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Critical Minerals in the Arctic: Forging the Path Forward

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Critical materials play a vital role in powering modern technologies, from renewable energy systems and electric vehicles to advanced electronics and national defense. However, the United States faces challenges in securing a reliable supply of these materials, which are essential for its economic competitiveness and national security. These materials include metals such as lithium, cobalt, rare earth elements, and graphite. They are essential for the manufacturing of high-tech products like batteries, semiconductors, magnets, and catalysts. With the increasing demand for electric vehicles, renewable energy systems, and advanced electronics, the United States heavily relies on critical materials to drive innovation and maintain its global economic competitiveness.

The United States faces several challenges in securing a stable supply of critical materials. One major challenge is the concentration of production in a few countries, primarily China. China dominates the global supply chain of critical materials, accounting for a significant share of mining, processing, and refining capacity. This dependency raises concerns about supply disruptions, geopolitical risks, and market manipulation.

This problem is complex requiring a multi-pronged approach to develop the best path forward. Attention from multiple agencies with private sector involvement is needed to address issues including resource definition, recovery technology development, recycling technologies, international relations, supply chain resilience and improvements and, domestic resource development policies. A successful outcome will necessitate a diverse approach, strong collaborations, exchange of information and practices, and perhaps most importantly, persistence.

Ensuring a reliable and sustainable supply of these materials is essential for the country's economic growth, technological advancement, and national security. By investing in domestic production, promoting responsible sourcing, and fostering international collaborations, the United States aims to strengthen its critical materials supply chains. These efforts will contribute to a more resilient and secure future, enabling the United States to maintain its position as a global leader in innovation and technology.

This overview explores the issue of critical materials supply chains in the United States, examining the importance of these materials, the challenges associated with their supply, efforts being made to address the issue, and research avenues.

America’s Arctic in the critical mineral arena

Arctic regions share many attributes that inspire and challenge resource development. Developing and sharing Arctic-friendly technologies and solutions across international borders, will strengthen Arctic relations, build Arctic economies, help disadvantaged communities and strengthen the nations critical mineral supply chain. Alaska is proud to participate alongside its Arctic colleagues in developing new technologies to meet this challenge.

Alaska's complex geological history has led to formation of a wide array of mineral deposit types containing commodities many list as critical. Alaska either has, is, or could produce almost all of the commodities on the US Geological Survey's 2022 list of critical minerals. Alaska is the largest producer of zinc in the nation, contains the nation's largest graphite deposit, is the state with the only domestic tin resources and, has been a producer of critical minerals in times of national need, e.g. During WWII Alaska contributed tin, PGE's, chrome, tungsten and antimony for the war effort. Most of the commodities produced to support the war effort have not been significantly produced since, and the resources remain in place, creating a ripe environment for meeting the nations need for these critical minerals.

Alaska is large in the domestic context, being about one fifth of the size of the contiguous states. Millions of acres of land selected by native corporations and the state were selected based on mineral potential. These, along with open federal lands provide almost half of Alaska's 400 million acres open to mineral development. Alaska has an active resource development industry known for rigorous environmental and social justice practices.

The University of Alaska is uniquely positioned to assist the national need for a stable critical minerals supply chain, with many of the necessary components to be a center of critical minerals research already in place, including the Mining Engineering and Mineral Processing, Geology, Economics and Chemistry departments, the Mineral Industry Research Laboratory, the unmanned aircraft program, the Geophysical Institute, the Institute of Northern Engineering, a strong relationship with the mineral industry, a strong state geological survey, and strong State of Alaska support for critical mineral research. Centered in the heart of Alaska's mineral industry, the University of Alaska's planned Alaska Critical Mineral Research Center creates potential broad research areas to focus on to facilitate Alaskan, American, and Arctic critical mineral production.

> Develop centers of excellence and innovation to research and develop solutions that support stable domestic supplies of critical minerals

What is important depends on your perspective

The perception of what constitutes a critical material is contingent upon one's perspective. Different industries and regions have distinct supply chains and material requirements. For instance, what is considered critical for a solar installation company in one country may not be for a vehicle manufacturer in another. Divergent perspectives arise from variations in supply chains and material needs. In the case of a thin-film solar panel manufacturer, concern might involve securing a stable supply of minerals like indium or tellurium. Conversely, a vehicle manufacturer might prioritize access to critical materials like lithium and cobalt, which are indispensable for the production of electric vehicle batteries. Engaging with industry to determine research needs is crucial to maximize research investment impacts.

> Establish a pathway for industry to engage in public-private partnerships to focus research.

Further, material criticality is dynamic. A material that is critical today may not be in the near future. Technological advancements play a crucial role in changing mineral criticality. For instance, the discovery of the Bayer process in 1888 revolutionized the extraction of aluminum from bauxite, significantly increasing its availability. Geopolitical forces also influence mineral criticality, as shifts in trade relationships, conflicts, and policy changes can impact the accessibility of certain minerals. As technologies advance and new applications emerge, the demand for certain minerals may increase or decrease, leading to shifts in their criticality over time. Potential for rapidly changing demand dynamics creates risk for mineral developers, disincentive to investment, and negatively impacts supply of these minerals.

> Establish domestic mineral policies that mitigate criticality fluctuation risk for mineral investment.

Supply chains

The supply chains for critical materials in the United States face potential bottlenecks that extend beyond domestic mining. Even if the United States enhances its domestic mining operations, challenges are present in other stages of the supply chain. These include processing, refining, and manufacturing, which are equally critical for a secure and reliable supply of critical materials.

The case of copper is illustrative. The top four countries in terms of identified reserves of copper are Chile, Australia, Peru and Russia which collectively account for 49% of global reserves. The top four countries in terms of primary mine production are Chile, Congo (Kinshasa), Peru, and China which collectively account for 52% of primary mine production. However, at the refining stage, the top four countries of China, Chile, Congo (Kinshasa), and Japan collectively account for 63% of refined production, with China alone representing 42% of global refining.

