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A Competitiveness Framework for Minerals and Metals

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Lindsey Ljungberg

Anna Perry

Meagan Reid

Rishab Sardana

Sarah Scott

Kelsi Van Veen

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 Please direct all correspondence to Lindsey Ljungberg, Meagan Reid, Sarah Scott, or Kelsi Van Veen, Office of Industry and Competitiveness Analysis, U.S. International Trade Commission, 500 E Street, SW, Washington, DC 20436, email: Lindsey.Ljungberg@usitc.gov, email: Meagan.Reid@usitc.gov, email: Sarah.Scott@usitc.gov, email: Kelsi.VanVeen@usitc.gov.

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This working paper presents a broad framework for assessing the competitiveness of mineral and metal industries across countries. Information is sourced from a combination of desk research and interviews with industry experts. The core factors of competition for mineral and metal industries are cost, product differentiation, and supply dynamics. Within each of these factors are two to three subfactors that are the most relevant drivers of the broader factor. The paper also covers other cross-cutting production conditions that can impact all three factors of competitiveness. These include government policies and regulations, foreign direct investment, and negative externalities and risk management.

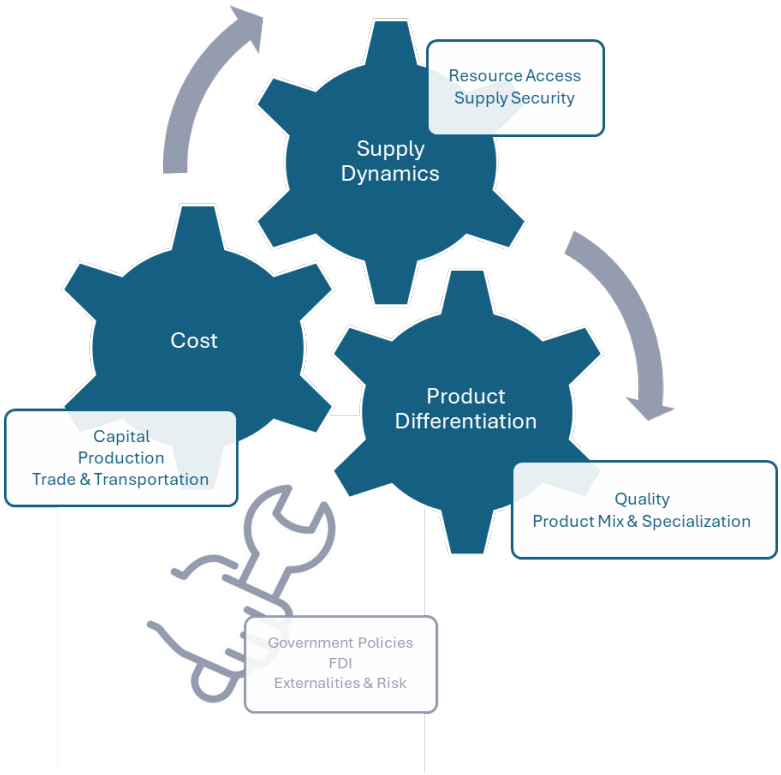
Introduction

Minerals and metals are of increasing importance across a wide range of sectors from defense to construction and infrastructure to energy transition and other advanced technologies. Recent U.S. trade policies look to establish the United States as a leading global producer of minerals and metals and to explore opportunities to advance the mining and processing of these products within the United States.[1] Globally, many countries have similar goals. Understanding the factors and conditions impacting the competitiveness of minerals and metals across countries is a crucial first step in determining how to achieve these goals. To that end, this working paper presents a broad framework for assessing the competitiveness of mineral and metal industries across countries.

An extensive review of academic and business literature, media reports, public data, and information from mineral and metal firms was combined with information from interviews with industry experts to identify the most important factors and conditions impacting competitiveness across countries. The core factors of competition for mineral and metal industries are cost, product differentiation, and supply dynamics. Within each of these factors are two to three subfactors that are the most relevant drivers of the broader factor (see figure 1). Other cross-cutting production conditions that can impact all three factors of competitiveness. These include government policies and regulations, foreign direct investment, and negative externalities and risk management.

[1] For example, see sections 2b and 9k of The White House, Executive Order 14154, "Unleashing American Energy," January 20, 2025.

Figure 1: Factors and Conditions Impacting the Competitiveness of Mineral and Metal Industries



Source: Developed by USITC staff.

The competitiveness factors and subfactors highlighted in figure 1 are those that were found to be common across a number of mineral and metal industries. Many of these factors and subfactors overlap and influence one another, suggesting that the framework is flexible and can be reorganized to meet the needs of a specific research question. This framework is intended to serve as a starting point for future analysis related to minerals and metals by identifying possible factors impacting a purchaser's sourcing decisions.

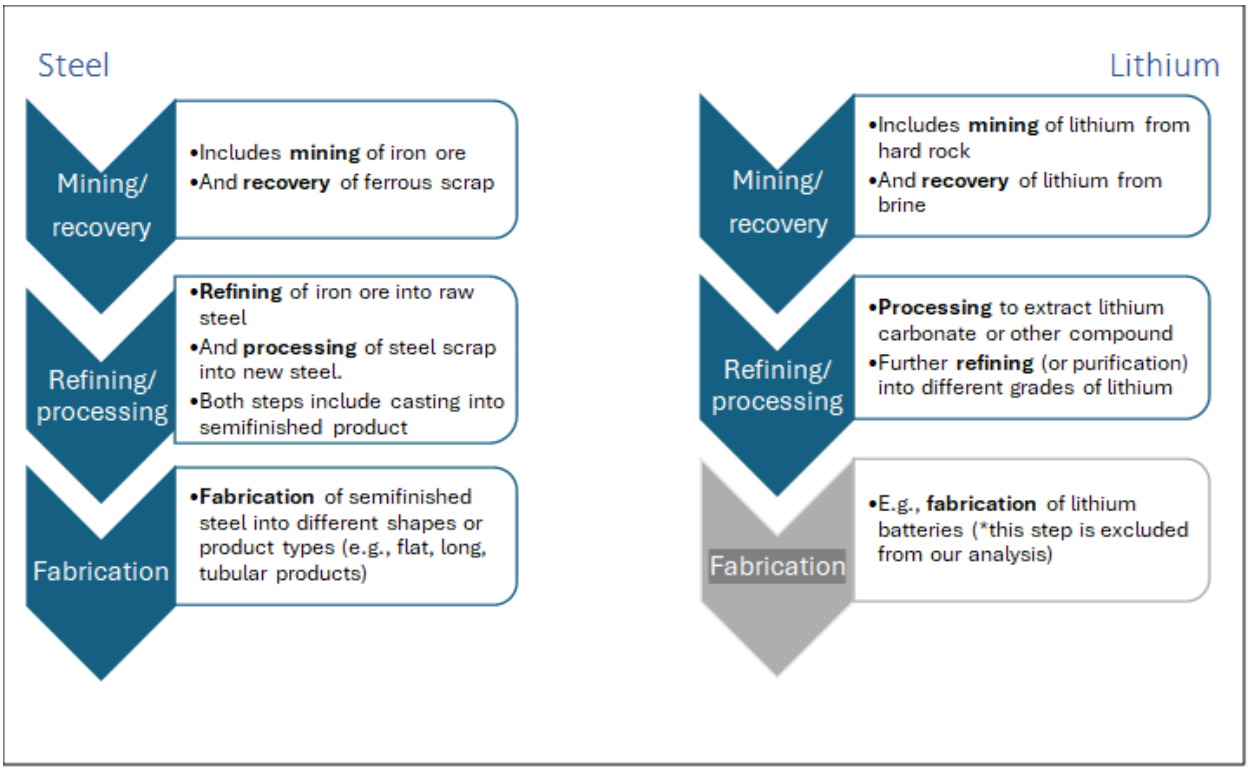
The next section of the paper defines the scope of the minerals and metals industries that were assessed. The main focus of the paper is the subsequent sections, which discuss each factor and subfactor of competition in detail, as well as the overarching conditions of competition which impact all of the aforementioned factors. The relevance of each of these factors and conditions varies across individual mineral and metal industries, and certain industries may be significantly affected by factors not identified in this paper. Examples of how the competitiveness factors affect individual mineral and metal industries are highlighted throughout the paper.[2]

[2] Lithium, nickel, and steel were used as the main industry examples throughout the paper, though examples from other mineral and metal industries are also included.

Defining the Scope of Mineral and Metal Industries

This framework for minerals and metals is unique from other USITC frameworks on competitiveness in that it considers multiple stages of a supply chain, each with distinctive conditions and factors of competition. To define the scope of the supply chain for minerals and metals, this paper considered the following stages of production: 1. mining and recovery, 2. refining and processing, and 3. fabrication. The last stage, fabrication, was included within the analysis to the extent that it did not significantly transform the product into something that could no longer be considered a mineral or metal. Figure 2 provides examples of the scope of the analysis for two specific mineral and metal products, steel and lithium.

Figure 2: Stages of production included within scope of this analysis



Source: Developed by USITC staff
Notes: Items in blue are considered within the scope of the analysis. The item in gray is excluded from the analysis as it represents a significant transformation into a product that would no longer be considered a mineral or metal. The mining and recovery stage includes exploration.

Core Factors

Cost

Industry representatives reported that cost, defined in this context as the price buyers pay for mineral and metal products, is one of the main factors impacting sourcing decisions.[3] The price buyers pay is largely a result of the costs producers face in making and delivering the product. The main costs incurred by mineral and metal producers include capital costs, production costs, and trade and logistics costs.[4] While other costs may also impact the competitiveness of certain minerals and metals, the aforementioned costs were most consistently highlighted in research and outreach efforts.

Costs can vary significantly across countries and tend to be more volatile in less established mineral and metal industries for which new end uses are often still being discovered or developed.[5] In these industries, prices can be constrained due to competition from other minerals and metals (or other substitutes). If the price of one mineral or metal becomes too high, buyers will begin to shift away from it to a relatively cheaper product that can serve similar purposes. For example, industry representatives point to an instance in 2022 where nickel prices surged and many battery producers, especially in China, switched production from lithium-ion batteries containing nickel (also known as NMC batteries) to lithium iron phosphate (LFP) batteries, which do not contain nickel.[6] This is less feasible in more developed industries where supply chains and production processes are more established. Countries' natural resource endowments also play a large role in impacting cost competitiveness for minerals and metals. As discussed below, less accessible or lower quality mineral deposits require higher capital costs, higher production costs, and potentially higher transportation costs.[7]

As sustainability and other environmental, social, governance (ESG) initiatives become more prevalent in mineral and metal and other industries[8], many mineral and metal producers are pushing for "green premiums" – which would allow them to charge a higher price for a product that is lower-emitting or produced in a more environmentally friendly way compared to a similar product. Most industry representatives interviewed for this paper agree that there is not currently sufficient demand to justify a green premium for most minerals and metals.[9] However, these industry representatives suggest that this

[3] Industry representative, interview with USITC staff, March 25, 2025.
[4] Note that some logistics costs may be incurred by purchasers rather than producers. This is discussed below.
[5] For example, one industry representative noted that lithium, nickel, cobalt and rare earth costs are particularly volatile as supply and demand factors are frequently changing. Industry representative, interview with USITC staff, March 25, 2025.
[6] Industry representatives, interview with USITC staff, March 13, 2025.
[7] As noted in "Supply," the economic viability of extracting minerals and metals is largely dependent on these cost factors and the prevailing market prices.
[8] The adoption of sustainability and ESG initiatives may be company driven or driven by stakeholders including investors, lenders, government agencies, consumers, and clients. Hutchison, "Adopting ESG," August 21, 2023.
[9] Industry representatives, interviews with USITC staff, March 14, 21, and 25.

