Bipartisan Policy Center

The Missing Midstream

IDENTIFYING INVESTMENT CHALLENGES FOR AMERICAN CRITICAL MINERAL PROCESSING PROJECTS

By Adam Johnson & John Jacobs

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AUTHORS

Adam Johnson
Managing Partner
Metis Endeavor

John Jacobs
Senior Policy Analyst
Energy Program
Bipartisan Policy Center

Summary

In today's increasingly high-tech economy, access to minerals like nickel, cobalt, copper, lithium, and rare earth elements, has emerged as a key concern for a simple reason: these materials are needed to make a wide array of goods and devices that have become indispensable, not only in daily life but also, in many cases, to the nation's long-term economic, security, and clean energy interests. Examples range from everyday consumer electronics, advanced medical equipment, and specialized alloys used in aircraft engines, satellites, and missiles to the new technologies—like electric vehicle batteries and renewable energy systems—that will be central to the coming energy transition.

As reliance on critical minerals has grown, the fact that China currently controls 80% of global capacity to process these minerals and an even larger share—nearly 90%—of global processing capacity for rare earth elements has drawn increasing alarm. Addressing this challenge has generated strong bipartisan support, both in efforts to diversify global supply chains and for increased investment to build up domestic processing capacity.[1] Midstream processing, in particular, is recognized as a vital link in the value chain for critical minerals, because this is the step that adds significant value to the raw materials by enhancing their purity, functionality, and suitability for use in advanced technologies.

This report explores the steps involved in minerals processing, current market dynamics for critical minerals, and the unique investment challenges of building a stronger domestic processing base. Among the challenges, we focus on six specific issues that will be especially critical to American success in overcoming China's current dominance of the critical minerals supply chain: feedstock availability, competition for labor, technology scale-up, market maturity, investor interest, and price competitiveness.

A key theme in our analysis is the need to consider each type of mineral individually when developing effective policies to address these challenges, particularly if the aim is to develop robust midstream processing capacity. Different minerals have different processing requirements and are subject to different market dynamics. Put simply, investors won't back new projects without some confidence that policies and capabilities are in place to navigate the risks and barriers each minerals market presents.

As a first step, it will be useful to distinguish between exchange-traded and non-exchange-traded minerals. Exchange-traded minerals benefit from established, transparent market mechanisms, while non-exchange-traded minerals are subject to the complexities of less regulated and more volatile markets. The supply chain dynamics for minerals that are not exchange-traded are more opaque and more vulnerable to supply uncertainties, including geopolitical risks. Not coincidentally, there is also a clear difference between exchange- and non-exchange-traded minerals when it comes to China's current influence over global markets in each group (Table 1).

Table 1. China's Influence on Markets: Exchange-Traded Vs. Not Exchange-Traded Minerals

Market share above 50% highlighted in red

		Exchange-Traded[2]				Not Exchange-Traded		
		Copper	Nickel	Cobalt	Lithium	Rare Earths[3]	Gallium	Graphite[i]
China's Influence	Mining (%)[4]	8.6%	3.3%	1.2%	14.6%	70.0%	98.1%	65.4%
	Processing (%)[iii,5]	42.3%	35.0%	72.0%	58.0%	87.0%	80.0%[6]	92.0%
	Export Rules					Restricted	Restricted	Restricted

Table 2 characterizes the degree of challenge for midstream investment in specific minerals along the six critical dimensions noted previously. As is evident from the table, access to skilled labor to expand domestic processing and price competitiveness are significant challenges for all critical minerals and rare earths; another significant challenge for most of the minerals and elements considered is feedstock availability. Market maturity and investor interest, by contrast, are major issues primarily for the non-exchange-traded minerals, including rare earths, gallium, and graphite.

[i] Data for mined and processed production is for natural graphite only.

Table 2. U.S. Midstream Investment Challenges by Mineral Type

Minor=not a primary barrier to investment. **Mild**=concerns investors. **Major**=primary barrier to investment.

	Copper	Nickel	Cobalt	Lithium	Rare Earths	Gallium	Graphite[ii]
Feedstock Scarcity Difficulty sourcing material domestically or from free trade nations	Minor	Major	Major	Minor	Major	Major	Mild
Competition for Labor Unpredictable availability of basic skilled labor	Major	Major	Major	Major	Major	Major	Major
Need for Technical Expertise Lack of experts with direct critical minerals processing experience	Minor	Mild	Mild	Minor	Mild	Major	Mild
Immature Market Inability to hedge, opaque pricing, lack of volume, etc.	Minor	Minor	Mild	Major	Major	Major	Major
Lack of Price Competitiveness Labor, energy, environmental adherence, and ongoing costs	Major	Major	Major	Major	Major	Major	Major
Lack of Investor Interest Lack of competitively priced risk capital for projects	Mild	Mild	Mild	Mild	Major	Major	Major

The purpose of this report is to help build a more nuanced understanding of the dynamics and challenges that apply, both to individual minerals and ubiquitously across this specific part of the value chain—midstream processing—that offers the most leverage for reducing current U.S. vulnerabilities in the critical minerals domain. Upcoming BPC reports will focus on policy responses. It is worth noting the high degree of congressional interest that currently exists—on both sides of the aisle—in taking action on these issues. This bipartisan interest is well-founded, given the substantial and urgent interests at stake—not only in terms of maintaining U.S. leadership in cutting-edge technologies, but also by reducing exposure to emerging geopolitical threats, reducing emissions, and enhancing national security in the years and decades to come.

[ii] Considering both natural and synthetic graphite. Feedstock availability for U.S. processing is primarily for synthetic graphite.

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Introduction

In an era where advanced technology, economic prosperity, and national security are inextricably linked, critical minerals—a term that encompasses metals like lithium, cobalt, nickel, and rare earth elements (REEs)[iii]—play a pivotal role as essential building blocks in many devices and materials that not only define the modern world but are key to meeting a range of emerging challenges, including climate change. The Department of Energy currently recognizes 50 minerals and 18 materials as "critical," both because they present supply chain risks and are used in everything from electric vehicle batteries and renewable energy technologies to consumer electronics, advanced medical equipment, and communications and defense systems.[7] Table 1 highlights the vast dependence of modern technologies on varied minerals.

Table 1. Advanced Technology Reliance on Different Critical Minerals[iv]

	Copper	Nickel	Cobalt	Lithium	Rare Earths[ii]	Gallium	Graphite[v]
EVs[8]	✓	✓	✓	✓	✓		✓
Aerospace[9, 10, 11]	✓	✓	✓	✓	✓	✓	
Defense Technologies[12,13]	✓	✓	✓	✓	✓	✓	✓
Mobile Electronics[14,15]	✓		✓	✓	✓	✓	✓
Satellites/Space[16,17,18]	✓	✓	✓	✓	✓	✓	✓
Robotics	✓	✓	✓	✓	✓	✓	✓
Wind Turbines[19, 20]	✓	✓			✓		
Solar Panels[xv, xvi,21]	✓					✓	
Nuclear Power[xvi]	✓	✓					
Energy Storage[xv, xvi, xvii]	✓	✓	✓	✓			✓
Grid Infrastructure[22]	✓						
LED Lighting[23]	✓	✓			✓	✓	

iii The term "rare earth elements" refers to a set of seventeen metallic elements, including the fifteen lanthanides on the periodic table plus scandium and yttrium. Although these elements are relatively abundant and widely distributed in the Earth's crust, they are often difficult to extract because they occur in low concentrations.

iv All include batteries where applicable.

v Application requirements incudes synthetic graphite.

