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Pedal to the metal: Policy overview of critical minerals used in lithium-ion batteries

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HIGHLIGHTS

- Lithium-ion batteries are the dominant battery design, and their demand is expected to grow in the coming decades.
- China dominates the production and refining of lithium-ion batteries' critical minerals; its policies preserve and exploit this dominance for other political gains.
- Other producer countries seek to increase production, as well as maximizing value through supply controls and internal investment.

Critical minerals play an important role in modern energy technologies but have sparked geopolitical, economic, and environmental concerns. Lithium-ion batteries (LIBs), which are increasingly popular due to their use in electric vehicle technology, are made of a variety of critical minerals. This review offers a policy-centered overview of these critical minerals, emphasizing their production, geographical disparity, and governance. Ultimately, this work highlights the differences in global power dynamics and the significance of LIB related critical mineral policies for global equity and environmental sustainability.

Critical materials have existed for centuries. One example is silk, once the world's most prized and traded textile [1]. Authorities in East Asia kept silk production techniques a closely guarded secret, preserving its value through relative scarcity [1]. Precious resources were also often tied to colonialism; the Spanish conquered the Americas for gold while the Belgians brutally extracted rubber from colonial Congo [2, 3]. The struggle over resources has even migrated to pop culture as antagonists seek to control the Unobtanium found on Pandora (Avatar), Vibranium found in Wakanda (Black Panther), and Spice found on Arrakis (Dune) [4]–[6].

These commodities are examples of critical materials, some of which are critical minerals—resources used in important technological and security applications with vulnerable supply chains. Supply threats can include a lack of accessible mineral deposits in the earth (due to cost, technological limitations, or land use restrictions), a low distribution or number of producers, or an unwillingness of producers to trade [7]. Furthermore, there are multiple stages of critical mineral production, and countries that mine critical mineral-containing ores are not always the same as those which refine those ores into higher value components. In a similar vein, countries possessing extensive geographic reserves—potentially viable deposits of a critical mineral—aren't necessarily its largest exporters [8]. Factors impeding the valorization of reserves include long lead times for mine construction, a need for new technological adoption, and local political opposition among others [9]–[11]. Critical mineral supply can thus be constrained at a variety of points, and nations controlling any part of the production process can make policy moves that have global impact, positioning critical mineral mining and refining capacity as emerging pillars of national competitiveness.

Conflict over critical minerals is not new; its modern form originated with the 2010 Senkaku Crisis [12]. In response to a diplomatic incident around the Senkaku Islands, China, the world's leading producer and refiner of rare earth elements (REEs), effectively halted their export to Japan. This was considered a severe measure due to the role of REEs in Japan's technological-manufacturing-based economy [12]. This incident spurred Japan to diversify its supply of REEs and demonstrated that critical minerals could be a potent political tool in the 21st century [13].

The European Union (EU) was quick to respond, publishing its inaugural list of critical materials and strategy for obtaining them in 2011 [14]. Other countries followed suit in short order: the United States (US) in 2017, Australia in 2019, and both India and South Korea in 2023 among others (1) [15]–[17]. Perhaps unsurprisingly, critical mineral geopolitics has an inherently national approach: each nation's critical minerals strategy depends on what resources they posses and wish to leverage.

Accordingly, this review primarily examines national policies regarding the production and acquisition of critical minerals. Furthermore, while critical minerals lists include materials for a variety of advanced technological applications,

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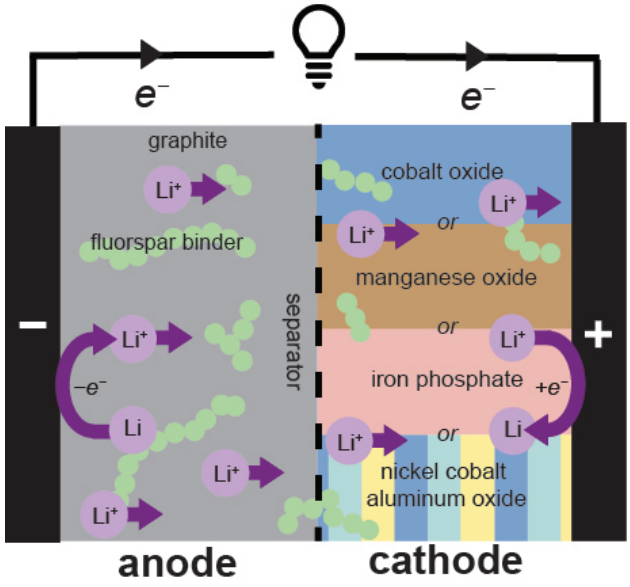