In terms of processing and refining, the United States relies heavily on foreign countries for these crucial steps. Limited domestic processing facilities and expertise ensure foreign transformation of raw materials into usable forms. Investing in domestic or allied processing capabilities will reduce dependence on foreign processing and mitigate potential disruptions. Engaging with processing facilities in allied countries to expand processing infrastructure and increase metal recovery in those facilities can strengthen the supply chain and reduce supply-chain vulnerability.

> Engage with smelting and refining facilities in the Americas and in geopolitically aligned countries to assess their capacities to recover CM from Alaskan ores, and develop process modification strategies to recover critical minerals not currently recovered.

Increasing Domestic supply

Geologic processes often concentrate several metals of economic interest together in a single deposit. Many critical minerals are produced as by-products in the extraction, processing, and refining of other, more economically significant metals. For example, germanium and indium are mostly produced as a by-product of zinc; gallium a by-product of aluminum, and tellurium is a by-product of copper production. Because the global demand of some critical minerals is small, mines dedicated exclusively to these metals would not be economically sufficient to warrant exploration. Those commodities will still need to be produced as co-products or by-products from production of more economically significant metals.

Baseline geological, geophysical and geochemical data is being acquired by the University of Alaska, the Alaska Division of Geological & Geophysical Surveys (DGGS) and the United States Geological Survey (USGS) through programs like the Department of Energy's (DOE) CORE-CM, and the USGS's Earth MRI. These programs are producing the modern digital baseline data of our sedimentary basins and crystalline rocks that industry uses to evaluate those regions for critical mineral resources. Much remains to be done, and these programs need to continue until domestic data coverage is complete. Increasing the speed and reducing the cost of data collection through automation may be achieved through drone based-surveys. The University of Alaska is well positioned to research and develop drone-carried geophysical equipment to conduct regional and prospect-scale surveys.

> Develop drone-carried geophysical survey equipment to reduce the cost, increase the speed and density of data collection.

Similarly, researching and developing drone-based hyperspectral surveying capability to make hyperspectral data acquisition and processing more practically available. Incorporating hyperspectral data in regional or prospect-scale surveys to support critical mineral assessments will facilitate resource discovery and development. One limitation with hyperspectral data is its limited utility in vegetated areas. Developing algorisms to filter vegetation signals from the data will broaden the usability of this method.

Modern geological data is geospatial and digital. Machine learning (ML), or artificial intelligence (AI) algorithms could leverage this digital geophysical, geochemical and geological data to predict locations of interest for critical minerals. These would allow national or state entities and industry to focus resources on highest potential areas and shorten the time to discovery and production.

> Develop AI or ML routines using a mineral systems approach to predict CM locations from integrated digital data.

High transportation and energy costs in remote arctic regions are a significant economic barrier to development. The costs for transporting concentrates for further processing and metal extraction at a distant facility can be insurmountable for remote locations. Process technologies that allow shipment of metals rather than ore from remote locations would greatly improve project economics, and increase domestic production. At the same time, many conventional refining and metal extraction processes are energy intensive, making them prohibitively expensive in remote Arctic areas that face some of the nation's highest energy costs. Processes which improve recovery efficiency or concentrate grade without requiring more energy have the greatest potential to enhanced value added activity. As an example, in the gold mining industry bio-oxidation of sulfides followed by gold leaching is a method to recover gold from appropriate ores. Extending this or similar process technology to appropriate critical mineral ores could significantly improve the economics of remote deposits, bringing more into production.

> Support metallurgical research to increase ability for onsite reduction to metals.

Industry investment can be incentivized by providing baseline metallurgical information that demonstrates recovery viability for deposits in a region. This can be achieved by conducting regional characterization studies for critical mineral deposits to determine whether the mineralogy is amenable to metallurgical recovery, and whether the ores contain deleterious elements that would impact economics. For example, do any of Alaska's belts of antimony deposits contain deleterious elements that would be barriers to development?

> Support mineral-system based metallurgical research to characterize regional belts of mineral deposits.

Advanced exploration and development projects focus metallurgical work on the dominant commodities in an orebody, frequently paying little to no attention to minor commodities that would be a by-product. Engaging with projects in the advanced exploration to development phase to characterize critical mineral content, and developing solution to production barriers would help facilitate critical mineral production from the next generation of domestic mines. E.g. cobalt is contained in the pyrite at the Bornite deposit in northwest Alaska, what metallurgical solutions can be developed to facilitate its recovery.

Barriers to critical mineral production must exist at current mining operations where the contained critical minerals are not being produced. Determining these barriers and researching solutions to facilitate critical mineral production where appropriate could bring rapid results e.g., ore at the Greens Creek and Red Dog mines contains significant barite, but neither mine produces barite as a salable product. By contrast the Palmer project, which is geologically similar to these deposits, is planning to produce barite as a salable product.

> Engage with industry to develop recovery circuits for critical minerals at existing and developing mines

Process waters from oil and gas production potentially contain critical minerals. Development of carbon resources that result in metal-rich brine production from organic deep-water sediments offer potential for by-product critical mineral production. On Alaska's North Slope some of the oil and gas source rocks are known to contain high REE, V, P and fluorine. Extraction techniques developed to extract critical minerals from Alaskan production waters could be utilized across the Arctic. Produced water and reservoir composition datasets may allow al mineral prediction of critical mineral content in undeveloped unconventional reservoir.

Reducing Import Levels

The demand for metals is expected to growth significantly between now and 2030. The rapid industrialization in emerging economies, particularly in Asia, will contribute to increased demand for metals. The transition towards renewable energy sources, including wind and solar power, will also spur the demand for metals like lithium, cobalt, and rare earth elements used in the production of batteries, permanent magnets, and energy storage systems. E.g., the International Monetary Fund forecast that graphite production will need to increase by almost 1000% to meet the need for electric vehicle batteries.

