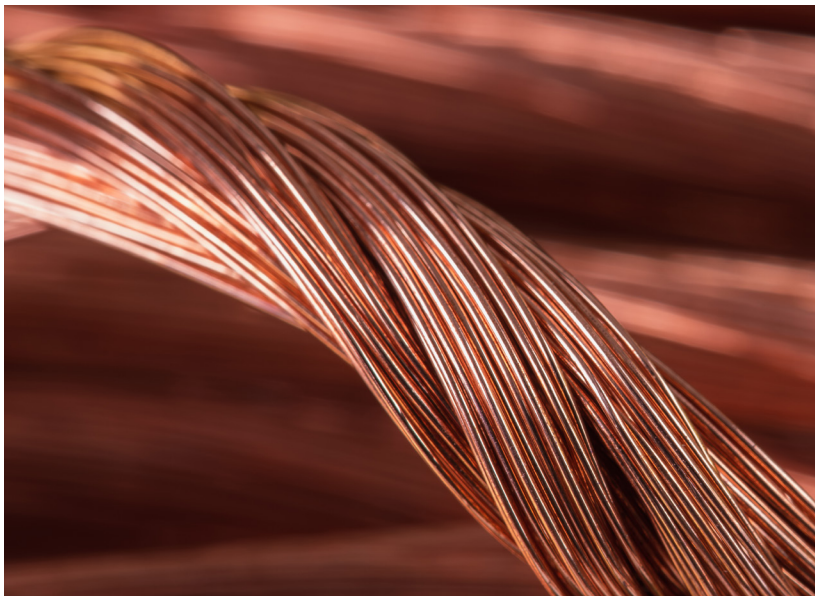
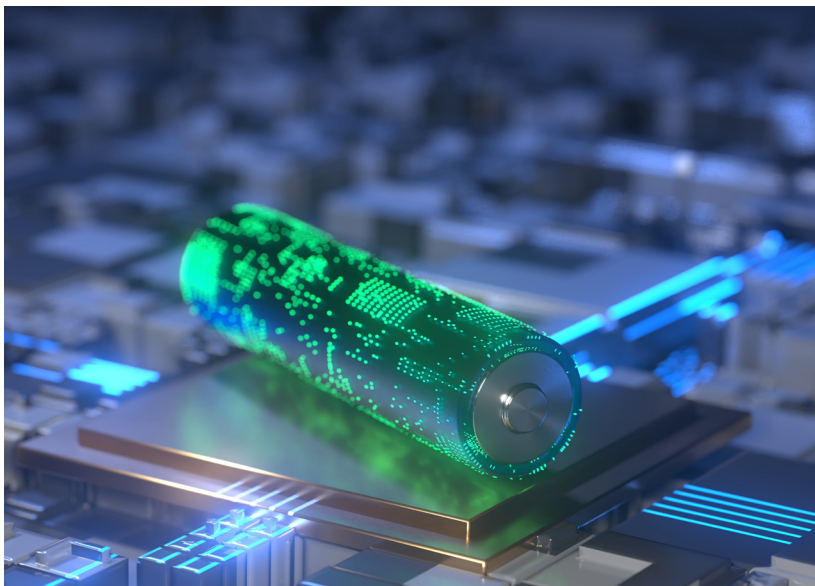
MILKEN INSTITUTE

SEPTEMBER 2025

Innovative Financing for Resilient Critical Mineral Supply Chains

Ashley Campany and Kanika Singh





ABOUT THE MILKEN INSTITUTE

The Milken Institute is a nonprofit, nonpartisan think tank focused on accelerating measurable progress on the path to a meaningful life. With a focus on financial, physical, mental, and environmental health, we bring together the best ideas and innovative resourcing to develop blueprints for tackling some of our most critical global issues through the lens of what's pressing now and what's coming next.

ABOUT FINANCIAL INNOVATIONS LABS

Financial Innovations Labs® bring together researchers, policymakers, and business, financial, and professional practitioners to create market-based solutions to business and public policy challenges. Using real and simulated case studies, participants consider and design alternative capital structures and then apply appropriate financial technologies to them.

ACKNOWLEDGMENTS

Ashley Campany and Kanika Singh prepared this report.

We are grateful to those who participated in the Financial Innovations Lab for contributing to the ideas and recommendations summarized in this report. We want to thank our Milken colleagues Caitlin MacLean, Théo Cohan, Karen Rogers, Michelle Stevenson, and Bridget Wiegman Doering for their work. Finally, we would like to thank Editor Dinah McNichols for her efforts on the report.

TABLE OF CONTENTS

INTRODUCTION

Minerals found in the Earth's crust possess unique properties that render them vital in modern economies, technological progress, and defense needs. They enable smartphones to respond to touch, vibrate, and glow to alert users, and provide auto-light adjustment for photos and videos. They are found in rechargeable batteries for remote-controlled devices, and their flame-retardant properties are used in industrial thermal suits and children's car seats. Their ability to retain magnetic strength at extreme temperatures is essential in guided missiles and aircraft. In the renewable energy space, minerals are used extensively in solutions such as wind turbines, and electric vehicles (EVs), which require between six and nine times the minerals of their fossil-fuel counterparts.[1]

In 2024 alone, the energy transition accounted for 85 percent of the growth in demand for minerals used in batteries such as lithium and nickel.[2] Adding to the demand are quantum computing and artificial intelligence (AI), which require minerals for chip stability and power usage. Demand for these minerals has become insatiable across industries, from manufacturing to defense, and is expected to increase exponentially.

However, the supply of these minerals stands in contrast to the growing global demand because of investment disparities between China and the rest of the world since 2013. A strategic multiyear Chinese state investment framework, with financing and insurance alongside policy support, has dominated the global mineral supply chain from cobalt in the Democratic Republic of Congo to nickel in Indonesia. This framework has enabled China to determine both supply and pricing. Western companies, in the absence of such extensive state-led assistance, have relied far more on the capital markets for fundraising, which has led to volatile investment cycles.

China has also used its control of key mineral supplies to deter competitors. A 2024 Chinese-led oversupply of nickel and lithium, for example, pushed commodity prices below the cost of production for many Western rivals, delaying fundraising and new projects and mothballing some operations. Private capital markets have not been a reliable funding source; private equity (PE) and venture capital (VC) flows ranged from $1.9 billion to $10.5 billion annually in the five-year period ending September 30, 2024.[3]

Other investor groups cite long lead times for mines to generate revenues and negative environmental and social risks as key barriers to investing beyond public equities. This fluid private-sector investor landscape impacts fundraising and, hence, future supplies. Finally, new supply risks are emerging as resource-rich countries assert their rights to greater management and economic control of minerals.

The uncertain landscape—China's near-monopolistic advantage, environmental concerns and regulations, surge in demand, and disruptions to supply—is prompting countries to undergo a significant policy review as they evaluate their import dependencies and supply risks. The first reaction has been to identify the minerals considered critical, and while there is no universally accepted definition, they are typically scarce at home, are subject to near-monopolistic supplies, have no known substitutes, and are vital inputs for economic growth and national security. The United States, for example, has identified 50 critical minerals and has determined 100 percent import reliance for 12, and greater than 50 percent import reliance for another 29. These minerals are so designated because they are "essential to the economic and national security of the United States, have a vulnerable supply chain, and serve an essential function in manufacturing a product."[4] Supply risks increased dramatically during trade and geopolitical tensions in 2024–2025, when China increased licensing restrictions on the export of rare earth elements (REEs) vital to US industries.

Across the world, governments are evaluating supply risks and reassessing policies and strategic partnerships. The International Energy Agency (IEA) estimates that half of the 200 critical mineral policies and regulations that it tracks, for 25 countries and regions, were enacted in just the past few years.

Recognizing the long lead times for mines to become operational, there is a broad push to diversify and increase supplies. In 2021 the US Department of Energy's Loan Program Office started to fund innovations in critical minerals projects to increase domestic supplies. In 2023, Saudi Arabia's Maa'den mining company formed a joint venture with US-based Ivanhoe Electric to use the latter's Typhoon geophysical surveying technology to identify metals deep below the surface, beyond the capacity of conventional mapping systems. Technology hubs and incubators promoting mining innovations are gaining traction across the world from Canada to Saudi Arabia and Australia.

Strong and rising demand, monopolistic supply chains, geopolitical tensions, and disruption risks and realities are sparking a global interest in investing in critical mineral supply chains. Against this backdrop, the Milken Institute began a Financial Innovations Lab project to identify the market failures in attracting investment at scale and explore innovative financial frameworks as remedies. The project included research, more than 100 stakeholder interviews, and sessions held alongside major Milken Institute conferences. Informed by insights and feedback, the team identified three financing frameworks with the potential to unlock greater diversity and scale of capital:

1. Pool funds into a syndicated investment model managed by experts to invest in mineral supply chain innovations via special purpose vehicles for targeted exposure and transparency.
2. Establish a revolving loan fund that includes host communities in the economic upside of projects, promoting best practices and helping secure the social license to operate.
3. Create a blended finance fund in which public capital reduces some of the mining-specific investment risks and catalyzes private investment.

The following report discusses the landscape of supply and demand for minerals and the investment challenges and proposes structures for financing models that would address key market failures and catalyze greater private-sector investment at the scale needed for resilient and sustainable supplies.

ISSUES AND PERSPECTIVES

Critical minerals possess unique properties that render them vital in consumer applications, health care, manufacturing, communications, and defense. These properties include the ability to withstand extreme stress and temperatures (up to 500°F and absolute zero, or -450°F), resist corrosion, possess superior magnetic and electrical conductivity, display phosphorescence, and offer high performance-to-weight ratios (i.e., are incredibly light). When alloyed with other elements, their properties can be enhanced, unlocking greater performance potential in equipment from smartphones and headsets to quantum chips and submarine guidance systems.

Demand Landscape

DAILY LIVING: FROM PHONES TO MEDICAL DEVICES

Five years ago, iPhones contained greater memory and processing power than the computers used in the 1969 Apollo project.[5] This quantum leap was facilitated by minerals, with some estimates that more than 50 percent of an iPhone's components are mined.

Containing on average 42 minerals,[6] iPhones and other smartphones are veritable mines. A smartphone's extended battery life and storage capacity, even its folding screen, rely on minerals such as lithium and graphite. REEs enable headphones to deliver the audio quality of much larger and high-fidelity sound systems. The smartphone market in 2024 accounts for roughly 7.2 billion units and is expected to grow by nearly 1 billion units to 8.06 billion in 2029, implying robust demand for minerals.[7]

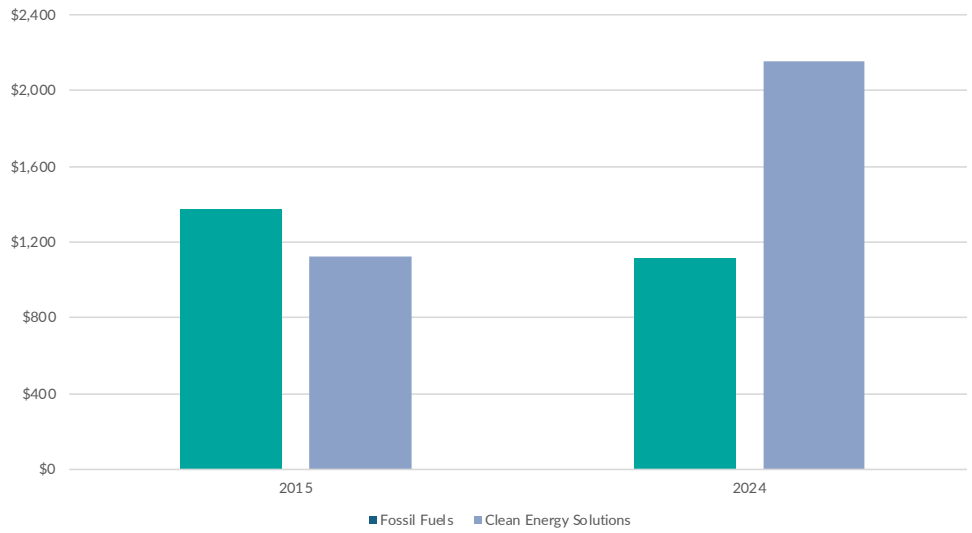
Minerals are also used in magnetic resonance imaging (MRI), X-rays, computed tomography (CT) scanners, and other biomedical imaging devices to enable early detection of health conditions, reducing the need for invasive surgery for diagnoses. REEs, for example, are used as powerful contrast agents, and their importance was reflected in a 2025 request for tariff exceptions by the American Hospital Association, which warned that "82% of health-care experts expect tariff-related expenses to raise hospital costs by at least 15%, and 90% of supply chain professionals expect procurement disruptions."[8]

THE GLOBAL ENERGY TRANSITION

Minerals are an essential component of the global investment in renewable energy technologies and infrastructure, which has been on an upward trajectory since 2020, surpassing $2 trillion in 2024 as seen

below.[9] They are used across the board in clean energy solutions ranging from nuclear reactors to solar panels.

Figure 1: Global Investment in Clean Energy Solutions and Fossil Fuels ($ billions)



Source: Milken Institute and IEA (2025), https://www.iea.org/reports/world-energy-investment-2025/executive-summary

Solar panels and wind turbines use copper, aluminum, and REEs to enhance charge and increase resistance to temperature swings, providing greater efficiency and stability. Wind turbine generators can contain several hundred kilograms of REE magnets that lower maintenance requirements and reduce costs, particularly for offshore installations. EVs need copper, lithium, and cobalt for energy storage, stability, and safety, and can contain up to a kilogram of REEs.[10]

The rapid deployment of renewable energy solutions is overtaking other industries as a demand source for minerals and is poised to continue as a strong force. In 2022, renewable energy investments accounted for 56 percent, 40 percent, and 16 percent of global lithium, cobalt, and nickel demand, respectively (up from 30 percent, 17 percent, and 6 percent, respectively, from the previous five years).[11] Looking ahead, with a global alignment with the Paris Agreement goals, these percentages could increase to 90 percent for lithium and 60–70 percent for nickel and cobalt.[12]

QUANTUM COMPUTING AND AI

Minerals are essential inputs in quantum computing and AI. The machines used "tend to like things quiet, still, and cold," meaning an environment isolated from any noise and at nearly absolute zero F, according to Internet and Technology Law. They also need a lot of power. In other words, they need minerals that provide stability at extreme temperatures, data storage, and conductivity for power. Google's new quantum chip, Willow, performs computations in "under five minutes that would take the world's fastest supercomputers 10 septillion years"[13]; it also needs large data centers with cooling systems, battery storage, and power, all of which require minerals.