Figure 1: Schematic of lithium-ion battery discharging.

this report focuses on those found in lithium-ion batteries (LIBs). LIBs are used in a variety of technologies, including electric vehicles (EVs) and grid-scale energy storage—both critical for decarbonization efforts [18]. Consequently, the LIB market is projected to be worth $91.6 billion in 2026 [19]. The review begins with a technical discussion of LIBs and the role played by their constituent critical minerals. After, the production of these minerals and surrounding policies are analyzed with an eye toward larger geopolitical trends.

How do lithium-ion batteries work?

LIBs are a type of rechargeable energy storage device in which lithium ions move between two electrodes to release or store electricity. LIBs have been widely adopted because of their long life cycle, fast charging potential, and high energy density compared to other battery architectures [18].

LIBs function by shuttling lithium back and forth through the battery. As seen in Figure 1, an LIB contains electrodes at each end of the cell; the positively charged cathode is on one side and the negatively charged anode is on the other. The two electrodes are separated by a separator, a porous material that allows lithium cations (positively charged lithium ions) to move from one electrode to the other. The electrolyte, a liquid solution that conducts electricity, flows through the separator and connects the two electrodes. During a "discharge" cycle (when stored electricity is released), neutral lithium atoms stored in the anode lose an electron, generating a lithium cation and an electron. This electron leaves the battery and provides current to the connected device (in this case, a lightbulb). Meanwhile, the lithium cations enter the electrolyte, travel through the separator, and arrive at the cathode where they gain an electron and return to their neutral state. They are subsequently stored in the cathode until there is no uncharged lithium available at the anode. During a "charging" cycle (when the battery is being recharged), the discharging process runs in reverse: neutral lithium loses an electron at the cathode, moves through the electrolyte and separator, and regains an electron at the anode, becoming stored as neutral lithium so that the battery is ready to be used again.

LIBs contain several critical minerals that are essential for their high performance [20]. Typically, the anode is a carbon-based material; graphite is the most popular choice [21]. Graphite is spacious enough for lithium ions to enter and exit between its layers (a process called intercalation) and strong enough to not break down over several cycles [22]. Cathodes employ different materials to store the lithium during discharging; a wide range of metal-based materials such as cobalt oxide, manganese oxide, nickel cobalt aluminum oxide, and iron phosphate are used [21]. Each of these materials has unique properties and can improve overall battery performance by increasing thermal stability, energy density, and power density [23]. For instance, cobalt and manganese improve battery stability, nickel increases capacity, and iron phosphate is energy-dense and compact [24, 25]. Finally, chemically resistant fluorinated polymers, whose fluorine comes from the mineral fluorspar, are used as binders to hold the electrodes together [26]. Electrolytes commonly contain fluorine as well [27].

Today, LIBs dominate the consumer electronics and devices market [28]. Their low cost, durability, and high power densities compared to traditional batteries have made them the chosen technology for EVs [29]. Current research efforts seek to recover and recycle LIB components, and several car manufacturers have committed to improving battery research and EV development [28]–[30]. While researchers are investigating alternative energy storage systems, including sodium-ion, zinc, and lead-acid batteries, these technologies still underperform compared to LIBs, as well as introducing additional recyclability or toxicity challenges [31]–[33].

