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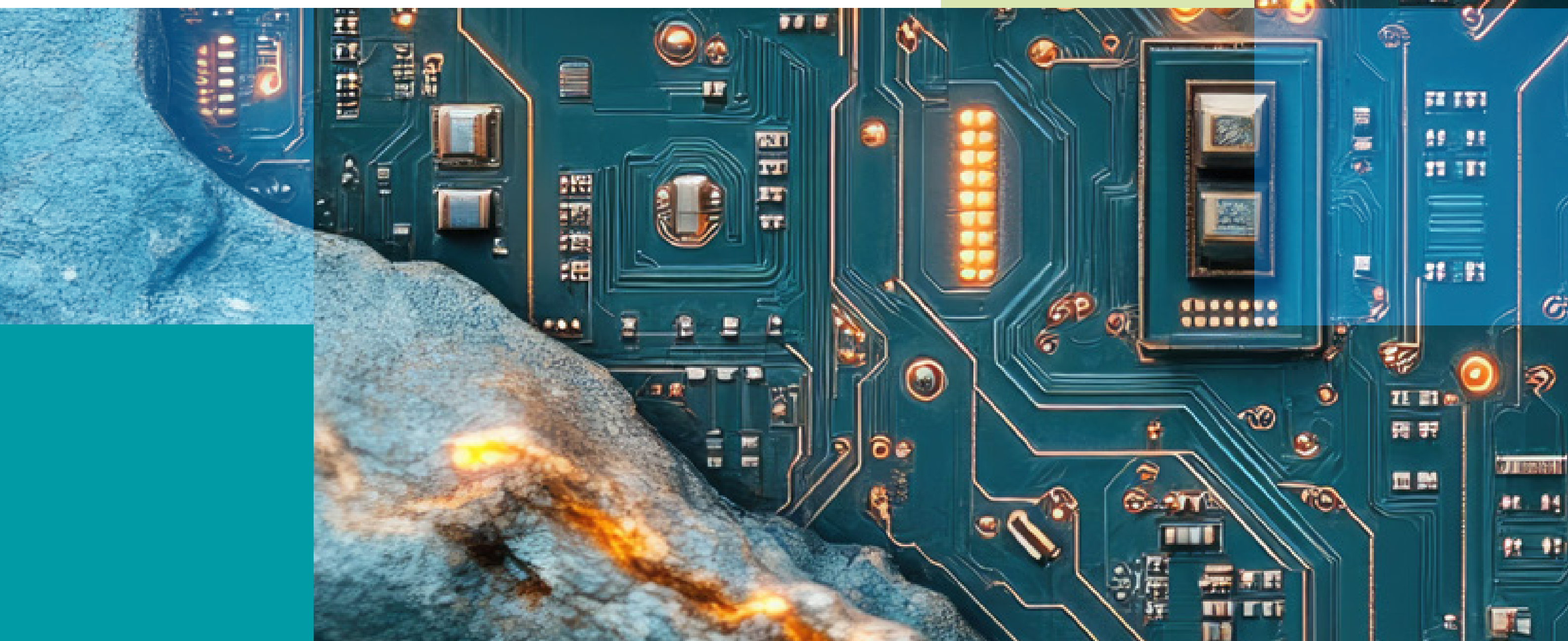
BRAZILIAN MINING

CRITICAL AND STRATEGIC MINERALS IN BRAZIL



A PASSPORT TO THE FUTURE

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CRITICAL AND STRATEGIC MINERALS IN BRAZIL

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Brasilia, 2025

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Illustrations, tables, and charts without a specified source were prepared by the team.

Brazilian Mining Institute – IBRAM

Critical and Strategic Minerals in Brazil: A Passport to the Future. E-book. Organizer: Brazilian Mining Institute. 1st ed. – Brasília: IBRAM, 2025. 268 p.: il.

1- Critical and Strategic Minerals. 2– Technology Readiness. 3– Energy Transition.

CDU: 622.3:342.1

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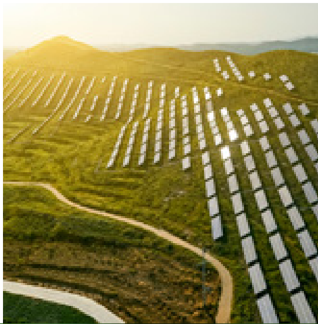
PRESENTATION IBRAM

This publication provides a technical and strategic framework for Critical and Strategic Minerals (CSMs) and their implications for the country's productive organization. More than an inventory of substances, it presents an integrated view of value chains, with emphasis on the technological stages of the respective mineral chains and on 25-year planning. In doing so, it outlines decisions and policies aimed at converting mineral and sustainable potential into economic, social, and technological value.



These minerals underpin several solutions we seek to see expand in Brazil: more modern cities, clean and affordable energy, more efficient transport, productive and connected agriculture, and healthcare with increasingly advanced equipment. For this reason, they are viewed as a passport to the country's future. After all, we are living in the Era of Critical and Strategic Minerals, just as we once lived through the Rubber Era or the Oil Era.

The guiding axis is the question of "how to do it." Based on evidence and recommendations, the CSM agenda is translated into an executable roadmap: accurate mapping, the planning of robust projects, licensing processes with predictability, the structuring of long-term financing, workforce qualification, integration of physical and digital infrastructure, adoption of origin traceability, and the expansion of industrial stages within the national territory. This sequencing increases efficiency, reduces risks, and creates conditions for geological knowledge to be converted into manufacturing, technological services, and exports with higher local content.

The document demonstrates that Critical and Strategic Minerals (CSMs) underpin decisive applications—health, connectivity, defense and energy, precision agriculture, and advanced materials—and that the global dynamics of clean technologies constitute a vector of opportunities. To seize these opportunities, it is essential to organize domestic value chains that add value, stimulate innovation, and disseminate productivity.

From a policy perspective, instruments that promote scale and durability stand out: specific national guidelines; integration among mining, environmental, and industrial regulations; financing and guarantee mechanisms; incentives to domestic demand for CSM-intensive goods; and cooperation among research centers, universities, and companies to accelerate R&D and manufacturing. In parallel, the digitization of processes and information systems that support rapid decision-making is emphasized.

The training dimension is crucial: technical and postgraduate capacity-building programs, centers of excellence, and testing and metrology networks focused on CSMs support technological adoption throughout the value chain. Equally essential are reliable logistics, stable regulatory signals, and efficient management of water and energy in order to ensure competitive costs.

In summary, the volume calls for converting knowledge into coordinated action. Brazil has capabilities that allow it to move from “map” to “product,” with impacts on qualified employment, technological densification, and competitive insertion into global value chains. This involves aligning climate ambition with industrial strategy, supported by clear governance, verifiable targets, and a commitment to results for society.

Raul Jungmann
President Director
Brazilian Mining Institute (IBRAM)

PRESENTATION CETEM

The global agenda for the decarbonization of the economy requires the establishment of coordinated actions between industrialized nations and those endowed with natural resources, largely consisting of critical and strategic mineral resources demanded for the energy transition.

The pursuit of energy efficiency solutions and food security is embedded as a fundamental requirement for achieving the intended targets for reducing or eliminating dependence on fossil fuels. One of the challenges that has guided the main public policies of countries today is the definition of the concepts of critical and strategic minerals.

Brazil occupies a privileged position in terms of its endowment of critical and strategic minerals for the energy transition. However, consolidating this leadership requires strengthening infrastructure and advancing the maturity of the other stages of the value chain.

In this context, coordination between government and the private sector is fundamental for the development of business models that combine economic viability with environmental sustainability. This challenge entails a complex equation, requiring an understanding of the potential of domestic supply, alignment with demand for critical and strategic minerals, the establishment of financing channels, and coordination aimed at the technological maturity of value chains.

The pathways toward a low-carbon economy involve the reconFiguretion of the automotive sector, energy converters (such as photovoltaic panels and wind turbines), batteries, and electric vehicles.

Countries that hold mineral reserves and are industrialized have a significant competitive advantage. Brazil's differential in terms of productive capacity lies especially in the diversity and grades of its mineral reserves and in an energy matrix based primarily on renewable sources, particularly hydropower, bioenergy, solar photovoltaics, and wind energy.

Understanding the country's productive potential and infrastructure in relation to the mining sector enables better comprehension and strategic projection of different productive sectors, such as the demand for phosphorus and potassium for fertilizer production and the demand for iron, aluminum, and copper, for example, for the production of equipment and for the construction and consolidation of infrastructure.

This study, developed by the Mineral Technology Center (CETEM), presents the Diagnostic and Technological Roadmap for critical and strategic minerals in Brazil as a means of supporting strategic actions aligned with the main global demands in favor of a low-carbon economy, grounded in the principles of the circular economy.

Dr. Silvia Cristina Alves França
Director – CETEM/MCTI

EXECUTIVE SUMMARY

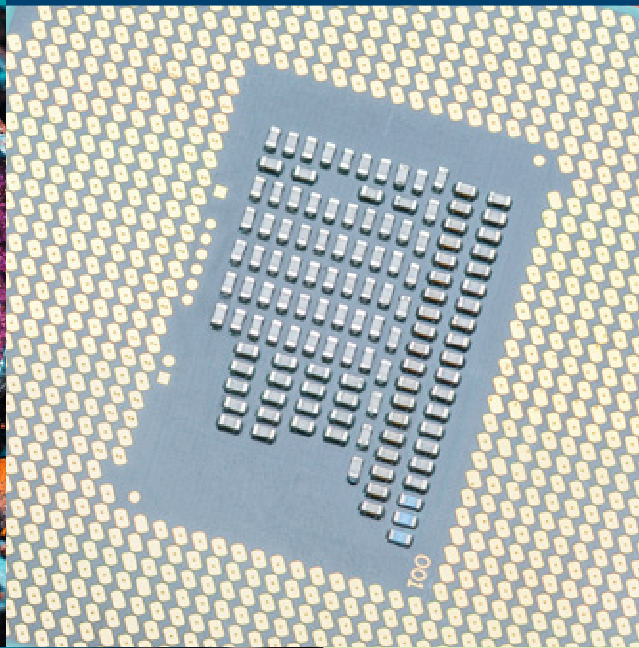
Global climate security requires a set of coordinated actions to promote short-term solutions that, among other aspects, foster the reduction of carbon emissions, the promotion of energy efficiency, and food security in the global context. The new contours of global geopolitics have redefined the context of the extraction and processing of critical and strategic minerals as fundamental inputs for technologies that are emerging as substitutes for fossil fuels.

A just energy transition, in turn, requires the re-signification of processes and products across different sectors of the economy, incorporating the principles of the circular economy and the United Nations' global targets for the transition agenda.

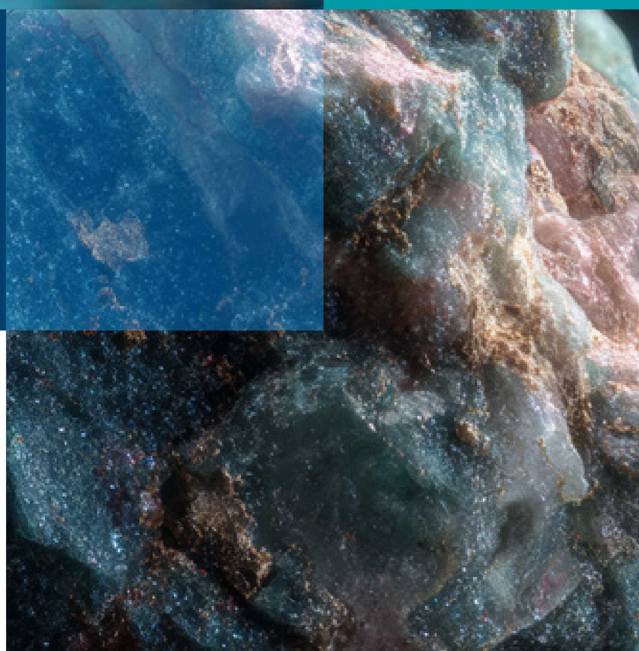
The primary means of promoting social justice and environmental sustainability lies in providing equitable conditions and, in this way, enabling developed countries to direct investments to create opportunities for developing countries, such as the capitalization of new sustainable business models, sustainable mining and resource circularity, the identification and incentivization of unique opportunities for each country, as well as conditions for solutions to become self-sustaining.

Brazil has recently initiated a process of reindustrialization based on government programs such as the Nova Indústria Brazil (NIB) Plan, the Climate Plan, the Ecological Transformation Plan (PTE), and the National Energy Transition Plan (PLANTE), among others.









As a result, sectors such as the aerospace, petrochemical, agribusiness, steelmaking, metallurgy, and automotive industries gain opportunities to specialize their value chains—from resource exploration (upstream), through the production of semi-manufactured goods (midstream), finished products (downstream), and more innovative and circular processes involving resource recovery.

The recent proposal of Bill No. 2,780 of 2024[1], which establishes the National Policy on Critical and Strategic Minerals (PNMCE), represents the country's response to the increased demand for critical and strategic minerals and results from the direction set by preceding regulatory instruments, as well as being inspired by the study Foundations for Public Policies on Critical and Strategic Minerals for Brazil[2], published in the same year.

As the holder of significant and diverse reserves of minerals essential to the energy transition, the country has stood out, for example, as one of the main suppliers of iron, niobium, tantalum, aluminum, graphite, and rare earth elements. Thus, Brazil's reindustrialization process converges with global strategies aimed at climate security through the decarbonization of the economy. The electrification of mobility—an emblem of the growing demand for critical and strategic minerals—has driven the structuring of public policies that establish concepts based on the strategic condition or criticality of mineral resources, following trajectories focused on reducing import dependence and increasing price predictability.

The concepts that characterize minerals as critical and strategic are defined in the regulations of different countries. This study presents an analysis of the regulations of 20 countries, from 2020 onward, that maintain lists of critical and strategic minerals, including the 2024 regulations of the European Union, the United Kingdom, Canada, and Japan, as well as the regulations of Bolivia and the Democratic Republic of the Congo, whose most recent CSM lists date from 2017 and 2018, respectively.

The present study provides a comprehensive diagnosis of the Brazilian mining sector, encompassing aspects such as the economy, regulation, political and corporate strategies, financing, and requirements for sectors such as food security, infrastructure, and defense, considering the energy transition as the central axis of the analyses.

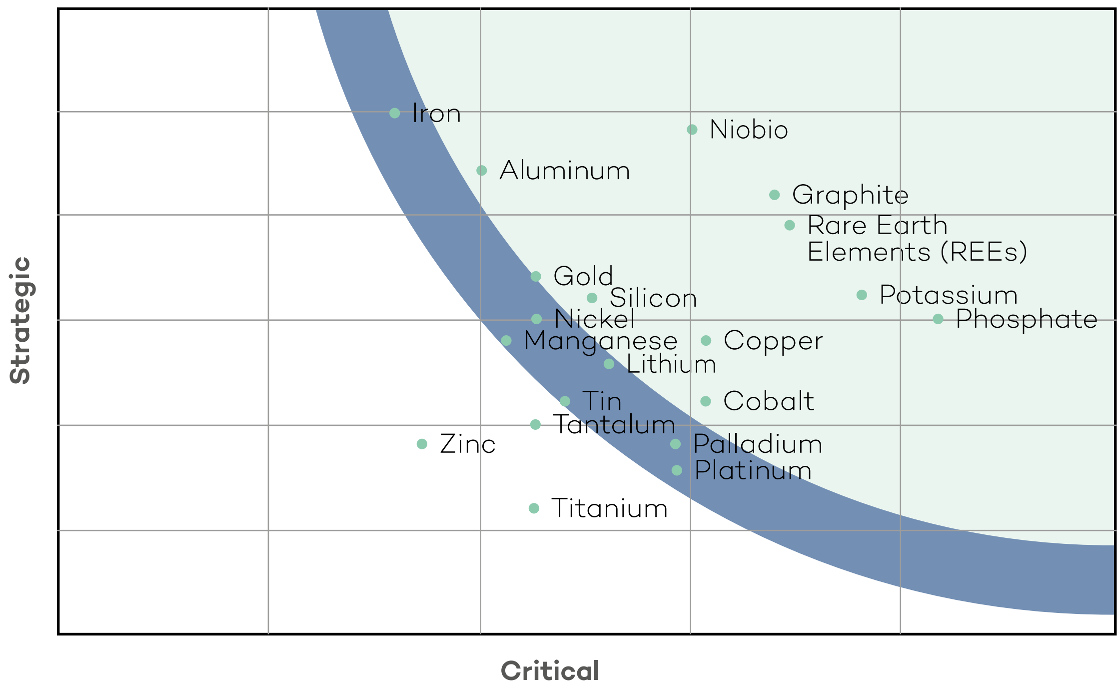
Significant investments in the decarbonization of productive processes are observed in the sector, stemming from mineral transformation, with the production of green steel and green aluminum. Combined with the potential of the Brazilian energy matrix and the substantial reserves of a wide range of mineral inputs, domestic minerals exhibit a more strategic than critical character, with the exception of potassium and phosphate, for which the country is highly import-dependent.

We present the technological roadmap for 20 minerals classified as critical and strategic, including the analysis of platinum group minerals (PGMs) and representatives of rare earth elements (REEs).

1 https://www.camara.leg.br/proposicoesWeb/fichadetramitacao?idProposicao=2447259

2 https://ibram.org.br/wp-content/uploads/2024/07/Fundamentos_para_politicas_publicas_em_minerais_criticos_e_estrategicos.pdf

Figure 1: Positioning of minerals according to criticality and strategic attributes.



The positioning of the minerals in the figure illustrates the strategic or critical positioning of the minerals analyzed, enabling an assessment of the main demands for minerals such as niobium and graphite, which have reached a higher stage of maturity as a result of long-term investments in research and development. While niobium has achieved value chain densification with applications in the production of batteries for electric vehicles through investments by CBMM, graphite already has applications derived from graphene production, with a significant level of solution maturity resulting from research and development initiatives by Gerdau Graphene.

Other minerals, such as manganese, lithium, palladium, and platinum, warrant greater attention as they are positioned at the frontier, with a trend of increasing global demand and with potential reserves that motivate investment in domestic processing and transformation processes to enable the national production and consumption of finished goods that contribute to climate security. The main topics analyzed and discussed in the study are presented below.

- **Conceptualization of critical and strategic minerals.**
  Both concepts encompass the importance and demand for minerals in the energy transition, with critical minerals defined as those that present supply risk due to import dependence, risk of supply disruption, or global reserve scarcity; whereas strategic minerals are those that present significant reserves, production potential, and applications in sectors of technological and commercial importance at the national level..

- **Investments in value chain densification for the mining sector.**
Identification of the economic and technical potential, as well as the degree of technological maturity of organizations operating in the country with respect to the different stages of the value chain (upstream, midstream, downstream, and recovery), in order to make the targeting of public development efforts and national and international investments more efficient, with a view to contributing to greater maturity in the production of mineral inputs in the country, prioritizing key value chains and requirements consistent with the mineral endowment and vocation.

- **Effects of the tax reform.**
The incidence of the Selective Tax (IS) on goods and services that are potentially harmful to health or the environment aims to promote sustainability and has prompted discussions regarding the impact of a maximum rate of 0.25% on the market value of products in the country. The impact of the IS on the export of mineral goods represents one of the main points of potential impairment to the sector's competitiveness, as do the Mineral Resources Inspection Fees (TFRM).

- **Provision of guarantees for investments in the sector.**
Expansion of geological mapping and identification of productive sectors as a means of evidencing mineral endowment and vocation in Brazilian states, strengthening mechanisms of financial stability and credibility in the country, generating employment and income, and enabling investments for the consolidation of infrastructure (access roads, energy supply, digitization, and waste treatment) as conditions for investment guarantees. In a coordinated manner, economic and financial mechanisms such as incentivized debentures and CFEM[3] can reach a level of synergy in support of investment guarantees.

- **Promotion of workforce training and capacity-building.**
An important risk to be mitigated is the discontinuity of competencies for value chain densification. Therefore, priority should be given to the establishment of integrated public–private actions to promote training and capacity-building, following the Chinese model that prioritizes specialized technical training linked to prioritized productive processes. Efforts should also seek the establishment of training and capacity-building hubs integrated with the private sector, such as CETEM, CIT SENAI (ISIs), Magbrás, LabFab, IPT, CDTN, and others. The potential for training specialists for work in sectors such as the circular economy and urban mining is also identified.

- **Agility and reliability in the environmental and mining licensing system.**
Implementation of the digitization of inspection and licensing processes for environmental and mining permits, in an integrated manner among the different institutions and levels of analysis of applications. As an example, the state of Pará currently has an average timeframe of six months for the issuance of environmental licenses, and the recent partnership

3 CFEM stands for Financial Compensation for the Exploitation of Mineral Resources, a type of "royalty" paid by mining companies in Brazil to compensate for the exploitation of public (mineral) resources.

established between the National Mining Agency (ANM), SERPRO, and the Brazilian Agency for Industrial Development (ABDI), which—through investments in process improvement and digitization—can ensure greater efficiency across the different technical and administrative phases under ANM's management.

- **Infrastructure for production specialization.**
  Investment in the acquisition and development of modern and automated machinery to increase productive efficiency; availability of energy supply; availability of water resources; and dedicated mechanisms for waste disposal. The establishment of conditions for shared use of infrastructure in order to mitigate costs and achieve the decarbonization of processes.

- **Stimulation of domestic demand formation.**
  Strengthening domestic demand, in addition to international demand, is a strategic condition to enable the development of markets and national value chains in the field of CSMs, whether in the manufacturing of renewable energy generation equipment (solar PV and wind) or clean technologies (batteries, electric vehicles, electrolyzers, etc.). Aligned with the guidelines of the Nova Indústria Brazil (NIB), this agenda requires the coordination of regulatory instruments, public procurement programs, transaction facilitation mechanisms, and technology transfer actions. Integrated with investments in research, development, and innovation (R&D&I), these measures constitute fundamental levers to position Brazil competitively, sustainably, and sovereignly within the global value chains of the new economy.

- **Digitalization in the mining sector.**
  In alignment with Mission 4 of the Nova Indústria Brazil (NIB) Plan, several national companies already deploy artificial intelligence (AI) applications to optimize processes, products, and business strategies. Vale, for example, has tools that enable the prediction of moisture content in its iron ore inputs with efficiency comparable to laboratory analyses in a fraction of the time, increasing speed and reliability.

- **Actions for food security.**
  The agricultural sector is highly relevant to the Brazilian economy, representing 5% of national GDP. Brazil stands out among the five largest fertilizer consumers, ranking fourth in nitrogen compounds, third in phosphates, and second in potassium consumption. However, according to data from the National Fertilizer Plan (PNF 2022–2050), the country is highly dependent on imports of these mineral inputs that form the basis for NPK fertilizer production, which totaled approximately 40 million tonnes consumed in 2020.

- **Harmonization of regulations for the energy transition.**
  Government plans for the country's growth and socioeconomic development set targets for reindustrialization and for incentives to education, science, technology, and health, with the energy transition serving as a common axis across most established plans. The integration of public policies reflects a significant degree of institutional maturity that may contribute to Brazil's leadership in the green and energy transition process toward climate security.

- **Powershoring[4] as a competitiveness factor for production in the mining industry.** Brazil occupies a prominent position on the global stage driven by powershoring, benefiting from an energy matrix that is significantly cleaner than the global average in terms of contribution to a low-carbon economy, and with costs approximately 50% lower than those of other countries. With more than 90% of its electricity matrix composed of renewable sources, the country is already decades ahead in terms of energy sustainability. This combination of abundance and low-cost renewable energy provides a solid foundation for the decarbonization of various sectors of the economy—especially those with high energy intensity, such as mining and the processing of critical and strategic minerals.

- **Consolidation of Brazilian industrial policy.** The set of ongoing government plans for Brazil's reindustrialization—such as the New PAC (Chief of Staff's Office), the Ecological Transformation Plan (Ministry of Finance), Nova Indústria Brazil (MDIC), the Mining Plan and the Energy Transition Plan (MME), and the Climate Plan (MMA)—share the energy transition as a common strategic axis, underscoring the importance of the theme and institutional alignment to enable actions oriented toward climate security. With institutional stability, low geopolitical risk, mineral diversity, and a broad territorial distribution of clean energy sources, Brazil presents itself as an ideal destination for value chains intensive in critical and strategic minerals, reinforcing its role in the transition to a low-carbon economy.

2023 → **2024**

PAC*
OFFICE OF THE CHIEF OF STAFF
R$ 1 trillion
2023 - 2026

1. Transportation
2. Social infrastructure
3. Sustainable and resilient cities
4. Water for all
5. Digital inclusion
6. Energy transition and security
7. Innovation for the defense industry
8. Education, science, and technology
9. Health

Ecological Transformation Plan (PTE)
MINISTRY OF FINANCE
R$ 10 billion

1. Sustainable finance
2. Technological upgrading
3. Bioeconomy
4. Energy transition
5. Circular economy
6. New infrastructure and climate change adaptation

New Industry Brazil (NIB)
MDIC
R$ 300 billion
2024 - 2033

1. Agro-industrial value chains
2. Health
3. People's well-being in cities
4. Digital transformation
5. Bioeconomy, decarbonization, and energy transition
6. Defense

National Energy Transition Plan (PLANT)
MME
R$ 300 billion
2024 - 2033

1. Agro-industrial value chains
2. Health
3. People's well-being in cities
4. Digital transformation
5. Bioeconomy
6. Decarbonization and energy transition
7. Defense

Climate Plan
MMA
R$ 10 billion
2024 - 2035

1. Mitigation opportunities
2. Impacts, vulnerability, and adaptation
3. Research and development
4. Education, capacity building, and communication

*New Growth Acceleration Program (PAC)

4 Strategy to attract investments to regions through: (i) the abundant supply of clean, secure, and affordable energy; (ii) port infrastructure and industrial zones; and (iii) the availability of freshwater and critical minerals to support the establishment of energy-intensive industrial plants for the production of green manufactured products capable of helping to accelerate the energy transition and decarbonization at the global level.The concept of Powershoring originated in two opinion articles authored by Jorge Arbache and published on the CAF portal and in the newspaper Valor, in November and December 2022, respectively: "Powershoring" and "Powershoring II. (https://www.caf.com/pt/blog/powershoring/)

The synergy between the energy transition and the Brazilian mining sector represents a unique opportunity for international repositioning. Even political decisions that signal setbacks with respect to the Paris Agreement—entailing the undermining of decarbonization targets and the prioritization of economic growth—may create space for Brazil to meet global demand for the supply of finished goods.

Focusing efforts on the effective implementation of reindustrialization plans and on the materialization of investments constitutes the guiding line for progress in structuring and potentially densifying the value chain of the mining sector. The allocation of resources focused on research, development, and innovation (R&D&I) and on the training of specialized labor has been the starting point for the advancement of high–technological-potential processes in several countries.

The electrification of mobility, the application of solutions based on artificial intelligence, and the growth in demand for critical and strategic minerals are elements of an equation that favors the country's industrial and technological development. By way of example, the production of low-CO_2 hydrogen finds in Brazil a particularly favorable environment for its implementation, due to its low economic and environmental cost.

In this scenario, the resumption of commitments to climate security can position Brazil as a global leader, thanks to the historical composition of its energy matrix with 90% renewable sources, the robustness of the environmental legal framework, the recent tax reform representing an important advance and alignment with international practices, and the potential for traceability enabled by the digitalization of the value chain.

Part I

DIAGNOSIS

1. INTRODUCTION

Mineral-origin resources are considered non-renewable resources with broad applications across different industrial sectors, including high demand in infrastructure, energy generation, aerospace technology, agribusiness, and defense. Potential impacts on human health and the environment during the stages of mineral extraction and processing underscore the importance of implementing regulatory and oversight mechanisms consistent with health, safety, and environmental requirements.

Critical and Strategic Minerals (CSMs) are prioritized in the National Mining Plan (PNM 2030[5]) and in Brazilian industrial policy. In general terms, minerals may be considered critical due to their importance at the global level, while strategic minerals are related to domestic demand and supply. More specific criteria that qualify minerals as critical or strategic in this study are presented in Table 1.

Table 1. Criteria used in the relative qualification of strategic and critical minerals in this study

Critical Minerals	**Minerais Strategics**
Exhibit significant domestic production demand	Possess substantial national mineral endowment
Lack significant national mineral endowment relative to demand	Have export demand in raw or processed form
Depend on imports at various stages of the value chain	Hold domestic economic importance, being used in production processes to strengthen the value chain
Present supply disruption risk	Applied in high-technology products
May require specialized processes and labor	Essential for the decarbonization of the economy and contribute to the energy transition

5 https://antigo.mme.gov.br/web/guest/secretarias/geologia-mineracao-e-transformacao-mineral/destaques--do-setor-de-energia/plano-nacional-de-mineracao-2030

1.1 Contextualization

The current global geopolitical scenario is characterized by movements that threaten to reverse the progress achieved under the Paris Agreement. These initiatives put at risk the pace of innovation and the development of technologies geared toward a low-carbon economy, directly affecting the dynamics of critical and strategic minerals. For this reason, more conservative scenarios are anticipated regarding the demand for these minerals up to 2050, and forecasts need to be reviewed in light of new political and economic arrangements, which remain recent and rapidly evolving. Such restructurings involve international trade tariff wars, unpredictability in supply chain dynamics, international pricing practices, and challenges to agreements for the decarbonization of the economy.

The United Nations is the custodian and responsible entity for the perpetuation and promotion of the 2050 Agenda. In 2021, the UN Secretary-General launched the Extractive Industry Transformation Working Group for Sustainable Development, aimed at supporting a just energy transition through sustainable mineral development. However, the UN suffers from resource constraints and discontinuities in the face of potential weakening of global efforts for climate security. Ahead of COP 30 in Belém (Brazil), the country is expected to take a position regarding strategies and public policies for the management of critical and strategic minerals.

Similarly, the Mineral Security Partnership (MSP[6]), in its pursuit of supply diversity, responsible mining, promotion of local economies, and facilitation of sustainable development, demonstrates low expectations given the global geopolitical scenario.

Up to December 2024, the frameworks and paradigms that shaped scenarios for critical materials and minerals over the previous ten years remained relatively stable. A reconfiguration of multilateral agreements based on sustainability and energy transition benchmarks is observed—on one hand, increasing tension in the

Sino-American relationship, and on the other, creating opportunities for diversification of economic agents in mineral trade while reducing supply disruption risk.

Although Taiwan has limited mineral resources, it accounts for approximately 60% of global microprocessor production—a sector representing around 15% of its GDP. The country occupies a strategic position both in the mineral input value chain and in advanced technology products such as smartphones and electric vehicles. The practice of nearshoring with China has enabled the supply of essential mineral inputs for the microprocessor industry. In this context, Taiwan has been expanding efforts to diversify its sources of inputs to ensure continuity and resilience in its production processes.

6 MSP - A transnational association led in 2023 by the United States, the European Union, Australia, Canada, Estonia, Finland, France, Germany, India, Italy, Japan, Norway, the Republic of Korea, Sweden, and the United Kingdom.

The concepts of resilience and flexibility have become priorities in the competition for mineral resources. While directives aimed at ensuring the dissemination of technological solutions for a low-carbon economy risk not being prioritized as goals through 2050—impacting demand for critical and strategic minerals—technological advances in information and communication remain a priority. Developments in 5G networks, electric vehicles, quantum computing, and artificial intelligence are increasingly widespread and accessible, demanding ever-growing quantities of critical and strategic minerals.

In both scenarios, there is potential growth in the search for diversified sources (countries with mineral reserves) or secondary stocks (residual stocks from post-consumer materials) of minerals essential to production or technological development of products and processes.

Therefore, by densifying the mineral sector value chain, Brazil can occupy an important space as a supplier of critical and strategic minerals, manufacturer of goods, and recoverer of secondary materials, aligned with circular economy strategies. With the potential strengthening of decarbonization targets, Brazil could consolidate its position as a global leader, both in possessing the greenest energy matrix and in holding significant reserves of the main critical and strategic minerals.

The development of the mineral sector requires the establishment of convergent mechanisms to manage social, environmental, cultural, economic, and technological demands. Geopolitical positions regarding the energy transition, which directly influence decision-making processes, must also be considered.

For example, addressing pollution, biodiversity loss, and conflicts in indigenous territories are also consequences of the pursuit of critical and strategic minerals, as highlighted by the UN[7] during the 24th session of the UN Permanent Forum on Indigenous Issues. In 2022, IBRAM publicly disclosed its stance on this matter, emphasizing that illegal mining, particularly on indigenous lands, must be combated and offenders penalized, while highlighting the importance of environmental preservation in compliance with legal provisions[8]. It is worth noting that ILO Convention No. 1698 establishes the principle of Free, Prior, and Informed Consent (FPIC)[9] institui o princípio do Consentimento Livre, Prévio e Informado (CLPI)[10] for indigenous peoples. Brazil has ratified the aforementioned Convention; however, the issue still lacks proper regulation by the National Congress. Therefore, mining activities in indigenous territories remain prohibited.

Fossil fuels (oil, coal, and natural gas), in turn, continue to be the primary source of energy, currently accounting for 81% of total consumption. For approximately two

7 https://news.un.org/pt/story/2025/04/1847571

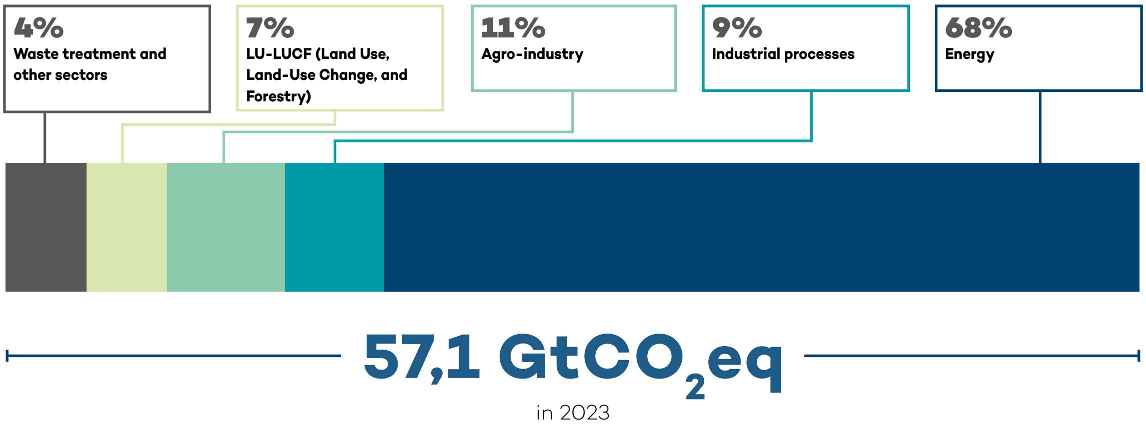
8 https://ibram.org.br/posicionamento-setorial/posicionamento-ibram-mineracao-em-terras-indigenas-2/

9 https://www.planalto.gov.br/ccivil_03/_ato2019-2022/2019/decreto/D10088.htm#anexo72

10 https://www2.camara.leg.br/legin/fed/decleg/2002/decretolegislativo-143-20-junho-2002-458771-convencaon169-pl.pdf centuries, these fossil fuels powered combustion engines and enabled the consolidation and advancement of industrialization worldwide through a linear economy with high levels of atmospheric emissions.

Figure 2 shows that the energy sector was responsible for 68% of global emissions in 2023. This data highlights why efforts to address the climate crisis led to the formulation of the concept of a "transition to a low-carbon economy," which, given the centrality of the energy sector, has become widely recognized as the "energy transition."

Figure 2: Anthropogenic GHG emissions by sector (2023), % of total.



Source: (Pivetta, 2024) apud UNEP, Emissions Gap Report 2024.

At the global level, this process involves replacing fossil fuel sources with renewables in electricity generation and industry, increasing the use of biofuels and electromobility in the transport sector, as well as introducing low-CO_2 hydrogen in hard-to-abate sectors, i.e., those in which electricity or biofuels are not technically viable solutions.

The progress of the energy transition has, in turn, revealed a new dependency: that on specific minerals and materials essential for enabling clean energy generation and storage technologies. These materials have come to be classified as critical and strategic minerals (CSMs). This becomes even more evident in light of long-term projections of global energy demand, resulting in higher energy consumption within the mineral sector.

Since the establishment of the international Paris Agreement in 2015, different nations have committed to promoting the decarbonization of the economy, thereby driving the pursuit of alternative technologies for energy generation through cleaner, renewable sources.

However, the development of these low-carbon technologies has largely been driven by their strong dependence on mineral inputs. In other words, one of the alternatives for reducing greenhouse gas (GHG) emissions is the substitution of fossil fuels, which can occur through the adoption of biofuels or electricity. In both cases, whether electricity generation technologies or vehicles powered by biofuels or hybrid systems, a significant amount of mineral resources is required throughout the value chain.

For instance, electric vehicles use 60 kg of copper, compared with 40 kg in hybrid vehicles and 24 kg in conventional combustion vehicles. Similarly, traditional vehicles contain approximately 100 mg of rare earth elements (REEs), while electric vehicles may contain 1 to 4 kg of REEs. These examples illustrate the leap in mineral input consumption required for equipment technologically designed for the energy transition.

The complexity of accessing mineral resources goes beyond technical and geological requirements, encompassing environmental, social, and governance (ESG) specifications. Translating mineral endowment[11] into production—ensuring volumes and supply mechanisms—represents the main challenge today for CSMs. While innovation speed in the fossil fuel era was mainly concentrated on performance improvements during consumption, today the innovation potential is distributed across the stages of the value chain. This is due to the current high demand for critical minerals, essential for energy generation technologies aimed at decarbonizing the economy, with projected growth in energy consumption from 28,000 TWh/year in 2022 to 110,000 TWh/year by 2050 (ETC Report 2023[12]).

Conversely, the demand for CSMs for the development of clean energy generation technologies is estimated to increase 2 to 4 times from 2022 to 2050, reflecting the complexity of decision-making for companies in the mineral sector.

Holding reserves of more than a hundred mineral substances, Brazil is on par with mineral powers such as Australia, Canada, Russia, China, and South Africa. Brazil's mineral trade balance in 2024 reached USD 34.95 billion, equivalent to 47% of the country's total trade balance of USD 74.55 billion that year12[13]. Metallic substances plus graphite accounted for 82% of the total value of Brazilian mineral production, with iron standing out at 72.8% of this total, followed in value by gold, copper, nickel, and aluminum. Lead, tantalum, chromium, tin, graphite, lithium, manganese, niobium, vanadium, and zinc contributed less than 0.5% of the total value of metallic substance production (ANM, 2023[14]).

11 Mineral endowment: "An inherent attribute of the geological substrate, mineral endowment corresponds to the territory's aptitude to host mineral deposits, encompassing known reserves and undiscovered potential resources." (from English, mineral endowment) (Cabral Júnior e Gamba, 2017) https://www.redalyc.org/journal/4716/471655316005/html/

12 https://www.energy-transitions.org/wp-content/uploads/2023/08/ETC-Materials-Report_highres-1.pdf

13 https://ibram.org.br/publicacoes/?txtSearch=&checkbox-section%5B%5D=161&checkbox-section%5B%5D=1236#publication

14 Brazilian Mineral Yearbook: Main Metallic Substances https://www.gov.br/anm/pt-br/assuntos/economia-mineral/publicacoes/anuario-mineral/anuario-mineral-Brazileiro/amb_2023.pdf

The low degree of value chain densification positions Brazil primarily as an exporter of mineral goods. The country's substantial reserves of iron, manganese, nickel, rare earth elements, lithium, and graphite do not always reflect its potential in manufacturing goods or finished products from these mineral resources.

However, it is important to note that value chain densification may not be viable for certain minerals—for example, iron ore, whose large-scale upstream production would not necessarily lead to gains in midstream or downstream processing due to, for instance, low competitiveness in the international market.

Specializing the production chain of goods based on mineral inputs can be the solution for the development of specific CSMs, aligned with the axes of the New Industry Brazil Plan[15]. The plan establishes six priority missions up to 2033, including the importance of the mineral sector, particularly in the missions presented in Table 2.

Table 2. Participation of CSMs in the missions of the New Industry Brazil (NIB) Plan.

Mission	Target for 2026 and 2033	Mineral Sector Participation
Mission 1 AGRO-INDUSTRIAL VALUE CHAINS	Promote GDP growth and agro-industry by up to 3% per year from 2024 to 2026 and up to 6% per year from 2027 to 2033.	Reduce dependence on phosphate and potassium imports.
	Expand mechanization of family farming to 28% in 2026 and 35% in 2033; increase technical capacity of family farming to 43% in 2026 and 66% in 2033, encouraging the supply of the market with domestically produced machinery and equipment and promoting regional development.	Production of CSMs for manufacturing equipment, especially those for infrastructure expansion (e.g., Fe, Al, Cu, Mn, graphite).

15 https://www.gov.br/mdic/pt-br/composicao/se/cndi/plano-de-acao/nova-industria-Brazil-plano-de-a-cao-2024-2026-1.pdf

Mission	Target for 2026 and 2033	Mineral Sector Participation
Mission 2 HEALTH	Produce 50% of national needs in medicines, vaccines, medical equipment and devices, materials, and other health inputs and technologies by 2026, and 70% by 2033.	Production of CSMs for renewable energy panels (Cu, Al, Si, Sn, Zn, Li, Ni, Mn, Co, etc.)[16].
Mission 3 URBAN INFRASTRUCTURE Sanitation, Housing, and Mobility	Build 2.0 million housing units through the "Minha Casa Minha Vida" Program (PMCMV), of which 500,000 with photovoltaic panels; increase to 6.9 million units (1.4 million with photovoltaic panels) by 2033.	Production of CSMs for renewable energy panels (Cu, Al, Si, Sn, Zn, Li, Ni, Mn, Co, etc.).
	Increase the share of electrified vehicles (electric and hybrid) with nationally produced batteries in the sale of new vehicles to 3% by 2026 and 33% by 2033.	Production of CSMs for national manufacturing of electric batteries (Cu, Al, Mn, Li, graphite, Ni, Co, REEs, etc.).
Mission 4 DIGITAL TRANSFORMATION	Digitally transform 25% of Brazilian industrial companies by 2026 and 50% by 2033, ensuring domestic production participation in new technology segments.	Production of equipment and precursors from CSMs (Al, Si, Mn, Ni, Co, Cu, Sn, REEs, etc.) for applications and technologies for digital transformation.
	Reduce the country's productive and technological dependence in nano- and microelectronics and semiconductors, strengthening the industrial chain for information and communication technologies.	Production of nano- and microelectronic products and semiconductors from CSMs (Li, Co, REEs, Ta, etc.) for applications and technologies for digital transformation.

16 https://www.bgs.ac.uk/discovering-geology/maps-and-resources/critical-raw-materials-resources/modern-life-doesnt-grow-on-trees/critical-minerals-in-medicine/

Mission	Target for 2026 and 2033	Mineral Sector Participation
Mission 5 BIOECONOMY, DECARBONIZATION, AND ENERGY TRANSITION	Promote the green industry and encourage technological innovation focused on decarbonization, increasing the share of biofuels and electric energy in the transport matrix by 27% in 2026 and 50% in 2033.	Production of CSMs for application in decarbonization technologies.
	Promote domestic production of renewable energy generation equipment.	Production of CSMs for application in converters for renewable energy generation (wind turbines and photovoltaic panels).
	Decarbonize the basic industry (cement, steel, and sustainable chemical industry).	Production of CSMs for application in sustainable inputs for basic industry (Fe, Cu, Al, Zn, Ni, graphite, etc.).
Mission 6 DEFESA E AEROESPACIAL	Densify productive chains of defense and aerospace, increasing multiplier potential and technological spillovers to other sectors.	Production of CSMs for application in defense and aerospace value chains, e.g., Ti, Co, REEs, Co, Ta, Al, Nb.
	Achieve 55% mastery of critical technologies[17] for defense by 2026 and 75% by 2033.	Specialization of the value chain to support the production of critical technologies from CSMs.

17 Critical technologies: "These are technologies crucial for ensuring national sovereignty and defense, such as radar, satellites, rockets, and turbines. A technology is considered mastered when a prototype product developed from it has been successfully tested in a real-world environment, outside the laboratory." Examples: KC390 (Embraer); Tanue Guarani (IVECO); Guarani Tower (ARIS).
(Source: https://www.gov.br/mdic/pt-br/composicao/se/cndi/plano-de-acao/nova-industri a-Brazil-plano-de--acao-2024-2026-1.pdf)

1.2 Global Scale of Mineral Goods Production

Present either directly or indirectly in all missions for the implementation of the *Plano Nova Indústria Brazil*, CSMs (Critical and Strategic Minerals) demonstrate fundamental importance for the specialization of different national value chains. Brazil is positioned as the second largest global reserve of rare earth elements after China; it holds more than 90% of the world's niobium reserves, as well as significant reserves of aluminum, manganese, nickel, tin, and graphite. According to international data (IEA, 2024[18]), Brazil possesses significant mineral reserves and at least one world-class project for the main CSMs.

The global mineral industry produced approximately 2.6 billion tonnes of metals in 2024 from the ferrous, non-ferrous, and precious groups, of which 93% correspond to iron ore (2.5 Bt). The broad dominance in iron ore production compared to other metal classes is due to its role as a fundamental raw material for the steel industry, which in turn has high demand in the construction sector, particularly in regions with rapid urban expansion and developing infrastructure.

To give a sense of scale, the global production of metals considered critical and strategic in this study for infrastructure development, industrial applications, and technologies important for the energy transition is several orders of magnitude smaller in tonnage compared to iron ore.

Production of aluminum, copper, nickel, manganese, zinc, and titanium, for example, ranges from tens of thousands to a few million tonnes, contributing between 2.7% and 0.14% of global metal production (Table 3). Although these metals are important for the development of low-carbon energy technologies, the demand for these metals—particularly aluminum and copper—is not exclusive to the energy transition, as they have broad applications in other industrial sectors, including steel production for construction, the automotive sector, and electronic products such as household appliances.

The production of, for example, niobium, lithium, rare earth elements (REEs), tin, cobalt, and tantalum, on the other hand, amounts to hundreds to tens of thousands of tonnes, contributing less than 0.01% of global production (Table 3). Within this group, the growing demand for lithium, REEs, and cobalt has been driven exclusively by the energy transition, due to their specific applications in certain low-carbon technologies (e.g., batteries, solar panels, and wind turbines).

18 World Energy Outlook 2024 - https://www.iea.org/reports/world-energy-outlook-2024

Table 3. Global production of metals in 2024 relevant for infrastructure, industry, and energy transition technologies.

Metals	Global production in 2024 (tonnes)	% of total global mineral production
Iron ore	2.500.000.000	93,0
Aluminium	72.000.000	2,7
Copper	23.000.000	0,85
Manganese	20.000.000	0,74
Zinc	12.000.000	0,44
Titanium	9.400.000	0,35
Nickel	3.700.000	0,14
Cobalt	290.000	0,01
Niobium	110.000	0,004
Tantalum	2.100	0,00008
Tin	300.000	0,011
Rare Earth Elements (REEs)	390.000	0,014
Lithium	240.000	0,009
Platinum Group Elements	360	0,00001

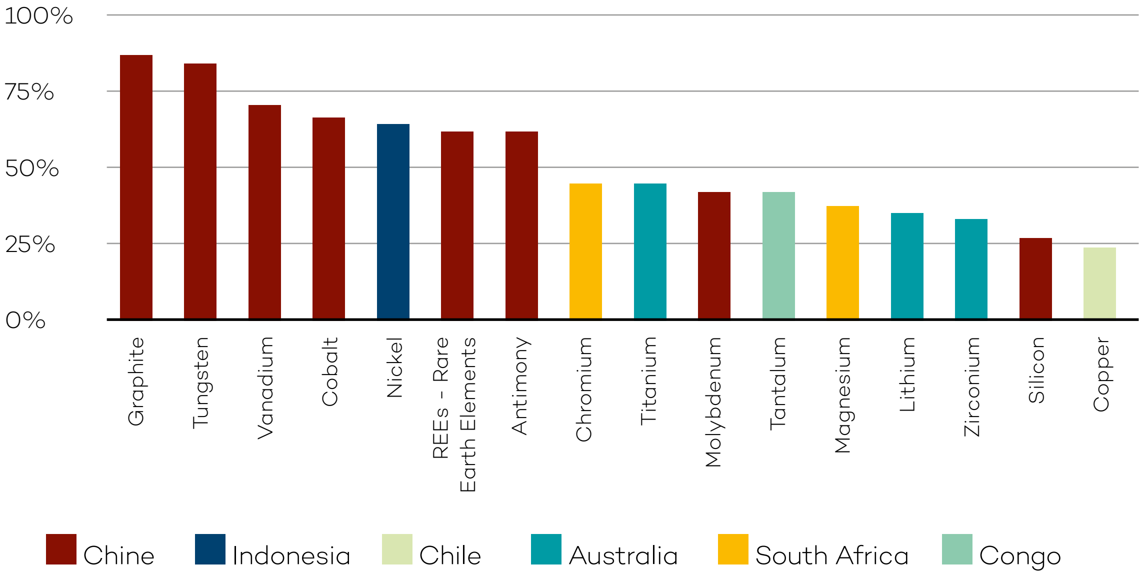
Note 1: Metals considered relevant for the development of infrastructure, industry, and with applications in low-carbon technologies for the energy transition.
Note 2: Tonnage values have been rounded. The percentage for each metal is estimated relative to total metal production in 2022 (2.1 billion tonnes).

Source: USGS Mineral Commodity Summary 2025[19]; (2) World Mining Data 2025[14].

The processes of mitigation and adaptation to global climate change result in cascading actions that encompass the development of decarbonization mechanisms

19 USGS Mineral Commodity Summary 2025 - https://pubs.usgs.gov/periodicals/mcs2025/mcs2025.pdf and incentives for the sustainable use of natural resources. The decision to achieve a low-carbon economy faces paradoxical challenges.

Figure 3: Leading nations in the global processing of critical and strategic minerals related to energy (IEA, 2025[20]).



Critical and strategic minerals are extracted and processed from a small set of countries, led by China, which holds about two-thirds of the processing and refining of these minerals (Figure 3). The current scenario of China's dominance is the result of a combination of long-term investments in strengthening the industry, public investments in consolidating the supply chain, export controls, low labor costs that became highly skilled, as well as decades of weak environmental regulation that allowed irregular mines and processing plants[21]. Although the scenario of low Chinese public control has changed in recent years, the positive economic outcomes are reflected in the high degree of industrialization and advances achieved, for example, in the mineral sector.

In light of the above, an imbalance is observed in the environments established for different nations, both in relation to the maturity of environmental regulation and to occupational health and safety criteria. Therefore, the path to strengthening industries in the mineral value chain needs to consider the same requirements for a low-carbon economy and a just energy transition.

20 Global Critical Minerals Outlook 2025. https://iea.blob.core.windows.net/assets/a33abe2e-f799-4787-b09b-2484a6f5a8e4/GlobalCriticalMineralsOutlook2025.pdf

21 https://www.oxfordenergy.org/wpcms/wp-content/uploads/2023/06/CE7-Chinas-rare-earths-dominance-and-policy-responses.pdf

A notable effect of technological options for substituting fossil fuels in the energy matrix is the pressure on the supply of critical mineral elements (CMEs). Supply disruptions can impact the pace of the energy transition by affecting availability and, consequently, making production costs unfeasible.