Critical minerals are of particular importance and value because their unique and often extraordinary properties make them irreplaceable in certain applications. Some of these minerals may form especially tight chemical bonds with surrounding elements, others may be unusually reactive within certain environments, while still others may have the ability to withstand extreme temperature or pressure conditions. Obtaining these minerals and converting them to purified metals can be difficult, with many presenting unique challenges in terms of extraction and processing. Lithium can be extracted in brine pools, for example, while REEs are often separated using organic solvents. In some cases, these unique characteristics play a role in giving particular regions and countries unusual leverage over the supply chain for critical minerals.

This report aims to begin demystifying a key step in that supply chain: the midstream processing of mineral concentrates into higher-purity products that are suitable for further conversion to the specific forms needed for a range of end uses. Understanding the midstream step is important to diagnose the barriers and deficiencies that may be limiting the growth of a robust and competitive critical minerals processing industry within the United States. Contrasted with China's strategic dominance in this area, the current disparity in processing capabilities is stark. This discrepancy poses a significant challenge for the United States and many of its allies, which, despite efforts to spur investment in the mining and recycling of critical minerals, still lag when it comes to the capability to process raw minerals into purified metals and advanced materials needed to make many modern technologies.

This paper focuses on copper, nickel, cobalt, lithium, gallium, REEs, and graphite, which together illustrate a range of unique supply chain considerations. By focusing on these minerals, we aim to:

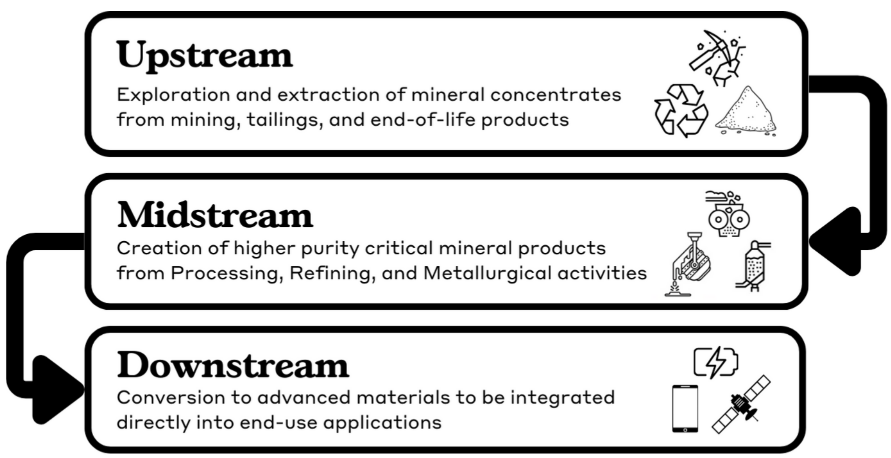
1. Illuminate the overlooked yet critical role of midstream processing in critical mineral supply chains,
2. Examine differences between exchange-traded and non-exchange-traded minerals, and
3. Assess the core challenges of establishing a robust and competitive processing industry in the United States.

In the sections that follow, we begin by reviewing the technical demands associated with the processing step (Section 2), before discussing the dynamics of current markets for particular minerals (Section 3). With this context, we then turn, in Section 4, to a discussion of the specific challenges that will have to be overcome to establish a robust midstream processing industry for critical minerals in the United States.

Minerals Processing: Role and Methods

Processing is the transformative step that follows the extraction of critical minerals, either directly from the Earth's crust or from other source materials, such as mining wastes. This step is analogous to the transformation of raw petroleum into gasoline or other liquid hydrocarbon fuels. Midstream is the step between the upstream exploration-and-extraction stage and the downstream stage of converting high-purity critical minerals into the specific forms required for end-use technologies and components.

OVERVIEW OF MINERAL PRODUCTION STAGES



Every mineral demands a unique processing solution, but the most common, commercially-proven techniques fall into three broad categories: physical beneficiation, hydrometallurgy, and pyrometallurgy. Each of these categories encompasses a variety of processing methods, from methods that rely on physical properties like density and magnetism to methods that involve complex chemical reactions and high-temperature treatments. This variety in processing methods, which is necessitated by the distinctive properties of different critical minerals, adds layers of complexity to the task of developing a unified strategy to increase domestic processing capability.

Physical beneficiation techniques may include:

- Crushing and milling to liberate minerals from source rock.
- Screening for size separation.
- Gravity separation, utilizing gravitational forces for separation.
- Magnetic and electrostatic separation, leveraging magnetic and electrical properties.
- Flotation and dense media separation, based on surface properties and buoyancy.
- Optical sorting, employing advanced algorithms for color and luminescence-based sorting.

Hydrometallurgical techniques may involve:

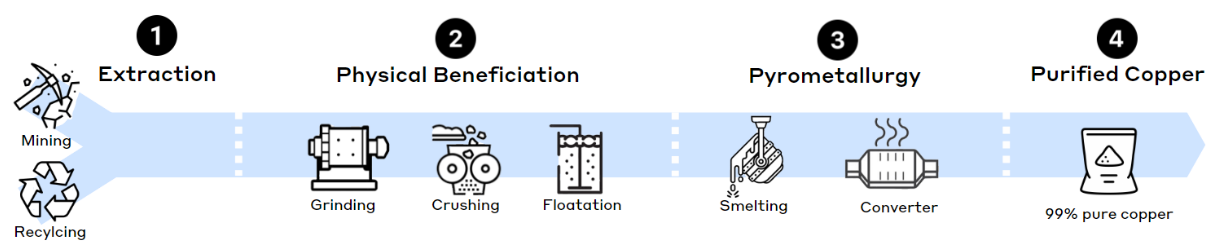
- Leaching to dissolve minerals.
- Evaporation and crystallization for mineral concentration.
- Solvent extraction and ion exchange for metal recovery.
- Precipitation and electrowinning to form and recover metal from solutions.

Pyrometallurgical techniques encompass:

- Roasting and calcining for impurity removal.
- Smelting and refining for metal extraction and purification.
- Sintering and converter processes to create larger, purer metal batches.

The visualizations in this section provide specific examples of some of the techniques noted above.

Pyrometallurgical Copper Process



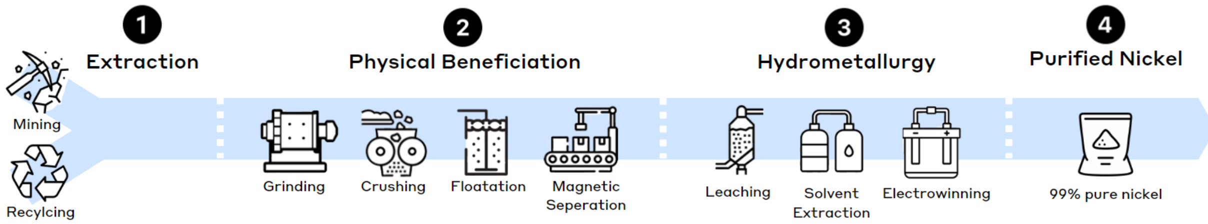
Two primary ways to source raw copper ore: mining and recycling. Both serve as starting points for obtaining raw material for processing.

Grinding and then curshing prepare the copper ore for flotation. Floatation increases copper concentration while reducing impurities, creating a copper-rich concentrate ready for thermal processing.

High-temperature smelting results in molten copper, known as matte. Further refining through converting and fire refining processes yields pure copper and valuable by-products.

After refining, copper reaches 99% purity and is ready for manufacturing.

Hydrometallurgical Nickel Process



Two primary ways to source raw nickel ore: mining and recycling. Both serve as starting points for obtaining raw material for processing.