AI is part of this demand source, contributing to greater investment needs in both data centers and energy. A simple ChatGPT query, for example, requires 10 times the electricity of a Google search.[14]

Minerals are central to these technological gains, from ensuring the performance of the chips to powering intense electricity needs. The global quantum computing market is estimated to grow at a 35 percent compound annual rate from $1.16 billion in 2024 to $12.6 billion by 2032,[15] and investment in data centers is expected to increase sixfold from $162.8 billion in 2024 to $608.5 billion in 2030.[16] The implications for power grids are significant. In an April 2025 report, the IEA estimates that data center–driven demand for power could "more than double globally by 2030 to around 945 terawatt-hours, slightly more than the entire electricity consumption of Japan," and in the United States, could account for half the nation's overall growth in demand for electricity.[17] This will contribute to future demand for copper, a vital mineral for power grids, which could increase by 70 percent over the next 25 years,[18] outstripping global supply by as much as 30 percent by 2035, according to the IEA.[19]

NATIONAL DEFENSE AND SECURITY

Minerals are needed across the entire US defense sector, from night goggles, unmanned aerial systems (drones), and fighter jets to submarines and satellites. Their valued properties include high strength-to-weight ratios, thermal and corrosion resistance, and strong conductivity, which improve safety, accuracy, and payload capacity.[20] REEs, for example, retain magnetic strength at elevated temperatures and are used in space assets (from satellites to rocket bodies and weapons) and missiles. As countries evaluate their critical mineral needs, they will encounter not only competition but also protectionist trade barriers, such as occurred during the 2024–2025 Chinese export controls on certain REEs, which were perceived as a retaliatory focus on US import reliance.

Critical minerals are the scaffolding of future economies. They are vital for daily lives, medical and technological progress, and national security. Increasing applications, including in quantum computing, will add to factors driving demand. To avoid price volatility, supply chokeholds, and economic disruptions, it is crucial to ensure that supply aligns with demand. This brings us to the supply landscape.

Supply Landscape

As noted, the supply side stands in contrast to exploding global demand, being subject to near monopolistic controls and pricing manipulations, which pose significant disruptive risks for global economic growth and progress.

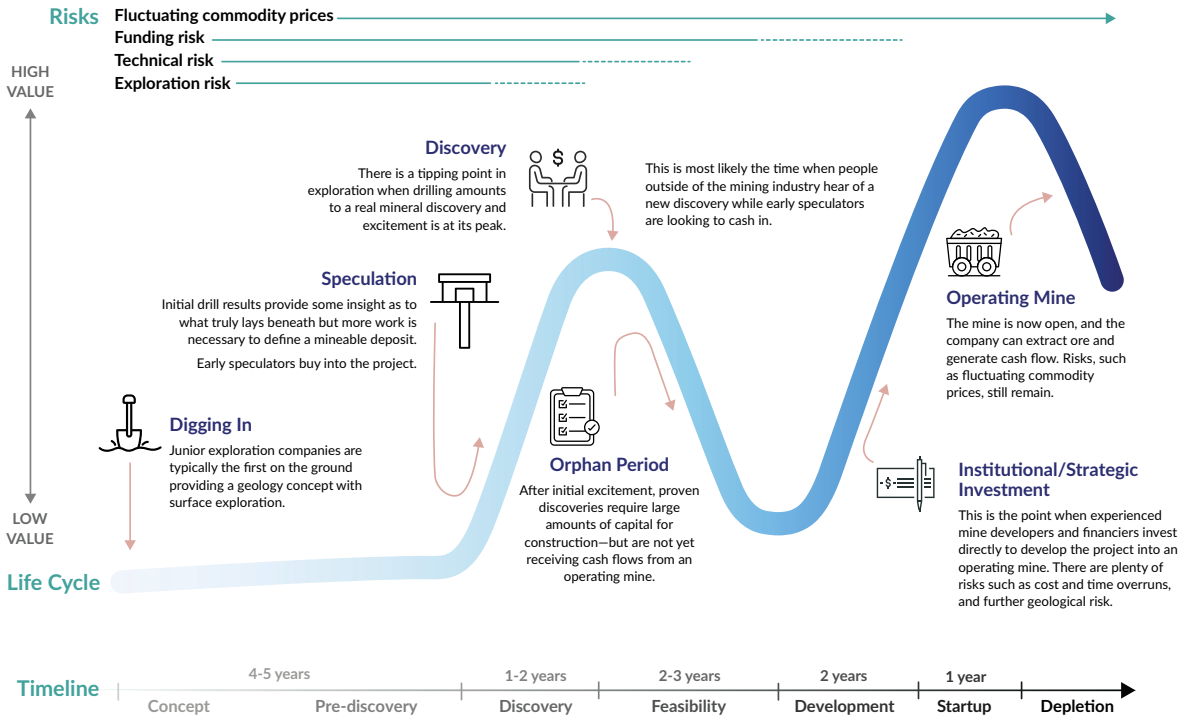
THE MINING LIFE CYCLE AND KEY TERMS IN THE SUPPLY LANDSCAPE

The Lassonde Curve, seen below, which was graphed by mining executive Pierre Lassonde in 1990, has become an industry standard.[21] It illustrates the risk and return potential of each phase of the mining life cycle—a valuable tool for investors and mining companies alike who need to assess a project's potential.

Resources are the naturally occurring mineral deposits, identified by exploration, mapping, and test drilling and then quantified. They include the mineral content, grade, and deposit size. Although resources carry potential value, the more important factor is the size of the *reserves*, meaning the amount of those resources that can be feasibly mined and refined for economic returns. This depends on multiple factors such as costs and the technology available and is determined in *feasibility studies*, which drive investor interest and the means to fund a project's costs against the inherent risks of commodity pricing, regulatory

barriers, and market conditions. The amount is also a dynamic estimate based on continued exploration, market conditions, and technological advancements. Finally, *supply* is what the market can access.

Figure 2: The Lassonde Curve: The Typical Lifcycle of a Mining Project



Source: SmallCapInvestor (2023), https://smallcapinvestor.ca/the-lassonde-curve-understanding-the-mining-life-cycle/

Broadly speaking, the Lassonde Curve divides the mining process into principal phases, each of which has risks, results in value creation, and therefore has implications for investors.

1. *Concept phase:* The site is procured, and exploration (mapping and extensive sample drilling) to determine development potential begins.
2. *Discovery phase:* This is when the deposits are found, and the mining company proceeds with advanced exploration and sampling to assess mineral quantity and grade. It is at the end of the discovery phase that resources are identified.
3. *Feasibility phase:* Detailed engineering, metallurgy, and financial studies will determine the reserves and therefore the project's viability and potential profitability.
4. *Development phase:* Environmental studies and permits address social concerns, the site is prepared for mine construction, and development begins.
5. *Startup phase:* The mine begins production for revenue generation.

LONG LEAD TIMES AND DELAYS

The Lassonde Curve illustrates the risks and the long lead time—how production spans years and cannot be rapidly adjusted to address shortages or a break in the supply chain. The exploration stage itself can span several years and is a function of the mining company's access to capital, skilled labor, and technology. Once resources are defined, scoping and feasibility studies begin to determine a reserve estimate. These involve permit applications, extensive testing, and pilot drilling. Because mines are typically in remote locations, the time to plan and build the transport, housing, and power infrastructure needed for production may be significant.

Consultations with local authorities and communities to minimize environmental impacts and avoid delays must be incorporated into planning for production. Factors such as policy changes, accidents, stringent environmental assessments, and community resistance can greatly alter the lead times. All of these factors have contributed to nearly tripling lead times for new mines over 2020–2024 to 17.8 years versus in 1990–1999.[22]

Although consensus about the need for greater diversification of mineral supplies is growing, this is not an industry where new supply can be turned on instantly to meet shortages/disruptions.

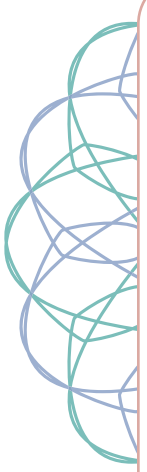
THE CHINA FACTOR

The current supply landscape is a result of starkly divergent national policies toward mining between China and much of the Western world. A general retreat from mineral mining in many countries due to concerns about environmental and social impacts, contrasts to a strategic and multiyear strategy by China to aggressively pursue resources at home and overseas. As a result, China now controls most mineral supplies and prices, deterring new investment at the scale required for uninterrupted global economic growth and technological progress.

During the early 1970s, US lawmakers, reacting to environmental events such as the oil-slicked Cuyahoga River fires in Cleveland[23] and the Valley of Drums (an area outside of Louisville strewn with waste-filled drums[24]), enacted legislation that affected the cost structures for many industries, including mining. The National Environment Policy Act (1969) required pre-permit environmental assessments and impact statements, and the Clean Water Act (1972) required stricter waste and pollutant management. In addition, past mining operations left behind a negative legacy and increased community resistance to reopening closed mines or beginning exploration activities. As the sector has retreated domestically, reliance on overseas supplies has increased.

In comparison, a different investment trend emerged in China with the One Belt and One Road Initiative in 2013, now known as the Belt and Road Initiative (BRI). Established by President Xi to develop an overseas infrastructure network to enhance trade, the BRI was broadened to include strategic investment in sectors that aligned with national policy priorities. The toolkit is comprehensive and a key reason for China's domination of global mineral supplies. It comprises policy support, state-led, low-cost, and continuous financing, and insurance, which combine to provide significant levers to lower the risk profile of otherwise unviable mining projects.

In the case of minerals, policy linked large public-sector infrastructure projects to resource supply agreements including mining concessions. Capital, provided by state-run policy and commercial banks to state-run and private Chinese enterprises, has been abundant, long term, and low cost. It has also been strategic—favoring early entry in mining projects, typically perceived as risky, and using equity structures to secure long-term access to resources. For example, Special Purpose Vehicles (SPVs) and Joint Ventures have been used extensively so that mineral allocation is based on the investor's stake. Specific projects, when aligned with domestic needs, receive continuous funding, with some securing, on average, 3.6x loans to ensure success.[25] China has deployed $1.3 trillion in 149 countries via the BRI toolkit over 2013–2025, and the percentage of the portfolio invested in metals and mining has grown steadily, from slightly less than 6 percent in 2013 to 20 percent in 2025, hitting $24.9 billion in six months in 2025, to surpass 2024's full year $21.4 estimate.[26] Metals and mining have been the second largest sector in the BRI portfolio since 2023. The third component of the toolkit, insurance, is provided through the state-owned China Export & Credit Insurance Corporation, more well known as Sinosure. Established in 2001 with registered capital of $481 million to centralize exporter and overseas lending–related insurance, Sinosure's role was elevated in 2011–2012 through reforms and a significant capital injection of $3.1 billion. Thereafter, insurance to BRI countries grew rapidly to more than $1.3 trillion by the end of 2022, with tenors up to 20 years,[27] a transformative de-risking tool that enables otherwise unbankable investments.



China's Dominance in the DRC

The Democratic Republic of the Congo (DRC) is the world's largest producer of cobalt and second for copper. It is also perceived as a high-risk investment area. China's domination of mining in the country reflects its ability to channel vast amounts of capital to secure access to key minerals.

In 2008, China and the DRC signed a $6 billion resource-for-infrastructure deal that would be split equally between infrastructure and resources, and a joint venture called Sicomines (Sino-Congolaise des Mines) with primarily Chinese ownership was named to lead the mining effort.[28] The DRC's gross domestic product at the time was close to $20 billion. From 2008 to 2022, China provided more than $11 billion in loans and grants to three major mining projects, representing 42 percent of its lending and grants to the DRC.[29] As of 2024, Chinese names controlled nearly all the DRC's cobalt mines, and hence 80 percent of the country's cobalt extraction and 67.5 percent of its refined product.[30]

The strategic and comprehensive BRI toolkit has helped shield Chinese investments from political risks and economic cycles, manage long lead times, and lessen the impacts of execution risks. It has also facilitated rapid and significant responses to changing policies in resource-rich countries to maintain access. This benefit was seen in Indonesia when the country started to ban the export of unprocessed nickel ores. China responded with multi-billion-dollar investments to build processing and refining capacity. The Indonesia Morowali Industrial Park (IMIP) is one result of this action. Financed by Chinese names with majority ownership, it was created to retain control over nickel. By end of 2018, more than $7 billion was invested in the park,[31] which now spans more than 13,500 acres, hosts more than 50 companies and 90,000 workers, and produces nickel and stainless steel to support China's EV industry.[32]

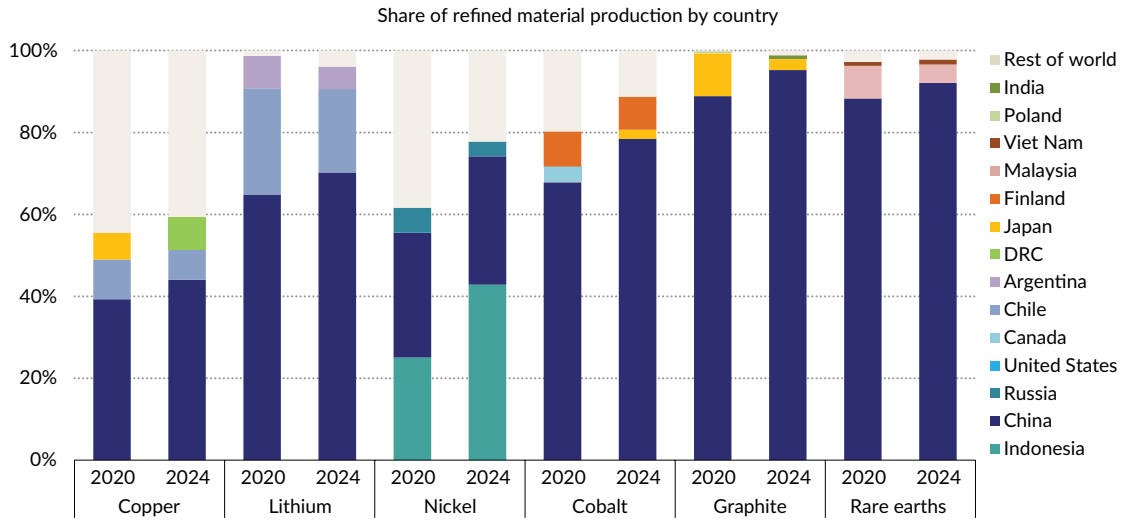
Across Indonesia, China has repeated this strategy at a smaller scale, and Chinese companies or shareholders now control as much as 90 percent of the nickel mining.[33] Because Indonesia–sourced nickel accounts for 43 percent of global refined product,[34] any disruption in operations will translate into a major supply shock. Meanwhile, China continues to channel money to Indonesia; the country was the largest recipient of BRI investment in 2024, at $9.3 billion.[35]