Thus, the growing demand for CMEs, such as copper, rare earth elements, lithium, graphite, cobalt, and nickel, combined with geopolitical uncertainties, results in the need for strategic actions guided by the guarantee of supply security.

CMEs are concentrated in a small set of countries holding mineral reserves, and when these countries also have mineral production capacity from these reserves, a dual condition is established regarding security both of mineral resources and of productive potential.

With the specialization of extraction and mineral processing, and achieving the application solutions of mineral sector inputs—such as the manufacturing of semiconductors, microprocessors, or special glass for photovoltaic panels—countries like China and the United States currently compete for the forefront in mineral production and autonomy regarding the supply of products with high technological content.

Although coordinated actions are encouraged by global initiatives, as proposed by relevant institutions such as the IEA and UN, countries perceive the need to seek solutions that consider technical specificities and sovereignty as principles for aligning strategies and mineral sector regulation.

Among the prioritized actions by leading countries in the energy transition are:

- Establish mechanisms to balance the demand and availability of CMEs;
- Mitigate the social, economic, and environmental impacts of mineral exploration and extraction;
- Develop technologies for the application of mineral inputs, such as the production of precursors for energy converters (e.g., batteries, photovoltaic panels, and wind turbines);
- Assess the potential for substitution or recycling of mineral inputs, considering the goal of diversifying supply;
- Establish national strategies aligned with international agreements for low-carbon economies.

Thus, the cost of clean energy production from the intensive application of minerals comes to consider variables such as environmental and social impacts, technological potential, mineral endowment, and regulation.

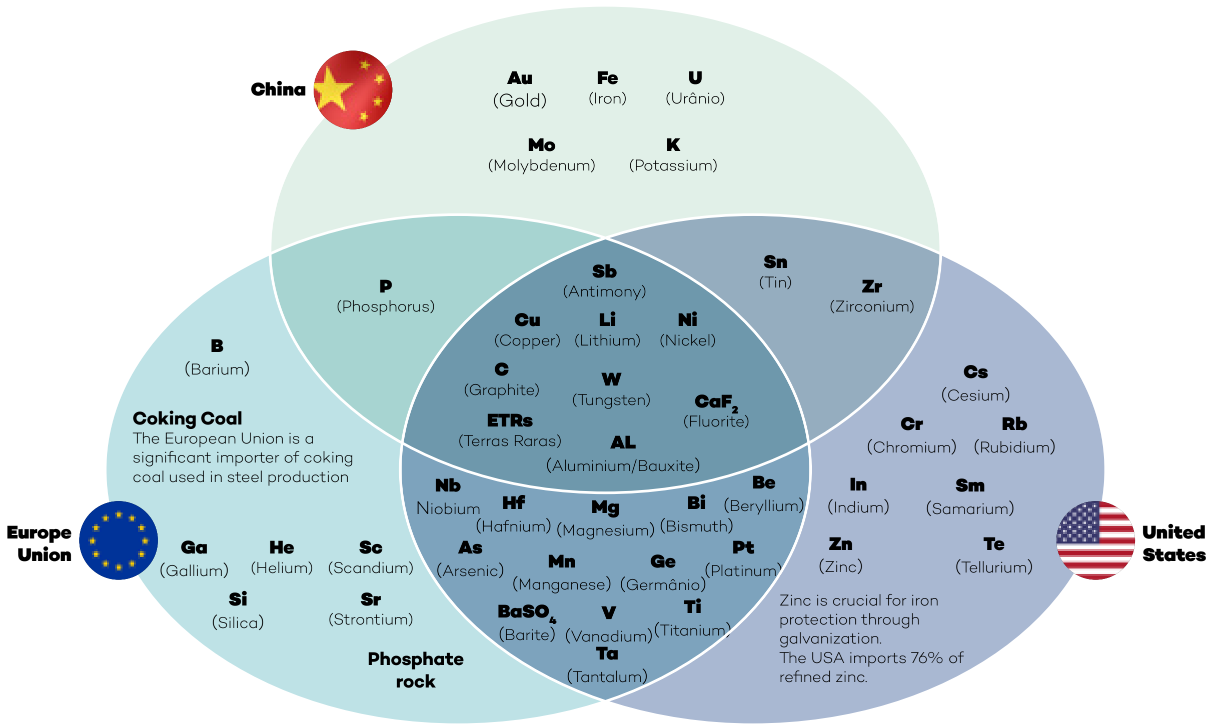
1.3 The energy transition as a window of opportunity

The mobilization of resources to leverage the energy transition conveys a clear message of growth opportunity for economies, protection of society, and preservation of ecosystems, revealing that addressing the climate crisis exposes a horizon of benefits through a clear commitment to overcome the mistakes of the past (UN, 2024[22]).

Countries or regions, such as the European Union, have defined their respective lists of minerals considered critical for the energy transition. These lists have been dynamic and constantly reassessed, as they reflect demand for metals and minerals for the development of low-carbon technologies, in a context of supply and production with strong global geopolitical centralization.

Figure 4 highlights the set of minerals classified as critical, which constitute the main demand for three major regions of the globe: the USA, the European Union, and China. Within this set, there are ten critical minerals with common demand across all three regions: aluminium, antimony, cobalt, copper, fluorite, graphite, lithium, nickel, REEs, and tungsten. There is also demand for critical minerals common to two regions, such as tin for China and the USA, and tantalum, manganese, niobium, platinum, and titanium for the USA and the European Union.

Figure 4: The set of critical minerals defined for the USA, China, and the European Union[23].



22 https://www.unep.org/resources/emissions-gap-report-2024

23 https://www.visualcapitalist.com/the-critical-minerals-to-china-eu-and-u-s-national-security/.

This excerpt reveals that Brazil holds a privileged global position for several CMEs, important for these three regions. In addition to securing the second global position as an iron ore producer, 90% of global niobium production, and 94% of mapped reserves of this metal, Brazil is also: (1) on the list of the five largest reserves of aluminium (5th), Sn (3rd), tantalum (3rd), graphite (2nd), REEs (2nd), manganese (4th), nickel (3rd); and (2) among the five largest producers of aluminium (4th), tin (5th), tantalum (4th), graphite (4th), lithium (5th), and silicon (3rd).

Research conducted by Bloomberg NEF in 2024[24] identifies the ten regions on the planet which, based on criteria such as geological reserves, mineral sector strategy, political stability, skilled labor, and environmental impact assessment, are considered important supplier markets for CMEs.

Table 4. General global information on the CMEs considered in this work.

Metal/ Mineral	Chemical Formula	Class	Global Reserves and by Country (Top 5/ 2024)	Global Producers and by Country (Top 5/ 2024)	Main Ore Minerals
Aluminum	Al	Non-ferrous metal	World = 29 Bt Papua New Guinea (7.4 Mt), Australia (3.5 Mt), Vietnam (3.1 Mt), Indonesia (2.8 Mt), Brazil (2.7 Mt)	World = 450 Mt Papua New Guinea (130 Mt), Australia (100 Mt), China (93 Mt), Brazil (33 Mt), Russia (6.3 Mt)[6]	Bauxite (aluminium hydroxides)
Cobalt	Co	Ferrous metal	World = 11 Mt DR Congo (6 Mt), Australia (1.7 Mt), Cuba (500,000 t), Indonesia (500,000 t), Philippines (250,000 t)[6]	World = 290,000 t DR Congo (145,000 t), Indonesia (9,500 t), Australia (7,000 t), Philippines (5,400 t), Cuba (5,300 t)[6]	1. By-products of primary Ni and Cu sulfide deposits Pentlandite - $(Fe, Ni, Co)_9S_8$ 2. By-products of secondary deposits (in regoliths)
Copper	Cu	Non-ferrous metal	World = 980 Mt Chile (190 Mt), Peru (100 Mt), Australia (100 Mt), DR Congo (80 Mt), Russia (80 Mt)[7]	World = 23 Mt Chile (5.3 Mt), DR Congo (3.3 Mt), Peru (2.7 Mt), China (1.8 Mt), USA (1.1 Mt)[6]	Copper sulfides: Chalcopyrite ($CuFeS_2$), Bornite (Cu_5FeS_4), Chalcocite (Cu_2S), Digenite (Cu_9S_5); Copper sulfo-arsenides: Enargite (Cu3AsS4); Copper carbonates: Malachite $Cu_2CO_3(OH)_2$, Azurite $Cu_3(CO_3)_2(OH)_2$

24 https://about.bnef.com/blog/brazil-transition-factbook-2025-the-numbers-behind-the-ambition/

Metal/ Mineral	Chemical Formula	Class	Global Reserves and by Country (Top 5/ 2024)	Global Producers and by Country (Top 5/ 2024)	Main Ore Minerals
Rare Earth Element s (REEs)	REEs	Non-ferrous metals	World = >90 Mt China (44 Mt), Brazil (21 Mt), India (6.9 Mt), Australia (5.7 Mt), Russia (3.8 Mt)[6]	World = 390,000 t China (270,000 t), USA (45,000 t), Myanmar (31,000 t), Australia (13,000 t), Nigeria (13,000 t)[6]	1. Primary deposits (hard rock): phosphates (Monazite) and carbonates (Bastnasite); 2. Secondary deposits (regoliths): ionically adsorbed on clay minerals surfaces
Tin	Sn	Non-ferrous metals	World = >4,2 Mt China (1.0 Mt), Burma (700.000t), Australia (620.000 t), Russia (460.000 t), Brazil (420.000t)[6]	World = 300.000t China (69.000t), Indonesia (50.000t), Myanmar (34.000 t), Peru (31.000 t), Brazil (29.000 t),	Tin oxides: Cassiterite (SnO_2) predominant
Phosphate	PO_4^{3-}	Polyatom ic ion	World = 74 Bt Marrocos (50 Bt), China (3,7 Bt), Egito (2,8 Bt), Tunisia (2,5 Bt), Russia (2,4 Bt)[6]	World = 240 Mt China (110 Mt), Marrocos (30 Mt), USA (20 Mt), Jordan (12 Mt), Arábia Saudita (9,5 Mt)	Phosphate rock: Fluorapatite [$Ca_5(PO_4)_3F$] and Hydroxyapatite [$Ca_5(PO_4)_3OH$]
Graphite	C	Industrial mineral	World = 290 Mt China (81 Mt), Brazil (74 Mt), Madagascar (27 Mt), Mozambique (25 Mt), Tanzania (18 Mt)[6]	World = 1,6 Mt China (1,3 Mt), Madagascar (89.000t), Mozambique (75.000t), Brazil (68.000t), Índia (28.000t)6	Graphite: Lump, Flake, Vein
Lithium	Li	Non-ferrous metals	World = 30 Mt Chile (9,3Mt), Australia (7 Mt), Argentina (4 Mt), China (3 Mt), USA (1,8 Mt)[6]	World = 240.000t Australia (88.000t), Chile (49.000t), China (41.000t), Argentina (18.000t), Brazil (19.000t)[6]	1. Hard rock deposits (pegmatites): Spodumene - ($LiAlSi_2O_6$); 2. Deposits em salares: salmouras ricas em Lithium
Manganese	Mn	Ferrous metal	World = 1,7 Bt South Africa (560 Mt), United States (500 Mt), China (280 Mt), Brazil (270 Mt), Gabon (61 Mt)6	World = 20 Mt South Africa (7,4 Mt), Gabon (4,6 Mt), Australia (2,8 Mt), Gana (820.000 t), China (770.000 t)[6]	Óxidos e carbonatos de Mn: Pirolusita (MnO_2) Rodocrosita ($MnCO_3$)
Iron	Fe	Ferrous metal	World = 88 Bt Australia (27 Bt), Brazil (15 Bt), Russia (14 Bt), China (7 Bt), Índia (3,4 Bt)[6]	World = 1,6 Bt Australia (580 Mt), Brazil (280 Mt), China (170 Mt), Índia (170Mt), Irã (59 Mt)6	Óxidos de Fe: Hematita (Fe_2O_3) Magnetita (Fe_3O_4)

Metal/ Mineral	Chemical Formula	Class	Global Reserves and by Country (Top 5/ 2024)	Global Producers and by Country (Top 5/ 2024)	Main Ore Minerals
Niobium	Nb	Ferrous metal	World = >17 Mt Brazil (16 Mt) Canada (1,6 Mt), USA (210.000t)[6]	World = 110.000t Brazil (100.000t), Canada (7.100t)[6]	Nb-Ta oxides: Columbite–Tantalite $[(Fe, Mn) (Nb, Ta_2)O_6]$[6] Pyrochlore $[(Na_3,Ca)_2$ $(Nb, Ti) (O, F)_7]$
Nickel	Ni	Ferrous metal	World = > 130 Mt Indonesia (55 Mt), Australia (24 Mt), Brazil (16 Mt), Russia (8,3 Mt), New Caledonia (7,1 Mt)[6]	World = 3,7 Mt Indonesia (2,2 Mt) Philippines (330.000t), Russia (210.000t), Canada (190.000t), China (120.000t)6	1. Primary deposits: Nickel sulfides Pentlandite ($FeNi_9S_8$) Millerite (NiS) 2. Secondary deposits (regoliths): Hydrated Mg silicates Garnierite $((Ni,Mg,Fe)_4$ $Si_6O_{15}(OH)_2.6H_2O)$
Gold	Au	Precious metal	World = 64.000t USA (12.000t), Russia (12.000t), Indonesia (3.600t), Canada (3.200t), China (3.100t)[6]	World = 3.300 t China (380 t), Russia (310 t), Australia (290 t), Canada (200 t), USA (160 Kt)6	Native metal - Au
Platinum Group Elements (Platinum - Palladium)	Pt - Pd	Precious metal	World = >81.000 t South Africa (61.000t), Russia (16.000 t), Zimbabwe (1.200t), USA (820 t), Canada (310 t)[6]	World = 170t South Africa (120t), Zimbabwe (19 t), Russia (18t), Canada (5,2t), USA (2,0t)[6]	Platinum and Palladium arsenides and sulfides $(Pt,Pd)As_2$, (Pt,PdS), (Pt,Pd,Ni)S), PtAsS
Potassium	K	Metal industrial	World = > 4,8 Bt K2O Canada (1,1 Bt), Laos (1 Bt), Russia (920 Mt), Belarus (750 Mt), USA (220 Mt)[6]	World = 48 Mt Canada (15 Mt), Russia (9 Mt), Belarus (7 Mt), China (6,3 Mt), Germany (3 Mt)[6]	K salts: Sylvite (KCl), Carnallite $(KMgCl_3.6H_2O)$
Silicon	Si	Semimetal	Not available	World = 9,7 Mt Si China (6,6 Mt), Russia (620.000t), Brazil (390.000t), Norway (340.000t), Iceland (130.000t)[11]	Quartz (SiO_2)
Tantalum	Ta	Ferrous metal	World = Not available China (240.000 t), Australia (110.000 t), Brazil (40.000 t)	World = 2.100 t Congo (880 t), Nigeria (390 t), Rwanda (350 t), Brazil (210 t), China (76 t)[6]	Tantalum oxide: Tantalite $(Fe,Mn) (Nb,Ta)_2 O_6$

Metal/ Mineral	Chemical Formula	Class	Global Reserves and by Country (Top 5/ 2024)	Global Producers and by Country (Top 5/ 2024)	Main Ore Minerals
Titanium (concentrado de rutilo ou ilmenita)	Ti	Ferrous metal	World = >560.000t Australia (215.000 t), China (110.000 t), Norway (37.000 t), South Africa (34.000 t), Madagascar (30.000 t)[17]	World = 9.400 t China (3.300 t), Mozambique (2.000 t), South Africa (1.400 t)[17]	Ti oxide: Rutile (TiO_2) or Ilmenite ($FeTiO_3$)
Zinc	Zn	Non-ferrous metals	World = 230 Mt Australia (64 Mt), China (46 Mt), Russia (29 Mt), Peru (20 Mt), Mexico (14 Mt)[6]	World = 12 Mt China (4 Mt), Peru (1,3 Mt), Australia (1,1 Mt), Índia (860 Kt), USA (750 Kt)[6]	Zn sulfide: Sphalerite – ZnS Zn silicate Willemite - Zn_2SiO_4

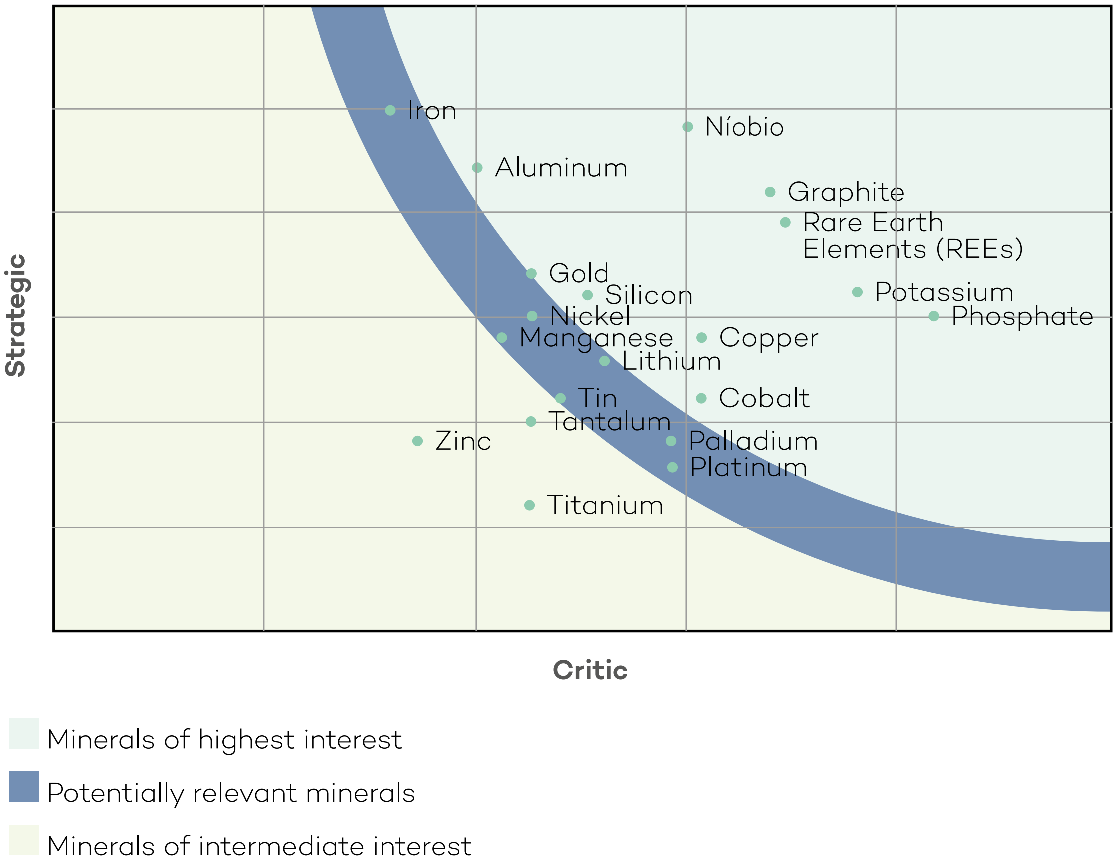
Source: https://worldpopulationreview.com/country-rankings/bauxite-production-by-country; 3 Brazilian Mineral Yearbook 2023; 4 Bauxite and Alumina 2023 Annual Publication, U.S. Geological Survey. January 2024; 5 https://elements.visualcapitalist.com/ranked-the-worlds-top-cobalt-producing-countries/; 6U.S. Geological Survey, Mineral Commodity Summaries, January 2025; 7 https://investingnews.com/daily/resource-investing/base-metals-investing/copper-investing/top-copper-reserves-country/; 8 https://investingnews.com/daily/resource-investing/base-metals-investing/copper-investing/top-copper-reserves-country/; 9 https://www.Brazilmineral.com.br/noticias/Brazil-e-o-segundo-em-reservas-de-terras-raras-no-World; 10 https://www.statista.com/statistics/267367/reserves-of-graphite-by-country/ e https://www.statista.com/statistics/267366/world-graphite-production/; 11 https://worldpopulationreview.com/country-rankings/silicon-production-by-country

1.4 MCEs: Criticality versus Strategic Positioning

The analysis of the set of critical and strategic minerals selected in this study allows for an assessment of each mineral based on its degree of criticality according to global parameters and its strategic positioning in relation to national demand and market (Figure 5). This study presents a qualitative-quantitative analysis methodology that may contribute to the review and update of Brazil's list of critical and strategic minerals.

To this end, three priority areas were highlighted. The first area identifies minerals of greatest interest, with a significant degree of criticality—for example, minerals such as phosphate and potassium, which are heavily dependent on imports for fertilizer production, a scenario that could change with projected investments in domestic production. Similarly, highly strategic minerals such as niobium and aluminum are indicated within this same area. Minerals like niobium, rare earth elements, and graphite, due to significant national reserves and investments in technology and innovation, demonstrate maturity within the value chain.

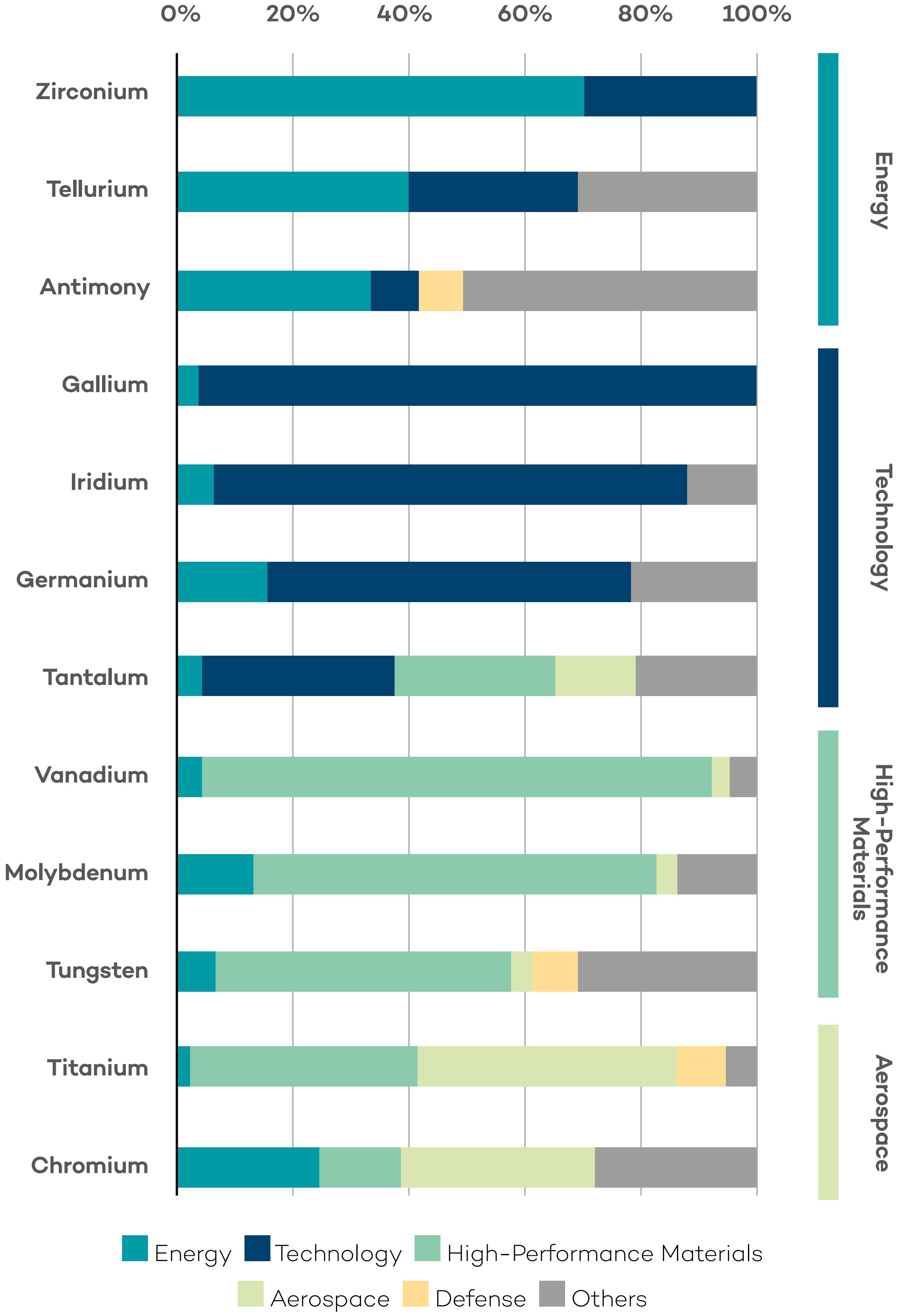
Figure 5: Positioning of minerals according to criticality and strategic attributes



On the other hand, minerals such as iron, aluminum, silicon, nickel, lithium, and cobalt, despite their significant demand in terms of volume or importance within high-tech product value chains, are considered potentially strategic and still have room for value chain densification. Emphasizing the need to assess their potential in relation to production costs and the level of value chain specialization, iron ore, for example, does not result in significant gains from scaling up production, whereas other minerals, such as niobium, provide substantial competitive advantage. Similarly, minerals such as manganese, tin, tantalum, platinum, and palladium are at the stage of expanding demand to meet production needs aligned with the energy transition. These minerals are considered potential new entrants for the Brazilian economy.

Mineral demand can affect costs depending on resource availability, market demand, and technological potential. According to data from the International Energy Agency (IEA, 2025), solutions for energy generation from renewable sources have positioned digital technologies as major consumers of various minerals. While in the 2000s silicon was highly demanded for the production of solutions for electronic equipment and digitalization, currently, with the advent of artificial intelligence (AI), the demand for copper (2%), silicon (2%), rare earths (3%), and gallium (11%) is expected to increase to supply data centers (IEA, 2025) (Figure 6).

Figure 6: Demand for critical minerals by sector in 2024 (IEA, 2025[25]).



25 IEA, 2025. Global Critical Mineral Outlook. https://iea.blob.core.windows.net/assets/a33abe2e-f799-4787-b09b--2484a6f5a8e4/GlobalCriticalMineralsOutlook2025.pdf

2. THE VALUE CHAIN OF CRITICAL AND STRATEGIC MINERALS

The value chain of Critical and Strategic Minerals (CSMs) includes the stages of mineral extraction and processing, and more recently, the introduction of circular economy principles, which involve value recovery. Activities such as waste processing and reintegration of secondary materials are therefore part of the chain. In this study, the stages considered include resource exploration (upstream), production of semi-finished goods (midstream), finished products (downstream), and more innovative and circular processes involving resource recovery (recovery).

The supply of mineral goods is related to mineral endowment (known reserves and undiscovered potential resources) and to the established production processes for ore beneficiation and mineral goods production. On the demand side, elements include the maturity level of the processing industry and the consumer market. Mineral goods are property of the Union. Therefore, authorization for extraction, beneficiation, and mineral commercialization is granted through research and mining concessions by the National Mining Agency (ANM) via the Mining Permit Decree[26]. The phases of the mining process are shown in Figure 7.

Figure 7: Simplified stages of a mineral project from exploration to extraction (ANM, 2024[27]).

EXPLORATION AUTHORIZATION REQUEST
- Submit mineral exploration plan.
- Request form.
- Research Plan and REPEM.

EXPLORATION AUTHORIZATION
- Notify the start of mineral research and submit investment declaration.
- Submit final exploration report.
- Payment of TAH fee and CFIEM declaration..

MINING PERMIT REQUEST
- Submit Environmental Operating License (LO).
- Submit Economic Exploitation Plan (PAE) and other required documents.

MINING CONCESSION
- Submit annual mining report (RAL).
- Pay CFEM monthly.
- Submit Mine Closure Plan.

26 https://www.gov.br/anm/pt-br/assuntos/exploracao-mineral/titulos-minerarios

27 https://www.youtube.com/watch?v=BsIz7LST_As

2.1 Supply and Demand of Mineral Goods

Strategic factors for the country include its diversified mineral potential as well as its global significance, resulting from its substantial share in the world reserves of numerous critical minerals (SGB, 2025[28]; USGS, 2025[15]).

This positions the country as a key player in meeting global demand for a wide range of critical minerals, such as those listed for the three major regions. This level reflects a clear perspective of ascension as a leader in supplying essential inputs for advanced technologies (IEA, 2021[29]).

Elements of mineral supply include both the occurrence of mineral reserves and the availability of processed minerals, whether as concentrates or in more advanced stages of the value chain.

For example, national niobium production results in the generation of REEs as a by-product of mineral extraction. Although available in Brazil, there is currently no significant demand to justify large-scale beneficiation for REEs.

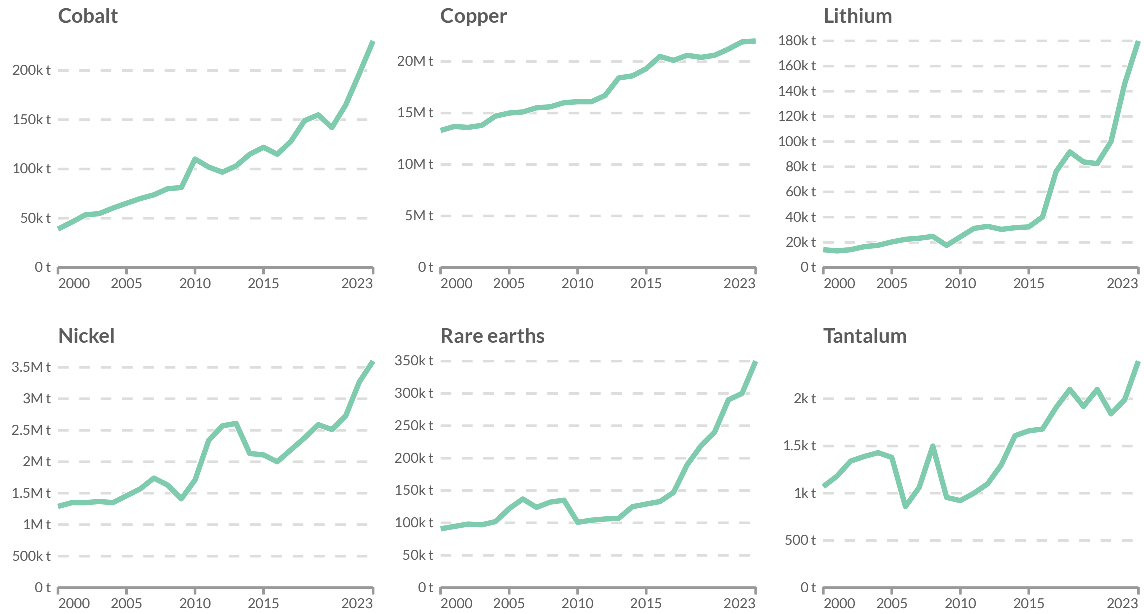
Processes such as large-scale production of rare-earth magnets have not yet been established. CIT Senai (MG), however, has installed a pilot plant with production capacity and potential to scale up permanent rare-earth magnet production in the medium and long term.

With the continuous increase in global demand for Critical and Strategic Minerals (CSMs) to support the development of low-carbon technologies, having adequate infrastructure to support all stages of the mineral project value chain has become critical (Figure 8). Lithium stands out among CSMs as the mineral with the highest demand for applications in energy transition solutions (Figure 9).

28 An overview of critical and strategic minerals potential of Brazil - https://sgb.gov.br/documents/d/guest/critical_and_strategic_mineral_potencial_of_brazil_2025?_gl=1*1fiuvge*_gcl_au*NTQ3NDQwNzc5LjE3Mzk3OTgzMzA.*_ga*MTM5ODAyMzc2LjE3MzkyODk2NDA.*_ga_HYCRRWGXHJ*MTc0NjAxMDE3Ny45LjEuMTc0NjAxMDE4OC40OS4wLjYwNDQxMzgzNw

29 World Energy Outlook 2021 - https://www.iea.org/reports/world-energy-outlook-2021

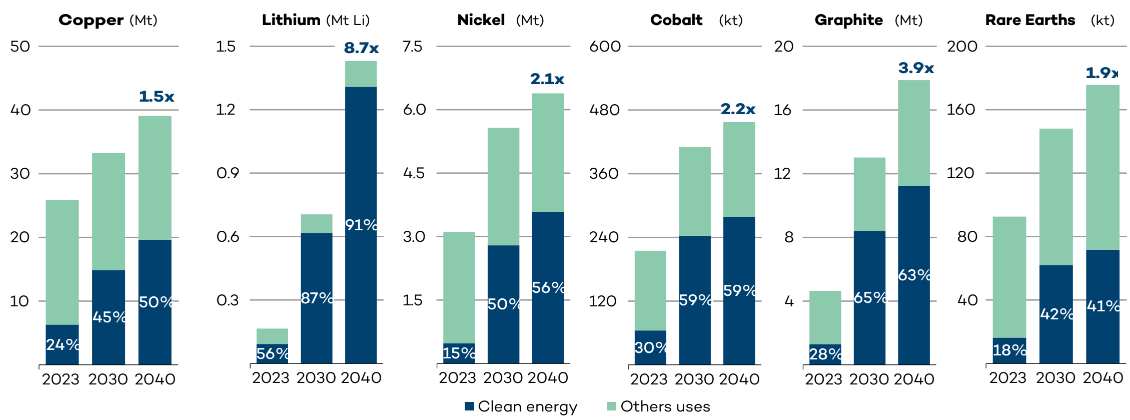
Figure 8: Global production of ferrous and non-ferrous metals between 2000 and 2023 considered essential for the development of low-carbon technologies.



Source: https://ourworldindata.org/grapher/global-mine-production-minerals.

Processed minerals in large volumes[30], also known as bulk minerals, have significant relevance in infrastructure composition due to their extensive use in urbanization and industrialization processes. They are applied in infrastructure elements such as construction, paving, machinery manufacturing, as well as in the development of logistics infrastructure, including roadways, railways, and ports. Examples of these minerals are demanded in construction (iron ore, sand, clay, gypsum, dolomite, ornamental stones, etc.), manufacturing (copper, aluminum, kaolin, etc.), and agriculture (phosphate, potassium, etc.).

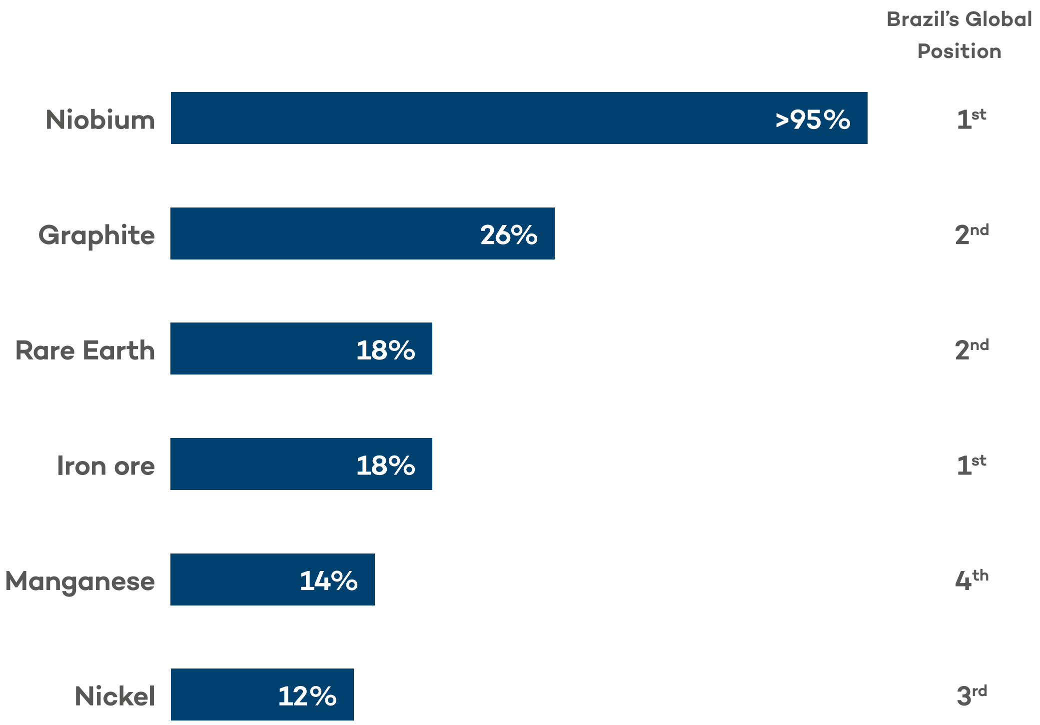
Figure 9: Growth in demand for major critical minerals (IEA, 2024).



30 Bulk minerals: Applying for bulk sampling on a Mineral Development Licence or Exploration Permit https://www.nrmmrrd.qld.gov.au/online-applications/remote-content?ver=1.01&external-uuid=91a3f71c-deac-4a28-a-523-96ab918f3ef1

Brazil ranks fourth as a promising market to supply global demand for Critical and Strategic Minerals (CSMs) based on its mineral endowment. In terms of geological reserves, Brazil holds the third position globally, with more than 15% of the world's reserves for four CSMs: graphite, rare earths, nickel, and manganese (Figure 10).

Figure 10: Global position of Brazil in relation to the reserves of selected key critical and strategic minerals.



Source: BloombergNEF's Energy Transition Metals Production Scores, United States Geological Survey e SGB, 2025[31].

The set of exemplified Critical and Strategic Minerals (CSMs) reflects the importance of Brazil's mineral reserves in relation to their potential applications for the main demands of the energy transition. However, beyond mineral endowment, the country must also meet the criteria for the effective extraction and application of mineral resources.

In this context, Brazil holds a geological potential that is not only diversified but also prominent on a global scale, due to its substantial share in the world reserves of numerous critical minerals (Table 4). This positions the country as a key player in meeting global demand for a wide range of critical minerals for the energy transition, as exemplified by the minerals listed for the USA, European Union, and China. This level reflects a clear perspective of ascension as a leader in supplying essential inputs for advanced technologies.

31 https://drive.google.com/file/d/11Y9VV8T7k6PKwpSjPUui0iElSnMt4LtP/view

The following criteria can be considered essential for the realization of a country's mineral vocation:

i. Knowledge of the potential of mineral reserves through geological mapping and mineral exploration;

ii. Existence of infrastructure for mineral extraction, such as access roads, energy supply, water, and storage areas;

iii. Machinery and corresponding maintenance;

iv. Downstream production processes;

v. Importing countries of semi-finished and finished goods.

2.2 Infrastructure

The mining industry has distinct infrastructure requirements depending on the type of ore, mining methods (surface or underground), and stages of mineral processing and beneficiation. In general, infrastructure is highly dependent on the location of mineral reserves, the project maturity stage (greenfield or brownfield), mine size, and ore complexity—these are key aspects for defining the respective extraction techniques, machinery used, and workforce. Similarly, the product resulting from ore extraction will guide the applied mineral processing methods, as well as the requirements for storage, transport, and production. Infrastructure also includes the availability of water and energy required for extraction and mineral processing.

Unlike most economic activities, mining has high locational rigidity, meaning it can only be performed in specific areas where deposits occur. Additionally, many mining projects, including in Brazil, tend to be located in remote areas, resulting in larger-scale, more complex infrastructure demands with higher costs. It is estimated that 60–80% of the costs related to a mining project derive from infrastructure installation (World Economic Forum 2014[32]). In this context, there is also increasing pressure from local stakeholders to ensure that the benefits of installed infrastructure are shared with the community and not restricted solely to mining operations, where companies are owners, operators, and have exclusive access.

It is also important to emphasize that the development of infrastructure is not only critical for the operations of the mining industry but is also a fundamental area within public policy, as it plays a crucial role in regional and national socioeconomic development, of which mining is part.

32 https://www3.weforum.org/docs/WEF_MM_NewModelsInfrastructureInvestment_ScopingPaper_2014.pdf

The process of granting mining titles, from exploration to mine commissioning, currently takes an average of 10 years, thus preventing mineral production in the short and medium term. To address this, the National Mining Agency (ANM) developed mechanisms to streamline environmental licensing and title granting.

For example, through ANM Resolution No. 37 of 2020[33], a **Usage Guide (GU)** is issued, which exceptionally authorizes mineral extraction in a titled area prior to the granting of a mining concession. The exception aims to enable:

I. Assessment of the technical-economic feasibility of mining mineral substances for the national and/or international market;

II. Extraction of mineral substances for analysis and industrial testing prior to granting a mining concession; and

III. Commercialization of mineral substances, at the discretion of ANM, in accordance with public policies, prior to granting a mining concession.

Another ANM initiative is the establishment of partnerships. Cooperation agreements with SERPRO and ABDI have enabled improvements and digitization of processes, thereby providing greater reliability and speed in processing. The Destrava Brasil program[34], aimed at reducing costs by increasing the efficiency of internal regulatory agency processes, facilitated cooperation between ANM and ABDI through workshops, training, and actions for normative and administrative modernization, as well as automated analysis of smart projects. Currently, ANM's database is managed by SERPRO[35]. Process digitization initiatives in the mineral sector are increasingly being incorporated by private companies, as exemplified by CSN Cataguazes and Vale[36].

The effective capacity of installed infrastructure, including land and/or river transport systems, logistics, energy supply networks, and water management, is vital for the economic viability of mining projects, making them more efficient, with lower costs and risks, and greater socioeconomic and environmental sustainability.

33 https://www.in.gov.br/en/web/dou/-/resolucao-n-37-de-4-de-junho-de-2020-260629588

34 https://www.abdi.com.br/destrava-Brazil-abdi-e-anm-concluem-treinamento-para-mapear-processos-da-agencia-de-mineracao/

35 https://www.serpro.gov.br/menu/noticias/noticias-2024/plataforma-gestao-recursos-minerais

36 Artificial Intelligence Models and Applications in the Mineral Sector. Quartas no CETEM. https://www.youtube.com/watch?v=8cL5orMd5QE&t=38s

The expansion and modernization of infrastructure in Brazil's mining districts is a strategic issue. The main hubs of significant reserves and MCE production in Brazil are concentrated in the following mining districts:

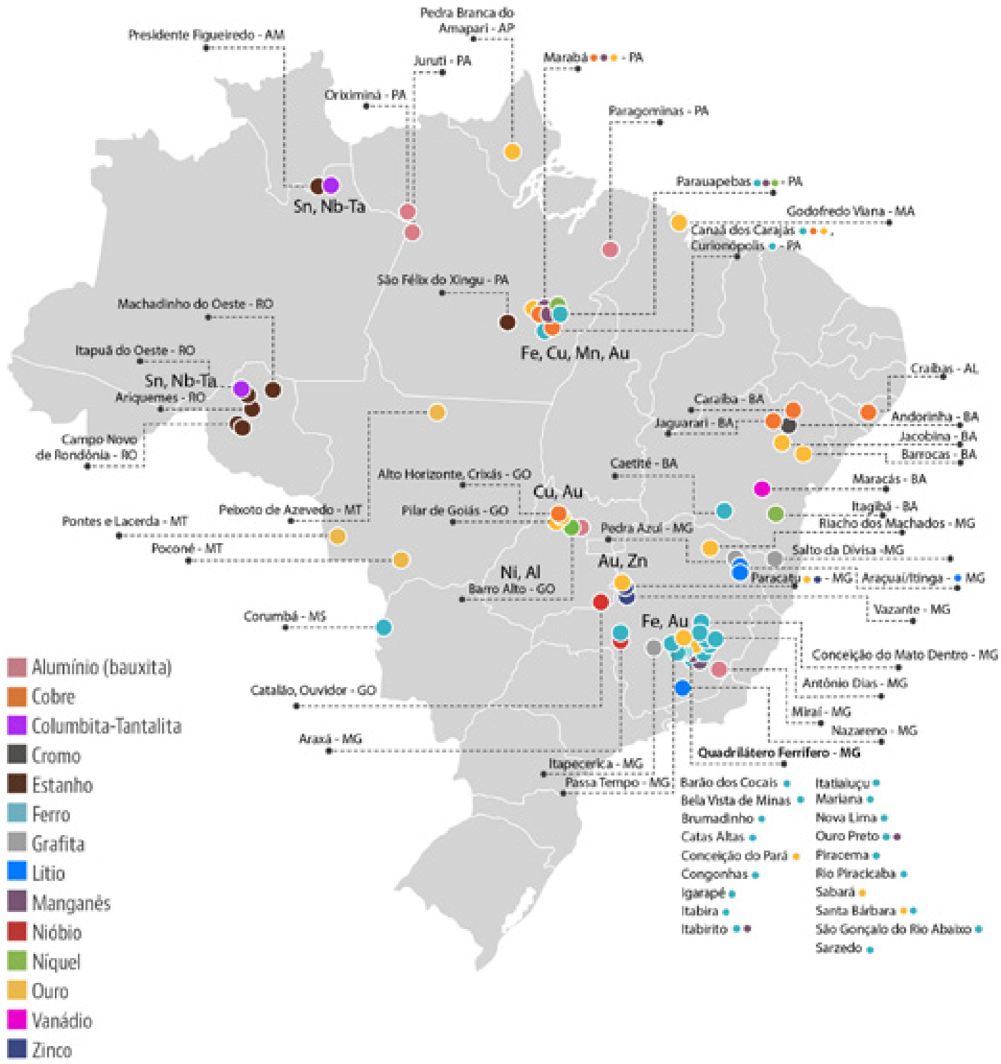
- **Minas Gerais** (Quadrilátero Ferrífero – Iron, Gold, manganese; Araxá – niobium; Vazante – Paracatu – Gold, Zinc and lead; Vale do Jequitinhonha – Lithium and Graphite);
- **Pará** (Carajás – Iron, Copper, Manganese, Gold and Nickel; Oriximiná, Parago-minas and Juruti– Aluminum; Tapajós – Gold);
- **Bahia** (Vale do Curaçá – Copper and Nickel; Rio Itapicuru and Jacobina – Gold, Maracás/Itagibá – Nickel and Titanium – vanadium; Mirabela – Palestina - Nickel);
- **Goiás** (Mara Rosa – Copper and Gold, Niquelândia – Nickel, Barro Alto – Nickel and Aluminum, Catalão – Phosphate; and Serra Dourada – Tin and terras raras);
- **Mato Grosso** (Juruena/Teles-Pires – Gold; Baixada Cuiabana and Alto Guaporé - Gold; Aripuanã – Zinc and Copper; Alto Jauru – Copper, Gold, chumbo and Zinc).

Rondônia stands out in tin (cassiterite) and manganese production, while Amazonas has significant tin and niobium–tantalum reserves. In these regions, the historical flow of mineral production for export from major mining districts and operating mines has relied on road, rail, and port networks. However, studies and events have demonstrated that for Brazil—with around 10% of global MCE reserves and potential for medium- and long-term production growth—to become a key player in the global supply chain of these mineral commodities, the expansion and modernization of infrastructure and logistics in these regions is required (Deloitte, 2025)[37] (Figure 11).

This action, which partially depends on public sector investments, involves not only the expansion of transportation routes for mineral production but also the generation and transmission of electricity, road transport electrification, 5G internet infrastructure, airports, and workforce supply centers such as SENAI and CEFET, among others. These measures are expected to promote economic growth and enhance Brazil's competitiveness in the international mining sector, maximizing benefits from mineral and resource exports, while also attracting new business and international partnerships.

37 Critical Minerals of the Future and Brazil's Strategic Role in the Transition to a Low-Carbon Economy. Deloitte, 2025: https://www.deloitte.com/content/dam/assets-zone4/br/pt/docs/industries/energy-resources-industrials/2025/Deloitte-minerais-criticos-2025.pdf

Figure 11: Location of Brazil's main metallic mineral reserves in 2022, including the MCEs selected in this study. Source: ANM 2023[38].



There are already signs of government initiatives planned to revitalize the infrastructure sector, thereby enhancing the competitiveness of the mineral industry. Notably, the National Railway Plan, with a projected investment of BRL 100 billion, aims to grant five major railway projects to the private sector. Among them:

- **East-West Corridor**
  Approximately 2,400 kilometers in length, it connects the West-East Integration Railway (FIOL) and the Center-West Integration Railway (FICO). FIOL starts in Ilhéus (BA), with one section already granted and another under construction as a public work. The third section is still pending. FICO is being executed by Vale as

38 https://www.gov.br/anm/pt-br/assuntos/economia-mineral/publicacoes/anuario-mineral/anuario-mineral-Brasileiro/amb_2023.pdf

part of the counterpart to the extension of its contracts in the sector and will later be extended to Lucas do Rio Verde (MT).

- **North-South Railway Extension**
  With 477 kilometers in length, it currently terminates in Açailândia (MA), where it connects with the Carajás Railway (EFC), owned by Vale. However, the EFC is primarily used for ore transport and has limited capacity for grain transportation. The railway will be extended to the port of Vila do Conde (PA), creating an alternative logistics route.

- **Southeast Railway Ring**
  With a layout of approximately 300 kilometers, it will connect Vitória (ES) to Itaboraí (RJ). This will allow the Vitória-Minas Railway network (EFVM), owned by Vale, to be linked to the network operated by MRS Logística.

- **Transnordestina**
  Originally promised in 2010 but halted for years, it is now scheduled for delivery in 2026 or 2027. Under the plan, the government will commit to granting its connection with the North-South Railway in Estreito (MA), adding 600 kilometers of track.

- **Ferrogrão**
  Spanning 933 kilometers between Sinop (MT) and Itaituba (PA), this is the most challenging project, with significant environmental and engineering risks. The progress of Ferrogrão currently depends on reconciliation in the Supreme Federal Court (STF), which was engaged due to potential impacts on conservation units.

Mining projects that require complex infrastructure to commence operations carry a high-risk profile, as the opening of the mine and extraction-related revenue are dependent on the completion and support of the implemented infrastructure. If infrastructure projects encounter obstacles, the mine may not be economically viable. Conversely, if the infrastructure is available but the mine is not ready for operation, the infrastructure asset will lack a market. Even with operational mines and available infrastructure, economic viability remains dependent on the commodity price volatility, unlike conventional infrastructure investments (e.g., electricity, communications) where revenue is derived from the infrastructure operation itself.

Investments in infrastructure, such as expanding distribution lines, self-generation of energy, construction of access roads, or storage facilities, can enhance competitiveness and justify investments in vertical integration of the production chain. With the goal of promoting decarbonization of the production process, Hydro's Alunorte facility[39] has planned a 531 MW solar plant to supply energy for alumina processing, which has been operational in Rio Grande do Norte since 2024..

39 https://Brazilmineral.com.br/noticias/projeto-de-usina-solar-fornecera-energia-para-alunorte

Considering Brazil's continental dimensions and the heterogeneity of mineral resources dispersed across different regions, there is a clear contrast between areas with high concentrations of critical and strategic minerals (CSMs) and areas that require significant infrastructure investment to ensure economic viability and the implementation of research, extraction, and mineral processing projects. This highlights public and private planning challenges to enhance stakeholder integration and promote efficiency and sustainability in the development of Brazil's CSM production (IBRAM, 2024; CSIS, 2021).