Scope and research methods

The following three sections explore the policy landscapes of minerals fundamental to the chemistry of an LIB: lithium, cathode materials, anode materials, and a mineral precursor to electrolyte and electrode binder components. Figure 2 provides a geographic overview of the major producing countries examined in this review and critical minerals for which they are major producers. While copper is a critical mineral needed for moving current from LIBs to the devices they power, it is not specifically used in the internal components of an LIB. Furthermore, despite the use of lithium-iron phosphate cathodes, we have omitted iron as it is not universally considered to be critical like other cathode materials. For each mineral, the policies of its largest producer were analyzed; if no country had a production share greater than 50%, the two largest producing countries were analyzed. Due to the changing landscape of critical minerals, we primarily studied policies enacted within the decade; proposed policies or prior policies were analyzed when necessary. The takeaways presented at the end of the piece came from discussions among the authors after each nation's policies were analyzed.

Lithium

Production landscape: South America and Australia lead the world in lithium production. Approximately 37% of known lithium reserves lie in the "Lithium Triangle," a region encompassing the Andean salt flats of South America [34, 35]. Chile is the region's leading producer, accounting for 25% of global lithium supply, while Argentina produces about 12% [34]. Elsewhere, Australia holds 23% of global lithium reserves; however, it leads the world in production with 32% of total lithium supply [34].

Despite raw lithium extraction occurring primarily in Chile and Australia, nearly 70% of global refining happens in China [36]. This concentration of refining, combined with significant lithium extraction (17% of global lithium) and domestic EV manufacturing industries, positions China as a market leader in lithium and lithium-based technologies [37].

Policy landscape: Chilean lithium resources are under government supervision, making the country a unique policy case (2). During the Cold War, thermonuclear war anxieties led lithium to be classified as a "strategic resource reserved for state control" (3). Today, the Chilean government is advancing plans to establish a national lithium company, which involves mandating state participation across the supply chain [38]. Growing international demand has placed the Chilean lithium governance model under heightened global scrutiny. On one hand, state control may facilitate foreign investment through adaptive policy design, stronger environmental regulation, and increased engagement with Indigenous communities [39]. On the other hand, regulatory uncertainty may deter investment, while economic pressures may undermine effective enforcement of environmental, social, and governance (ESG) policies [39]. Some foreign companies have already established environmental policies and Indigenous benefit sharing policies [40]–[42]; however, future development and enforcement of these policies is uncertain. As Chilean lithium strategy evolves, the balance between sovereignty, market competitiveness, and social and environmental authority remains uncertain.

In contrast, Australia has pursued a market-oriented approach through its 2023 Critical Minerals strategy [15]. This strategy highlights six focus areas: technology research and development, international partnership attraction, Indigenous community engagement, ESG standard enforcement, infrastructure investment, and workforce growth [15]. Legislative measures have since been implemented to advance these goals. The Australian government has invested $3.4 billion AUS in geoscience mapping, implemented tax incentives to encourage domestic lithium refining, and established formal trade frameworks with the US and EU (4, 5, 6).

Meanwhile, China is leveraging its refining capacity to control supply and cement its position as a leader in the lithium supply chain. By 2030, China is projected to own and operate 39% of global lithium extraction via investment in the Lithium Triangle and refinery growth [43]. Since lithium was classified as a strategic mineral in 2016 (7), lithium regulations have tightened, increasing state control over the sector (8). Internally, the government has started aligning ESG standards with international frameworks and centralized the mining approval process (8)[44]. Externally, the government has exercised control over foreign licensing of lithium products (9). These policies effectively decrease Chinese lithium supply and increase cost, prompting international importers, such as the US and EU, to decrease reliance on Chinese lithium [45].

Cathode materials

A variety of cathode materials are employed in LIBs; among the most common are lithium-cobalt oxide, lithium-manganese oxide, lithium-nickel-manganese-cobalt oxide, and lithium-nickel-cobalt-aluminum oxide [23]. This section identifies where each metal used is produced and the policies surrounding its production.