could become more important in the future and have a significant impact on individual countries' relative competitiveness in mineral and metal production.[10]

Capital Costs

Industry representatives noted that capital costs play a significant role in impacting the competitiveness of mineral and metal industries across countries. Capital costs are costs spent to buy or maintain long-term assets. In mineral and metal industries this typically includes purchases or leases of land, buildings, and equipment or machinery, as well as exploration and initial excavation costs, and costs associated with other infrastructure developments. Countries may encourage capital investment through favorable interest or tax rates and other investment incentives that help firms recoup capital expenditures faster or reduce expenditures altogether.[11] In the mineral and metal space, many countries are incentivizing capital investment via grants and subsidies aimed at bolstering critical mineral supply chains. For example, since 2020, the U.S. Department of Defense has awarded more than $439 million to projects aimed at expanding domestic supplies of rare earth elements.[12] Conversely, high interest rates or restrictive government regulations may increase capital costs or deter capital investment altogether.[13] Meanwhile a country's natural resource endowments and infrastructure needs also impact capital costs, with higher costs typically occurring in areas where natural resources are less accessible, or infrastructure is less developed.[14]

In general, capital costs, in real terms, have been increasing in recent years. There are a number of reasons for this. For one, for many mined products, the most accessible or highest quality mineral deposits have already been extracted. Shifting to less accessible deposits or lower quality deposits often requires additional investment in machinery, energy, and technology.[15] Second, quality and purity standards for many minerals and metals are increasing as their use in higher value downstream products increases, which also necessitates additional investment in technology to improve quality.[16] Finally, a growing focus on sustainable and safer mining and refining practices has also increased costs.[17]

Increasing capital costs make newer entrants less competitive compared to older, more established industry participants. Similarly, countries that subsidize capital costs have an advantage over countries that do not.[18] Many industry experts attribute China's dominance in the lithium and rare earths

[10] See also subsection on "Sustainability Products."
[11] See also subsection on "Government Policies and Regulations."
[12] Awards figure is as of January 2025. Vergun, "Securing Critical Minerals Vital to National Security, Official Says," January 10, 2025.
[13] See also subsection on "Government Policies and Regulations."
[14] See also subsection on "Presence of Natural Resources."
[15] Porter et al., "Promoting Metals and Mining Sustainability in Critical Supply Chains," May 13, 2024; S&P Global, *Industry Credit Outlook 2024: Metals and Mining*, January 9, 2024, 4.
[16] Industry representative, interview with USITC staff, March 25, 2025. See also, subsection on "Quality."
[17] S&P Global, *Industry Credit Outlook 2024: Metals and Mining*, January 9, 2024, 3–5.
[18] See also subsection on "Government Policies and Regulations."

industries markets to these circumstances, which allow them to offer a lower price for their products compared to new entrants that must charge higher prices to yield a return on their capital investments.[19]

Production Costs[20]

Raw Material Inputs

For many minerals and metals, raw material input costs have a significant impact on the final cost of the product. While many raw material inputs for mineral and metal production are other mineral and metal commodities with globally benchmarked prices, variability in these input costs from different sources and production processes still exist and play an important role in competitiveness. For example, according to a steel industry representative, the costs of iron ore and ferrous scrap are the most significant costs in determining the final cost of a steel product.[21] The representative also noted that these raw material costs are the most variable of all input costs, with iron ore costs being more variable than ferrous scrap costs. This tends to give a competitive advantage to countries with larger shares of electric arc furnace (EAF) production.[22]

Similarly, since secondary unwrought inputs are much cheaper than primary unwrought inputs, wrought aluminum producers in countries with high levels of secondary aluminum production have a competitive advantage. A 2017 USITC report on aluminum competitiveness found that unwrought aluminum inputs accounted for between 70 and 87 percent of wrought aluminum producers' business costs.[23]

Energy

Energy costs also have a significant impact on the final cost of many mineral and metal products. As noted in the discussion on capital costs, in extractive businesses, shifting to less accessible and lower quality deposits require higher energy intensities.[24] Meanwhile, a push for more sustainable mineral and

[19] China has been a major supplier of rare earth elements and lithium since at least the early 2000's. For more information on China's subsidies in mineral and metal industries, see "Government Policies and Regulations." Industry representatives, interview with USITC staff, March 25, and May 6, 2025; Milewski, "The West's Pursuit of Rare Earths Hits Resistance from China," February 21, 2024; Mining.com, "Opinion: Tariffs on Minerals from China Are Not Enough," May 15, 2024.

[20] "Production costs" refer to the on-site costs of mining, refining or processing, or fabricating a mineral or metal product. Underlying production costs include material input costs, labor costs, energy costs, and any other inputs used at the production site. Production costs do not include costs incurred before production begins (such as capital costs for machinery), or after the product leaves the production area (such as transportation and trade costs).

[21] Industry representative, interview with USITC staff, March 21, 2025.

[22] EAF steelmaking uses electricity to melt ferrous scrap and some other iron-based inputs to create new steel. Traditional integrated steel production (also known as BF-BOF production) produces steel from iron ore. Because ferrous scrap costs are less variable compared to iron ore costs, EAF producers don't have to build in as much buffer in their budgets for input costs.

[23] USITC, *Aluminum: Competitive Conditions Affecting the U.S. Industry*, June 2017, 106, 118.

[24] For example, according to one report, "the average copper ore grade for producing mines declined by 25% between 2006 and 2016, requiring 46% more energy to ensure a 30% production boost." Porter et al., "Promoting Metals and Mining Sustainability in Critical Supply Chains," May 13, 2024.

metal production has called for lower energy use and a transition to lower-emitting energy sources, which can have mixed effects on costs.

The type of energy and efficiency of the technology used in different countries yields vastly different energy costs. In the USITC's 2017 report on aluminum competitiveness, Canada was found to have the lowest electricity cost of the countries evaluated at $252 per metric ton of aluminum produced.[25] This was due to the availability of low-cost hydroelectric power and newer, more efficient smelter technology. Meanwhile, China and the United States had the highest electricity costs ($614 and $532 per metric ton, respectively). This was attributed to high-cost, grid-sourced electricity in the United States and less energy efficient smelter technologies in both countries. Consequently, Canada had the lowest overall cost of production while China and the United States had the highest.[26] Similarly, nickel industry representatives noted that energy was the most significant driver of overall cost and pointed to Indonesia's low-cost, coal-powered electricity as one of the reasons nickel from Indonesia is often priced lower than nickel from other countries.[27] Finally, industry representatives for the steel industry note that countries with a larger share of EAF production versus BF-BOF production benefit from lower energy costs. One reason for this is that EAFs can be powered down on nights and weekends, whereas BF-BOFs continue to use energy even when not actively producing.[28]

Labor

Labor costs are also an important factor impacting production costs and overall cost competitiveness. Generally, labor costs in mineral and metal industries have been increasing since at least the early 2000's, with one source noting that labor costs are soon to become the biggest expense for mining industries.[29] One reason for this is the need for better compensation due to increased safety risk as mine depths increase.[30] Another is a shortage in supply of skilled laborers.[31] Generally, developing countries have lower labor costs compared to developed countries. For example, a 2022 report on global BOF steel production costs estimated average labor costs per metric ton of steel to be less than $10 for BOF steel workers in Vietnam, Ukraine, and India, and $13 for workers in China.[32] Meanwhile, the United States,

[25] USITC, *Aluminum: Competitive Conditions Affecting the U.S. Industry*, June 2017, 70, 104, 108–10.
[26] In addition, the report found that electricity accounted for up to 40 percent of a primary aluminum smelter's production costs and that access to low-cost electricity was the most important determinant in decisions on where to construct new smelters. It also found that countries with access to low-cost electricity were better able to manage during times in which global aluminum prices declined. USITC, *Aluminum: Competitive Conditions Affecting the U.S. Industry*, June 2017, 70, 104.
[27] Industry representatives, interview with USITC staff, March 14, 2025.
[28] Industry representative, interview with USITC staff, March 21, 2025.
[29] Stutt, "Labour Costs Will Soon Beat Oil as Mine's Biggest Expense, New Data Indicate," June 6, 2023; Deloitte, "Mining Spotlight On: Sliding Productivity and Spiraling Costs," 2014.
[30] Deloitte, "Mining Spotlight On: Sliding Productivity and Spiraling Costs," 2014.
[31] Industry representatives, interview with USITC staff, March 25, 2025; Abenov et al., "Mining Industry Employment and Talent Challenges," February 14, 2023; Mitchell, "Top 10 Mining and Metals Risks in 2025," accessed April 16, 2025; Banks, "How Will Labor Shortages Impact Metal Fabrication in 2022?" accessed April 16, 2025.
[32] M'barek et al., "Global Steel Production Costs: A Country and Plant-Level Cost Analysis," January 2022.

Japan, Italy and Germany had significantly higher labor costs; $66 per metric ton for BOF workers in the United States, $55 in Japan, $56 in Germany, and $57 in Italy.

In extractive industries, labor costs can vary based on geological resources and the extraction and processing technologies used. For example, in the lithium industry, labor costs for hard rock lithium mining are generally higher than labor costs for brine extraction.[33] While this is due in part to the relatively high labor costs in Australia where most hard rock mines are located, it is also attributed to the fact that significantly fewer workers are needed for brine extraction.[34]

Trade and Transportation Costs

Trade and transportation costs for minerals and metals include tariffs and customs-related costs, as well as transportation and other logistics costs such as insurance, warehousing fees, and security-related fees. Unlike most other costs discussed, these costs can have unique impacts on customers in different markets. For example, an additional import duty on minerals and metals in one market would likely have little impact on buyers outside of that market. Similarly, transportation costs are often a relative function of the distance between production and consumption and may be a more significant factor for consumers who are further away compared to consumers in a nearby market.

Tariff Treatment and Other Trade Actions

Tariff treatment and other trade actions can have positive or negative impacts on cost competitiveness. Preferential duties on imported inputs lower production costs while preferential duties in the consuming country can lower delivered costs. [35] Conversely, higher tariffs on imported inputs can increase production costs while higher tariffs on exports to the consuming country can increase delivered costs.[36]

In recent years, minerals and metals have increasingly been subject to U.S. tariffs. Since March 2018, imported steel and aluminum products from most countries into the United States have been subject to additional tariffs.[37] A 2022 USITC report on the economic impact of these tariffs found that the tariffs decreased imports of covered steel and aluminum products while increasing domestic production and prices. These findings suggest that the tariffs may have increased U.S. producers' competitiveness for

[33] Webb, "Lithium Sector: Production Costs Outlook," May 10, 2019.
[34] Lower labor costs in brine extraction are likely offset by higher capital costs compared to hard rock mining. Moreover, prices received for brine extracted product are typically higher as the product has gone through some processing onsite whereas hard rock-produced lithium will still need to be transported out for processing. When including the processing stage, costs and prices received for products are typically on par for each production method. ACF Equity Research, "Lithium Extraction – Mineral Deposits Vs. Salt Brines," September 14, 2023; "Lithium Extraction – Mineral Deposits Vs. Salt Brines," September 14, 2023.
[35] Preferential duty treatment is when a country pays a tariff rate that is lower than the normal tariffs applied to imports from third countries.
[36] As noted in section on "Government Policies and Regulations," tariff treatment and other trade actions can also have an impact on supply factors and product differentiation.
[37] The scope, in terms of product and country coverage, and duty rate of these tariffs has changed over the years. As of April 2025, the tariffs cover most steel and aluminum articles from all countries at a duty rate of 25 percent ad valorem. 90 Fed. Reg. 9807, February 18, 2025; 90 Fed. Reg. 9817, February 18, 2025.

those products vis-a-vis other countries competing in the U.S. market.[38] More targeted tariffs on products from specific countries can decrease the competitiveness of products from that country while creating opportunities for third countries. For example, the United States recently increased tariffs on several critical minerals from China including cobalt, manganese, tungsten, and chromium, potentially increasing the delivered costs of these minerals to U.S. consumers.[39] This has the potential to make those critical minerals from other countries more cost competitive relative to China in the U.S. import market.