It is not only the production of specific minerals with special properties that is critical to advancing renewable energy adoption, but also the establishment of ethical principles and an adequate regulatory framework, enabling commitment to integration actions among governments, companies, universities, and research centers (Instituto Igarapé, 2023).

2.3 Food Security

Brazil occupies a prominent position in the global agricultural landscape, ranking as the fourth-largest grain producer and the second-largest grain exporter, potentially reaching 5% of GDP[40] in 2025, while mining accounted for approximately 3.5% of GDP in 2019[41].

The National Fertilizer and Plant Nutrition Council (CONFERT), established to formulate and implement sector policies, plays a key role in developing Brazil's fertilizer production chain. By promoting coordination among government entities, private sector, and the scientific community, CONFERT aims to reduce external dependence while fostering domestic production and technological innovation (Brazil, 2022) [Decree No. 10,991, 2022].

The development of the National Fertilizer Plan (PNF), among other responsibilities, seeks to estimate the adequate supply of inputs required by Brazilian agribusiness, ensuring greater security and competitiveness in food production.

According to the United States Department of Agriculture (USDA, 2025), presented in Table 2, Brazil accounts for 7.6% of the world's cultivated area (equivalent to 148.6 million hectares) and is responsible for 6.8% of global production of key crops, totaling 330.3 million metric tons.

40 https://www.cnaBrazil.org.br/noticias/cna-preve-crescimento-do-pib-do-agronegocio-em-2025-mas--cenarios-externo-e-interno-sao-desafiadores-para-o-setor

41 https://repositorio.ipea.gov.br/bitstream/11058/12702/1/TD_2950_web.pdf

Table 5. Share of Brazilian Grain Production (2023/24) [x 10^6 t].

Produto	Brazil	Brazil (%)	World (%)
Wheat	8,1	2,5	1,1
Rice	7,2	2,2	1,4
Grains (total)	140,1	42,4	5,0
Oilseeds	160,3	48,5	24,4
Cotton	14,6	4,4	12,9
Total (Brazil)	**330,3**	**-**	**6,8**

*Includes: cotton, barley, palm derivatives, canola, sunflower, peanut, cottonseed, soy, oilseeds, rice, sorghum, rye, oats, corn, coarse grains, wheat. Source: USDA (2025)[42].

This high productivity, however, is directly linked to the demand for supplementation of essential nutrients such as potassium and phosphorus to ensure agricultural performance of Brazilian soils. Driven by this demand, Brazil ranks as the fourth-largest consumer of fertilizers worldwide, accounting for 10.4% of global consumption, as shown in Table 6.

Table 6. Consumo mundial e do Brazil de fertilizantes em 2021 (x 103 toneladas de nutrientes).

Nutrient	Brazil	Brazil (%)	World (x 10^3 t)	Brazil Share (%)
N	5.981	29,3%	109.167	5,5%
P_2O_5	6.567	32,2%	48.707	13,5%
K_2O	7.835	38,4%	38.395	20,4%
Total	**20.383**	**-**	**196.269**	**10,4%**

Source: ANDA (2024).

The development and validation of raw materials for fertilizers using domestically available sources can represent a significant contribution to the agromineral sector, provided they are combined with high efficiency in production systems.

42 USDA - US Department of Agricuture. World Agricultural Production. Foreign Agriculture Service. Washington: USDA, 2025. Available at: <https://apps.fas.usda.gov/psdonline/circulars/production.pdf>. Accessed on: 23 jul. 2025.

In a tropical environment, with regard to increased environmental sustainability, the national production of fertilizers adapted to the characteristics of Brazilian soils can: (i) mitigate erosive effects that compromise soil quality, and (ii) enable the reduction of greenhouse gas emissions (Brazil, 2021). In other words, the adoption of plant nutrition technologies suited to the Brazilian environment, using domestic inputs, has the potential to revolutionize Brazilian agribusiness by enabling fertilizer technologies that promote environmental sustainability and higher productivity per hectare cultivated.

Agrominerals have significant economic relevance in the contemporary geopolitical context, which is why they are defined by several countries as critical minerals for their economies and food security. According to Decree 10,657 of 2021, which defined strategic minerals for Brazil, fertilizers are categorized as strategic minerals because they are "minerals that the country depends on for large-scale imports and those for which demand is expected to increase." However, self-sufficiency in the production of inputs used in the agricultural sector is a strategic goal for the country, given Brazil's global leadership position in agriculture.

In Brazil, 14 types of fertilizers are classified and approved for use in four distinct formulations (powder, meal, granule, and liquid), with a wide range of nutrient content. Fertilizers are composed of macronutrients and micronutrients, commercially formulated with variable NPK ratios (nitrogen, phosphorus, potassium), with or without the addition of micronutrients and other intermediate chemical-organic nutrients (e.g., boron, chlorine, copper, sulfur, iron, manganese, molybdenum, zinc).

The essential inputs for the production of basic and final fertilizers depend on::

1. Organic and mineral natural resources;

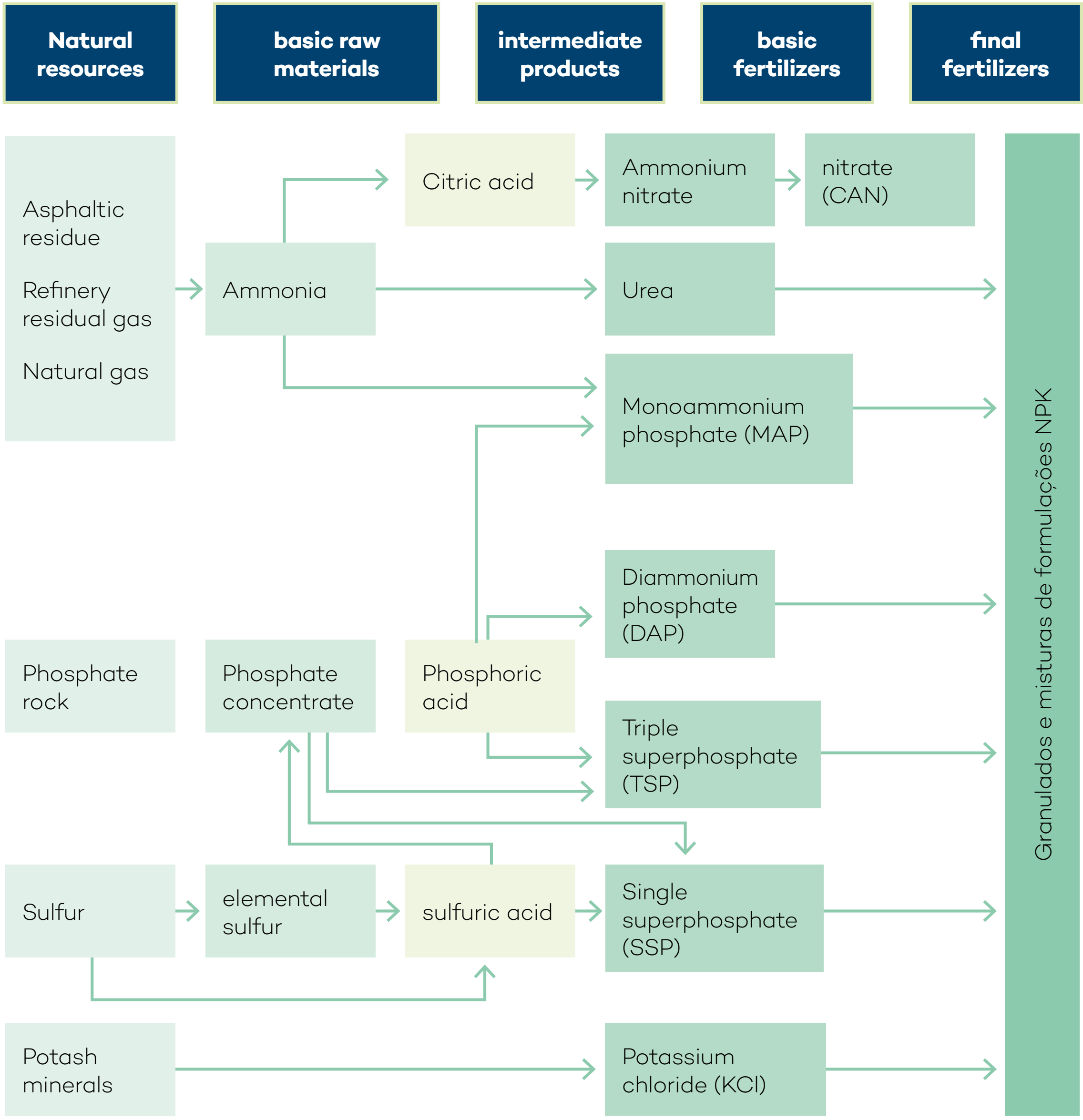
2. Industrial organo-chemical production of basic raw materials (ammonia, phosphate concentrate, sulfur); and

3. Intermediate products (nitric acid, phosphoric acid, sulfuric acid).

From these inputs and intermediates, basic fertilizers are produced (ammonium nitrate, urea, monoammonium phosphate – MAP, diammonium phosphate – DAP, triple superphosphate – TSP, single superphosphate – SSP, potassium chloride), which, when combined in different NPK formulations, with or without the addition of micronutrients, form the final fertilizers. This illustrates the intrinsic relationship between the mineral industry, chemical industry, and the demand for inputs derived from critical and strategic minerals.

The fertilizer production chain encompasses a wide range of sectors and economic activities that interact to support agricultural production, including the energy sector, chemical industry, mining, and oil and gas industries. The fertilizer production chain is schematically illustrated in Figure 12.

Figure 12: Schematic framework of the fertilizer production value chain



Source: Prepared based on Brasil (2021).

China is the world's leading producer of phosphate fertilizers, accounting for 38.6% of global output, followed by the United States (15.9%), Morocco (10.3%), and Russia (7%). However, according to the most recent available data, Russia is Brazil's main supplier of monoammonium phosphate (MAP), representing 47% of imports, followed by Morocco (30%) and the United States (4%). In 2023, Brazil imported 5.2 million tonnes of MAP, corresponding to 58% of the country's total phosphate fertilizer imports.

Brazilian phosphate fertilizer production by Mosaic amounts to approximately 3.4 million tonnes, of which 1.09 million tonnes are MAP, 467 thousand tonnes are triple superphosphate (TSP), and 1.2 million tonnes are single superphosphate (SSP), in addition to 696 thousand tonnes of other phosphate products. Overall, this domestic output enables a significant reduction in external dependence.

Domestic production is concentrated in a limited number of states, sourced from alkaline–carbonatite deposits (Minas Gerais: Tapira, Serra do Salitre, Araxá; Goiás: Catalão; São Paulo: Cajati, Registro; Bahia: Angico dos Dias) and sedimentary deposits (Minas Gerais: Arraias, Pratápolis; Mato Grosso do Sul: Bonito).

Mosaic Fertilizantes is the leading producer, with a 52% share, followed by CMOC (20%), Yara (11%), Itafós (5%), Galvani (4%), Mineração Curimbaba (3%), Grupo Scheffler (2%), EDEM (2%), and Mineração Morro Verde (1%). Despite considerable external dependence, Brazil presents strong potential for expanding phosphate production, with official reserves estimated at 5.2 billion tonnes (460 Mt of P_2O_5) associated with open-pit deposits. Current mineable reserves total 2.9 billion tonnes (317 Mt of contained P_2O_5, with an average grade of 10%). The sector comprises 4,331 active mining titles and 18 mines operated by 39 companies (CPRM, 2024; ANM, 2025).

The main sources of agricultural potassium are potassium chloride (KCl) and potassium sulfate (K_2SO_4). It should be noted that 90% of global potassium production derives from KCl, which is obtained through mineral extraction from potash rocks. Potassium sulfate, in turn, is an alternative nutrient source for chlorine-sensitive crops but depends on a chemical process combining KCl and sulfuric acid (H_2SO_4).

In 2023, Brazil imported 13.1 million tonnes of KCl, representing a 17.2% increase compared to the previous year. Canada and Russia were the main suppliers, accounting for 66.7% of imports, followed by Uzbekistan (8.9%), Israel (8.3%), and Belarus (8.3%). Regarding K_2SO_4, the main suppliers are Germany (67.3%), followed by Egypt (16.9%), China (5.2%), and Taiwan (3.8%). Between 2022 and 2023, K_2SO_4 imports totaled 39 thousand tonnes, a decrease of 27.9% compared to the previous period.

According to USGS data (2025), Brazil's estimated potassium reserves total 2.3 million tonnes, positioning the country as the world's 12th largest reserve holder. These reserves are concentrated in the states of Amazonas and Sergipe. However, due to the concentration of domestic production in Sergipe—outside the main transport corridors and far from high-demand regions—the country relies heavily on imports despite holding significant potassium reserves. Mosaic's operation in Sergipe has a production capacity of 501 thousand tonnes but produced only 363 thousand tonnes in 2023, below its potential, due to competition from external suppliers.

In the case of potassium, the continued expansion of agriculture points to an alarming import dependence that could reach 97%, placing Brazil in a position of economic vulnerability. To reverse this scenario, the long-term vision is clear: invest in the sustainable growth of domestic fertilizer production. This involves scaling up potassium chloride (KCl) production from evaporite deposits and expanding domestic potassium oxide (K_2O) production through the exploitation of silicate rocks and the recycling of residual mineral and organomineral sources, including rock powder application (rochagem) and remineralizers.

The Mercosur Common Nomenclature (NCM) for mineral remineralizers plays a crucial role in the development of Brazil's fertilizer value chain. Although diverse and linked to multiple productive sectors, proper classification directly affects taxation, regulatory oversight, and standardization of these strategic inputs for sustainable agriculture. Correct fiscal classification under the NCM not only facilitates trade and logistics but also fosters research and innovation by defining the regulatory scope and encouraging domestic production of alternatives to conventional fertilizers.

Consistent investment across the domestic fertilizer value chain is essential to reduce external dependence and add value to Brazilian agribusiness, enabling lower production costs and the adoption of more environmentally sustainable fertilizers adapted to tropical soils and climates. In the Brazilian context, the main challenge faced by companies is shortening the distances between input-producing regions, processing industries, and agro-industrial producers. In this regard, it is necessary to identify the main domestic producers of NPK compounds and micronutrients, whether or not they are incorporated into final fertilizers.

From a strategic perspective, Brazil's phosphate and potash fertilizer value chains are located relatively close to the Cerrado region, which coincides with the country's agricultural frontier expansion area. This indicates that integrating phosphate, potash, and nitrogen production hubs represents a clear opportunity for expansion and consolidation of the national fertilizer value chain.

The success of this effort requires coordinated action by both the public and private sectors. Currently, three projects stand out in the national landscape: (i) the Autazes Project, developed by Potássio do Brasil in Autazes (Amazonas), with potential annual production of 2.2 Mt of KCl; (ii) the South Atlantic Potash Project in the state of Sergipe, which, although still in the exploration phase, encompasses a large area with potential for KCl and NaCl extraction; and (iii) the Mosaic Fertilizantes project in Rosário do Catete (Sergipe), which exploits carnallite with an annual capacity of up to 500 thousand tonnes.

One particularly promising strategy for addressing the challenge of effectively utilizing Brazil's potassium reserves is the operation of Potássio do Brasil's plant in

Autazes, Amazonas. The project aims to supply 18% of Brazil's potash fertilizer consumption, with the potential to reach a 35–50% share of domestic consumption by 2050. Key advantages of the Autazes Project for Brazilian agribusiness include lower-cost fertilizer delivery and improved logistics, given its strategic location within the country's agricultural expansion frontier. The project is expected to scale up production and overcome logistical and financial challenges related to the need for high working capital for imports, which are typically made up to 100 days before actual use.

In addition, waste recovery and recycling—practices well established in other countries but still incipient in Brazil—represent a promising alternative pathway. Public incentive policies, recycling programs, tax reductions for recycling companies, and attractive financing lines can significantly strengthen domestic production.

The federal government's strategy, through the Nova Indústria Brasil (NIB) plan/program and other initiatives, aims to strengthen domestic industry and boost agricultural productivity by reducing dependence on imported agromineral inputs. This approach has the potential to increase food production, enhance food security, and stabilize prices. The NIB will allocate BRL 300 billion to the sector by 2026, with 83% of these resources provided by BNDES.

The National Fertilizer Plan (PNF 2050) and the Studies for the National Mining Plan 2030 provide comprehensive diagnostics and proposals to strengthen the agromineral sector, addressing structural and industrial challenges through targeted actions aligned with strategic objectives. These initiatives define five strategic objectives, namely:

1. Modernize, reactivate, and expand existing fertilizer plants and projects in Brazil;

2. Improve the business environment in Brazil to attract investments into the fertilizer and plant nutrition value chain;

3. Promote competitive advantages in the domestic fertilizer production chain to improve supply to the Brazilian market.

4. Expand investments in R&D&I and in the development of Brazil's fertilizer and plant nutrition value chain;

5. Adapt infrastructure to enable the integration of logistics hubs and the viability of new ventures.

These objectives set out in the PNF 4 highlight that food security and mineral security are interdependent.

It is important to emphasize that Brazil holds a price-taker position in global markets for several products and intermediate inputs that are vital to agribusiness. Therefore, within the agroindustrial sector, the country must:

i. map companies engaged in the extraction of minerals and inputs for NPK fertilizers, both those already operating and those in the structuring phase;

ii. promote credit and investment initiatives in infrastructure and logistics to ensure the flow of production to target consumers;

iii. prioritize the assessment of applied mineral research projects related to NPK; and

iv. invest in value-chain densification and technological innovation within the sector.

Although fertilizers are subject to tariffs in many countries due to their potential environmental impacts, they benefit from tax incentives for imports in Brazil[43]. CONFAZ Agreement No. 100, established in 1997, reduced the incidence of ICMS on agricultural products, including fertilizers.

43 https://www.ipea.gov.br/cts/pt/central-de-conteudo/artigos/artigos/309-politica-tributaria-e-incentivo--a-tecnologias-sustentaveis-o-Brazil-na-contramao

This agreement was extended through December 2026[44], representing one of the factors affecting domestic mineral production for fertilizer manufacturing. This extension introduced a clause aimed at equalizing the tax burden between imported and domestically produced products. It is important to emphasize that maintaining this tariff equalization mechanism is essential to improve the competitiveness of domestically produced fertilizers vis-à-vis imported products[45].

2.3.1 External and internal geopolitical aspects of agrominerals

There is evidence highlighting the relevance of NPK fertilizers to the global food security–related market, such as long-term demand—driven by population growth and soil nutrient depletion—and supply concentration among a limited number of suppliers, which is subject to high price volatility, as illustrated by conflicts such as Russia–Ukraine and United States–China, among others.

With respect to external dependence, Brazil is a net importer of NPK fertilizers with growing demand, given that the country is the world's largest net exporter of agricultural products and food, and holds the largest endowment of arable land, freshwater resources, and agroindustrial production capacity.

To meet global and domestic food demand under a sustainable agricultural production paradigm, Brazil requires: (i) a more favorable business environment; (ii) substantial investment in science, technology, and innovation adapted to tropical conditions; and (iii) investments in logistics and infrastructure to enhance efficiency in the mineral input production chain.

Regarding the global fertilizer market, according to GlobalFert Outlook data[46], based on the period analyzed, China, India, the United States, and Brazil account for 58% of global fertilizer consumption. Within this ranking, China stands out as the leading consumer of nitrogen, phosphorus, and potassium, accounting for 24% of total global fertilizer production.

The current state of the art of the main countries responsible for global fertilizer production and consumption in 2024 is illustrated in Figure 13, which highlights India's rise relative to the United States. In the previously analyzed period, the United States occupied India's current position, while India has emerged as the world's second-largest producer of phosphorus and third-largest producer of nitrogen. The supply of agromineral inputs places countries in a position of vulnerability within the contemporary geopolitical landscape. Indeed, the composition of fertilizers imported by Brazil underscores the critical importance to the agricultural sector of supplies originating from China, Morocco, Canada, and Russia.

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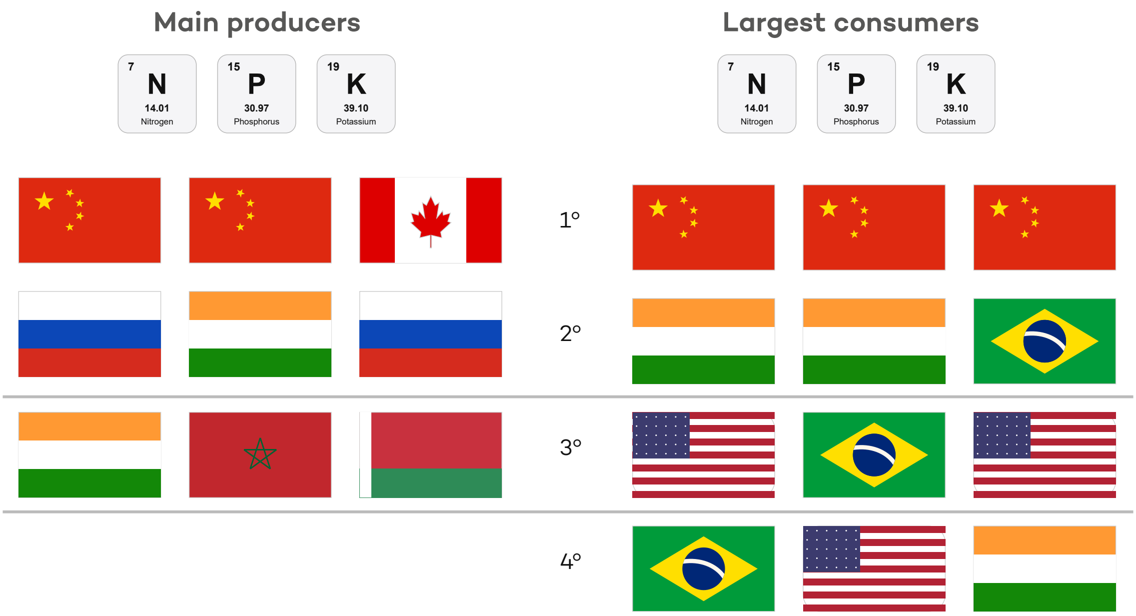
44 https://abag.com.br/convenio-de-icms-e-renovado/#:~:text=O%20Conv%C3%AAnio%20ICMS%20100%2F1997,do%20Estado%20de%20S%C3%A3o%20Paulo.

45 Extension of CONFAZ Agreement No. 100 through December 2026.

46 GlobalFert Outlook.

Figure 13: Major fertilizer-producing countries and largest consumers in 2024.



Source: Prepared based on GlobalFert (2024)[47].

National agricultural production ensures food security for the Brazilian population and constitutes a source of employment and income for Brazilian agriculture both in the present and in the future, when the sector may become a driver of opportunity generation through the expansion of mineral production associated with the domestic fertilizer industry. However, Brazil's current context is characterized by a high level of dependence on external sources of fertilizer supply, as approximately 80% of domestic consumption is imported.

The efficiency of agromineral production depends on incentives for mineral exploration and the production of essential raw materials, which in turn require an industrial logistics structure capable of fostering value chain development, from production to demand centers. To achieve the full potential efficiency of Brazilian agribusiness, strategic public policies are required to shield the country from instabilities in global supply, in light of the price volatility of agromineral inputs, while simultaneously remaining attractive to investors in this industry.

This strategy must be linked to the value chain as a whole and promote the adoption of agricultural practices suited to the characteristics of Brazilian soils. By encouraging the use of domestic technologies, such measures can not only ensure food security but also add value to Brazilian agribusiness by reducing production costs and promoting the use of environmentally sustainable fertilizers.

47 https://globalfert.com.br/outlook-globalfert-2024/

2.4 Defense and the aerospace sector

The escalation of tensions between the United States and China in the context of sanctions between the two countries[48] demonstrates that this dispute is not merely an economic issue, but rather involves the supply of critical raw materials—over which China holds significant control—while the United States dominates advanced technologies, particularly in the defense and aerospace sectors[49]. For Brazil, this geopolitical scenario opens a window of opportunity to position itself as a player in the global market for critical and strategic raw materials, while also promoting the densification of its industrial value chains.

Enhancing Brazil's military–industrial complex requires not only substantial investment in R&D&I, infrastructure, and logistics, but also secure access to critical and strategic minerals relevant to the sector. Critical and strategic minerals (CSMs) are closely linked to national defense, as they constitute essential inputs for the advancement of cutting-edge military technologies.

In this context, the national defense and aerospace sectors were incorporated into the federal government's Nova Indústria Brasil (NIB) plan, particularly under Mission 6, entitled "Strategic technologies for national sovereignty and defense." By allocating a budget of BRL 112.9 billion to the development of innovative technologies in this sector, the NIB establishes a strong commitment to strengthening the defense industrial base[50], prioritizing advanced technologies such as satellites, radar systems, and rocket launchers[51].

Looking toward 2050, CSMs are expected to be indispensable to the national defense sector, as these minerals underpin advances in military and aerospace technologies. Within this geopolitical context of competition for access to mineral resources and advanced technologies linked to the energy transition, holding reserves of CSMs becomes strategically relevant.

48 Maher, Kit; Liu, John. Trump invokes wartime powers to increase production of critical minerals. CNN Business. New York: CNN, 21 mar. 2025. Available at: <https://edition.cnn.com/2025/03/21/business/trump-increase-production-critical-minerals-hnk-intl/index.html>. Accessed on:: 29 mar. 2025.

49 King & Spalding. Summary of Trump Administration Executive Orders on Critical Minerals. King & Spalding, 11 fev. 2025. Available at: <https://www.kslaw.com/news-and-insights/summary-of-trump-administration-executive--orders-on-critical-minerals>. Accessed on: 30 mar. 2025.

50 43 Planalto. One year of Nova Indústria Brasil (NIB) marked by the launch of Mission 6 targets and investments in the defense industry. Brasília: Planalto, February 12, 2025. Available at: <https://www.gov.br/planalto/pt-br/acompanhe-o-planalto/noticias/2025/02/um-ano-da-nova-industria-Brazil-nib-e-celebrado-com-lancamento-das-metas-da-missao-6-e-investimentos-na-industria-da-defesa>. Accessed on: 26 mar. 2025.

51 50 Agência GOV. Nova Indústria Brasil, one year on: Mission 6 allocates BRL 112.9 billion to defense technologies. Brasília: Agência GOV, February 12, 2025. Available at: <https://agenciagov.ebc.com.br/noticias/202502/nova-industria-Brazil-um-ano-missao-6-tem-r-112-bilhoes-para-tecnologia-de-defesa>. Accessed on: 25 mar. 2025.

In this regard, certain minerals stand out due to Brazil's competitive advantages and their association with aerospace applications[52]:

- **Rare earth elements (REEs):** used across a wide range of advanced technologies and aerospace electronic components.
- **Niobium:** essential for the development of high-strength metal alloys used in aircraft engines, airframes, and missiles.
- **Lithium:** used in the production of lightweight, high-performance batteries applied in unmanned aerial vehicles and satellites.
- **Silicon:** used in semiconductor manufacturing, integral to electronic systems such as navigation, communications, and flight control.
- **Platinum group metals:** applied in rocket engines and other space technologies, as well as electronic circuits.s.
- **Cobalt:** used in superalloys for jet engines and in high-performance batteries.

Thus, the industrialization of critical mineral resources not only strengthens national defense autonomy but also positions Brazil as a potential global player in frontier technologies. Brazil holds abundant mineral reserves, notably niobium—accounting for approximately 90% of global production—which is critical for metal alloys in the aerospace and defense sectors (SGB, 2025). Despite holding the world's third-largest rare earth reserves, which are essential for advanced technologies, Brazil's production remains incipient, with China as the leading global supplier.

In this context, a recent development is the issuance of Ordinance GM-MD No. 840 of February 14, 2025, under the Nova Indústria Brasil program, which defines critical technologies for national defense with the objective of guiding research, development, and innovation planning within the Ministry of Defense and the Armed Forces[53]. According to the ordinance, the list of critical technologies for the defense sector will be updated every four years under the responsibility of the Secretariat for Defense Products of the Ministry of Defense. These technologies are designated as critical due to their application in strategic projects for the current and future development of defense systems. The ordinance identified the following technological areas, as presented in Table 7.
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52 Deloitte. Enhancing Critical Mineral Supply Chain Resilience for Aerospace and Defense. James Williams & Julia Arkell (Orgs.). London: Deloitte, 2023. Available at: <https://www.deloitte.com/global/en/Industries/energy/blogs/enhancing-critical-minerals-supply-chain-resilience-for-aerospace-and-defense.html>. Accessed on: 8 abr. 2025.

53 52 **Brazil. Ministry of Defense. Ordinance GM-MD No. 840, of February 14, 2025.** Available at: <https://www.in.gov.br/en/web/dou/-/portaria-gm-md-n-840-de-14-de-fevereiro-de-2025-613426661>. Accessed on: 27 mar. 2025.

Table 7. Tecnologias críticas para o setor de defesa e para a soberania nacional.

Critical technology	Technology specificity	Relevant technological area*
Batteries	High-capacity and high-efficiency batteries. Energy storage devices and rapid energy release systems.	Energy storage
Biodefense	Application of biotechnology for the identification of pathogens and other biological threats.	Biotecnologia
Multispectral camouflage	Development of accessories or coatings with low-detectability properties.	Advanced materials
Hypersonic combustion	Processes related to combustion in air-breathing engines operating in hypersonic regimes.	Hypersonics
Post-quantum cryptography	Post-quantum cryptographic algorithms.	Cryptography
Cyber defense	Handling of cyber anomalies. Cyber semantics. Cybersecurity of cyber-physical systems.	Cyber defense
Decontamination and treatment of chemical, biological, and nuclear agents	Protective equipment, decontamination systems and agents, and antidotes to mitigate the effects of chemical, biological, and nuclear attacks or incidents.	Biological, Nuclear, Chemical and Radiological Defense (BNCRD)
Detection and identification of chemical, biological, and nuclear agents	Advanced sensors, environmental monitoring systems, and protective equipment to detect and mitigate chemical, biological, and nuclear threats.	Biological, Nuclear, Chemical and Radiological Defense (BNCRD)
Detection of stealth objects	Radars for low-observable (stealth) object detection, designed to identify stealth aircraft or vehicles.	High-sensitivity radars
Nuclear fuel cycle mastery	Industrial process for the production of uranium hexafluoride and the fabrication of fuel elements.	Nuclear reactors

Critical technology	Technology specificity	Relevant technological area*
Guidance and navigation at high speed	Guidance and navigation for hypersonic and aerospace systems.	Guidance, control, and navigation
Additive manufacturing	Use of metamaterials in additive manufacturing.	Advanced manufacturing
Structural composite materials	Production and applications of carbon fiber and lignin fiber.	Advanced materials
Refractory materials	Materials capable of withstanding extremely high temperatures. Ceramic materials, metamaterials, and special alloys for aerospace applications.	Advanced materials
Underwater acoustic monitoring	Advanced technologies for underwater detection.	Sensors
Nanotechnology	Nanostructured materials for structural applications.	Nanotechnology
Optical processing	Optical processors.	Photonics
Propellants	Production of inputs compliant with military specifications and development of high-performance solid propellants with reduced sensitivity.	High energy-density materials
Space propulsion	Liquid and hybrid rocket engines.	Space propulsion systems
Ballistic protection	Ballistic and anti-mine protection systems. New metal alloys.	Advanced materials
Quantum technologies	Secure quantum communications and quantum sensors.	Quantum
Pressurized water nuclear reactor	Nuclear power reactors and nuclear fuel.	Nuclear reactors
Underwater acoustic networks	Advanced technologies for tactical data transfer.	Communications

Critical technology	Technology specificity	Relevant technological area*
Heat removal in hypersonic regimes	Heat removal from critical systems operating under hypersonic conditions.	Hypersonics
High-precision active and passive sensors	Multispectral vision, monitoring, and underwater detection.	Sensors
Energy pulse systems	High-energy generators (microwaves or lasers) enabling the future development of systems capable of producing damage to aerial, terrestrial, or naval targets.	Directed energy
Space systems	Launch systems and space monitoring systems.	Space systems
Computer vision	Image and pattern recognition. Large-scale data analytics.	Artificial intelligence

Source: Ordinance GM-MD No. 1,112 of March 4, 2024,
ratified by Ordinance GM-MD No. 840 of February 14, 2025.

The data highlight the opportunity for national development arising from the technological maturity of Brazil's industrial base, contributing to the autonomy of the national production system beyond the defense sector alone. There is a clear mobilization of public and private resources to strengthen high-technology value chains, such as the production of satellites, launch vehicles, and radar systems—technologies in which Brazil has demonstrated development potential and increasing competitiveness of its domestic industrial chain in international trade.

Uranium is the primary input for nuclear energy, which represents an important source of clean and sustainable energy. Brazil holds the world's eighth-largest uranium reserves and is among the few countries that have mastered enrichment technology for peaceful purposes. However, the country is currently able to mine only 40% of the uranium required to supply Angra 1 (640 MW)[54] and approximately 50% of total domestic demand.

54 Rodrigues, Robson. Uranium extraction attracts private investors and may make Brazil self-sufficient. Valor Econômico. Rio de Janeiro: Globo, January 23, 2025. Available at: < https://valor.globo.com/empresas/noticia/2025/01/23/extracao-de-uranio-atrai-investidor-privado-e-pode-tornar-o-Brazil-autossuficiente.ghtml >. Accessed on: April 28, 2025.

Uranium mining activity in Brazil was exclusively government-controlled until the Senate approved Provisional Measure No. 1,133/2022, which was converted into Law No. 14,514/2022[55], This legal framework allowed private investment in the extraction of nuclear minerals in Brazil. Under this new regulatory regime, the sector began to foresee the entry of new companies into an activity that had previously been exclusive to Indústrias Nucleares do Brasil (INB). The relaxation of the monopoly and the possibility of partnerships with INB encouraged private companies to invest in uranium extraction in the country. Indeed, this represents an opportunity to intensify uranium exploitation and move toward national self-sufficiency, while also stimulating sectoral dynamism and providing greater legal certainty not only for the electricity sector, but also for defense, healthcare, and agriculture.

2.4.1 The interface of CSMs with military defense technologies in the current geopolitical landscape

As a paradigm adopted by many nations, the challenges to be overcome in order to ensure a stable supply of critical minerals are widely recognized. Two relevant strategies stand out: the United States policy *Strategy to Ensure Secure and Reliable Supplies of Critical Minerals*[56] which seeks to identify priority actions to reduce economic vulnerability related to mineral input supply; and the European Union's *Raw Materials Initiative*[57], which aims to identify priority actions to mitigate vulnerabilities associated with the supply of mineral inputs deemed strategic.

Strategic sectors such as the military industry, semiconductor manufacturing, and renewable energy generation are particularly sensitive to this competitive environment, given the inherent difficulty of securing critical minerals in the short term.

In this context, investment in advanced technologies to enhance the maturity of Brazilian research and innovation constitutes a strategic vector for integrating Brazil's vast mineral potential into CSM industrial value chains and for disseminating science, technology, and innovation (ST&I) initiatives within the military–industrial sector. This movement strengthens national sovereignty and expands development opportunities across multiple areas. The industrialization of critical minerals not only consolidates the country's defensive autonomy but also positions Brazil as a relevant actor in the global landscape of advanced technologies.

In parallel, industrialized countries have been pursuing new alternatives to diversify mineral sources, including investments in domestic mining and partnerships with resource-rich countries such as Canada, Australia, and Brazil.

55 Planalto. Medida Provisória Nº 1.133, de 12 de agosto de 2022. Available at:<https://www.planalto.gov.br/ccivil_03/_ato2019-2022/2022/Mpv/mpv1133.htm>. Accessed on: April 28, 2025

56 USDC – United States Department of Commerce. A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals. Washington: USDC, 2020. Available at: <https://www.commerce.gov/sites/default/files/2020-01/Critical_Minerals_Strategy_Final.pdf>. Accessed on: April 30, 2025.

57 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52008DC0699

As such, Brazil faces a historic opportunity to leverage its economy and establish a leadership position in the production and refining of critical minerals for advanced technologies essential to the energy transition. The definition of a robust strategic planning framework and an effective political–regulatory architecture will enable the attraction of investments and value-added initiatives along mineral value chains, allowing for the expansion of the industrial infrastructure required for the development of advanced technologies more broadly, and not solely for defense applications.

Embraer is a global aerospace company headquartered in Brazil that manufactures aircraft for commercial, executive, agricultural aviation, as well as defense and security. The company has strategically invested in Innovation & Technology (I&T) and Research and Development (R&D). Embraer has delivered more than 8,000 aircraft and is Brazil's leading exporter of high value-added goods. The company has announced investments in several areas: (i) USD 3.5 billion through 2030, focused on aerospace innovation; (ii) BRL 20 billion through 2030, aimed at strengthening its market position with a focus on innovation and sustainability; and (iii) investments in startups to accelerate the development of emerging technologies[58].

Embraer's aircraft manufacturing depends on a wide range of metals and alloys (aluminum, titanium, alloy steels, and superalloys) as well as high-technology components (Table 8), many of which require minerals classified as critical and strategic for the aerospace industry, as their supply may be exposed to risks arising from geopolitical factors, scarcity, or other constraints.

Table 8. Aircraft Components and CSMs

Component	Mineral requirements
Engines	Superalloys (cobalt, nickel, and others) to withstand high temperatures and pressures
Structures	Aluminum and titanium (predominant), advanced alloys (other elements) to enhance performance
Electronics and Avionics	Rare earth elements, germanium, and other minerals for communication, navigation, and control systems
Landing Gear Systems	High-strength steels and other alloys to support aircraft weight during takeoff and landing

Source: Embraer (2022)[59].

58 MPA – Ministry of Ports and Airports. Federal Government and Embraer announce BRL 20 billion in investments in Brazil through 2030. Brasília: MPA, February 12, 2025.: <https://www.gov.br/portos-e-aeroportos/pt-br/assuntos/noticias/2025/02/governo-federal-e-embraer-anunciam-r-20-bilhoes-em-investimentos-no-Brazil-ate-2030>. Accessed on: April 30, 2025

59 EMBRAER – Empresa Brasileira de Aeronáutica S/A. Annual Report 2022 – ESG. São José dos Campos: Embraer, 2022. < https://esg.embraer.com/br/pt/assets/Embraer-Relatorio-Anual-de-Sustentabilidade-2022.pdf >. Accessed on: April 29, 2025

The integration of Brazil's vast mineral potential into the scope of industrial value chains associated with CSMs has, at its interface with the military–industrial sector, a strategic vector for the dissemination of STI initiatives that contribute to strengthening national sovereignty. This, in turn, broadens the horizon of possibilities for sustainable industrial development that combines different national initiatives.

The aforementioned NIB program reflects a firm commitment to leveraging the development of cutting-edge Brazilian technologies. By allocating a significant budget of BRL 112.9 billion to Mission 6, linked to the national defense sector through 2030, a decisive step will be taken toward the formation of a broad techno-scientific knowledge network, as well as toward the establishment of productive and laboratory infrastructure that invariably contributes to the densification of CSM-related value chains, given their importance to the development of advanced technologies.

Among the specific actions defined in the NIB Action Plan are the construction of the Orion Complex – a maximum biological containment NB4 laboratory – and the Brazilian Multipurpose Nuclear Reactor (RMB). To this end, the plan establishes as a key objective the autonomy of value chains associated with critical defense technologies, particularly regarding the materials and inputs required for their development. With the substantial investment in the national defense sector, a window of opportunity is revealed for the expansion of the mineral value chain, which invariably enhances the competitive advantages of national industry and increases Brazil's level of sovereignty over its mineral resources.

Uranium ore

3. LEGAL AND REGULATORY APPROACH

3.1 Introduction

Brazil presents a robust legal and regulatory framework with regard to environmental aspects. Mineral regulation has undergone restructuring aimed at strengthening Brazilian Mineral Policy as applied to the environmental sector. The consolidation of the National Mining Plan, in its previous version (PNM 2030[60])), set out a future vision for the sector based on four probable scenarios, namely: (i) on the path to sustainability; (ii) uneven development; (iii) intermittent growth; and (iv) the threat of stagnation. Fourteen years after the publication of that document, it is evident that the country is currently experiencing a combination of the sustainability scenario and intermittent growth, as a result of the alignment of government strategies, investments primarily from private sources, and the ongoing improvement of environmental licensing mechanisms.

The National Mining Plan 2050 (PNM 2050[61])), submitted for public consultation in 2023 and not yet formally approved, builds an understanding regarding the definition of critical and strategic minerals, as well as the need to consider dynamic listings subject to periodic updates.

The text of the PNM 2050 was based on studies that addressed the following main topics:

1. Geological knowledge
2. Mineral exploration and production
3. Mineral value chains for the energy transition
4. Competitiveness of the Brazilian mining industry
5. Sustainable development of the Brazilian mining industry

60 https://www.gov.br/mme/pt-br/arquivos/pnm-2030.pdf

61 https://www.gov.br/mme/pt-br/assuntos/secretarias/geologia-mineracao-e-transformacao-mineral/pnm-2050

The studies were carried out by the Brazilian Geological Survey (SGB/CPRM), Fundação Gorceix, the Institute for Applied Economic Research (IPEA), and the consultancy Deloitte, in addition to independent consultants.

The articulation of these topics constitutes the primary guideline for the formulation of public policies and corporate strategies for the sector. It is important to note that the occurrence of large-scale accidents in Brumadinho (MG) and Mariana (MG) also prompted the restructuring of the regulatory framework related to environmental protection and societal response mechanisms. These normative instruments, together with the publication of the study Foundations for Public Policies on Critical and Strategic Minerals for Brazil, published in 2024[62], provided inputs for the proposal of Bill No. 2,780 of 2024[63] which establishes the National Policy on Critical and Strategic Minerals (PNMCE) and the Committee on Critical and Strategic Minerals (CMCE), the latter linked to the National Mining Policy Council.

Recent public policies such as the Ecological Transformation Plan (PTE), the New Growth Acceleration Program (Novo PAC), and the New Industry Brazil Plan (NIB) already signal a coordinated movement among regulatory, financial, and industrial instruments to consolidate the country as a priority destination for investments aimed at the decarbonization of the global economy (Figure 14). This positioning is supported by institutional stability, low geopolitical risk, mineral diversity, and the broad territorial distribution of clean energy sources.

Figure 14: Regulatory instruments of relevance to CSMs.

Brazilian Mineral Policy (MME)	• Decree No. 11,108/2022 • National Council for Mineral Policy (CNPM) • National Mining Plan 2030 (PNM 2030) and National Mining Plan 2050 (PNM 2050)
National Energy Transition Policy (MME)	• National Energy Transition Forum (FONTE) • National Energy Transition Plan (PLANTE)
National Policy on Climate Change (MME)	• Law No. 12,187 of 2009 • Decree No. 7,390 of 2010

The **National Inventory of Energy Resources**, as presented in the **EPE Technical Note within the scope of the National Energy Plan 2050**, demonstrates not only the consolidation of Brazil's renewable energy matrix, but also the abundant availability of

62 https://ibram.org.br/wp-content/uploads/2024/07/Fundamentos_para_politicas_publicas_em_minerais_criticos_e_estrategicos.pdf

63 https://www.camara.leg.br/proposicoesWeb/fichadetramitacao?idProposicao=2447259

resources that enables its continuous expansion in a sustainable manner and at comparatively lower costs.

These elements provide the country with a fundamental competitive advantage in attracting investments aimed at green industrialization and the production of energy-intensive goods from renewable sources.

In the specific context of critical and strategic minerals, the normative dimension becomes even more complex. Most countries tend to adopt public policies and strategic plans that minimize supply disruption risks in industrialized countries and/or leverage new business opportunities for producing countries, seeking to reduce external dependence and mitigate geopolitical and economic risks. At the same time, countries with geological potential, such as Brazil, see opportunities to integrate into global value chains, especially in sectors related to the energy transition, digital technologies, electric mobility, and energy storage. Consequently, new strategies emerge through the structuring of business models for a low-carbon economy with a circular approach.

Public policies for the mineral sector in Brazil are consolidated and primarily address the regulation of mineral exploration and mining, infrastructure, the regime for payment and application of royalties (CFEM), procedures for environmental licensing, as well as the prevention and mitigation of potential socio-environmental impacts. However, the changing dynamics of relations between mining and territorial stakeholders require updates and adaptations to regulatory systems to cover additional sustainability parameters.

In this scenario, new regulatory requirements arise that go beyond the mineral production axis and advance the structuring of integrated value chains, the promotion of local industrialization through the establishment of market-dependent factories or competitive supply options, the strengthening of research and innovation, demand development, and strategic international cooperation. Brazil, therefore, faces a window of opportunity to revisit its legal framework, aligning it with sustainable development objectives, climate commitments, and the growing global emphasis on supply chain resilience.

3.2 Strategic new alliances and international regulation

Industrialized countries that demand minerals and countries with mineral endowments often have different political objectives and commercial strategies. ESG-based regulations and cooperation agreements are more prevalent in developed producing economies and mineral-demanding countries, as they tie trade agreements to environmental criteria, requiring low-carbon mining practices. Resource-endowed countries, in turn, focus efforts on maximizing the economic benefits from their mineral resources and enabling project development financing.

To strengthen supply chain resilience, countries have intensified cooperation—both multilaterally and bilaterally—aimed at identifying strategic projects and deepening collaborative relationships.

Global perspectives, however, emerge in light of the resumption of tariff-related issues that could impact multilateral trade agreements and respective supply chains. The recent Chinese imposition of tariffs on critical minerals and restrictions on the export of magnets and essential metals, in response to unilateral U.S. government actions, heightens concerns about global scarcity and the trend for countries to diversify materials, invest in domestic mining, and partner with allied countries in bilateral agreements and even regional alliances, or friendshoring.

In this scenario, resource-endowed countries see regional alliances as a means to reduce vulnerability through technical cooperation and partnerships in attracting foreign investments.

The same scenario reinforces the storage systems (stockpiles) of mineral-demanding countries to ensure supply and protect the national economy under conditions of supply risk and commodity price fluctuations in international markets. This is not a recent demand. In 1939, the U.S. enacted the Strategic and Critical Materials Stock Piling Act, a federal law for acquiring and retaining stocks of certain strategic and critical materials important for national security. In 2021, the plan was expanded to include critical materials needed for the energy transition.

In Japan, the national rare metals stockpiling project was established in 1983 as a cooperation between government and private sector to ensure natural resource security and economic stability. In South Korea, the national critical mineral stock will be reinforced to 100 days from the current 54, and pre-feasibility studies for critical mineral bases will be launched. In emergencies, companies requiring specific resources will be supplied within an 8-day window through an agile distribution system to mitigate supply and demand shocks.

Public financing mechanisms are also employed to expand internal supply sources through state-owned companies, direct capital investment, or government procurement programs designed to guarantee a buyer for materials meeting specific criteria. Government programs can incentivize innovation and private sector capital to diversify and expand critical materials supply chains. Some examples include the United States' Inflation Reduction Act[64] (IRA), the European Union's Critical Raw Materials Act, and Japan's Economic Security Act. These frameworks aim to promote local or regional supply chains through tax credits, government investment, regulation, incentives for new mineral research projects, and strategic reserves.

A critical aspect of this new context is the diversification of supplier countries and bilateral and multilateral trade agreements, aimed at strengthening critical materials supply chains.

64 https://commodityinsights.spglobal.com/energy-transition-global-acquisition-ira-report.html?utm_campaign=q3_2023energytransitionglobalacquisitionadsirareport&utm_content=tax&gclid=CjwKCAjwgZCoBhBnEiwAz35RwlmFTxk-5wdELHVHSzozj32HCEfVbjPS5mku6h1KMp_ZkUd9MWMHFRoCc5sQAvD_BwE

Within the scope of the European Raw Materials Act, in July 2023, the EU and Japan signed the Administrative Arrangement on Cooperation in Critical Raw Materials Supply Chains[65], aiming to innovate supply chain risk management and advance topics of innovation, recycling, and circularity.

Other relevant agreements[66] on critical materials are part of the Minerals Security Partnership (MSP). Launched in June 2022, it remains under coordination of the U.S. Department of State and aims to stimulate government and private sector investments in partner countries—Australia, Canada, Finland, France, Germany, Japan, South Korea, Sweden, the United Kingdom, the European Union, and, more recently, India. Additionally, there is the Australia-India Cooperation Agreement on Critical Minerals Assets and Supply Chains, also from June 2022; and in March 2023, the U.S.-Japan Critical Minerals for Batteries Trade Agreement (lithium, nickel, cobalt, graphite, and manganese) to help the Japanese automotive and metallurgical sectors access the benefits of the U.S. Inflation Reduction Act (IRA). In 2025, the U.S. issued Executive Orders No. 14,154[67], a "fast-track" mechanism for domestic production, and No. 14,156[68], qdeclaring a national energy emergency, citing critical mineral scarcity as a direct threat to national economic security. Both reinforce the need to expand collaborative alliances with strategic partners and reference the Mineral Security Partnership (MSP) as a means to increase domestic production and mitigate geopolitical risks, although current MSP operations remain uncertain.

The geographical distribution and the pursuit of supply security are at the core of global natural resource disputes, resulting in social, environmental, and political conflicts. The deepening of regional chains and the establishment of new trade routes may deepen the divide between "Western" and "Asian" supply chains, limiting the effectiveness of global ESG standards. For these reasons, and because public policies in the mineral sector are strongly influenced by market demand, it is a priority to reinforce the need to safeguard sustainable development principles aligned with circular economy principles.

Geopolitical uncertainty and the search for technological solutions for a low-carbon economy have consolidated as challenging ingredients for structuring consistent regulatory instruments. The Global Atlas for Environmental Justice[69] reports that 45% of mining-related conflicts occur in Latin America, where activities requiring intensive water and land use occur near sensitive areas (diverse ecosystems and vulnerable communities), resulting in conflicts and generating challenges for organizations to obtain social licenses to operate.

65 https://single-market-economy.ec.europa.eu/news/enhancing-cooperation-japan-critical-raw-materials-supply-chains-through-new-administrative-2023-07-06_en

66 https://www.pwc.com/gx/en/issues/tla/content/PwC-Mine-Report-2023.pdf

67 https://www.whitehouse.gov/presidential-actions/2025/01/declaring-a-national-energy-emergency/

68 https://www.whitehouse.gov/presidential-actions/2025/01/unleashing-american-energy/

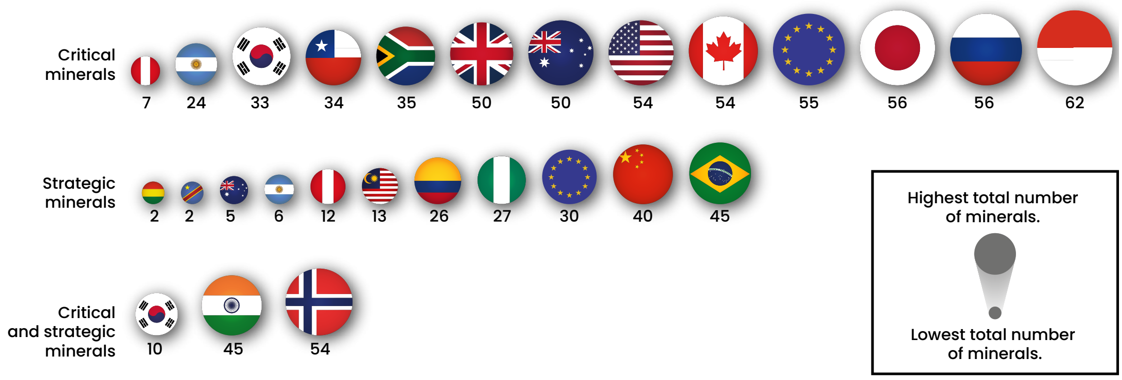
69 https://ejatlas.org/commodity&sa=D&source=docs&ust=1688912279408091&usg=AOvVaw0rAIT4AJ57lrXI3f-uxPr2

An expanded analysis of international regulations for defining and managing critical and strategic minerals, covering 21 countries plus the European Union, shows diversity in definitions for minerals and materials considered critical and strategic. Both listed minerals/materials and each of the 17 rare earth elements and 5 platinum group elements were accounted for (Figure 15).