Cobalt

Production landscape: The Democratic Republic of the Congo (DRC) is the world's leading producer of cobalt, supplying 73% of world production [34]. Indonesia accounts for 13% of production, but no other country has a production share greater than 3% [34]. Despite this large-scale production, roughly 30% of cobalt is produced via artisanal and small-scale mining (ASM) [46]. ASM miners work outside regulated environments with hand tools and minimal safety equipment; injury, child labor, and sexual violence are common at ASM sites [46, 47]. A 2019 lawsuit accused major companies including Apple, Microsoft, and Tesla of employing child labor through buying ASM-sourced cobalt, prompting a move away from cobalt-based LIBs [48, 49].

While the DRC produces raw cobalt, 67% of global cobalt is refined in China. Despite increasing cobalt production into the 21st century, many Western investors shied away from the DRC due to prior regional instability [50]. Conversely, China invested heavily into its burgeoning mining sector as part of a broader effort regarding battery material supply [50]. The majority of the DRC's cobalt thus travels to China [49, 50].

Policy landscape: To avoid discouraging cobalt consumption, the DRC has taken political steps to address ASM. The 2002 Mining Code regulates mining activity in the country, and a 2018 amendment created a government agency (EGC) to regulate ASM (10, 11, 12). In February 2025, a formal pathway was established for companies to collaborate with EGC to incorporate ASM into their standard operations; however, a December decree suspended all ASM production and largely remains in effect (13, 14).

Externally, the DRC seeks to maximize the value of its exports. The DRC established the Agency for the Regulation and Control of Strategic Mineral Substance Markets (ARECOMS) in 2019 (15). In 2020, ARECOMS excepted cobalt hydroxide from a quasi-enacted 2013 ban, a more valuable form of cobalt which has since become the nation's primary export (16). In February 2025, ARECOMS suspended all cobalt exports for four months; this suspension was then renewed until September 2025 (17, 18). Afterward,

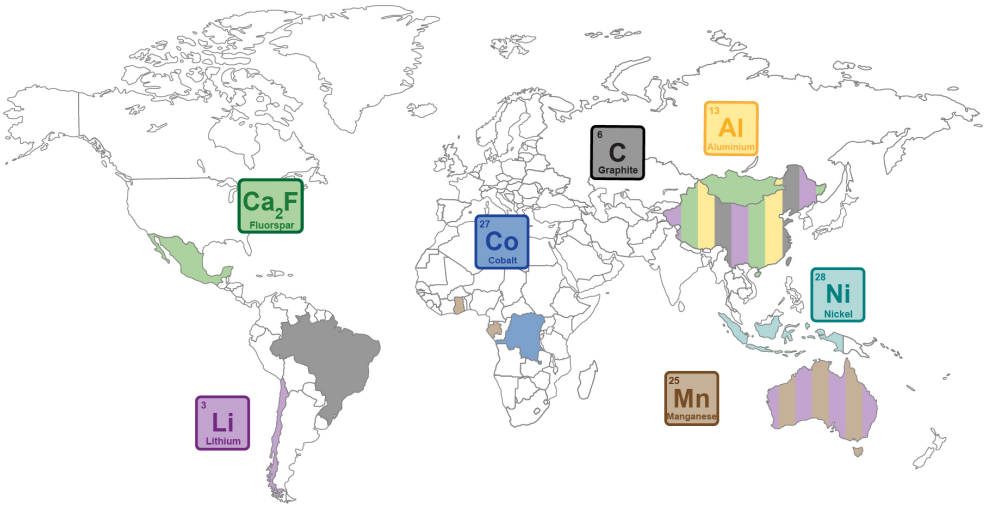

Figure 2: Global distribution of critical minerals for lithium ion batteries discussed in this work

a quota system was introduced, with the 2026 quotas representing roughly half of current output levels [51] (19). Such measures aim to raise the value of exported cobalt while encouraging domestic consumption and increasing domestic supply.

These policies seem to be successful. Since the ARECOMS supply restrictions, the price of cobalt has increased 240% with demand expected to remain steady [52]. Furthermore, foreign concerns about ASM production appear to have waned, as China has recently inked a minerals deal with the DRC and a US firm recently acquired a large Congolese mining company [53, 54].