Elsewhere, in other regions and for other commodities, China's ability to provide financing has resulted in opportunistic investments to increase control. In the DRC in 2016 and again in 2020, when US-based Freeport McMoRan was selling copper and cobalt sites, the competitive bids came from Chinese names. China Molybdenum Company won both times.[36] Across the world, two Peruvian copper mines received $16 billion from 2010 to 2023, or 75 percent of China's total financial assistance to the country, with Las Bambas, one of the two mines, receiving a total of $12.3 billion from six Chinese banks.[37]

Chinese mining companies have not followed the same Environmental, Social, and Governance (ESG) guidelines as the rest of the world. The result, along with the inexpensive financing, has been stark cost-competitiveness. In Indonesian nickel, for example, the ramp-up time for Chinese operations is measured in months versus the West's five-year average, and capital intensity for projects run a third lower. They also use highly emission-intensive production processes, generate higher mining waste, and are associated with higher accidents and waste disposal failures.[38] In early 2025, the Indonesian government ordered an environmental audit of IMIP, citing illegal construction, air pollution, and the discovery of 12 million metric tons of illegal tailing deposits.[39]

Of the 20 critical minerals that the IEA analyzed for its 2025 outlook, China now leads the supply of 19, with a market share of greater than 70 percent. And China leverages this market share: 75 percent of these minerals have shown greater price volatility than oil.[40] As noted above, Chinese dumping of nickel in early 2024[41] forced mining giant BHP to shutter a flagship operation at a potential loss of $300 million EBITDA (earnings before interest, taxes, depreciation, and amortization), despite identifying nickel as one of its preferred "future-facing" metals.[42] In October 2024, US officials warned Portugal, a country with lithium reserves seeking to increase domestic production, that Chinese producers were flooding the market, causing a "predatory" price drop of approximately 80 percent for the year, to prevent competition.[43] Meanwhile, the demand for lithium remained unabated, up by 30 percent that same year.[44]

Figure 3: China's Increasing Share of Key Refined Minerals (2020–2024)



Source: IEA (2025), https://www.iea.org/news/diversification-is-the-cornerstone-of-energy-security-yet-critical-minerals-are-moving-in-the-opposite-direction

The Chinese disruptions can manifest for various reasons including geopolitical tensions. In 2010, a Sino-Japanese maritime clash led to a Chinese export ban on REEs, which disrupted global supply chains and caused prices to soar.[45] More recently, in 2025, amid tariff hikes announced by President Trump that led to retaliatory Chinese export restrictions on REEs, the European Association of Automative Suppliers warned of the "shutdown of several production lines" as inventories dwindled.[46] China is not the only country tightening restrictions on its mineral exports, as shown in Figure 4, although it is the most influential.

Figure 4: Chinese Export Restrictions Announced Since 2023

		By	Market share
Material	Lithium	Zimbabwe	9%
	Gallium	China	99%
	Germanium	China	74%
	Antimony	China	74%
	Rare earths	China	92%
	Graphite	China	98%
	Cobalt	DRC	68%*
	Tungsten	China	44%
	Bismuth	China	80%
	Indium	China	70%
	Tellurium	China	77%
	Molybdenum	China	81%
	Nickel	Philippines	9%
Technology	Rare earths	China	92%
	LFP cathode	China	98%
	Lithium refining	China	72%

Source: IEA (2025), https://iea.blob.core.windows.net/assets/a33abe2e-f799-4787-b09b-2484a6f5a8e4/GlobalCriticalMineralsOutlook2025.pdf

China's ability to manipulate commodity prices to align with its national priorities at the expense of Western supply chain resilience is adversely impacting global investment. According to the IEA, spending for exploration of critical minerals "flatlined" to $6.7 billion in 2024, after climbing by roughly 20 percent between 2020 and 2023, and investment by mining majors grew by a mere 5 percent in 2024 (versus 14 percent in 2023) to just over $50 billion. These are unwelcome developments, given that the IEA estimates that demand by 2040 will require investment of between $500 and $600 billion in mines and refining.[47] There is therefore an urgent need to re-draw the investment framework to create diversified and secure supply chains to ensure sustainable access.

GLOBAL RESPONSE AND LANDSCAPE

National Lists

As noted, governments have been assessing their dependencies and, mindful of shifting markets and trade policies, have been mapping out solutions. In the US, the policy evolution dates to the Obama administration, when the US joined the EU and Japan in 2012 to file a complaint in the World Trade Organization against China's REE restrictions. In 2017, the Department of the Interior broadened its definition of critical minerals essential to the economy and national security and vulnerable to supply chain interruption, increasing the number from 17 to 35. The Energy Act of 2020 codified this definition;[48] and in 2022, the US Geological Service (USGS) updated the list to cover 50 minerals.[49]

Since 2011, the EU has defined Critical Raw Materials (CRMs) via the European Commission as a set of non-energy, non-agricultural raw materials that are considered critical due to their high economic importance and exposure to high supply risk, often caused by a high concentration of supply from a few third countries. Most recently (2024), the EU listed 34 CRMs to identify projects for financing to strengthen the value chain, diversify imports, and improve capacity to monitor and mitigate supply risks, circularity, and sustainability.[50]

Policy Response

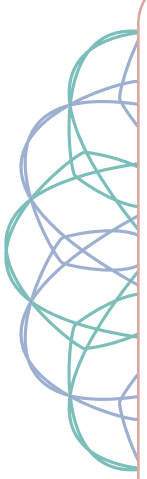
While re-working domestic policies, governments are also working across borders. Referred to as mineral diplomacy, this trend among importing countries seeks international coordination to secure mineral supply chains. Their approach includes a spectrum of policies, partnerships, funding tools, and incentives to promote and facilitate domestic and foreign investment in mineral supply chains.

One such transnational alliance is the Minerals Security Partnership (MSP), formed in 2022. In this US State Department–led multinational alliance, MSP member countries work to secure diverse, resilient, and stable supplies of raw materials through strategic projects. They leverage their engagement with the MSP, development finance institutions (DFIs), and export credit agencies. The MSP also engages with countries outside the formal membership that have mineral reserves and adhere to MSP's strategic goals.[51]

Other recent US initiatives include multiple executive orders to promote domestic production of minerals and the establishment of the National Energy Dominance Council, a cabinet-level body chaired by the Secretary of the Interior, to advise the President on strategies to enhance US energy production and security, including critical minerals, by streamlining permitting, reducing regulations, and promoting private-sector investment.[52]

In 2024, the EU enacted its Critical Minerals Raw Materials Act to build capacity and resilience of domestic supply chains with clear goals for domestic extraction, processing, and recycling: 10 percent for extraction, 40 percent for processing, and 25 percent for recycling of total mineral demand by 2030. In March 2025, the European Commission identified 47 projects in 13 Member States for priority financing and expedited permitting policies, shortening the approval time frame to 5–10 years from 15–27 years. Twenty-five of the projects comprise extraction, 24 processing, 10 recycling, and 2 substitutions of raw materials; among the minerals covered are lithium, nickel, cobalt, manganese, and graphite.[53] The Act also calls for the EU to "reinforce international engagement to develop mutually beneficial partnerships with third countries."[54]

While known for its oil and gas reserves, the Middle East, and specifically Saudi Arabia and the United Arab Emirates, is a growing influence in the minerals space, which presents an attractive opportunity for economic diversification and allows the region to capitalize on its strategic location near resource-rich Africa. The UAE has already invested more than $1.1 billion in Zambian copper mines,[55] and *The New York Times* reports that "Persian Gulf investments in Africa, primarily by the Emirates, have exploded in recent years." Countries in the Middle East, particularly the UAE, have poured close to $110 billion in investments spanning mining, technology, supply chain infrastructure, including ports, and military bases.[56] Countries are also pursuing efforts to increase domestic production as seen in Saudi Arabia, where under the Vision 2030 Initiative, simplified and streamlined processes for exploration and mining licenses, tax incentives and exemptions, and public–private partnerships aim to attract companies and investors.[57]



Policy Responses Focused on Mining Innovations

Newlab, a venture platform and innovation hub headquartered in Brooklyn, NY, focuses on critical technologies, which it defines as those strategically significant to the economic resilience, security, and competitiveness of a region's foundational industries, infrastructure, and supply chains. It offers facilities for startups in the Brooklyn Navy Yard, Detroit, and Uruguay's national innovation campus and matches them with investors and partnerships. During a regional meeting conference in January 2025, Newlab announced a new campus in Saudi Arabia, which will serve as an innovation hub for the Middle East and North Africa. Newlab Riyadh will aim to develop innovations broadly in energy, logistics, and advanced manufacturing, with a Mining Studio dedicated to promoting technological advances across the value chain. It will operate in partnership with key pillars of the government including the Saudi National Industrial Development and Logistics Program, the Ministry of Industry and Minerals, and the Saudi Geological Survey.[58]

Canada's Mining Innovation Accelerator (MICA) was founded in 2021 with public-sector capital of $40 million from the national Strategic Innovation Fund. Its partners include technology hubs, polytechnics, and colleges across the country. Membership dues create a sustainable funding model. MICA has financed 40 innovations totaling $27 million thus far.[59]

Financing Response

Financing is also being redrawn to catalyze investment through tax credits, loans, and investment funds focused on strategic parts of the value chain. Resource-rich countries such as Canada and Australia have expanded tax incentives to boost exploration. The Canadian Mineral Exploration Tax Credit will support junior miners' exploration efforts by allowing investors to claim a 15 percent tax rebate on projects.[60] Australia, home to some of the world's largest reserves of lithium, REEs, cobalt, and nickel, is encouraging greater domestic processing with the Critical Minerals Production Tax Incentive, which provides a refundable tax offset of 10 percent, for up to 10 years, for plants operational by June 2040.[61]

Countries are also providing upfront financing for exploration to increase domestic supplies. Canada, among the top 5 producers of 10 critical minerals, launched a Critical Minerals Strategy in 2022 for infrastructure build. The resulting Critical Minerals Infrastructure Fund provides up to $1.5 billion until 2030 for clean energy and transportation infrastructure to support mining operations. The Indigenous Natural Resources Partnerships Program works to ensure the social license to operate, enhancing the economic involvement of Indigenous organizations in resource development projects.[62]

In 2024, Saudi Arabia announced that estimates of its untapped mineral resources had nearly doubled, from $1.3 trillion in 2016 to $2.5 trillion, with rare metals "used in electric vehicles and advanced technology products" accounting for 10 percent of the increase. The state planned to issue more than 30 mining exploration licenses to international investors and had allocated $182 million to its mining exploration program.[63]

In Europe, identified CRM projects will receive streamlined permitting processes as well as funding from the European Commission, Member States, financial institutions, and long-term offtake agreements, requiring €22.5 billion to become fully operational.[64] (An offtake agreement exchanges long-term capital inflow for a set supply of product at a set price for a set period.) Separately, critical mineral–specific investment funds are emerging, often in public–private partnerships. A few to highlight:

- Critical Metals Investment Fund: Under its 2030 Investment Plan, the French government will provide €500 million to attract private financial and industrial partners and reach a €2 billion target. The fund is being managed by the private equity fund InfraVia Capital Partners.[65]
- The Raw Materials Fund: Managed by the German DFI KfW Dev Bank, the fund's eligible projects, with minerals classified in the CRM List spanning mining, processing, and recycling, have the potential to receive between €50–€150 million each.[66]
- Made in Italy Fund: Italy has allocated an initial €1 billion to finance projects that expand access to critical raw materials and technology that supports supply chains. The goal is to attract international and private capital to double the fund size.[67]
- The European Bank for Reconstruction and Development (EBRD) and the European Union Joint Equity Facility: Part of the EBRD's new Junior Mining €150 million Framework, this facility will combine €25 million from the EBRD matched with €25 million from the EU's Horizon Europe program and aims to mobilize up to €100 million. It will support early-stage small- and mid-cap mining companies for mineral exploration in EU member states and countries covered by Horizon Europe.[68]

In the US, government agencies have provided loans to jumpstart domestic exploration, de-risk the early stage, and act as a catalytic force for private-sector investors. The Department of Energy (DOE) loans program office has made financial commitments, with lithium taking the lead, to help with domestic battery and EV sales. In October 2024, for example, DOE closed on a $2.3 billion loan to the Lithium Americas Thacker Pass project in Nevada. In January 2025, DOE finalized a $1 billion loan for the Rhyolite Ridge Lithium-Boron Project, also in Nevada.[69] Also in January 2025, the US Export-Import Bank (EXIM) expanded its mandate to include overseas financing via a Supply Chain Resiliency Initiative with the aim of reducing dependence on China for critical materials.[70]

Private Financing Landscape

Although public-sector attention to the sector has grown for well over a decade, it will take increased partnerships with private financing to meet the scale of future demand. Industry stakeholders acknowledge the need to educate investors on industry efforts to improve their environmental and social practices and the adoption of innovations. However, the sector has inherent challenges that can deter new investor groups. Time, for example, presents challenges for both the mining company and investor—the long lead time as miners conduct exploration and analysis, during which they need large capital inflows; the time investors require to perform due diligence on the site, the company, potential permitting and legal requirements; and the wait time for potential returns.

The early stages of exploration and development tend to be challenging for investors, who are understandably wary of funding risk without a predictable outcome. At the same time, the mining company often lacks sufficient collateral assets for traditional loans and typically raises funds by selling stakes in the company. This kind of early-stage equity raise is the most dilutive and expensive for the mining company and can delay exploration. However, once the preliminary drilling studies demonstrate feasibility and map the mineral reserves, it becomes easier for the company to project future profitability and thus to raise capital from additional sources such as alternative financing that does not take an equity stake in the business. These arrangements typically involve revenue royalties and commodity streaming, wherein the investor provides capital in exchange for discounted pricing on a percentage of the mine's production.