Looking ahead to 2050, the growth in demand for metals is projected to continue, driven by transformative global trends. The global population is expected to reach nearly 10 billion by 2050, leading to increased consumption. The continued shift towards sustainable energy systems and the electrification of various sectors, including transportation and industrial processes, will sustain the demand for metals.

Without increased domestically available supplies, increased global demand for these commodities will deepen the nation's exposure to an insecure supply chain, and threaten the domestic conversion to renewable energy. The International Monetary Fund concluded that without increased metal availability, demand-based commodity inflation alone could negatively impact the energy transition.

Rapid development of recycling technologies will be crucial to both reduce the environmental impact from increased use of CM's, and reduce the need for new mineral production to meet this demand. Electric car batteries are a clear example of the need for enhanced recycling technologies, with the number of batteries in production, being used and being disposed of projected to rapidly increase with the transition to electric vehicles.

> Develop new recycling solutions to reduce the risks and impacts from global increases in metal demand.

Domestic Mineral and Economic Policies

Global markets are small for some critical mineral commodities, in terms of the tons of mineral consumed or the dollar value of the global demand, e.g., tellurium. These small market commodities are easily dominated by a handful of producers, or single nation, making them susceptible to price manipulation and supply constraints. Price manipulation creates a particular risk to mineral investors who need assurance that minerals can be produced profitably prior to investing capital in exploration or development. This investment risk nominally increases as the market size of the commodity and number of producers decreases. Risks associated with small market resource development include commodity substitution, new technologies reducing demand, recycling improvements, production technology improvements and, market manipulation and inelasticity. Risks associated with small market commodities deter investment by the minerals industry. National or international policy agreements that mitigate these risks will increase mineral investment and improve critical mineral availability.

> Develop national or international policies or incentives to de-risk market manipulation will spur industry investment in critical mineral development.

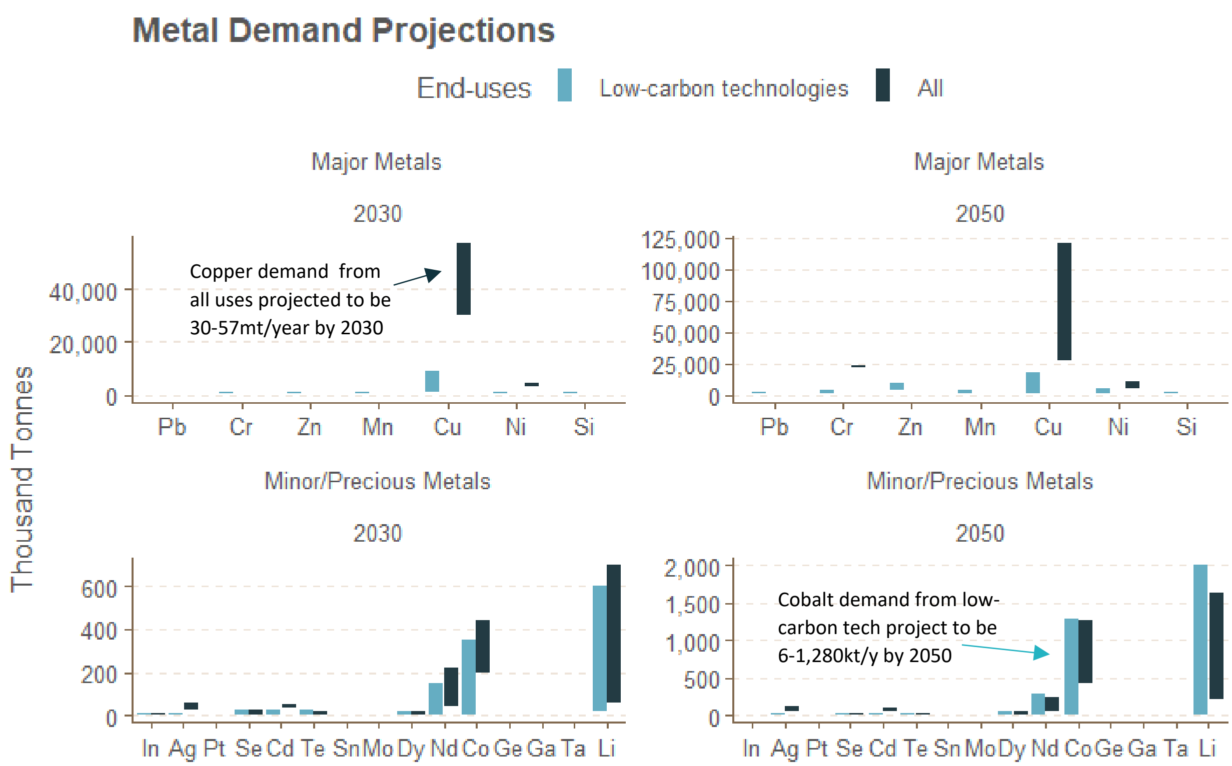
> Conduct economic analyses and develop economic and regulatory policy option for incentivizing critical mineral development in rural areas near disadvantaged communities

The environmental and social impacts associated with mining and processing these materials present sustainability challenges that need to be addressed. Environmental regulations in Arctic nations are often more rigorous that in less developed countries. This creates uneven economic conditions favoring development in