Nickel

Production landscape: Indonesia produces 67% of the world's nickel and holds 42% of known reserves [34]. No other country approaches Indonesia's production; the next largest producer is the Philippines (7%), followed by Russia (5%), Canada (4%), and New Caledonia (4%) [34]. Notably, Chinese foreign investment has also helped Indonesia become the world's leader in nickel refining [55]. This homegrown refining industry is somewhat exceptional, placing Indonesia in a stronger production position than many other critical mineral producing nations.

Policy landscape: Indonesian nickel mine production increased from 152 to 2608 thousand tonnes from 2015 to 2025 [56]. To curb oversupply, the Indonesian government introduced a supply quota, meaning prices are no longer solely determined by market forces (20). Moreover, in downstream processing, the Indonesian government has goals to expand domestic refining capacity and attract foreign investment. In 2020, Indonesia placed an export ban on raw nickel ore to encourage domestic processing and manufacturing (21). This policy successfully drew substantial foreign investment, primarily from China. By 2024, 70% of nickel mining business permits were held by domestic companies, whereas 70% of nickel smelting business permits were held by international firms [57]. Bilateral economic frameworks have been established to support this investment and other projects related to energy infrastructure and manufacturing growth (22). In particular, Indonesian leaders have emphasized the importance of domestic value-added production through the expansion of the EV manufacturing industry [58, 59]. Overall, the Indonesian government seeks to strengthen control over nickel by implementing mining quotas and expanding nickel-product manufacturing, while still maintaining an attractive environment for foreign smelting investment.

Despite the nickel sector's growth, ESG concerns have intensified. Most Indonesian energy is derived from coal, generating high carbon emissions from nickel mining and processing [60]. Further, mining activities have caused an estimated 5% decrease in national forest cover, while generating human health concerns and violating land rights agreements [61, 62]. In response, international mining frameworks have advanced, encouraging Indonesian companies to adopt ESG standards [63]. However, adoption is inconsistent across the Indonesian nickel industry; while larger companies show progress, mining persists due to regulatory support and resource limitation [63]. The Indonesian government is actively improving development strategies to improve and enforce ESG policies across the sector [58, 64].

Manganese

Production landscape: While manganese is mainly used in steel production the global market for use in cathodes is projected to reach 39 million metric tons by 2030 [65]–[67]. No single nation produces the majority of manganese supply: South Africa is the world's largest producer (38%), followed by Gabon (25%), Ghana (10%), and Australia (8%) [34]. While African nations dominate the global raw manganese supply, they only contribute about 13% of refined manganese exports [66]. The bulk of manganese refining occurs in China (58% in 2020) due to a lack of ore-refining infrastructure in these producing nations [66, 68].

Policy landscape: Manganese falls under the auspices of South Africa's critical minerals strategy as a highly

critical mineral [69]. The 2025 Critical Minerals and Metals Strategy and simultaneously proposed Mineral Resources Development Bill (MRDB) call for the development of an Export Management System and renewed investment in local infrastructure and exploration. In particular, the strategy calls for investing in local manufacturing of manganese products and research and development of LIB cathode materials [69].

Notably, Gabon seems poised to adopt a similar strategy to the DRC. In June 2025, the Gabonese government announced a manganese export ban effective January 1, 2029 [70]. Rather than exporting the bulk of its manganese to Europe and China, the ban is designed to encourage development of an in-house refining industry, giving its exports more value and Gabon greater trading flexibility [71].

Aluminum

Production landscape: Aluminum is smelted from the raw mineral bauxite, an abundant mineral that can support growing global demand [34]. Unlike many critical minerals, aluminum recycling is robust; 75% of all aluminum produced is still in use [72]. Yet, aluminum is still considered a critical mineral due to the breadth of its applications. China is the world's largest aluminum producer (56%), followed by India (5%), Russia (5%), and Canada (4%) [34].