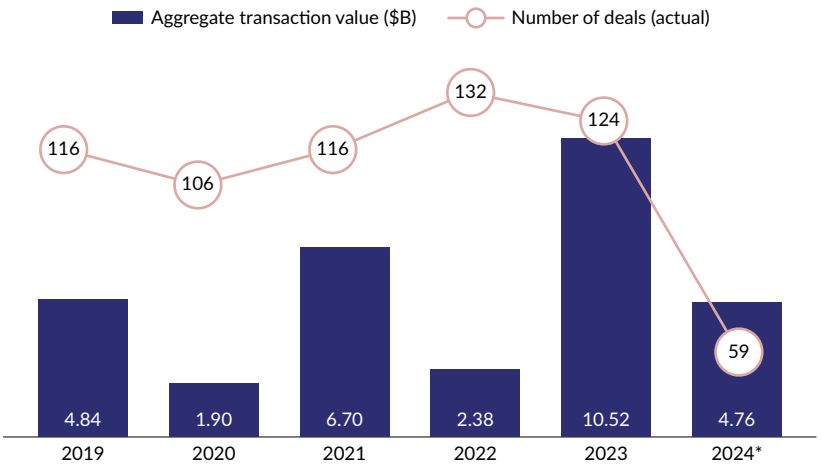
The cheapest source of capital—debt—rarely becomes available until after exploration when a project approaches the completion of a definitive feasibility study (DFS), which provides a detailed technical and financial analysis of reserves, metallurgical tests, and any regulatory, social, and environmental impacts. Once the DFS determines that a project is ready for development, preconstruction and contract hiring begins. The permitting process, if not already under way, can also begin. A DFS significantly reduces the perceived risks and increases lender confidence.

Although additional financing becomes more readily available as the project moves from the development phase to the mining phase, the type of financing can be ill-matched to the needs of the mining company. For example, PE and VC flows can be volatile. Mining investments often do not meet return profiles or may be unfamiliar to the teams performing due diligence.

Typically, in mining, these PE and VC flows have been viewed as opportunistic, driven by trends and headlines, as shown in Figure 5. From 2019 to 2024, investors leaped into metals and minerals in 2023, responding to EV news stories and the surging need for lithium, nickel, cobalt, and other critical metals.[71]

The following year, when China flooded the market with these metals, investor interest dried up, and deal pricing and numbers declined by nearly 50 percent.

Figure 5: Global Private Equity/Venture Capital–Backed Investments in Metals and Mining, 2019–2024



* Year to date through Sept. 30, 2024

Analysis includes global whole-company acquisitions, minority state acquisitions, asset acquisitions and rounds of funding announced between Jan. 1, 2019 and Sept. 30, 2024, where the buyer/investor in the deal is or includes a private equity or venture capital firm and where the target's primary industry is classified by S&P Global Market Intelligence as metals and mining. Excludes terminated deals and add-on acquisitions.

Source: S&P Global (2024), https://www.spglobal.com/market-intelligence/en/news-insights/articles/2024/10/sharp-drop-in-private-equity-metals-and-mining-sector-deals-in-2024-85749521

Offtake agreements, while not new to mining, are relatively recent in early-stage investment in minerals. These agreements between the mining companies and the end-users who need the minerals provide guaranteed revenue streams for the former and reduce financial risk. In addition, offtake deals can establish strategic partnerships for future expansion that reduce the project's vulnerability to cyclicality. For example, in February 2024, Canadian Nouveau Monde Graphite (NMG) secured financing and offtake agreements with General Motors (US) and Panasonic (Japan) to support the expansion of a mine and the construction of a battery material plant. Through a six-year supply agreement, NMG will supply active anode material to GM, which has committed to a total equity investment of US$150 million.[72] In parallel, Panasonic signed a supply offtake agreement with NMG. The two agreements will cover 85 percent of NMG's planned production, providing strong commercial backing and enhancing NMG's bankability for lenders and investors. It will also establish North America's first fully integrated natural graphite production from mining to battery material processing for EV and lithium-ion battery markets.

Although the new trend to finance expansion with offtake agreements reflects private-sector recognition that strategic capital has a role to play, opportunity exists for much greater engagement among stakeholders, beyond auto companies. The minerals industry is expected to require almost $2.1 trillion by 2050 to support global net-zero goals.[73] The industry and the timing are ripe for investment.

Industry Efforts to Attract Greater Investment

BEST PRACTICES AND STANDARDIZATION

In 2023, four metals councils—the Copper Mark, the Mining Association of Canada, the International Council on Mining and Metals (ICMM), and the World Gold Council—announced a goal to create a Consolidated Mining Standard Initiative (CMSI) that would publish a single standard for mining companies, no matter the size of their operation or the material they extract. The Copper Mark is an independent promoter of ESG standards in copper, nickel, zinc, and molybdenum mining. The Towards Sustainable Mining initiative was launched by the Mining Association of Canada in 2004 with three focus areas: communities, environmental stewardship, and energy efficiency. ICMM sets standards for nearly a third of the world's mining companies. Finally, the World Gold Council oversees standards in that industry.

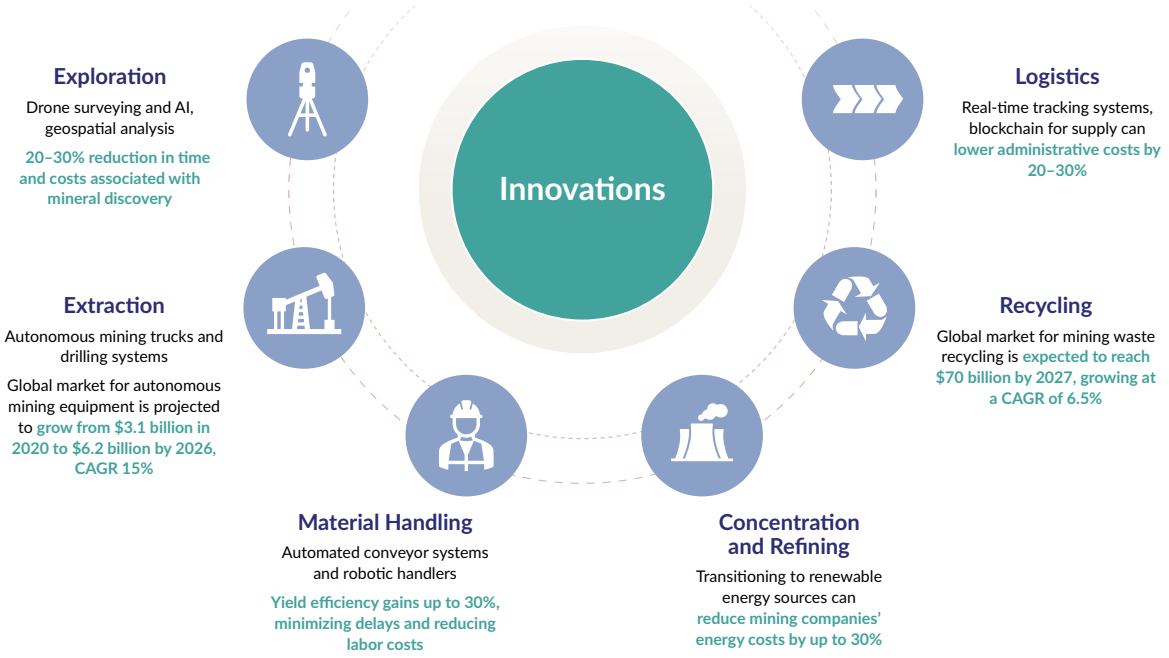
In 2024 the first draft of a CMSI was published for review; a second review round takes place this year. The CMSI promotes an easily understood best practices framework and will follow four main pillars: ethical business practices, worker and social safeguards, social performance, and environmental stewardship. To incentivize adoption, it provides an easy on-ramp implementation via three certification levels.

The CMSI aims to simplify the current mining standards landscape across the value chain, making it easier for investors to understand a member company's ESG practices. Approximately 100 mining companies across 60 countries are expected to adopt the standard, giving it the widest coverage of any voluntary mining standard that exists to date.

MINING TECHNOLOGY INNOVATIONS

Innovations in mining technologies are transforming the industry, reducing exploration times, and enhancing efficiency, safety, and profitability. Their integration, from exploration to recycling, offers investors a path to engage in technological progress and diversify portfolios with significant growth potential and financial returns as seen in Figure 6. Advanced tools such as AI drone resource mapping, automated drilling systems, digital twinning of mining sites, and real-time data analytics all optimize operations, reduce costs, and lower environmental impacts. The demand for these technologies is tremendous. For example, the global market for autonomous mining equipment is projected to grow from $3.1 billion in 2020 to $6.2 billion by 2026.[74]

Figure 6: Impact of Mining Technology Innovations on Environmental, Social, and Governance (ESG), Costs, and Yields



Source: The Mining Association of Canada, Prospect Innovation (2024)

One such application is the ability of innovations to reduce early-stage risks. For example, Massachusetts-based VerAI, specializing in minerals discovery, is de-risking the early stage by using AI to find mineral deposits in underexplored covered terrains, reducing the time to locate minerals and costs by a projected 90 percent.[75]

Similarly, innovations in processing can help scale up domestic components of a supply chain as seen in another Massachusetts company, Phoenix Tailings, which leverages patented technology to extract metals and rare earths from mining waste, without toxic byproducts or carbon emissions. Finally, they can help create new revenue streams by repurposing mining waste. Canadian R&D firm Envicore transforms mining tailings into materials for use in the construction of buildings and infrastructure. The innovation also helps to address concerns about the treatment and storage of mining waste. Mining conglomerate Vale is also repurposing mining waste for construction in Brazil.

Modern technologies can reduce early-stage risks, streamline processes, shorten lead times, lower ESG impacts, and improve sustainability. They lower lead times and costs, increase yields, and improve safety concerns. They also offer investors a compelling opportunity to diversify their portfolios, capitalize on the surging global demand for minerals, and align with national priorities and economic goals.

BARRIERS

Through conversations with stakeholders, the Milken Institute Lab process identified three broad areas that pose as barriers to attracting the scale and diversity of capital needed to meet current and future demand for critical minerals:

1. The negative environmental and social impacts associated with mining
2. A failure to finance innovations that lower impacts and boost efficiency and yields
3. A financing misalignment in the risk and duration of the capital needed and available

The Environmental and Social Impacts Associated with Mining

The mining industry faces significant scrutiny from local communities, governments, investors, and nongovernmental organizations due to a range of interconnected risks such as land use and displacement, loss of biodiversity, high water usage, emissions, and poor waste management, which can all increase community resistance and imperil the social license to operate. The industry's historical performance and legacy of safety and environmental failures have impacted investor and community perceptions and heighten the challenges to efforts to increase domestic production.

Mines impact the environment in many ways. First, mines disrupt biodiversity. Regarding critical minerals, S&P Global reports, "Of the 1,276 mining sites that intersect with KBAs [key biodiversity areas], 29% are for extracting minerals needed for the low-carbon energy transition. Moreover, of these transition mineral sites in KBAs, 67% are exploration sites, meaning they are being assessed for future development into operational mines to meet the demands of the energy transition."[76]

Operations generate dust and emissions that degrade air quality, impacting nearby communities. Emissions occur throughout the value chain, from diesel-powered drilling machinery to energy-intensive chemical processes used in processing and refining. There are also broader impacts from the supporting infrastructure—the development of transportation networks (road and railway), power, and housing.

High water usage is another concern for communities. The entire mining process—from exploration to extraction, processing, and pumping of minerals through pipelines to downstream operations—requires extensive amounts of water. Water is also needed to cool machinery and control dust. Greater than 50

percent of lithium and copper mines are situated in areas with already extremely high or high levels of water stress, according to the World Resources Institute.[77]

In Chile, home to significant copper and lithium reserves, extraction has been reported to consume more than 65 percent of mining hub Salar de Atacama's underground water supply, threatening indigenous farming communities and raising concerns about contamination of freshwater sources used for drinking, livestock, and agriculture.[78] In 2022, Chile finally modernized a 1980s water code that had allowed mining companies to acquire private water rights in perpetuity. Water is now a national good for public use and prioritized for human consumption. Stricter regulations and oversight have followed, and mining companies are pumping water from the Pacific Ocean and using desalinization plants in their operations. The Chilean story provides one example of why new mines will likely face challenges and competition for water from existing homes, industry, and agriculture.

Mining has traditionally been a high-risk occupation, and despite regulatory oversight, enhanced safety regulations, technological advances, and proactive industry practices, issues persist. The International Council on Mining and Metal, which includes 251 members, reported that 42 fatalities occurred in 2024, an increase for the second consecutive year but lower than the 45 in 2021.[79] However, this only accounts for members. It would not, for example, include the Chinese nickel hub IMIP in Indonesia, which accounted for nearly half of the 101 accident-related deaths at nickel facilities in the country between 2015 and the first half of 2024.[80]

Failure to engage with the community from an early stage has halted or significantly delayed mining operations. One such example is the Resolution Copper Mine in Arizona, a multinational project headed by Rio Tinto (UK) and BHP (Australia). Since 2004, these two firms have invested more than $2 billion in the project, which could create thousands of jobs and contribute to the state's economy. The project is expected to supply 25 percent of US copper demand during its 40 years of operation.[81] Yet, it has been mired in controversy, multiple lawsuits, and local opposition from the San Carlos Apache Tribe and other Indigenous groups who fear destruction of nearby sites that they consider sacred. In 2021, the US Forest Service (USFS), the federal agency in charge of the approval process, withdrew its Final Environmental Impact Statement (EIS) to enable "additional review and tribal consultation." In April 2025, however, in line with the administration's priorities on mineral supplies, the Resolution was fast-tracked for permitting,[82] and in June 2025, USFS republished its Final EIS.

If companies prioritize environmental and social concerns, engage stakeholders early, and adopt innovations that reduce their impact and boost safety, then they can build trust, contribute positively to local communities, and secure the social license to operate—thereby avoiding disruptions, which is a key business risk in the sector.