Among the most recurrent minerals in the lists analyzed are lithium, nickel, cobalt, copper, graphite, manganese, and tungsten. Countries with the most extensive lists in terms of variety of minerals and materials include Indonesia (62), Russia (56), Japan (56), European Union (55), United States (54), Norway (54), and Canada (54). In August 2025, a new U.S. listing[70] was published, excluding iron, arsenic, and iron from the previous list. Lead, silicon, silver, rhenium, potassium, copper, and hafnium were included.

Figure 15 indicates the number of critical and strategic materials considered in each country's list.

Figure 15: Number of minerals by category (critical, strategic, critical and strategic) in countries with specific regulation.



The Inter-American Development Bank (IADB[71]) and the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF[72]) recognize that the current challenges for designing competitive mining models in Latin America lie in strengthening institutions, enhancing inter-jurisdictional and inter-ministerial coordination, articulating the role of municipalities, advancing the territorial development agenda, and creating new models of territorial participation and management that translate into tangible benefits for local economies and communities.

This recognition of the pursuit by territorial actors of sustainability, the guarantee of the conservation of natural resources, and the protection of social values and local culture are part of the objectives for sustainable development and have been incorporated into the regulatory framework and into the agenda of banks and financial agents.

70 https://www.usgs.gov/news/science-snippet/department-interior-releases-draft-2025-list-critical-minerals

71 https://publications.iadb.org/publications/spanish/document/Haciauna-nueva-vision-compartida-sobre-el--sector-extractivo-y-su-rol-en-el-desarrollo-sostenible-de-America-Latina-y-el-Caribe.pdf

72 https://www.igfmining.org/country-support/mining-policy-framework/

The procedures for environmental licensing and the granting of mining rights are the first frontier to curb irregular practices that are harmful to the environment. Likewise, authorization for mineral extraction is determinant for access to markets. In view of the challenge of reconciling multiple interests of the agents involved, there is little cooperation among the various bodies involved, bureaucracy, and the weakening of the competent authorities. The degree of complexity of the interaction among the agents and the harmonization of interests directly influence the time spent on the issuance of permits that precede licenses. And time is a factor of high impact on the decision for external investment.

In this way, the Licensing Regime[73] consists of a type of request that grants greater agility for the extraction of minerals employed in civil construction. Recent actions are therefore based on the modernization of the licensing process, preserving the reliability of the processes, such as the initiative of the Secretariat for the Environment and Sustainability (SEMAS-PA)[74] of the state of Pará and of the Secretariat for the Environment and Sustainable Development of Goiás (SEMAD-GO)[75]. The state of Pará promoted dialogue between government and companies, the integration of ESG agendas with the licensing process through initiatives such as the Amazon Now State Plan, the Sustainable Territories Program, Regulariza Pará, the Fisheries Management Program, the Forest Restoration Program, and the State Bioeconomy Program. An innovation implemented by the state of Goiás is the monitoring of post-environmental licenses, which aims at compliance with the established conditions, with inspections carried out in person or remotely, as well as the Ipê System[76], launched in 2020, which, based on a set of careful actions, allowed the reduction of the time for the issuance of licenses by up to 95.3% of the time.

An important initiative signed at the beginning of 2025 with the hiring of the company B3 by the ANM seeks the provision of specialized services for the evaluation and availability of mining areas through the digitalization of auctions, with the forecast of making approximately 105 thousand areas available in the next 5 years[77]. The first ANM availability notice with B3 is expected for the last quarter of 2025 and the contract between the institutions provides for the holding of 15 rounds[78].

The new challenges, as highlighted in the version released for public consultation at the Ministry of Mines and Energy (MME), are focused on how the country will address issues related to sustainability, the improvement of regulatory governance in the mining sector, the increase in investments in geological and mineral research, and the consolidation of value chains of minerals and metals that are strategic for the energy

73 https://www.planalto.gov.br/ccivil_03/_ato2019-2022/2020/lei/l13975.htm

74 https://www.semas.pa.gov.br/2025/03/12/para-se-destaca-em-conferencia-internacional-sobre-minerais-estrategicos-e-descarbonizacao/

75 https://goias.gov.br/meioambiente/categoria/meio-ambiente/licenciamento-ambiental/

76 https://goias.gov.br/sistema-ipe-chega-a-10-mil-licencas-emitidas/

77 https://valor.globo.com/empresas/noticia/2025/04/29/b3-firma-parceria-com-agncia-nacional-de-minerao--para-conduzir-leiles-de-reas-minerrias.ghtml

78 https://agenciainfra.com/blog/leilao-de-areas-minerais-exigira-garantia-para-afastar-aventureiros/

transition. With regard to the value chain, the promotion of competitiveness and private investments, in a broader manner, will be the drivers of the development of the mining industry in its different stages.

National progress regarding the mineral regulatory framework requires prior understanding of Brazilian industrial policy. Industrial policy is a set of strategies, instruments, and actions of the State aimed at the transformation and strengthening of the national productive structure. Its objective is to stimulate economic sectors considered strategic, through incentives for innovation, technological modernization, workforce training, international insertion, and sustainable development. Industrial policies may be vertical (focused on specific sectors) or horizontal (covering aspects such as infrastructure, credit, or technological training). And, in the context of critical and strategic minerals, industrial policy acts both in ensuring the supply of these essential inputs and in fostering industrial sectors that depend on them, such as renewable energy, electric mobility, semiconductors, defense, and agriculture.

In this way, Brazilian public policies aimed at industrial, energy, and technological development establish important connections, even if not always explicit.

At the federal level, the existing regulation is distributed across the following thematic areas: energy, transportation, structuring of the mining sector, and public policies, as set out below.

Table 9. Rnational regulation of sectors of interest to brazilian industry

ENERGY	
Law No. 9,993 of July 24, 2000	Allocates resources from the financial compensation for the use of water resources for the purpose of electric power generation and from the exploitation of mineral resources to the science and technology sector.
Resolution No. 2 of February 10, 2021	Establishes guidelines on research, development, and innovation in the energy sector in the country, prioritizing: (I) hydrogen; (II) nuclear energy; (III) biofuels; (IV) energy storage; (V) technologies for sustainable thermoelectric generation; (VI) digital transformation; and (VII) strategic minerals for the energy sector.
Law No. 14,300 of January 6, 2022	Institutes the legal framework for distributed microgeneration and minigeneration, the Electric Energy Compensation System (SCEE), and the Social Renewable Energy Program (PERS).
MME Resolution No. 4 of March 2023	Establishes the National Hydrogen Program, creates the Program Steering Committee, and provides for other measures.

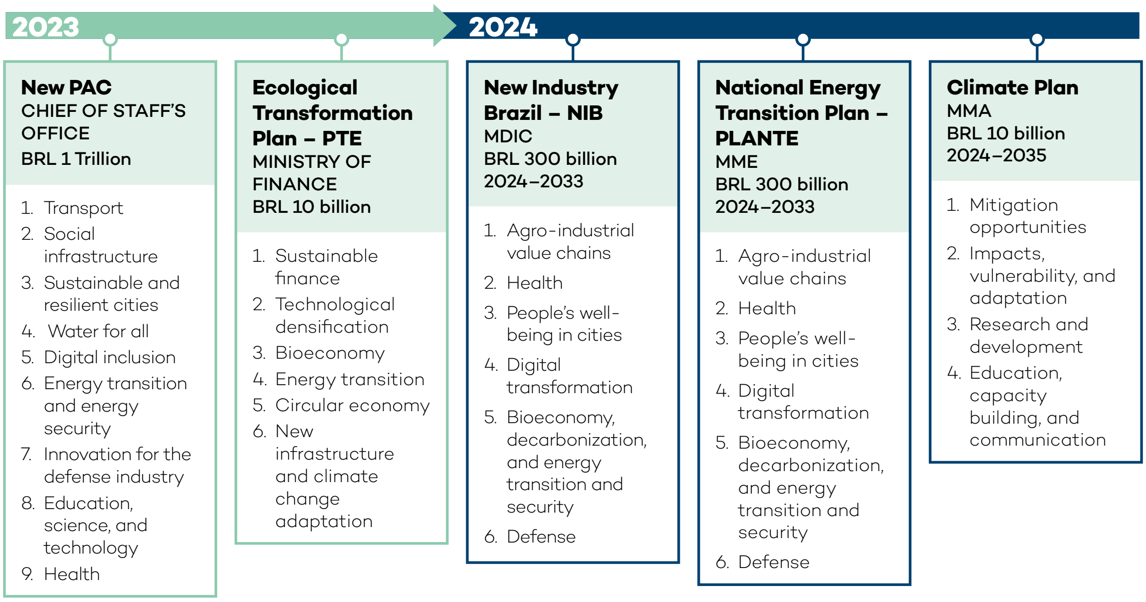
TRANSPORT	
Future Fuel Law – Law No. 14,993 of October 8, 2024	Provides for the promotion of low-carbon sustainable mobility and the capture and geological storage of carbon dioxide; establishes the National Sustainable Aviation Fuel Program (ProBioQAV), the National Green Diesel Program (PNDV), and the National Program for the Decarbonization of Natural Gas Producers and Importers and for Incentives to Biomethane; amends Laws Nos. 9,478 of August 6, 1997; 9,847 of October 26, 1999; 8,723 of October 28, 1993; and 13,033 of September 24, 2014; and repeals a provision of Law No. 10,438 of April 26, 2002.
MOVER – Law No. 14,902 of June 27, 2024	Establishes the Green Mobility and Innovation Program (Mover Program); amends Decree-Law No. 1,804 of September 3, 1980; and repeals provisions of Law No. 13,755 of December 10, 2018. Item IV – National Fund for Industrial and Technological Development (FNDIT).
STRUCTURING OF THE MINERAL SECTOR	
Law No. 13,575 of December 26, 2017	Creates the National Mining Agency (ANM); extinguishes the National Department of Mineral Production (DNPM).
Law No. 13,540 of December 18, 2017	Amends Laws Nos. 7,990 of December 28, 1989, and 8,001 of March 13, 1990, to provide for the Financial Compensation for the Exploitation of Mineral Resources (CFEM).
ANM Resolution No. 13 of August 8, 2019	Establishes regulatory measures aimed at ensuring the stability of mining dams.
MME Resolution No. 2 of June 18, 2021	Defines the list of strategic minerals for the country, in accordance with the criteria set forth in Article 2 of Decree No. 10,657 of March 24, 2021.
Decree No. 10,657 of March 24, 2021	Establishes the Policy to Support Environmental Licensing of Investment Projects for the Production of Strategic Minerals – Pro-Strategic Minerals; provides for its qualification within the scope of the Investment Partnerships Program of the Presidency of the Republic; and establishes the Interministerial Committee for the Analysis of Strategic Minerals Projects.
ANM Resolution No. 68 of April 30, 2021	Provides for the rules related to the Mine Closure Plan (PFM).

Decree No. 11,108 of June 29, 2022	Establishes the Brazilian Mineral Policy and the National Mineral Policy Council.
ANM Resolution No. 95 of August 7, 2022	Consolidates the normative acts that provide for the safety of mining dams.
Law No. 14,514 of December 29, 2022	Provides for the company Indústrias Nucleares do Brasil S.A. (INB), for the research, extraction, and commercialization of nuclear minerals, their concentrates and derivatives, and of nuclear materials, and for mining activity.
STRUCTURING OF THE MINERAL SECTOR	
Decree No. 11,482 of April 6, 2023	Provides for the National Council for Industrial Development (CNDI).
Decree No. 11,413 of February 13, 2023	Establishes the Reverse Logistics Recycling Credit Certificate, the Structuring and Recycling Certificate for General Packaging, and the Future Mass Credit Certificate, within the scope of the reverse logistics systems provided for in Article 33 of Law No. 12,305 of August 2, 2010.
PUBLIC POLICIES	
Law No. 12,305 of August 2, 2010	Establishes the National Solid Waste Policy; amends Law No. 9,605 of February 12, 1998; and provides for other measures.
Decree No. 9,406 of June 12, 2018	Regulates Decree-Law No. 227 of February 28, 1967 (Mining Code), Law No. 6,567 of September 24, 1978, Law No. 7,805 of July 18, 1989, and part of Law No. 13,575 of December 26, 2017.
MCTI Decree No. 10,746 of July 9, 2021	Establishes the Policy on Science, Technology, and Innovation for Advanced Materials and the Advanced Materials Steering Committee.
Decree No. 10,657 of March 24, 2021	Establishes the Policy to Support Environmental Licensing of Investment Projects for the Production of Strategic Minerals – Pro-Strategic Minerals; provides for its qualification within the scope of the Investment Partnerships Program of the Presidency of the Republic; and establishes the Interministerial Committee for the Analysis of Strategic Minerals Projects.

Decree No. 11,120 of July 5, 2022	Authorizes foreign trade operations involving lithium minerals and ores and their derivatives.
Decree No. 11,108 of June 29, 2022	Establishes the Brazilian Mineral Policy and the National Mineral Policy Council.
Decree No. 11,547 of June 5, 2023	Provides for the Low-Carbon Industry Technical Committee (CTIBC).

The structuring of national programs for Industrial Policy and Mineral Policy demonstrates a significant level of integration, with the establishment of aligned decarbonization targets, the implementation of sustainability actions, and, in particular, the establishment of targets for energy transition and energy security across the vast majority of public policy instruments (Figure 16). Aligned with the most up-to-date international strategies, these instruments guide the implementation of key plans for industrial development.

Figure 16: Main national programs for industrialization.



4. STRATEGIC MINERALS: CURRENT SCENARIO AND FUTURE PERSPECTIVES

4.1 Introduction

One of the most critical points in the energy transition value chain lies at its very beginning: mining. As the most sensitive link and the slowest to implement, mining activity requires incentive policies, value-addition strategies, and partnerships with producing countries to ensure a stable and sustainable supply. The extraction of minerals such as copper, lithium, and cobalt depends on geographic factors and takes, on average, more than a decade to materialize from prospecting to production. The combination of long lead times with high geographic concentration (such as the well-known dominance of the Congo in the cobalt market, for example) increases the risks of scarcity. It is urgent to diversify suppliers, promote reuse through recycling, and establish strategic partnerships that enable value addition in producing countries, especially in emerging and developing markets.

In light of all these variables, it becomes evident that countries need to build differentiated national strategies. No country will be competitive across all stages of clean technology supply chains. An effective strategy is to focus on local comparative advantages, such as the availability of mineral resources, access to low-cost renewable energy, the existing industrial base, or workforce skills. Successful strategies should combine national specialization with international partnerships, while complying with global rules and promoting the development of strategic sectors

An essential part of this strategy lies in the expansion of physical infrastructure, as it constitutes the backbone of the new energy economy. Infrastructure development—such as power grids, hydrogen pipelines, and carbon capture and storage systems—will be fundamental to enabling this new industrial base. Energy infrastructure will become a new geostrategic asset: grids, pipelines, and storage systems need to be accelerated to avoid bottlenecks. However, such projects often face lengthy planning and permitting processes, frequently exceeding five years, which calls for institutional reforms to accelerate approvals and prevent infrastructure from becoming a bottleneck to progress and the deployment of clean technologies.

International cooperation, as a key element, proves indispensable to overcoming these challenges in a coordinated and efficient manner. Even with a focus on industrial sovereignty, international cooperation remains essential to ensuring energy security and productive scale. No country will be able, on its own, to ensure the resilience and sustainability of global clean energy supply chains.

Collaboration among governments, companies, and international institutions will be fundamental to establishing common standards, enabling cross-border investments, and ensuring that the benefits of the new energy economy are broadly distributed and shared.

4.2 Material use and the energy transition

Global material use could nearly double by 2060, increasing from 89 to 167 gigatonnes (Gt), with a strong emphasis on non-metallic minerals. Metal use will grow at an even faster pace, with significant environmental impacts. This increase will be led by emerging economies, such as BRICS+ countries, Vietnam, and African countries, with moderate growth in developed countries (OECD, 2019).

Despite the absolute increase, an annual reduction of 1.3% in the material intensity of the global economy is expected, reflecting greater technological efficiency and the growing importance of the services sector. Recycling is expected to gain traction, but barriers such as the costs of secondary production still limit its potential. Projections indicate parallel growth between primary and recycled materials.

Material use is intrinsically linked to greenhouse gas emissions. It is estimated that by 2060, two-thirds of global emissions—which may reach 75 Gt CO_2-eq—will originate from activities related to material production and consumption, particularly in the construction (concrete) and steelmaking (iron and steel) sectors, which together will account for approximately 24% of total emissions.

These data reinforce the urgency of transitioning to a circular economy. The use of recycled materials presents significantly lower environmental impacts per kilogram than primary mining, and its broader adoption can mitigate emissions, reduce pressure on ecosystems, and increase the resilience of critical mineral supply chains.

In this context, it is suggested that public policies should integrate resource efficiency, innovation, and foreign trade in a coordinated manner to support environmental and material security goals. The expansion of circularity and the valorization of secondary materials will be decisive in ensuring a sustainable energy transition, with lower geopolitical vulnerability and greater economic inclusion.

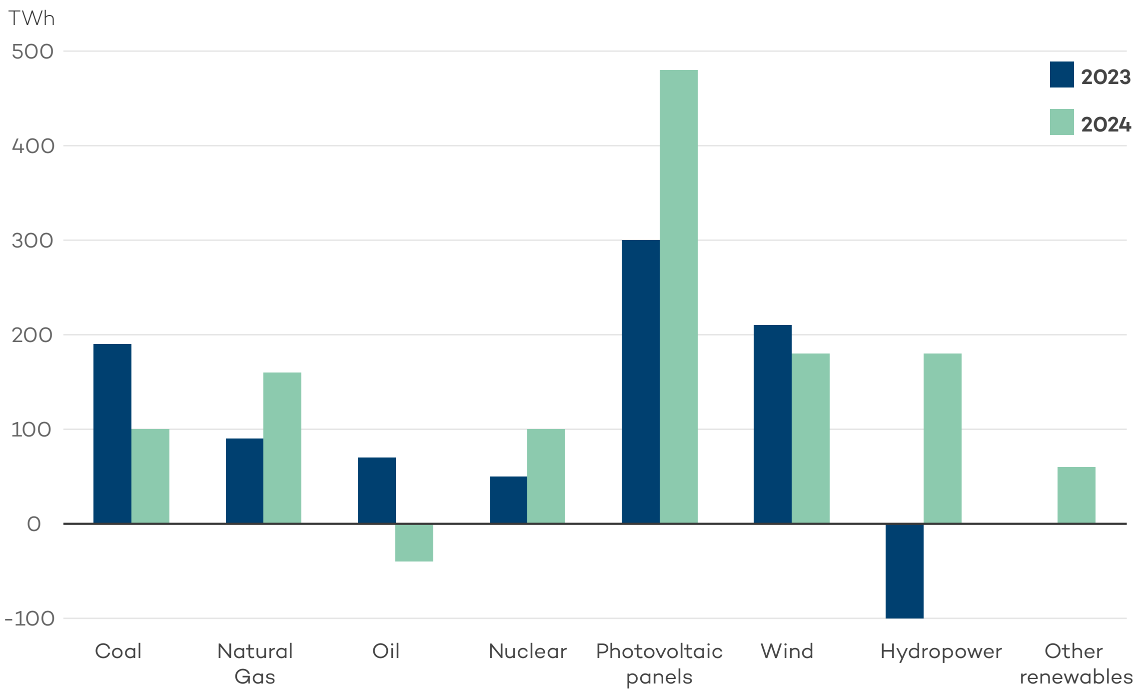
4.3 Demand drivers for critical minerals and materials

The substitution of fossil fuels with clean energy technologies—such as wind farms, solar power plants, and electric vehicles—has significantly increased demand for critical minerals and materials. Electric vehicles use six times more minerals than conventional vehicles, while onshore wind turbines consume up to nine times more materials than gas-fired thermal power plants (IEA, 2021).

According to the IEA report (2025)[79], global energy demand grew by approximately 2.2% in 2024 alone, with 80% of demand growth concentrated in emerging economies, led by China and India, followed by the United States in third place.

Figure 17 highlights photovoltaic panels as the main sustainable alternative for power generation among developed countries.

Figure 17: Annual variation 2023–2024 in global electricity generation



Source: (IEA, 2025).

Since 2010, the amount of minerals required per unit of installed renewable generation capacity has increased by 50%, driven by the intensification of investments in this sector. Figure 18 presents an estimate of renewable energy capacity additions through 2030.

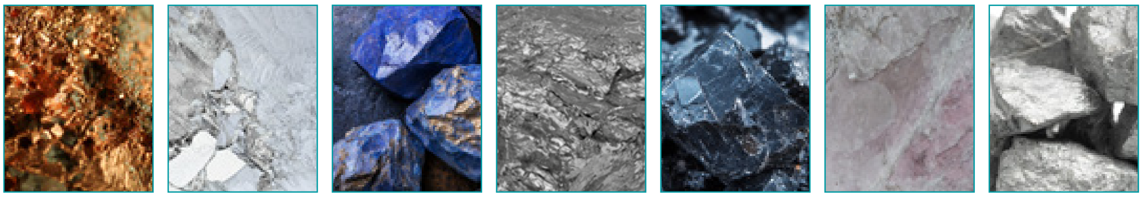
79 https://iea.blob.core.windows.net/assets/5b169aa1-bc88-4c96-b828-aaa50406ba80/GlobalEnergyReview2025.pdf

Figure 18: Requirements for the large-scale deployment of energy transition technologies (ETC, 2024[80]).

	Wind	Solar	T&D grids	Electrolyzers	Heat Pumps	Storage, and EVs
Capacity in 2022	940 GW	1240 GW	70 million km	~0,2 Mt H_2	~200 million units	10 million electric vehicle sales, 16 GW of stationary storage
	(x2,5)	**(x4)**	**(x1,5)**	**(x100)**	**(x3)**	**(x6)**
Required scale in 2030	2400–2600 GW	4900–5100 GW	100 million km	>20 Mt H_2	~600 million units	65 million annual EV sales, 500 GWh of stationary energy storage

Each renewable energy technology requires a specific set of minerals. The production of traction batteries for electric vehicles relies heavily on lithium, nickel, cobalt, manganese, and graphite. Wind turbines and electric vehicle motors, in turn, require various rare earth elements. Copper and aluminum are essential for the expansion and efficient operation of electricity grids. Figure 19 presents critical minerals, associated challenges and main uses related to the energy transition, as well as the three leading producing and processing countries.

Figure 19: Critical minerals, challenges, and main uses associated with the energy transition.[81]



	COPPER	NICKEL	COBALT	GRAPHITE	RARE EARTH	LITHIUM	PLATINUM
Main uses	Solar energy (photovoltaics), nuclear power, electricity grids, batteries, hydrogen.	Solar energy (photovoltaics), nuclear power, electricity grids, batteries, hydrogen.	Electric vehicles, electronics, and batteries.	Electric vehicles, electronics, and batteries.	Permanent magnets, wind turbines, batteries, hydrogen.	Electric vehicles, electronics, and batteries.	Catalysts, batteries.
Key challenges	Limited availability of viable substitutes; many mines approaching the end of their productive life; increasing exposure to climate and water stress.	Potential future supply restrictions from Indonesia and the Philippines; environmental concerns.	Production and refining concentrated in the Democratic Republic of the Congo; supply diversification linked to nickel and copper.	Production and processing are highly concentrated for both natural and synthetic graphite.	Highly concentrated across the entire value chain.	Production highly concentrated in South America; exposure to climate stress.	PGM deposits are rare and costly to process and produce; reserves are concentrated, with associated environmental concerns.

80 https://thedocs.worldbank.org/en/doc/11ed02930623289f8851ebd991dc19d9-0070012024/original/Trends-in-Sustainable-Public-Procurement-Chris-Browne.pdf

81 A Global Guide to Critical Minerals - https://www.bakermckenzie.com/-/media/files/insight/guides/2023/global--guide-to-critical-minerals.pdf

Estimates indicate that this trend will intensify over the coming decades. In a scenario aligned with the Paris Agreement goals, global demand for critical minerals could increase by 40% for copper and rare earth elements, 60–70% for nickel and cobalt, and nearly 90% for lithium over the next two decades. Electric vehicles are already emerging as the main consumers of lithium and, by 2040, are expected to also lead global nickel consumption. This growing dependence on minerals to enable the decarbonization of the economy creates unprecedented challenges for governments and decision-makers, particularly regarding supply chain security and price stability.

If carbon neutrality targets are pursued more ambitiously—for example, in a net-zero emissions by 2050 scenario—global demand for these critical minerals could multiply fourfold, requiring up to six times more mineral inputs in 2040 than are currently consumed.

From a market perspective, there is a significant differentiation between minerals based on their maturity. Minerals such as copper and nickel [as well as iron and aluminum] have been widely used in industry for decades and have relatively mature markets, with established production, trade, and regulatory infrastructure. In contrast, minerals like cobalt and lithium are part of more recent markets, with emerging structures and higher sensitivity to supply and demand fluctuations. Rare earth elements (REEs) and platinum group metals (PGMs), in turn, display more complex market dynamics. REEs encompass 17 distinct metals, essential for wind turbines and electric vehicle motors. PGMs are crucial for manufacturing catalysts used in hydrogen production. Despite their strategic importance, demand for REEs is expected to grow more modestly (Boer, Pescatori, & Stuermer, 2021[82]).

The growth of the lithium-ion battery market and electric vehicles will be the main driver of demand for transition minerals. Lithium is expected to lead this growth, followed by graphite, cobalt, and nickel. Energy generation from solar and wind sources, in turn, is expected to triple mineral demand by 2040. In contrast, technologies such as hydropower, biomass, and nuclear energy, being less intensive in critical minerals, will contribute less significantly. The advancement of renewable hydrogen will also drive demand for nickel, zirconium, and PGMs.

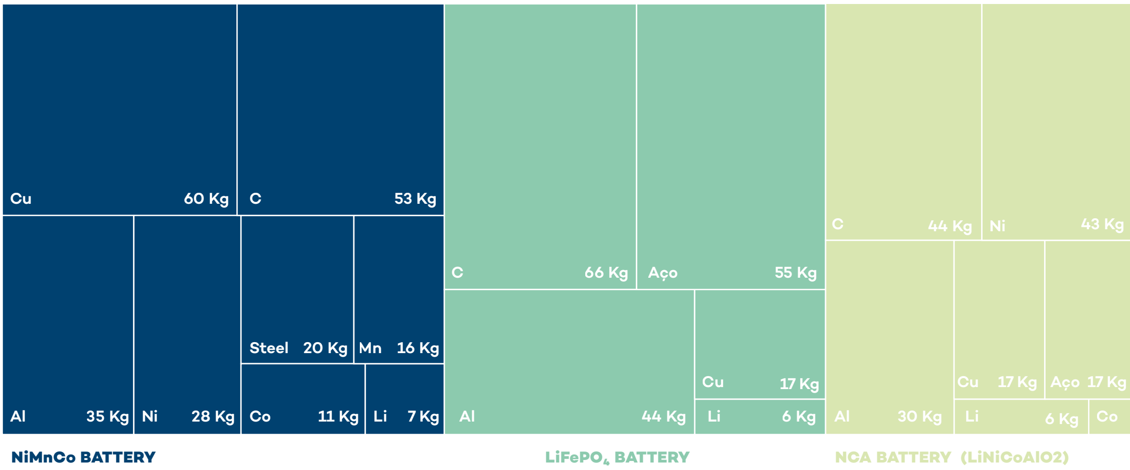
Estimates indicate that more than 3 billion tonnes of critical minerals will be needed by 2050 to support the global energy transition[79], and that the battery market could grow from USD 105 billion in 2023 to nearly USD 240 billion by 2030. Similarly, it is estimated that the Asia-Pacific market represents about 40% of global sales, with an average annual growth of 9.6%.

Even the composition of materials per product may fluctuate due to both technological innovations and emerging political-economic tensions

Figure 20 presents the average weight of minerals demanded by electric vehicles and their main producing countries.

82 Energy Transition Metals - https://www.imf.org/en/Publications/WP/Issues/2021/10/12/Energy-Transition-Metals-465899

Figure 20: Minerals and metals for electric vehicles by weight (in kg) and main producing countries.



Main producers:

- 27 **Co** Cobalto — Australia, Canada, Democratic Republic of the Congo (DRC), Madagascar, Philippines, Russia
- 6 **C** Carbono — Brazil, Canada, China, India, Madagascar, Mozambique
- 3 **Li** Lítio — Argentina, Australia, Chile, China, Zimbabwe
- 26 **Fe** Ferro — China, Brazil, India, Germany, Japan, South Korea, United States
- 28 **Ni** Níquel — Australia, Brazil, Canada, Indonesia, New Caledonia, Philippines, Russia
- 29 **Cu** Cobre — Australia, Canada, Chile, DRC, Kazakhstan, Mexico, Peru, United States, Zambia
- 25 **Mn** Manganês — Australia, Brazil, Côte d'Ivoire, India, Gabon, Ghana, Georgia, South Africa
- 13 **Al** Alumínio — China, India, Russia, Canada, United Arab Emirates, Australia

Source: Adapted and translated from IGF (IGF, 2022)

Despite projections of strong growth, the future of demand for critical minerals is subject to several uncertainties. Technological advances, changes in public policies, and the pace of deployment of transition technologies may significantly alter projected scenarios. A key uncertainty, however, lies in the effectiveness of public policies. Coordination among different sectors—energy, industry, agriculture, and transport—will be essential to ensure predictability, reduce investment risks, and attract private capital to new projects. It is estimated that, before 2040, energy transition minerals will already be more profitable than coal, which still represents the main source of revenue for global mining (IEA, 2021); (Hodge, 2022[83]).

The increase in demand for critical minerals, in turn, raises legitimate concerns regarding supply security and the costs of the transition. These costs are understood as a basket of synergistic elements, including social, economic, and environmental costs.

83 The global mining industry: corporate profile, complexity, and change. https://ideas.repec.org/a/spr/minecn/v35y2022i3d10.1007_s13563-022-00343-1.html#download

Imbalances between supply and demand may generate price volatility and delays in strategic investments. As minerals represent a significant share of battery costs, variations in lithium or nickel prices may increase final costs by up to 6%. In the case of power grids, copper and aluminum account for 20% of total investments. Any restriction in the supply of these inputs may directly affect costs and the timelines for deployment of the required infrastructure (IGF, 2022).

Supply chain–related risks are multiple: geographic concentration of production, long development cycles for new projects, declining ore grades, environmental and social pressures, and climate vulnerabilities. A large share of rare earths and cobalt production is concentrated in China and in the Democratic Republic of the Congo, respectively. In addition, China plays a central role in the refining of these minerals and in several links of the value chains, such as batteries and solar panels (IEA, 2021).

The decline in ore quality, as in the case of copper, increases costs and the energy intensity of extraction. Poorly managed mining can also cause serious environmental and social impacts, including soil and water contamination, ecosystem destruction, and human rights violations, such as child labor in artisanal operations (IEA, 2021).

Supply chain resilience therefore depends on well-articulated public policies, clear regulatory signals, incentives for innovation, and financing mechanisms that encourage responsible and sustainable production. Recycling can alleviate part of the pressure on primary supply, especially with the increase in the volume of discarded batteries and renewable energy equipment after 2030. It is estimated that, by 2040, recycling could reduce by around 10% the need for primary extraction of some minerals.

To address these challenges and coordinate international action, there are movements toward the creation of global governance for transition minerals. The launch, in 2020, of the UN Secretary-General's initiative on critical minerals, and the creation in 2022 of a working group dedicated to the transformation of sustainable extractive industries, signal this new direction. During the 2023 Climate Ambition Summit in New York, the issue of critical minerals was addressed as one of the three central pillars of the green transition, alongside industrial decarbonization and the large-scale expansion of global battery production.

4.4 Outlook for demand for critical minerals and materials and the energy transition

The energy transition toward a low-carbon economy imposes a new pattern of demand for natural resources, especially critical minerals and materials. Unlike the fossil fuel–based economy—centered on the extraction, processing, distribution, and consumption of oil, coal, and natural gas—the clean energy technologies require a significantly larger volume of mineral-based materials for their construction, operation, and the development of associated infrastructure. This includes not only extraction and processing, but also the development of equipment, components, storage structures, and transport systems.

The new technological paradigm underpinning decarbonization is directly associated with technologies such as photovoltaic solar panels, wind turbines, electric vehicles, batteries, modern transmission grids, and hydrogen systems. Each of these solutions presents its own mineral demand profile. Depending on the type of technology, the degree of material intensity may vary significantly, both in volume and in the diversity of minerals used (ETC, 2023).

The increase in demand for these materials does not occur in isolation. It is embedded in a context of profound transformations in the global productive structure, which includes both countries that concentrate the production and export of these minerals and those that dominate the more advanced stages of the value chains—such as refining, component manufacturing, and technological integration into products. This concentration of productive capacities and competencies generates imbalances that must be understood and addressed. Tensions arising from Sino-American disputes require the positioning of countries that hold reserves and/or are producers of critical and strategic minerals. High-impact decisions taken within a short period of time may secure trade relationships with strong influence over the future of climate security.

In addition, the expansion of demand is taking place on a supply base that remains limited, both in terms of available volumes and installed production capacity. Extraction and refining are capital-, technology-, and time-intensive processes, with average project development timelines exceeding a decade. These factors make the supply of these inputs vulnerable to geopolitical shocks, market instability, and price volatility.

In this context, several multilateral organizations and research centers have emphasized the need for coordinated international support to less developed economies. In particular, the contribution of UNCTAD (2022) stands out, warning of the risk that climate policies anchored in exclusionary trade criteria may reinforce historical asymmetries. The organization proposes actions aimed at strengthening the productive capacities of developing countries, so that they can not only export raw materials, but also capture greater value along their respective value chains.

One of the central points of UNCTAD's argument is the risk that certain countries may become "losers" in the transition due to the obsolescence of fossil fuel–based assets, while others, endowed with abundant strategic minerals, may become "winners" if they succeed in adding value to their mineral production. This requires active industrial policies, incentives for local innovation, investment attraction, and, above all, productive and social inclusion[84].

In this sense, the development of a green industrial policy proves to be essential. Such a policy must go beyond extraction, promoting the establishment of refining plants, material processing facilities, component industries, and R&D centers. The construction of endogenous capabilities will be decisive for mineral-producing countries to position themselves in a qualified manner within the global value chains associated with the energy transition.

UNCTAD also presents a comprehensive mapping of key energy transition technologies, their associated raw materials, current production volumes, and the countries with the largest shares. This analysis highlights the complexity of the new energy regime and the need to expand not only extraction, but also refining and technology manufacturing. It is essential to increase global supply based on criteria of sustainability, security, and governance.

Finally, it is important to emphasize that, although the minerals used in the energy transition are, to a large extent, durable and recyclable, their extraction and processing remain subject to significant environmental and social impacts. These impacts vary according to the type of mineral, the extraction method, the territorial context, and the quality of social and environmental governance. Therefore, progress in the energy transition must be accompanied by rigorous environmental sustainability criteria, respect for the rights of local communities, and mechanisms for monitoring and transparency.

84 UNCTAD Annual Report 2023 - https://unctad.org/publication/annual-report-2023

5. ENERGY TRANSITION TECHNOLOGIES AND MINING

5.1 Introduction

The energy transition represents a strategic movement aimed at establishing, within global society, a development model with lower dependence on fossil fuels. This vision has taken different conceptual forms over time, such as sustainable development, clean development, and economic decarbonization, among others.

Within this framework, Brazil stands out due to the choices made in harnessing its energy resources, associated with the availability of financial resources and exposure to imports—an issue that became evident since the oil shocks of the 1970s. At that time, the decision to pursue biofuels led the country to intensify its energy transition, resulting today in an energy matrix that is approximately 50% renewable. Its electricity matrix exceeds 90% renewable sources, with particular emphasis on the recent expansion of installed wind and solar capacity.

In addition, Brazil occupies a unique position in the energy transition process due to its significant potential as a holder of abundant renewable energy resources. This favorable condition is further strengthened by its critical mineral resources, forest assets, and carbon absorption potential, which collectively reinforce the country's role in global decarbonization efforts. This competitive advantage places the Brazilian mining sector at the center of global energy transition dynamics.

Thus, by combining substantial mineral resources with vast renewable energy potential, Brazil has a strategic opportunity to add domestic value by integrating into the global technological value chains that are essential to the energy transition. This repositioning would enable the country not only to supply raw materials, but also to participate in high value-added industrial processes, while ensuring the sustainable and competitive supply of the mining sector's growing energy demand—thereby consolidating Brazil as a reference in sustainable mining within the new low-carbon economy.

Unlike fossil fuels, critical minerals exhibit distinct supply and demand dynamics. Figure 21 illustrates these differences and highlights the importance of the supply of these minerals for the energy transition.

Figure 21: Differences between critical minerals and fossil fuels.

FOSSIL FUELS	CRITICAL MATERIALS
LARGE-SCALE MINING In 2021, **15 billion tonnes of fossil fuels** were extracted[1]	**SMALL-SCALE MINING** Approximately **10 million tonnes of energy transition minerals** were produced in 2022[2]
HIGH REVENUE GENERATION Oil and gas exports alone reached **USD 2 trillion in 2021**[3]	**LOWER PROFIT GENERATION** Exports of copper, nickel, lithium, cobalt, and rare earths reached **USD 96 billion in 2021**[4]
BURNED AS FUEL Fossil fuels are primarily burned as fuel, accounting for nearly **94% of their use**[5]	**INPUT FOR MANUFACTURING** Critical materials are energy assets with a typical lifecycle ranging from **10 to 30 years**.
RISK TO ENERGY SECURITY Supply disruptions can lead to immediate energy shortages and sharp price increases	**RISKS TO THE ENERGY TRANSITION** Supply disruptions may delay the deployment of new clean energy assets, but do not directly affect energy prices or energy supply.
NON-RECYCLABLE They are primarily consumed through combustion and cannot be recovered or reused.	**REUSABLE AND RECYCLABLE** High potential for reduced use, reuse, and recycling.

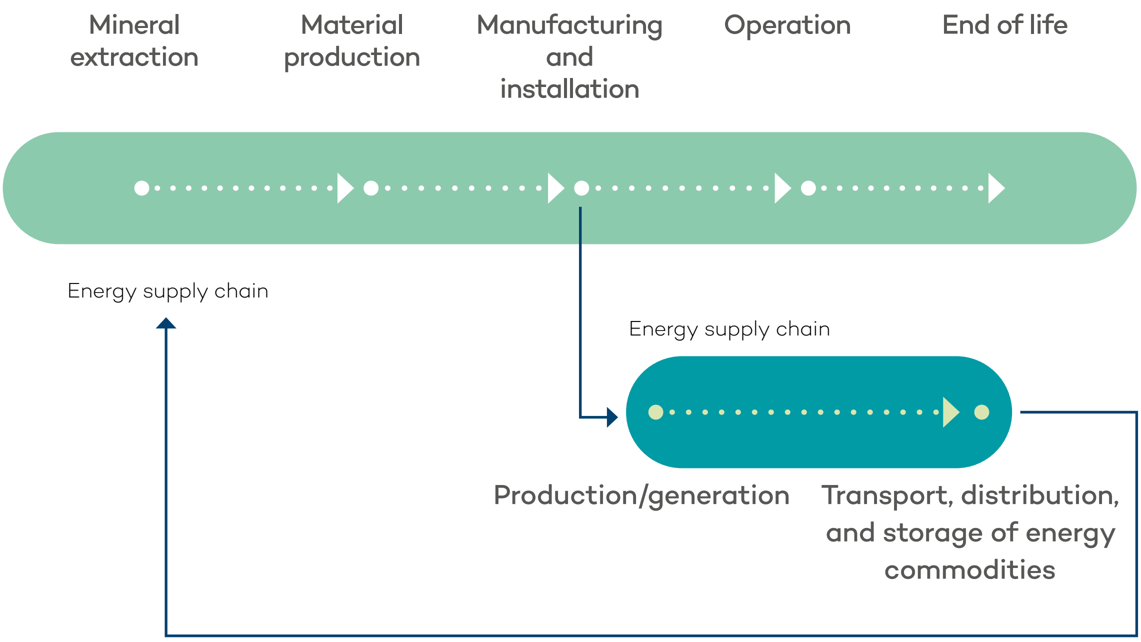
[1] The data are from 2021 and were obtained from BP's Statistical Review of World Energy. Oil and coal data were available in tonnes; gas data were converted from billion cubic meters (bcm) to billion tonnes. [2] According to IRENA calculations, the production of materials (copper, lithium, graphite, nickel, cobalt, manganese, rare earth elements, and platinum group metals) for renewable energy–related technologies in 2022 amounted to approximately 10 million tonnes (megatonnes). [3] In 2021, crude oil exports generated USD 951 billion; refined petroleum generated USD 746 billion; liquefied natural gas generated USD 162 billion; and natural gas in gaseous form generated USD 173 billion. [4] In 2021, exports of copper ores and concentrates generated USD 91.1 billion; nickel ores and concentrates generated USD 4.24 billion; and cobalt ores and concentrates generated USD 118 million. With regard to rare earth metals, scandium and yttrium generated USD 586 million. [5] Calculated based on the IEA's World Energy Balance (2020), Available at: www.iea.org/Sankey.
Source: (IRENA, 2023[85])

85 Renewable energy statistics 2023 - https://www.irena.org/Publications/2023/Jul/Renewable-energy-statistics-2023

As stated, the need for **energy transition materials (ETMs)** unfolds along two main axes: the first is related to the construction and installation of technologies for harnessing energy from renewable sources; the second relates to clean technologies, such as batteries, which are essential for mobility, energy storage, and the flexible use of energy in alignment with demand.

In this sense, there is a strong correlation between energy supply chains and their technologies, as technology supply chains require energy at every stage of their production, from mining to manufacturing. Likewise, energy supply chains depend on new technologies, such as solar panels or wind turbines, to generate and distribute energy, as illustrated in Figure 22.

Figure 22: Stages and interdependencies of technology and energy supply chains.



Source: (IEA, 2024).

Energy supply chains focus on delivering energy in usable forms to final consumers, involving energy generation, transformation, transport, storage, and distribution, and encompass the following stages:

1. **Energy generation/transformation:** includes the conversion of primary energy sources, such as sunlight or wind, into electricity, or the transformation of primary fuels into more usable forms, such as hydrogen or synthetic fuels.

2. **Transport and transmission:** : involves moving energy from generation sites to where it is needed, either through transmission lines for electricity or pipelines for liquid or gaseous fuels.

3. **Distribution and storage:** includes the distribution of energy to end users and its storage for later use, ensuring that supply matches demand.

Technology supply chains, in turn, encompass the entire process of bringing a clean energy technology to market, from raw material extraction to final installation and decommissioning of the technology, involving the following stages:

- **Raw material extraction:** involves the mining of essential minerals, such as lithium, nickel, cobalt, and rare earth elements.

- **Material processing:** refers to the conversion of raw minerals into usable forms, such as refined metals or processed chemical compounds.

- **Component manufacturing:** involves the creation of specific parts required for the technology, such as solar panels, wind turbine blades, or battery cells.

- **Assembly and installation:** components are assembled into products, such as solar panel arrays or wind turbines, and then installed at their destination sites.

- **Operation and maintenance:** ensures that the technology operates effectively throughout its entire lifecycle.

- **Decommissioning and recycling: i**nvolves the safe dismantling of the technology and the reuse or recycling of its components at the end of its useful life.

According to the International Energy Agency's Net Zero Emissions Scenario (IEA), six energy and technology supply chains will be critical for the clean energy transition, as together they will contribute to approximately half of the cumulative emissions reductions by 2050 under this scenario.

These supply chains are divided into two main categories:

i. clean energy supply chains;

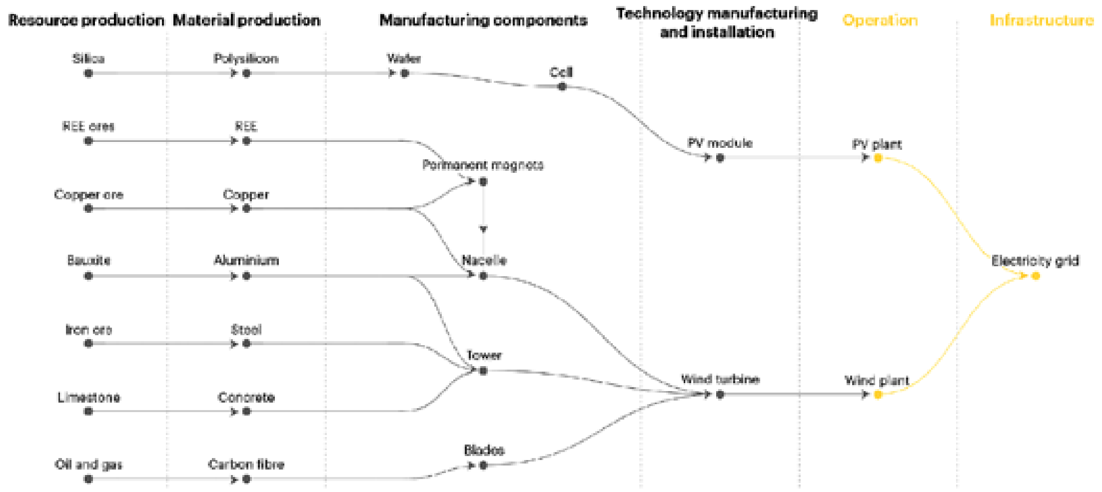
ii. clean technology supply chains.

5.2 Clean energy supply chains

5.2.1 Low-emissions electricity

- **Solar photovoltaic (PV) energy and wind energy:** includes energy and technology supply chains for the manufacturing, installation, and maintenance of solar panels and wind turbines. See Figure 23.

Figure 23: Low-emissions electricity **– Solar PV and Wind**

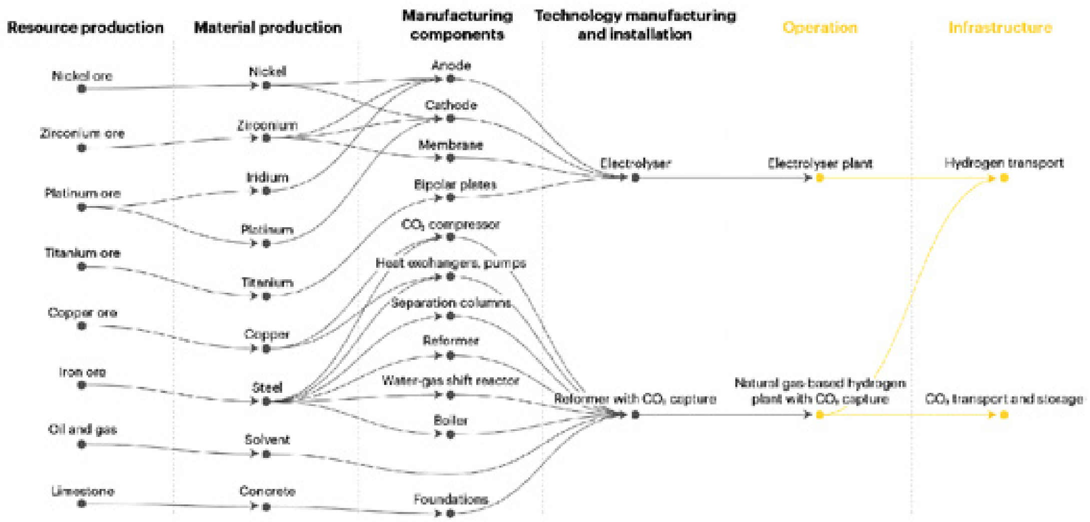


Source: (IEA, 2024)

5.2.2 Low-emissions hydrogen

- **Electrolysis and natural gas plants with carbon capture and storage (CCS):** the supply chain includes technologies for hydrogen production through electrolysis and natural gas plants that capture and store CO_2 emissions. See Figure 24..

Figure 24: Low-emissions hydrogen – electrolyzers and gas reforming with CO_2 capture

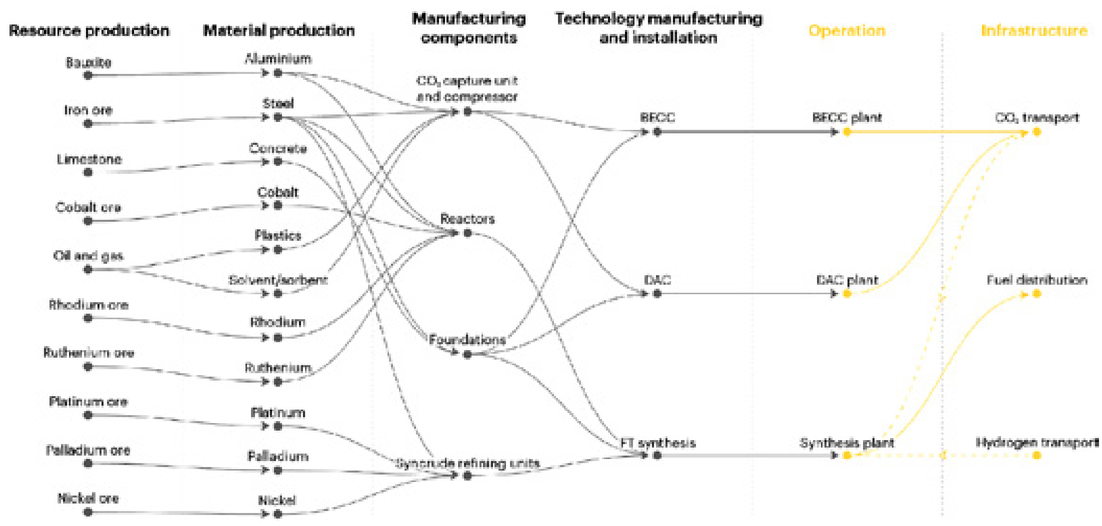


Source: (IEA, 2024)

5.2.3 Low-emissions synthetic fuels

- **Direct Air Capture (DAC) and Bioenergy with Carbon Capture (BECC):** these technologies provide the CO_2 required for the production of synthetic fuels and are connected to the low-emissions hydrogen supply chain. See Figure 25..