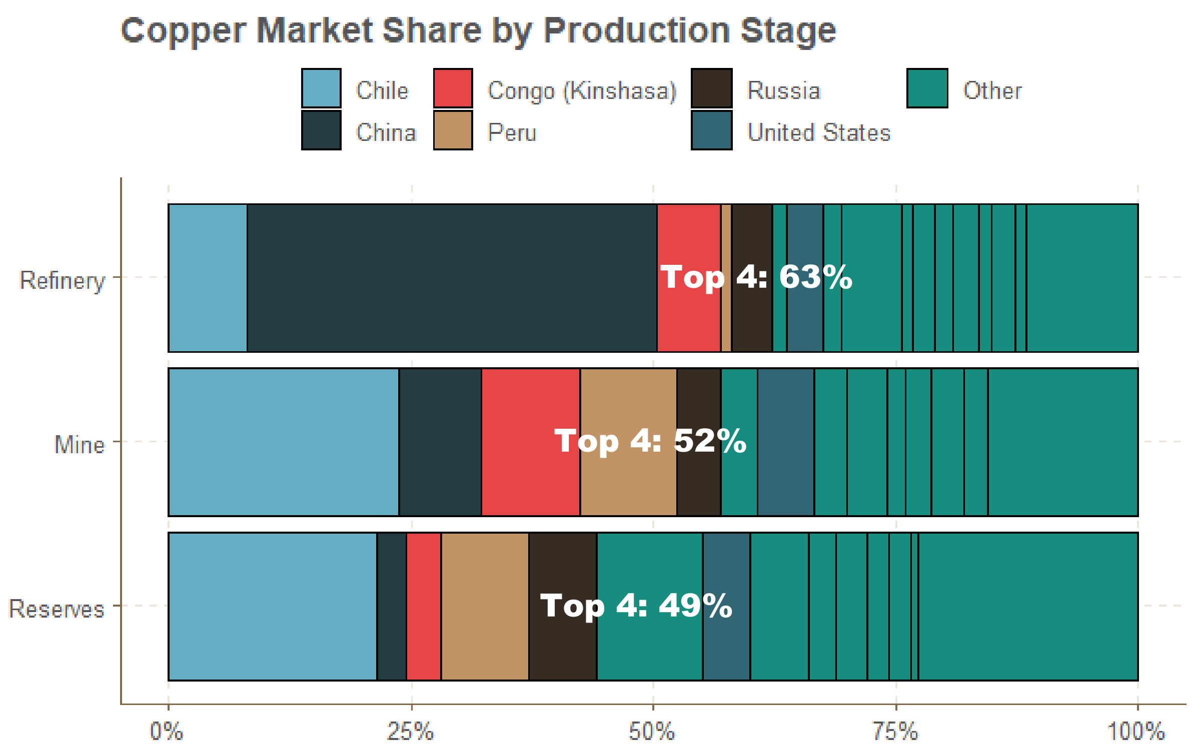
> Develop import regulations requiring critical minerals imports meet US environmental and social justice standards

regions with less stringent environmental and social policies. This can be rectified by developing import regulations requiring critical minerals imports meet rigorous environmental and social justice standards.

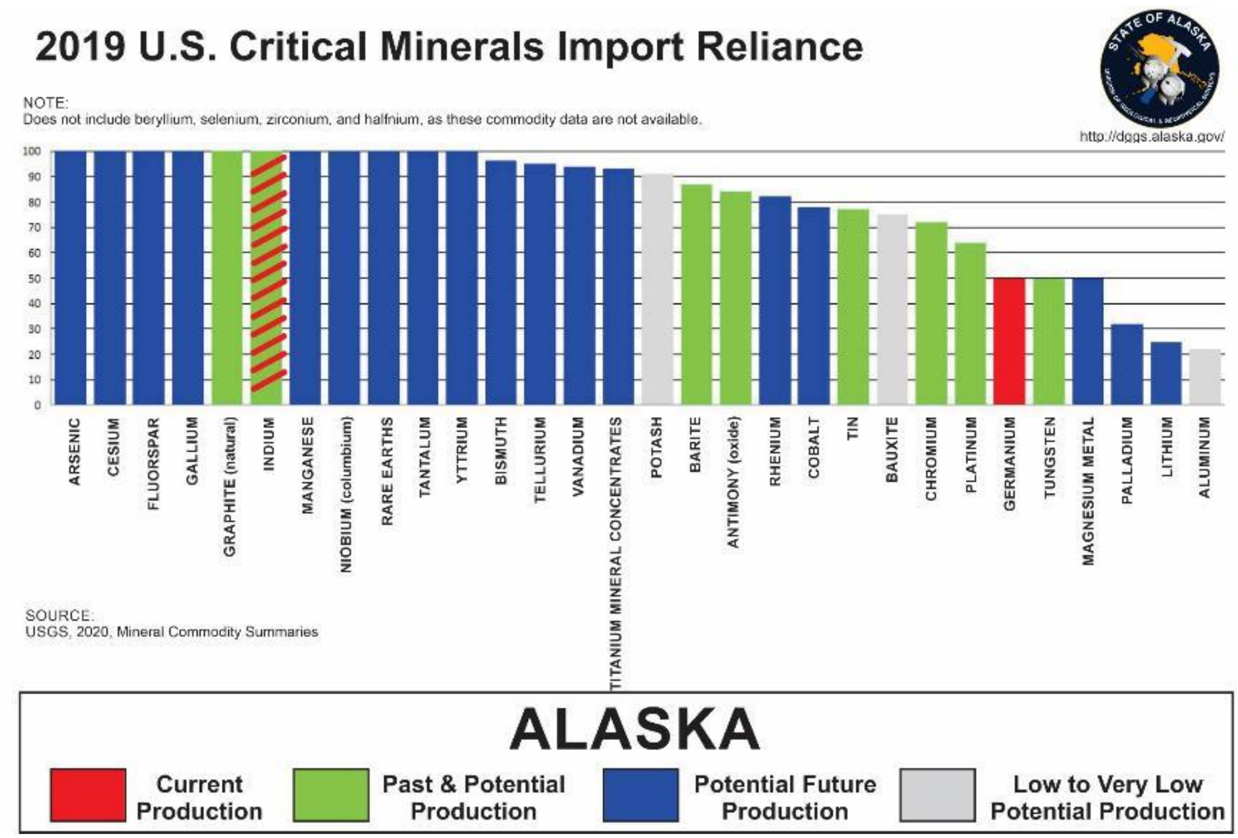
This document briefly outlines just a few of the many areas of research needed to improve the nations critical mineral supply chain. The University of Alaska and the State of Alaska are committed to work with our federal partners and Arctic colleagues to help the US and allied nations meet this challenge.