Other types of non-traditional trade measures such as carbon border taxes can also impact cost competitiveness.[40] The European Union's Carbon Border Adjustment Mechanism, set to go into effect in 2026, levels duties on steel and aluminum based on the carbon intensity of the production processes. This will likely increase cost competitiveness for countries with low-emitting production processes while decreasing cost competitiveness for countries with higher emitting processes.

Transportation

Transportation costs are primarily impacted by proximity to market and ease of transport.[41] While these costs can be paid by the supplier or the consumer, they primarily impact the supplier in terms of direct operating costs or the price-competitiveness of their product. Operations that are vertically integrated with several production process steps occurring in close proximity can significantly reduce transportation costs. For example, mining companies that can refine at or near the extraction source benefit from significantly lower transportation costs by avoiding transporting the bulky, unusable materials of the ore or compound.[42] Producers of minerals and metals also see production cost advantages when they can source raw materials from nearby with few logistical issues. For example, industry representatives from the U.S. steel industry note that the United States has a cost advantage over other steel producers due to its ability to source all its iron ore and ferrous scrap domestically.[43]

Minerals and metals are transported via a variety of means including trucks, ships, and trains. Countries with access to multiple modes of transportation and more developed infrastructure tend to have a competitive advantage in terms of transportation costs. As noted above, infrastructure development can also contribute to capital costs. Countries with less developed infrastructure may cover the costs of some infrastructure development to incentivize investment.

[38] USITC, *Economic Impact of Section 232 and 301 Tariffs on U.S. Industries*, March 2023, 20, 21.
[39] 89 Fed. Reg. 76581, September 18, 2024.
[40] Other types of trade measures impacting cost competitiveness include rules of origin requirements and export restrictions.
[41] Ease of transport is determined by several components including available modes of transportation, transportation infrastructure, shipment size and weight, and packaging.
[42] For example, aluminum ore mining operations typically refine and convert the bauxite into alumina (aluminum oxide) at or near the mine site. This process removes the oxide and silicate minerals from approximately 2 tons of bauxite to produce 1 ton of alumina. Springer and Hasanbeigi, "Emerging Energy Efficiency and Carbon Dioxide Emissions," June 2016, 6.
[43] Industry representative, interview with USITC staff, March 21, 2025.

Product Differentiation

Product differentiation refers to the ability of a supplier to provide a product that consumers perceive as unique or more valuable than similar products.[44] Although many mineral and metal products are considered to be commodities and largely homogeneous, important distinctions can be made based on quality, grade, origin, extraction or processing method, and sustainability or ESG considerations.[45] Moreover, because many mineral and metal commodities have a relatively low price elasticity of demand, factors associated with product differentiation can have a larger impact on customers' sourcing decisions.[46]

In research and discussions with industry, quality was the most important product differentiator for minerals and metals. The ability to either specialize in certain types of products or supply a desirable product mix was also important. Product differentiation factors are largely determined by consumer demand. Countries and suppliers with the best ability to meet a consumer's preferences will typically have the largest competitive advantage in terms of product differentiation.

Quality

To maintain competitiveness in purchaser markets, suppliers must provide the product quality demanded by the consumer. For many mineral and metal products, quality is determined by the purity level of the product. Consumers of minerals and metals demand certain purity levels to ensure optimal function of the downstream product. Countries with a competitive advantage in quality are those best able to meet these purity requirements, either due to advantageous geological endowments or better refining or processing methods.

The battery industry, which is the largest consumer of lithium, requires lithium suppliers to obtain specific purity qualifications.[47] Battery-quality lithium needs to be purified to at least 99.5 percent lithium, with specific impurities making up the remaining 0.5 percent.[48] A crucial indicator of lithium quality, and whether it will be used in the battery industry, is its extraction source. Lithium ore extracted from hard rock, such as spodumene, possesses the highest-purity lithium, while lithium extracted from brine tends to be lower-purity and requires longer lead-times to reach ideal purification levels.[49]

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[44] Porter, *Competitive Strategy*, 1998.
[45] Recabarren et al., "Product Differentiation in Mineral Commodities Based on Sustainability Indicators," October 2024.
[46] Consumers of commodity products with low price elasticity of demand may be less affected by changes in price, making product differentiation factors more important in sourcing decisions. However, certain product differentiation efforts may increase costs. Recabarren et al., "Product Differentiation in Mineral Commodities Based on Sustainability Indicators," October 2024.
[47] In 2024, batteries accounted for 87 percent of global lithium consumption. According to industry representatives, the qualification process for lithium to be used in battery production can take up to one year. USGS, "Mineral Commodity Summary, Lithium: 2025," January 2025; industry representative, interview with USITC staff, March 25, 2025.
[48] The type of impurity also affects quality; magnesium is among the specific impurities needed for battery-grade lithium. Choe et al., "Re-Evaluation of Battery-Grade Lithium Purity toward Sustainable Batteries," February 8, 2024.
[49] Industry representatives, interview with USITC staff, March 25, 2025.

Countries like Australia, the main source of hard-rock lithium ore, have a natural competitive advantage in the battery market over countries producing lithium from brine, such as Chile, Argentina, and Bolivia.[50] Nickel products are also differentiated in the market by purity standards.[51] Canada, Russia, Australia, and Norway are among the countries that maintain a competitive advantage with the highest purity nickel reserves.[52]

Beyond purity, other industry, regional, or international quality standards may be important to consumers of minerals and metals. These can either be mandated by governments or industries, or follow voluntary guidelines.[53] In the steel industry, for example, ASTM International's standards are used to classify, evaluate, and specify the properties of steel products in order to provide end-users assurance in the quality of their purchases.[54] ESG standards are also growing in importance and may create new opportunities for product differentiation in the future.[55]

Product Mix and Specialization

Product mix and product specialization are two approaches for suppliers to meet consumers' needs. Expanding product mix allows suppliers to reduce risk and compete in a broader consuming market. Product specialization refers to a supplier focusing on the production optimization of a single or few products, which can increase efficiency, lower costs, and improve quality. Market conditions—such as shifting consumer preferences, technological advancements, or geopolitical risks—and emerging competition can influence whether a supplier may expand its product mix or specialize to remain competitive.

Product Mix

Offering an expanded product mix allows suppliers to compete in a broader end-use market while reducing dependence on a single product. This serves as a means of mitigating risk associated with demand shifts on individual products and allows for multiple sources of revenue. A wide product offering can also increase competitiveness as buyers seek to consolidate their sourcing to one or a few suppliers.

The U.S. steel industry offers an expansive product mix, making it an attractive sourcing option for a variety of downstream users. As such, the domestic steel industry supplies 70-90 percent of domestic demand across a variety of end-use markets.[56] Because the industry is equipped to produce a variety of products, it can shift production in line with changes in demand. For example, if demand in the

[50] MIT Climate Portal, "How is Lithium Mined?" February 12, 2024.
[51] Nickel purity standards are traditionally differentiated between class 1 (99.8 percent nickel purity) and class 2 (less than 99.8 percent purity). Zeb Nickel Corp, "Why Nickel," accessed May 9, 2025.
[52] Industry representatives, interview with USITC staff, March 14, 2025.
[53] See Government Policies and Regulations for more information.
[54] ASTM International, "Steel Standards," accessed May 15, 2025.
[55] Industry representative, interview with USITC staff, March 21, 2025. For more information see subsection on "Sustainability Products" under "Product Mix and Specialization."
[56] Downstream industries' ability to meet their demand through domestic suppliers can enhance competitiveness across the supply chain by avoiding potential trade barriers and bolstering predictable yet flexible supplier-purchaser relationships. CRS, "Domestic Steel Manufacturing: Overview and Prospects," May 17, 2022, 2. See "Trade and Transportation Costs," and "Government Policy and Regulations" for more information.

construction market decreases, steel producers might shift focus towards increasing production for the automotive industry.

Product Specialization

Product specialization can increase efficiency, lower costs, and improve quality as a supplier focuses on optimizing production of one or a few products. Industry representatives often noted consumer preference for sourcing certain mineral and metal products from producers or countries where a focus on specialization resulted in more advanced production processes or higher-skilled labor.[57] However, specialization can create additional risk in the case of a shift in consumer preferences or supply constraints.

While the U.S. steel industry's competitive strategy largely focuses on its wide product mix, other countries benefit from specializing in high-value and niche products. Though Japan also produces a wide variety of steel products, a key element to its international competitiveness strategy within the steel industry is the identification of niche markets for highly specialized steel products.[58] Industry representatives note that Japan is one of just a few sources of high-quality grain oriented electrical steel, a specialty product used in high-demand power transformers, electric motors, and electrical generators. These products are particularly competitive in the U.S. market, which currently has limited domestic production despite growing demand.[59]

Sustainable Products

Some producers of minerals and metals have begun to expand their product mix or specialize in low-carbon or "green" products. Producing more sustainable versions of otherwise homogeneous products creates new opportunities for product differentiation. Significant growth is anticipated in the green steel market in the coming decades.[60] The trend is motivated by environmental regulations, increasing demand for sustainable materials, and technical advances in steel production that allow for reduced carbon emissions. Traditional steel production is a large contributor to greenhouse gas (GHG) emissions.[61] Investment in technologies such as EAF steel making is increasing in the United States, European Union, and other countries due to its lower-emitting production relative to traditional blast

[57] Industry representatives, interviews with USITC staff, March 21, March 25, and May 5, 2025

[58] Cabaro Group, "Unveiling Japan's Steel Saga," February 14, 2024.

[59] Industry representative, interview with USITC staff, March 21, 2025.

[60] Green steel refers to steel produced using renewable energy and low-carbon processes. Green steel technologies include EAF production, carbon capture technologies, the incorporation of non-fossil fuel energy, and hydrogen-based steelmaking, among others. A 2024 study on global steel demand found that hydrogen-based green steel is expected to make up 35 percent of global steel demand by 2050. Watari and McLellan, "Global Demand for Green Hydrogen-Based Steel," August 2024, 630. See also OECD, "Latest Developments in Steelmaking Capacity and Outlook Until 2026, June 12, 2024.

[61] Iron and steel production are estimated to account for approximately 7 percent of global GHG emissions and 11 percent of global carbon dioxide emissions. DOE, "U.S. Department of Energy Announces $28 Million to Decarbonize Domestic Iron and Steel Production," April 18, 2024.

furnace methods.[62] In EU countries, increased capacity in EAF production and other green steel technologies is expected to come online in the next few years.[63] This transition is supported by the EU's regulatory policies that favor lower-emitting steel production.[64]

The steel industry, along with many other mineral and metal industries, has adopted the use of Environmental Product Declarations (EPDs) to provide information about a product's environmental impact throughout its lifecycle.[65] The EPD process follows international standards (International Organization for Standardization, or ISO), which ensures consistency in the information provided in the declaration and outlines a third-party review process. Using EPDs allows suppliers to align with industry standards, meet regulatory requirements, and be transparent about performance criteria. Companies may expand their product mix to include—or specialize in—EPD-branded products to access new market segments and gain a competitive advantage in supplying consumers who rely on EPDs to gain certain accreditations, meet regulatory requirements, and differentiate their products.[66]

Supply Dynamics

Supply dynamics refer to the variables that impact a producer's ability to manage an efficient, resilient supply chain. The two main variables that make up supply dynamics for mineral and metal industries, determined through research and industry outreach, are resource access and supply security. Resource access tends to be more relevant to industries involved in the mining and recovery stage of the supply chain, while supply security applies more broadly to industries across the supply chain, from mining to fabrication.