Figure 25: Low-emissions synthetic hydrocarbon-based fuels



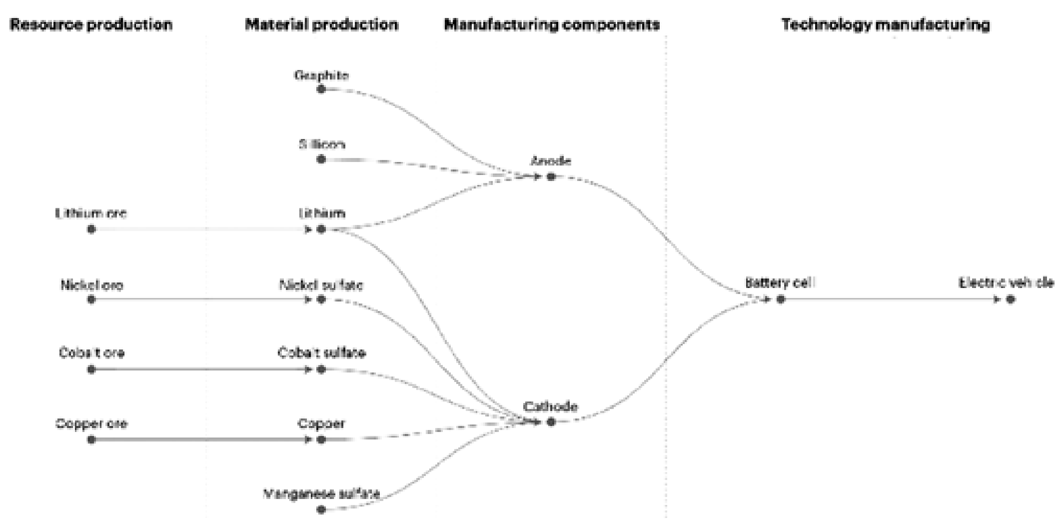
Source: (IEA, 2024)

5.3 5.2 Clean technology supply chains

5.3.1 Light-duty electric vehicles

- **Battery supply chain:** involves mineral extraction, component production, assembly, and battery recycling for electric vehicles (Figure 26).

Figure 26: Batteries for electric vehicles

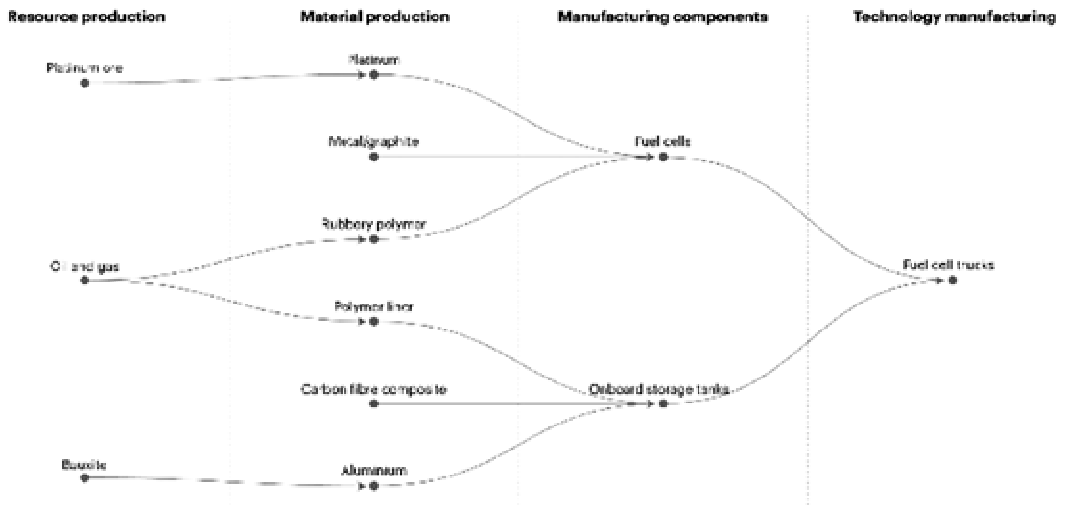


Source: (IEA, 2024)

5.3.2 Heavy-duty truck transport

- **Fuel cell supply chain:** includes the production and supply of fuel cells, which are essential for the operation of these trucks. See Figure 27.

Figure 27: Fuel cell trucks

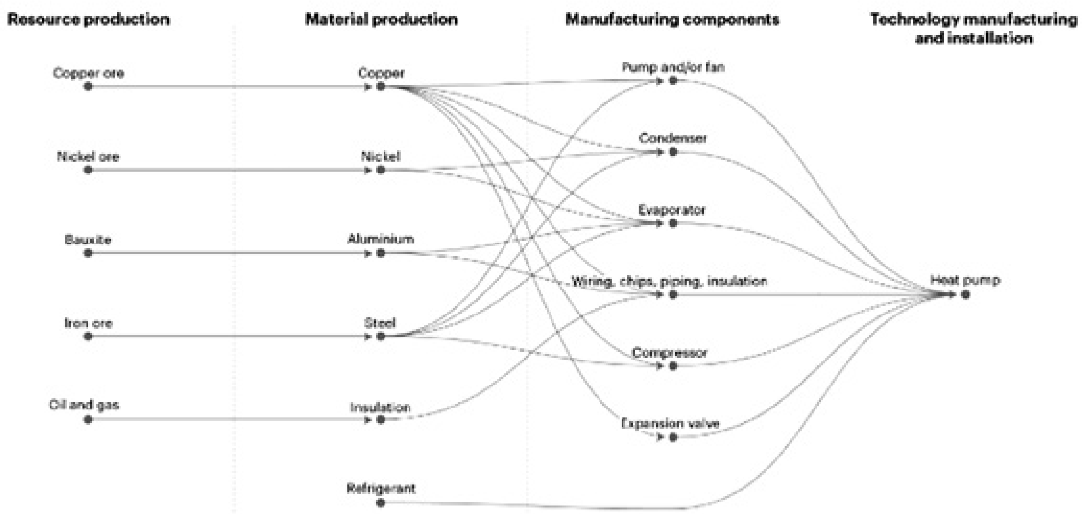


Source: (IEA, 2024)

5.3.3 Building and industrial heat pumps

- **Efficient heating and cooling technologies:** focused on the installation and operation of heat pumps that increase energy efficiency in buildings and in low- and medium-temperature thermal processes in industry. See Figure 28.

Figure 28: Heat pumps for building and industrial applications



Source: (IEA, 2024)

The assessment of the risks of these supply chains is vital to anticipate and mitigate challenges that may arise, ensuring continuity and effectiveness in the transition to a clean energy economy. The resilience and sustainability of these supply chains are essential pillars to achieve the necessary emissions reductions and meet global climate goals.

5.4 Brazil as a leader in the energy transition

As demonstrated, the expansion of infrastructure for the generation, transmission, and storage of renewable energy, propelled by the energy transition, will require large volumes of capital goods intensive in strategic minerals. In this scenario, these resources gain centrality in industrial, energy, and climate policies, demanding integrated strategies to ensure a secure, sustainable, and competitive supply.

To meet the growing demand, the mining industry will need to expand the extraction and processing of minerals such as lithium, copper, nickel, graphite, and rare earths. However, mining, due to its energy demand, has a significant environmental footprint, especially when supported by fossil sources.

Thus, the energy transition will depend on the decarbonization of the mineral sector itself, particularly regarding the value-adding stages of mineral goods. It is noted, therefore, that the sector has advanced initiatives to mitigate these effects, with increasing adoption of renewable sources, electrification of equipment, waste reuse, and energy efficiency solutions. In this context, the energy transition will depend not only on the increased supply of these minerals but also on the progressive decarbonization of the mining production chains themselves.

The expansion of renewable sources will be the engine of the transition, with renewable electricity as a central vector to reduce emissions in the energy sector. In the net-zero emissions scenario, electricity should represent more than half of final consumption by 2050 (IEA, 2023b).

In this context, Brazil stands out. With a predominantly renewable energy matrix — hydro, wind, solar, and biomass — the country has significant comparative advantages. About 45% of the energy supplied in Brazil is renewable, compared to an average of 12% in the OECD. In the electricity sector, this differential is even higher: in 2023, more than 90% of electricity in the National Interconnected System originated from renewables, compared to just over 30% in the OECD (EPE, 2024).

This position is reinforced by strategic attributes: abundance of natural resources, carbon absorption capacity, forest assets, and a large stock of critical minerals. The possibility of integrating mining with clean energy gives Brazil a structural advantage to produce transition inputs in a sustainable manner and aligned with international standards.

The country's continental geography — with large extension, climatic diversity, and geological wealth — favors the diversification of renewable sources and the decentralization of the mineral industry. This allows the development of production chains adapted to regional realities, promoting sustainable and distributed mining.

Brazil thus has the opportunity to lead the low-carbon economy through an innovative industrial policy that combines mineral extraction and renewable energy. This will allow meeting growing global demand sustainably, attracting investments, and boosting economic and social growth — with job creation, income, and regional development — within a just transition framework.

It is therefore imperative to go beyond the production of low-cost renewable energy and strengthen the value chains of the energy transition — from mining and refining to the manufacturing of final products such as solar cells, batteries, electrolyzers, wind turbines, and smart grid components.

The Brazilian industry can internalize high value-added production stages with a competitive carbon footprint. As national and international regulations adopt criteria such as Life Cycle Analysis (LCA), Brazil will be able to offer the global market low-emission products, produced with almost 100% renewable energy. This is a strategic window to position the country as a protagonist in the energy transition and in the geopolitics of critical minerals.

5.4.1 The race between federated entities in Brazil

The state of Goiás, the main national producer of rare earths in Brazil, created under Law No. 23,597/25[86], the State Authority of Critical Minerals of Goiás (Amic-GO), established the Special Zones of Critical Minerals (Zemc), and created the State Fund for the Development of Critical Minerals (FEDMC).

AMIC-GO will be an agency directly linked to the State Government, with administrative, financial, and technical autonomy to plan, promote, regulate, and oversee all activities related to critical minerals in Goiás.

The state of Minas Gerais, a pioneer in lithium production, established through the Secretariat of Economic Development the strategic project "Vale do Lítio"[87], which aims to position the state as a global protagonist in the lithium value chain. The actions and incentives of the Lithium Valley Project are carried out through coordination and collaboration with government agencies, municipalities, federal entities, companies, sector representative organizations, and civil society.

The State Secretariat of Economic Development (SEDE) is responsible for the overall coordination of the project, ensuring articulation among the various actors and mo-

86 https://portal.al.go.leg.br/noticias/157683/minerais-estrategicos-e-terras-raras

87 https://desenvolvimento.mg.gov.br/inicio/projetos/projeto/1170 nitoring the implemented actions. The State Secretariat of Planning and Management (SEPLAG) is responsible for monitoring activities related to human development axes and sectoral policies.

5.5 For a green mineral sector in Brazil

Based on studies developed by Aramendia *et, al.* (2023[88]) and Feix & Hache (2025)[89], it is possible to project Brazil's potential to use renewable sources to meet the energy demand of the exploration and processing of strategic and critical minerals.

Reference is made to the estimated energy consumption per ton of critical mineral, according to Ecoinvent 3.8 data[90], considering scenarios with different levels of uncertainty (low, medium, and high).

Based on these parameters, total energy demand for the exploration of Brazilian reserves is calculated, respecting sustainability and technical feasibility criteria. This demand is then compared with the installed capacity and expansion potential of renewable sources in the country — solar, wind, hydro, and biomass. The objective is to assess to what extent these sources can meet demand, considering different supply and consumption scenarios.

This exercise provides inputs to analyze the technical and strategic feasibility of using renewables in the mineral sector's energy supply, promoting synergies between the energy transition and national production of minerals essential for global decarbonization. The approach includes not only current reserves but also perspectives for expanding renewable generation, allowing a more robust view of the balance between mineral demand and clean energy supply.

The analysis highlights the strategic role of renewable sources in supporting the sustainable expansion of Brazilian mining, contributing to the planning of public policies, infrastructure investments, and alignment of the country with climate goals. The combination of critical mineral resources and national renewable potential creates an opportunity to consolidate a low-carbon, environmentally responsible, and economically competitive production chain.

Regarding the sustainability of the mineral sector, it should be noted that 91.6% of the mining area is concentrated in the Amazon, with the states of PA and MT leading

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88 https://doi.org/10.1016/j.gloenvcha.2023.102745

89 The exercise was carried out based on the data presented by Aramendia et al. (2023) and Feix & Hache (2025), which provide information on the final energy demand of each element, as well as an estimated energy conversion efficiency factor of 58%. However, since this value is considered high and potentially optimistic, a more conservative efficiency factor, widely referenced in the specialized literature, of 20% was adopted. This choice aims to mitigate overestimation risks and ensure greater robustness in the analyses.

90 https://doi.org/10.1016/j.resourpol.2025.105516 the concentration of mining activities, while MG has the largest mineral industry (MAPBiomas, 2021[91]).

The table 10 present the energy demand per mineral production with different efficiency standards. The values relate both to the processed volume and to the specific energy consumption for each mineral species.

Table 10. Energy demand used in mining by type of mineral or metal extracted from ore

Minerals	Final Energy (GJ/t)	Primary Energy (58% efficiency) (GJ/t)	Primary Energy (20% efficiency) (GJ/t)
Aluminum	31,0	53,4	155,0
Cobalt	38,0	65,5	190,0
Copper	53,0	91,4	265,0
Tin	96,0	165,5	480,0
Rare Earth	40,0	69,0	200,0
Phosphate	0,3	0,5	1,5
Graphite	1,1	1,9	5,5
Lithium	12,5	21,6	62,5
Manganese	1,0	1,7	5,0
Iron Ore	0,7	1,2	3,5
Niobium	15,6	26,9	78,0
Nickel	33,1	57,1	165,6
Gold	135.494,0	233.610,3	677.470,0
Potassium	0,3	0,5	1,5
Silicon	0,2	0,4	1,1
Tantalum	1.308,0	2.255,2	6.540,0
Titanium	3,6	6,2	18,0
Zinc	6,4	10,9	31,8

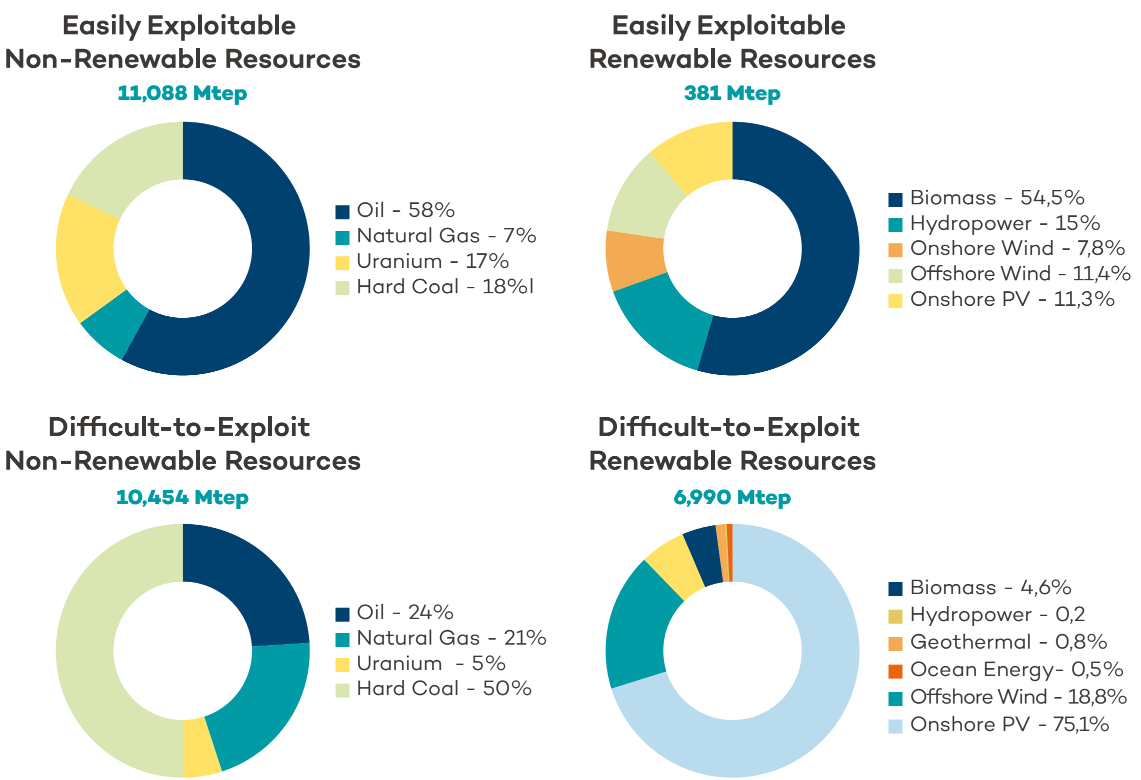
91 https://Brazil.mapbiomas.org/wp-content/uploads/sites/4/2023/11/MapBiomas_Mineracao_2022_30_09_1.pdf-_.pdf

Gold, resulting in a higher concentration of the production chain, reaches much higher levels of energy demand, especially due to the energy consumption for small volumes processed through long-duration pyrometallurgical techniques. On the other hand, iron ore, processed in large volumes, presents energy efficiency due to economies of scale and a low degree of production chain concentration, with production primarily of large volumes for export of concentrates or semi-manufactured goods.

According to the National Energy Balance (BEN), 154 Mtoe from renewable sources are currently used to meet national energy demand (EPE, 2024). If the surplus between the total potential and this consumption were fully directed to supply the energy demand of current global mineral production, this production could grow up to 20 times.

Even considering only the "easy" renewable potential — defined by the PNE 2050 based on criteria such as: discovered conventional resources and contingents of oil and natural gas; minable portion of measured and indicated coal and uranium reserves (Lagoa Real/Caetité - BA and Santa Quitéria – CE), already accounting for losses in mining and processing; biomass-fired power plants; hydroelectric plants outside protected areas; photovoltaic solar; onshore wind; small hydro plants; and offshore wind up to 10 km from the coast — this balance would allow meeting approximately 64% of the energy demand of current mineral production. The graphs in Figure 28, in turn, illustrate Brazil's energy resource availability by "easy" and "difficult" potential.

Figure 29: National energy availability until 2050.



Source: EPE (2020).

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It is worth highlighting the decision of the National Energy Policy Council (CNPE), through Resolution No. 2/2021, to encourage the use of Research and Development (R&D) resources from the energy sector in the value chain of critical and strategic minerals (CSMs). The measure aims to reduce the costs of renewable energy technologies and ensure Brazil's independence in this strategic sector (IN nº 2/2021)[92].

The adoption of a renewable energy matrix in the stages of mining, refining, and production of critical and strategic minerals represents a unique opportunity for Brazil to consolidate its position as a global energy transition leader and to take the lead in supplying these inputs at an international scale.

By integrating sources such as solar, wind, hydro, and biomass into mineral sector activities, the country can not only significantly reduce the carbon footprint of the production chain but also add competitive value to its products in a market increasingly driven by sustainability criteria. This integration strengthens national energy security, attracts sustainable investments, and positions Brazil as a reliable partner in the global supply chains of the new green economy.

In this scenario, Brazil has the opportunity to transform its vast energy and mineral potential into a strategic advantage. With one of the largest supplies of renewable sources in the world and a significant stock of essential minerals, the country has all the conditions to develop a low-carbon, efficient, and environmentally responsible mineral value chain — a decisive factor for the success of the global energy transition.

92 https://www.in.gov.br/en/web/dou/-/despacho-do-presidente-da-republica-307393461

6. ECONOMY OF THE ENERGY TRANSITION AND MINING

6.1 Introduction

The Brazilian mineral sector plays a strategic role in the national and global economy, both due to the volume of exported commodities and the potential for the production of critical minerals, essential for the energy transition and the digitalization of the economy[93]. This economic relevance, however, is directly conditioned by a series of economic factors affecting everything from the feasibility of new ventures to the international competitiveness of the sector, such as fiscal policies, the dynamics of international prices, environmental and financial regulations, as well as incentives for regional development that shape the mining activity landscape.

Economic aspects strongly influence the different stages of the mineral sector value chain in Brazil, enabling extraction, transformation, and mineral production. More recently, the condition of criticality imposed by import dependency or the risk of supply disruption of certain mineral goods can result in investments in the development of technologies employing alternative mineral substances, as well as the recovery of secondary materials through circular economy practices.

The world is entering a new era of industrial development, shaped by the emergence of energy generation and clean technology value chains. Sectors that, until two decades ago, were experimental — such as photovoltaic solar, wind, batteries, and electric vehicles — now occupy a central place in industrial and energy policies. This growth reflects both the climate urgency and the economic benefits of these technologies. The so-called new energy economy already moves billions and promises to profoundly transform production chains, labor markets, and global trade patterns (IEA, 2024).

This overall scenario, together with the long maturation time of new projects, the decrease in ore grades in existing projects, and the complexity of economically and sustainably extracting ore, explains why access to capital has become the main risk factor for the mineral industry, especially for junior or mid-sized companies in 2025, despite the strong demand for CSM production.

93 https://valor.globo.com/opiniao/noticia/2025/04/25/disputa-geopolitica-exige-plano-para-minerais-criticos.ghtml

Among these factors, five key elements stand out for the mining business environment in Brazil:

i. Global demand and commodity prices;

ii. Incentivized debentures;

iii. CFEM,

iv. Selective taxes; and

v. Regional and sectoral incentives.

Global demand and commodity prices define project profitability and sustainability, with price volatility directly impacting mining operations, especially in strategic markets such as critical minerals. Incentivized debentures, in turn, emerge as a strategic alternative for financing infrastructure and innovation projects, including in the mining value chain, increasing the attractiveness of sector investments.

Furthermore, CFEM, regional and sectoral tax incentives, and the emerging selective tax complete this landscape, influencing both sector competitiveness and the capacity for investment in innovation and sustainability.

CFEM ensures the redistribution of economic benefits from mining to producing regions, while regional tax incentives aim to reduce inequalities in economic development. The selective tax, still under debate within the Tax Reform framework, raises concerns about its potential impact on the competitiveness of mineral exports, especially in a global context that demands an industrial policy aligned with the security of supply of strategic minerals.

Global Demand and Commodity Prices

The global market for mineral commodities is highly influenced by factors such as international demand, economic policies, and geopolitical events. Brazil, as one of the world's largest producers of minerals such as iron, gold, and niobium, is directly impacted by these dynamics. For example, high demand for iron ore in China has driven Brazilian prices and exports in recent years.

Additionally, the growing demand for critical minerals, driven by the energy transition and digitalization, places Brazil in a strategic position. The country holds approximately 10% of global critical mineral reserves, including the world's largest niobium reserve and significant reserves of graphite, rare earths, and lithium. However, production is still limited, representing a small fraction of the global output of these minerals.

To leverage this potential, it is essential to develop policies that encourage sustainable exploration and industrialization of these resources. This includes investments in research and development, logistics infrastructure, and international partnerships. The increased valuation of critical minerals in the global market can generate significant revenues for the country and promote the development of national technologies..

Incentivized Debentures

Incentivized debentures are debt securities issued by companies to finance infrastructure projects, including those in the mineral sector. Established by Law nº 12,431/2011, essas debêntures oferecem isenção de Imposto de Renda para investidores pessoas físicas, tornando-se uma opção atrativa de investimento. Essa medida visa atrair capital privado para setores Strategics da economia Brazileira, como a mineração.

Recently, the Ministry of Mines and Energy (MME) published guidance for the issuance of these debentures and held a public consultation on the topic in January 2025, highlighting their role in financing projects associated with the energy transition. Decree No. 11,964/2024 regulates the issuance of infrastructure debentures, establishing criteria for projects to be considered priority and thus eligible for fiscal benefits, including investments in mine development and mining stages.

In the context of critical minerals, these debentures can be fundamental to financing exploration and processing projects of minerals essential for emerging technologies, such as lithium, cobalt, and rare earths. Fundraising through this instrument can accelerate the development of national value chains, reduce import dependency, and strengthen Brazil's position in the global strategic minerals market.

The regulations proposed by the Ministry of Mines and Energy (MME) represent an important milestone once the final ordinance is published.

Financial Compensation for Mineral Exploration (CFEM)

CFEM is a financial payment made by mining companies to the Union, States, and Municipalities for the exploitation of mineral resources. Established by the Federal Constitution of 1988 and regulated by Law nº 7,990/1989, CFEM aims to compensate for the impacts of mining activity and promote the development of mining regions.

The collection of CFEM is distributed as follows: 60% to the municipalities where the extraction occurs, 15% to the States, 15% to municipalities affected by mining activity, and 10% to the Union. In 2024, more than BRL 7.4 billion were transferred related to CFEM, resources that can be used in infrastructure, health, education, and other priority areas.

In the context of critical minerals, CFEM can serve as an instrument to promote the sustainable development of producing regions. The collected funds can be directed to professional training, research, and innovation, strengthening the local value chain and promoting value addition to the extracted minerals.

Selective Tax

The Selective Tax (IS), foreseen in the Tax Reform under discussion in the National Congress, aims to tax products and services that generate negative externalities, such as fossil fuels and products harmful to health. However, the inclusion of mineral goods under IS has raised concerns in the mineral sector, which warns of possible impacts on competitiveness and investment attractiveness.

Studies indicate that the application of IS on mining could result in significant additional costs for the sector, affecting the trade balance and potentially compromising the country's foreign exchange reserves. Furthermore, there is a risk of loss of revenue for mining municipalities, which rely significantly on the revenues generated by mining activity.

It is essential that IS regulation considers the specificities of the mineral sector, particularly regarding critical minerals. A balanced approach can ensure fiscal sustainability without compromising the development of strategic value chains for the country. Public policies aimed at densifying productive chains, such as the Nova Indústria Brasil, are crucial for creating consistent domestic demand across the different clean energy and technology supply chains.

Regional and Sectoral Incentives

Regional and sectoral tax incentives are mechanisms used to attract investment and promote economic development in specific areas. In the mineral sector, state programs offer ICMS reductions and ISS exemptions for companies establishing themselves in regions with lower economic development. For example, the State of Pará grants tax incentives that can reach up to 95% for strategic activities.

With the approval of the Tax Reform, there is a tendency to unify consumption taxes, such as ICMS and ISS, under the new Goods and Services Tax (IBS). This change may impact the tax incentives currently granted by States and Municipalities, requiring a reassessment of investment attraction policies.

For the mineral sector, especially regarding critical minerals, it is essential that new incentive models consider specific infrastructure, logistics, and training needs.

Maintaining policies that encourage the exploration and beneficiation of these minerals can position Brazil as a leader in the production of essential inputs for the energy transition and the digital economy.

6.2 Energy Transition and Brazilian Mining

Accelerated by the energy transition, the new scenario has led countries to promote a true race for secure and sustainable clean energy supply chains. Governments of major countries are redesigning their strategies to ensure continuous and reliable access to essential inputs and equipment. This involves controlling everything from the extraction of critical minerals to the manufacturing and installation of technologies such as batteries, electrolyzers, solar panels, and wind turbines. Strengthening these value chains is seen as a way to reduce external vulnerabilities, achieve climate goals, and boost economic competitiveness

However, developing more resilient chains requires addressing structural risks that have become more visible in recent years — mainly due to the pandemic and the war in Ukraine. Today, a large portion of technology and input production is highly concentrated in a few countries, with China responsible for more than 70% of the manufacturing capacity of technologies such as solar panels and batteries, as well as dominating the refining of minerals such as lithium, nickel, and cobalt, which may represent a systemic risk to energy transitions. This degree of centralization creates systemic risks, making the entire chain vulnerable to external shocks, such as extreme weather events, unilateral political decisions, or logistical crises.

Despite these risks, this new energy economy not only presents challenges — it also offers significant economic opportunities and job creation. The energy transition economy has the potential to mobilize approximately USD 650 billion per year by 2030 and create nearly 14 million jobs. The largest sources of employment include electric vehicles, photovoltaic solar, wind turbines, and heat pumps, which will be the main drivers of this economic transformation in the medium and long term.

Full utilization of these opportunities, however, has been hindered by various bottlenecks and delays in industrial project implementation. Despite a large number of announcements of new factories and production centers, especially outside Asia, many of these projects are still in early stages. Barriers such as lengthy environmental licensing, regulatory uncertainties, high energy costs, and lack of adequate infrastructure prevent these investments from advancing at the necessary pace to meet growing global demand.

In this scenario, international trade becomes a critical tool to balance supply and demand and accelerate the dissemination of energy solutions, although the impact of recent measures on international trade from the new Trump administration is still unknown. Equipment such as solar modules, batteries, and wind components circulating widely between countries ensures that regions without productive capacity can continue advancing decarbonization. International trade remains essential but requires active diversification policies and stable trade agreements to avoid disruptions and guarantee supply security.

In this context, some economic aspects are essential in decision-making at all stages of the mineral chain in Brazil, from mineral prospecting to product commercialization. The sector is directly affected by factors such as global demand, commodity prices, and public policies. Thus, the combination of these factors — from the global market to fiscal incentives — defines the conditions for mining growth in Brazil, especially in the production of critical minerals, essential for securing value chains and supporting strategic sectors of the economy.

The global repositioning regarding the concept of globalization, the rollback of Paris Agreement measures, the economic feasibility of implementing circular economy principles, and the valorization of the Brazilian economy are important elements for reconfiguring production and consumption strategies. While mining has traditionally been represented by intensive production processes, some companies such as Tupy (SC) and CBMM (MG), and initiatives with CIT Senai (MG) and ISI Senai Electrochemistry (PR), have begun investing in integrated, flexible, small-scale production units, strongly based on R&D and innovation. This new model has consolidated and, unlike production scale-up, proposes productive efficiency through flexibility and integration (scale fit), reducing uncertainties and mitigating potential risks inherent in innovative processes.

One direct consequence of replacing fossil fuels is the possibility of surplus oil production[94], as observed in the last quarter of 2024. Political uncertainty does not allow us to affirm that, despite the technological maturity of several energy transition solutions, long-term infrastructure mobilization and investments in the production of critical and strategic minerals are a priority. On one hand, short- and medium-term process investments for densifying the CSM chain may provide some degree of decision-making security, but macroeconomic instability still requires caution for long-term investments.

Thus, investments in small-and medium-scale flexible processes, based on the concept of **scale fit**, can result in measures with a lower degree of uncertainty and with potential for future scaling, depending on market response and international political positioning. For this purpose, investment in research, development, and innovation must be prioritized. Brazil has consolidated examples, such as junior companies that, in addition to mineral extraction, advance to more developed stages of the value chain.

94 https://www.cnnBrazil.com.br/economia/macroeconomia/iea-preve-excedente-no-mercado-global-de-petroleo-para-2025/

Table 11. R&D Investment by Companies in the Mineral Sector

Company	Number of Direct Employees in Brazil	R&D Investment	Revenue	Percentage of Revenue Invested in R&D
ArcellorMittal	19,000 (2024)	US$ 286 million (2022[95])	R$ 71,6 billion (2022[96])	1,40
CBMM	2,000 (2024)	R$ 270 Million (2024)	R$ 6,98 billion (2024[97])	3,87
Tupy	13,000 (2023)	R$ 84,4 Million (2023)	R$ 2,8 billion (2024 [98])	3,01
VALE	50,000 (2023)	R$ 790 Million (2025)[99]	R$ 31,6 billion (2024 [100])	2,50

Table 11 presents public data on R&D investment values and the respective percentage relative to revenue for some companies in the mineral sector. It can be observed that, for the analyzed set, the value does not exceed 4% of revenue.

As an example, Tupy, a Brazilian multinational that positions itself as a reference company in iron casting and machining for capital goods, together with MWM, a manufacturer of engines and generators, has flexible and diversified production processes based on open innovation, startup acceleration, with a percentage of 95% recycled inputs in the process in 2023[101]. The company invested more than R$ 84 million in research and development in 2023 and achieved revenue from by-product sales of R$ 29 million in the same year, equivalent to over 164,000 tons of by-products used as raw materials for other industries.

95 https://Brazil.arcelormittal.com/sala-imprensa/noticias/Brazil/arcelormittal-e-a-segunda-corporacao-que--mais-pratica-inovacao-aberta-no-Brazil

96 https://tinyurl.com/2bdenyfa

97 https://cbmm.com/pt/midias/releases/resultados-cbmm#:~:text=O%20lucro%20l%C3%ADquido%20da%20CBMM,automotivo%2C%20estrutural%20e%20aplica%C3%A7%C3%B5es%20especiais

98 https://www.tupy.com.br/tupy-registra-resultado-operacional-solido-e-evolucao-dos-novos-negocios/

99 https://einvestidor.estadao.com.br/ultimas/vale-vale3-investimento-6-milhoes-ufmg/

100 https://oglobo.globo.com/economia/negocios/noticia/2025/02/19/vale-registra-lucro-de-us-62-bi-em--2024-queda-de-23percent-ante-2023.ghtml

101 https://www.tupy.com.br/sustentabilidade/#relatorios

6.3 Circular Economy and Mining

The first edition of the document published by IBRAM in 2024, **"Foundations for Public Policies on Critical and Strategic Minerals for Brazil"**, adopted the following, widely accepted definition of circular economy, which was reviewed by experts from different countries and sectors through an international consensus process promoted by ISO – International Organization for Standardization:

> **Circular economy:** an economic system that uses a systemic approach to maintain a circular flow of resources through the addition, retention, and recovery of their value, while contributing to sustainable development.
>
> Note 1: Resources can be considered both in stocks and in flows.
> Note 2: From a sustainable development perspective, the input of virgin resources is kept as low as possible, and the circular flow of resources is maintained as closed as possible to minimize emissions and losses (resource waste) in the economic system.

Source: Norma ISO 59004:2024.

The definition above considers the circular economy as part of the economic system, highlights the relationship between resource and value, and proposes the incorporation of circular economy practices into existing processes, aiming to contribute to sustainable development. Urban mining is a secondary term of the circular economy. Urban mining is a concept that refers to the recovery of valuable materials present in urban solid waste. Instead of extracting natural resources from the ground, urban mining seeks to recover precious metals and other materials, contributing to the circular economy and environmental preservation.

In addition to the definition above, six principles have been developed to guide circular economy strategies in organizations, namely:

1. **Systemic thinking:** organizations adopt a life-cycle perspective and apply a long-term approach when considering their impacts on environmental, social, and economic systems.

2. **Value creation:** organizations recover, retain, or add value, providing effective solutions that contribute to socioeconomic and environmental value and use resources efficiently.

3. **Value sharing:** organizations collaborate with stakeholders along the value chain or value network in an inclusive and equitable manner, for the benefit and well-being of society, through sharing the value created by delivering a solution.

4. **Resource management:** organizations manage stocks and flows sustainably, including closing, slowing down, and reducing resource flows, contributing to the accessibility and availability of resources for present and future generations, and reducing risks associated with dependence on virgin resources.

5. **Resource traceability:** organizations collect and maintain data to allow traceability of resources throughout their value chains and are responsible for sharing relevant information with stakeholders.

6. **Ecosystem resilience:** organizations develop and implement practices and strategies that protect and contribute to the resilience and regeneration of ecosystems and their biodiversity, including preventing harmful losses and emissions, considering planetary limits.

The principles above create the foundations for the reach, interactions, and possible value interfaces between circular economy links and value chains, justifying the dual scope and title of this subchapter: Circular Economy and Value Chain.

The value chain refers to all stages involved in transforming a natural resource into a final product until delivery to the consumer.

In the case of critical minerals (such as lithium, cobalt, rare earth elements, etc.), this chain includes:

1. **Exploration and extraction:** locating and removing ore from the Earth's crust.
2. **Beneficiation:** separation and purification of minerals.
3. **Processing:** transformation into materials useful for industry (e.g., batteries, electronics).
4. **Manufacturing:** production of components and final products.
5. **Distribution and consumption:** delivery to the consumer or industrial user.
6. **Disposal or reuse:** end of life of products, which can generate waste or recycling opportunities.

The practice of circular economy in the mineral value chain is not yet widely adopted. However, several companies have achieved significant levels of maturity, particularly with mineral production from tailings or reinsertion of post-consumer products into production processes. For example, the Brazilian multinational company Tupy has sand regeneration processes in its production plants with a monthly volume of 4,000 tons, as well as the use of residual material as input and the commercialization of by-products. The company also obtained financing of R$ 58 million from BNDES in 2024 for the digital transformation of the Betim (MG) and Joinville (SC) manufacturing units, as well as for research and innovation for the development of MWM ethanol engines to replace diesel engines[102]. Both projects aim to contribute to the decarbonization targets of the transport sector.

Among the most accessible measures for replacing fossil fuels in the machines and vehicles used by the mining sector are biofuels, such as biodiesel, which can be used directly if competitively priced, or, by transforming the combustion cycle, ethanol or biomethane. There is also the possibility of electrifying this equipment, provided that the electrical grids in the areas where the sector operates are reinforced.

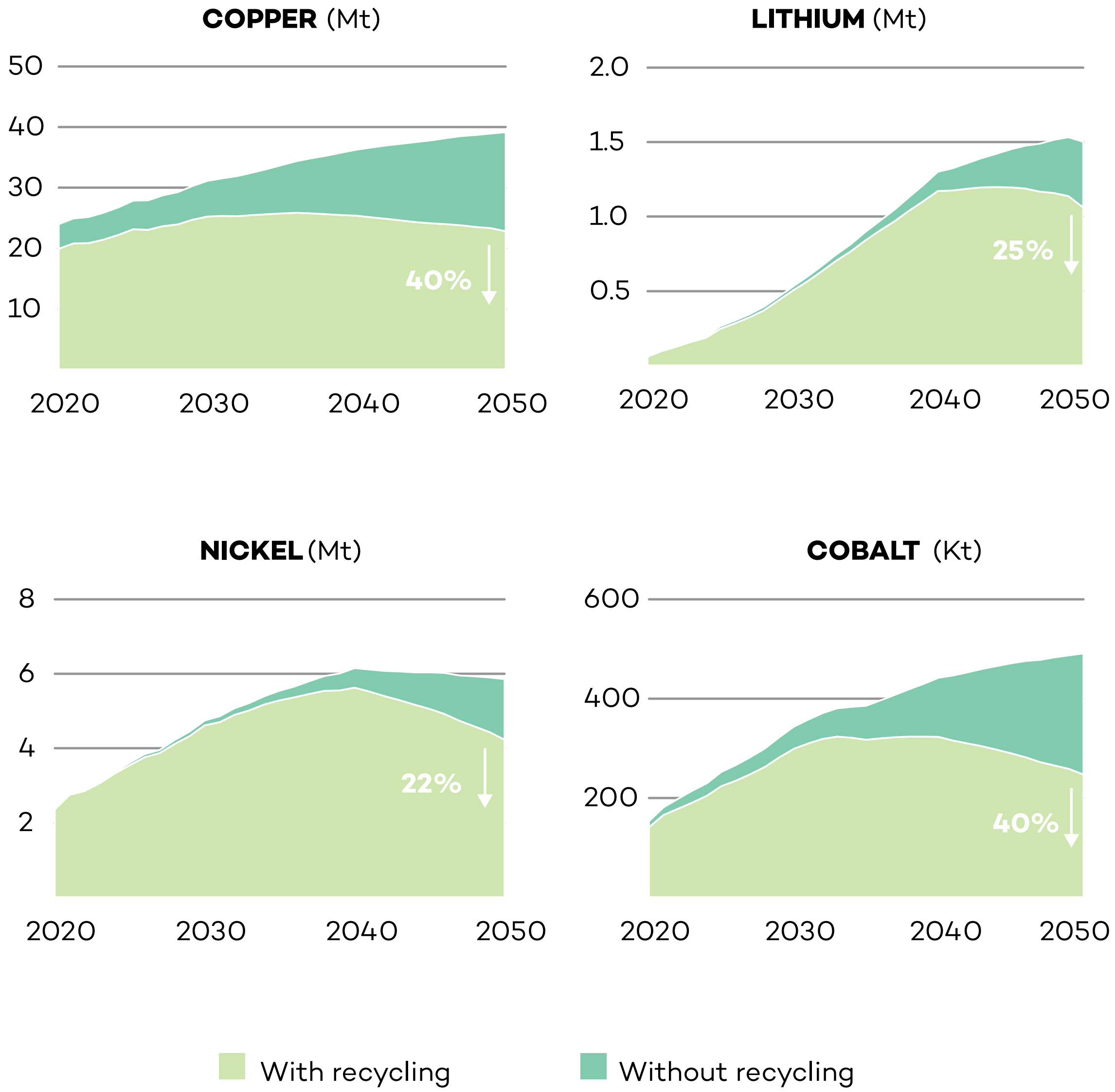
As shown in Figure 30, the contribution of recycled volumes in scenarios up to 2050 demonstrates the potential for secondary material recovery, ranging from 40% for copper and cobalt to 22–25% for nickel and lithium, respectively.

The development of value recovery solutions based on circular economy principles is strongly linked to investment in R&D&I. Recent studies highlight the potential economic returns from implementing solutions based on secondary material recovery, aiming at the decarbonization of the economy[103].

102 https://www.tupy.com.br/tupy-reforca-investimentos-por-meio-do-bndes-mais-inovacao/

103 https://www.tatasustainability.com/pdfs/Resources/_ETC_Report.pdf

Figure 30: Reductions in mining demand due to recycling in the presented scenario.



Source: IEA, 2024[104].

104 IEA, 2024. Recycling of Critical Minerals. https://iea.blob.core.windows.net/assets/3af7fda6-8fd9-46b7-bede--395f7f8f9943/RecyclingofCriticalMinerals.pdf

7. CONCLUDING REMARKS

The current geopolitical scenario is marked by developments that jeopardize the progress of the Paris Agreement, negatively impacting the pace of innovation and the development of technologies for a low-carbon economy. In this context, the projected growth trajectory until 2050 for the demand for critical and strategic minerals, essential for the energy transition, is being reassessed from a more conservative perspective. The current scenario includes an international trade tariff war, disruptions in global supply chains, fluctuations in international prices, and the weakening of multilateral commitments aimed at decarbonizing the economy.

The United Nations, as the custodian and responsible entity for the promotion and continuity of the 2050 Agenda, plays a central role in advancing a just and sustainable energy transition. In 2021, the Secretariat launched the Extractive Industry Transformation Working Group to align mineral development with sustainable development principles. However, the recent shift of the United States toward a growth-centered agenda weakens multilateral commitments to climate security, disrupts UN governance, and pressures companies and investors to follow national directions over global agreements.

In this context, expectations of uncertainty regarding Brazil's position at COP 30 in Belém are growing, while the UN itself faces signs of institutional fragility and resource limitations. Among countries and activists, a lack of leadership and skepticism prevail, contributing to scenarios marked by uncertainty, conservative revisions of critical mineral demand, and a contraction of investments in decarbonization solutions.

Similarly, the Mineral Security Partnership (MSP[105]), in its pursuit of supply diversity, responsible mining, promotion of local economies, and facilitation of sustainable development, demonstrates low expectations given the global geopolitical scenario.

Until December 2024, the boundary conditions and paradigms shaping scenarios for materials and critical minerals over the previous ten years remained relatively stable. The U.S. stance against the Paris Agreement, however, reverberates globally, demanding a reconfiguration of multilateral agreements102 based on sustainability and energy transition references, heightening tension in Sino-American relations and questioning global climate security.

105 MSP – Transnational association led in its organization in 2023 by the United States, European Community, Australia, Canada, Estonia, Finland, France, Germany, India, Italy, Japan, Norway, Republic of Korea, Sweden, United Kingdom.

Although Taiwan has limited mineral resources, it accounts for approximately 60% of global microprocessor production—a sector representing about 15% of its GDP. The country occupies a strategic position both in the mineral input value chain and in advanced technological products, such as smartphones and electric vehicles. Nearshoring with China has enabled the supply of minerals essential to its microprocessor industry. The imminent risk of mineral supply disruption and technology sharing with China, to the detriment of commercial relations with the United States, represents some of the motivations behind the polarization of political and commercial relations, pushing Taiwan toward a more resilient position by seeking to diversify sources of inputs for maintaining productive processes.

The concepts of resilience and flexibility are now prioritized in the competition for mineral resources. While efforts to ensure the diffusion of technological solutions for a low-carbon economy risk not being prioritized as targets by 2050, impacting the demand for critical and strategic minerals, technological advances in information and communication remain a priority. Progress in 5G network technologies, electric vehicles, quantum computing, and artificial intelligence is increasingly widespread and accessible, demanding ever more critical and strategic minerals.

In both scenarios, there is potential growth driven by the pursuit of diversified sources (nations with mineral reserves) or secondary stocks (residual stocks from post-consumer materials) of essential mineral resources to supply production or technological development of products and processes. Therefore, through the densification of the mineral extraction and processing value chain, Brazil can occupy an important position as a supplier of critical and strategic minerals, manufacturer of goods, and recycler of secondary materials in alignment with circular economy strategies. With the eventual strengthening of decarbonization targets, Brazil can consolidate its role as a global leader both in possessing the greenest energy matrix and significant reserves of key critical and strategic minerals.

8. RECOMMENDATIONS TO LEVERAGE THE POTENTIAL OF CRITICAL AND STRATEGIC MINERALS

The growing importance of the mineral sector for climate and energy security, especially regarding critical and strategic minerals, stems from a recent and accelerated set of innovations in both clean energy generation and clean energy technologies, such as solar photovoltaic generation, wind power, batteries, and electric vehicles, which dictate the pace and an increasing demand for these minerals.

All scenarios developed in recent years by various national and international agencies and think tanks point to significant changes in factors expected to impact the future demand for critical and strategic minerals in Brazil and worldwide. These factors range from the development of innovative processes associated with the decarbonization of the economy to the definition of the international trade environment. It is evident that we are witnessing a crucial moment for decision-making that will guide the development of mining in the short, medium, and long term. The sector will play an increasingly strategic role in a greener and more sustainable economy, where geopolitical issues related to the uneven distribution of mineral resources become even more significant.

The driving force for sector development lies particularly in the direction of economic incentives aimed at establishing and consolidating more flexible business models. In this regard, business models based on the scale fit approach, in addition to scale up, tend to provide the required agility in decision-making processes and productive performance with lower risk, as they require fewer resources and infrastructure. In this context, junior companies have already been effectively operating in the MCE ecosystem in Brazil, notably in the growing ETR industry.

Among the conditions impacting Brazil's positioning concerning critical and strategic minerals analyzed in this study are: international political instability regarding the 2050 Agenda commitments, the global advance of decarbonization technologies, national economic growth and mineral sector performance, strategic and economic alignment with producing or consuming nations, and the potential for national innovation.

The densification of the productive chain in the MCE segment constitutes an important strategy for the sector, aiming to promote economic development with job and income generation, integration and maturity of productive sectors, as well as reduced dependence on international inputs and processes. However, political and trade relations need to be broadly considered in decision-making.

Below, the main axes are synthetically analyzed as recommendations for sector development, focusing on decision-making for critical and strategic minerals at the national, regional, and global levels. These axes are extensively detailed in the publication Fundamentos para Políticas Públicas em Minerais Críticos e Estratégicos no Brasil[106], published by IBRAM in 2024.

A. NATIONAL SCOPE

Definitions and alignment of national strategies for market acquisition based on powershoring and circularity principles.

A.1 Incentives for Mineral Production and Processing

Establish financial incentives through the mobilization of resources and prioritization of direction, continuously, through increased investment in R&D&I, junior companies, startups, research centers, and academia.

PROPOSED FISCAL AND TAX INCENTIVES[107, 108] CAN BE IMPLEMENTED FROM THE FOLLOWING ANGLES:

a. Creation of a special customs regime for export and import of goods intended for research, mining, processing, and the production chain of critical and strategic minerals;

b. Exemption from withholding income tax (IRRF) on payments or credits to companies abroad for the use of trademarks, patents, or licenses of technology or processes, when employed in the processing, wholly or partly, of critical and/or strategic minerals in Brazil;

c. Exemption from Cide-Remittances, covering the same cases as the IRRF mentioned above;

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106 Fundamentos para Políticas Públicas em Minerais Críticos e Estratégicos no Brasil, Available at: https://ibram.org.br/publicacoes/e-book/page/2

107 https://www.conjur.com.br/2025-set-14/politica-fiscal-para-minerais-criticos-e-estrategicos-reflexoes-a-partir-da-experiencia-estrangeira/

108 https://www.cnnBrazil.com.br/economia/macroeconomia/governo-planeja-serie-de-decretos-para-minerais-criticos-e-estrategicos/

d. Explicit inclusion in the Lei do Bem (Law nº 11.196/2005), dof legal entities that develop critical and/or strategic mineral projects;

e. Extension of REIDI (Law nº 11.488/2007) to the mining and processing of critical and/or strategic minerals and the related production chain, allowing suspension of PIS/Cofins on acquisitions of goods and services for project infrastructure. By exempting PIS/Cofins on acquisitions via REIDI, the miner avoids the need to appropriate credits that would require reimbursement, gaining a cash flow effect;

f. Update Article 5, II, of Decree nº 6.144/2007, including mineral infrastructure essential for the energy transition in the "energy sector," covering the generation and transmission of electricity from hydro, wind, nuclear, solar, and thermal sources;

g. Allow full deduction of personal income tax (IRPF) for companies regarding mineral research expenses in the year incurred. Development (pre-production) expenses could be amortized at an accelerated rate, e.g., 30% per year;

h. Refundable corporate tax (IRPJ/CSLL) credits applied to expenditures necessary for the development of critical and strategic mineral projects: in the mineral research/exploration phase and in the industrial plant/refinery development phase;

i. Processing, refining, and transformation projects of MCEs—when structured as infrastructure works and directly related to storage/generation/transmission/electric mobility chains—are functionally included in the "energy sector," according to Article 2 of Law nº 11.488/2007 and may qualify as energy sector infrastructure when intended to enable energy technologies (storage, renewable generation, electric mobility, wind/solar networks, etc.);

j. Accelerated depreciation and amortization of fixed assets, intangibles, and/or financial assets acquired for the development of industrial plants/refineries;

k. Zero IOF rate on foreign exchange operations related to investments, by debt or capital, in critical and strategic mineral projects; and on credit operations, domestic and foreign, related to financing these projects;

l. Zero import duty on the acquisition of machinery, equipment, and intermediate products necessary for critical and strategic mineral projects.

A.2 Workforce Training and Capacity Building

Establish integrated centers for training and developing specialized human resources in different segments of the sector, including support areas such as equipment maintenance, environmental management, and regulatory compliance.

A.3 Infrastructure Development

Establish mechanisms for the provision and management of resources (water, energy, and waste) in an integrated and efficient manner, based on industrial ecosystem concepts, as well as the structuring of integrated access routes.

A.4 Digitalization of Mining

Develop and enhance applications that integrate digital technologies into mineral sector operations, enabling traceability and process optimization through efficient use of resources, thereby increasing safety and sustainability in the sector.

A.5 Production Chain Densification

Support production specialization by implementing processes that advance to the midstream, downstream, and green manufacturing stages, as well as recovery based on the circular economy concept.

A.6 Mechanisms to Stimulate MCE Demand

Promote R&D&I for the development and enhancement of processes and products that drive domestic and export demand for critical and strategic minerals, including resource mobilization, infrastructure consolidation, and training of researchers, process and product engineers[109, 110] Encourage the creation of new businesses based on the increased use of critical and strategic minerals and materials.