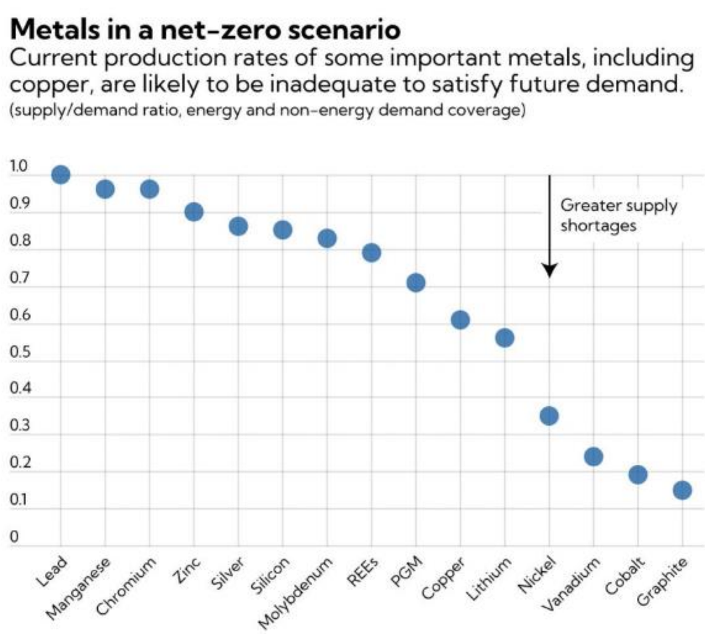
Source: Watari, T., Nansai, K., & Nakajima, K. (2020). Review of critical metal dynamics to 2050 for 48 elements. *Resources, Conservation and Recycling*, *155*, 104669. Synthesis of global demand projections from 546 data points from 88 published studies.



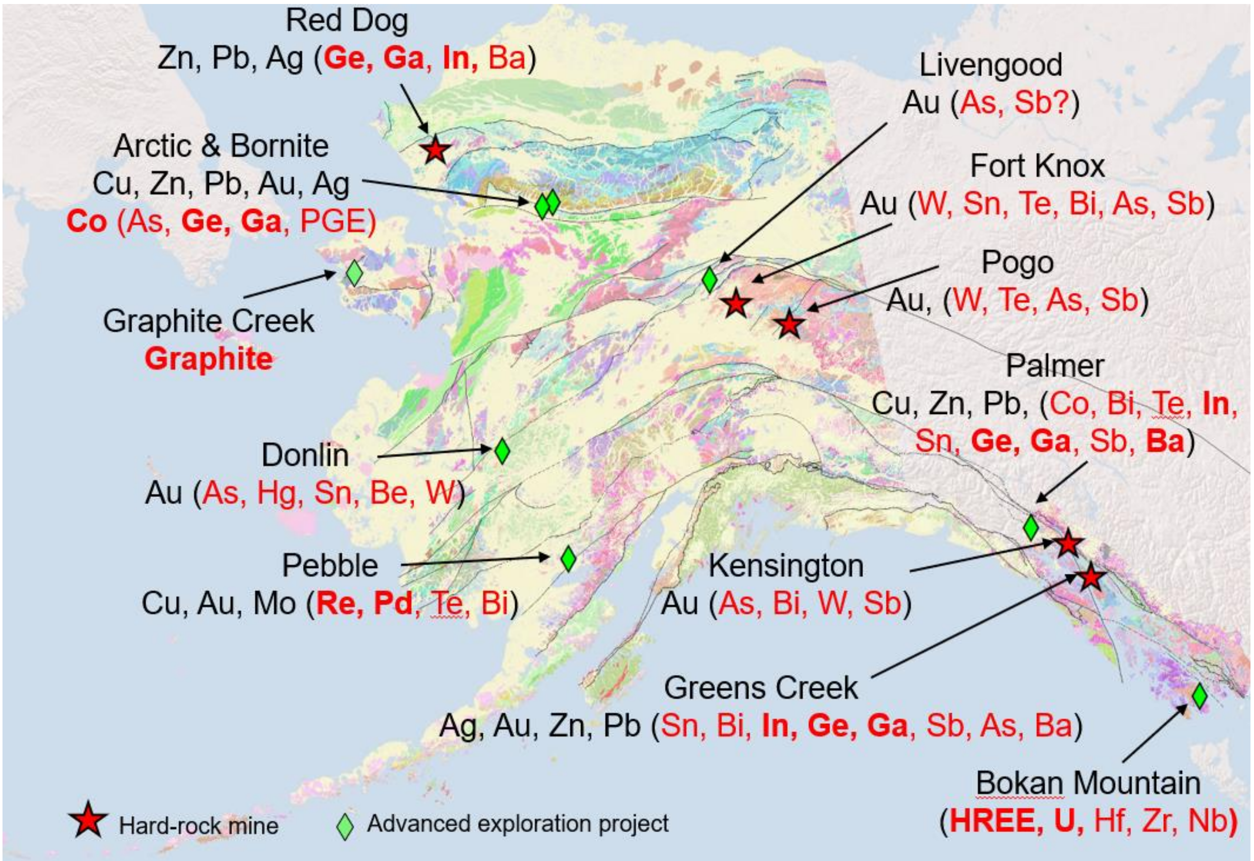
Source: Authors' visualization of data from USGS Mineral Commodity Summary 2022, Copper. Top four countries' market share at each stages reported.