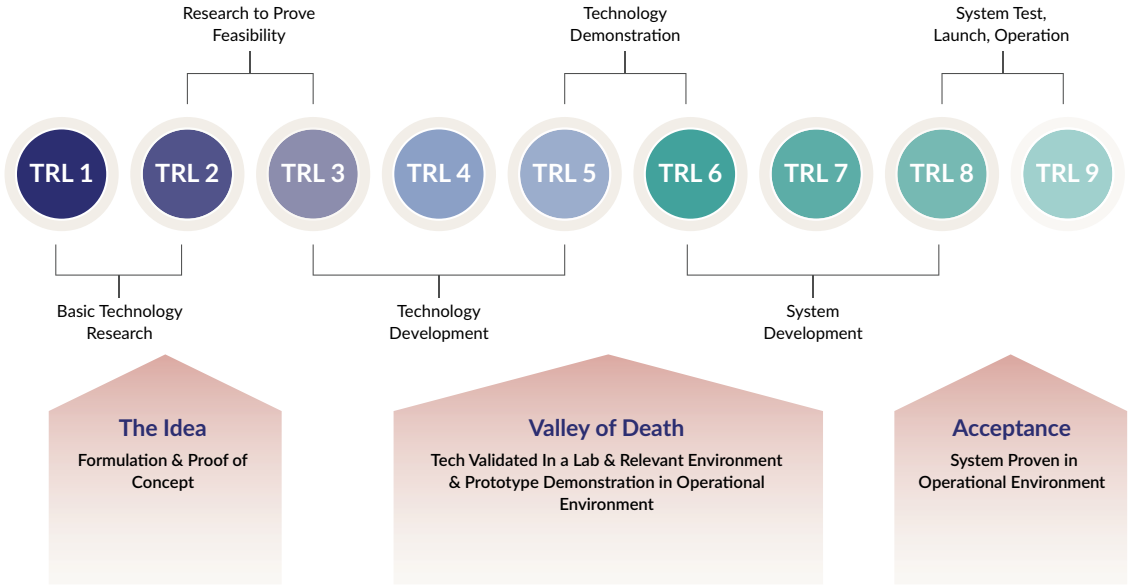
A Failure to Adopt Innovations at Scale

Technological advances have helped lower environmental and social impacts, improve efficiencies and yields, and open up a range of investment opportunities. Yet many of the startups designing new technologies struggle to access capital and remain trapped in a cycle of investor wariness and reticent sector adoption. Their work often remains siloed across the industry. Some major mining companies and investment firms—Vale, BHP, and Orion, for example—have their own VC arms. Technology platforms and accelerators exist but are not coordinating efforts, resulting in funding overlaps and competition in the same space. Although competition yields many benefits, the lack of collaboration or knowledge sharing can

result in duplicated work, waste resources, and slow progress toward overall industrywide goals to attract a greater pool of investment capital.

The funding landscape for mining tech startups is fraught with challenges and often depends on their Technology Readiness Level (TRL), a measurement developed by NASA and since adopted by other organizations, including DOE and the Department of Defense, to determine the maturity/readiness of a particular technology and to finance it accordingly. The TRL is a critical framework that guides companies through product development and signals to investors the risks and potential for success; but it is just one tool and it is not foolproof. Investors or companies interested in licensing the technology want proof that the technology works in a real-world setting. As one Lab participant said, "No one wants to be first. Everyone wants to be second."

Figure 7: A Typical Technology Readiness Level Scale



Source: MKA Insights (2019), https://mkainsights.com/insights/fundamentals-operations/trl; TWI (2025), https://www.twi-global.com/technical-knowledge/faqs/technology-readiness-levels#; Milken Institute (2025)

Generally, mining tech startups are able to fundraise in the early TRL 1–3 stages, where ideas are in the lab at the concept phase. The challenge arises in the TRL 4–8 range, spanning development and demonstration, as shown in Figure 7. This range is called the "valley of death," that is, the funding gap where capital-intensive development lives or dies, contingent on financing. Here, traditional venture capitalists, often seeking three to five times returns within a short two to four years, stay away, deterred by long lead times before the concept is proven and high upfront costs.

The mining industry is generally reluctant to adopt technologies. Driven by commodity price volatility, mining companies can be risk averse and choose to not incur the additional costs to change their equipment or retrain workers to adopt the innovations because even small delays can cost millions. They may require startups to prove that their technology will not disrupt operations or introduce unforeseen risks—which can become a chicken-and-egg situation. As a result, technologies such as AI and robotics, which are rapidly scaling in other sectors, struggle to gain traction at the same pace in mining.

For technology innovations that lower the ESG risk premium and create additional revenue streams to achieve scale, there must be a shift in industry to embrace change, and a shift in investors to provide the capital and opportunity to bridge the gap between startup potential and market adoption.

The Financing Misalignment in Capital Duration and Risk

Misalignment between the nature of capital currently available and the needs of the sector contributes to volatile investment cycles, a failure for sustainable and resilient supply chains. In the early stages of the mining life cycle, investors face risks related to the discovery of the mineral, including assessments of its grade and quantity. Changing market conditions, national policies, ESG considerations, and available technologies also pose as risks while project feasibility is being determined. The permitting process often requires approvals from different agencies and levels of government, and consultation with communities. Even in mining-friendly Canada, securing a permit can take 15 years.[83]

Mineral projects also seem to have larger cost over-runs and delays than other sectors, by 15–20 percent.[84] The time to begin production in the Goro mine in New Caledonia, estimated to contain one of the largest nickel deposits in the world, was 28 years,[85] which was fraught with local resistance, environmental failures, and vulnerability to nickel price swings.

During operations, investors face a different set of risks. Mining accidents, environmental disasters, commodity price manipulation, changing policies, and trade issues may affect a project's outcome and investment returns. In Brazil, for example, the repercussions of a 2015 dam collapse that resulted in toxic waste release, death, and widespread damage are still being felt, and the implicated mining companies face rising compensation demands.[86] In Africa, countries in the Sahel belt are revising national policies to boost domestic control, such as mine nationalization and higher royalties, that significantly alter the risk profile for investors.[87]

Amid these risks, in the absence of state financing and insurance such as that provided by China, fundraising for Western companies has been relegated to the capital markets. And Chinese price manipulation has exposed this vulnerability. The high correlation (93 percent) between commodity prices and stock prices[88] implies that Chinese-led dumping depresses commodity prices and negatively impacts fundraising for many companies. It also disproportionately affects junior mining companies, which typically lead exploration projects and therefore new supply.

The private capital markets have not been a reliable source of financing. PE and VC have short time horizons for returns and sensitivity to interest rates and commodity prices. As described above, in response to the price collapse of lithium and cobalt, investors stepped away from the minerals space in 2024 and announced deals hit a five-year low.[89] In the absence of reliable and stable funding sources, mining has veered toward offtake agreements and end-users are now financing mineral projects. However, these remain niche deals, with only large automakers engaged.

The sector's inherent high risks and long lead times cannot be funded by cyclical and volatile capital markets. The misalignment is a significant market failure in the context of global demand, national security, and supply risks. To promote greater diversity of capital and mineral supplies, financing and policy tools must be revisited to lower risks and better align the availability of capital with the needs of the sector.

INNOVATIVE FINANCING FRAMEWORKS

The Milken Institute has, for over a year, through research and sessions, engaged stakeholders to identify and refine innovative financing frameworks that address key challenges and attract diversified, at-scale pools of capital to build resilient and sustainable mineral supply chains. Three frameworks emerged from this work: A **syndicated investment model** to invest in innovations; a **revolving loan fund** that includes communities to build stronger partnerships and secure the social license to operate; and a **blended fund** with a public-sector role to de-risk investing and catalyze greater private-sector capital.

A Syndicated Investment Model

A syndicated investment model (SIM) enables existing pools of capital to invest in an asset together. Popular in sectors with high capital and due diligence needs and long lead times, such as real estate, a SIM can be an effective solution when investors cannot dedicate the time and human capital and/or may be unwilling to finance the entire investment opportunity. Typically, a team with sector expertise manages the investment from identification to due diligence to exit. Investors contribute capital and may choose to be involved, or not, in most decisions. This has been popular in sectors that require upfront and large amounts of capital and have a lead time before revenue generation, with both debt and equity syndicate models.

Stakeholders raised the SIM as a potential solution to financing innovations in mining at scale. Currently, innovators struggle to secure financing to navigate the "valley of death" funding gap between concept and proven commercial viability. Some have secured funding from government programs such as DOE's Advanced Research Projects Agency–Energy (ARPA-E) or an innovation-focused fund but cite intense competition for a limited pool of funds. One innovator spoke of an agreement with a user for a pilot to prove commercial viability, but this is not the norm.

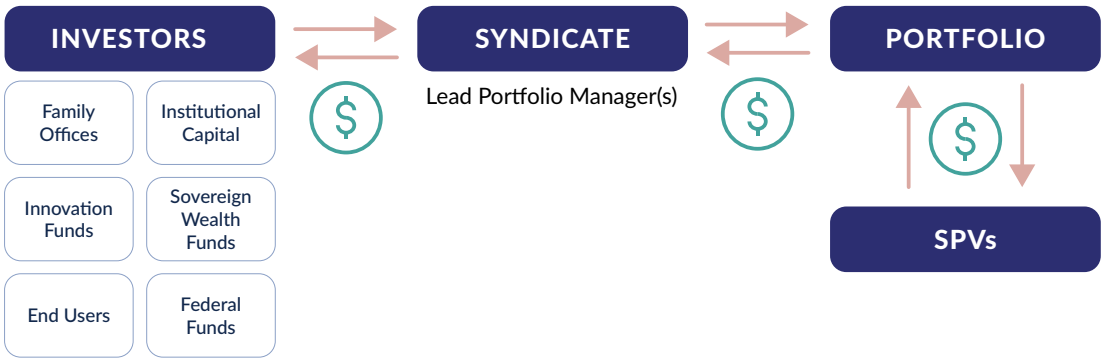
New investor groups, such as institutional investors and sovereign wealth funds, are deterred from investing in mining innovations, citing the significant human and financial capital needed for due diligence and management in a field of which they have little knowledge. The stigma attached to a sector still associated with negative environmental impacts or social resistance was also cited as a deterrent.

This model could address some of these challenges. A group of anchor investors would pool capital in a SIM focused on innovation in mineral supply chains. Stakeholders cited two groups as potential investors—family offices and innovation-focused funds—based on the assumption that they have a greater risk tolerance than investors new to both mining and innovation. Climate-focused funds with mandates on decarbonization

and ESG could also be considered as potential early investors. This setup could provide the funding for an inaugural SIM focused on innovation in mineral supply chains, managed by a lead investment team with mining industry expertise.

Expertise was cited as key to demonstrate returns and attract new investor groups to enter the SIM. Investments would be directed via SPVs allocated to different minerals or regions to accommodate investor profiles and interests. This approach would increase transparency and provide investors with the option to opt out of areas that do not align with their risk tolerance or mandate. Finally, with proof of success, SPVs investing in improved environmental impacts could be securitized as green bonds to increase marketability.

Figure 8: Syndicate Investment Model: A Proposed Version for Mining



Source: Milken Institute (2025)

Public-sector engagement was discussed as a useful add-on if the investments align with national policies. Governments could provide tax incentives to invest in innovations and physical space, which would provide a boost for start-up companies. A real-world example exists: The Australian Automation and Robotics Precinct (AARP), spread over 100 acres and managed by a state government's land development agency, is the country's largest trial, test, and demonstration grounds for robotics and automation.[90] The US has something similar: The Idaho National Laboratory, established in 1949 on land provided by the federal government, played a key role in developing nuclear technologies. It continues its work today in nuclear and other renewable energy, defense and security solutions, as well as research collaborations.[91]

The syndicate investment model would provide at-scale financing for innovations, whether in the US or elsewhere. Including marquee names from family offices, sovereign wealth funds, and institutional capital would elevate the concept, shine a light on the investment opportunity and potential of innovations, and prove transformative for the mining industry.

NEXT STEPS

- Identify the group of innovation-focused funds and family offices to establish a SIM and select the lead portfolio managers.
- Expand the discussion with climate funds to gauge interest in joining the anchor SIM group.
- Select an asset class for the first SPV that would be an easy lift, considering anchor investors' mandates and host region's policy priorities.
- Discuss the structure (e.g., evergreen to avoid disruptions), liquidity, and exit parameters.
- Explore discussions with relevant regional authority for incentives.

A Revolving Loan Fund

A revolving loan fund (RLF) is an effective measure to fill gaps in financing for a community interested in co-investing in a project but lacking the financial skills and/or credit score to access capital at terms that work for them and make the investment viable. An RLF is a pool of capital, typically provided as a grant or zero-cost loan that can come from public or philanthropic money. It is used to provide direct loans at terms more favorable than what would be available elsewhere, from banks or capital markets. Repayments of the principal and interest are reinvested into the fund to create a cycle of lending—hence the use of "revolving." The fund is structured to be self-sustaining over time and can use capital markets to issue new debt to raise additional capital.

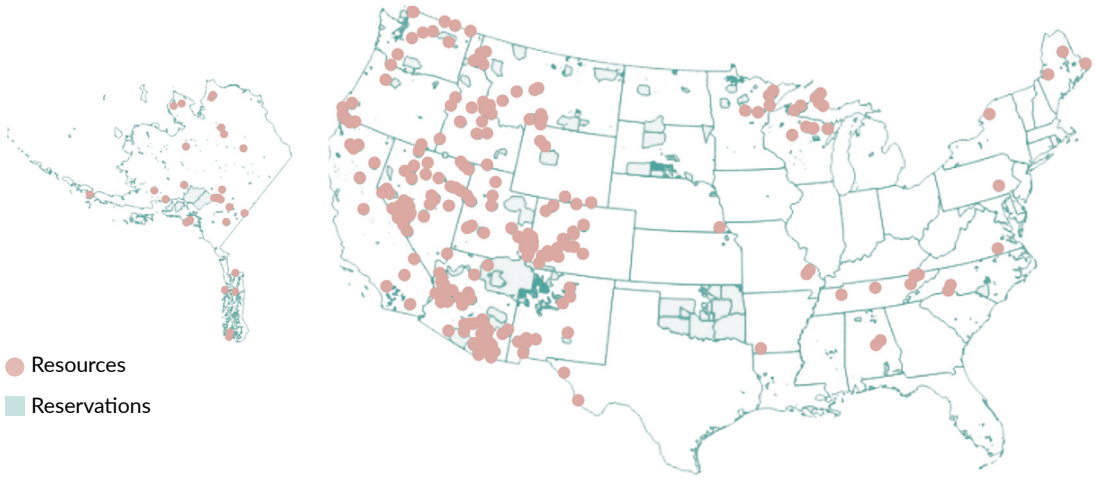
RLFs could be used by communities that live near mineral reserves. Mining typically occurs in remote and rural areas, and communities may need assistance and incentives to support the project. A 2022 global study of more than 5,000 mining projects associated with the energy transition found that nearly 70 percent of projects are located on or near Indigenous peoples' lands and farmland.[92] These communities, likely in need of financing in order to co-invest in a project, could use an RLF. Further, community involvement could facilitate faster project development by securing a social license to operate, a top five business risk for C-suites in the mining industry.[93]

The Clean Water State Revolving Fund is an example of a successful RLF.[94] As a federal–state partnership, it provides low-cost financing to communities for water quality infrastructure projects. Authorized by federal legislation, the Environmental Protection Agency gives grants to set up state-level RLFs (up to 80 percent, with states contributing 20 percent). At the state level, the fund functions as a bank, providing low-interest loans. It has operational control, with the freedom to set loan terms (tenors up to 30 years, and interest rates varying from zero percent to market rate). Repayments recycled back to finance new projects enable the fund to "revolve" at the state level.

