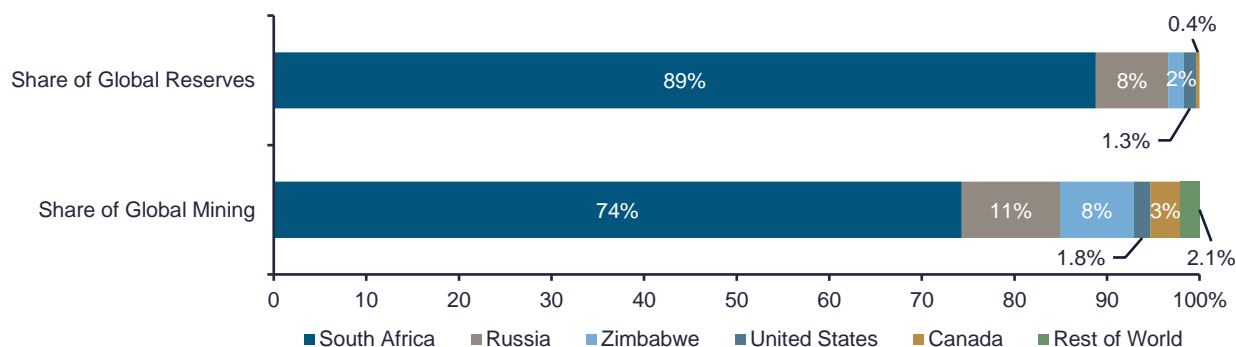
Suppliers seeking out other sources of supply will likely turn to South Africa. While South African ores typically produce less palladium than Russian ore deposits, the more significant issue for suppliers as they look to South Africa for diversification purposes are the dysfunctional energy system and ongoing power outages, the embattled state-owned freight rail utility Transnet, and complex mining policy.

74. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

3. Healthcare Critical Materials

Platinum

Five Most Significant Countries in the Platinum Supply Chain⁷⁵



Platinum metals are conductive, dense but malleable, and highly resistant to corrosion, making them an ideal group of metals in the production of surgical tools and electronic implants. Some of the most common medical items reliant on platinum metals include pacemakers, hearing aids, catheters, defibrillators, neuromodulation devices, and cancer treatment drugs.

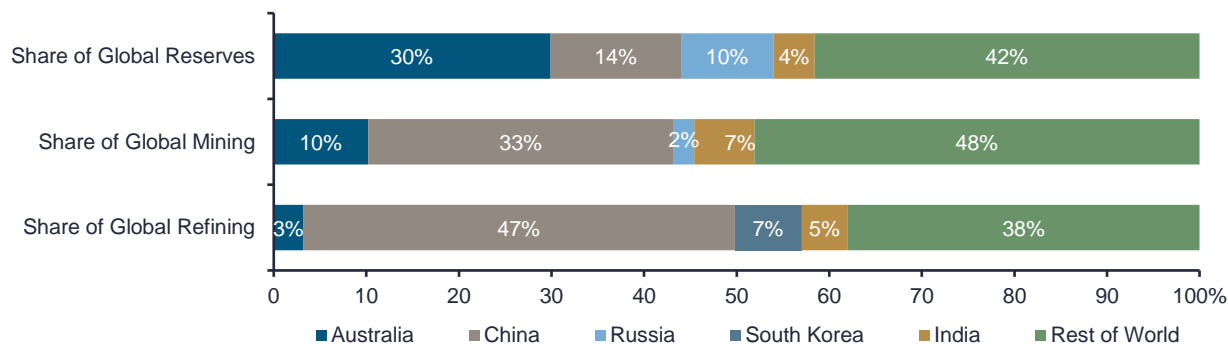
Compared to other healthcare critical materials, platinum reserves and production is the most concentrated. South Africa by far accounts for the highest reserve levels with 89% of known global reserves, while Russia accounts for 8% and Zimbabwe 2%. Production levels are nearly as stark: South Africa accounts for 75%, Russia 11%, and Zimbabwe 8%.

Given the concentration of platinum reserves and production, the top risk for the material is socio-economic and political risks in South Africa. The country has maintained an open and market-friendly policy towards the mining sector. The main risks come from other domestic problems, such as the structural problems the electricity sector in the country is facing. Russia and Zimbabwe also play an important role, thus production and trade problems could lead to supply disruptions. For instance, in 2013 Zimbabwe changed regulations to require platinum producers to start refining products locally, which required the build-up of costly local refineries and added cost pressures to the supply of platinum globally. Furthermore, the war in Ukraine and subsequent sanctions on Russian metal refineries also created supply bottlenecks that led to a sharp rise in prices in H2 2022.

75. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

Zinc

Five Most Significant Countries in the Zinc Supply Chain⁷⁶



Zinc is a foundational health supplement often found in food and multivitamins, and it is also important in the production of components for medical devices due to its role in the galvanizing process to protect iron and steel from rust. Zinc is also crucial for die-casting other metals into highly customizable and precise shapes needed for medical tools, devices, and implants. Given its versatility, zinc is found in a range of medical products from electronic monitoring devices to portable oxygen supplies.

Zinc supply chains are relatively diversified compared to other healthcare materials. The two most significant national actors are Australia for its 31% control of global zinc reserves and China for its 33% control of global production. China is also by far the top refiner of zinc at about 47% of global refining capacity.

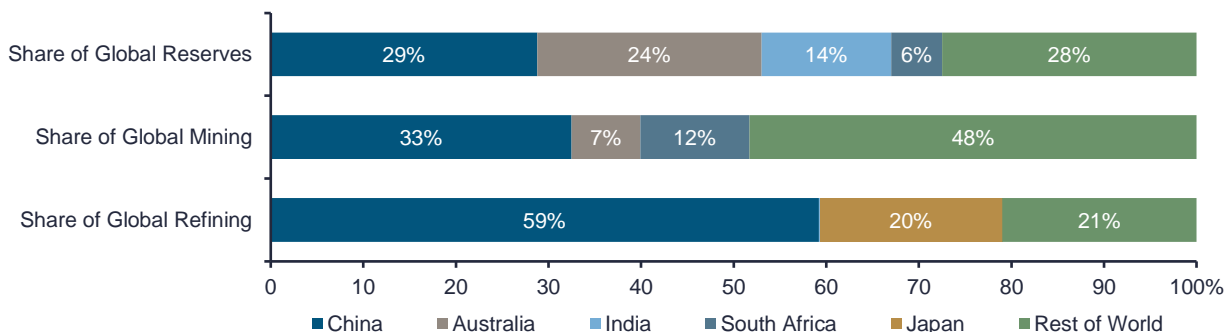
China’s role in industrial manufacturing — which relies on zinc — further incentivizes the country to cement its control of zinc production and refining. In fact, China became a net exporter of refined zinc in 2022 for the first time since 2007. China’s growing lead in zinc exports has, in part, been driven by making up for decreased output from the EU, Canada, and Mexico. In the EU, for instance, high power prices linked to Russia’s invasion of Ukraine led to the closure of three smelters and curtailed refining capacity at other facilities.⁷⁷ Given these and other dynamics, China’s dominance over the zinc supply chain is expected to expand in the years ahead.

76. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

77. Reuters.

Titanium

Five Most Significant Countries in the Titanium Supply Chain⁷⁸



Titanium is a primary component of most surgical tools and implants. More than 70% of surgical implant devices and 95% of orthopedic implants are primarily made from titanium, making it a critical input for the healthcare sector. It is a preferred metal in the healthcare industry because of its strength-to-weight ratio, high fatigue limit, and corrosion resistance. Titanium is most commonly found in items such as defibrillators, pacemakers, batteries, bone growth stimulators, drug pumps, and many other electronic and non-electronic medical devices.

Similar to zinc, China and Australia are the most significant actors in the titanium supply chain. China holds about 29% of global reserves, while Australia holds 24% and India 14%. China also controls about 33% of global titanium production, while Mozambique stands at about 11% and South Africa 12%.

Consensus estimates suggest that demand for titanium is expected to grow by 5–7.5% annually through the 2020s, driven by a range of sectors, including aerospace and defense, automotive, and healthcare. However, there was a supply crunch for the metal throughout 2022 following Russia’s invasion of Ukraine. As many Western companies stopped sourcing refined titanium from Russia, they turned to producers / sellers in China and Japan, who struggled to keep up with the new demand. In Japan, for instance, two of the few high-grade manufacturers of titanium globally reportedly reached near capacity.⁷⁹ Non-Russian producers are expected to slowly ramp up production and refining capacity through new facilities, but this is expected to drive titanium prices higher over the coming years.

78. USGS 2022–2023, S&P Global Commodity Insights, Benchmark Mineral Intelligence, Rystad Energy, and other industry estimates.

79. Financial Times.

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