Costs and product differentiation interact with supply dynamics. Typically, cost-effective production requires a secure supply of mineral and metal inputs, which can be supported through strategies like vertical integration and supplier diversification. Access to a scarce, valuable resource can also be critical for product differentiation, allowing a producer to offer a high-quality product that is not easily substitutable. Likewise, a lack of resource access and inefficient supply chain management can hinder

[62] On average globally, EAFs emit less GHG emissions than blast furnaces to produce semifinished steel. Fortune Business Insights, "Electric Arc Furnace Market Size, Share," April 21, 2025; Nemag, "The Switch from Blast Furnaces to Electric Arc Furnaces," accessed May 9, 2025; Worldsteel, "Sustainability Indicators: 2023 Report," November 2023; OECD, "Latest Developments in Steelmaking Capacity and Outlook Until 2026," June 12, 2024, 15.
[63] Fastmarkets, "European Steel Sector Calls for Action Plan to Safeguard Industry in Face of Crisis," November 14, 2024; OECD, "Latest Developments in Steelmaking Capacity and Outlook Until 2026," June 12, 2024, 15; Nemag, "How Switching to an Electric Arc Furnace Affects Your Grab Productivity," accessed May 29, 2025.
[64] For example, the EU introduced an emissions trading system (ETS) in 2005 that established a "cap and trade" structure requiring multiple industries, including the steel industry, to pay a set price for the amount of GHG emissions a facility emits. European Commission, "About the EU ETS," accessed May 14, 2025. Industry representative, interview with USITC staff, March 21, 2025.
[65] Steel Tube Institute, "Environmental Product Declarations (EPDs)," accessed May 9, 2025; AISC, "Steel's Environmental Footprint," accessed May 9, 2025.
[66] For example, developers in some countries may be required to submit an environmental impact report on their construction project. These purchasers may be incentivized to source raw materials with EPDs, as their environmental footprints tend to be lower than the generic data provided in national databases. Tunley Environmental, "EPDs," August 19, 2024; Zacharia, "The Business Case for Investing in EPDs," March 5, 2024.

competitiveness by limiting the producer's ability to deliver their final product (i.e., manufacturing and shipping delays, increased costs, and lower quality products).

Resource Access

Resource access as a competitiveness factor is a precursor to developing supply security. An industry can gain resource access through a country's natural endowment or through circular supply chains, which are structured to recover raw materials from end-of-life products and other waste streams as inputs for production. Resource access across industries or countries becomes a dynamic factor of competitiveness when considering uncertainty in supply levels or sources over time.

Presence of Natural Resources

Mining industry competitiveness is often characterized by the economic viability of the country's mineral deposits.[67] The presence of high-grade ores in locations with available or easy to develop infrastructure creates a clear comparative advantage for the endowed country, as it can produce a higher-value product at a lower cost.[68] More mature industries may rely on investment and advanced technology to remain competitive, as the most profitable deposits are targeted first before extraction shifts to less attractive, lower-quality deposits.[69]

Mining competitiveness has also been measured as the breadth of minerals a country exports weighted by the scarcity of those minerals globally.[70] Countries that export a range of minerals tend to be less vulnerable to mineral substitutions, and more able to adapt to technological changes that shift downstream demand.[71] As such, industries in a country with a range of mineral resources and extraction infrastructure tend to maintain a greater comparative advantage over other countries involved in any single mineral industry.[72]

Some deposits allow producers to economically extract multiple metals from the same mine, offering additional resilience to market price volatility. For example, most cobalt is mined as a byproduct of the copper and nickel industries, and copper-cobalt and nickel-cobalt mines benefit from lower average production costs.[73] This advantage is sometimes reflected in pricing, in which a nickel-cobalt product is sold for just the price of the nickel, essentially treating the cobalt as free.[74] Indonesia, the world's largest nickel producer, is expected to gain global market share in the cobalt industry as it expands capacity to

[67] Valverde-Carbonell et al., "Minerals' Criticality and Countries' Mining Competitiveness," November 1, 2024.
[68] See also subsection on "Capital Costs."
[69] Porter et al., "Promoting Metals and Mining Sustainability in Critical Supply Chains," May 13, 2024; S&P Global, *Industry Credit Outlook 2024: Metals and Mining*, January 9, 2024, 4. See also "Capital Costs."
[70] Valverde-Carbonell et al., "Minerals' Criticality and Countries' Mining Competitiveness," November 1, 2024.
[71] See also 'Competition from Viable Substitutes'. Valverde-Carbonell et al., "Minerals' Criticality and Countries' Mining Competitiveness," November 1, 2024.
[72] Valverde-Carbonell et al., "Minerals' Criticality and Countries' Mining Competitiveness," November 1, 2024.
[73] Industry representative, interview by USITC staff, March 14, 2025; Yao, "The Cobalt Expansion Drive is a Copper Story," March 2, 2023.
[74] Industry representative, interview by USITC staff, March 14, 2025; Yao, "The Cobalt Expansion Drive is a Copper Story," March 2, 2023.

process cobalt from its nickel mines.[75] Other mines with co-mineral deposits—such as gold-antimony mines—may reduce production of one metal to prioritize production of the other depending on demand and market conditions.[76]

Uneven Distribution of Natural Resources and Temporal Uncertainty

For the mineral and metal industries, competition is driven in part by the scarcity of finite resources and unequal distribution of mine, production, and processing activity globally. The most glaring example of this dynamic for country competitiveness is China's dominance in critical minerals. China controls 85 to 90 percent of rare earth mine-to-metal refining in the global supply chain, in part due to early and long-term investment strategies in its mining and processing capabilities.[77] As the leading producer of 30 critical minerals, China also maintains a stronghold in global reserves. For example, China currently accounts for 86 percent of global gallium reserves.[78] While other countries are investing to mine their own reserves, China still maintains a global advantage by controlling the processing and refining capacity of minerals and metals used in technological and defense applications essential to national security.

The discovery of mineral deposits and technological advancements in extraction over time have led to total global reserves for many critical minerals increasing at a faster rate than extraction.[79] Deposit discoveries—while often unpredictable—tend to be geographically diverse, leading to greater competition across countries; for example, China's share of global rare earth deposits has fallen from 50 percent to 34 percent in just a decade.[80] Global supply and distribution of reserves of a mineral or metal may shift drastically following a technological breakthrough. For example, McKinsey estimates that 80 percent of currently nonviable lithium reserves could become profitable to extract with emerging direct lithium extraction (DLE) technology.[81] DLE technology allows for recovery of high purities of lithium directly from various brine solutions at a much faster rate than conventional methods. This advancement has the potential to give countries with unconventional brine resources—such as the United States' oilfield brines—a new supply stream for lithium, which would increase the country's ability to compete in the industry.[82]

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[75] Indonesia's increased cobalt processing capacity and nickel production is expected to drive the share of global cobalt supply that results as a byproduct of nickel mining from 25 percent to 41 percent by 2030. Benchmark Mineral Intelligence, *Cobalt Market Report 2023*, May 2024, 43; Benchmark Source, "Two-Fifths of Cobalt Could Come from Nickel Mines by 2030," September 15, 2023.

[76] For example, the largest gold-antimony mine in the world drastically reduced antimony production from 2021-2023 to maximize gold production. USGS, *Mineral Commodity Summaries 2024: Antimony*, January 2024.

[77] Cohen, "Resource Realism: The Geopolitics of Critical Mineral Supply Chains," September 13, 2023.

[78] Reserves refer to those identified mineral deposits that are economically and technically possible to extract. Cohen, "Resource Realism: The Geopolitics of Critical Mineral Supply Chains," September 13, 2023.

[79] USGS's mineral commodity summaries indicate that global known reserves for cobalt, lithium, and nickel increased from 2013 to 2022. Cohen, "Resource Realism: The Geopolitics of Critical Mineral Supply Chains," September 13, 2023.

[80] Cohen, "Resource Realism: The Geopolitics of Critical Mineral Supply Chains," September 13, 2023.

[81] Leke Services, "Lithium Sourcing in the US," November 5, 2024.

[82] The Smackover Formation—a geological formation in the Southeast United States known historically for oil and gas—contains lithium and bromine-rich brines that are now a target for DLE technology investment. Plante et al., "Old Oil Fields Reimagined as Lithium Sources," September 20, 2024.

Closed-Loop Approach in Absence of Primary Resources

In the absence of natural resource endowments and other primary inputs, a country may also gain competitive edge and supply chain resilience through investment in a circular supply chain.[83] For example, due to its maturity, the U.S. steel industry has access to the world's largest supply of ferrous scrap, and many steel companies are now integrating their own captive scrap supply.[84] Access to ferrous scrap became especially advantageous following Russia's invasion of Ukraine; the conflict led to a pig iron shortage, a primary input in which U.S. producers had imported up to 80 percent from Russia and Ukraine.[85] Steel makers turned toward higher-quality scrap and shredded scrap supply to replace pig iron inputs, lessening the domestic industry's exposure to global supply disruptions.[86]

Producers can increase their access to secondary resources through methods such as captive recovery programs, vertical integration, and partnerships with downstream producers or third parties. In the United States, annual aluminum scrap collection increased from 5 billion pounds in the 1980s to 11.3 billion pounds in the 2010s.[87] Consequently, secondary aluminum production also increased its share of total U.S. aluminum production from 20-30 percent in the 1980s to more than 80 percent today. Like steel, the aluminum industry takes advantage of its captive scrap production and reintegrates it into the production process, simultaneously reducing waste and input costs. Third-party partnerships with dross processors allow even internal waste products to be upgraded into usable aluminum and reintegrated into the supply chain.[88] Producers have also invested upstream in plants and technology to sort and process external scrap.[89] Finally, secondary aluminum producers have also partnered with downstream aluminum consumers such as beverage can producers to collect manufacturing scrap to be reintegrated back into the aluminum production process.[90]

Major investments in EV-battery recycling plants aim to take advantage of a rapidly increasing supply of end-of-life EV batteries containing critical minerals that are otherwise subject to more volatile markets globally.[91] Investments in capacity to process end-of-life products that have steady consumer demand create a sustainable supply stream of upstream inputs for domestic industries that may otherwise be wholly import dependent or lack supply security.

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[83] A circular supply chain is structured to minimize waste streams, incorporating end-of-life products such as scrap as inputs for further production.
[84] Industry representative, interview by USITC staff, March 21, 2025.
[85] Industry representative, interview by USITC staff, March 21, 2025.
[86] Asenov and Leppold, "Where Will the U.S. Steel Market Get its Prime Scrap?" May 3, 2022.
[87] The Aluminum Association, "Infinitely Recyclable," accessed May 13, 2025.
[88] Aluminum dross is a by-product of the aluminum melting and casting processes made up of oxidized aluminum and other waste material. The aluminum within dross is often recovered and reused in production.
[89] Green, "$40m Aluminum Recycler Breaks Ground in Logan County," September 9, 2024.
[90] For example, in 2023, aluminum producer Novelis entered a long-term partnership with Ball Corporation, an aluminum can maker, to supply aluminum sheet and recover the manufacturing scrap produced in the can-making process to recycle it into new aluminum sheet. Novelis, "Novelis Enters Long-Term Agreement," September 11, 2023.
[91] Many critical mineral and metal industries are still growing as new end-uses emerge, leading to volatile markets. Industry representative, interview by USITC staff, March 25, 2025; Hubert, "Circular Economy: A Competitive Advantage for Industry Transformation," April 2025.