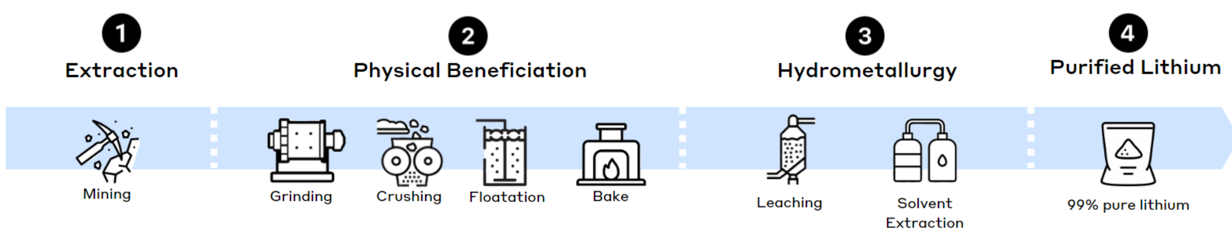
Grinding and then crushing prepare the nickel ore for flotation and magnetic separation, which are used to concentrate the nickel content. This increases the efficiency of the hydrometallurgical process that follows.

Concentrated ore is leached with acid or ammonia, separating nickel and leaving impurities behind. Solvent extraction then isolates nickel from other elements. Finally, electrowinning recovers high-purity nickel.

After refining, nickel reaches 99% purity and is ready for manufacturing.

In addition to recycling, raw lithium can be extracted in two primary ways that require different subsequent processing techniques. Lithium spodumene requires traditional hard rock mining, while extracting lithium brine is more akin to drilling a well. Which technique is utilized depends on geology. Argentina, Bolivia, and Chile are part of the "Lithium Triangle", home to the largest lithium brine reserves in the world. Meanwhile, about 50% of global lithium mining happens in Australia due to its rich reserves of spodumene.

Lithium Spodumene Process



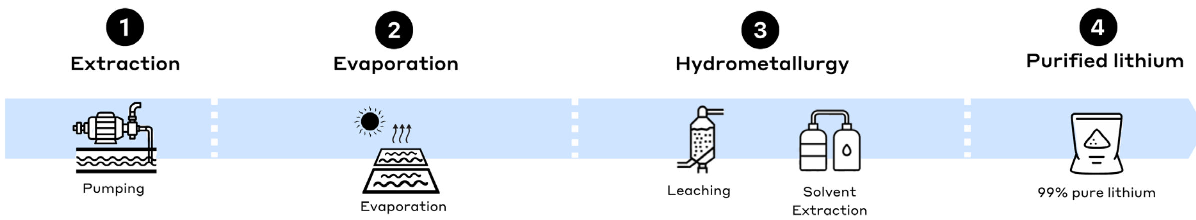
Spodumene, one of the most common lithium-bearing minerals in the world, is a hard rock mineral that needs to be mined for extraction.

Grinding and then crushing prepare the lithium ore for flotation, which concentrates the lithium content. Concentrated spodumene is then heated in a kiln to convert it into a form that can be leached.

Concentrated ore is leached with acid or ammonia, separating lithium and leaving impurities behind. Solvent extraction then isolates lithium from other elements.

After refining, lithium reaches 99% purity and is ready for manufacturing.

Lithium Brine Process



Brine is naturally occurring underground water that is rich in dissolved lithium salts. The first step is to pump the brine to the surface.

Brine is transferred to large, shallow evaporation ponds. Here, the sun and wind evaporate the water over months to years, which concentrates the lithium to levels that can be chemically processed.

Concentrated brine is is leached with acid or ammonia, separating lithium and leaving impurities behind. Solvent extraction then isolates lithium from other elements.

After refining, lithium reaches 99% purity and is ready for manufacturing.

The Need for Mature Mineral Markets

As important as the technical challenges of processing critical minerals are, the market dynamics that drive supply and demand and prices for these minerals are more so. Market dynamics create (or fail to create) conditions for private investment in expanding supply chain capacities. As is clear from even a cursory examination, there are distinct differences in the market environment for critical minerals that are traded on public commodity exchanges and those that are not. Organized marketplaces, such as the Chicago Mercantile Exchange and the London Metal Exchange, among others, provide transparency and reduce the economic friction associated with putting these minerals to use.

The primary objective of an exchange is to increase market liquidity by connecting bona fide buyers and sellers. This means the business of the exchange is to grow the pool of buyers and sellers as its core profit-making function. However, this is not the only function of a modern commodity trading exchange. Exchanges also facilitate the development of a sophisticated ecosystem of investors, regulatory agencies, banks and financial organizations, industry experts, market analysts, data providers, technology firms, and other important stakeholders—it would be difficult to coalesce these varied participants absent an organized market in the form of an exchange.

In other words, a public commodity exchange represents a mature market in which buyers can efficiently connect with sellers, thereby making it easier and less risky for mineral producers to do business.

The contrast between critical minerals traded on major public exchanges and those that are not has distinct implications for investor interest, geopolitical stability, and supply chain resilience.

Table 2. Benefits of Mature Markets

Benefits	Description
Greater Liquidity	Enhances the ease of trading, ensuring smoother and more efficient market operations and reducing the risk of supply disruptions.
Price Transparency	Facilitates informed decision-making and risk management by providing clear, real-time market data, which stabilizes investment and procurement strategies.
Hedging	Allows participants to mitigate financial risks associated with price volatility, ensuring more stable and predictable cost and revenue streams.
Regulatory Oversight	Ensures fair trading practices and market stability, thereby instilling investor confidence and maintaining the integrity of the market.
Product Standardization	Streamlines trading by guaranteeing uniform quality, simplifying valuation, and facilitating more efficient and reliable transactions.
Supply Chain Visibility	Allows for better risk assessment and strategic planning by providing clear insights into global trade dynamics and potential supply disruptions.
Increased Data Availability	Enhances market analysis and forecasting, enabling stakeholders to make more informed and strategic decisions.
Ecosystem Development	Unites various stakeholders, fostering a stable and collaborative market environment that enhances efficiency and innovation in the supply chain.

Exchange-Traded Dynamics

In sum, the market for exchange-traded minerals benefits from greater stability and the ability to attract a wider and more robust set of participants through greater market transparency and liquidity. Drawing a greater number of potential suppliers from a wider set of regions into the market also has important benefits in terms of reducing geopolitical tensions, improving access to capital, and providing an international forum to ensure fair standards for environmental, labor, and human rights.

For a major Western Original Equipment Manufacturer (OEM), procurement teams employ specific strategies when sourcing critical minerals that are exchanged-traded, such as nickel and copper, versus those that are not, such as rare earths and graphite. The benefits of liquidity, meaning the ability to buy and sell quickly, and transparent price discovery provide a valuable procurement advantage. Utilizing the services of brokers and traders, the teams have significant market data available to develop insights and lock-in prices using standardized and regulated contracts. When transactions are regulated, they have stronger enforcement mechanisms, and the parties involved are carefully vetted. These transactions can also include capital being held as collateral in accounts at licensed clearing houses.

Not Exchange-Traded Dynamics

Markets for non-exchange-traded minerals, by contrast, are more complex and require a more nuanced understanding, owing to their limited transparency and greater susceptibility to geopolitical influences. The supply chain dynamics for minerals that are not exchange-traded are less predictable and susceptible to greater disruptions due to supply uncertainties and non-market forces. These differences are obvious when considering China's influence on exchange-traded vs. non-exchange-traded minerals.

The sourcing of minerals not traded on public exchanges, such as rare earths and graphite, requires a more hands-on approach with significantly less reliable market information. An OEM procurement team must engage directly in negotiations and build long-term relationships with miners and refiners. Strategic alliances or joint ventures are often leveraged in resource rich regions to secure a stable supply of minerals. Due diligence is paramount in these transactions to ensure quality, ethical sourcing, and compliance with international regulations, including those concerning conflict minerals. Independent audits and certifications are typically necessary to substantiate suppliers' claims.