Policy landscape: As the leading producer, China's policy takes advantage of its resources while seeking to preserve them through recycling. In 2017, China instituted a 45 million ton cap on primary aluminum production, keeping global production somewhat muted [73]. Moreover, in 2025, ten departments of the Chinese government released the Action Plan for the High-Quality Development of the Aluminium Industry (2025–2027) (23). This plan retains the production cap but calls for 15 million tons of domestic production to come from recycled aluminum, along with an expansion of bauxite reserves and clean energy used in mining. A 2024 announcement eliminated restrictions to importing scrap aluminum (24). These policies represent both a concerted effort to shore up domestic production and an attempt to guide demand through China; the production cap combined with imports of recyclable scrap aluminum hinders the ability of other nations to meet their needs without Chinese aluminum.

Other nations have responded by encouraging domestic production and recycling. In March 2025, the US implemented a 25% tariff on aluminum articles; in June, the US raised these tariffs to 50% (25, 26). In November 2025, the EU announced plans to restrict aluminum scrap exports [74]. A striking example is in two 2026 trade deals between India and the US and the EU: despite general reductions in tariffs, aluminum tariffs remained conspicuously in place, suggesting a worldwide move toward protecting domestic aluminum production [75].

Anode materials, electrolytes, and binders

Unlike the diversity of cathode materials, 95% of commercial LIBs employ graphite (or variations) as the anode material [76]. Thus, in addition to graphite, this section discusses fluorspar–a critical mineral used in the production of fluorine–containing chemicals found in most LIBs.

Graphite

Production landscape: Graphite can either be obtained through mining (natural graphite) or through chemical synthesis (synthetic graphite) [77]. Natural graphite is cheaper and higher capacity than synthetic graphite, so critical minerals lists usually refer to natural graphite [34, 78].

China is the world's leading producer and refiner of both natural graphite, producing 78% of the world's supply [34, 36]. The next three largest producers are Madagascar (4%), Tanzania (4%), and Brazil (4%) [34]. However, Brazil has the second largest share of graphite reserves (25.5%), and its mining companies are forecasting $21.3 billion in investments by 2030 [34, 79]. Thus, Brazil may become a prominent supplier of graphite in the coming decades.

Policy landscape: China has leveraged its graphite as a negotiation tool. In September 2025, the US Bureau of Industry and Security (BIS) announced a new rule that any entity at least 50% owned by a polity on the Entity List was subject to the Export Administration Regulations (27, 28). As this included many Chinese companies, the Chinese Ministry of Commerce responded by announcing a series of mineral export controls; Order 58, announced in October 2025, included graphite and other materials related to LIBs (29). After discussion between Presidents Donald Trump and Xi Jinping, the US suspended implementation of the BIS rule while the export restrictions were called off (30, 31).

Elsewhere, Brazilian industry seeks to protect domestic production. In March 2026, GrafTech Brasil Participações Ltda (GrafTech Brazil), the nation's largest graphite producer, filed a complaint alleging cheap graphite imports from China and India undercut domestic production [80]. A few days later, the Department of Trade Defense of the Foreign Trade Secretariat announced an official investigation into the matter (32).

Fluorspar

Production landscape: Calcium fluoride, also called fluorite or fluorspar, is the raw mineral source of fluorine for all commercially produced fluorine-containing chemicals (fluorochemicals) [81]. As with graphite, China is the world's largest fluorspar producer (62%), but it is also the largest consumer and importer to satisfy internal demand and power an industry converting fluorspar to fluorochemicals [82]. Additionally, fluorspar production is somewhat diverse: Mexico and Mongolia each capture 13% of the world's share [34]. In fact, Mexico is the world's largest fluorspar exporter; the bulk of its supply goes to the US [83]. Other nations have recently undertaken efforts to produce fluorspar; a fluorspar mine recently opened in Newfoundland and mines are projected to open within the decade in the US and Germany [84]–[86].