Supply Security Throughout the Value Chain

Supply constraints can hinder competitiveness at every step of an industry's value chain. Mineral and metal industries have different strategies to mitigate such constraints and remain competitive depending on the industry's needs and supply chain structure.

Vertical Integration

For some mineral and metal industries, managing supply constraints involves vertically integrating the supply chain.[92] Companies in the nickel industry, for example, typically have both mining and refining operations.[93] Vertical integration gives the company control over multiple steps in the supply chain, therefore mitigating the risk of disruptions from supply shocks and price volatility. It also reduces costs and provides greater quality control, which each enhance the integrated company's competitive edge in the market.[94]

Vertical integration can occur downstream from a company's operations, such as a nickel mining company purchasing a refinery, or upstream, such as an aluminum producer purchasing a bauxite mine. A mine's location is determined by the presence of resource deposits, but vertical integration downstream can occur wherever a company chooses to invest its assets.[95] In the steel industry, manufacturers often vertically integrate both downstream and upstream to secure their supply chain. For example, ArcelorMittal, a large multinational steelmaker, owns mining, steelmaking, and distribution operations all over the world.[96] Purchasing trucking fleets and having control over transportation operations is also a growing trend in the steel industry, which contributes to a company's supply chain stability and competitiveness in market delivery.[97] As previously mentioned, steel companies may also invest in a circular supply chain to boost competitiveness, which is another means of vertical integration for mineral and metal industries.

Supplier Diversification

One of a company's biggest obstacles when vertically integrating is securing infrastructure, often due to various challenges such as regulatory hurdles, capital constraints, or financial burdens.[98] When vertical integration is not possible or not practical for an industry, it may secure its supply chain through supplier diversification. Recent global events such as the COVID-19 pandemic and the Russian invasion of Ukraine

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[92] Other industries that use minerals and metals as intermediate inputs, such as battery and electrical vehicle (EV) industries, may also vertically integrate by acquiring a mining company to secure their supply needs and have a competitive edge in their industry. This is not accounted for in our analysis of competitiveness in the mineral and metal industries.

[93] Industry representative, interview by USITC staff, March 14, 2025.

[94] EOXS, "Streamlining Success: The Advantages of Vertical Integration in Metals," accessed April 16, 2025.

[95] There are many factors that influence where a company chooses to invest. See sections on "Government Policies and Regulations," and "Foreign Direct Investment," for more information.

[96] ArcelorMittal, "Strategy," accessed April 16, 2025.

[97] Industry representative, interview by USITC staff, March 21, 2025.

[98] This is not an exhaustive list of challenges. See sections on "Cost," "Government Policies and Regulations," and "Foreign Direct Investment," for more information.

have highlighted the vulnerabilities that supply chains face when unexpected disruptions occur. As previously mentioned, the United States sourced up to 80 percent of pig iron from Russia and Ukraine prior to the war. Relying on a single supplier, or region, can hinder competitiveness during shocks by delaying delivery times and increasing costs. To increase competitiveness, countries may explore diversifying their domestic supply chain to mitigate disruptions from global shocks.[99]

In mineral and metal industries, companies are incentivized to build long term relationships with their suppliers.[100] Minerals and metals are often used as intermediate inputs in other industries, and suppliers at each step of the value chain must go through qualification processes to ensure their inputs meet the production requirements of the finished product. For example, a lithium supplier must meet the qualifications of a cathode manufacturer, who must meet the qualifications of the battery manufacturer. Multiple industries describe the qualification process to be intensive and lengthy.[101] For this reason it is often difficult and untimely to find alternative suppliers, which can pose challenges when supply disruptions occur. Building relationships with multiple suppliers can provide a company with options if a supply disruption were to occur.

Cross-Cutting Conditions Impacting Competitiveness

Government Policies and Regulations

Government policies and regulations can have significant impacts, both positive and negative, on a country's competitiveness and the factors that impact its competitiveness in minerals and metals. Industry representatives frequently highlighted subsidies, permitting, and trade measures as types of policies and regulations impacting the competitiveness of mineral and metal industries.[102] Other relevant government policies and regulations include environmental regulations, tax incentives, and preferential funding. These government policies and regulations typically target production, pollution, labor, land permitting, and trade. Some policies and regulations, such as subsidies, have straightforward impacts—in this case, lowering production or input costs, encouraging increased supply, and ultimately increasing overall competitiveness. Other policies and regulations may have more nuanced impacts on individual competitiveness factors, making the overall impact on competitiveness less predictable. For example, environmental regulations may increase costs related to compliance but encourage the production of more sustainable, differentiated, products that consumers demand. Finally, geopolitical considerations and government policies to address them also impact competitiveness.

[99] See subsection on "Geopolitical Considerations" for more information.
[100] Industry representatives, interviews by USITC staff, March 14, and 25, 2025.
[101] Industry representative, interview by USITC staff, March 14, and 25, 2025.
[102] Industry representatives, interviews with USITC staff, March 14, 21, and 25, and May 6, 2025.

Subsidies

Countries such as China take a comprehensive approach to support their mineral and metal industries, using a variety of government policies and regulations to ensure they maintain global competitiveness. Subsidies are one of the main tools used in this approach. In China, many companies in mineral and metal industries are State-Owned Enterprises (SOEs), meaning that the Chinese government exercises ownership or control of the enterprise. According to the OECD, the Chinese government provides many benefits to SOEs, particularly through direct and indirect subsidies. Direct subsidies include rebates and tax breaks, whereas indirect subsidies include other forms of preferential treatment such as below-market loans, land and energy subsidies, and non-neutral enforcement of competition rules.[103] Between 2009 and 2019, the Chinese government gave an estimated $100 billion in direct and indirect subsidies to the lithium refining industry in the form of subsidies, rebates, and tax exemptions.[104]

Permitting

Mineral and metal projects typically require specific licensing and permits to begin operations. Requirements for obtaining licenses or permits can include environmental impact assessments, licensing fees, reclamation bonds, and providing plans of operation, among others. In countries with a relatively strict or bureaucratic regulatory environment, the processes to approve mining can take a relatively large resource commitment, both in terms of time and costs to meet the requirements needed for permitting. The relatively higher burden associated with strict permitting requirements may make it harder for a country to compete compared to a country with a lower regulatory burden.

A recent report on global mine development times found that the United States has the second-longest mine development time in the world, behind Zambia.[105] Permitting was found to be a key reason for this. The average time to secure permits for a U.S. mine is 7-10 years, compared to 2-5 years in Australia and Canada.[106] Uncertainty associated with long project development timelines in the United States are cited as a top reason for a lack of investment in mining projects compared to countries with shorter timelines.[107] Recently, the United States has created a program to streamline environmental reviews and permitting processes for domestic infrastructure projects, the FAST-41 program. [108] The first projects selected for expedited permitting are intended to boost domestic production of critical minerals and reduce reliance on foreign supply chains; these projects have been added to the federal permitting dashboard under the FAST-41 program. They include copper, gold, lithium, and coal projects.

[103] OECD, Quantifying the Role of State Enterprises in Industrial Subsidies, June 24, 2024.
[104] Wald, "The US Wants to End Its Reliance on Chinese Lithium. Its Policies Are Doing the Opposite.," January 23, 2024.
[105] Bonakdarpour et al., *Mine Development Times: The U.S. in Perspective*, June 2024, 6, 13.
[106]DOI, "Trump Administration Adds Key Mining Projects to FAST-41," April 18, 2025.
[107] Bonakdarpour et al., *Mine Development Times: The U.S. in Perspective*, June 2024, 6.
[108] FAST-41 was established under Title 41 of the "Fixing America's Surface Transportation Act" on December 4, 2015. DOE, "FAST-41," accessed May 9, 2025; DOI, "Trump Administration Adds Key Mining Projects to FAST-41," April 18, 2025.

Trade Measures

As discussed in "Cost," trade measures and tariffs can impact cost competitiveness in a variety of ways. Trade measures may also impact product differentiation by encouraging production of differentiated products that may receive preferential trade treatment. For example, trade measures like the EU ETS and the EU's Carbon Border Adjustment Mechanism (CBAM) may encourage producers of steel and aluminum to focus or expand their product mix to include lower-carbon products.[109] Trade measures can impact supply by encouraging or discouraging global trade and changing sourcing patterns. Some resource-rich developing countries that export upstream inputs to higher-value downstream producers have employed export controls to promote development of domestic downstream industries. Examples of these measures include Indonesia's ban on nickel ore exports and Zimbabwe's bans on chromium ore exports and raw lithium exports.[110] While these policies may encourage the development of downstream processing industries, thus increasing a countries' competitiveness in new market segments, they can reduce potential revenue sources for the upstream industries.

Geopolitical Considerations

Geopolitics also play an increasingly important role in competitiveness and supply chain stability while influencing government policy decisions. In mineral and metal industries, many countries are investing in domestic capacity and imposing protectionist trade policies to reduce import dependence and strengthen domestic supply chains, a strategy known as "resource nationalism." The end-use applications for minerals and metals span across numerous critical industries, such as defense, technology, and transportation. In particular, the defense end-uses of critical minerals lend concern to the national security implications of foreign supply shocks. As such, the U.S. government recently expanded its federal investments and formed a strategy for critical mineral security using Executive Orders, legislation, and the newly established National Energy Dominance Council.[111] These policies and plans are aimed at increasing domestic competitiveness to further production of critical minerals and enhance supply chain resiliency.[112]

Foreign Direct Investment

Foreign direct investment (FDI)—when companies invest abroad to establish a new physical market presence or gain control of an existing market—is common in the mineral and metal industries to help

[109] See European Commission, "About the EU ETS," accessed May 14, 2025 and European Commission, "Carbon Border Adjustment Mechanism (CBAM)," October 17, 2023.

[110] Perry et al., "Export Restrictions on Minerals and Metals: Estimation and Analysis of Supply Chain Effects from Zimbabwe's Chromium Ore Export Ban," February 2024; Guberman et al., "Export Restrictions on Minerals and Metals: Indonesia's Export Ban of Nickel"; Reuters, "Zimbabwe Bans Raw Lithium Exports to Curb Artisanal Mining," December 21, 2022.

[111] Torres, et al., "Securing the US' Critical Minerals Supply Chain," March 6, 2025.

[112] For example, the U.S. Department of Defense (DoD) has provided funding for projects to encourage domestic production capacity development such as an award of $35 million to build a U.S.-based rare earth separation plant in Mountain Pass, California. U.S. Department of Defense, "DoD Awards $35 Million to MP Materials to Build U.S. Heavy Rare Earth Separation Capacity," February 22, 2022.

companies remain competitive.[113] For the investor, FDI can boost competitiveness across each of the discussed core factors by gaining economies of scale, reducing costs, diversifying capabilities, and securing access to foreign supply.[114] For the host country, FDI can provide capital, technology, and employment opportunities that stimulate the overall economy while allowing them to compete in new markets.[115] There are multiple avenues for foreign direct investment; of most relevance to mineral and metal competitiveness, this section will focus on horizontal and vertical investments.