In negotiating contracts for non-exchange traded minerals, the team must tailor agreements to include specific terms on pricing, delivery schedules, and quality specifications. Often, the mineral product will be non-standard or "spec'd in" to the OEM's needs, making the qualifications more difficult and therefore more challenging for new entrants to break into the supply chain. The risks associated with these minerals extend beyond price fluctuations to include supply chain disruptions and ethical sourcing challenges, requiring a comprehensive approach to risk management. Because these contracts are also negotiated directly with single sources, there is also idiosyncratic risk associated with the individual supply partner.

Table 3. China's Influence on Markets: Exchange-Traded Vs. Not Exchange-Traded Minerals

Amounts above 50% highlighted in red

		Exchange-Traded[24]				Not Exchange-Traded		
		Copper	Nickel	Cobalt	Lithium	Rare Earths[25]	Gallium	Graphite[vi]
China's Influence	Mining (%)[26]	8.6%	3.3%	1.2%	14.6%	70.0%	98.1%	65.4%
	Processing (%)[iii,27]	42.3%	35.0%	72.0%	58.0%	87.0%	80.0%[28]	92.0%
	Export Rules					Restricted	Restricted	Restricted

Challenges to Establishing Robust Midstream Processing in the United States

A robust midstream processing capability is essential for the United States to achieve mineral independence, diversify supply sources, and ensure overall supply chain resiliency. China's ability to leverage its extensive processing and refining infrastructure to achieve a dominant position in the global critical minerals market is proof that such an approach is effective. Although it mines less of these minerals domestically than some other large nations, China processes minerals not only from its own mines, but also from mining partners located abroad and from global recycling efforts. This capability not only allows China to control a large portion of the world's processed minerals but also instills confidence among global suppliers in the Chinese market as a reliable purchaser of raw materials.

[vi] Data for mined and processed production is for natural graphite only.

Developing robust midstream processing capabilities is imperative for the United States to achieve its own success as a leader in global supply chains for critical minerals. This would not only enable the processing of domestically mined materials but also attract raw materials from different parts of the world and contribute to building a vibrant domestic ecosystem for advanced manufacturing. Realizing this worthwhile vision requires overcoming several challenges.

Domestic processing challenges include:

1. ensuring the availability of domestic and internationally sourced feedstock,
2. nurturing a capable workforce,
3. fostering technological innovation,
4. establishing flourishing markets of buyers and sellers,
5. reducing risks for private capital, and
6. ultimately competing on price and quality.

When assessing these investment challenges, it's important to remember that markets for all minerals are not created equal. The investment challenges for individual projects will depend on which type of mineral is being processed, and therefore which markets processors are buying from and selling into.

Table 4 summarizes investment challenges for different types of mineral processing projects in the United States. The remainder of this section describes these investment challenges in more depth and explains why existing barriers are higher for some types of minerals than others.

Table 4. U.S. Midstream Investment Challenges by Mineral Type

Minor=not a primary barrier to investment. **Mild**=concerns investors. **Major**=primary barrier to investment.

	Copper	Nickel	Cobalt	Lithium	Rare Earths	Gallium	Graphite[vii]
Feedstock Scarcity Difficulty sourcing material domestically or from free trade nations	Minor	Major	Major	Minor	Major	Major	Mild
Competition for Labor Unpredictable availability of basic skilled labor	Major	Major	Major	Major	Major	Major	Major
Need for Technical Expertise Lack of experts with direct critical minerals processing experience	Minor	Mild	Mild	Minor	Mild	Major	Mild
Immature Market Inability to hedge, opaque pricing, lack of volume, etc.	Minor	Minor	Mild	Major	Major	Major	Major
Lack of Price Competitiveness Labor, energy, environmental adherence, and ongoing costs	Major	Major	Major	Major	Major	Major	Major
Lack of Investor Interest Lack of competitively priced risk capital for projects	Mild	Mild	Mild	Mild	Major	Major	Major

FEEDSTOCK SCARCITY

Challenge	**Without sufficient feedstock, midstream processing and refining facilities will not be able to produce.**
Why is this important?	Investors will not invest into midstream businesses that are unable to attain feedstock.
Does this impact all critical minerals?	This impacts some more than others. Specifically, those minerals that are not traded on public commodity exchanges will generally be more complex to source. Another important factor will be trade relations between the United States and large mining jurisdictions for specific minerals.

Securing reliable feedstocks is foundational for establishing competitive mineral processing facilities, especially in the United States where the stakes are high due to substantial capital costs and ongoing operational costs. In this context, any disruptions in feedstock supply can significantly derail the economics of mineral processing projects.

The availability of mineral feedstocks is influenced by a myriad of factors. In the United States it takes nearly 16 years, on average, to obtain permits and

vii Considering both natural and synthetic graphite. Feedstock availability for U.S. processing is primarily for synthetic graphite.

start production at a new mine.[29] While permitting reforms could accelerate this timeline, U.S. processors will likely need to rely on internationally sourced feedstocks. Geopolitical dynamics that can complicate the accessibility and stability of these resources, combined with the inherent scarcity of certain minerals and the complexities of local extraction processes all pose further challenges. Environmental considerations also weigh heavily. Moreover, establishing a robust feedstock supply chain can itself necessitate significant infrastructure investments. To overcome these barriers, domestic processors can nurture relationships with potential suppliers in the United States and allied nations, while also accelerating recycling initiatives.

COMPETITION FOR LABOR

Challenge	**Midstream processing and refining facilities require skilled workers to fill positions such as electricians, mechanical operators, and machinists, and to handle maintenance, quality control, and other key tasks.**
Why is this important?	Investors will not risk investing in midstream businesses if they lack confidence that these businesses can hire the workforce they need to produce.
Does this impact all critical minerals?	Yes. Shortages of skilled labor are impacting infrastructure projects across the U.S. economy, including in the critical minerals sector.

The scarcity of skilled labor in the United States presents a significant challenge for the critical minerals industry, which finds itself vying with numerous other industries for a limited pool of talent. Key positions, including machinists, electricians, maintenance staff, equipment operators, and construction workers, are in high demand across several sectors.

According to data from the Bureau of Labor Statistics, the U.S. industrial manufacturing sector alone faced a shortfall of over 600,000 workers in 2023,[30] and this gap is widening. Critical minerals projects are not only competing with semiconductor and battery manufacturing companies, which often offer higher wages, but also grappling with a dearth of qualified people for highly specialized jobs that are critical for operational efficiency and quality control (e.g., chemists, quality control analysts, and laboratory technicians).

Other kinds of specialists that are in short supply include mining engineers, metallurgists, and geologists. McKinsey reports a 39% decline in graduates with degrees in mining engineering since 2016,[31] a field that is already struggling with limited talent. Meanwhile, the broader labor deficit in the manufacturing sector is projected to escalate to 2.1 million positions by 2030,[32] with a potential for deepening labor shortages in other, ancillary sectors like construction, which experienced a labor shortage of 650,000 workers in July 2023.[33]

NEED FOR TECHNICAL EXPERTISE

Challenge	**Processing certain minerals can be a complex industrial process that requires particular technical expertise as well as general labor to operate the facility. Standing up these complex facilities without technical expertise can create significant obstacles to successful execution.**
Why is this important?	Reducing execution risk is of primary concern for major capital-intensive projects.
Does this impact all critical minerals?	Not to the same extent. The U.S. has more experience and expertise operating midstream projects for some types of minerals compared to others.

First-hand knowledge and experience in designing and operating scaled industrial processes is extremely important for achieving operational excellence and maintaining commercial competitiveness in the critical minerals sector. However, the United States suffers from a noticeable scarcity of professionals with direct experience in midstream techniques for producing high-purity critical minerals and related materials.