A.7 Mecanismos de formação de demanda por MCEs

Promover a PD&I para o desenvolvimento e aprimoramento de processos e produtos que puxem a demanda por Critical Minerals e Strategics no mercado doméstico e com vistas também à exportação, considerando captação de recursos, consolidação de infraestrutura, formação de pesquisadores, engenheiros de processos e de produtos e, ainda, fomento a criação de novos negócios baseados em maior uso de minerais e materiais críticos e Strategics;

A.8 Optimization of Processes and Products

Given the imbalances in implementing solutions based on R&D&I, disparities already evident between nations may worsen. Brazil should prioritize incentives for the use of

109 https://p3mgeo.sgb.gov.br/

110 https://www.gov.br/anm/pt-br/anm-lanca-paineis-interativos-para-dados-economicos-do-setor-mineral

shared infrastructure, application of artificial intelligence, and digital and automated tools for rapid implementation of mechanisms to improve process and product efficiency, as well as the prediction and mitigation of socio-environmental impacts.

A.9 Transparent and Effective Application of the Mining Financial Compensation (CFEM)

Enable the allocation of CFEM resources to R&D&I, in accordance with the legal provisions of Law nº 13.540/2017 [111] ("Art. 2º", § 2º, item III), as well as investments in preventive and mitigative measures for potential socio-environmental impacts.

Ensure the regularity of federal transfers to the entities specified in Law nº 13,540/2017 ("Art. 2", §2) and maintain transparency in both revenue and public expenditures related to CFEM application.

A.10 Competition Among Federal Entities

The state of Goiás, the main national producer of rare earths in Brazil, established via Law nº 23.597/25[112] the Goiás State Critical Minerals Authority (Amic-GO), which sets up Special Zones for Critical Minerals (ZEMC) and creates the State Fund for Critical Minerals Development (FEDMC).

AMIC-GO will be directly linked to the State Government, with administrative, financial, and technical autonomy to plan, promote, regulate, and supervise all activities related to critical minerals in Goiás.

The state of Minas Gerais, pioneer in lithium production, launched through its Secretariat of Economic Development the strategic project "Vale do Lítio"[113], aiming to position the state as a global leader in the lithium value chain. Actions and incentives from the Lithium Valley Project are carried out through coordination and collaboration with state government bodies, municipalities, federal entities, companies, industry representatives, and civil society.

The Secretariat of Economic Development (SEDE) is responsible for overall coordination of the project, ensuring articulation among various actors and monitoring the implementation of actions. The Secretariat of Planning and Management (SEPLAG) monitors activities related to human development axes and sectoral policies.

111 https://www.planalto.gov.br/ccivil_03/_ato2015-2018/2017/lei/l13540.htm

112 https://portal.al.go.leg.br/noticias/157683/minerais-estrategicos-e-terras-raras

113 https://desenvolvimento.mg.gov.br/inicio/projetos/projeto/1170

B. REGIONAL SCOPE

Integrated actions within the framework of relations between BRICS countries, the Global South, and Latin America, according to nearshoring and friendshoring dynamics.

B.1 Alignment of Regional Goals Among Countries

Promote the development of integrated actions for sustainable production and consumption (SDG 12) based on the convergence of common interests among mineral-producing or consumer nations.

B.2 Policy Alignment Based on Geological and Productive Potential

Harmonize regulations for the mineral sector among countries eligible for friendshoring to enable geological mapping, maximize mineral production, encourage commercial environments for the sector, and promote workforce training.

B.3 Promotion of Logistics Development

Prioritize structuring and optimizing logistics routes between neighboring countries to integrate processes and reduce costs in the medium and long term.

B.4 Economic Incentives for Junior Companies

Promote mechanisms to attract international junior mining companies with a focus on nearshoring strategy, particularly for actions that specialize the value chain based on minerals of shared interest.

C. GLOBAL SCOPE

Perspectives for integration with other countries and national leadership in the MCE sector.

C.1 Mitigating Supply Risk of MCEs

Contribute to the establishment of a global environment for sustainable mineral production, based on artificial intelligence tools and circular economy concepts, aiming to reduce uncertainty regarding supply and increase credibility in MCE availability.

C.2 Positioning Regarding Economic Sanctions and Global Perspectives

Contribute to defining a political and strategic alignment for different MCEs to establish clear national stances on economic sanctions and agreements of intent with producing and consuming nations.

C.3 Formation of an Integrated Mineral Supply and Demand Data Network

Contribute to creating a global integrated information network on MCE supply and demand to align short-, medium-, and long-term actions regarding the provision of mineral inputs, semi-manufactured goods, and finished products.

C.4 Implementation of Integrated Traceability Networks

Develop and implement international trade information monitoring networks to ensure traceability of irregular operations, as well as manage data to increase predictability and reduce uncertainty in MCE management.

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Part II

TECHNOLOGICAL ROADMAP

9. TECHNOLOGICAL ROADMAP OF THE VALUE CHAIN

Significant advances have been made possible through the consolidation of information on Brazilian critical and strategic minerals, contributing to the improvement of different stages of the value chain, generating employment, enabling the identification of investment opportunities, and expanding knowledge about the mining sector.

Beyond analyzing minerals relevant to Brazil's trade balance and critical for supplying fundamental sectors of the economy, the technological roadmap allows the identification of the potential of minerals across a temporal scale and at different stages of the value chain.

This study expands the analysis presented in the previous roadmap (2024), using data obtained from the Comexmin[114] platform of the National Mining Agency (ANM). The platform correlates traded volumes with the National Classification of Economic Activities (CNAEs), allowing for an advanced understanding of the maturity of the value chain, although it does not cover all materials present in final products, which requires complementary studies.

Thus, this stage of the study presents the analysis of 17 minerals (aluminum, cobalt, copper, tin, phosphate, graphite, lithium, manganese, iron, niobium, nickel, gold, potassium, silicon, tantalum, titanium, and zinc), as well as the rare earth elements (REEs) and the platinum group metals (PGMs).

For the value chain analysis, the production stages of the substances and minerals analyzed were divided into the following classes:

- **UPSTREAM:** corresponds to the mining stage and its products, such as mineral substances obtained from the beneficiation of mineral resources;

- **MIDSTREAM:** includes fractions of mineral concentrates and stages of the chemical industry, corresponding to the production of chemical compounds (oxides, hydroxides, carbonates, etc.) and metallurgical products, which in turn subdivide into steel products, castings, metals, and alloys (e.g., rolled sheets, etc.);

114 https://www.gov.br/anm/pt-br/anm-lanca-paineis-interativos-para-dados-economicos-do-setor-mineral

- **DOWNSTREAM[115]:** represents final products that can be classified based on mineral substances, or predominantly containing the analyzed substance, when the class includes the terms "works of," parts and components, accessories, and products (e.g., wires and cables, pipes, accumulators, etc.);

- **RECOVERY:** includes the recovery of substances from post-consumer products or substances resulting from productive processing, regardless of their position in the value chain, which may be identified as waste, residues, ashes, scraps, shavings, among others.

As cadeias de valor, neste novo formato de classificação, ainda que a nível de substância, permitem vislumbrar as etapas produtivas de cada mineral. A análise se utiliza dos dados de produção nacional e dados comércio exterior, com o objetivo de verificar se as etapas da cadeia refletem a maturidade do setor sob a perspectiva de volumes negociados, além de indicar as lacunas e possíveis demandas para a política industrial Brazileira.

The data comprising the traded values in Brazil (imports and exports) of minerals and substances defined as strategic or critical for the roadmap were identified and considered from the foreign trade data classes provided on the ComexStat[116] platform and the IBGE Automatic Retrieval System – SIDRA[117].

The following sections present the fact sheets of the critical and strategic minerals (CSMs) analyzed in the study, providing an overview of the minerals, best practices, future outlook, production data, export and import data organized as a Material Flow Analysis (MFA) for each stage of the value chain, and the respective Technological Roadmap.

115 Materiais multicompósitos, como eletroeletrônicos e outros requerem análises mais aprofundadas.

116 https://comexstat.mdic.gov.br/pt

117 https://sidra.ibge.gov.br/Table/7752

ALUMINUM

UPSTREAM MINING — Aluminun ore (Bauxite)

MIDSTREAM CHEMICALS/METALLURGY — Chemicals (aluminates, phosphates), powders, flakes, alloys, sheets, etc.

DOWNTREAM FINAL PRODUCTS — Wires and cables for winding, capacitors, etc.

RECOVERY RECUPERAÇÃO — Waste, residues, ashes, scraps.

Overview and demand

Aluminum is a highly versatile metal, widely used across various industrial sectors due to its physicochemical properties. It stands out for its low density, high corrosion resistance, good thermal and electrical conductivity, as well as excellent malleability and recyclability. These characteristics make aluminum a strategic material for applications in the automotive, aerospace, construction, electronics, and packaging industries, among others.

With large reserves of the ore and ongoing investments in technology, Brazil seeks greater efficiency and control over its production chain. Recycling, which consumes 95% less energy than primary production, makes the sector more sustainable and aligned with decarbonization targets, reinforcing the strategic role of aluminum in the circular economy.

Aluminum production in Brazil is characterized by a vertically integrated value chain, encompassing all stages of the process, from bauxite extraction to refining, reduction, final transformation, and manufacturing of finished products. The metal's ability to be recycled indefinitely without compromising its physicochemical properties makes it a strategic input for the circular economy. Primary aluminum production from bauxite is among the industrial processes with the highest global electricity demand.

The high recycling rate in Brazil, supported by a predominantly renewable energy matrix, enhances efficiency and sustainability. The aluminum recycling process consumes 95% less energy than primary production, significantly contributing to decarbonization in industries such as transportation, packaging, energy, and construction.

In 2024, Brazil maintained its position as the fourth-largest global producer of bauxite, producing 33 million tons. It is also the fourth-largest holder of bauxite reserves worldwide (2.7 Gt), representing 9% of the global total (SGB, 2025). The main producing states include Pará, Minas Gerais, and Goiás, with major companies such as MRN (Mineração Rio do Norte), Alcoa, CBA, Norsk Hydro, and Terra Goyana.

According to ABAL, primary aluminum production reached 1.1 million tons in 2023[118]. In the second quarter of 2025 alone, Alcoa produced 543 tons of primary aluminum, showing continuous growth over the past three years.

Aluminum consumption in Brazil reached 1.8 million tons in 2024, representing an increase of approximately 13.5% compared to the previous year[119]. Driven by the construction sector due to the resumption of major projects and investments, demand is expected to grow further in the energy sector with increased need for aluminum cables for installation and maintenance of power grids. Despite growth in national production potential, protectionist tariffs have limited exports since March 2025, with a decrease of around 25% in aluminum exports in the first half of 2025[120].

ABAL data shows that aluminum recycling reached 904,000 tons in 2022[121], corresponding to 50% of national consumption. Primary aluminum production costs are concentrated in alumina production (38%) and energy consumption (32%), according to Companhia Brasileira de Alumínio (CBA, 2020[122]). These factors indicate that primary aluminum processing costs and the drive for decarbonization make aluminum recycling highly competitive for meeting domestic demand.

China accounts for 60% of global alumina and aluminum production. Brazil, with 13 mines in operation and 33 Mt of bauxite production in 2024[123],was the third-largest global alumina producer and ranked eighth in aluminum production. In alumina production, Brazil benefits from predominant use of clean energy (hydroelectric) and low CO_2 emissions. The aluminum value chain generated 512,000 direct jobs and a turnover of R$ 135.1 billion in 2023[124].

In the recovery stage, Brazil also stands out with a 99% recycling rate for beverage aluminum cans in 2023 (world-leading), while the industry recycled 850,000 tons of aluminum. This represents 57% of domestic aluminum product consumption, compared to the global average of around 30%.

118 https://www2.camara.leg.br/atividade-legislativa/comissoes/comissoes-permanentes/cft/apresentacoes-em-eventos/apresentacoes-de-convidados-em-eventos-2025/audiencia-publica-impactos-a-economia-brasileira-com-o-aumento-das-tarifas-dos-eua/associacao-brasileira-do-aluminio-abal/view

119 Brasil Mineral. Abril de 2025. https://www.brasilmineral.com.br/noticias/consumo-de-aluminio-no-brasil-cresce-135-em-2024

120 Valor Econômico. Julho de 2025. https://valor.globo.com/empresas/noticia/2025/07/10/setor-de-aluminio-pede-resposta-diplomatica-e-comercial-calibrada-e-estrategica-aos-eua.ghtml

121 https://www.linkedin.com/posts/aluminioabal_abal-ind%C3%BAstriadoalum%C3%ADnio-sustentabilidade-activity-7308204211362566147-GjMM/?originalSubdomain=pt

122 https://conteudos.xpi.com.br/acoes/relatorios/companhia-brasileira-de-aluminio-cbav3-crescimento-com-qualidade-de-um-dos-lideres-em-custos-de-producao-iniciando-a-cobertura-com-compra/

123 SGB - An overview of critical and strategic minerals potential of Brazil, 2025.

124 121 ABAL Interview – Base year 2023

Figure 31: Bauxite: Reserves by Country

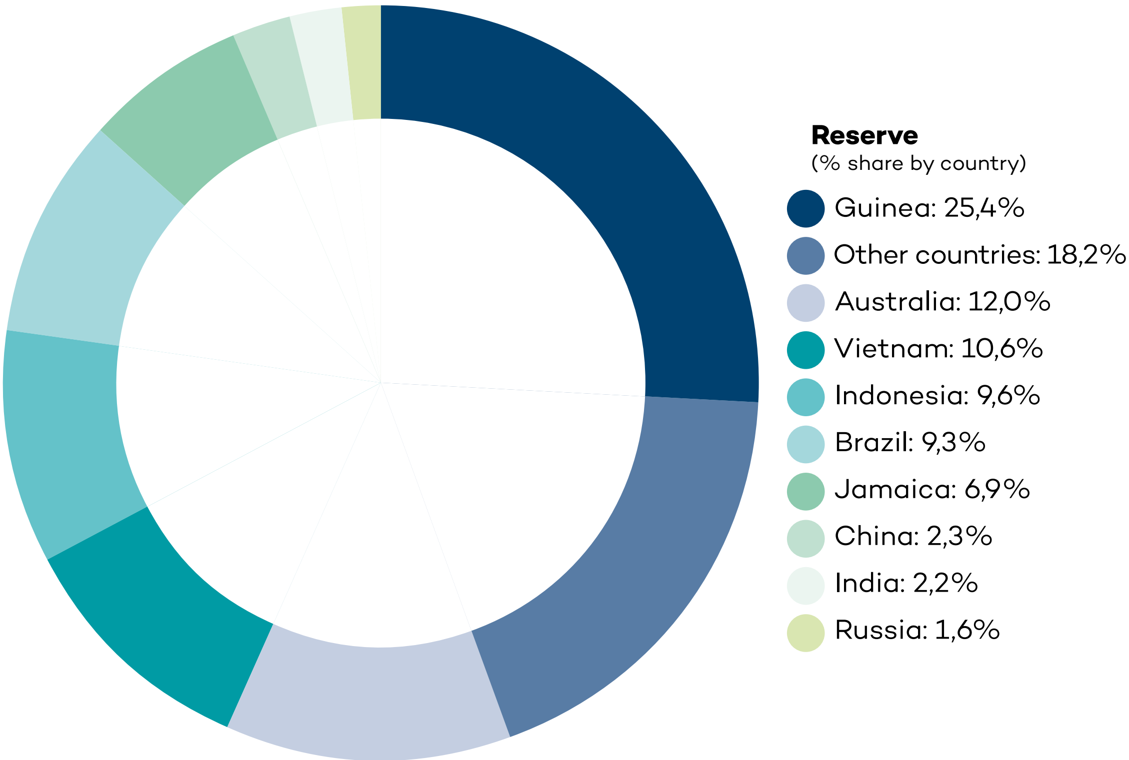
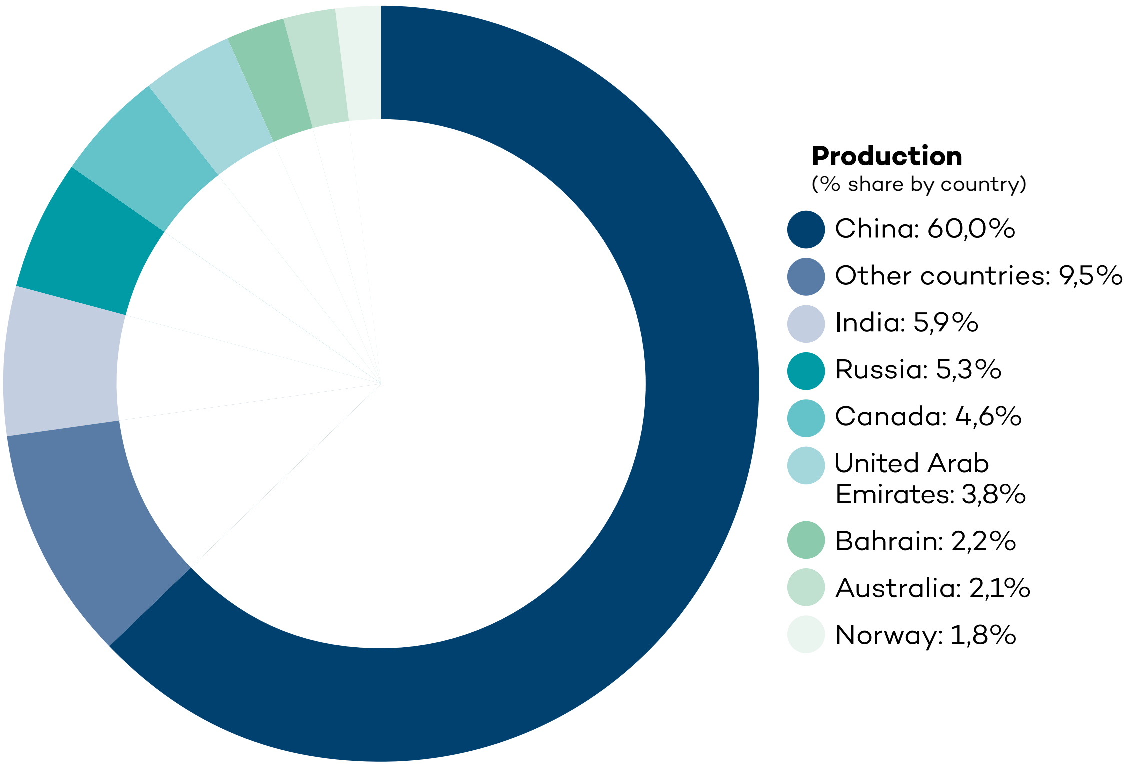


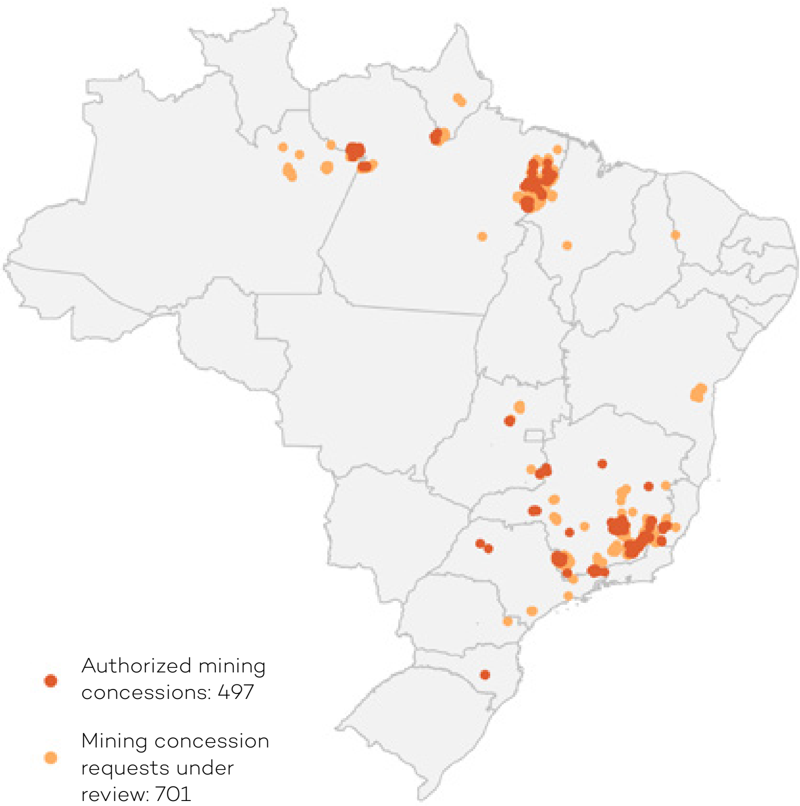
Figure 32: Aluminum: Production by Country



Source: USGS, 2025

Figure 33: Map of Authorized Aluminum Exploration in Brazil (2025)

Figure 34: Map of Aluminum Mining Concessions in Brazil (2025)



Best Practices

In 2023, aluminum scrap recycling in Brazil totaled approximately 850 thousand tons, corresponding to about 57% of the national metal consumption during the period. This performance significantly exceeds the global average, estimated at around 30%, highlighting the strategic importance of aluminum recycling within the circular economy and its contribution to carbon emissions mitigation.

In 2024, Mineração Rio do Norte (MRN) achieved, for the sixth consecutive year, the Gold Seal from the Brazilian GHG Protocol Program, recognizing its greenhouse gas (GHG) management practices. In 2023, the company reduced its emissions by 21% and set a target to reduce GHG emissions by 23% by 2030. In addition to the Gold Seal, MRN is certified under ISO 14001 and the Aluminium Stewardship Initiative (ASI), reaffirming its commitment to sustainability.

Alcoa has invested in renewable energy to achieve its Net Zero target by 2050, with initiatives such as 100% renewable energy use at Alumar (MA) and the conversion to natural gas in Poços de Caldas (MG), resulting in carbon emission reductions. The company also implemented a Filter Press in Poços de Caldas to improve waste management and invests in technologies such as Elysis, which eliminates GHGs in the aluminum reduction process. These efforts are part of a global energy transition strategy, focusing on green aluminum and low-carbon products. Alcoa is recognized for its sustainable operations and participates in initiatives such as the Aluminium Stewardship Initiative (ASI).

CBA has excelled in adopting circular economy practices, transforming waste into raw materials for new production processes. In 2023, co-products generated at the Aluminum plant (SP) accounted for 33% of total waste, generating R$ 18 million in revenue, a 27% increase compared to the previous year. The company also invests in decarbonization, producing aluminum with 100% renewable energy and emissions of only 2.56 t CO_2e/t aluminum, below the global average of 12.8 t CO_2e/t. By 2030, targets include a 40% reduction in emissions in alumina and furnace production, 35% in the production chain, and 13.5% in Scope 3 emissions. CBA is certified by the Aluminium Stewardship Initiative (ASI) and was recognized in the 2025 Sustainability Yearbook by S&P Global.

Hydro renewed its Technical-Scientific Cooperation Agreement with the Federal University of Pará (UFPA) until 2029, initiated in 2020. The program has already invested R$ 15 million and benefited 180 professionals in 17 projects. The partnership aims to strengthen research, especially focused on decarbonization, circular economy, and waste reuse, such as using açaí seeds as biomass and developing low-carbon cement. The collaboration also promotes qualified technical training and integration between university and industry, benefiting Hydro operations in Pará.

Future Outlook

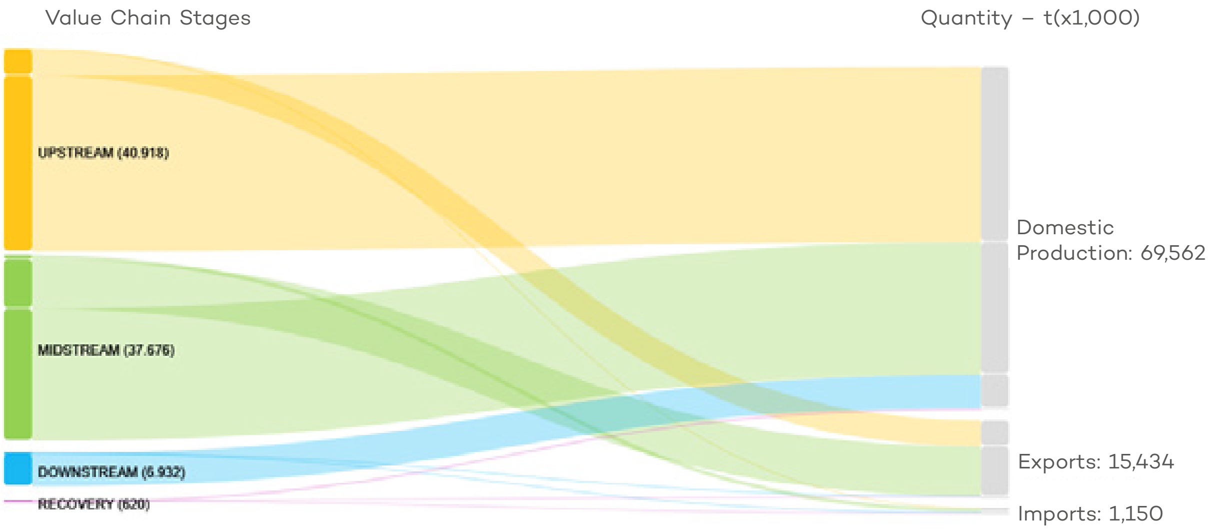
Aluminum plays an essential role in the energy transition, being crucial for the production, transmission, and utilization of renewable energy. Its properties, such as lightness, corrosion resistance, and recyclability, make it ideal for various applications in this sector. Aluminum is used in manufacturing essential components for wind turbines, solar panels, and other renewable energy generation systems, contributing to the efficiency and durability of these technologies.

Moreover, aluminum cables are widely used in electric power transmission and distribution networks, enabling efficient delivery of generated energy to consumers. It is also used in battery construction and other energy storage systems, helping ensure grid stability and reliability.

Regarding energy efficiency, aluminum is critical across various sectors, such as transportation, construction, and industry, contributing to reduced energy consumption and carbon emissions. Its high recyclability allows material reuse, reducing energy consumption and greenhouse gas emissions associated with primary production.

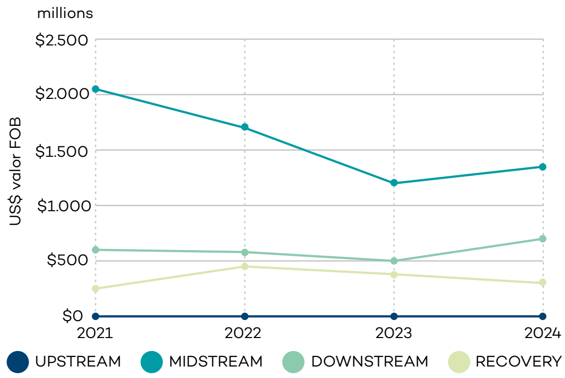
In summary, aluminum is a strategic material for the energy transition, supporting the production, transmission, storage, and efficient use of renewable energy while promoting sustainability and reducing carbon emissions.

Figure 35: Material Flow Analysis (MFA) of Imported and Exported Volumes in Relation to Industrial Production Data According to Aluminum Value Chain Stages for the Year 2021

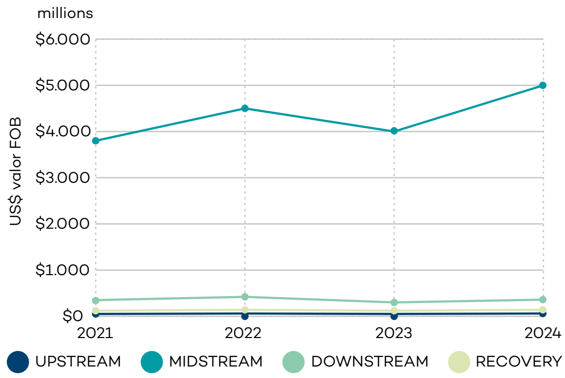


Source: Data obtained from the ComexStat Platform, 2025 (for the year 2021) and from Industrial Production data (SIDRA/IBGE) for 2021.

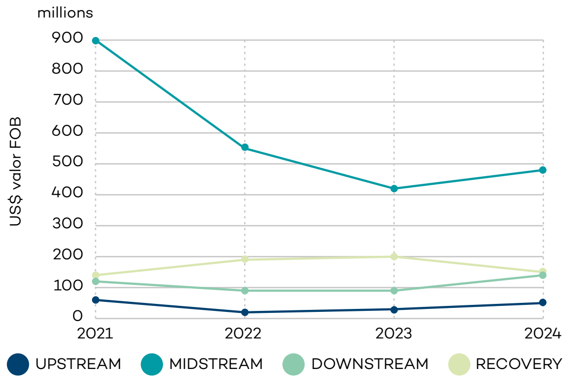
Graph 1. Aluminum: Imports in Value FOB US$ (millions) between 2021 and 2024



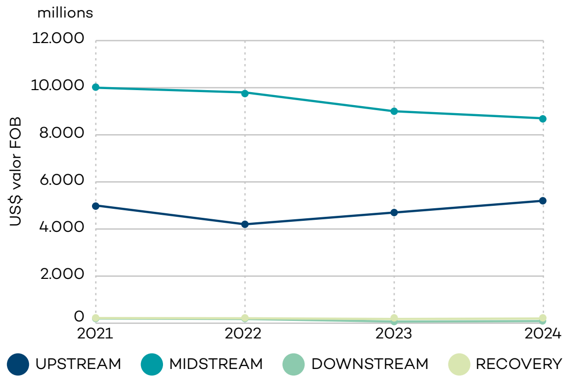
Graph 2. Aluminum: Exports in Value FOB US$ (millions) between 2021 and 2024



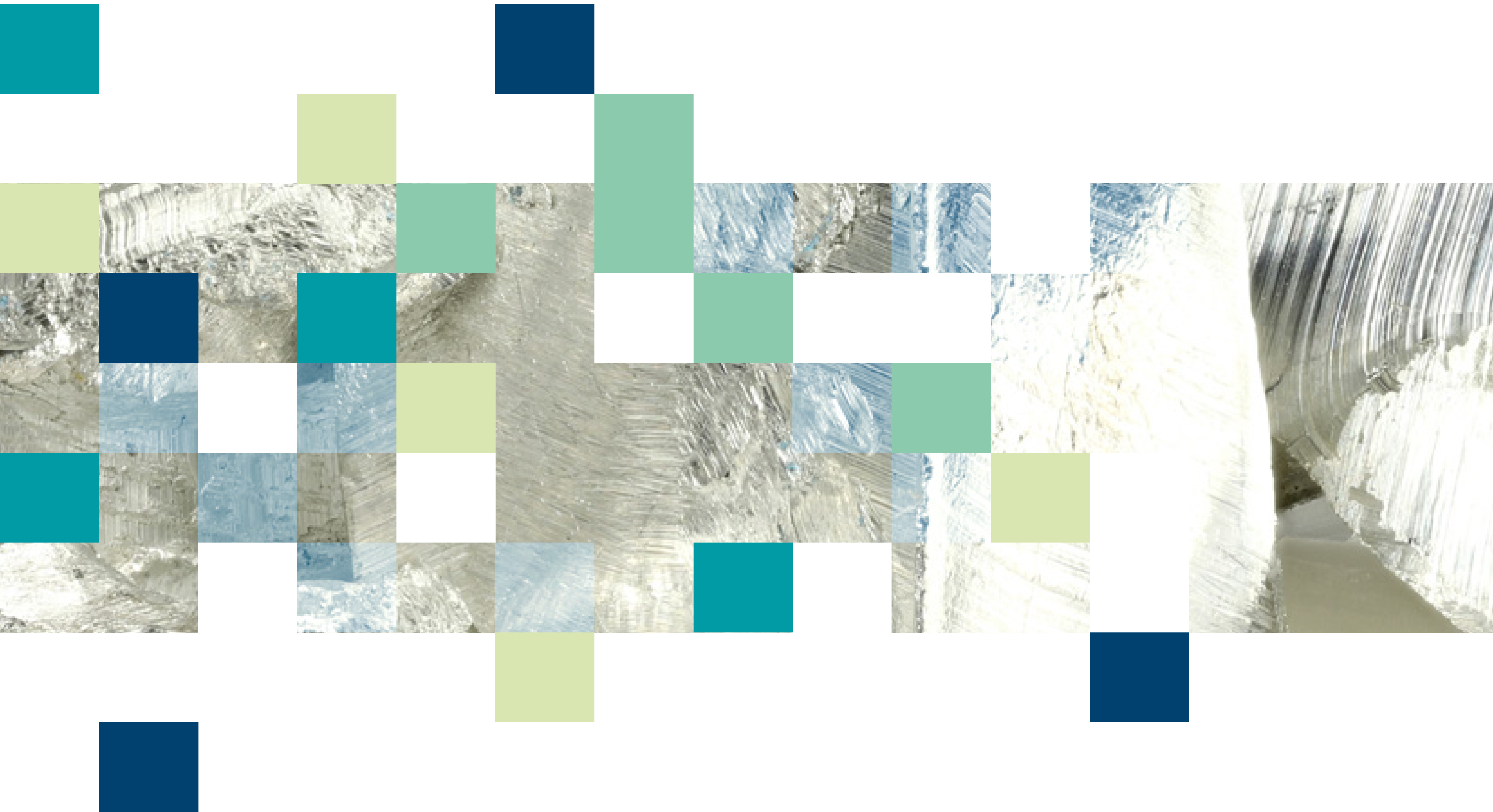
Graph 3. Aluminum: Imports in Net Kg (millions) between 2021 and 2024



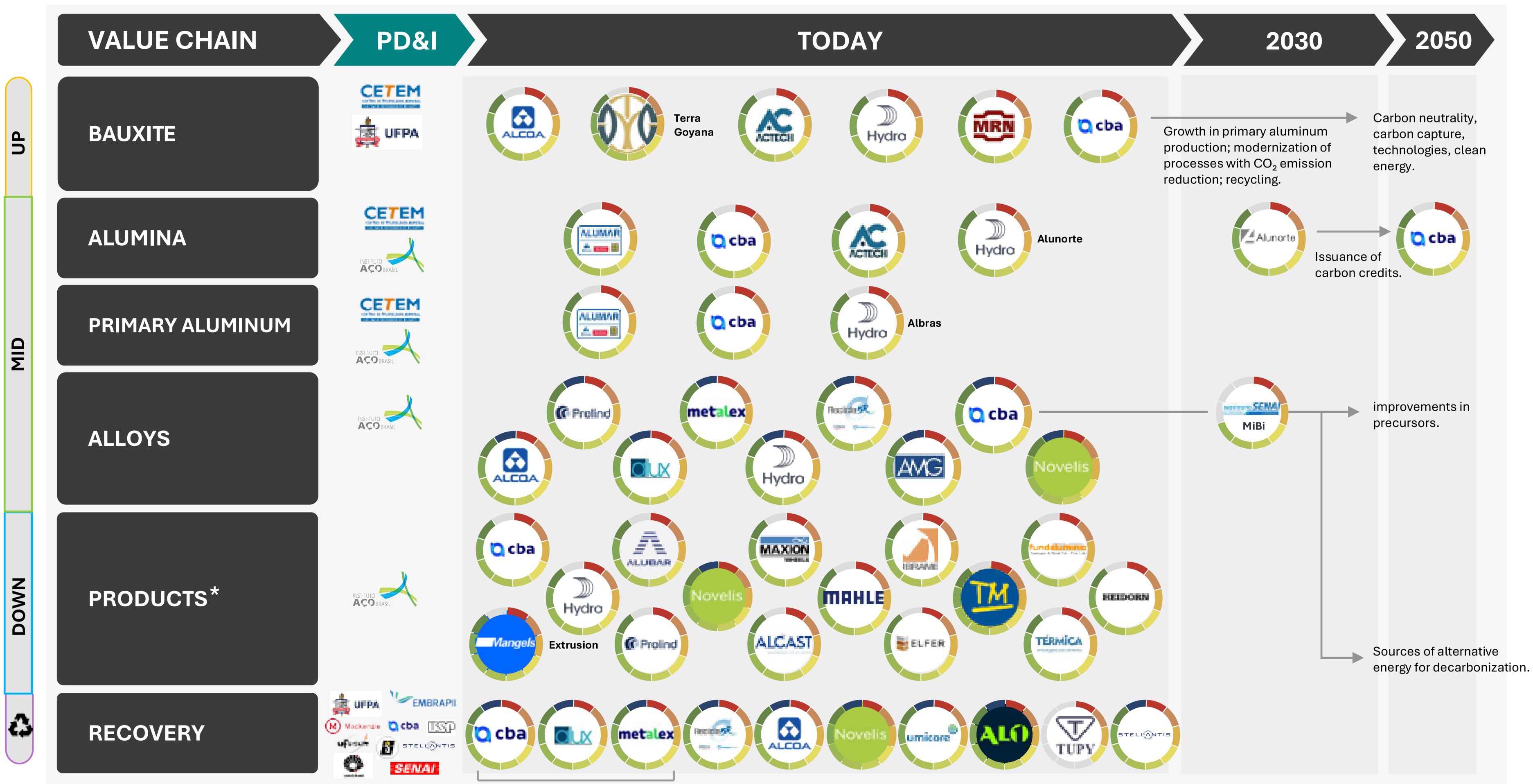
Graph 4. Aluminum: Exports in Net Kg (millions) between 2021 and 2024



Source: Data obtained from the ComexStat platform, 2025.



ALUMINUM



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https://www.hydro.com/pt-BR/aluminium/sobre-aluminio/aluminium-recycling/
https://abal.org.br/sustentabilidade/reciclagem/reciclagem-no-brasil/
https://www.cometais.com.br/reciclagem-de-residuos-de-aluminio/
https://www.brasilmineral.com.br/noticias/demanda-pelo-metal-deve-crescer-40-ate-2030
https://www.brasilmineral.com.br/noticias/hydro-renova-parceria-com-ufpa-ate-2029

COBALT

UPSTREAM MINING — Cobalt ore

MIDSTREAM CHEMICALS/METALLURGY — Chemicals (oxides, hydroxides, chlorides), powders, compounds, alloys, etc.

DOWNSTREAM FINAL PRODUCTS — Pellets, tablets, wires, works and components for batteries

RECOVERY RECUPERAÇÃO — Waste, residues from cobalt metallurgy

Overview and demand

Cobalt does not occur in its elemental state and is typically found associated with lead, copper, tin, nickel, platinum, palladium, silver, gold, and manganese ores. Its main applications are in the production of superalloys for aircraft turbines, providing corrosion resistance, and as a key component in lithium-ion batteries and various electronics (laptops, cell phones, TVs).

The global supply of cobalt ores and concentrates[125] comes primarily from the Democratic Republic of Congo (DRC), which in 2023 accounted for 73% of global production, about 170,000 tons, projected to rise to 202,700 tons in 2024, representing 75.6% of global production. Indonesia produced around 17,000 tons in 2023 (7.3% of the total), projected to grow 79.89% to 32,000 tons in 2024, driven by nickel industry expansion and hydrometallurgy projects. Russia produced 8,800 tons (3.8%), Canada 5,000 tons (2.2%), and Australia 4,600 tons (2%), with significant reserves (1.7 Mt) mostly in nickel deposits. Other contributors include the Philippines, Cuba, Madagascar, and the USA, with the latter resuming activities in Idaho, Montana, and Missouri but still dependent on imports. China controls 80% of global cobalt refining.

In Brazil, cobalt reserves are estimated at 70 kt. Production was interrupted in recent years due to economic feasibility, but between 2010–2017, Brazil produced around 20,198 tons, representing 2.6% of global production. According to the Brazilian Mineral Yearbook (AMB, 2024[126]) there are six nickel mining areas and five processing plants (three large, two medium), along with 173 Exploration authorizations.

Votorantim Metais (now Nexa Resources) has been the main producer, supplying cobalt for chemical industries (cobalt sulfates and octoates) and manufacturers of special alloys and superalloys, a sector still underdeveloped in Brazil.

125 https://natural-resources.canada.ca/minerals-mining/mining-data-statistics-analysis/minerals-metals--facts/cobalt-facts

126 https://www.gov.br/anm/pt-br/assuntos/economia-mineral/publicacoes/anuario-mineral/anuario-mineral--Brazileiro/anuario-mineral-Brazileiro-principais-substancias-metalicas-2024

Figure 36: Cobalt: Reserves by Country

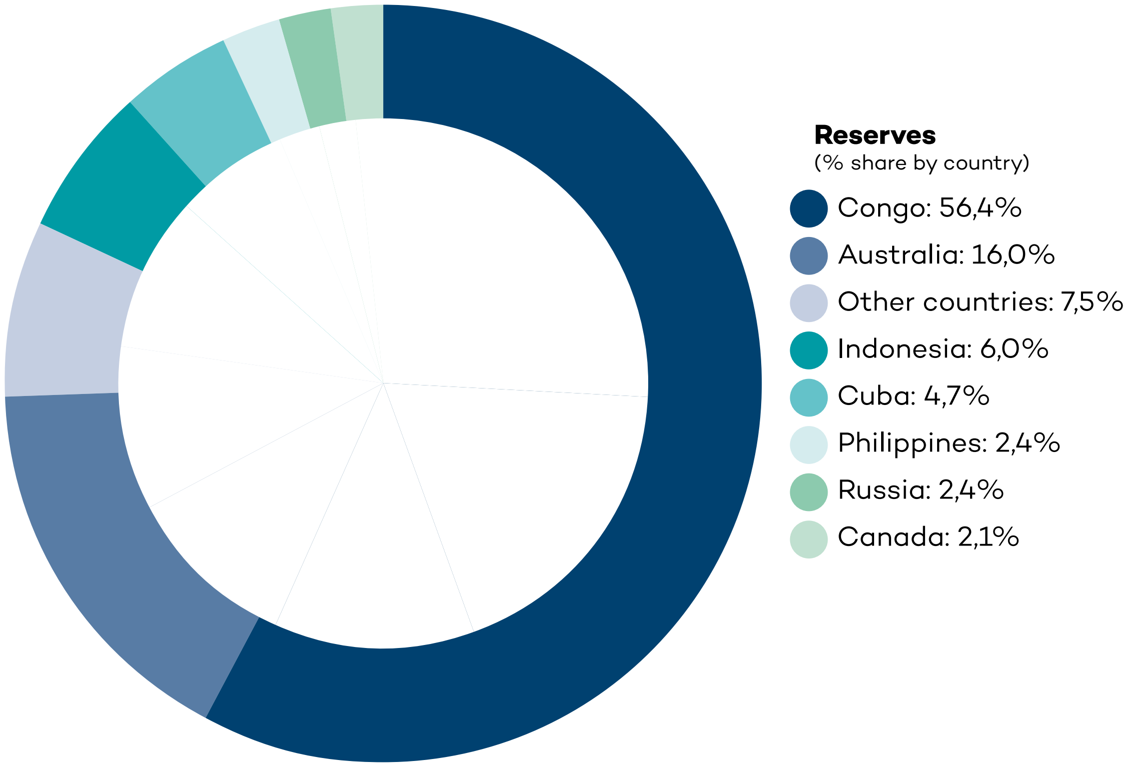
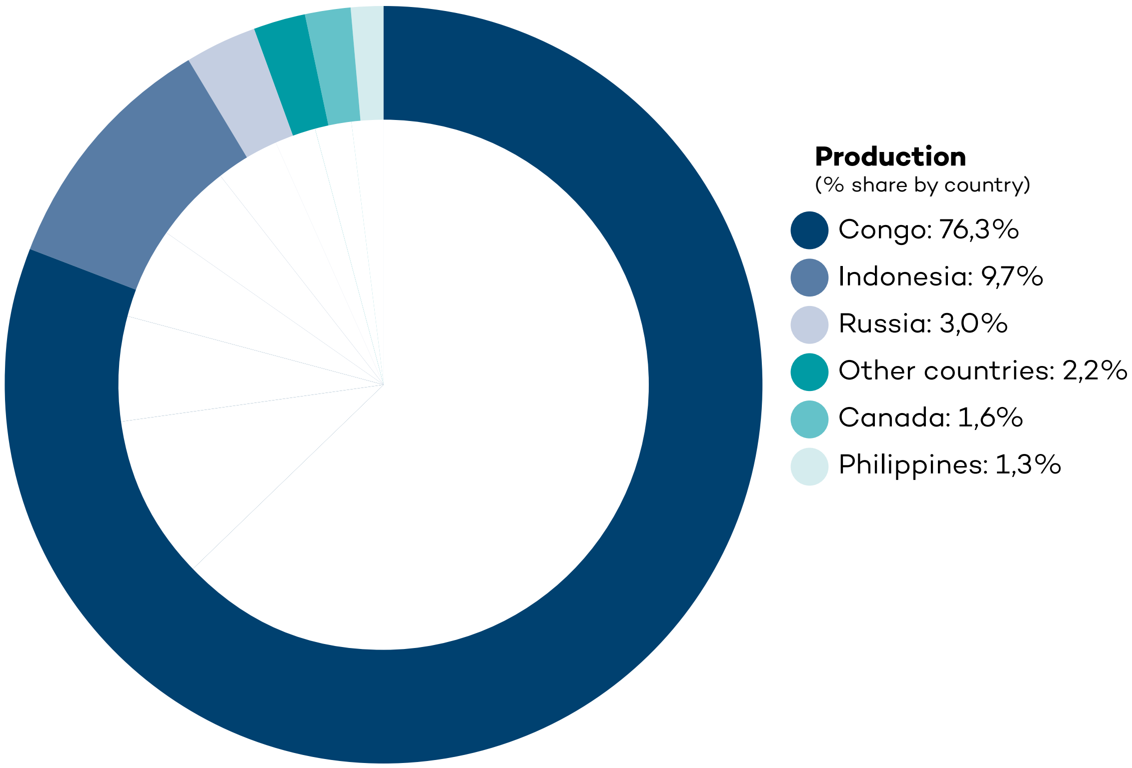


Figure 37: Cobalt: Production by Country



Source: USGS, 2025

Figure 38: Map of Cobalt Exploration Permit Authorizations in Brazil (2025)

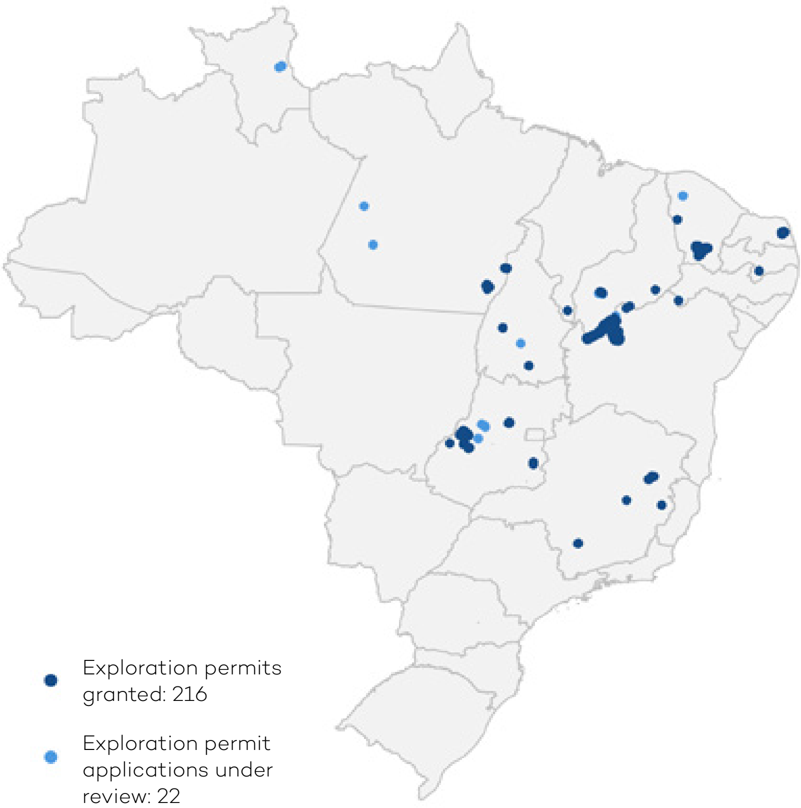


Figure 39: Map of Cobalt Mining Concessions in Brazil (2025)

Best Practices

The metallurgical processing method for cobalt extraction varies significantly according to ore mineralogy and grade, the desired final product and its purity, while also considering environmental regulations, logistics, and economic and technological risks. Pursuing sustainable cobalt mining requires mineral efficiency, minimization of risks and environmental impacts, and metal recovery from existing mines to reduce the volume of limonitic tailings. For sulfide or oxidized ores, processing is commonly integrated with copper or nickel production through hydrometallurgy, involving calcination (for sulfides), leaching, base metal electrolysis, subsequent removal of cobalt-containing impurities, followed by selective precipitation and cobalt electrowinning. Lateritic ores, on the other hand, are generally processed via pyrometallurgy, influenced by iron and Manganesecontent, as exemplified by Codemin in Niquelândia (GO). Nickel matte flotation is another route to extract cobalt from sulfide ores, used by Nexa Resources in Fortaleza de Minas (MG). A promising future perspective lies in the exploration of shallow-water cobalt deposits, particularly marine nodules and polymetallic sulfides in cobalt-rich and ferromanganese crusts, which represent potential sources of multiple strategic metals.

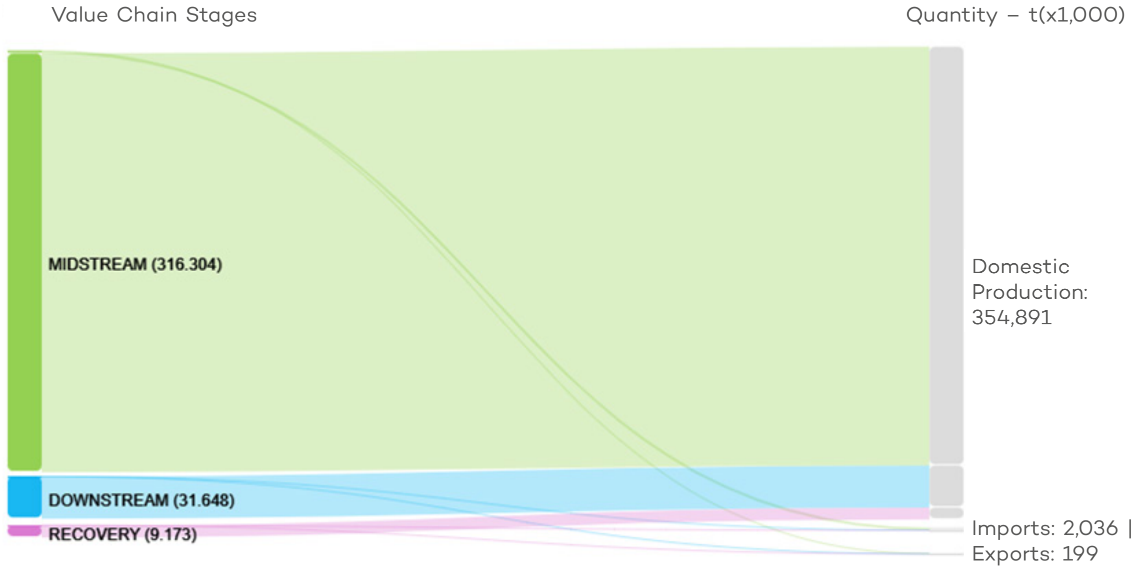
Future Outlook

Given the global production dominance of cobalt in the Democratic Republic of Congo (DRC), Brazil has the opportunity to stand out by promoting mining with higher socio-environmental credibility. In the DRC, approximately 30–50% of production comes from artisanal mining, associated with labor and environmental issues.[127]. Technological characterization studies of nickel and manganese deposits (sulfide and lateritic) are crucial to identify and quantify cobalt content. To enable national production, investment in R&D&I is essential to develop extractive metallurgy processes (including biohydrometallurgy and cobalt recovery from magnesian laterites) and technologies for the economic exploitation of cobalt in offshore deposits on the Rio Grande Rise.