Horizontal FDI is an investment by which the investor expands its existing capabilities in one step of the supply chain. Vertical FDI is an investment by which the investor develops or acquires new capabilities in other stages of the supply chain. Foreign investments in mineral and metal industries are typically vertical, intended to gain access to either upstream capabilities (reserves and raw materials) or downstream capabilities (distribution).[116] For example, many countries are investing in the lithium reserves within the lithium triangle to gain market access in lithium extraction.[117] In March 2024, Ganfeng, a Chinese company, acquired a mining group, Lithea, for approximately $962 million to develop Argentina's lithium reserves. Through this purchase, Ganfeng gained rights to the Pozuelos and Pastos Grandes lithium salt lakes in Argentina.[118]

Since 2013, China has used government policy to expand critical mineral supply chains abroad through infrastructure investments as part of its Belt and Road Initiative (BRI). Chinese companies control much of the critical mineral production in the Democratic Republic of the Congo (DRC), where the infrastructure is not secure enough to support the industry. Through the BRI, China has subsidized construction and upgrades to the country's rail system which is critical for transporting critical minerals.[119]

It takes an average of almost 18 years for a mine to become operational once mineral deposits are discovered.[120] The long lead time for developing a mining project poses uncertainty and risk for the investor. To determine if the investment will likely be profitable, investors will often look at the regulatory and economic conditions in the project's location. Specifically, it is important that regulatory and economic conditions are stable enough to anticipate a successful return on investment in 15-20

[113] Per OECD guidelines, establishing a controlling interest of at lest 10 percent in a foreign-based company is required to be considered FDI. OECD. *OECD Benchmark Definition of Foreign Direct Investment (Fifth Edition)*. May 5, 2025.
[114] See "Cost," "Product Differentiation" and "Supply Dynamics" for more information.
[115] CFI Team, "Foreign Direct Investment (FDI)," accessed April 16, 2025.
[116] See "Supply Security Throughout the Value Chain" for more information.
[117] The lithium triangle refers to the region of the Andes where Bolivia, Chile, and Argentina. This area holds a significant supply of lithium reserves.
[118] Go, FDI Intelligence, "Chinese companies expanding footprint in global lithium mines," June 26, 2023. Cardozo, Institute for Security and Development Policy, "The Lithium Battle: Strategies of China and U.S. in Argentina," August 21, 2024.
[119] U.S. International Development Finance Corporation, "Strengthening Critical Mineral Supply Chains by Countering China's Dominance," May 13, 2025.
[120] Manalo, "Average Lead Time Almost 18 Years for Mines Started in 2020–23," April 10, 2024.

years.[121] Countries with relatively stable regulatory environments have a competitive edge over those with unstable environments in receiving foreign investments.

Negative Externalities and Risk Management

The mineral and metal industries' ability to measure externalities and manage their associated risks is an emerging, cross-cutting factor for competitiveness. Externalities in extractive industries reflect costs or benefits from production or consumption of raw materials that are not directly captured in market transactions, or prices.[122] Companies in these industries are often associated with producing negative externalities, in which costs from their production activities are borne externally by a third-party (such as labor exploitation, health damages to workers, greenhouse gas emissions, biodiversity loss, and waste generation). Historically, the lack of government regulations and market mechanisms to capture these externalities encouraged producers to ignore the external costs, and benefit from increased cost-competitiveness in the short-term. However, both increasing efforts to account for externalities and industries' increasing vulnerability to negative impacts on the financial and natural assets from which they depend on indicates that integration of externalities into asset management, operation, and investment decisions may increase long-term competitiveness.[123]

Companies that successfully manage risks associated with negative externalities such as labor issues, corruption and weak governance, climate change, and nature loss can improve key factors of competition, including supply security and resource access, product differentiation, and production costs. Risk management can be more difficult for companies operating in areas with weak governance and corruption issues. Weak governance can undermine regulatory bodies, hampering oversight of environmental standards. Corruption may lead to bypassing environmental impact assessments or artificially speeding up licenses, which would benefit companies that may not be expected to follow the same regulations as others.[124] The mineral and metal industries are also increasingly vulnerable to impacts from nature loss and climate change due to their high dependence on natural assets such as water supply and climate stability, which have not historically been considered in risk management strategy.

The cobalt industry in the DRC is an example of an industry that faces externalities related to labor, corruption, and the environment. Both weak governance and corruption have plagued DRC's ability to properly enforce mining licenses and other regulatory requirements.[125] DRC has the world's largest

[121] Industry representatives, interviews with USITC staff, May 6, 2025.
[122] Investopedia, "How Do Externalities Affect Equilibrium and Create Market Failure?" February 14, 2025.
[123] Qarahasanlou et al., "Deciphering Climate Change Impacts on Resource Extraction Supply Chain," July 30, 2024; Radebe and Chipangamate, "Mining Industry Risks, and Future Critical Minerals and Metals Supply Chain Resilience in Emerging Markets," April 1, 2024; TNFD, "About US," accessed May 1, 2025.
[124] See section on "Government Policies and Regulations" for more information about license and permitting requirements for mining.
[125] DRC has signaled some willingness to improve environmental protections and initiated reforms in 2019 by launching a state-owned entity to buy and control the artisanal cobalt facilities and created a watchdog to ensure regulation enforcement in cobalt mining. However, weak governance and widespread corruption have allowed companies to flout the laws. Both EGC and ARECOMS have been unsuccessful due to weak enforcement. Fitzgerald

reserves of cobalt and much of its production comes from artisanal and small-scale mines (ASM).[126] ASMs are less regulated, which often results in labor exploitation—particularly of children—in the DRC.[127] The lack of regulation also increases health risks to those working in ASMs, including chemical exposure, dust inhalation, poor sanitation, and mining accidents. Such risks have lasting impacts on miners' health, resulting in cancer, diseases, musculoskeletal disorders, or death.[128] These externalities can lead to import restrictions and loss of sales, weakening the industry's ability to compete in certain markets. For example, in March 2025, legislation was reintroduced in the U.S. Congress that bans imports of any goods containing cobalt refined in China and assumed to be extracted using child and forced labor in DRC.[129]

Impacts from nature loss and climate change—including decreased freshwater availability, erosion and flooding on operating and disposal sites, and damage to production and transportation infrastructure (e.g., unstable ice roads)—disrupt companies' operations and investments.[130] Considering mines and manufacturing sites can operate for more than a century, investments must incorporate adaptation considerations of these impacts for site infrastructure. Certain nature-based solutions in extraction technology also reduce environmental risks and costs while improving resource access.[131] For example, investment in natural stream restoration can yield lower maintenance costs while providing additional passive revenue to the company through carbon credits.[132] Rio Tinto, the second largest metals and mining company globally, claims it will have 500,000 hectares of land managed through forms of nature-based solutions by the end of 2025.[133] One increasingly promising nature-based innovation, biomining, uses microorganisms to recover metals from ores and waste, reducing chemical pollution risks and input costs while increasing resource access through closed-loop approaches.[134]

Because companies in these industries make large-scale capital investments over long-term planning horizons, uncertainty surrounding the scale of nature loss and climate change impacts is a challenge the

et al., *Digging into the Problem*, February 2025; Emmanuel Umpula, "Formalising Artisanal Cobalt Mining in the DRC," accessed May 9, 2025; Davey, "The Environmental Impacts of Cobalt Mining in Congo," March 28, 2023.

[126] Artisanal and small-scale mining (ASM) refers to mining performed by individuals or small groups who use a highly intensive labor and limited or rudimental amount of machinery, mostly on an informal or unregulated basis. OECD, *Due Diligence Guidance for Responsible Supply Chains of Minerals*, April 6, 2016; Pact, "Artisanal and Small-Scale Mining," accessed May 14, 2025; Artisanalmining.org, "ASM Inventory," accessed May 14, 2025.

[127] U.S. Department of Labor, "ILAB Lithium-Ion Batteries Storyboard," accessed May 14, 2025.

[128] Davey, "The Environmental Impacts of Cobalt Mining in Congo," March 28, 2023.

[129] Rep. Smith, "Text - H.R.2310 - 119th Congress (2025-2026)," March 24, 2025.

[130] SIF, *Nature-Related Risks in the Global Insurance Sector*, November 2021; Qarahasanlou et al., "Deciphering Climate Change Impacts on Resource Extraction Supply Chain," July 30, 2024.

[131] Aguilar, "Mining's Next Chapter," January 30, 2025.

[132] Natural stream restoration can include construction of wetlands and forested riparian buffers, which serve as carbon sinks and companies can be compensated for their value through carbon credit trading programs. Kos and Jaros, "In Tune with Nature," March 2024.

[133] Nature-based solutions broadly refer to approaches focused on sustainably managing and restoring natural ecosystems. Rio Tinto, "Nature Solutions," accessed April 30, 2025.

[134] Aguilar, "Mining's Next Chapter," January 30, 2025.

industry must navigate to remain competitive in the future.[135] The Task Force on Climate-related Financial Disclosures (TCFD) and the Task Force on Nature-related Financial Disclosures (TNFD) are international organizations that provide corporate reporting guidance for companies to disclose dependencies on climate and nature and incorporate these risks into their strategic planning and resource management.[136] The International Council on Metals and Mining (ICMM), whose 24 members represent one-third of the global industry, collaborated with TNFD to develop sector-specific guidance for metals and mining industries.

The ICMM has commitments related to effective risk-management for potential industry impacts on the wellbeing of people and the environment. This includes the provision of Human Rights Due Diligence Guidance, which provides member companies with guidance on how to assess and address human rights impacts in high-conflict areas.[137] ICMM also partnered with TNFD to release specific guidance for the sector, and has committed to disclosing nature-related risks and opportunities in priority areas by 2026.[138] ICMM notes that responsible management of these risks is essential for access to land and capital, key factors in the competitiveness framework, as well as overall reputation.[139] Adoption of the TNFD can attract investment opportunities and brand loyalty to firms, enhancing market competitiveness.[140]

Conclusion

The three main factors of competition for mineral and metal industries are cost, product differentiation, and supply dynamics. Additionally, other cross-cutting conditions including government policies and regulations, foreign direct investment, and negative externalities and risk management can also impact each of the factors of competition and the overall competitiveness of mineral and metal industries. The relevance of particular factors and conditions may vary by individual mineral and metal industry and may change over time as consumer demand changes. Nonetheless, this framework serves as a starting point for assessing a country's advantages and challenges in mineral and metal industries broadly. Further

[135] Qarahasanlou et al., "Deciphering Climate Change Impacts on Resource Extraction Supply Chain," July 30, 2024; Radebe and Chipangamate, "Mining Industry Risks, and Future Critical Minerals and Metals Supply Chain Resilience in Emerging Markets," April 1, 2024.

[136] The TFCD disbanded in 2023 after fulfilling its original mandate; the disclosure guidance and monitoring is since monitored by the IFRS Foundation. As of October 2024, corporations had $17.7 trillion in assets under management involved in nature-related reporting, indicating large-scale market adoption of nature-related risk management. TFCD, "About," accessed April 17, 2025; TNFD, "Who Has Adopted?" accessed April 17, 2025.

[137] ICMM, "Human Rights Due Diligence Guidance," accessed May 12, 2025.

[138] Company members include Alcoa, Glencore, Hydro, and Rio Tinto. Association members cover a variety of minerals and metals: aluminum, cobalt, chromium, copper, lithium, manganese, and nickel, among others. ICMM, "How TNFD Is Shaping Nature-Positive Outcomes," accessed May 1, 2025; ICMM, "Our Members," accessed April 30, 2025.

[139] ICMM's commitments also include actions to achieve a 'no net loss' of biodiversity by the time of site closures. ICMM, "Position Statement," accessed April 30, 2025; ICMM, "How TNFD Is Shaping Nature-Positive Outcomes," accessed May 1, 2025.

[140] Jakobs, "Aligning Business Strategy with Nature," March 10, 2025.

research must be done in order to fully assess a country's competitive position in a specific mineral or metal industry.

Bibliography

Abenov, Timur, Margot Franklin-Hensler, Tino Grabbert, and Thibaut Larrat. "Mining Industry Employment and Talent Challenges." McKinsey, February 14, 2023. https://www.mckinsey.com/industries/metals-and-mining/our-insights/has-mining-lost-its-luster-why-talent-is-moving-elsewhere-and-how-to-bring-them-back.