A dearth of this type of expertise has implications for many aspects of successfully scaling critical minerals processes, from the ability to swiftly pinpoint and address inefficiencies to accurately estimating project timelines, preemptively tackling challenges, minimizing costs, and training new hires. And successful scaleup is ultimately essential to achieve cost competitiveness and sustain consistent, high-quality production at the level needed to meet growing market demand.

IMMATURE MARKET

Challenge	**Immature markets are characterized by opaque pricing and few buyers and sellers. This hinders market stability and growth. Current challenges in market maturity for some minerals are exacerbated by centralized pricing and supply controls in China, which can influence global prices and deter broader industry participation.**
Why is this important?	Market immaturity creates complex price volatility and volume risk that is difficult for domestic projects to navigate and deters investment.
Does this impact all critical minerals?	These challenges primarily impact minerals that are not traded on public exchanges. However, market volatility can also be an issue for a mineral like cobalt, which is traded on public exchanges but has a supply chain that is still heavily concentrated.

Robust and liquid markets for commodities play a crucial role in risk reduction because they offer key advantages such as hedging capabilities, price transparency, product standardization, a diverse buyer base, and the involvement of independent financial stakeholders.

The ability to hedge risk, for example, is a fundamental function of mature markets. This can involve using financial instruments like futures contracts to lock in prices, thereby protecting against price volatility and uncertain market conditions. For instance, a critical mineral processing company might employ futures contracts to secure a stable price for copper, thereby reducing its exposure to market fluctuations and buying greater certainty about its own future operating costs. This stability not only boosts investor confidence and operational efficiency, but can also attract a broader range of investors, including more risk-averse investors who may be able to offer more favorable financing terms. Finally, effective hedging allows for precise budgeting and strategic planning, empowering producers and customers to make confident operational decisions.

Confidence and transparency in pricing are likewise important to foster healthy dynamics between producers and customers, promote diversification of feedstocks and sources, and ultimately reduce the potential for supply chain disruptions. The current global market for some critical minerals suffers from opaque pricing, particularly in cases where processing is heavily centralized in specific regions or countries, like China. These markets are more susceptible to price manipulation and will be less attractive to new participants because of the additional price risks they present.

In contrast, transparent pricing, even in markets with few dominant players, provides investors with clarity, builds trust, supports more accurate forecasts, and helps to create a positive investment environment. These benefits are further enhanced by product standardization. Standardization simplifies transactions for both producers and customers, further stabilizing the market and promoting sustainable growth.

LACK OF PRICE COMPETITIVENESS

Challenge	Need to incur capital costs of new infrastructure and high operational costs make U.S. processed minerals more expensive in a global market dominated by lower-priced products.
Why is this important?	This directly affects a midstream project's ability to attract customers and investors, as well as its ability to sustain operations through lower price commodity cycles.
Does this impact all critical minerals?	Yes. However, some are impacted to a greater degree than others as they need to overcome technical scaling issues and other factors.

Minerals processed in the United States will not find customers if they are not price-competitive in global markets. In 2023, the United States was ranked 78th among 87 countries in manufacturing cost competitiveness by *US News & World Report*.[34] China, by contrast, ranked second—behind India. This result reflects not only the higher energy and labor costs in the United States, but the additional competitive disadvantages in terms of R&D investment, lack of experience operating novel, and initial diseconomies of scale. Such diseconomies often require a greater relative investment in highly educated labor and engineering to scale commercial operations.

Moreover, centralized regimes in countries like China have strategically subsidized domestic mineral supply chains, enabling their businesses to offer products and services at significantly lower costs than their American counterparts. As a result, foreign entities can saturate the market with more affordable products, exerting downward pressure on domestic prices and compelling customers to choose between lower-priced, high-volume products from established manufacturers abroad, typically in China, and higher-priced offerings from U.S. manufacturers with unproven scalability.

This dynamic also affects investor confidence. Knowing that many global competitors are subsidized, investors considering midstream business ventures in the United States may be apprehensive to commit capital or demand higher returns to offset perceived risks.

LACK OF INVESTOR INTEREST

Challenge	**Investors must navigate a potentially long payback period while committing significant upfront capital for mineral processing projects.**
Why is this important?	Significant private investment is required to finance the critical minerals industry within the United States.
Does this impact all critical minerals?	This impacts some minerals more than others. Projects involving minerals that are part of the battery supply chain and are also traded on public commodity exchanges have the greatest access to various forms of capital. Projects that involve other types of minerals require less capital in many cases, but often face other challenges due to the complexity of either the value chain or other factors.

The previous risks ultimately feed into whether investors are interested in a sector or project. However, "investor interest" is also dependent on opportunity cost. The technology sector, for example, can offer lower capital costs and higher upside compared to industrial projects. Therefore, to invest in industrial projects, investors require more favorable financial terms that results in more expensive capital for the project developer.

Increasing investor interest in the critical mineral sector would improve access to capital at terms that are conducive to achieving strong business outcomes. As investors are predominately interested in potential risks and returns relative to other investments (i.e., risk-adjusted returns), the multitude of risk factors is ultimately what weighs on investor interest. These factors will vary with individual projects, but can encompass issues like permitting challenges, labor availability, technical expertise, and access to other forms of Minor-cost financing, which itself will be affected by project maturity, macroeconomic conditions, and commercial viability.

The fact that project costs for new critical mineral processing facilities in the United States are often higher than they would be in other parts of the world presents a potentially significant investment hurdle. Higher costs can apply to a range of upfront project expenses, including for materials, workers, engineering design, permitting, legal services, technology requirements, and recruitment. An environment of higher interest rates and shifting macroeconomic conditions exacerbates the challenge, as do the lengthy payback periods typical of industrial projects. In China, by contrast, costs are not only lower, but significant investments have already been made in capacity and technology development, often supported by policy-driven subsidies or capital infusions over the course of decades. Resulting cost disparities are a significant obstacle to raising the necessary capital for new critical minerals projects in the United States.

Conclusion

Diversifying the critical minerals processing sector is vital to prevent supply disruptions that could stall the energy transition, hamstring economic competitiveness, and leave the U.S. vulnerable to national security concerns. The challenges to establishing a robust midstream processing industry for critical minerals in the United States are formidable and will require a nuanced approach that is sensitive to the unique market dynamics and technology requirements of different minerals. There are important distinctions, for example, between currently exchange-traded and non-exchange-traded minerals; distinctions that call for thoughtful policy responses, if the aim is to unlock significant private sector investment and propel the nation to a leading role in global supply chains for critical minerals.

Congressional interest in bolstering domestic processing capabilities for critical minerals, meanwhile, is strong on both sides of the aisle, as reflected in recently passed legislation, including the Energy Act of 2020, the Bipartisan Infrastructure Law, the CHIPS and Science Act, and the fiscal year 2024 National Defense Authorization Act.[35,36,37,38] The House Select Committee on Strategic Competition Between the United States and the Chinese Communist Party recently signaled bipartisan appetite to do more on this topic by recommending that Congress "[a]uthorize and appropriate a critical mineral Resilient Resource Reserve to insulate American producers from price volatility and PRC weaponization of its dominance in critical mineral supply chains."[39]

The specific challenges outlined in this report provide a framework for developing effective policy responses. Forthcoming BPC recommendations will propose specific strategies for leveraging current bipartisan momentum to implement well-designed policies and programs for de-risking domestic processing projects and catalyzing private sector investment in this vital industry.