Stakeholders discussed this solution in the context of "onshoring" mining operations and Native American lands. Tribal Nations control about 100 million acres of land (making the aggregation of their land the equivalent to the fourth-largest state in the country). There is also a significant presence of mineral resources and reserves in proximity of reservations.[95]

Onshoring: a business process that involves relocating a company's business operations from overseas back to the home country. Often referred to as "bringing jobs back home," in the context of the US and North America, it means returning operations from overseas locations closer to home.

Figure 9: Resources of Critical Minerals and Tribal Reservations



Note: Resources include palladium, platinum, rhodium, antimony, beryllium, chromium, cobalt, copper, graphite, lithium, magnesium, manganese, nickel, niobium, scandium, tantalum, titanium, tungsten, vanadium, tin, ytrium, zinc, and zirconium)

Source: S&P Global, US Census Bureau, Milken Institute (2025)

In agreement with interested Tribal Nations, land could be utilized across the value chain, for example, for the infrastructure required for projects, testing innovations, refining and processing, and stockpiling. The RLF would bridge credit constraints faced by Tribal Nations, which, while having a nation-to-nation relationship with the federal government and the power to determine governance structures and enforce laws, are shut out from most public financing tools.[96] Land is held in trust by the Bureau of Interior, limiting Tribal Nations' ability to use it as a tax source or collateral. Access to the tax-exempt municipal bond market is very constrained, ruling out what is typically a reliable capital source for most local governments. For example, over a 30-year period, Tribal municipal bond issuance was under $4 billion, compared to total market issuance of more than $6.5 trillion.[97]

The lack of access to capital has placed Tribal Nations at a significant disadvantage in revenue generation and credit standing and has naturally impacted the ability to deliver economic growth and development on par with the rest of the country for many. As of June 2025, Tribal Nations face an even more challenging federal funding landscape; federal funding for projects faces an uncertain future and the White House has rolled back a prior Executive Order that would have improved consultation and funding pathways (among other goals). However, Senate legislation to increase Tribal Nations' access to the bond market has been introduced and merits attention.[98]

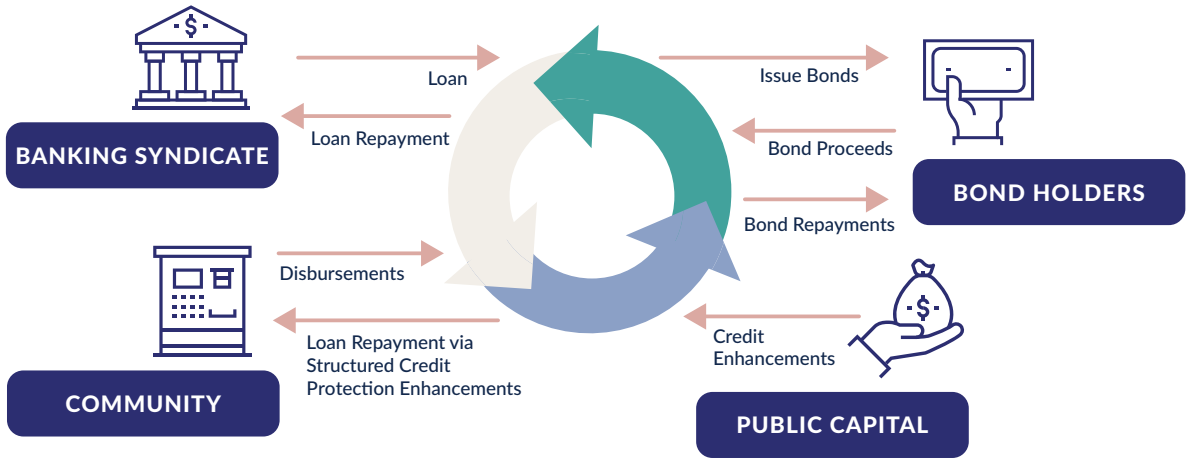
In a challenging federal policy and financing landscape, mining-friendly states and neighbors keen to capture a portion of the economic activity from the onshoring of mineral supply chains could provide the first pool of capital for an RLF. Economic inclusion of Tribal Nations could be an effective pathway to engage those near mineral resources, foster communication and build partnerships, and lower the risks of disruptions and delays, while promoting economic development. The fund could finance a range of economic activities

around a project, including skills training, the provision of services, construction of infrastructure, and investing in innovations. It could also finance downstream from mining activities, including processing and storing, in line with the supply chains' interests of the host communities.

An additional financing pathway, using private money to establish the RLF, is noted in Canada, which utilizes a consortium of financial institutions. The RLF, the First Nations Finance Authority (FNFA), is owned completely by First Nations and engages with the consortium on behalf of its borrowing members. The FNFA was created through national legislation, which ensured that First Nations were recognized as governments for lending opportunities and defined powers, a regulatory framework, and a borrowing structure. Its current investment grade rating acknowledges the implicit guarantee it has from the government. FNFA borrows from a banking syndicate to meet member requests. It has stringent requirements for borrowers to adhere, including (1) the FNFA right to intercept revenue streams from the source (e.g., forestry or gaming revenues from the government); (2) the creation of a debt reserve fund to hold 5 percent of the loan as escrow, and (3) intervention rights to gain access to the First Nation's revenues if loans are not serviced.[99]

FNFA leverages these requirements to establish its creditworthiness among the financial institutions and capital markets. Once FNFA has borrowed funds, it will, based on financial market conditions, use the financial consortium to issue a bond at a lower interest rate, to pay off the initial loan. Each bond issuance will have a fund into which the borrower pays to ensure regular repayment.

Figure 10: A Revolving Loan Fund Inclusive of Public and Private Capital



Source: Milken Institute (2025)

It is critical to note that Tribal sovereignty rights, recognitions, and legal status differ between the US and Canada. Further, backing from the US federal government is unlikely. However, the financial consortium option offers a promising pathway for Tribal Nations to increase access to broader capital markets, currently a challenge beyond gaming. If invested in innovation that improves the environmental stewardship of the project, the fixed income issuance could be classified as green bonds, increasing the appeal of the bonds to a greater group of investors. As the fund establishes credibility, it could opt to securitize assets, providing host communities with greater options to monetize their investments. It could also just opt for regular bond issuance to access more capital, which can be "revolved" to provide more loans.

As talk of onshoring supply chains gains momentum, RLFs offer Tribal Nations and other communities access to investment opportunities in relevant projects. They can accelerate the economic development of the community and secure the social license to operate, de-risking a key component of investing in mineral supply chains.

NEXT STEPS

- Identify Tribal Nations interested in being involved in a stakeholder mapping exercise that would then extend to relevant counties or states and establish a governance structure to ensure respect for Tribal land and norms.
- Identify the investment team to run the RLF, ideally either a Native Community Development Financial Institution or organization with embedded trust working with Tribes.
- Convene investment managers and legal advisors to provide pro-bono services to start the discussion for the RLF and participation parameters for Tribal Nations, including federally chartered corporations that separate the business entity from their governing bodies.
- Identify the financing pillar(s) to stand up the RLF (i.e., the capital and the source).
- Determine the consortium of financial institutions to begin engagement with the RLF for later access to capital markets.

A Blended Fund Approach

A blended fund—popular in sectors that need patient capital and tools to lower early-stage risks—can catalyze greater private-sector investment. Applied in mining, such a fund can also lower the cost of the initial capital requirements and support viability during commodity price swings, preserving balance sheet strength to ensure operational continuity and therefore diversity in mineral supplies.

There is a broad agreement that the current financing landscape for early stages in mineral supply chains must be realigned to ensure secure supplies. As it stands today, the landscape cannot price in the risks posed by the BRI toolkit and Chinese price manipulation, which can result in shutting down exploration efforts, which are key for diversified supplies. As noted above, price declines due to dumping can lead to asset sales to Chinese names and therefore greater concentration of supplies. There is a role for a blended finance fund with greater public-sector engagement, and one that is more innovative than seen currently.

Blended finance structures have been particularly effective in the world of development finance, mobilizing nearly $250 billion since the launch of the UN's Sustainable Development Goals.[100] Key to this structure is the entry of donor or concessional capital at the start. This capital is provided either as a grant or at favorable terms (e.g., low or zero interest rates, flexible repayment schedules), which finances the risky development phase and lowers the overall cost of the project. Donors and concessional capital enter early and sacrifice some returns for capital preservation (or enter with grants). The willingness of an investor group to cap its returns incentivizes investment from others. For example, the United Arab Emirates did so for its inaugural climate finance fund, which would invest only in developing countries, to incentivize greater private-sector engagement. According to a participating institution, this approach worked and attracted capital that might not have come

in otherwise.[101] In addition to this form of capital, the use of guarantees/insurance and technical assistance facilities has increased and is reported to be featured in a quarter of recent blended finance frameworks.[102] Combined, these forms of early support in a project increase feasibility by financing early-stage risks and capital needs, and lower the overall cost structure, which can catalyze greater private-sector investment.

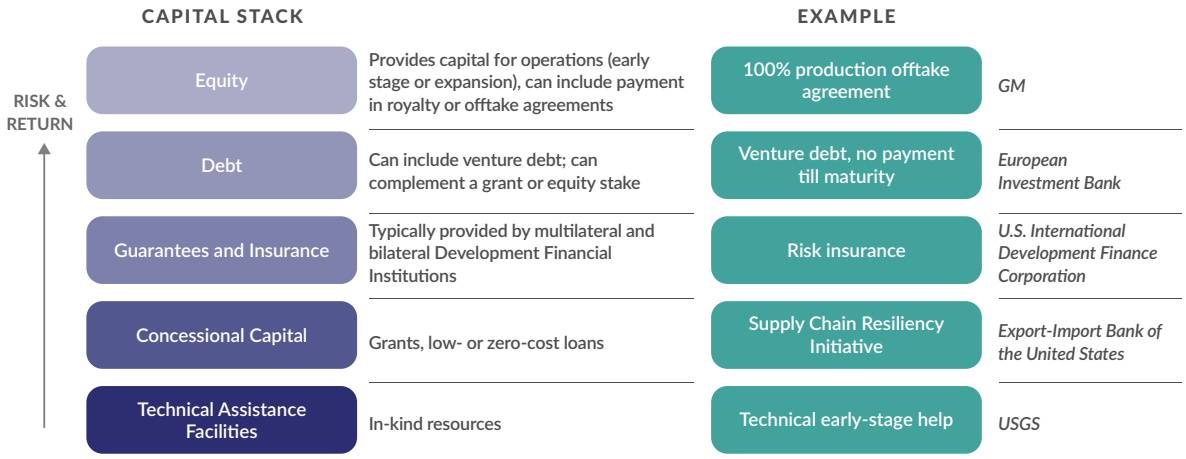
Stakeholders agreed that the blended finance framework lends itself to the mining sector and could provide the catch-up that the rest of the world needs. A stronger role for the public sector—capital and in-kind assistance—could provide game-changing levels of de-risking, strategic financing, and asset protection. In overseas jurisdictions, a comprehensive in-kind and financing toolkit, in collaboration with aligned partners, could be a counterforce to Chinese investment and secure supplies with greater regard for environmental concerns and positive social impact. Although not a blended fund, the Lobito Rail Corridor provides an example of how allied countries and DFIs are investing in the economic development of a region, from agriculture to solar energy, centered around a rail corridor for key minerals.[103]

Stakeholders suggested the following adaptations to the blended fund approach to de-risk early stages of mining projects and attract greater private-sector capital:

- **Technical Assistance Facilities:** Common in development finance, these facilities commit in-kind resources. The USGS could assist in exploring and assessing mineral reserves and mapping of resources. The EBRD helps identify best practices and regulations in overseas jurisdictions, including six sub-Saharan countries. Assistance could be linked to co-investment and off-take agreements if needed.
- **Guarantees and Insurance:** Guarantees and insurance are a known feature in overseas investment. Provided by the government, they do not require upfront cash outlays and must be deployed at a greater scale. The US has offered risk insurance via the International Development Finance Corporation (and its predecessor) in overseas projects that cover asset expropriation, currency or political violence risks, and breach of contract.
- **Concessional Lending:** Here, DFIs have played a significant role in energy investments in developing countries, and a similar role is being noted in mining. The EBRD provides equity and debt financing for early-stage activities (including prefeasibility and feasibility studies, resource certification, drilling and greenfield development). Debt financing (currently offered to operational and creditworthy companies) is typically for 7–10 years but can extend to 15 years. In the US, as noted, EXIM has recently broadened its role via its Supply Chain Resiliency Initiative, which provides financing to overseas projects to facilitate imports of critical minerals.[104]
- **Unique Debt Structures:** One such structure is venture debt financing, which is popular in Silicon Valley for early-stage companies with the potential for high growth. Venture debt is typically offered after or in conjunction with equity, which is viewed as validation of the project. In early 2024, the European Investment Bank announced that it would use this structure to finance a first-of-its-kind carbon storage and energy generation project in Sardinia, in conjunction with a grant from a fund.[105] Debt repayments are not due until maturity, and the lender has the option to convert to a small equity stake. The result is preservation of the borrower's balance sheet, helping it withstand policy and price volatility and thus increase its chances of operational success. There is also a halo effect for private investors with the DFI's involvement.

- **Equity Investments** with offtake agreements**:** Currently seen with major auto names, upfront financing in return for product should be expanded to a broader group of end users. Industries from aerospace to consumer electronics and defense can provide the capital to build mines and processing plants in return for secure supplies. This approach enhances the resiliency of supply chains, insulating multi-year projects from interest rate and policy turbulence, providing greater surety of supplies.

Figure 11: A Blended Financing Framework for Critical Minerals



Source: Milken Institute (2025)

NEXT STEPS

As of July 2025, there have been significant policy signals and changes in the US with respect to mineral supply chains. The DFC, up for reauthorization in fall 2025, could be expanded. Geopolitical tensions and agency and department funding cuts, including funding for innovative mining solutions, could set back policy execution and delay the securing of mineral supplies. The landscape is shifting, but nevertheless, some key actions related to the blended finance approach warrant consideration in Washington, DC:

- Create a single entity that coordinates all public-sector, in-kind, capital support for mineral projects, particularly for overseas jurisdictions where supplies are proven but perceived investment risks are higher. This entity will provide greater clarity and efficiency in policy execution and tool deployment, and a signaling effect for greater private-sector investment.
- Broaden the DFI toolkit to include financial market instruments that will provide guardrails around overseas projects. Option contracts, whether exercised or not, can increase revenue certainty, enhance the project's attractiveness to private investors, and ensure that supplies survive price volatility. For example, by purchasing a put option, the mining company or private-sector investor has the ability to transfer its output or equity stake to the government arm that sold the contract, under pre-determined prices or conditions. The government will purchase the stake or commodity, should the option be exercised. The existence of the contract can be catalytic for private investors by lessening the volatility and risks around the project. For the government, should the contract be exercised, this action improves the chances that the critical mineral asset remains under its control.