Past, present and potential Alaska critical mineral production. Source State of Alaska, DGGS.



Plot of metals needed for net zero energy transition. A ratio of 0.1 indicates current supply is one tenth the supply needed for this scenario. Source – International Monetary Fund.



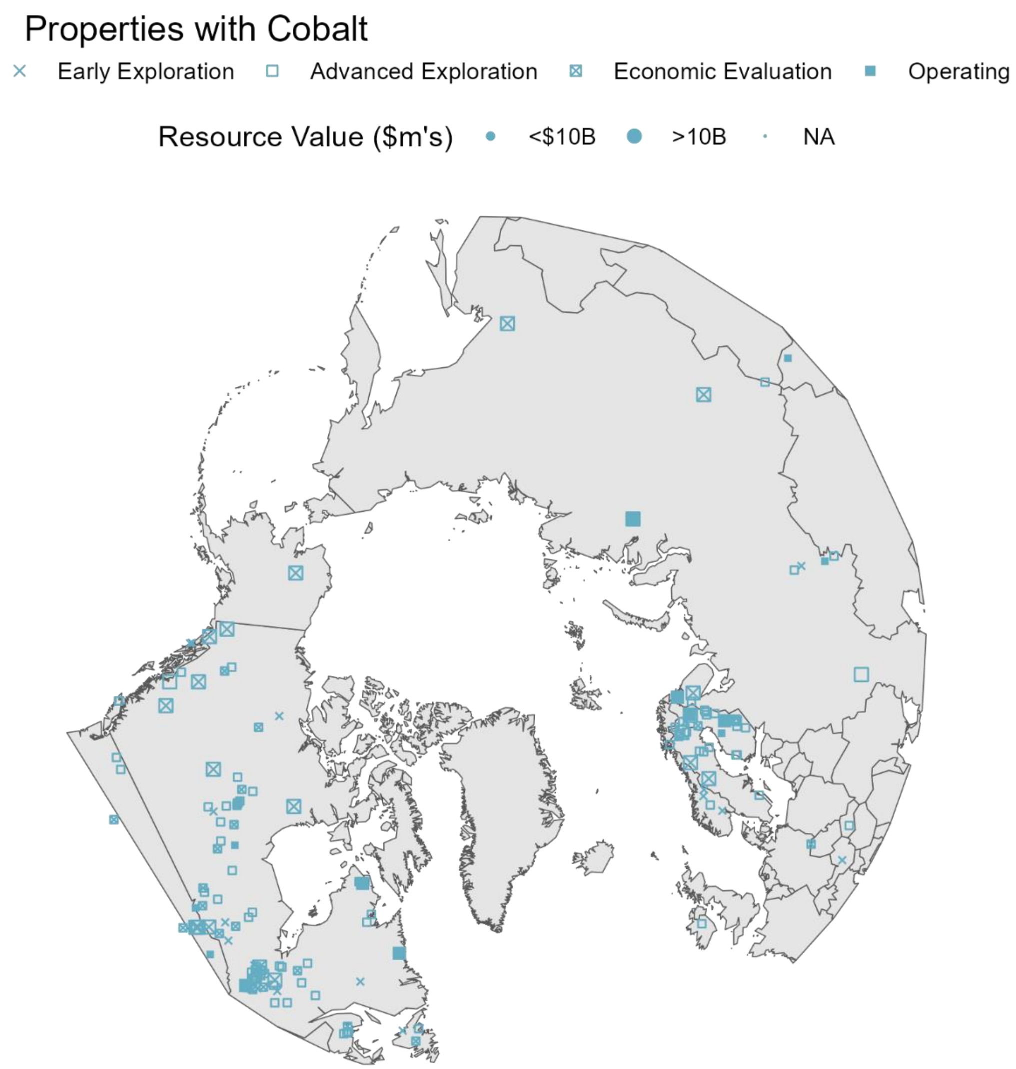
Current mines and advances projects showing contained ore metals (black) and critical minerals (red).