The PROAREA Program (2009) by SGB-CPRM, through the PROERG Project, has already mapped 10.3% of cobalt crust deposits in this area, aiming to identify the strategic mineral potential of the South and Equatorial Atlantic. Other promising projects include Vale's Vermelho Project (Pará), expected to produce nickel and cobalt via hydrometallurgy for the battery sector (24 kt Ni and 1.2 kt Co), and the Brazilian Nickel project (Piauí), with potential to extract 36 kt of cobalt as a by-product from lateritic nickel leaching. Additionally, SGB-CPRM, CETEM, and the German Mineral Resources Agency are developing the BioCobalt project (cobalt mineral potential assessment) and BioProLat (reassessment of the Rondônia tin province).

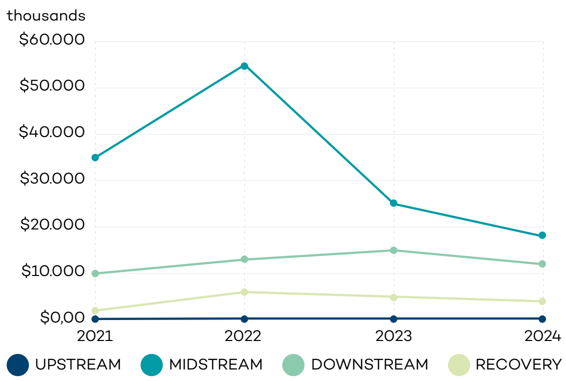
127 https://www.metal.com/pt/newscontent/103207307

Figure 40: Material Flow Analysis (MFA) of imported and exported volumes relative to industrial production data by stages of the Cobalt value chain for 2022

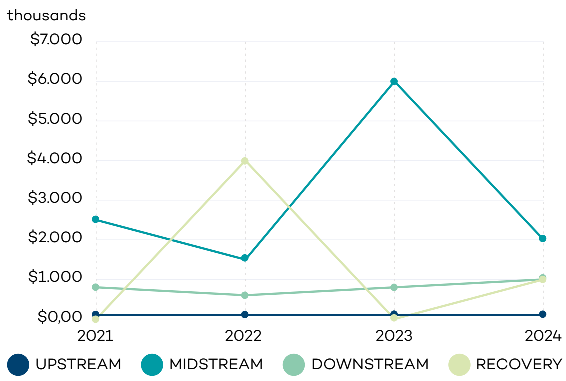


Source: Data obtained from the ComexStat Platform, 2025 (year 2022), and Industrial Production data (SIDRA/IBGE) for 2022

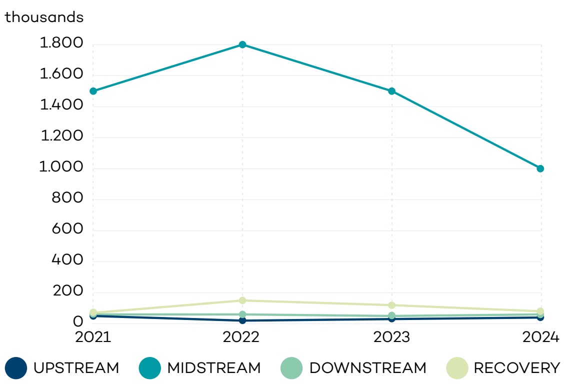
Graph 5. Cobalt: Imports in Value US$ FOB (thousands) between 2021 and 2024



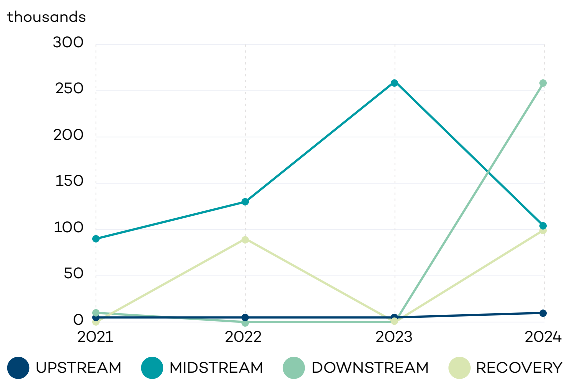
Graph 6. Exports in Value US$ FOB (thousands) between 2021 and 2024



Graph 7. Cobalt: Imports in Net Weight kg (thousands) between 2021 and 2024

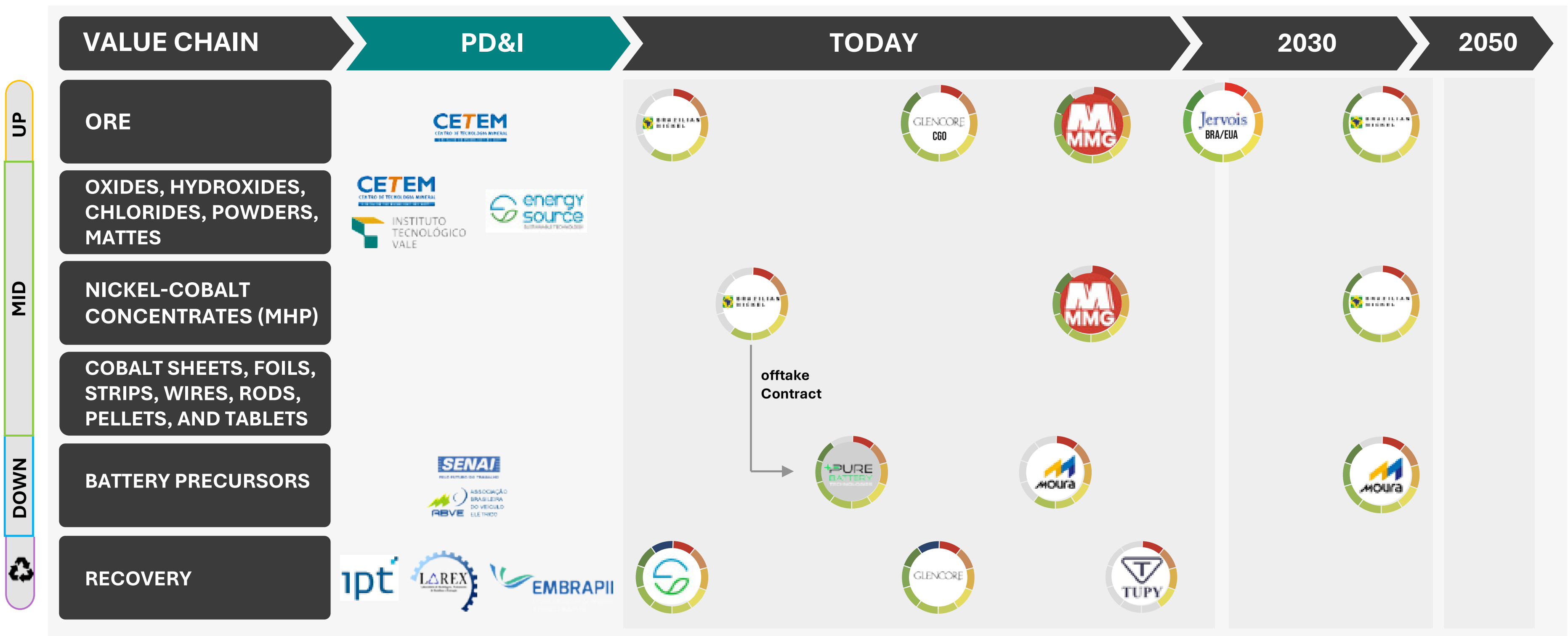


Graph 8. Cobalt: Exports in Net Weight kg (thousands) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.

COBALT



Source:
https://www.carboncreditmarkets.com/single-post/cobalto-reservas-minerais-baterias-e-tecnologia
http://larex.poli.usp.br/recuperacao-de-cobalto-de-catalisadores-exauridos-da-industria-petroquimica-atraves-de-reducao-termoquimica/
https://www.techmet.com/brazilian-nickel/
https://valorinternational.globo.com/economy/news/2022/11/15/us-unveils-investment-in-nickel-cobalt-in-brazil.ghtml

https://www.brasilmineral.com.br/noticias/brazilian-nickel-firma-acordo-para-fornecer-niquel-e-cobalto-para-a-franca[12:14, https://www.techmet.com/brazilian-nickel/
https://www.brasilmineral.com.br/noticias/brazilian-nickel-tem-avancos-no-financiamento-para-projeto-piaui

COPPER

UPSTREAM MINING — Copper ore

MIDSTREAM CHEMICALS/METALLURGY — Chemicals (oxides, hydroxides, etc.), concentrates, mattes, alloys,

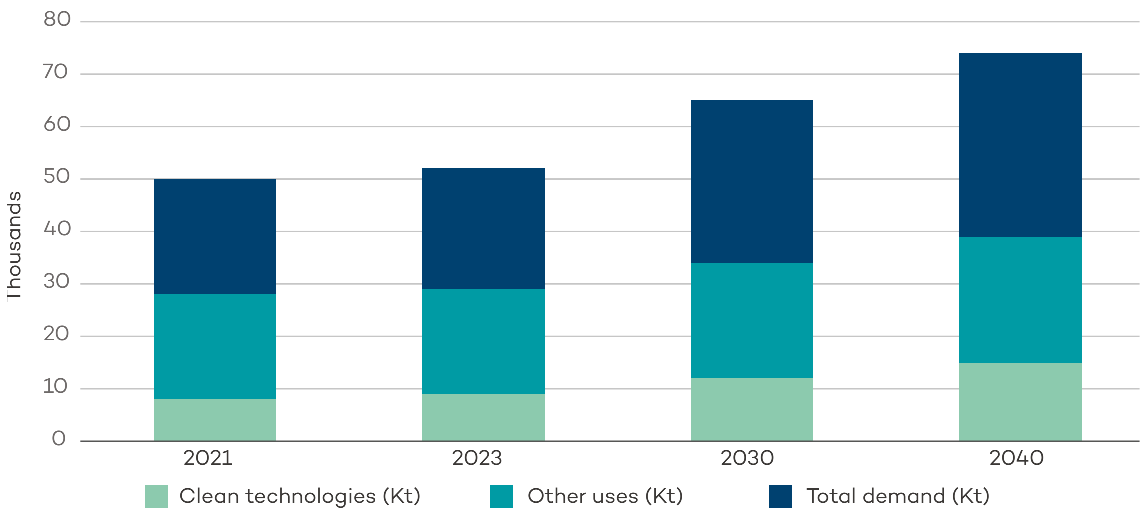
DOWNTREAM FINAL PRODUCTS — Wires and cables, pipes, structures, etc.

RECOVERY RECUPERAÇÃO — Copper waste, residues

Overview and demand

Copper is a key mineral for the energy transition and remains essential for the maintenance and expansion of urban and industrial infrastructure. Due to its high electrical and thermal conductivity, corrosion resistance, and malleability, it is widely used in electrical wiring, civil construction, electronics, power generation and transmission, electric vehicles, and industrial equipment[128]. Its demand is proportional to economic growth and to land use and occupation; therefore, it is more susceptible to economic and political factors. It is driven by the energy transition (renewable energy, electric vehicles, and smart grids) and by the electrification of the economy[129]. The International Energy Agency (IEA) calculated that global copper demand could grow by 40% by 2040[130].

Figure 41: Global copper demand (kt).



Source: Adapted from: IEA, 2024.

128 International Copper Study Group (ICSG) – Copper Market Forecasts 2024.

129 International Energy Agency (IEA) – The Role of Critical Minerals in Clean Energy Transitions, 2022.

130 https://www.iea.org/reports/copper

Considering the years 2023 and 2024, Chile stands out as the largest global producer, being responsible for 35% of world production, approximately 5.36 Mt, and with estimated reserves of 190 Mt (19% of the global total)[131]. In 2023, Peru produced a record 2.76 Mt of copper, exceeding the previous year by 13%. North American production in 2023 reached 1.1 Mt, a decrease of 11% compared to 2022, but still securing the United States one of the top five global positions in copper production[132]. Recent U.S. tariffs imposed on copper imports aim to stimulate domestic production. In 2023, Australia produced approximately 810 thousand tonnes of copper[133,] maintaining production practically unchanged compared to 2022. Canada was the 12th largest global copper producer in 2023, and in 2024 it was the second-largest exporter of copper to the United States (USD 4 billion). China, in 2024, was responsible for approximately 50% of global production/refining, with growth of 5% in the first quarter of 2024[134]. The accelerated expansion of Chinese capacity, with the expansion of smelters, has affected sector profitability and threatens the viability of projects in other countries.

Brazil is the 13th largest global producer of copper, with estimated reserves of 17 Mt, which places it in 10th position globally in reserves, but 18th in production (SGB, 2025). Production is concentrated in the State of Pará (Carajás mineral province) and in Goiás[135]. In 2023, national production reached approximately 380 thousand tonnes of contained copper.

Best Practices

Best practices in the copper mining and beneficiation sector are related to technological innovation in extraction, with the implementation of methods such as in-situ leaching and bioleaching to reduce environmental impacts[136], as well as to process optimization, such as the use of more efficient reagents and process control techniques to increase recovery and reduce input consumption in flotation processes[137]. Or even the use of AI for geological data analysis, identification of prospective areas, and process optimization, also with the objective of reducing costs and increasing operational safety. With respect to sustainability, new practices for tailings recovery, mine life extension, and secondary extraction of metals stem from experiences with shared and open innovation with initiatives such as Mining Hub[138].

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131 https://pubs.usgs.gov/periodicals/mcs2024/mcs2024-copper.pdf

132 https://www.opportimes.com/os-10-maiores-exportadores-de-Copper-para-os-estados-unidos-em-2024/

133 https://www.Brazilmineral.com.br/noticias/producao-mundial-em-minas-cresce-6-milhoes-de-toneladas--em-dez-anos

134 https://www.infomoney.com.br/mercados/china-apos-frenesi-de-usinas-de-Copper-viabilidade-de-fabricas-no-World-esta-em-jogo/

135 Agencia Nacional de Mineração (ANM) - Sumário Mineral de Copper 2024

136 International Council on Mining and Metals (ICMM)- “Sustainable Mining Practices: Copper Sector”, 2023

137 Mining Magazine - “Advances in Copper Flotation”, 2023

138 https://mininghub.com.br/blog/

Figure 42: Copper: Reserves by Country

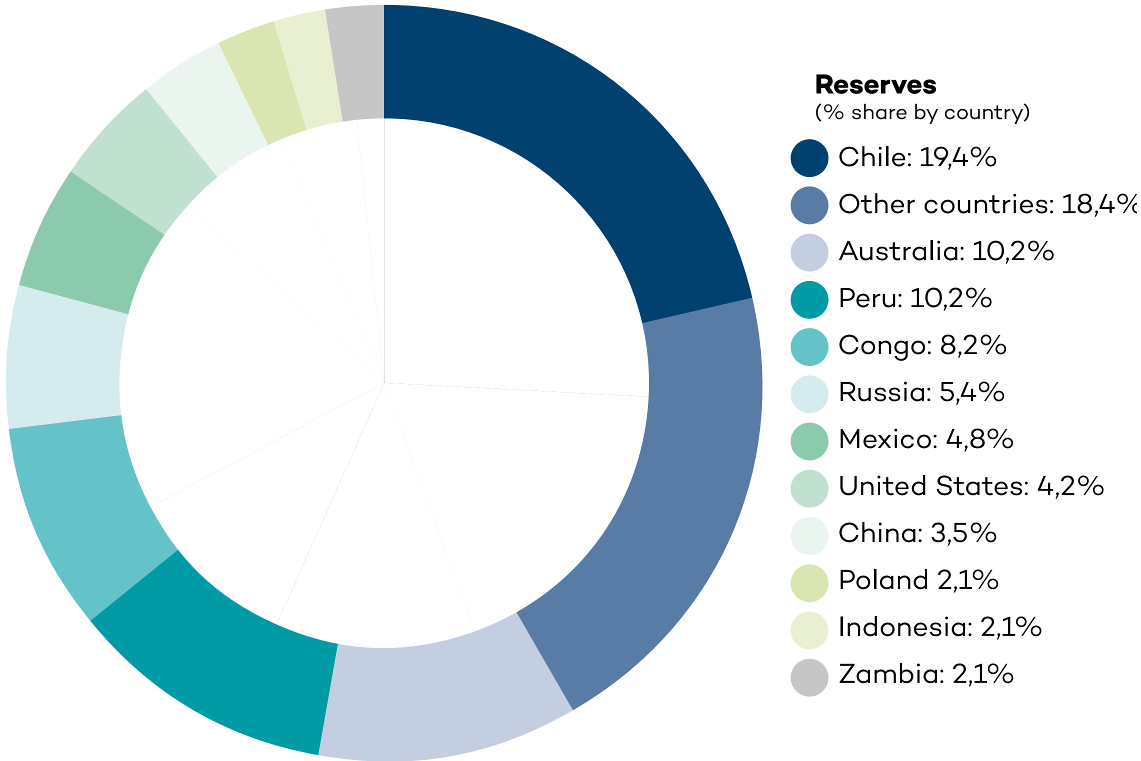
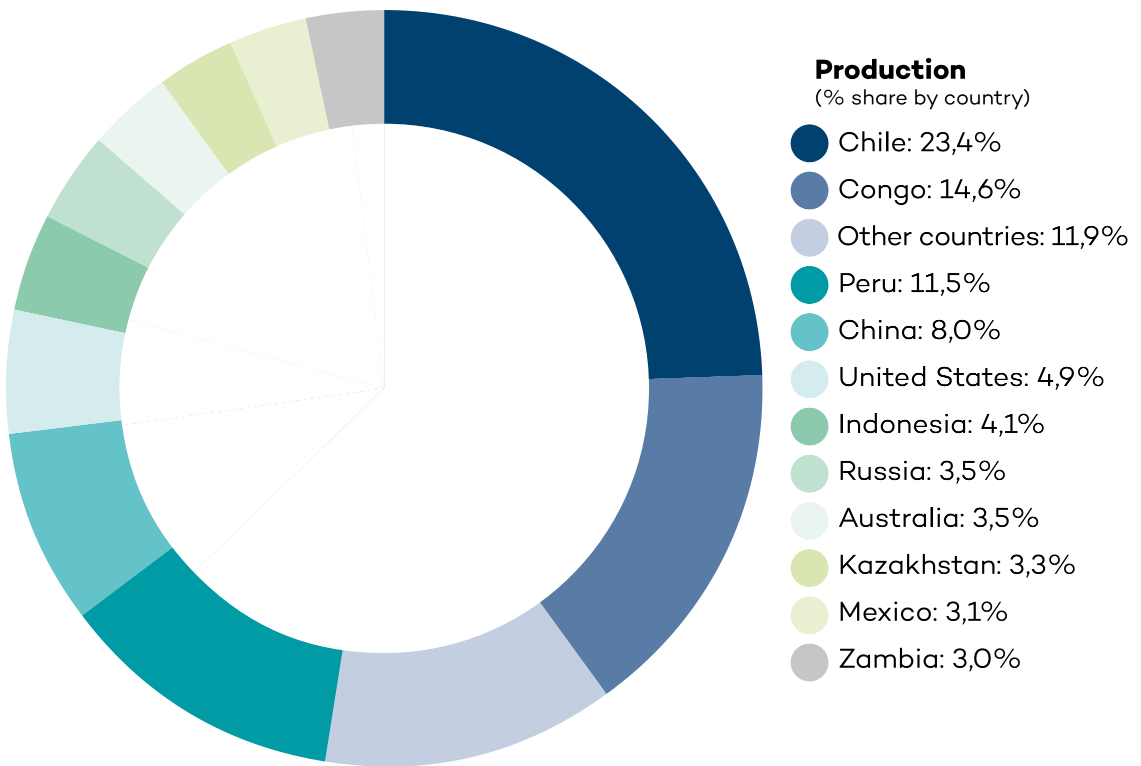


Figure 43: Copper: Production by Country



Source: USGS, 2025

Figure 44: Map for Authorization of Copper Exploration in Brazil (2025)

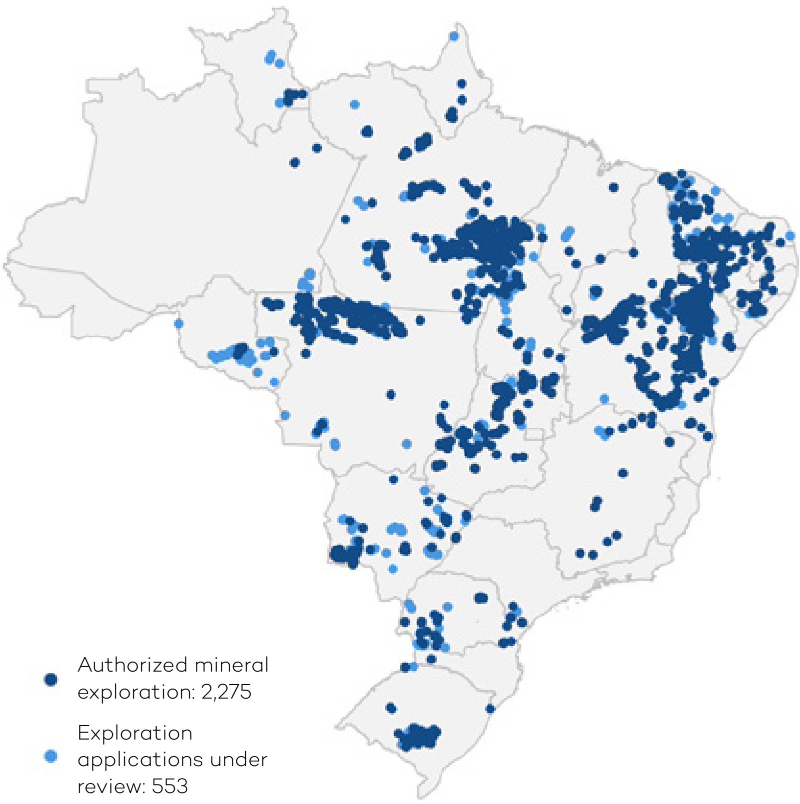


Figure 45: Map for Granting of Copper Mining Concessions in Brazil (2025)

Copper recovery from scrap already represents around 30% of global supply, and initiatives to increase this share are expanding[139]. With respect to governance, there are expectations that investments in copper, nickel, and lithium will be aligned with the Decennial Mineral Resources Plan 2025–2034, which prioritizes strategic minerals for the energy transition.

Vale Base Metals (Basic Metals of Brazil) operates copper assets at the Salobo and Sossego Complexes. Together with the Onça Puma complex (nickel extraction), they total approximately 11,500 direct and indirect jobs, with 77% of employees hired locally, 23% of the workforce and leadership positions held by women, and 43% of leadership positions held by Black professionals. All three mines are located in the State of Pará, and the Salobo Complex represents the largest copper operation in Brazil, with reserve life estimated through 2060. At the Sossego Mine, the company is developing a project to use copper mining tailings for the production of pavers (bricks). The project is currently in the testing phase. There are also studies for the utilization of timber in areas of vegetation clearance.

Future Outlook

In view of repeated projections of strong demand growth, the trend for the coming years is a global race for new copper projects, with greater pressure for environmental and social responsibility in operations. Copper traceability—from mine to final product—is becoming a market requirement. Brazil, with its large deposits, can expand its participation in this market, provided it invests in cleaner processes, increases recycling, and ensures sustainable mining practices.

Vale Base Metals of Brazil's operations for copper production aim at expanding output in the short and medium term. Currently, Vale's copper production projects involve investments on the order of BRL 25 billion. The company projects growth from 280 thousand tonnes of copper produced to 450 thousand tonnes by 2030, and approximately 600 thousand tonnes of copper by 2035[140]. Other specific initiatives for growth of operations at the Salobo and Sossego mines are listed below[141]:

139 International Copper Association (ICA) - "Copper Recycling and Circular Economy"

140 Entrevista a Vale Base Metals efetuada em 16 de maio de 2025.

141 https://www.gov.br/mme/pt-br/assuntos/secretarias/geologia-mineracao-e-transformacao-mineral/seminario-sobre-mineracao-e-transformacao-mineral-de-minerais-estrategicos-para-a-transicao-energetica/4-1-vale-bm_mme_forum_feb2024_jlm_final_short.pdf

SALOBO – SUMMARY TECHNICAL OVERVIEW

- Short-Term Objective: Increase asset reliability through improvements in maintenance and operational efficiency.

- Performance Indicator: Productivity of electric shovels increased by +8% between 1Q23 and 1Q24.

- Ongoing Initiatives:
  - ✓ Elimination of bottlenecks at Salobo I and II.
  - ✓ Production ramp-up at Salobo III.

- Technical and Strategic Opportunities:
  - ✓ Resource increase through additional drilling.
  - ✓ Extension of mine life through cut-off adjustments and utilization of complementary resources.
  - ✓ Productivity gains (~30%) with technologies such as coarse particle flotation, with an expected 10% reduction in all-in copper costs by 2026.

- Execution Risks:
  - ✓ Potential overestimation of cost reductions.
  - ✓ Resource increase may be lower than projected, which would limit economies of scale and planned cost reductions.

SOSSEGO – SUMMARY TECHNICAL OVERVIEW

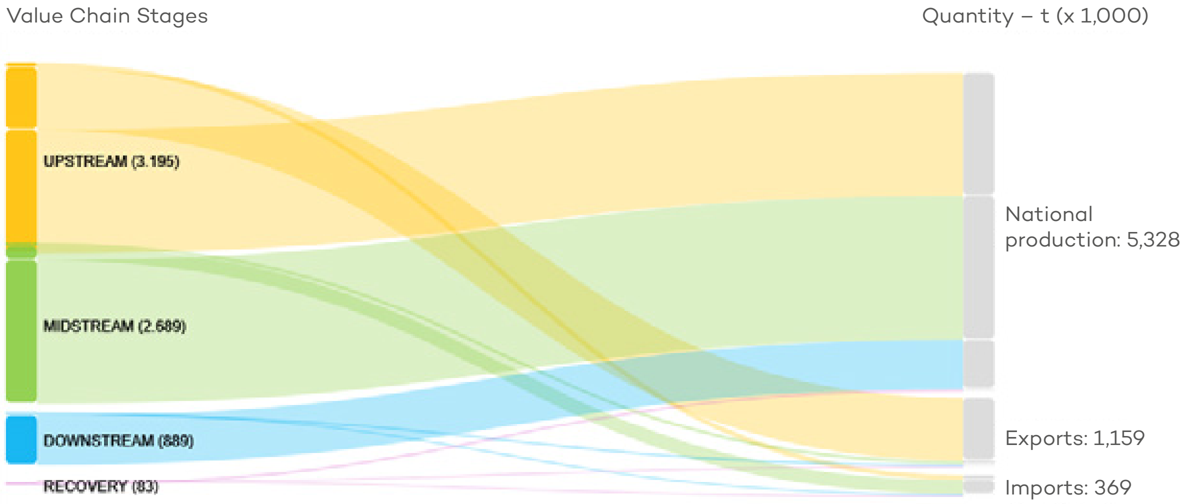
- Current Capacity and Target:
  - ✓ Optimization of plant utilization, with throughput of up to ~13 Mtpa.
  - ✓ Target of 11.6 Mtpa in 2026 and 12.7 Mtpa in the long term.

- Projects and Investments:
  - ✓ Approval of the Bacaba project underway.
  - ✓ Optimization of geological sequencing in the South Hub.

- Geological Potential:
  - ✓ Estimate of 50 Mt of ore in underground areas (~850 kt of copper) with high grade concentration.

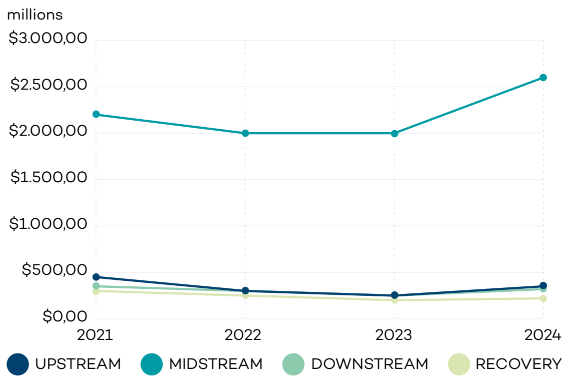
- Execution Risks:
  - ✓ Transition from open-pit operation to underground mining.
  - ✓ Technical and timing challenges in excavating deep layers, with the need for strategic use of Bacaba to supply ore in the medium term.

Figure 46: MFA of imported and exported volume, in relation to industrial production data according to the stages of the Copper value chain for the year 2022.

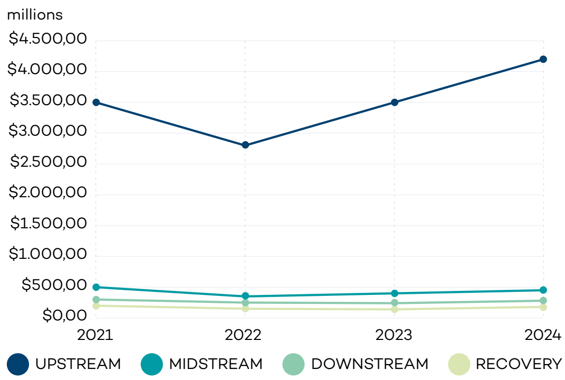


Source: Data obtained from the ComexStat Platform, 2025 (year 2022), and from Industrial Production data (SIDRA/IBGE) for 2022.

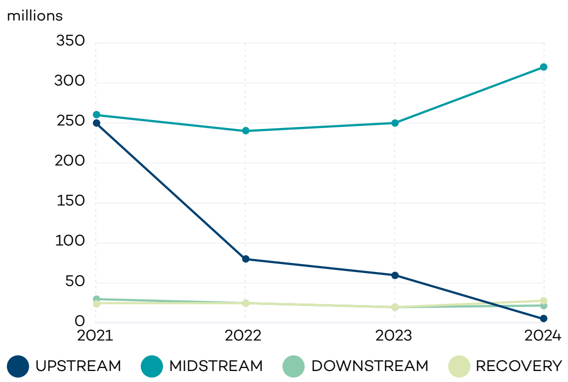
Graph 9. Copper: Imports in Value FOB USD (millions) between 2021 and 2024



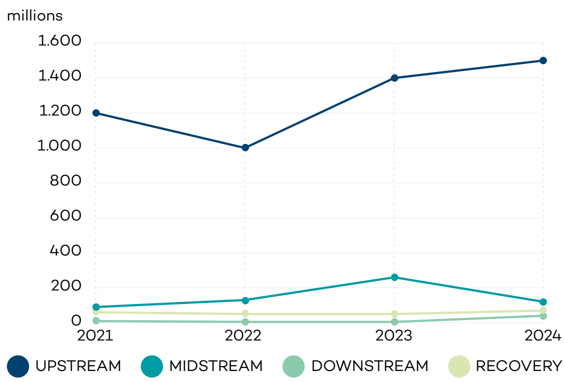
Graph 10. Copper: Exports in Value FOB USD (millions) between 2021 and 2024



Graph 11. Copper: Imports in Net Weight Net kg (millions) between 2021 and 2024

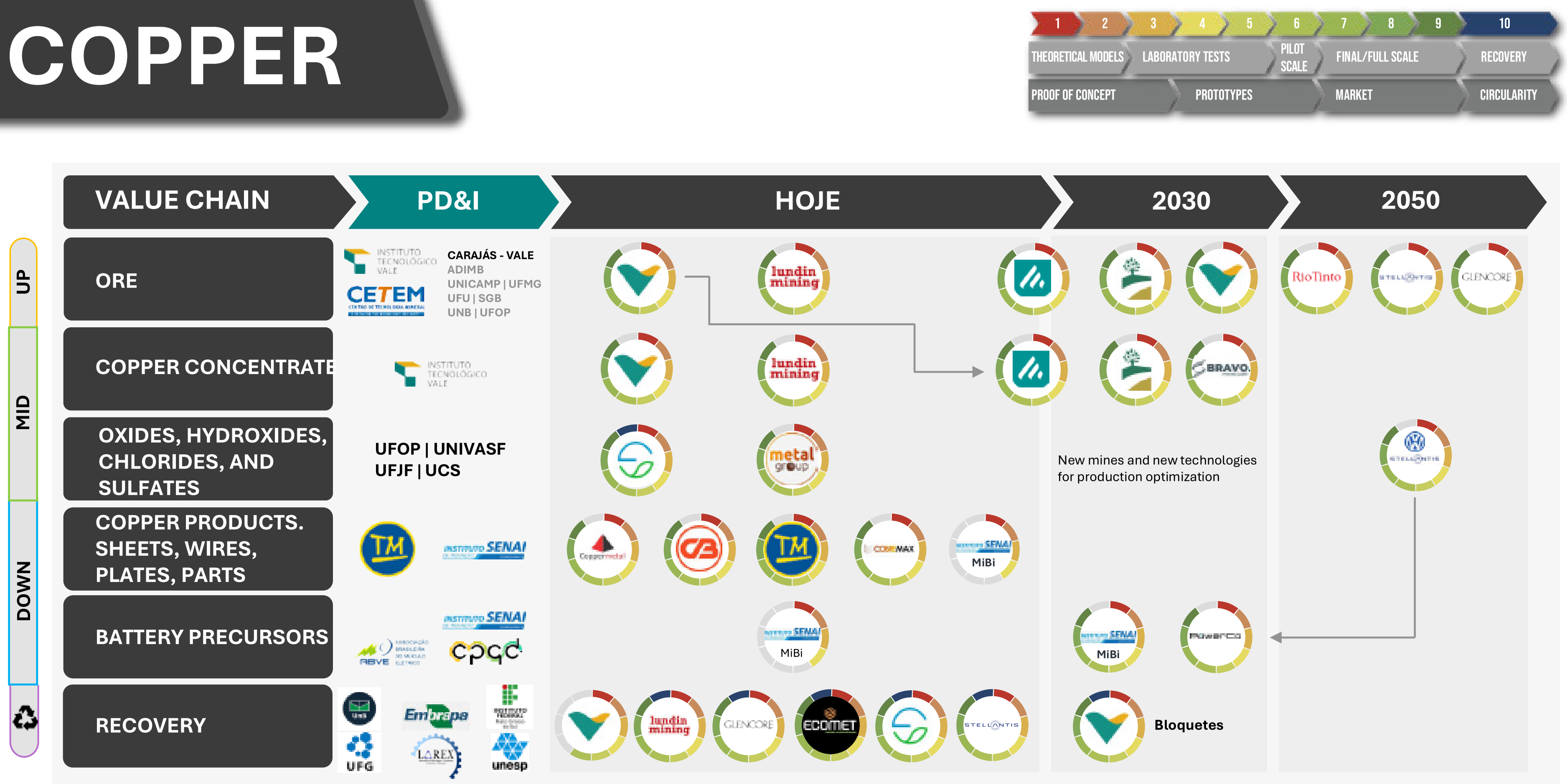


Graph 12. Copper: Exports in Net Weight Net kg (millions) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.

COPPER



Source:
https://www.autoindustria.com.br/2023/06/12/volkswagen-e-stellantis-investirao-em-minas-de-niquel-e-cobre-no-brasil/ https://www.cpqd.com.br/
https://www.vale.com/pt/mineracao
https://vale.com/pt/w/vale-anuncia-70-bi-reais-de-investimentos-no-programa-novo-carajas-pa-ate-2030-em-solenidade-com-o-presidente-lula/-/categories/1968812

TIN

UPSTREAM MINING — Tin ore

MIDSTREAM CHEMICALS/METALLURGY — Chemicals (salts and other stannates), concentrates, tin in crude forms

DOWNTREAM FINAL PRODUCTS — Tin products (alloys, bars, profiles, etc.)

RECOVERY RECOVERY — Waste and residues

Overview and demand

Tin is obtained mainly from cassiterite and is used in the form of tinplate sheets, solder, chemical products, pewter (a tin alloy with copper, antimony, and bismuth), and bronze. Tin production began in the 1980s and placed Brazil on the global stage based on deposits in the northern region, notably the Pitinga mine, in the state of Amazonas, which accounts for 40% of national production, and the Santa Bárbara, Massangana, Cachoeirinha, and Bom Futuro mines, in the state of Rondônia.

Cassiterite is also found in Minas Gerais, Pará, Goiás, Amapá, and São Paulo. Measured tin ore reserves in 2020 were on the order of 636 thousand tcont (contained), while indicated and inferred reserves totaled 1.17 million tcont, which combined place Brazil in 3rd position in the global ranking of measured tin ore reserves and 5th position in the ranking of exporters. China holds approximately 26% of global tin reserves, about 1.1 Mt, and produced 68 thousand tonnes in 2023 (USGS, 2025). According to data from ANM, in 2023 there were a total of 1,830 mining processes for tin mining, among which 50 companies hold active mining concessions.

The Gross Mineral Production Value (VPM) of tin in 2023 was BRL 62.5 million (13.84 million t – ROM), and the Beneficiated VPM reached BRL 1.59 billion in the same year (41.18 t), resulting from the exploitation of 48 active mines. The states of Pará and Rondônia lead national production, with 22 active mines in Pará and 19 mines in Rondônia.

Global demand for tin is directed to the electronics industry, which consumes between 50% and 70% of total production, especially in solders for devices such as smartphones and computers. The forecast is for annual growth of 2.59% through 2029, reaching 475,460 tonnes. The availability of substitutes, such as aluminum and tin-free steel for the production of metal products, has reduced the pace of market growth. However, the shift in focus toward tin recycling has created opportunities. For example, the USGS, using the average resale price of tin based on S&P Global Platts Metals, estimates that the North American market produced USD 280 million from the recovery of tin derived from scrap.

Figure 47: Tin: Reserves by Country

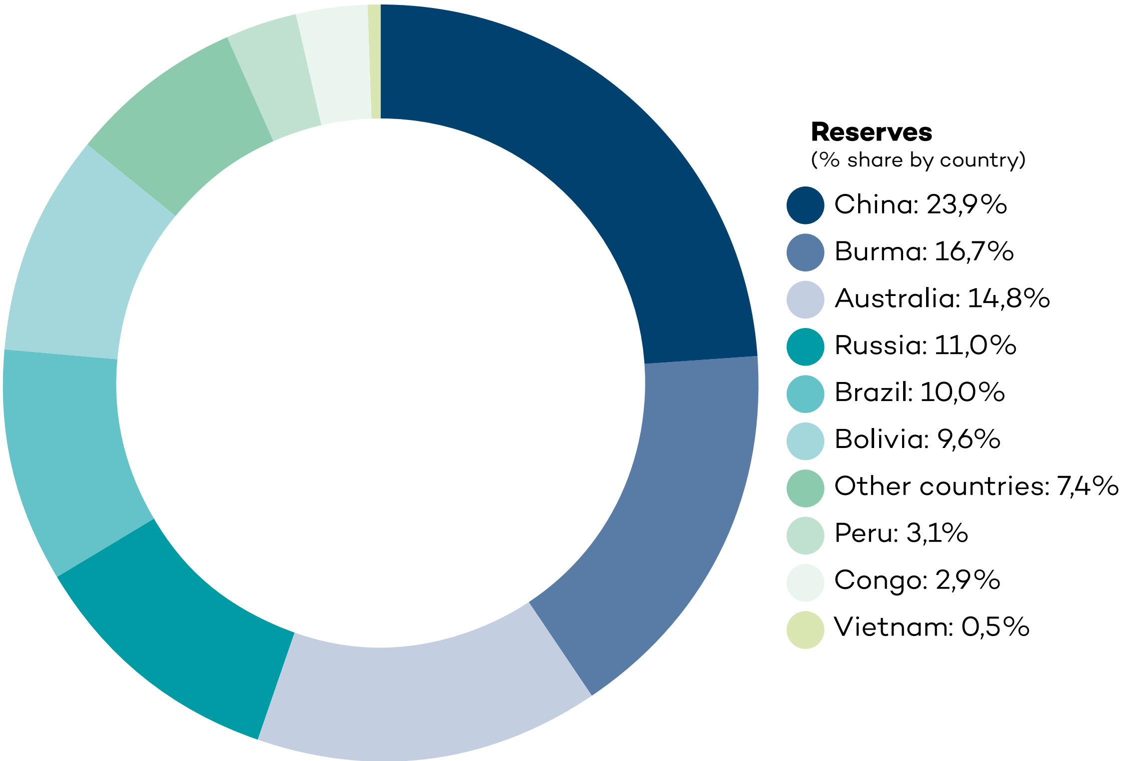
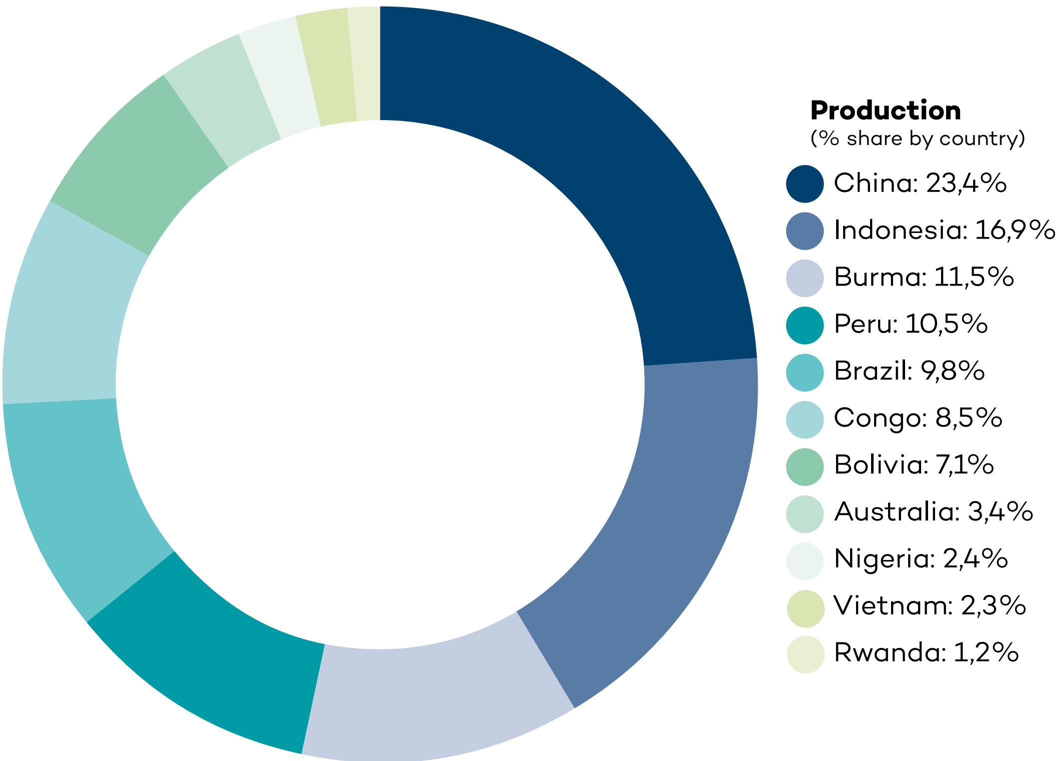


Figure 48: Tin: Production by Country



Source: USGS, 2025

Figure 49: Map for Authorization of Tin Exploration in Brazil (2025)

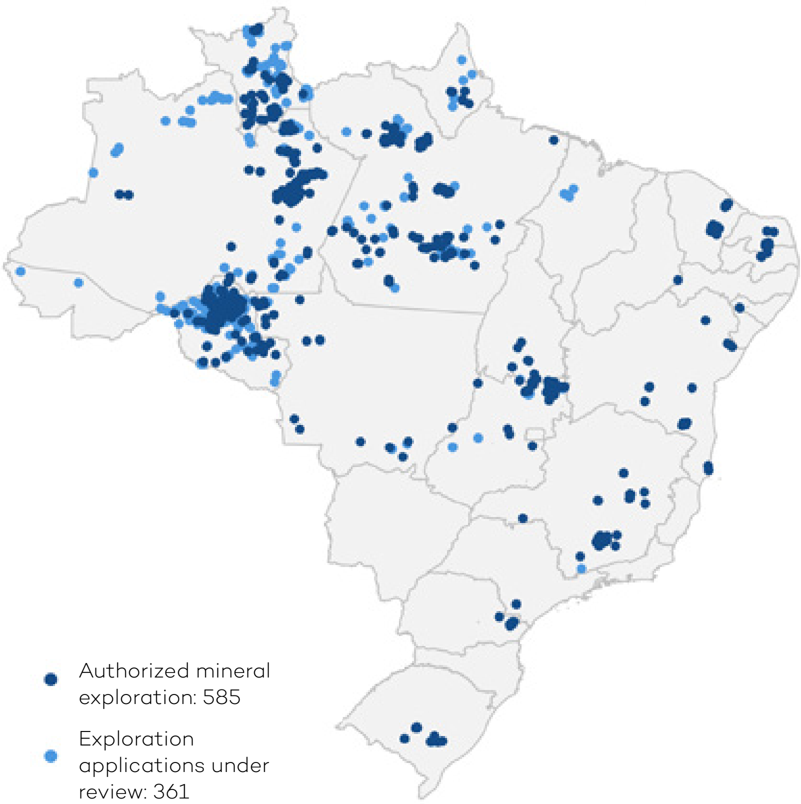
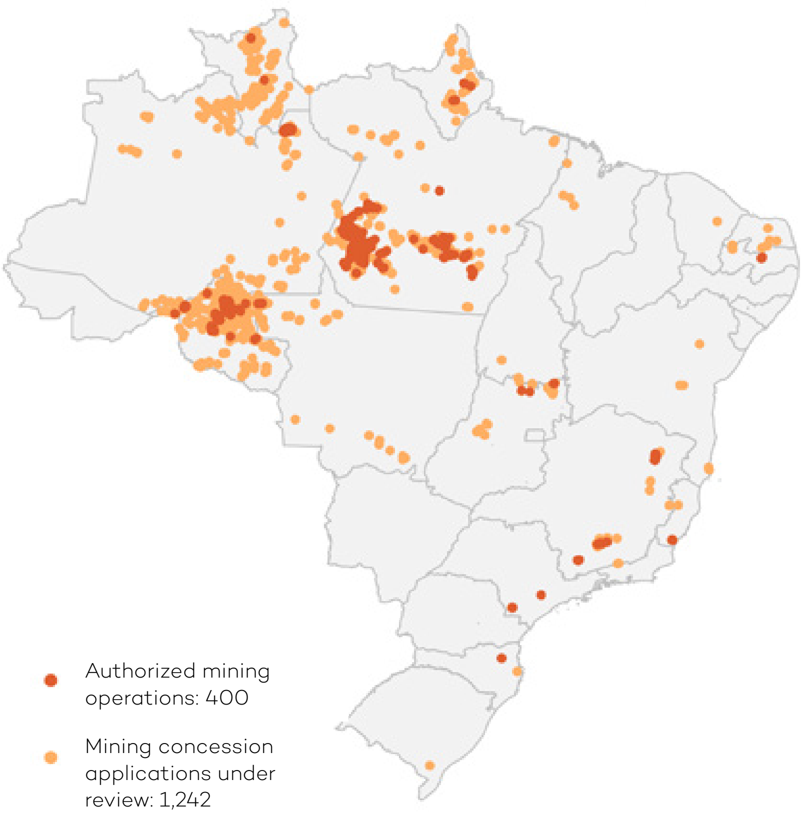


Figure 50: Map for Granting of Tin Mining Concessions in Brazil (2025)



Best Practices

Since the discovery of tin deposits in the Northern region, with significant economic importance at the national and international levels, several initiatives by CPRM, in partnership with various federal government ministries, have aimed at the environmental management of tin exploitation in the Amazon biome.

Best practices in the region are understood as strict control of water and air quality, the recovery of degraded areas through revegetation, and constant dialogue with local communities. The coexistence of mining with the preservation of the tropical forest, the rights of Indigenous and riverine populations, and the need for sustainable regional development require an integrated and responsible approach by companies, government, and civil society.

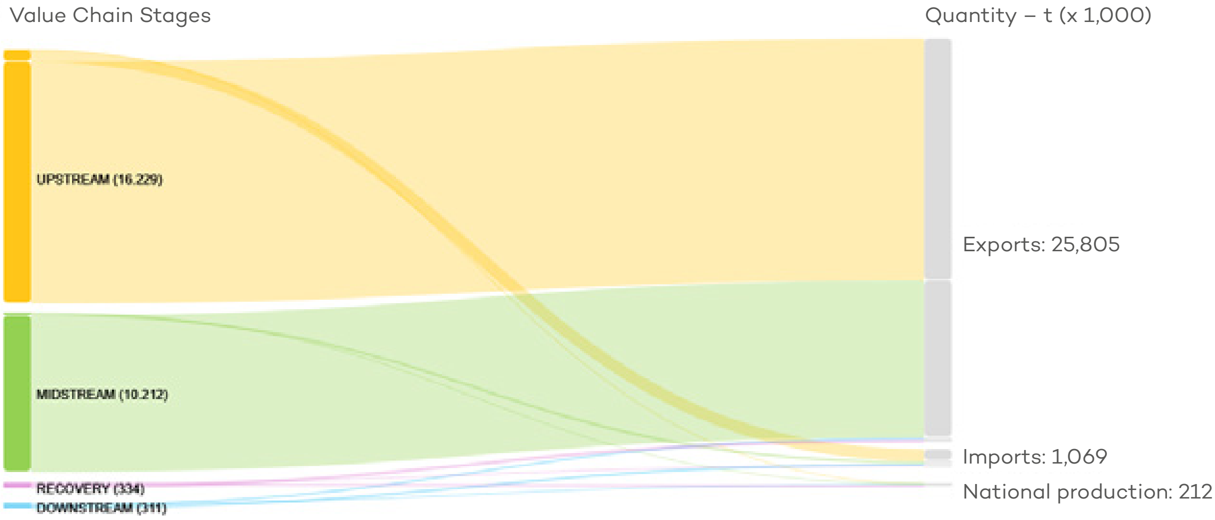
Among the initiatives for the expansion and sustainable exploitation of tin mining, the following have been employed by SGB-CPRM: detailed geological mapping; optimization of mining operations and selective mining that prioritizes the extraction of higher-grade tin and reduces the volume of material processed; use of gravimetric beneficiation technology that optimizes processing with water recycling; as well as concern with waste management and reforestation of degraded areas.

Future Outlook

There is a trend toward increasing global demand for tin, because in addition to its crucial application in several lead-free solder industries and the manufacture of electronic circuits, its use is growing in renewable energy technologies, such as lithium-ion batteries, solar cells, superconductors, and protective coatings for electronic equipment.