Policy landscape: Mexico has the world's largest share of fluorspar reserves, but obstacles prevent the realization of its fluorspar supply [34]. A 2022 review found that "Despite vast regulatory development for the mining industry, the Mining

Law is outdated and does not reflect the best practices in social issues, mine closure, and ASM" [87]. In response, the Mexican government updated its Mining Law with particular emphasis on environmental protection and regulation (33). Unfortunately, the law has not been effectively enforced since its enactment [88]. Nevertheless, at the 2026 Critical Minerals Ministerial, a multilateral initiative for securing critical mineral access, Mexico and the US published a Critical Minerals Action Plan, wherein the two nations committed to mutual investments, regulatory standards, trade measures, and coordinated responses to supply crises (34). Thus, despite internal production concerns, fluorspar trade with the US will likely continue into the foreseeable future.

Mongolia's policy is defined by relationships with its two geographic neighbors–China and Russia–and its efforts to cultivate "third neighbor" relationships with other polities. In 2021, 88% of Mongolian fluorspar went to China (58%) and Russia (30%). The trilateral relationship between Mongolia, China, and Russia is also critical, and the recent approval of the Power of Siberia 2 pipeline suggests increasing infrastructural collaboration in the future [89]. Simultaneously, Mongolia has sought to cultivate critical minerals relationships elsewhere. A 2017 Framework Agreement with the European Union and 2023 Memorandums of Understanding on mineral resources with the US and South Korea represent a "third neighbor" approach to critical minerals (35, 36, 37). The extent to which fluorspar will flow away from Mongolia's geographic neighbors remains to be seen.

Takeaways and recent developments

Although each nation and mineral exhibit complex policy dynamics, there are consistent themes that occur in the LIB critical minerals landscape.

1. China is the dominant player in LIB materials. In addition to being the leading producer of aluminum, graphite, and fluorspar, China controls over 70% of refining for lithium, cobalt, manganese, and graphite (data unavailable for fluorspar and aluminum) [36]. By wielding export restrictions and production quotas, China can insulate itself from the critical mineral actions of other nations and leverage its mineral access to dissuade other unwanted political moves.

2. Nations controlling the majority of world supply of a critical mineral seek to control production and encourage consumption. China (aluminum), the DRC (cobalt), and Indonesia (nickel) have all implemented export quotas to restrict global supply, encourage domestic industrial development, and direct international consumption. China seeks to further corner the aluminum market through controlling recycled materials, while the DRC and Indonesia seek to regulate ASM and improve environmental standards so as not to deter foreign investment and consumption. These nations also seek to develop refining at home and increase the value of their mineral exports.

3. Nations without majority control of a resource that can be produced domestically take policy steps to encourage domestic production. The US (aluminum), the EU (aluminum), India (aluminum), South Africa (manganese), Gabon (manganese), and Brazil (graphite) have all enacted policy or taken other strategic measures to bolster domestic manufacturing by discouraging imports. Tariffs are a common lever, as are export controls and investigations into unsavory trade practices by other nations. In a similar vein, the DRC (cobalt), Indonesia (nickel), and Gabon (manganese) seek to bolster domestic refining through export limitations.

These trends imply an animated policy landscape, where every player seeks to further their control irrespective of their current standing. As an example, polities without control over critical minerals are rushing to secure their supply. In December 2025, the EU adopted the RESourceEU Action Plan with the goal of halving its external critical mineral dependence by 2029 [90]. The plan seeks to mobilize 3 billion EUR within the year for stockpiling and diversifying supply chains, the latter through expanding 15 existing bilateral partnerships [90]. Similarly, the US launched Project Vault in 2026, establishing a $12 billion public-private partnership for construction of critical mineral storage facilities [91]. At the same time, China's recent mineral deal with the DRC suggests it does not wish to relinquish its dominant position [53].

There is also a rise of multilateral efforts to secure critical mineral access. The US chaired the inaugural Critical Minerals Ministerial and announced the creation of the Forum on Resource Geostrategic Engagement (FORGE) [45]. 55 nations attended, signing several Memorandums of Understanding and bilateral agreements [45]. South Africa's critical mineral strategy similarly promotes regional collaboration to develop battery-building infrastructure [69].

As the demand for LIB critical minerals continues to grow, it is impossible to escape the geopolitics of mineral supply and the increasingly demanded ESG standards for mineral production. Swift, comprehensive action is thus necessary to ensure one's place in the evolving landscape.

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