Copper Processing

Bipartisan Policy Center

INVESTMENT CHALLENGES FOR U.S. PROJECTS

Copper is a key mineral in many cutting-edge technologies from grid infrastructure to advanced electronics. Its production commences with the extraction of its ores, which are subsequently crushed and ground. After a concentration phase, primarily through froth flotation, the copper minerals are isolated. This concentrated copper is then smelted and refined to eliminate impurities, employing oxidation in converters and electrolytic refining in a sulfuric acid and copper sulfate solution. The final product, which is nearly 99.99% pure copper, plays a pivotal role in the energy transition. Copper is extensively utilized in renewable energy systems such as wind turbines, solar panels, and energy storage units, as well as in electric vehicles and their charging infrastructure — all of which are foundational to a sustainable energy future. Furthermore, recycling used copper components aids not only in meeting the rising demand in these sectors but also in promoting a circular economy.

Applications requiring copper.

China's Influence	Mining (%)	8.6%
	Processing (%)	42.3%
	Export Rules	
Electric Vehicles (incl. batteries)		✓
Aerospace		✓
Defense Technologies		✓
Mobile Electronics (incl. batteries)		✓
Satellites/Space (incl. batteries)		✓
Robotics (incl. batteries)		✓
Wind Turbines		✓
Solar Panels		✓
Nuclear Power		✓
Energy Storage		✓
Grid Infrastructure		✓
LED Lighting		✓

Risks to establishing domestic copper processing.

Feedstock Scarcity	Minor	Feedstock challenges are due to long permitting timelines.
Competition for Labor	Major	Labor challenges arise from specialized skill deficits, more attractive opportunities in competing sectors, and location discrepancies.
Need for Technical Expertise	Minor	Scaling copper processing in the U.S. requires efficient energy use and strict environmental adherence.
Immature Market	Minor	Copper is a relatively more mature market than other critical minerals but still suffers from Chinese competition and processing concentration.
Lack of Price Competitiveness	Major	Price competitiveness is hindered by logistics and local energy cost trade-offs, and expensive raw material sourcing, compared to Chile and Peru.
Lack of Investor Interest	Mild	Investor hesitation is influenced by the significant capital, environmental compliance, lower-cost international competition, and market volatility.

Overview of copper processing.

Upstream Material	Common Mid-Stream Technologies	Mid-Stream Product Outputs
Copper-containing ores	▪Physical Beneficiation [crushing, grinding, flotation, leaching, gravity separation, magnetic separation] ▪From Sulfide Ore: oPyrometallurgy of sulfide ores [roasting, smelting, converter refining, electrolytic refining] ▪From Oxide Ore: oHydrometallurgy [leaching, solvent extraction ("SX"), electrowinning]	High purity copper anode or cathode material

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Nickel Processing

Bipartisan Policy Center

INVESTMENT CHALLENGES FOR U.S. PROJECTS

Nickel, a linchpin in modern technology, is mined from ores like laterite and sulfide. After extraction, these ores are crushed, ground, and processed through magnetic separation and flotation to produce a nickel-rich concentrate. Smelting in flash furnaces yields a matte, which is further refined using pressure leach techniques and high-temperature refining to surpass 75% nickel content. The final purification, including electrorefining and the Mond process, results in nickel exceeding 99.98% purity. Essential for lithium-ion batteries in electric vehicles, nickel enables higher energy density and efficiency. It's also key in manufacturing durable alloys for renewable energy infrastructure. With the rise of EVs and sustainable power sources, recycling nickel from end-of-life products is vital for resource conservation and environmental sustainability, underpinning a stable, circular economy.

Applications requiring nickel.

China's Influence	Mining (%)	3.3%
	Processing (%)	35.0%
	Export Rules	
Electric Vehicles (incl. batteries)		✓
Aerospace		✓
Defense Technologies		✓
Mobile Electronics (incl. batteries)		
Satellites/Space (incl. batteries)		✓
Robotics (incl. batteries)		✓
Wind Turbines		✓
Solar Panels		
Nuclear Power		✓
Energy Storage		✓
Grid Infrastructure		
LED Lighting		✓

Risks to establishing domestic nickel processing.

Feedstock Scarcity	Major	Dependence on imports from politically sensitive areas like Indonesia and Russia, environmental constraints on new mining, and global competition hinder feedstock sourcing.
Competition for Labor	Major	Labor shortages are due to specialized skill needs, attractive alternatives, and geographical mismatches.
Need for Technical Expertise	Mild	Improvements in high-pressure acid leach (HPAL) techniques and refining electro-winning for pure nickel production must be aligned with existing infrastructure and new recycling efforts.
Immature Market	Minor	Cost competitiveness against global rivals, who benefit from significant economies of scale, is the primary market concern.
Lack of Price Competitiveness	Major	Price competitiveness in nickel is impacted by Indonesia and Russia's lower production costs and favorable regulatory environments.
Lack of Investor Interest	Mild	Investor caution stems from high start-up costs, competition from Indonesia and Russia, and demand fluctuations in steel and battery sectors.

Overview of nickel processing.

Upstream Material	Common Mid-Stream Technologies	Mid-Stream Product Outputs
nickel-containing ores	▪Physical Beneficiation [crushing, grinding, screening, flotation, magnetic separation, gravity separation] ▪From Sulfide Ore: ○Hydrometallurgy and Pyrometallurgy [froth flotation, smelting, leaching, SX, electrowinning] ▪From Laterite Ore: ○Hydrometallurgy [high-pressure acid leaching, SX, electrowinning] ▪Electrometallurgy: Electrorefining	High purity nickel metals, salts, and alloys

Cobalt Processing

Bipartisan Policy Center

INVESTMENT CHALLENGES FOR U.S. PROJECTS

Cobalt, essential for high-energy-density batteries, is procured from minerals like cobaltite. Post-extraction, the ore undergoes refining—first through comminution and concentration, then via pyrometallurgy to create cobalt matte, and finally through hydrometallurgical processes including acid leaching and electrowinning to achieve high purity levels. In battery production, cobalt is crucial for maintaining cathode structure integrity, enhancing energy retention, and ensuring thermal stability, which are vital for electric vehicle performance. As the electric mobility market expands, recycling cobalt becomes imperative, providing a sustainable alternative to direct mining, reducing environmental impact, and addressing ethical sourcing concerns.

Applications requiring cobalt.

China's Influence	Mining (%)	1.2%
	Processing (%)	72.0%
	Export Rules	
Electric Vehicles (incl. batteries)		✓
Aerospace		✓
Defense Technologies		✓
Mobile Electronics (incl. batteries)		✓
Satellites/Space (incl. batteries)		✓
Robotics (incl. batteries)		✓
Wind Turbines		
Solar Panels		
Nuclear Power		
Energy Storage		✓
Grid Infrastructure		
LED Lighting		

Risks to establishing domestic cobalt processing.

Feedstock Scarcity	Major	Feedstock availability for cobalt is challenged by the DRC's dominance in production, political instability, human rights issues, geopolitical risks, and competition from China.
Competition for Labor	Major	Labor difficulties are due primarily to niche skill shortages, better prospects in other industries, and geographic mismatches.
Need for Technical Expertise	Mild	Scaling requires advancing extraction and purification for varied ores, creating greener and safer methods, while improving recoveries.
Immature Market	Major	Pricing volatility due to sourcing from unstable regions like the Congo and few domestic supply chain counterparties add risk to domestic projects.
Lack of Price Competitiveness	Major	Price competitiveness is constrained by stringent environmental regulations and high labor costs compared to China, where most cobalt processing occurs.
Lack of Investor Interest	Mild	Investor caution stems from high startup costs, stringent environmental laws, cheaper foreign competition, and volatile prices in part due to demand uncertainty.

Overview of cobalt processing.