ACF Equity Research. "Lithium Extraction – Mineral Deposits Vs. Salt Brines." September 14, 2023. https://acfequityresearch.com/lithium-extraction-mineral-deposits-vs-salt-brines/.

Adjusting Imports of Aluminum Into the United States. 90 Fed. Reg. 9807. February 18, 2025. https://www.federalregister.gov/documents/2025/02/18/2025-02832/adjusting-imports-of-aluminum-into-the-united-states.

Adjusting Imports of Steel Into the United States. 90 Fed. Reg. 9817. February 18, 2025. https://www.federalregister.gov/documents/2025/02/18/2025-02833/adjusting-imports-of-steel-into-the-united-states.

Aguilar, Tatiana. "Mining's Next Chapter: Innovation, Sustainability and Progress." World Economic Forum, January 30, 2025. https://www.weforum.org/stories/2025/01/mining-innovation-resource-stewardship-global-progress/.

The Aluminum Association. "Infinitely Recyclable." https://www.aluminum.org/Recycling.

American Institute of Steel Construction (AISC). "Steel's Environmental Footprint." Accessed May 9, 2025. https://www.aisc.org/sustainability/leed-v4/#129026.

ArcelorMittal. "Strategy." ArcelorMittal. Accessed April 16, 2025. https://corporate.arcelormittal.com/about/strategy.

Artisanal Mining (ASM). "ASM Inventory." Accessed May 14, 2025. https://artisanalmining.org/Inventory/.

Asenov, Grace, and Kimberly Leppold. "Where Will the U.S. Steel Market Get Its Prime Scrap?" Fastmarkets, May 3, 2022. https://www.fastmarkets.com/insights/where-will-the-us-steel-market-get-its-prime-scrap/.

ASTM International. "Steel Standards." Accessed May 15, 2025. https://store.astm.org/products-services/standards-and-publications/standards/steel-standards.html.

Banks, Martin. "How Will Labor Shortages Impact Metal Fabrication in 2022?" *Manufacturing Tomorrow*, March 7, 2022. https://manufacturingtomorrow.com/story/2022/02/how-will-labor-shortages-impact-metal-fabrication-in-2022/18341/.

Benchmark Mineral Intelligence. *Cobalt Market Report 2023*. Cobalt Institute, May 2024. https://www.cobaltinstitute.org/wp-content/uploads/2024/05/Cobalt-Market-Report-2023_FINAL.pdf.

Benchmark Source. "Two-Fifths of Cobalt Could Come from Nickel Mines by 2030." Benchmark Source, September 15, 2023. https://source.benchmarkminerals.com/article/two-fifths-of-cobalt-could-come-from-nickel-mines-by-2030.

Bonakdarpour, Mohsen, Frank Hoffman, and Keerti Rajan. *Mine Development Times: The U.S. in Perspective*. S&P Global, June 2024. https://cdn.ihsmarkit.com/www/pdf/0724/SPGlobal_NMA_DevelopmentTimesUSinPerspective_June_2024.pdf.

Cabaro Group. "Unveiling Japan's Steel Saga: A Riveting Tale of Industrial Triumph." February 14, 2024. https://blog.cabaro-group.com/exploring-the-success-story-of-japan-s-steel-production/.

Cardozo, Gustavo "The Lithium Battle: Strategies of China and U.S. in Argentina," August 21, 2024. Institute for Security and Development Policy, https://www.isdp.eu/the-lithium-battle-strategies-of-china-and-u-s-in-argentina/.

Corporate Finance Institute. "Foreign Direct Investment (FDI)." Accessed April 16, 2025. https://corporatefinanceinstitute.com/resources/economics/foreign-direct-investment-fdi/.

Choe, Gogwon, Hyungsub Kim, Jaesub Kwon, Woochul Jung, Kyu-Young Park, and Yong-Tae Kim. "Re-Evaluation of Battery-Grade Lithium Purity toward Sustainable Batteries." *Nature Communications* 15, no.1185, February 8, 2024. https://doi.org/10.1038/s41467-024-44812-3.

Cohen, Jared. "Resource Realism: The Geopolitics of Critical Mineral Supply Chains." Goldman Sachs, September 13, 2023. https://www.goldmansachs.com/insights/articles/resource-realism-the-geopolitics-of-critical-mineral-supply-chains.

Davey, Charlotte. "The Environmental Impacts of Cobalt Mining in Congo." Earth.Org, March 28, 2023. https://earth.org/cobalt-mining-in-congo/.

Deloitte. "Mining Spotlight On: Sliding Productivity and Spiraling Costs." 2014. https://bionanouni.wdfiles.com/local--files/teaching-im010-horario-2014i/Deloitte_14-Mining-Spotlight-On_Sliding-Productivity-and-Spiraling-Costs.pdf

Emmanuel Umpula, Eric Bisil. "Formalising Artisanal Cobalt Mining in the DRC: Much Work Remains." International Institute for Environment and Development (IIED), accessed May 9, 2025. https://www.iied.org/formalising-artisanal-cobalt-mining-drc-much-work-remains.

EOXS. "Streamlining Success: The Advantages of Vertical Integration in Metals." Accessed April 16, 2025. https://eoxs.com/new_blog/streamlining-success-the-advantages-of-vertical-integration-in-metals/.

European Commission. "Carbon Border Adjustment Mechanism (CBAM)." October 17, 2023. https://trade.ec.europa.eu/access-to-markets/en/news/carbon-border-adjustment-mechanism-cbam.

European Commission. "About the EU ETS." Accessed May 14, 2025. https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/about-eu-ets_en.

Fitzgerald, Susannah, Matthieu Salomon, Caroline Avan, Sophie Rickard, Yblin Roman Escobar, Tobias Kind-Rieper, Micol Martini, and Sofia Venturini. "Digging into the Problem: How Corruption Facilitates Socioenvironmental, Human Rights, and Indigenous Peoples' Rights Harms in the Mining Sector." February 2025. https://media.business-humanrights.org/media/documents/Digging-into-the-Problem.pdf.

Fortune Business Insights. "Electric Arc Furnace Market Size, Share." April 21, 2025. https://www.fortunebusinessinsights.com/electric-arc-furnaces-market-104745.

Green, Mark. "$40m Aluminum Recycler Breaks Ground in Logan County." *Lane Report*, September 9, 2024. https://www.lanereport.com/176402/2024/09/40m-aluminum-recycler-breaks-ground-in-logan-county/.

Guberman, David, Samantha Schreiber, and Anna Perry. "Export Restrictions on Minerals and Metals: Indonesia's Export Ban of Nickel." *USITC Working Papers*, February 2024. https://www.usitc.gov/publications/332/working_papers/ermm_indonesia_export_ban_of_nickel.pdf.

Go, Jiyeong. "Chinese companies expanding footprint in global lithium mines," FDI Intelligence, June 26, 2023. https://www.fdiintelligence.com/content/752cc95b-5c0c-53a4-b1c4-7a8482af466a.

Hubert, Xavier. "Circular Economy: A Competitive Advantage for Industry Transformation." April 2025. https://rla.org/media/article/view?id=1880.

Hutchison, Cathy. "Adopting ESG: What It Is, Its Drivers, and How to Take Action." Salas O'Brien, August 21, 2023. https://salasobrien.com/news/adopting-esg/.

International Council on Mining and Metals (ICMM). "How TNFD Is Shaping Nature-Positive Outcomes." Accessed May 1, 2025. https://nature.icmm.com/working-for-nature/articles/how-tnfd-is-shaping-nature-positive-outcomes.

International Council on Mining and Metals (ICMM). "Human Rights Due Diligence Guidance." Accessed May 12, 2025. https://www.icmm.com/en-gb/guidance/social-performance/2024/hrdd-guidance.

International Council on Mining and Metals (ICMM). "Our Members." Accessed April 30, 2025. https://www.icmm.com/en-gb/our-story/our-members.

International Council on Mining and Metals (ICMM). "Position Statement: Nature." Accessed April 30, 2025. https://www.icmm.com/en-gb/our-principles/position-statements/nature.

Investopedia. "How Do Externalities Affect Equilibrium and Create Market Failure?" February 14, 2025. https://www.investopedia.com/ask/answers/051515/how-do-externalities-affect-equilibrium-and-create-market-failure.asp.

Jakobs, Emil. "Aligning Business Strategy with Nature: The Role of Taskforce on Nature-Related Financial Disclosures (TNFD)." *California Management Review Insights*, March 10, 2025. https://cmr.berkeley.edu/2025/03/aligning-business-strategy-with-nature-the-role-of-taskforce-on-nature-related-financial-disclosures-tnfd/.

Kos, Paul, and Chris Jaros. "In Tune with Nature." *Global Mining Review*, March 2024. https://www.stantec.com/content/dam/stantec/files/PDFAssets/trade-publication-articles/004/global-mining-review-mine-reclamation-03-2024.pdf.

Leke Services. "Lithium Sourcing in the US: Is DLE Really the Key to The Lithium Revolution?" November 5, 2024. https://leke.services/post/lithium-sourcing-in-the-us-is-dle-really-the-key-to-the-lithium-revolution.

M'barek, Badr Ben, Ali Hasanbeigi, and Matthew Gray. *Global Steel Production Costs: A Country and Plant-Level Cost Analysis.* Transition Zero, January 2022. https://static1.squarespace.com/static/5877e86f9de4bb8bce72105c/t/61e790b43ddb95393be8dcc1/1642565821704/Global+Steel+Production+Costs+-+Jan2022.pdf.

Manalo, Paul. "Average Lead Time Almost 18 Years for Mines Started in 2020–23." S&P Global Market Intelligence, April 10, 2024. https://www.spglobal.com/market-intelligence/en/news-insights/research/average-lead-time-almost-18-years-for-mines-started-in-2020-23.

Milewski, Anthony. "The West's Pursuit of Rare Earths Hits Resistance from China." *The Oregon Group*, February 21, 2024. https://theoregongroup.com/investment-insights/the-wests-pursuit-of-rare-earths-hits-resistance-from-china/.

Mining.com. "Opinion: Tariffs on Minerals from China Are Not Enough." May 15, 2024. https://www.mining.com/opinion-tariffs-on-minerals-from-china-are-not-enough/.

MIT Climate Portal. "How is Lithium Mined?" February 12, 2024. https://climate.mit.edu/ask-mit/how-lithium-mined#.

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

Nemag. "How Switching to an Electric Arc Furnace Affects Your Grab Productivity." Accessed May 9, 2025. https://www.nemag.com/dry-bulk-blog/how-switching-to-an-electric-arc-furnace-affects-your-grab-productivity.

Notice of Modification: China's Acts, Policies, and Practices Related to Technology Transfer, Intellectual Property, and Innovation. 89 Fed. Reg. 76581. September 18, 2024. https://www.federalregister.gov/documents/2024/09/18/2024-21217/notice-of-modification-chinas-acts-policies-and-practices-related-to-technology-transfer.

Novelis, Inc. "Novelis Enters Long-Term Agreement to Supply Aluminum Beverage Can Sheet to Ball Corporation." September 11, 2023. https://investors.novelis.com/news-events/press-releases/detail/20/novelis-enters-long-term-agreement-to-supply-aluminum-beverage-can-sheet-to-ball-corporation.

Organisation for Economic Cooperation and Development (OECD). *OECD Benchmark Definition of Foreign Direct Investment (Fifth Edition)*. May 5, 2025. https://doi.org/10.1787/7f05c0a3-en.