Minerals, Critical Materials, and the Arctic

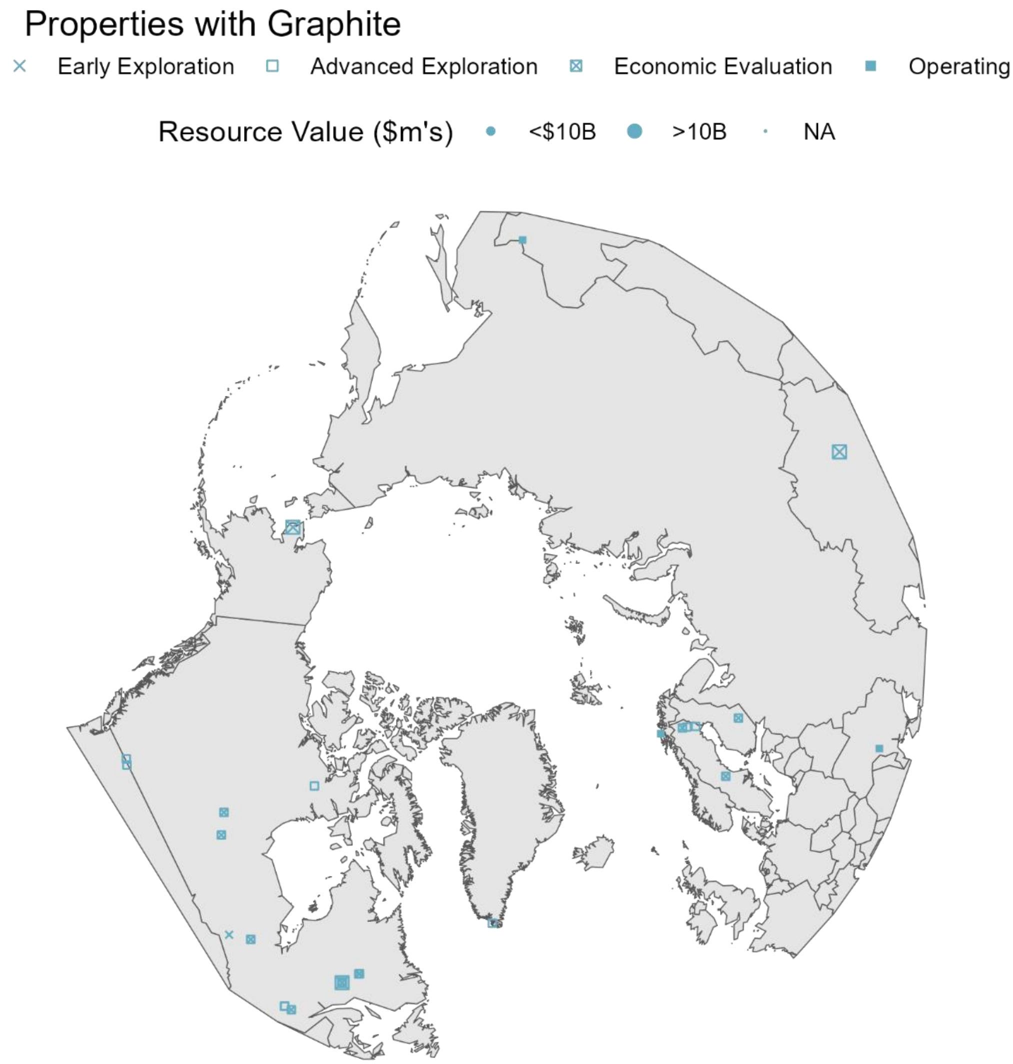
	Fraction of Properties Above Latitude			Fraction of In-situ Value Above Latitude		
Commodity	50°	60°	66°	50°	60°	66°
Tellurium	31%	15%	4%	94%	94%	93%
Gallium	54%	14%	4%	83%	73%	19%
Germanium	29%	21%	7%	45%	39%	16%
Antimony	17%	6%	1%	41%	7%	2%
Tungsten	16%	7%	1%	36%	5%	1%
Iridium	14%	8%	5%	34%	34%	33%
Platinum	23%	9%	4%	33%	20%	19%

Vanadium	16%	7%	4%	32%	11%	4%
Cadmium	26%	6%	4%	28%	5%	4%
Zinc	21%	7%	1%	24%	15%	1%
Uranium	27%	4%	1%	24%	20%	0%
Ilmenite	9%	3%	2%	23%	12%	12%
Tantalum	20%	5%	1%	22%	7%	0%
Nickel	22%	8%	3%	22%	14%	9%
Lead	19%	6%	1%	22%	7%	1%
Silver	18%	6%	1%	19%	7%	5%
Chromite	13%	3%	1%	18%	3%	2%
Cobalt	19%	8%	3%	17%	13%	11%
Copper	20%	6%	2%	17%	7%	4%
Titanium	18%	6%	3%	16%	2%	2%
Rare Earth Elements	21%	6%	2%	16%	10%	6%
Molybdenum	23%	4%	1%	16%	4%	1%
Gold	17%	6%	1%	16%	6%	4%
Bauxite	7%	5%	1%	15%	14%	13%
Niobium	29%	7%	1%	14%	7%	1%
Graphite	20%	7%	3%	9%	5%	2%
Lithium	16%	2%	0%	9%	1%	0%
Manganese	4%	1%	0%	6%	1%	1%

Source: Author's calculations based on data from S&P CIQ Metals and Mining Database. Fraction of Properties is the percentage of projects and mines above a given latitude relative to all properties in the database which contains identified quantities of the listed commodity. In-situ value is an estimate of the in-situ value of the total resources and reserves of the project using prices from S&P, above the specified latitude, as a fraction of the total estimated in-situ value of all properties containing the specified commodity.



Source: Author's visualization based on data from S&P CIQ Metals and Mining Database. Early exploration is projects that are listed with status: satellite, target outline, closed, exploration, or grassroots. Advanced exploration is projects that are listed with status: advanced exploration or reserves development. Economic evaluation is projects that are listed with status: commissioning, construction planned, construction started, feasibly, feasibility complete, feasibility started, prefeasibility /scoping. Operating is projects that are listed with status: operating, limited production, pre-production, expansion, residual production. Resource value is an estimate of the in-situ value of the total resources and reserves of the project using prices from S&P.