Upstream Material	Common Mid-Stream Technologies	Mid-Stream Product Outputs
Cobalt-containing ores	▪Physical Beneficiation [crushing, grinding, screening, flotation, magnetic separation, gravity separation] ▪From Sulfide Ore: ○Hydrometallurgy and Pyrometallurgy [froth flotation, smelting, leaching, SX, electrowinning] ▪From Laterite Ore: ○Hydrometallurgy [high-pressure acid leaching, SX, electrowinning] ▪Electrometallurgy: Electrorefining	High purity cobalt metals, salts, and alloys

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Lithium Processing

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INVESTMENT CHALLENGES FOR U.S. PROJECTS

Lithium, the lightest metal, is pivotal in manufacturing high-capacity rechargeable batteries. Extracted from brine pools or hard-rock ore like spodumene, the raw lithium undergoes an extensive refinement process. From evaporation of brines to chemical conversion of ores, the lithium is precipitated and then purified to yield lithium carbonate or lithium hydroxide. Lithium's electrochemical potential makes it the bedrock of lithium-ion batteries, providing exceptional energy-to-weight ratios crucial for portable electronics and electric vehicles (EVs). Its role in enabling longer charge cycles and battery stability is unmatched, facilitating the transition to clean energy. Facing skyrocketing demand, the sustainable extraction and recycling of lithium are critical. They ensure a steady supply chain while minimizing ecological disruption, making lithium a cornerstone of both technological advancement and environmental stewardship.

Applications requiring lithium.

China's Influence	Mining (%)	14.6%
	Processing (%)	58.0%
	Export Rules	N/A
Electric Vehicles (incl. batteries)		✓
Aerospace		✓
Defense Technologies		✓
Mobile Electronics (incl. batteries)		✓
Satellites/Space (incl. batteries)		✓
Robotics (incl. batteries)		✓
Wind Turbines		
Solar Panels		
Nuclear Power		
Energy Storage		✓
Grid Infrastructure		
LED Lighting		

Risks to establishing domestic lithium processing.

Feedstock Scarcity	Minor	Processing faces hurdles from dependency on imports, environmental and regulatory challenges in expanding local mining, and surging global demand competition.
Competition for Labor	Major	Labor difficulties are due primarily to niche skill shortages, better prospects in other industries, and geographic mismatches.
Need for Technical Expertise	Minor	Scaling requires optimizing extraction from brine pools due to its high solubility, enhancing purification, and advancing recycling technologies for battery recovery.
Immature Market	Major	Processing faces significant pricing volatility challenges, scarcity of established domestic industry counterparties, and intense competitive commercial realities.
Lack of Price Competitiveness	Major	Pricing in lithium is undermined by global competition, including Chile and Argentina's low-cost operations.
Lack of Investor Interest	Mild	Investor hesitation arises from high initial costs, strong competition from South America, electric vehicle demand volatility, and market opacity.

Overview of lithium processing.

Upstream Material	Common Mid-Stream Technologies	Mid-Stream Product Outputs
Lithium-containing spodumene or brine	▪From Spodumene, Hard Rock Ore: oPhysical Beneficiation [crushing, grinding, screening, flotation, magnetic separation, gravity separation] oHydrometallurgy and Pyrometallurgy [concentration, acid roasting, sulfate solution processing, purification, precipitation] ▪From Lithium Brine: oHydrometallurgy [pumping, evaporation, lithium carbonate precipitation, crystallization, conversion to lithium hydroxide if required] ▪Direct Lithium Extraction ("DLE")	Lithium carbonate or lithium hydroxide

Rare Earth Elements Processing

Bipartisan Policy Center

INVESTMENT CHALLENGES FOR U.S. PROJECTS

Rare earth elements (REEs), vital for cutting-edge technologies, are sourced from minerals like bastnaesite. Their extraction involves intricate processes, including solvent extraction and ion exchange, to isolate and purify each metal due to their chemically similar natures. REEs are critical in manufacturing powerful magnets, energy-saving lighting, and efficient catalytic converters—key components in wind turbines, electric vehicles (EVs), and electronics. With surging demand propelled by clean energy and tech sectors, sustainable sourcing, and recycling of REEs become crucial. These practices help circumvent resource scarcity and ensure an equilibrium between technological advancement and environmental conservation.

Applications requiring rare earth.

China's Influence	Mining (%)	70.0%
	Processing (%)	87.0%
	Export Rules	Restricted
Electric Vehicles (incl. batteries)		✓
Aerospace		✓
Defense Technologies		✓
Mobile Electronics (incl. batteries)		✓
Satellites/Space (incl. batteries)		✓
Robotics (incl. batteries)		✓
Wind Turbines		
Solar Panels		
Nuclear Power		
Energy Storage		✓
Grid Infrastructure		
LED Lighting		

Magnetic Rare Earths = Neodymium, Praseodymium, Dysprosium, and Terbium

Risks to establishing domestic rare earth processing.

Feedstock Scarcity	Major	Domestic processing faces challenges from limited mining, lack of midstream counterparties, and intense price competition with China.
Competition for Labor	Major	Labor competition challenges are due to the specialized skill requirements, higher attractiveness of alternative sectors, and remote facility locations.
Need for Technical Expertise	Mild	Scaling requires optimized separation techniques due to closely related chemical properties, advancing recycling from electronic waste, and integrating these methods into scaled infrastructure.
Immature Market	Major	Significant commercial hurdles exist, including reliance on a few large buyers, opaque global markets with volatile pricing, and intense global competition on price and delivery certainty.
Lack of Price Competitiveness	Major	Price competitiveness in rare earths is hindered by China's dominance, which benefits from established economies of scale to undercut global prices.
Lack of Investor Interest	Major	Investor reluctance stems from high capital costs, China's dominance, complex technologies, strict environmental regulations, and market opacity.

Overview of rare earth processing.

Upstream Material	Common Mid-Stream Technologies	Mid-Stream Product Outputs
Rare earth concentrate	▪Physical Beneficiation [gravity separation, magnetic separation, crushing, grinding, flotation] ▪Hydrometallurgy and Pyrometallurgy [leaching, SX, calcination, precipitation, electrowinning, molten salt electrolysis] ▪Ion-exchange methods may replace SX	Rare earth oxides, metals, and alloys

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Gallium Processing

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INVESTMENT CHALLENGES FOR U.S. PROJECTS

Gallium, vital in electronics, is sourced as a byproduct from bauxite and sphalerite. It undergoes purification, including solvent extraction and electrolysis, to achieve high purity. Essential in semiconductors like gallium arsenide (GaAs) and gallium nitride (GaN), it's used in integrated circuits, LEDs, and solar cells, valued for high-speed operation and thermal stability. With growing demands from 5G and renewable energy sectors, sustainable gallium supply through efficient recycling and innovative extraction is crucial, balancing technological advancement with environmental sustainability.

Applications requiring gallium.

China's Influence	Mining (%)	N/A%[1]
	Processing (%)	98.1%
	Export Rules	Restricted
Electric Vehicles (incl. batteries)		
Aerospace		✓
Defense Technologies		✓
Mobile Electronics (incl. batteries)		✓
Satellites/Space (incl. batteries)		✓
Robotics (incl. batteries)		✓
Wind Turbines		
Solar Panels		✓
Nuclear Power		
Energy Storage		
Grid Infrastructure		
LED Lighting		✓

Risks to establishing domestic gallium processing.

Feedstock Scarcity	Major	Feedstock challenges stem from lack of domestic mining, reliance on by-product extraction from overseas aluminum and zinc production, and intense competition from global demand.
Competition for Labor	Major	Labor hurdles are due to specialized skill shortages, appealing alternatives in other fields, and geographical challenges.
Need for Technical Expertise	Major	Gallium's unique properties requires complex low-temp extraction, improved purification from aluminum / zinc ores, innovative e-waste recycling, integrated with metal processing infrastructures.
Immature Market	Major	There are limited domestic partners in a niche market and high costs due to immature economies of scale, made worse by fierce competition from China, which dominates over 95% of the market.
Lack of Price Competitiveness	Major	Price competitiveness is challenged by China's dominance, which benefits from cheaper labor, energy, and raw materials.
Lack of Investor Interest	Major	Investor hesitation arises from high initial costs, strong competition from South America, electric vehicle demand volatility, and market opacity.