CONCLUSION

There is an urgent need for innovative financing frameworks to ensure resilient, sustainable, and secure supplies of the minerals critical to the manufacture of everything from smartphones and EV batteries to defense and medical imaging. The Milken Institute believes that the solutions will help shift the negative ESG narrative on investing in mining, include host communities, and catalyze greater deployment of private-sector capital. Three specific areas need to be financed. First, financing innovations, which will play a key role in increasing the attractiveness of investment in mineral supply chains for a broad group of investors. Second, communities need to be engaged in the economic upside to promote a better way to move forward and mitigate delays. Finally, guardrails should be provided to lower risks for private capital and protect projects from price volatility.

The Milken Institute's Financial Innovation Lab process has identified three financing frameworks that will address the key deterrents to entry of private capital at the scale and diversity required to meet global demands. A SIM will elevate the financing of innovations that lower the risks and negative impacts associated with mining as well as boost yields. An RLF will engage host communities, promote best practices, and help secure the social license to operate for projects. Finally, a blended finance fund with innovative adaptations will lower early-stage risks, reduce the impacts of price manipulation, and catalyze private-sector investment. The public sector will play a role, in varying degrees, in all three solutions—a reflection of the need to play catch-up to China and to attract more private-sector capital into this space.

The world currently faces an increased concentration of key mineral supplies, to the detriment of the environment, host communities, and global supply chain stability. The Institute believes that the proposed financing frameworks are timely and can lead to resilient and sustainable supply chains of the minerals deemed critical for progress on all fronts, including health, economic, technological, environmental, and defense, for the world.

ENDNOTES

1. *The Role of Critical Minerals in Clean Energy Transitions* (International Energy Agency, May 5, 2021), https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions.
2. *Global Critical Minerals Outlook 2025* (International Energy Agency, May 21, 2025), https://www.iea.org/reports/global-critical-minerals-outlook-2025.
3. Joyce Guevarra and Shambhavi Gupta, "Sharp Drop in Private Equity Metals and Mining Sector Deals in 2024," S&P Global Market Intelligence, October 24, 2024, https://www.spglobal.com/market-intelligence/en/news-insights/articles/2024/10/sharp-drop-in-private-equity-metals-and-mining-sector-deals-in-2024-85749521.
4. Linda Rowan, "Critical Mineral Resources: The U.S. Geological Survey (USGS) Role in Research and Analysis," Congress.gov, February 21, 2025, https://www.congress.gov/crs-product/R48005.
5. Shane Lasley, "Miracle of Metals Make Smartphones Smart," *Metal Tech News*, June 27, 2020, https://www.metaltechnews.com/story/2020/01/01/tech-metals/miracle-of-metals-make-smartphones-smart/114.html.
6. "Geology of a Cell Phone," NC DEQ, January 2, 2024, https://www.deq.nc.gov/energy-mineral-and-land-resources/geological-survey/geoscience-education/geology-cell-phone.
7. Josh Howarth, "How Many People Own Smartphones? (2025–2029)," *Exploding Topics*, June 18, 2025, https://explodingtopics.com/blog/smartphone-stats.
8. "AHA Urges Department of Commerce to Enact Tariff Exceptions for Critical Minerals Used in Medical Devices," American Hospital Association, May 16, 2025, https://www.aha.org/news/headline/2025-05-16-aha-urges-department-commerce-enact-tariff-exceptions-critical-minerals-used-medical-devices.
9. *World Energy Investment 2024* (International Energy Agency, June 6, 2024), https://www.iea.org/reports/world-energy-investment-2024.
10. "What Is Driving Growth in the Rare Earth Metals Market?" Okon Recycling, April 16, 2025, https://www.okonrecycling.com/magnet-recycling-and-applications/magnet-technology/driving-growth-rare-earth-metals-market/.
11. *Critical Minerals Market Review 2023* (International Energy Agency, July 11, 2023), https://www.iea.org/reports/critical-minerals-market-review-2023.
12. *The Role of Critical Minerals in Clean Energy Transitions* (International Energy Agency, May 2021), https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions.
13. Hartmut Neven, "Meet Willow, Our State-of-the-Art Quantum Chip," Google, December 9, 2024, https://blog.google/technology/research/google-willow-quantum-chip/.
14. Sonal Bhutra and Pihu Yadav, "ChatGPT Uses 10 Times More Power Than Google Searches, Says Goldman Sachs," *CNBCTV18*, June 28, 2024, https://www.cnbctv18.com/technology/chatgpt-uses-10-times-more-power-than-google-searches-says-goldman-sachs-19435551.htm.

15. "Quantum Computing Market Size, Share & Growth Report, Summary 2024–2032," *Fortune Business Insights*, July 7, 2025, https://www.fortunebusinessinsights.com/quantum-computing-market-104855.

16. "Assessment of the $608+ Billion Hyperscale Data Center Industry, 2030—Key Trends, Disruptions, Pricing, Supply Chain, Technology, Regulations, Investments, and the Impact of AI," *GlobeNewswire News Room*, March 6, 2025, https://www.globenewswire.com/news-release/2025/03/06/3038281/28124/en/Assessment-of-the-608-Billion-Hyperscale-Data-Center-Industry-2030-Key-Trends-Disruptions-Pricing-Supply-Chain-Technology-Regulations-Investments-and-the-Impact-of-AI.html.

17. *Energy and AI* (International Energy Agency, April 10, 2025), https://www.iea.org/reports/energy-and-ai.

18. Sam Farrell and Laura Whitton, *BHP Insights: How Copper Will Shape Our Future* (BHP, September 30, 2024), https://www.bhp.com/news/bhp-insights/2024/09/how-copper-will-shape-our-future.

19. *Global Critical Minerals Outlook 2025: Executive Summary* (International Energy Association, May 21, 2025), https://www.iea.org/reports/global-critical-minerals-outlook-2025/executive-summary.

20. Gregory Wischer, Gregory Autry, et al., "Mineral Supply Chains and Space Assets: Mitigating Manufacturing Dependencies," *Æther: A Journal of Strategic Airpower & Spacepower* 11 (July 9, 2024), https://www.airuniversity.af.edu/Portals/10/AEtherJournal/Journals/Volume-3_Number-2/Wischer_et_al.pdf.

21. "The Lassonde Curve–Understanding the Mining Life Cycle," SmallCapInvestor, March 31, 2023, https://smallcapinvestor.ca/the-lassonde-curve-understanding-the-mining-life-cycle/.

22. Paul Manalo, "From 6 Years to 18 Years: The Increasing Trend of Mine Lead Times," S&P Global Market Intelligence, April 11, 2025, https://www.spglobal.com/market-intelligence/en/news-insights/research/from-6years-to-18years-the-increasing-trend-of-mine-lead-times.

23. "The 1969 Cuyahoga River Fire (US National Park Service)," National Park Service, accessed May 10, 2025, https://www.nps.gov/articles/story-of-the-fire.htm.

24. "A.L. Taylor Valley of the Drums Superfund Site," University of Louisville Superfund Research Center Community Engagement Core, October 11, 2022, https://storymaps.arcgis.com/stories/a8a2e5df0f064ce69656a1f6cae5c336.

25. Brooke Escobar, Ammar A. Malik, et al., *Power Playbook: Beijing's Bid to Secure Overseas Transition Minerals* (AIDDATA, A Research Lab at William & Mary, January 28, 2025), https://www.aiddata.org/publications/power-playbook-beijings-bid-to-secure-overseas-transition-minerals.

26. Christoph Nedopil Wang, *China Belt and Road Initiative (BRI) Investment Report 2025 H1* (Green Finance & Development Center, July 17 2025), https://greenfdc.org/china-belt-and-road-initiative-bri-investment-report-2025-h1/.

27. Yunnan Chen and Zongyuan Zoe Liu, *Hedging Belts, De-Risking Roads: Sinosure in China's Overseas Finance and the Evolving International Response* (ODI Global, December 14, 2023), https://odi.org/en/publications/hedging-belts-de-risking-roads-sinosure-in-chinas-overseas-finance-and-the-evolving-international-response/.

28. "The Chinese Power Grab: Tracking the Complicated Evolution of Sino-Congolese Relations," Mining.com, September 3, 2019, https://www.mining.com/web/the-chinese-power-grab-tracking-the-complicated-evolution-of-sino-congolese-relations/.

29. Lea Thome, Katherine Walsh, et al., "Chasing Copper and Cobalt: China's Mining Operations in Peru and the DRC," AIDDATA, February 27, 2025, https://www.aiddata.org/blog/chasing-copper-and-cobalt-chinas-mining-operations-in-peru-and-the-drc.

30. Farrell Gregory and Paul J. Milas, "China in the Democratic Republic of the Congo: A New Dynamic in Critical Mineral Procurement," Strategic Studies Institute, US Army War College, October 17, 2024, https://ssi.armywarcollege.edu/SSI-Media/Recent-Publications/Article/3938204/china-in-the-democratic-republic-of-the-congo-a-new-dynamic-in-critical-mineral/.

31. "Tsingshan Morowali Nickel Operation," Wood Mackenzie, December 17, 2024, https://www.woodmac.com/reports/metals-tsingshan-morowali-nickel-operation-27952638/.

32. "Indonesia Morowali Industrial Park (IMIP)," Nickel Industries, accessed June 11, 2025 https://nickelindustries.com/section/indonesia-morowali-industrial-park-imip/.

33. "China Controls Indonesia's Nickel Industry," *Indonesiabusinesspost.com*, November 30, 2022, https://indonesiabusinesspost.com/497/Politics/china-controls-indonesias-nickel-industry.

34. *Global Critical Minerals Outlook 2025*.

35. *China Belt and Road Initiative (BRI) Investment Report 2024*.

36. "Freeport-McMoRan Completes Sale of Undeveloped Project in the Democratic Republic of Congo for $550 Million," Freeport-McMoran, December 14, 2020, https://investors.fcx.com/investors/news-releases/news-release-details/2020/Freeport-McMoRan-Completes-Sale-of-Undeveloped-Project-in-the-Democratic-Republic-of-Congo-for-550-Million/default.aspx.

37. "Chasing Copper and Cobalt: China's Mining Operations in Peru and the DRC."

38. "The Rise and Rise of Indonesian HPAL–Can It Continue?" Wood Mackenzie, April 4, 2023. https://www.woodmac.com/news/opinion/rise-of-indonesian-hpal/.

39. Thomson Reuters, "Indonesia Finds Environmental Violations in Morowali Nickel Hub," *102.7 WBOW*, June 18, 2025, https://1027wbow.com/2025/06/18/indonesia-finds-environmental-violations-in-morowali-nickel-hub/.

40. *Global Critical Minerals Outlook 2025*.

41. Rick Mills, "Indonesia and China Killed the Nickel Market," Mining.com, May 4, 2024, https://www.mining.com/web/indonesia-and-china-killed-the-nickel-market/.

42. Jennifer L, "Nickel Market in Turmoil: BHP to Halt Operations Due to Price Plunge," Carbon Credits, May 20, 2025, https://carboncredits.com/nickel-market-in-turmoil-bhp-to-halt-operations-due-to-price-plunge/.

43. Reuters, "China Is Oversupplying Lithium to Eliminate Rivals, US Official Says," *US News and World Report*, October 8, 2024, https://money.usnews.com/investing/news/articles/2024-10-08/china-is-oversupplying-lithium-to-eliminate-rivals-us-official-says.

44. *Global Critical Minerals Outlook 2025*.

45. "How Japan Solved Its Rare Earth Minerals Dependency Issue," World Economic Forum, October 13, 2023, https://www.weforum.org/stories/2023/10/japan-rare-earth-minerals/.

46. "Urgent Action Needed as China's Export Restrictions on Rare Earths Disrupt European Automotive Supply Chains," CLEPA, April 6, 2025, https://www.clepa.eu/insights-updates/press-releases/urgent-action-needed-as-chinas-export-restrictions-on-rare-earths-disrupt-european-automotive-supply-chains/.

47. *Global Critical Minerals Outlook 2025*.

48. "Critical Minerals Resources: National Policy and Critical Minerals List," Congress.gov, July 17, 2025, https://www.congress.gov/crs-product/R47982.

49. Jason Burton, "US Geological Survey Releases 2022 List of Critical Minerals," USGS, February 22, 2022, https://www.usgs.gov/news/national-news-release/us-geological-survey-releases-2022-list-critical-minerals.

50. *Implementing the EU's Critical Raw Materials Act* (European Parliament, November 24, 2024), https://www.europarl.europa.eu/RegData/etudes/BRIE/2024/766253/EPRS_BRI(2024)766253_EN.pdf.

51. "Minerals Security Partnership," US Department of State, accessed May 14, 2025, https://www.state.gov/minerals-security-partnership.

52. "Establishing the National Energy Dominance Council," The White House, February 14, 2025, https://www.whitehouse.gov/presidential-actions/2025/02/establishing-the-national-energy-dominance-council/.

53. Chris Randall, "Critical Raw Materials Act: EU Funds 47 Raw Materials Projects," Electrive, March 25, 2025, https://www.electrive.com/2025/03/25/critical-raw-materials-act-eu-funds-47-raw-materials-projects/#:~:text=The%2047%20projects%2C%20located%20in%2013%20EU%20member,recycling%20and%20two%20the%20substitution%20of%20raw%20materials.

54. "European Critical Raw Materials Act," European Commission, accessed March 13, 2025, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan/european-critical-raw-materials-act_en.

55. Thomas Biesheuvel and Taonga Mitimingi, "Abu Dhabi's IRH to Invest $1.1 Billion in Mopani Copper Mine," Mining.com, December 22, 2023, https://www.mining.com/web/abu-dhabis-irh-to-invest-1-1-billion-in-zambias-mopani-copper-mines/.

56. "The Africa Debate UAE," *Dubai Times*, July 23, 2025, https://dubaitimes.com/uae-investments-in-africa-reach-110-billion-says-minister.

57. "Mining Regulations and Investment Opportunities," Saudi Arabia Mining, accessed June 15, 2025, https://saudiminingconsulting.com/sectors/mining-regulations-and-investment-opportunities.