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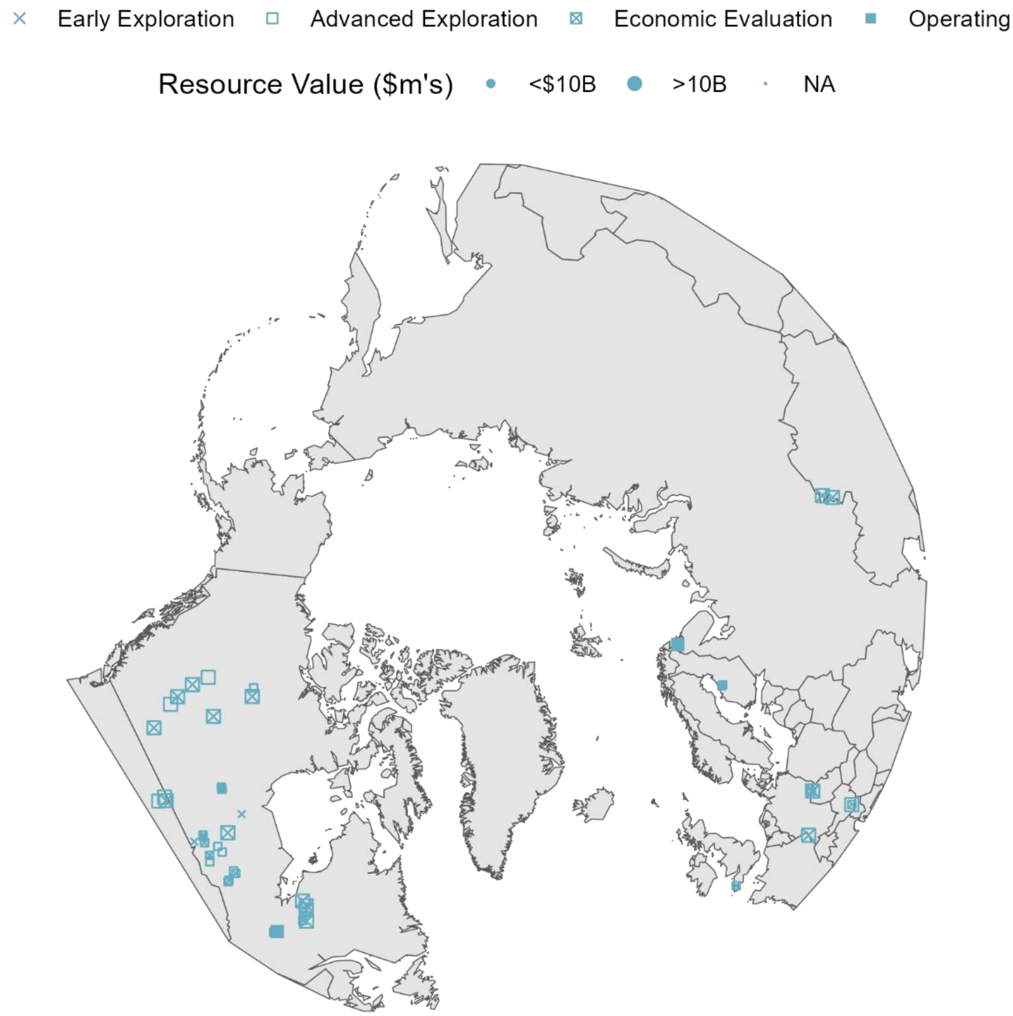
Properties with Lithium



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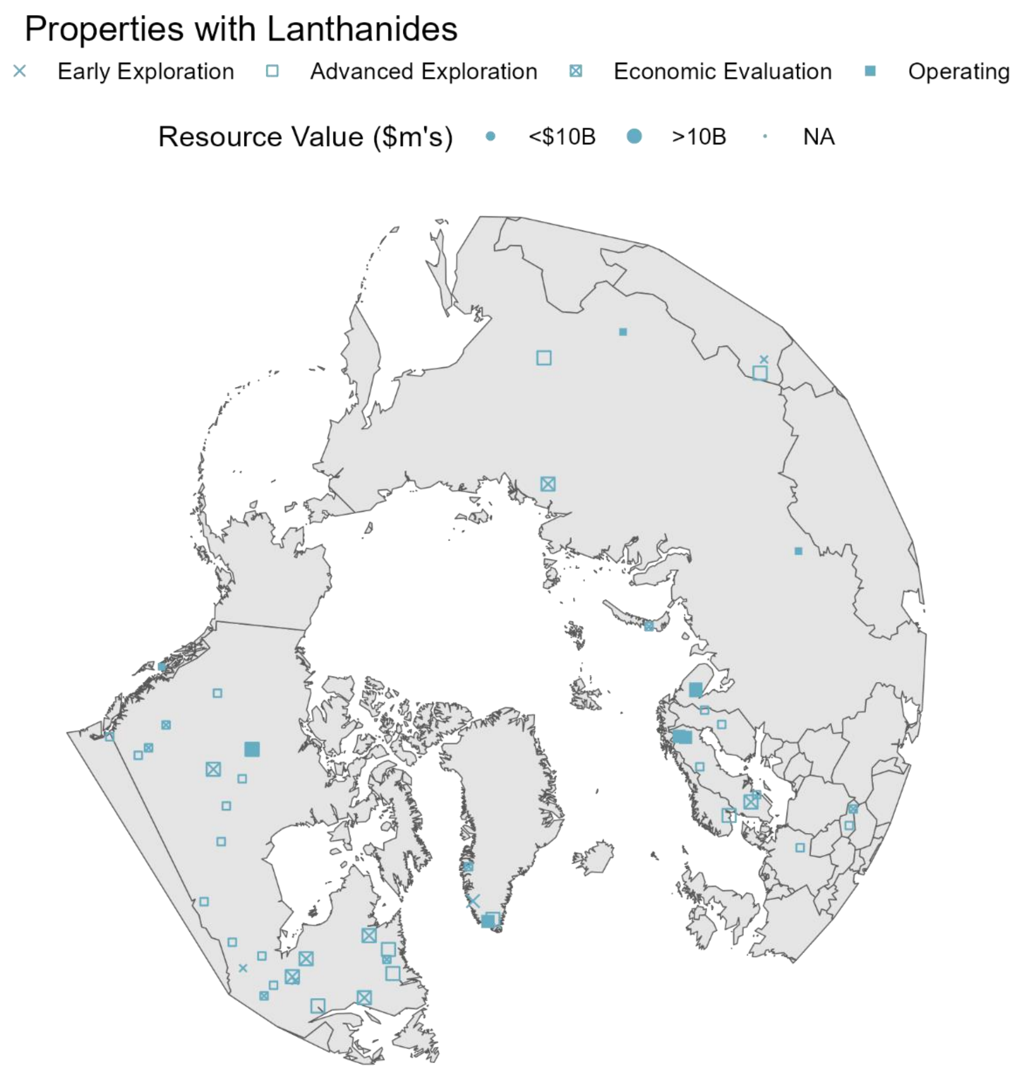

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