Organisation for Economic Cooperation and Development (OECD). "*OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas: Third Edition*." April 6, 2016. https://doi.org/10.1787/9789264252479-en.

Organisation for Economic Cooperation and Development (OECD). *Latest Developments in Steelmaking Capacity and Outlook Until 2026.* June 12, 2024. https://one.oecd.org/document/DSTI/SC(2024)3/FINAL/en/pdf.

Organisation for Economic Cooperation and Development (OECD). *Quantifying the Role of State Enterprises in Industrial Subsidies*. June 24, 2024. https://www.oecd.org/en/publications/quantifying-the-role-of-state-enterprises-in-industrial-subsidies_49f39be1-en.html.

Pact. "Artisanal and Small-Scale Mining." Accessed May 14, 2025. https://www.pactworld.org/our-expertise/mining.

Pan, Zihuan. "Green Steel Premiums Not Enough to Offset Technology Costs in the Short Term: China Steel Congress." *Fastmarkets*. September 5, 2024. https://www.fastmarkets.com/insights/green-steel-premiums-not-enough-to-offset-technology-costs-in-the-short-term/.

Perry, Anna, Samantha Schreiber, and David Guberman. "Export Restrictions on Minerals and Metals: Estimation and Analysis of Supply Chain Effects from Zimbabwe's Chromium Ore Export Ban." *USITC Working Papers,* February 2024. https://www.usitc.gov/publications/332/working_papers/export_restrictions_on_minerals_and_metals_perry_schreigber_guberman.pdf.

Plante, Michael, Vaughn Hajra, and Sasha Samperio. "Old Oil Fields Reimagined as Lithium Sources." Federal Reserve Bank of Dallas. September 20, 2024. https://www.dallasfed.org/research/swe/2024/swe2413.

Porter, Michael E. "Competitive Strategy: Techniques for Analyzing Industries and Competitors." 1998. http://ijevanlib.ysu.am/wp-content/uploads/2023/02/Michael-E.-Porter-Competitive-Strategy.pdf.

Porter, Stanley, Ian Sanders, John Diasselliss, Brad Johnson, Kate Hardin, and Abhinav Purohit. "Promoting Metals and Mining Sustainability in Critical Supply Chains." Deloitte Insights, May 13, 2024. https://www2.deloitte.com/us/en/insights/industry/mining-and-metals/sustainability-in-metals-and-mining-energy-transition.html.

Qarahasanlou, Ali Nouri, A. H. S. Garmabaki, Ahmad Kasraei, and Javad Barabady. "Deciphering Climate Change Impacts on Resource Extraction Supply Chain: A Systematic Review." *International Journal of System Assurance Engineering and Management*, July 30, 2024. https://doi.org/10.1007/s13198-024-02398-5.

Radebe, Nomkhosi, and Nelson Chipangamate. "Mining Industry Risks, and Future Critical Minerals and Metals Supply Chain Resilience in Emerging Markets." *Resources Policy* 91, April 1, 2024: 104887. https://doi.org/10.1016/j.resourpol.2024.104887.

Recabarren, José I., Emilio Castillo, Andreína García, and Jorge Cantallopts. "Product Differentiation in Mineral Commodities Based on Sustainability Indicators: The Case of Copper Mining." *Journal of Cleaner Production* vol. 476, no 143786, October 2024. https://doi.org/10.1016/j.jclepro.2024.143786.

Rep. Smith, Christopher H. [R-NJ-4]. "Text - H.R.2310 - 119th Congress (2025-2026): COBALT Supply Chain Act." Legislation, March 24, 2025. https://www.congress.gov/bill/119th-congress/house-bill/2310.

Reuters. "Zimbabwe Bans Raw Lithium Exports to Curb Artisanal Mining." December 21, 2022. https://www.reuters.com/world/africa/zimbabwe-bans-raw-lithium-exports-curb-artisanal-mining-2022-12-21/.

Rio Tinto. "Nature Solutions." Accessed April 30, 2025. https://www.riotinto.com/en/sustainability/climate-change/nature-solutions.

S&P Global. "Industry Credit Outlook 2024: Metals and Mining." January 9, 2024. https://www.spglobal.com/_assets/documents/ratings/research/101591888.pdf.

Springer, Cecilia, and Ali Hasanbeigi. "Emerging Energy Efficiency and Carbon Dioxide Emissions-Reduction Technologies for Industrial Production of Aluminum." Ernest Orlando Lawrence Berkeley National Laboratory. June 2016. https://eta-publications.lbl.gov/sites/default/files/06-06-16_lbl_ceg_aluminum_ee_techs.pdf.

SSAB. "Comparing 'Green Steel' Technologies: A Scorecard Based on CO_2 Reduction." Accessed May 30, 2025.

Steel Tube Institute. "Environmental Product Declarations (EPDs)." Accessed May 9, 2025. https://steeltubeinstitute.org/resources/leed-epd/.

Stutt, Amanda. "Labour Costs Will Soon Beat Oil as Mine's Biggest Expense, New Data Indicate." *Mining.com*. June 6, 2023. https://www.mining.com/labour-costs-will-soon-beat-oil-as-mines-biggest-expense-new-data-indicate/.

Task Force on Climate-Related Financial Disclosures (TCFD). "About." Accessed April 17, 2025. https://www.fsb-tcfd.org/about/.

Taskforce on Nature-Related Financial Disclosures (TNFD). "About US." Accessed May 1, 2025. https://tnfd.global/about/.

Taskforce on Nature-Related Financial Disclosures (TNFD). "Who Has Adopted?" Accessed April 17, 2025. https://tnfd.global/.

Taskforce on Nature-related Financial Disclosures (TNFD). *Additional Sector Guidance Metals and Mining*. June 2024. https://tnfd.global/wp-content/uploads/2024/06/Additional-Sector-Guidance-Metals-and-mining.pdf?v=1719526916.

Torres, Timothy, Janelle Chia, and Yu Jing Kew. "Securing the US' Critical Minerals Supply Chain: Three Steps to Resilience." *Access Partnership*. March 6, 2025. https://accesspartnership.com/securing-us-critical-minerals-supply-chain/.

Tunley Environmental. "EPDs: Competitive Advantage for Green Building." August 19, 2024. https://www.tunley-environmental.com/en/insights/epds-as-competitive-advantage-for-green-building.

United Nations Development Programme (UNDP) Sustainable Insurance Forum. "SIF Scoping Study: Nature-Related Risks in the Global Insurance Sector." November 2021. https://www.sustainableinsuranceforum.org/view_pdf.php?pdf_file=wp-content/uploads/2021/11/UN_Nature-Related-Risks-in-the-Global-Insurance-Sector_v9.pdf

U.S. Department of Defense (DOD). "DOD Awards $35 Million to MP Materials to Build U.S. Heavy Rare Earth Separation Capacity." U.S. Department of Defense, February 22, 2022. https://www.defense.gov/News/Releases/Release/Article/2941793/dod-awards-35-million-to-mp-materials-to-build-us-heavy-rare-earth-separation-c/.

U.S. Department of Energy (DOE). "U.S. Department of Energy Announces $28 Million to Decarbonize Domestic Iron and Steel Production." April 18, 2024. https://arpa-e.energy.gov/news-and-events/news-and-insights/us-department-energy-announces-28-million-decarbonize-domestic-iron-and-steel-production.

U.S. Department of Energy (DOE). "FAST-41." Accessed May 9, 2025. https://www.energy.gov/oe/fast-41.

U.S. Department of Interior (DOI). "Trump Administration Adds Key Mining Projects to FAST-41." Press Release, April 18, 2025. https://www.doi.gov/pressreleases/trump-administration-adds-key-mining-projects-fast-41.

U.S. Department of Labor. "ILAB Lithium-Ion Batteries Storyboard." Accessed May 14, 2025. https://www.dol.gov/agencies/ilab/reports/child-labor/list-of-goods/supply-chains/lithium-ion-batteries.

U.S. Geological Survey (USGS). *Mineral Commodity Summaries 2024.* January 2024. https://pubs.usgs.gov/periodicals/mcs2024/mcs2024.pdf.

U.S. Geological Survey (USGS). *Mineral Commodity Summaries 2025.* January 2025. https://pubs.usgs.gov/periodicals/mcs2025/mcs2025.pdf

U.S. International Development Finance Corporation. "Strengthening Critical Mineral Supply Chains by Countering China's Dominance," May 13, 2025. https://www.dfc.gov/investment-story/strengthening-critical-mineral-supply-chains-countering-chinas-dominance.

U.S. International Trade Commission (USITC). *Economic Impact of Section 232 and 301 Tariffs on U.S. Industries*. USITC Publication 5405. March 2023. https://www.usitc.gov/publications/332/pub5405.pdf.

U.S. International Trade Commission (USITC). *Aluminum: Competitive Conditions Affecting the U.S. Industry.* USITC Publication 4703. June 2017. https://www.usitc.gov/publications/332/pub4703.pdf.

Valverde-Carbonell, Jorge, Carlo Pietrobelli, and María de las Mercedes Menéndez. "Minerals' Criticality and Countries' Mining Competitiveness: Two Faces of the Same Coin." *Resources Policy* 98 (November 1, 2024): 105359. https://doi.org/10.1016/j.resourpol.2024.105359.

Vergun, David. "Securing Critical Minerals Vital to National Security, Official Says." U.S. Department of Defense News, January 10, 2025. https://www.defense.gov/News/News-Stories/Article/Article/4026144/securing-critical-minerals-vital-to-national-security-official-says/https%3A%2F%2Fwww.defense.gov%2FNews%2FNews-Stories%2FArticle%2FArticle%2F4026144%2Fsecuring-critical-minerals-vital-to-national-security-official-says%2F.

Wald, Ellen. "The US Wants to End Its Reliance on Chinese Lithium. Its Policies Are Doing the Opposite." *Atlantic Council*. January 23, 2024. https://www.atlanticcouncil.org/blogs/new-atlanticist/the-us-wants-to-end-its-reliance-on-chinese-lithium-its-policies-are-doing-the-opposite/.

Watari, Takuma, and Benjamin McLellan. "Global Demand for Green Hydrogen-Based Steel: Insights from 28 Scenarios." *International Journal of Hydrogen Energy* vol. 79 pages 630–35. August 19, 2024. https://doi.org/10.1016/j.ijhydene.2024.06.423.

Watson, Christopher. "Domestic Steel Manufacturing: Overview and Prospects." Congressional Research Service, May 17, 2022. https://sgp.fas.org/crs/misc/R47107.pdf.

Webb, Adam. "Lithium Sector: Production Costs Outlook." S&P Global Market Intelligence, May 10, 2019. https://pages.marketintelligence.spglobal.com/lithium-sector-outlook-costs-and-margins-confirmation-CD.html.

The White House. "Unleashing American Energy." Executive Order 14154, January 20, 2025. https://www.whitehouse.gov/presidential-actions/2025/01/unleashing-american-energy/.

Worldsteel Association. "Sustainability Indicators: 2023 Report." November 2023. https://worldsteel.org/wp-content/uploads/Sustainability-indicators-report-2023.pdf.

Yao, Shunyu. "The Cobalt Expansion Drive is a Copper Story." S&P Global Market Intelligence, March 2, 2023. https://www.spglobal.com/market-intelligence/en/news-insights/research/the-cobalt-expansion-drive-is-a-copper-story.

Zacharia, Melina. "The Business Case for Investing in EPDs." One Click LCA, March 5, 2024. https://oneclicklca.com/en/resources/case-studies/the-business-case-for-investing-in-epds/.

Zeb Nickel Corp. "Why Nickel: Class 1 Vs. Class 2 Nickel." Accessed May 9, 2025. https://zebnickel.com/why-nickel/.