58. "Open Call: Advancing the Mining Sector in Saudi Arabia," Newlab, June 26, 2025, https://www.newlab.com/post/mining-innovation-studio-program.

59. "Home Page," Mining Innovation Commercialization Accelerator, accessed May 15, 2025, https://micanetwork.ca/.

60. Dean Belder, "Mining Industry's Exploration Spending Lagging, Will Budgets Grow in 2025?" *Investing News Network*, March 18, 2025, https://investingnews.com/exploration-financing-cyclical-low/.

61. "Incentive for Critical Minerals Production and Processing in Australia," Department of Industry, Science and Resources, February 14, 2025, https://www.industry.gov.au/news/incentive-critical-minerals-production-and-processing-australia.

62. "Critical Minerals Infrastructure Fund," Government of Canada, May 30, 2025, https://www.canada.ca/en/campaign/critical-minerals-in-canada/federal-support-for-critical-mineral-projects-and-value-chains/critical-minerals-infrastructure-fund1.html; "Canada Fleshes Out Details of Critical Minerals Strategy," Mining.com, December 9, 2022, https://www.mining.com/feds-flesh-out-details-of-critical-minerals-strategy/.

63. Elias Al Helou, "Future Minerals Forum: Saudi Arabia Boosts Mineral Reserves to $2.5 Trillion," *Economy Saudi Arabia*, January 10, 2024, https://economysaudiarabia.com/news/future-minerals-forum-saudi-arabia/.

64. "Commission Selects 47 Strategic Projects to Secure and Diversify Access to Raw Materials in the EU," European Commission, March 24, 2025, https://ec.europa.eu/commission/presscorner/detail/en/ip_25_864.

65. "France Launches a Critical Metals Investment Fund," Mining South East Europe, December 5, 2025, https://www.miningsee.eu/france-launches-a-critical-metals-investment-fund/.

66. "Raw Materials Fund," KFW, accessed May 14, 2025, https://www.kfw.de/Rohstofffonds/index-2.html.

67. "EU'S €2.5bn Critical Minerals Investment Seeks Private Sector Collaboration," *InvestorNews*, May 17, 2024, https://investornews.com/critical-minerals-rare-earths/eus-e2-5bn-critical-minerals-investment-seeks-private-sector-collaboration/.

68. Lucia Sconosciuto, "EBRD and EU to Mobilise up to €100 million for Critical Raw Materials Investments," European Bank for Reconstruction and Development, July 31, 2024, https://www.ebrd.com/home/news-and-events/news/2024/ebrd-and-eu-to-mobilise-up-to-100-million-for-critical-raw-materials-investments.html#.

69. Jeniffer Solis and Nevada Current, "DOE Finalizes Nearly $1B Loan for Contentious NV Rhyolite Ridge Lithium Mine," This Is Reno, January 21, 2025, https://thisisreno.com/2025/01/doe-finalizes-nearly-1b-loan-for-contentious-nv-rhyolite-ridge-lithium-mine/.

70. "Export-Import Bank of the United States Board of Directors Approves Supply Chain Resiliency Initiative to Protect US Jobs and Shift Critical Mineral Supply Chains Back to the United States and Away from the People's Republic of China," Export-Import Bank of the United States, January 8, 2025, https://www.exim.gov/news/export-import-bank-united-states-board-directors-approves-supply-chain-resiliency.

71. "Sharp Drop in Private Equity Metals and Mining Sector Deals in 2024."

72. Jonathan Lopez, "GM and NMG Announce Agreement for Active Anode Material Supply in Quebec," GM Authority, February 15, 2024, https://gmauthority.com/blog/2024/02/gm-and-nmg-announce-agreement-for-active-anode-material-supply-in-quebec/.

73. "Sharp Drop in Private Equity Metals and Mining Sector Deals in 2024."

74. Vivek Salgaocar, "Unearthing Opportunity: Why the Time Is Now to Invest in Mining Technologies for Sustainable Growth," World Economic Forum, September 19, 2024, https://www.weforum.org/stories/2024/09/sustainable-mining-technology-investment-opportunity/.

75. "About Us," Ver-Ai, accessed May 14, 2025, https://ver-ai.com/.

76. Esther Whieldon, Joerg Rueedi, et al., "Rocks and Hard Places: The Complicated Nexus of Energy Transition Minerals and Biodiversity," S&P Global, November 22, 2025, https://www.spglobal.com/esg/insights/featured/special-editorial/rocks-and-hard-places-the-complicated-nexus-of-energy-transition-minerals-and-biodiversity.

77. *Global Critical Minerals Outlook 2025: Reliable Supply of Minerals* (International Energy Agency), May 5, 2021, https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/reliable-supply-of-minerals.

78. Shivani Lakshman, "More Critical Minerals Mining Could Strain Water Supplies in Stressed Regions," World Resources Institute, January 10, 2024, https://www.wri.org/insights/critical-minerals-mining-water-impacts.

79. "Transparent Safety Data Reporting," ICMM, accessed July 21, 2025, https://www.icmm.com/en-gb/our-work/health-and-safety/safety-data-and-indicators.

80. A. Anantha Lakshmi and Diana Mariska, "Indonesia: Workers Allege 'Production First, Safety Later' Culture at IMIP Nickel Complex Leads to Unsafe Conditions and Rising Accidents," Business & Human Rights Resource Centre, November 24, 2024, https://www.business-humanrights.org/en/latest-news/indonesia-imip-nickel-park-workers-allege-poor-safety-accidents-deaths-union-retaliation-restricted-movement-of-chinese-staff/.

81. "The Resolution Copper Project," Resolution Copper, accessed June 15, 2025, https://resolutioncopper.com/.

82. John Zadeh, "Resolution Copper's Fast-Track Status Accelerates US Mining Priorities," *Discovery Alert*, April 19, 2025, https://discoveryalert.com.au/news/resolution-copper-fast-track-status-2025-us/#:~:text=This%20designation%2C%20announced%20by%20the%20Trump%20administration%20in,under%20the%20Federal%20Permitting%20Improvement%20Steering%20Council%20%28FPISC%29.

83. "Permitting and Authorizations," Mining Association of BC, accessed April 13, 2025, https://mining.bc.ca/permitting/.

84. Astor Luft, "Are Mining Companies Ready for the Next Investment Upcycle?" Independent Project Analysis, March 23, 2023, https://www.ipaglobal.com/news/article/are-mining-companies-ready-for-the-next-investment-upcycle/.

85. Paul Manalo, "Discovery to Production Averages 15.7 Years for 127 Mines," S&P Global Market Intelligence, June 6, 2025, https://www.spglobal.com/market-intelligence/en/news-insights/research/discovery-to-production-averages-15-7-years-for-127-mines.

86. Ione Wells, "Mining Giants Sign $30bn Settlement for Brazil 2015 Dam Collapse," *BBC*, October 25, 2024, https://www.bbc.com/news/articles/cx2dk8yy4kjo.

87. Simone Clarke, "Mali, Niger &Amp; Burkina Faso: The Alliance of Sahel States Reshaping Africa & Rejecting Western Influence," MEFeater, March 4, 2025, https://www.mefeater.com/mali-niger-burkina-faso-the-alliance-of-sahel-states-reshaping-africa-rejecting-western-influence/.

88. Sigurd Mareels, Anna Moore, et al., "Through-Cycle Investment in Mining," McKinsey & Company, July 8, 2025, https://www.mckinsey.com/industries/metals-and-mining/our-insights/through-cycle-investment-in-mining.

89. "Sharp Drop in Private Equity Metals and Mining Sector Deals in 2024."

90. "Welcome to the AARP," Australian Automation and Robotics Precinct, accessed May 30, 2025, https://www.theaarp.com.au/.

91. "History of INL," Idaho National Laboratory, accessed May 13, 2025, https://inl.gov/history/.

92. John R. Owen, Deanna Kemp, et al., "Energy Transition Minerals and Their Intersection with Land-connected Peoples," *Nature Sustainability* 6, no. 2 (December 1, 2022): 203–211, https://www.nature.com/articles/s41893-022-00994-6.

93. Paul Mitchell, "Top 10 Risks and Opportunities for Mining and Metals Companies in 2025," EY, October 1, 2024, https://www.ey.com/en_us/insights/energy-resources/risks-opportunities.

94. "Clean Water State Revolving Fund (CWSRF)," US Environmental Protection Agency, accessed May 11, 2025, https://www.epa.gov/cwsrf.

95. Samuel Block, "Mining Energy-Transition Metals: National Aims, Local Conflicts," MSCI, June 3, 2021, https://www.msci.com/www/blog-posts/mining-energy-transition-metals/02531033947#.

96. Matthew Gregg, "Separate But Unequal: How Tribes, Unlike States, Face Major Hurdles to Access the Most Basic Public Finance Tools," Brookings, December 3, 2021, https://www.brookings.edu/articles/separate-but-unequal-how-tribes-unlike-states-face-major-hurdles-to-access-the-most-basic-public-finance-tools/.

97. Matthew Gregg and John Morseau, "Tax Code Constraints Limit Tribal Tax-exempt Bonding," Federal Reserve Bank of Minneapolis, April 24, 2025, https://www.minneapolisfed.org/article/2024/tax-code-constraints-limit-tribal-tax-exempt-bonding.

98. "Overview of the Tribal Tax and Investment Reform Act of 2025," NAFOA, June 18, 2025, https://nafoa.org/policy-alert-overview-of-the-tribal-tax-and-investment-reform-act-of-2025/.

99. "First Nations Finance Authority Ratings Raised to 'AA-' from 'A+' on Strengthened Market Position; Outlook Stable," S&P Global, August 21, 2024, https://disclosure.spglobal.com/ratings/en/regulatory/article/-/view/type/HTML/id/3234482.

100. "Blended Finance," Convergence, accessed May 10, 2025, https://www.convergence.finance/blended-finance.

101. Alastair Marsh, "BlackRock, TPG Deal with UAE Find New Way to Juice ESG Returns," *Bloomberg*, December 15, 2023, https://www.bloomberg.com/news/articles/2023-12-15/blackrock-tpg-deal-with-uae-finds-new-way-to-juice-esg-returns.

102. "First Nations Finance Authority Ratings Raised to 'AA-' from 'A+' on Strengthened Market Position."

103. "Lobito Corridor Investment Promotion Authority," Lobito Corridor, accessed June 25, 2025. https://www.lobitocorridor.org/.

104. “Supply Chain Resiliency Initiative,” Export-Import Bank of the United States, accessed May 10, 2025, https://www.exim.gov/about/special-initiatives/supply-chain-resiliency-initiative.

105. “Energy Dome–Catalyst,” European Investment Bank, February 19, 2024, https://www.eib.org/en/projects/all/20230127.

PARTICIPANT LIST

This list includes participant organizations from interviews and curated convenings.

A10 Invest; Sigma Lithium

Activate New York

Alaska Industrial Development and Export Authority

America's Frontier Fund

Appian Capital

Arias Resource Capital Management

ARPA-E

Ausenco

BC First Nations Energy and Mining Council

BHP

Breakthrough Energy

British Columbia Investment Group

CalPERS

Capricorn Investment Group

Cherokee Nation Businesses

Citibank

Clareo

Compass Minerals

CREO

CrossBoundary Group

Cuberg

Datavolt

Dunes Point Capital

Eldridge Industries

Embassy of Argentina, Washington, DC

Employ America

Energy Source Minerals

Engine No 1

Envicore

European Bank for Reconstruction and Development

Fannon Global Advisors

First Nations Finance Authority

First Nations Major Projects Coalition

First Peoples Worldwide

Fondo de Ahorro de Panama

Fortescue

GEG Geosleeve

GEM Global Emerging Markets

Glencore

Initiative for Responsible Mining Assurance

Inspire Resources

Inter-American Developmental Bank

International Council on Mining and Metals

Justice Capital

Lightdale

Litore Partners

Longhouse Capital Partners

M4E Lithium

Manara Minerals

Materion

McKinley Management

Mining Innovation Commercialization Accelerator

Mining Association of Canada

Mission Driven Finance

Mosaic Insurance

MP Materials

MUFG

NEI Investments

New York State Common Retirement Fund

Newlab

Open Mineral

Orion Industrial Ventures

Orion Resource Partners

Phoenix Tailings

Principal Asset Management

Principal to Principal

Prospect Innovation

Rodell Consulting

Royal London Management

Saudi National Industrial Development and Logistics Program (NDLIP)

Sigma Lithium

State of Oklahoma

Talon Metals

Texas A&M University

Total Impact Capital

Tulsa Innovation Lab

US Agency for International Development

US Department of Defense, Office of Strategic Capital

US Department of Energy

US International Development Finance Corporation

VERAI

Warwick Investment Group

Wyoming Retirement System

Yamaha Motor Ventures

ABOUT THE AUTHORS

Ashley Campany is an associate director on the Innovative Finance team at the Milken Institute. She is responsible for research, development, execution, and follow-up for the Institute's Financial Innovations Labs. Campany has experience in marketing, fundraising, business development, and investor relations, working within financial institutions and startup ecosystems. Most recently, she was responsible for strategic business initiatives, partnerships, and project management at a startup nonprofit organization, The ELLA Works Foundation. Before ELLA, she was an investor services associate at Centerbridge Partners, where she worked across private equity, real estate, and credit, providing servicing to Centerbridge's institutional client base, responding to ad hoc investor inquiries and due diligence questionnaires, and reviewing capital fund activity. Previously, she was an investor relations associate at Foundation Credit, a boutique asset management firm focused on municipal credit, where she serviced its existing client base and cultivated relationships with prospective investors. Prior to Foundation Credit, she focused on business development and partnerships at Loeb Enterprises, a New York-based private investment and venture collective. Campany graduated from Union College with a BA in political science.

Kanika Singh is director of Innovative Finance at the Milken Institute. She is responsible for executing the Institute's signature research projects, the Financial Innovations Labs, with a specific focus on the market failures and financing gaps in climate solutions. Prior to joining the Milken Institute, Singh worked in New York's hedge fund industry, where she led macroeconomic investments in emerging markets by employing a cross-sectoral and global strategy to identify investment opportunities for chief investment officers. She also served as the lead economist at international financial institutions in London and Singapore, collaborating with clients that included investment banks, central banks, and sovereign wealth funds. Singh has a proven track record in rigorous macroeconomic analysis, investing in developing countries, and portfolio management in financial markets. Additionally, she built and maintained relationships in C-suite and policy circles. She holds an MS in sustainability management from Columbia University and an MS in economics from the London School of Economics.

LOS ANGELES | WASHINGTON | NEW YORK | MIAMI | LONDON | ABU DHABI | SINGAPORE