Overview of gallium processing.

Upstream Material	Common Mid-Stream Technologies	Mid-Stream Product Outputs
Gallium-containing materials	▪From Bauxite Residues: oHydrometallurgy [leaching, SX, electrowinning, precipitation, zone purification (a specialized refining process)] ▪From Zinc Ores oPyrometallurgy and Hydrometallurgy [roasting, leaching, SX, electrowinning, zone purification]	High purity gallium metal, liquid metal alloys, and Ga-compounds

1 Nearly all gallium is a byproduct of processed bauxite and zinc-processing residues.

Graphite Processing

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INVESTMENT CHALLENGES FOR U.S. PROJECTS

Graphite, essential in various industries, is obtained both naturally from ore deposits and synthetically from amorphous carbon sources like petroleum coke. Natural graphite undergoes flotation for purification, while synthetic graphite is produced through high-temperature treatment, yielding a pure, consistent material. Valued for its conductivity and thermal resistance, graphite is used in electrodes, refractories, and lithium-ion battery anodes, enhancing energy storage and charge efficiency. With the rise in electric vehicles and electronics, sustainable sourcing of natural graphite and advanced production of synthetic variants are crucial to meet increasing demands while minimizing environmental impacts.

Applications requiring graphite.

China's Influence	Mining (%)	65.4%
	Processing (%)	92.0%
	Export Rules	Restricted
Electric Vehicles (incl. batteries)		✓
Aerospace		
Defense Technologies		✓
Mobile Electronics (incl. batteries)		✓
Satellites/Space (incl. batteries)		✓
Robotics (incl. batteries)		✓
Wind Turbines		
Solar Panels		
Nuclear Power		
Energy Storage		✓
Grid Infrastructure		
LED Lighting		

Risks to establishing domestic graphite processing.

Feedstock Scarcity	Mild	Heavy reliance on imports, particularly from China, and the growing demand competition limits availability of domestic feedstock for processing.
Competition for Labor	Major	Labor availability issues arise from niche skill scarcity, superior options in competing industries, and remote operational areas.
Need for Technical Expertise	Mild	Scaling complexity is due to advancing separation of flake graphite because of its layered structure, purification for battery-grade quality, and developing efficient recycling from lithium-ion batteries.
Immature Market	Major	Volatile and opaque pricing, lack of domestic commercial and technical counter-parties, high costs due to underdeveloped economies of scale, all constrain industry development.
Lack of Price Competitiveness	Major	Price competitiveness in graphite is compromised by China's dominance and economies of scale, which leverages extensive mining and low regulatory costs
Lack of Investor Interest	Major	Investor caution is driven by high capital needs, competition from China, demand volatility, and market opacity.

Overview of graphite processing.

Upstream Material	Common Mid-Stream Technologies	Mid-Stream Product Outputs
Natural graphite-containing ore	▪Physical Beneficiation [crushing, milling, flotation] ▪Pyrometallurgy and Hydrometallurgy [thermal and chemical purification] ▪Shaping and Sizing [milling, spheroidization] ▪Surface Coating	Higher-purity shaped graphite or graphene
Petroleum coke, coal tar pitch, and other high-carbon materials	▪Physical Beneficiation [mixing raw materials] ▪Pyrometallurgy [carbonization, graphitization] ▪Shaping and Sizing (milling, spheroidization) ▪Secondary Treatments, if needed [oxidation, surface functionalization] ▪Pyrometallurgy and Hydrometallurgy [thermal and chemical purification] ▪Machining and further shaping ▪Surface Coating	Synthetic graphite

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Appendix

Mid-Stream conversion overview for select critical minerals.

	Upstream Material	Common Mid-Stream Technologies	Mid-Stream Product Outputs
Copper	**Copper-containing ores**	• **Physical Beneficiation** [crushing, grinding, flotation, leaching, gravity separation, magnetic separation] • From Sulfide Ore: — **Pyrometallurgy** of sulfide ores [roasting, smelting, converter refining, electrolytic refining] • From Oxide Ore: — **Hydrometallurgy** [leaching, solvent extraction ("SX"), electrowinning]	High purity copper anode or cathode material
Nickel	**Nickel-containing ores**	• **Physical Beneficiation** [crushing, grinding, screening, flotation, magnetic separation, gravity separation] • From Sulfide Ore: — **Pyrometallurgy** [flash smelting, converter refining, roasting] • From Laterite Ore: — **Hydrometallurgy** [high-pressure acid leaching, SX, electrowinning] • Electrometallurgy: Electrorefining	High purity nickel metals, salts, and alloys
Cobalt	**Cobalt-containing ores**	• **Physical Beneficiation** [crushing, grinding, screening, flotation, magnetic separation, gravity separation] • From Sulfide Ore: — **Hydrometallurgy** and Pyrometallurgy [froth flotation, smelting, leaching, SX, electrowinning] • From Laterite Ore: — **Hydrometallurgy** [high-pressure acid leaching, SX, electrowinning]	High purity cobalt metals, salts, and alloys
Lithium	**Lithium-containing spodumene or brine**	• From Spodumene, Hard Rock Ore: — **Physical Beneficiation** [crushing, grinding, screening, flotation, magnetic separation, gravity separation] — **Hydrometallurgy** and **Pyrometallurgy** [concentration, acid roasting, sulfate solution processing, purification, precipitation] • From Lithium Brine: — **Hydrometallurgy** [pumping, evaporation, lithium carbonate precipitation, crystallization, conversion to lithium hydroxide if required] • Direct Lithium Extraction ("DLE")	Lithium carbonate or lithium hydroxide

	Upstream Material	Common Mid-Stream Technologies	Mid-Stream Product Outputs
Rare Earths	**Rare earth concentrate**	• **Physical Beneficiation** [gravity separation, magnetic separation, crushing, grinding, flotation] • **Hydrometallurgy** and **Pyrometallurgy** [leaching, SX, calcination, precipitation, electrowinning, molten salt electrolysis] • Ion-exchange methods may replace SX	Rare earth oxides, metals, and alloys
Gallium	**Gallium-containing materials**	• From Bauxite Residues: — **Hydrometallurgy** [leaching, SX, electrowinning, precipitation, zone purification (a specialized refining process)] • From Zinc Ores — **Pyrometallurgy** and **Hydrometallurgy** [roasting, leaching, SX, electrowinning, zone purification]	High purity gallium metal, liquid metal alloys, and Ga-compounds
Graphite (natural)	**Natural graphite-containing ore**	• **Physical Beneficiation** [crushing, milling, flotation] • **Pyrometallurgy** and **Hydrometallurgy** [thermal and chemical purification] • Shaping and Sizing [milling, spheroidization] • Surface Coating	Higher-purity shaped graphite or graphene
Graphite (synthetic)	**Petroleum coke, coal tar pitch, and other high-carbon materials**	• **Physical Beneficiation** [mixing raw materials] • **Pyrometallurgy** [carbonization, graphitization] • Shaping and Sizing (milling, spheroidization) • Secondary Treatments, if needed [oxidation, surface functionalization] • **Pyrometallurgy** and **Hydrometallurgy** [thermal and chemical purification] • Machining and further shaping • Surface Coating	Synthetic graphite

Endnotes

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2 Traded on Western exchanges such as the London Metal Exchange or the Chicago Mercantile Exchange

3 Focusing on the magnetic rare earths specifically Neodymium, Praseodymium, Samarium, Dysprosium, and Terbium

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1225 Eye St NW, Suite 1000
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