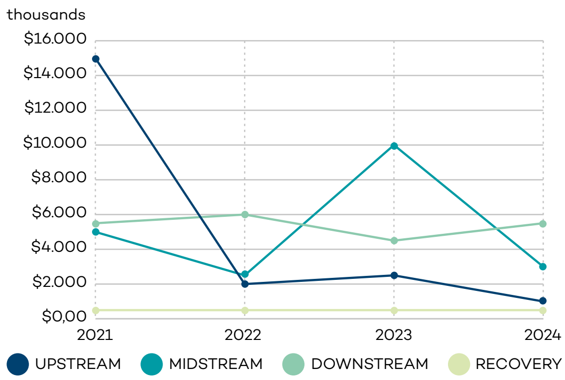
To optimize the utilization of deposits currently in operation, it is essential to use sustainable technologies, adopt circular economy and recycling techniques, as well as strengthen governance mechanisms, environmental licensing, and Local Productive Arrangements (APLs), which can boost tin mining, especially in locations that host the cassiterite mineral in the sensitive regions of the Amazon, Cerrado, and Pantanal biomes.

Figure 51: MFA of imported and exported volume, in relation to national industrial production data according to the stages of the Tin value chain for the year 2021

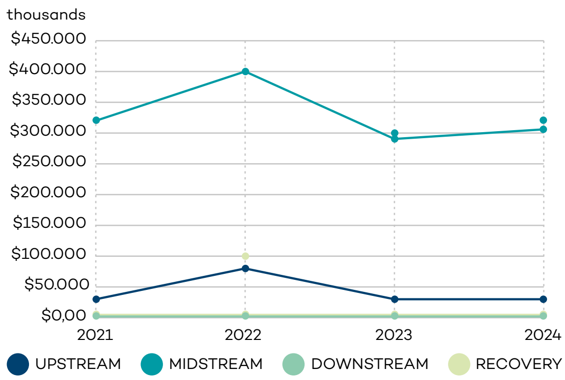


Source: Data obtained from the ComexStat Platform, 2025 (year 2021), and from Industrial Production data (SIDRA/IBGE) for 2021.

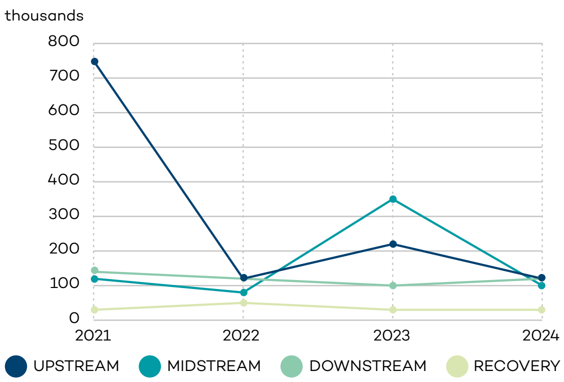
Graph 13. Tin: Imports in Value FOB USD (thousands) between 2021 and 2024



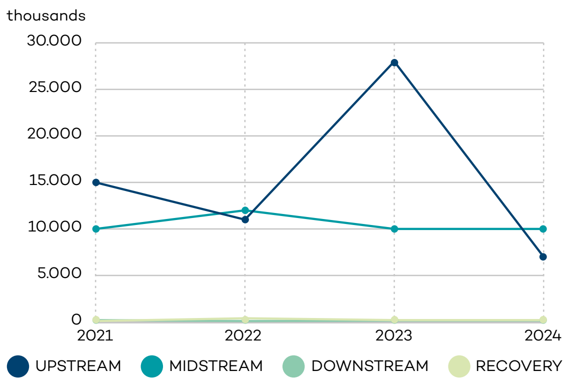
Graph 14. Tin: Exports in Value FOB USD (thousands) between 2021 and 2024



Graph 15. Tin: Imports in Net Weight Net kg (thousands) between 2021 and 2024

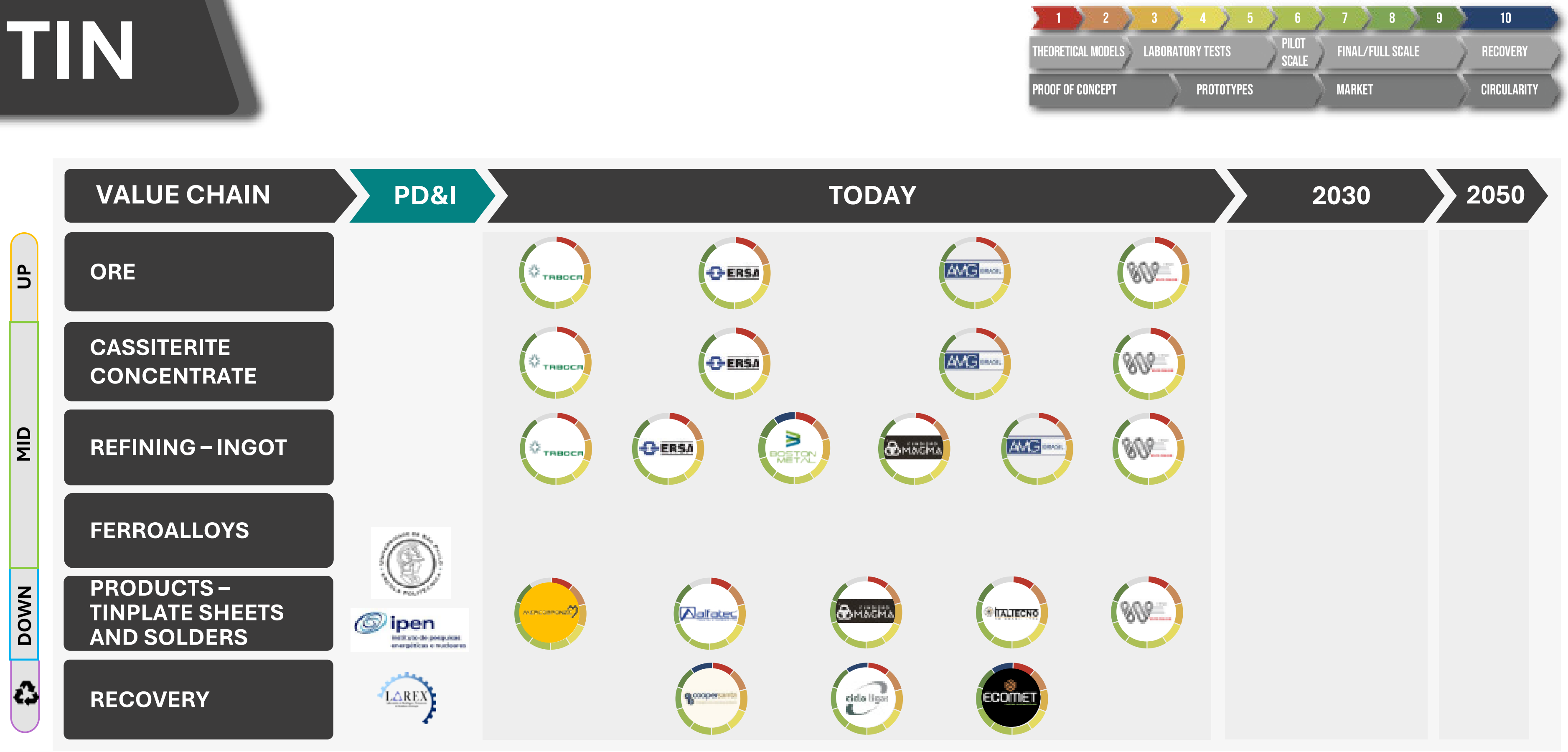


Graph 16. Tin: Exports in Net Weight Net kg (thousands) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.

TIN



https://www.csn.com.br/quem-somos/grupo-csn/ersa/
https://www.cicloligas.com.br/blog/cacamba-para-sucata/reciclagem-de-estanho-em-sorocaba-conheca-a-ciclo-ligas/#:~:text=estanho:%20Ciclo%20Ligas-,Vantagens%20e%20Benef%C3%ADcios%20da%20Reciclagem%20de%20Estanho,produtos%20e%20tecnologias%20mais%20ecol%C3%B3gicas.
https://www.brasilmineral.com.br/noticias/mineracao-taboca-e-vendida-para-a-chinesa-cnmc-por-us-340-milhoes
https://larex.poli.usp.br/desenvolvimento-de-rota-tecnologica-para-recuperacao-do-estanho-contido-no-residuo-de-fesn-gerado-durante-o-processamento-da-cassiterita/
https://www.brasilmineral.com.br/maiores/amg[14:52, 25/04/2025]
https://www.brasilmineral.com.br/maiores/whitesolder
https://www.teses.usp.br/teses/disponiveis/85/85134/tde-16092015-102833/pt-br.php
https://www.teses.usp.br/teses/disponiveis/3/3133/tde-01082024-134658/pt-br.php

REEs

UPSTREAM MINING — Rare earth ores

MIDSTREAM CHEMICALS/METALLURGY — Mixed carbonates, chemicals (oxides, chlorides, compounds, salts), alloys and other metals.

DOWNTREAM FINAL PRODUCTS — Components for electronics, magnets

RECOVERY RECUPERAÇÃO — Waste and residues from magnets and batteries

Overview and demand

Neodymium, praseodymium, terbium, and dysprosium are rare earth elements known for their magnetic properties and are used in the production of permanent magnets, especially neodymium–iron–boron (NdFeB) magnets.

Rare earth elements (REEs) are extracted from primary deposits in rock or from ionic clay deposits. Ionic clay deposits, found in China and Brazil, produce higher amounts of heavy and critical rare earth oxides and generate lower environmental impacts compared to hard-rock deposits.

The rare earths produced by Serra Verde, in Brazil, are considered critical materials by the United States and the European Union.

Figure 52: REEs: Reserves by Country

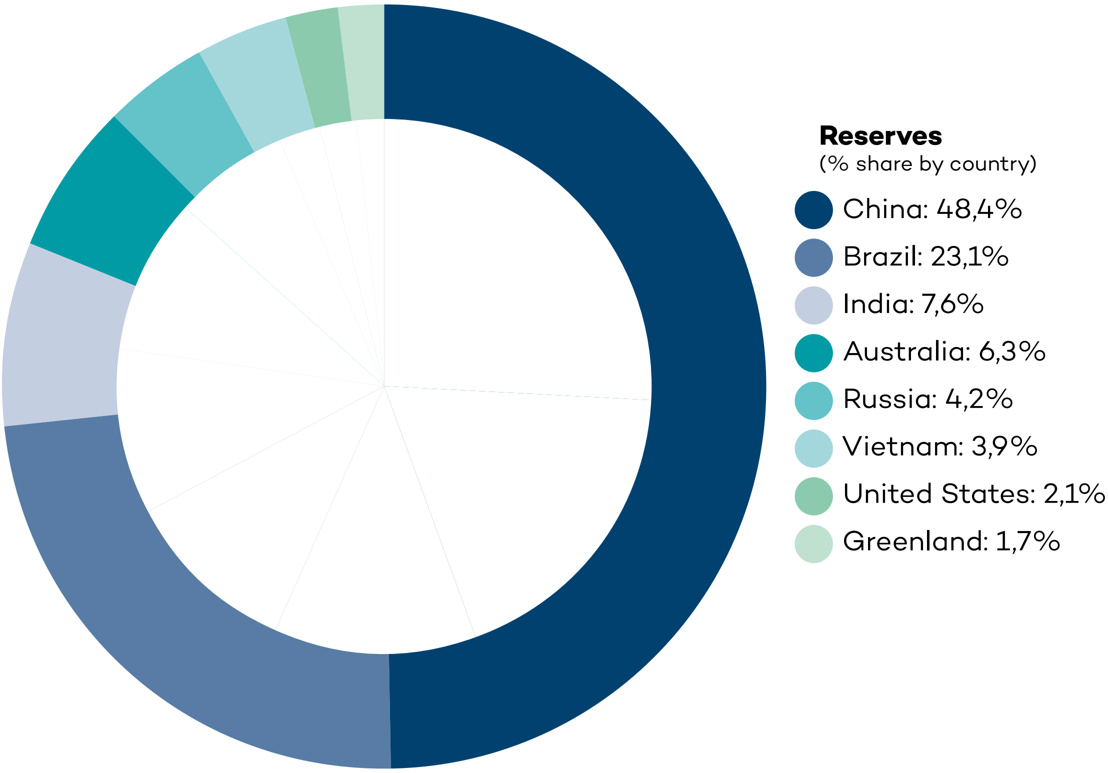
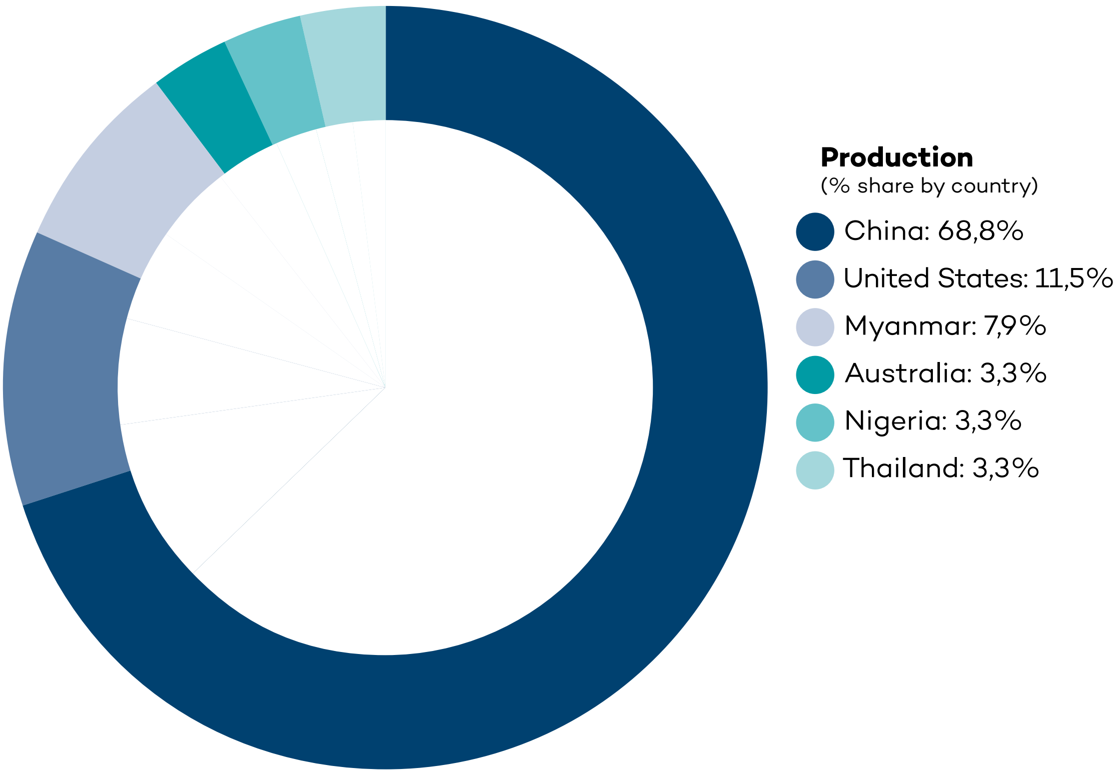


Figure 53: REEs: Production by Country



Source: USGS, 2025

Figure 54: Map for Authorization of Rare Earth Exploration in Brazil (2025)

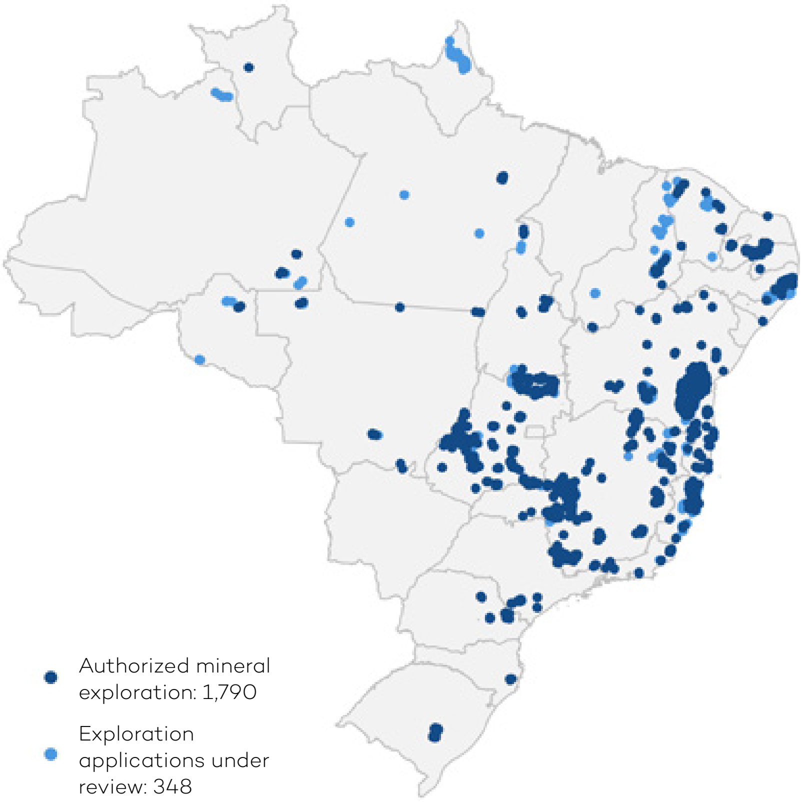


Figure 55: Map for Granting of Rare Earth Mining Concessions in Brazil (2025)

Best Practices

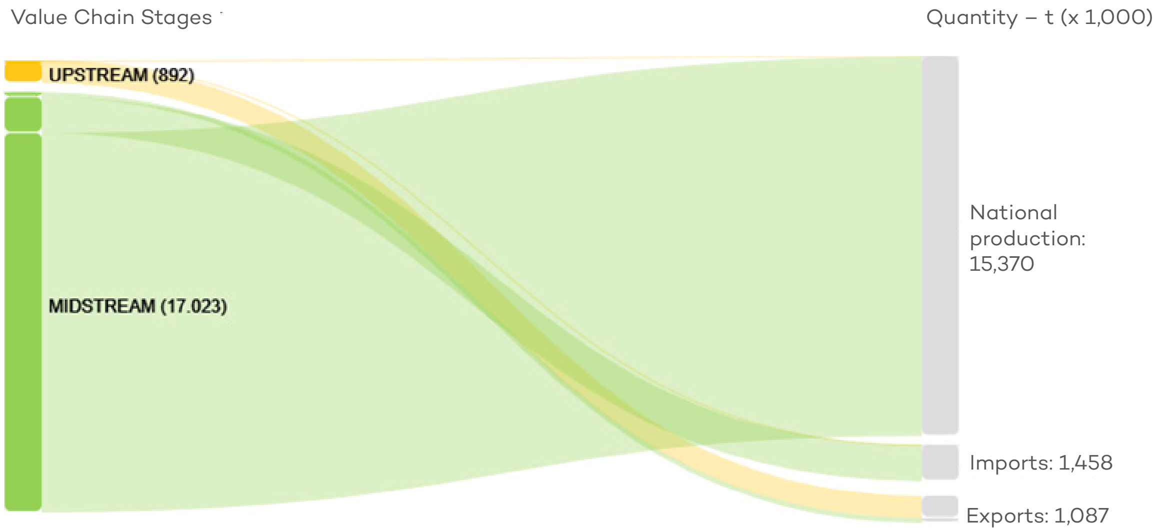
Serra Verde Mining, which in early 2024 carried out the startup of the first industrial enterprise for the mining and processing of rare earths in Brazil, was elected Mining Sector Company of the Year, in the Social Governance category, mainly due to its work engaging the community of the municipality of Minaçu during the implementation and start-up phases of its project, which is pioneering in the country. Approximately 70% of the workforce employed at Serra Verde is local, and of this share, nearly 30% is composed of women.

Future Outlook

Demand for REEs, especially for permanent magnets used in electric motors, is expected to grow significantly by 2040. However, REE production is complex and scarce, with China dominating global production. Resource limitations and the concentration of production in China generate supply risk, which may delay the transition to renewable energy. The discovery and exploitation of ionic clay REE deposits offer major opportunities for Brazil to play an important role in the global REE value chain.

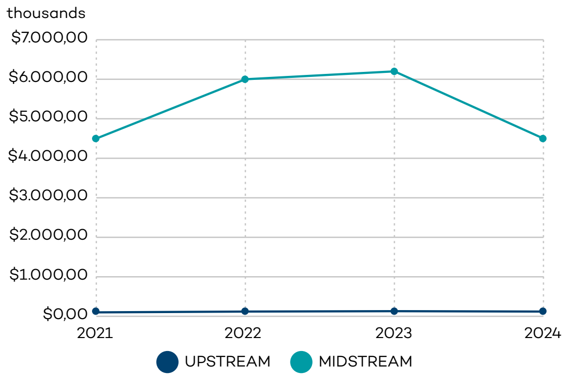
The Nova Indústria Brasil program and applied research projects, such as Mag Bras, have the potential to enable high-technology production in Brazil by leveraging rare earth (REE) reserves present in ionic clays. These initiatives stimulate the creation of skilled jobs, foster innovation in the advanced materials sector, and promote sustainable development, aligning with national goals to strengthen domestic industry and accelerate the transition to a low-carbon economy.

Figure 56: MFA of imported and exported volume, in relation to national industrial production data according to the stages of the REE value chain for the year 2022.

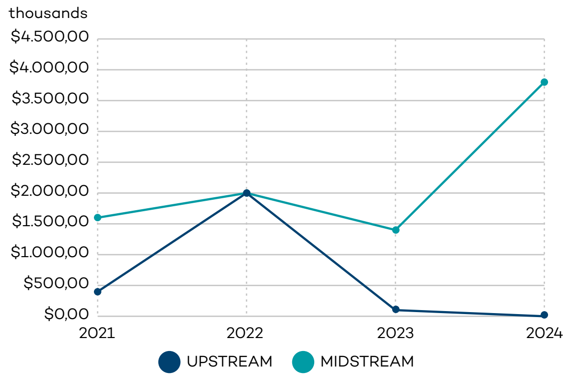


Source: Data obtained from the ComexStat Platform, 2025 (year 2022), and from Industrial Production data (SIDRA/IBGE) for 2022.

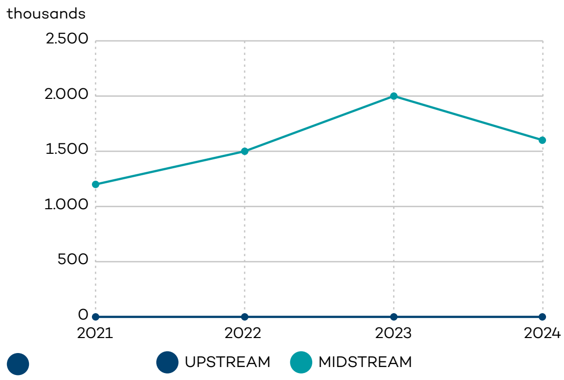
Graph 17. REEs: Imports in Value – FOB USD (thousands) between 2021 and 2024



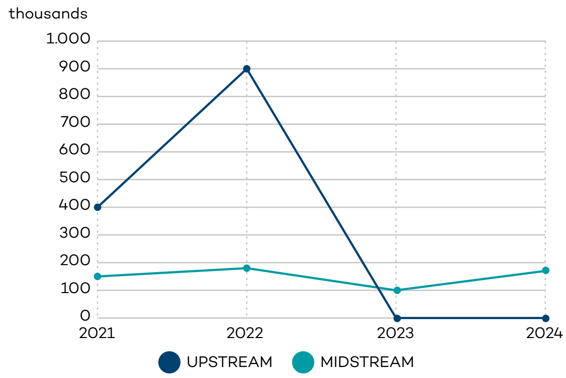
Graph 18. REEs: Exports in Value – FOB USD (thousands) between 2021 and 2024



Graph 19. REEs: Imports in Net Weight – Net kg (millions) between 2021 and 2024

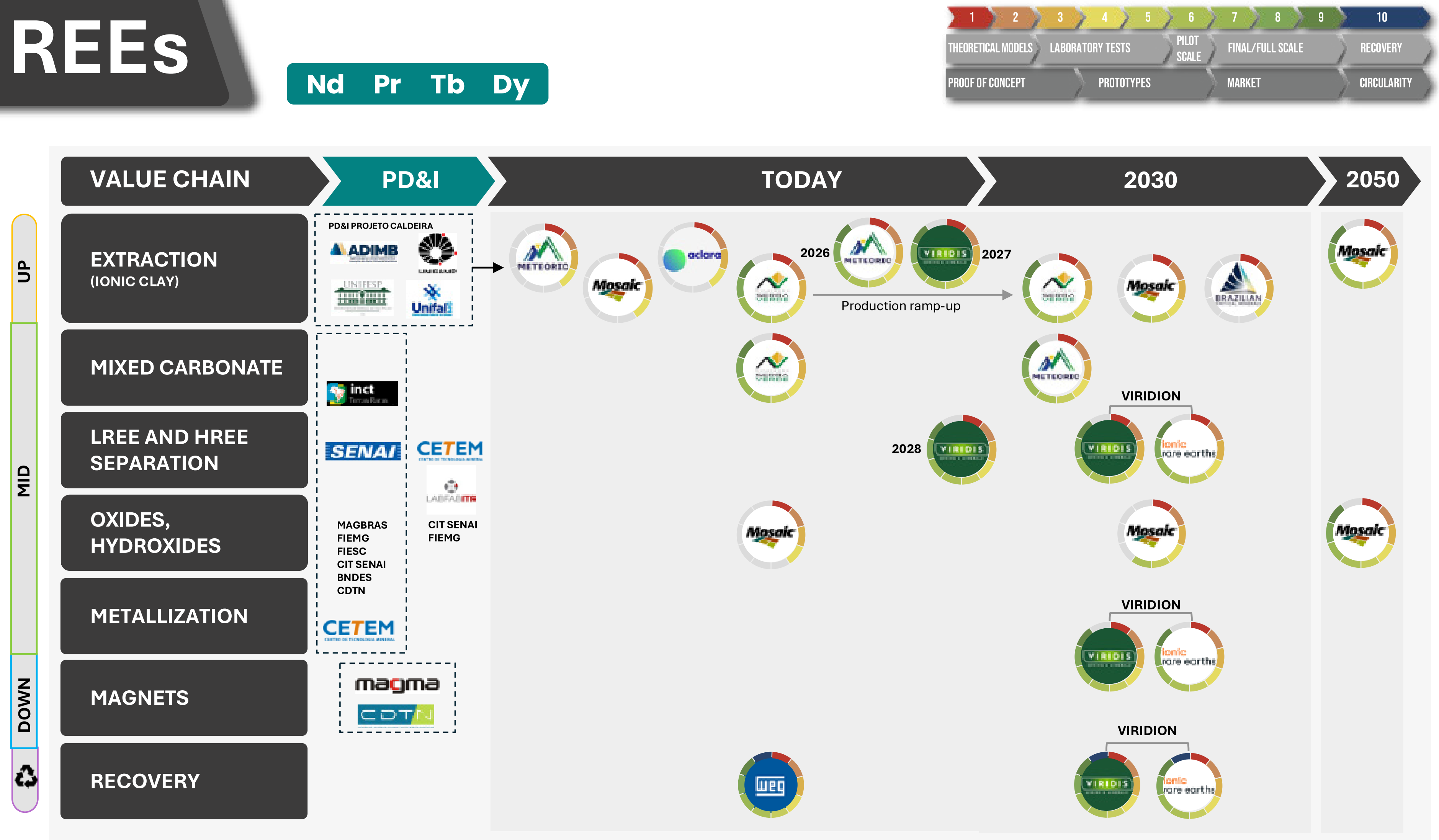


Graph 20. REEs: Exports in Net Weight – Net kg (millions) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.

REEs



Sources:
https://www.carboncreditmarkets.com/single-post/cobalto-reservas-minerais-baterias-e-tecnologia
http://larex.poli.usp.br/recuperacao-de-cobalto-de-catalisadores-exauridos-da-industria-petroquimica-atraves-de-reducao-termoquimica/
https://www.techmet.com/brazilian-nickel/
https://valorinternational.globo.com/economy/news/2022/11/15/us-unveils-investment-in-nickel-cobalt-in-brazil.ghtml

https://www.brasilmineral.com.br/noticias/brazilian-nickel-firma-acordo-para-fornecer-niquel-e-cobalto-para-a-franca[12:14, https://www.techmet.com/brazilian-nickel/
https://www.brasilmineral.com.br/noticias/brazilian-nickel-tem-avancos-no-financiamento-para-projeto-piaui

Iron

UPSTREAM MINING — Iron ore

MIDSTREAM CHEMICALS/METALLURGY — Chemicals (chlorides, sulfates, salts) and alloys, ingots, concentrates, granules, sinter, pellets

DOWNTREAM FINAL PRODUCTS — Works, parts and components, accessories and products (bars, profiles, plates, sheets, etc.)

RECOVERY RECOVERY — Waste and residues, slag

Overview and demand

Iron is the most produced and consumed metal in the world, forming the basis of the steel industry and being essential for sectors such as civil construction, automotive, shipbuilding, and oil and gas[142]. The main raw material of the industry is iron ore, which is predominantly transformed into steel.

Brazil is the second-largest global producer of iron ore, behind only Australia, and the largest exporter, with production concentrated in the states of Minas Gerais and Pará. In 2023, the country produced approximately 436 million tonnes[143].

Global demand for iron ore remains robust, especially driven by the growth of emerging economies and by the energy transition, which requires large volumes of steel for green infrastructure, such as wind farms, solar power plants, and railway projects[144].

142 World Steel Association - "Steel Statistical Yearbook 2023

143 National Mining Agency (ANM) – Brazilian Mineral Summary 2024 – Iron

144 International Energy Agency (IEA) - "Iron and Steel Technology Roadmap", 2022

Figure 57: Iron: Reserves by Country

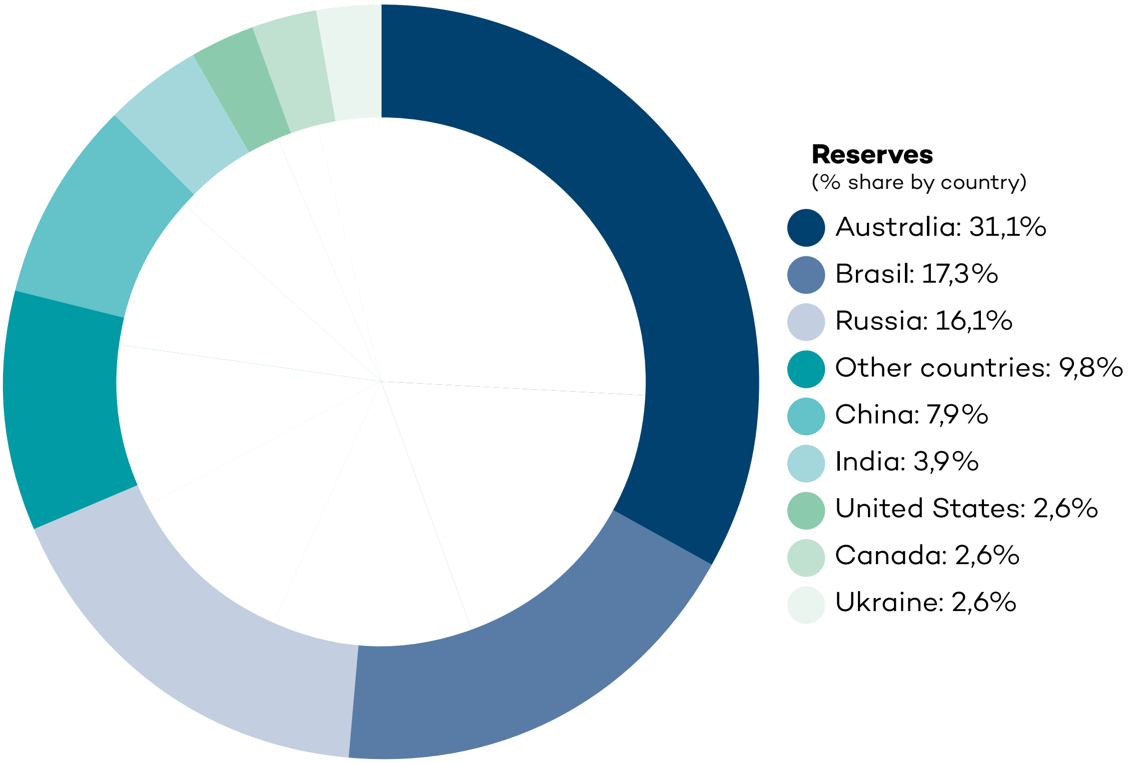
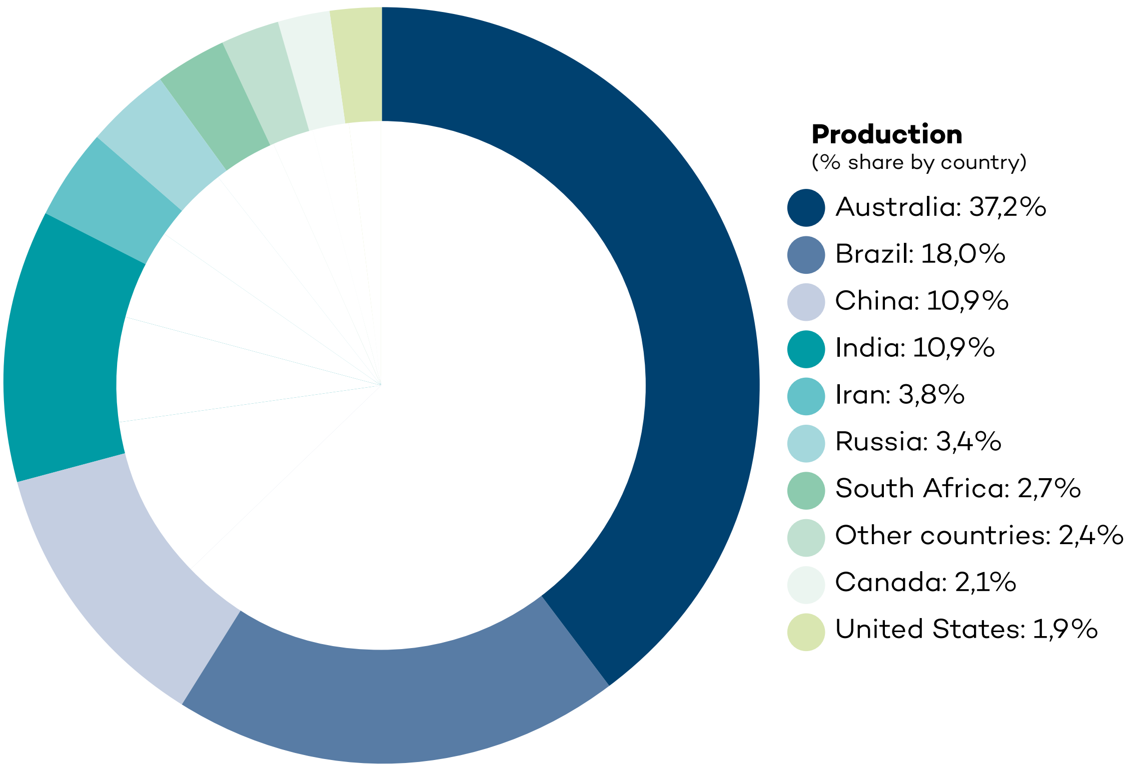


Figure 58: Iron: Production by Country



Source: USGS, 2025

Figure 59: Map for Authorization of Iron Exploration in Brazil (2025)

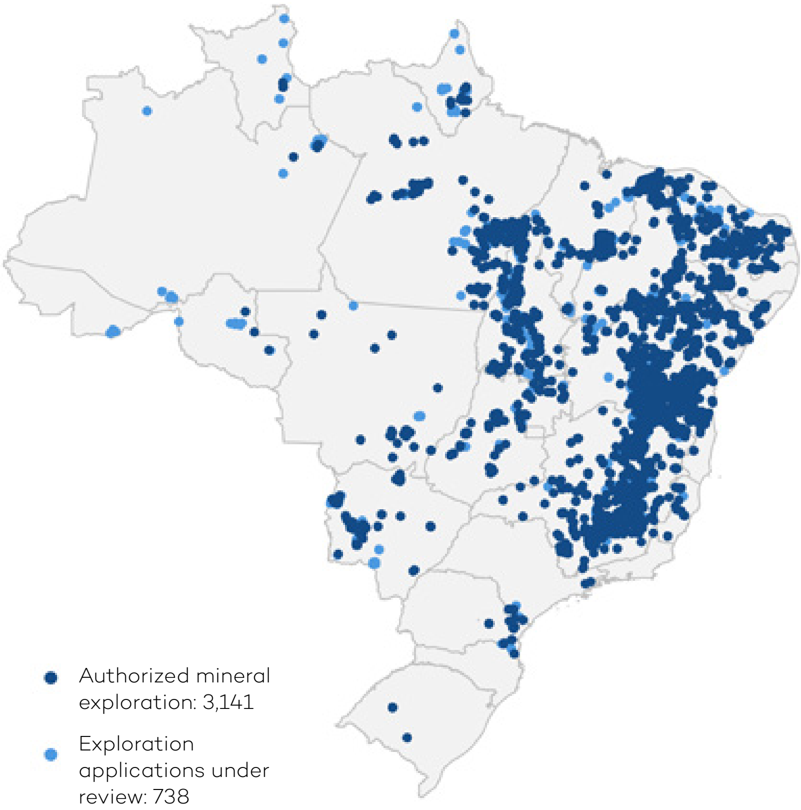
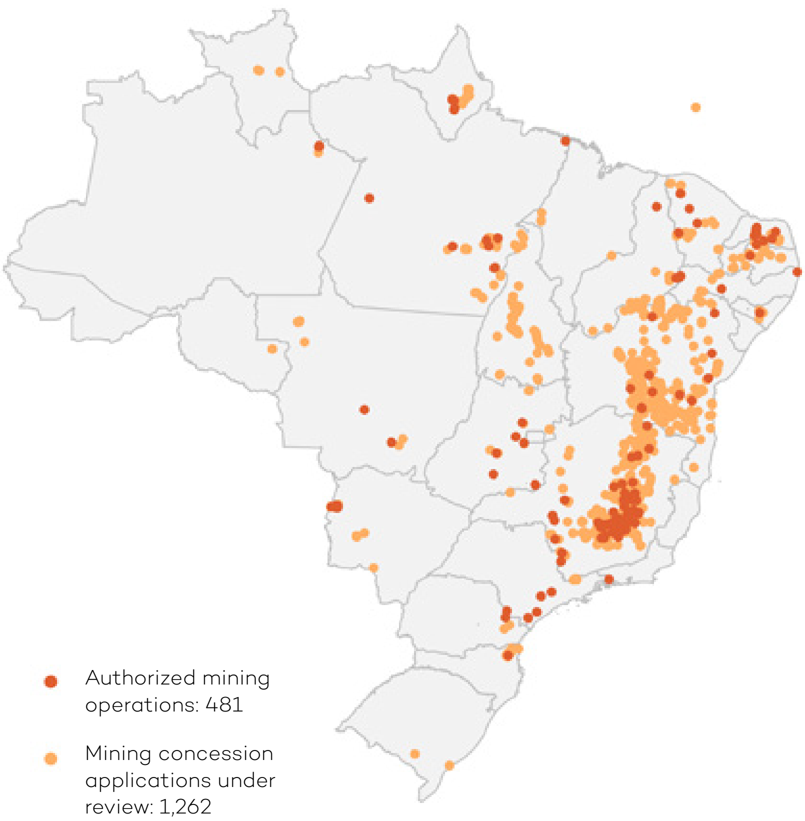


Figure 60: Map for Granting of Iron Mining Concessions in Brazil (2025)



Best Practices

The decarbonization of the steel industry, responsible for approximately 8% of global greenhouse gas (GHG) emissions[145], represents a strategic challenge for achieving net-zero emission targets by 2050. Companies such as Vale, Gerdau, and ArcelorMittal, in partnership with technology developers such as Boston Metal, are leading efforts focused on new production routes, the use of lower-carbon raw materials, and the adoption of innovative technologies.

The transition to low-carbon steel production processes, such as hydrogen-based direct reduction **(DRI – Direct Reduced Iron)**, requires the use of ultra-high-grade iron ore, a raw material that is scarce in the global market[146].

In this context, Vale, the world's largest supplier of high-quality iron ore pellets for DRI plants, plays a central role. The company is developing innovative solutions such as iron ore briquettes, which eliminate the sintering stage and reduce GHG emissions in the steelmaking process by up to 10%. In addition, Vale plans to deploy proprietary technology to produce iron ore with iron content above 68% through dry concentration, as well as to expand the production of DR-grade pellets.

Gerdau, in turn, operates with a carbon intensity below the global average, driven by a production matrix largely based on scrap recycling (73%) and the use of charcoal from planted forests. The company aims to reduce its Scope 1 and 2 emissions from 0.91 to 0.82 t CO_2e per ton of steel by 2031, with carbon neutrality planned for 2050. To achieve these goals, Gerdau invests in renewable energy, open innovation, forestry expansion, and pilot projects involving biofuels and natural gas for low-carbon steelmaking[147,148,149].

ArcelorMittal leads innovation initiatives through the XCarb® Innovation Fund, with significant investments in Boston Metal.

The company is expanding the production of DRI-grade pellets at facilities in Brazil, Mexico, and Canada (Port-Cartier), and is also studying the integration of DRI

145 https://vale.com/pt/briquete-de-minerio-de-Iron#:~:text=O%20briquete%20de%20min%C3%A9rio%20de%20Iron%20reduz%20a%20emiss%C3%A3o%20de,%C3%B3xido%20de%20nitrog%C3%AA-nio%20(NOX).&text=Dispensa%20o%20uso%20da%20%C3%A1gua%20na%20sua%20fabrica%-C3%A7%C3%A3o.&text=Reduz%20a%20emiss%C3%A3o%20de%20particulados,minera%C3%A7%-C3%A3o%20em%20seu%20processo%20produtivo.

146 Nicholas, S., & Basirat, S. (2022). Iron ore quality a potential headwind to green steelmaking. Institute for Energy Economics and Financial Analysis, 28.

147 https://www2.gerdau.com.br/wp-content/uploads/2022/03/ESG-comunicacao-metas-de-carbono.pdf

148 https://www.be8energy.com/pt/noticia/gerdau-e-be8-estabelecem-parceria-para-estudos-de-uso-de--novo-biocombustivel#:~:text=Maior%20recicladora%20da%20Am%C3%A9rica%20Latina,no%20estado%20de%20Minas%20Gerais.

149 https://agencia.petrobras.com.br/w/negocio/petrobras-e-gerdau-estabelecem-acordo-para-estudos-de--negocios-de-baixo-carbono#:~:text=De%20acordo%20com%20Fl%C3%A1via%20Souza,tonelada%20de%20a%C3%A7o%20at%C3%A9%202031.

processes with electric melting in partnership with Air Liquide[150]. At the same time, ArcelorMittal is evaluating technologies that enable the use of lower-quality iron ores, seeking to adapt its production to the context of scarcity of DR-grade ore.

Boston Metal is developing the MOE (Molten Oxide Electrolysis) technology, which produces liquid steel without CO_2 emissions by using renewable electricity and allowing the use of iron ore with varying grades. This flexibility represents a strategic advantage in the face of limited availability of high-grade iron ore. The MOE technology is modular, operates with renewable electricity, and is expected to reach commercial maturity by 2035[151]. It is supported by companies such as Vale, ArcelorMittal, and BMW.

Across the value chain, the iron industry has advanced in making mining and beneficiation more efficient and sustainable, with emphasis on:

- **The use of dry beneficiation technologies:** reducing water consumption and minimizing environmental impacts and risks associated with tailings dam[152].
- **Automation and Mining 4.0:** including autonomous trucks, automated drilling rigs, and remote monitoring systems to improve safety and operational efficiency[153].
- **Emissions reduction in steelmaking:** through the adoption of alternative routes such as the use of green hydrogen in the production of pig iron and low-carbon steel.
- **Tailings management and recovery of degraded areas:** including the reuse of tailings for aggregate production and the implementation of structured environmental rehabilitation programs[154].

150 Shahabuddin, M., Brooks, G., & Rhamdhani, M. A. (2023). Decarbonisation and hydrogen integration of steel industries: Recent development, challenges and technoeconomic analysis. Journal of Cleaner Production, 136391.

151 https://Brazilmineral.com.br/noticias/boston-metal-avanca-com-seu-processo-inovador-para-producao--de-aco-verde

152 Vale S.A. - Relatórios de Sustentabilidade, 2023

153 Mining Technology - "Automation in Iron Ore Mining", 2023

154 International Council of Mining and Metals (ICMM) - "Good Practices in Tailings Management.

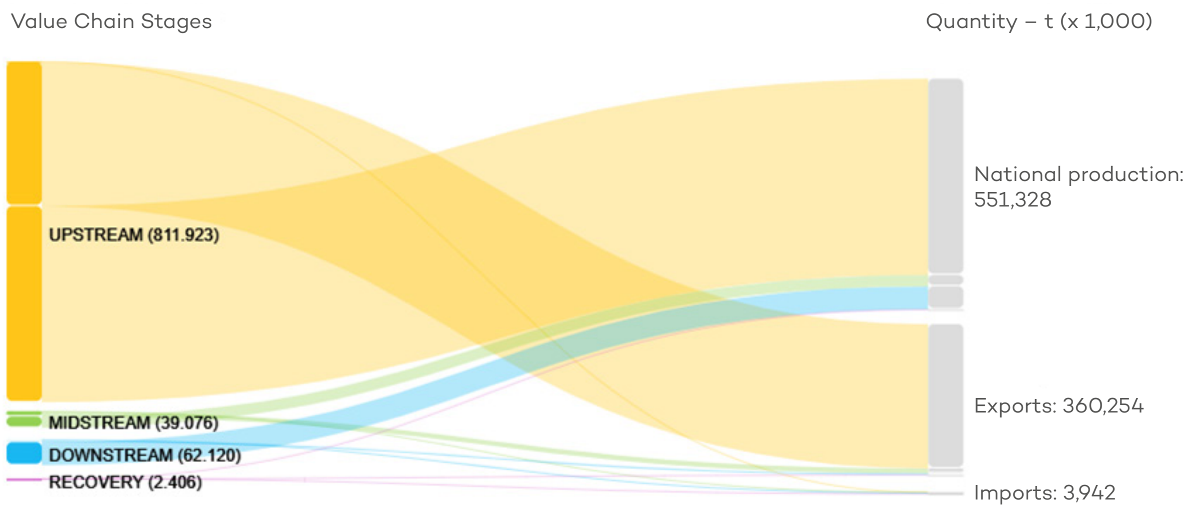
Future Outlook

The iron and steel sector is undergoing a structural transformation driven by decarbonization objectives. Low-carbon steelmaking, particularly hydrogen-based direct reduction projects (DRI-H_2), is expected to gain global prominence over the coming decades[155].

Brazil, due to the high quality of its iron ore (with elevated iron content) and its relatively clean energy matrix, holds significant competitive advantages to position itself as a strategic supplier of premium iron ore for green steel production[156].

In addition, increasing digitalization of operations, the strengthening of ESG practices — including workforce training and capacity building[157] —, partnerships with research and development institutions[158], and growing international requirements for traceability and environmental certifications will be decisive factors shaping the future of the sector.

Figure 61: Material Flow Analysis (MFA) of imported and exported volumes in relation to national industrial production data, according to the stages of the iron value chain, for the year 2022.



Source: Data obtained from the ComexStat Platform, 2025 (year 2022), and from Industrial Production data (SIDRA/IBGE) for 2022.

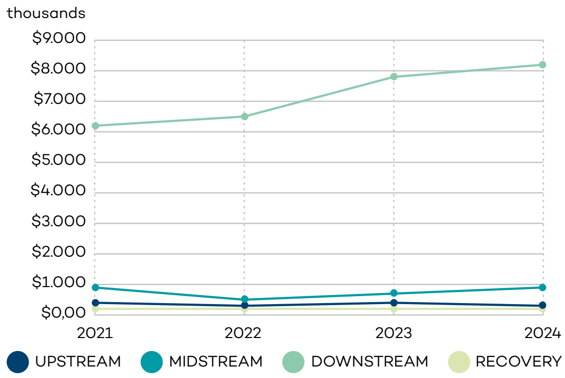
155 Hydrogen Council - "Hydrogen in Steelmaking", 2023.

156 BloombergNEF - "Green Steel: Market Outlook 2024

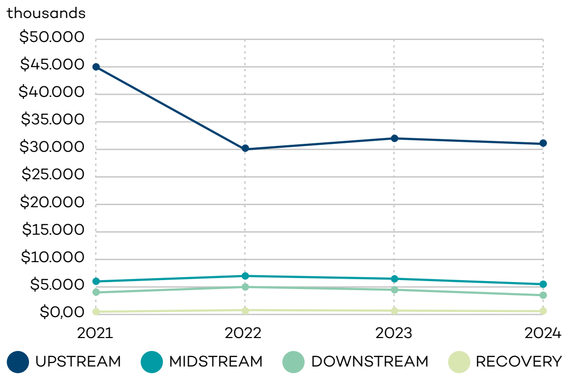
157 https://www.Brazilmineral.com.br/noticias/anglo-american-e-senai-formam-mais-de-100-pessoas-no-minas-rio

158 https://vale.com/pt/w/vale-e-ufmg-anunciam-parceria-para-solucoes-inovadoras-em-mineracao-circular-1/-/categories/1968800

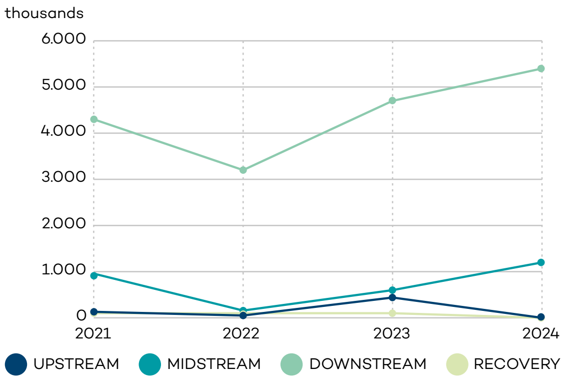
Graph 21. Iron: Import Value US$ FOB (millions) between 2021 and 2024



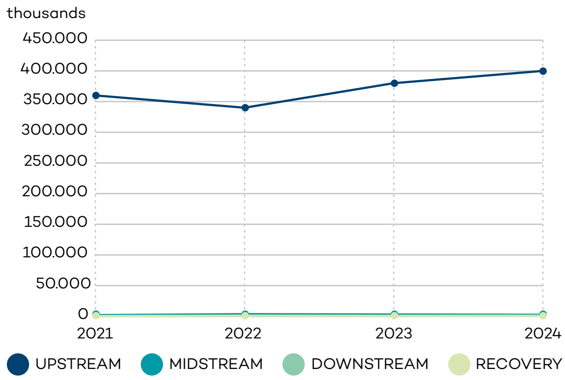
Graph 22. Iron: Export Value US$ FOB (millions) between 2021 and 2024



Graph 23. Iron: Import in Net Kg (millions) between 2021 and 2024

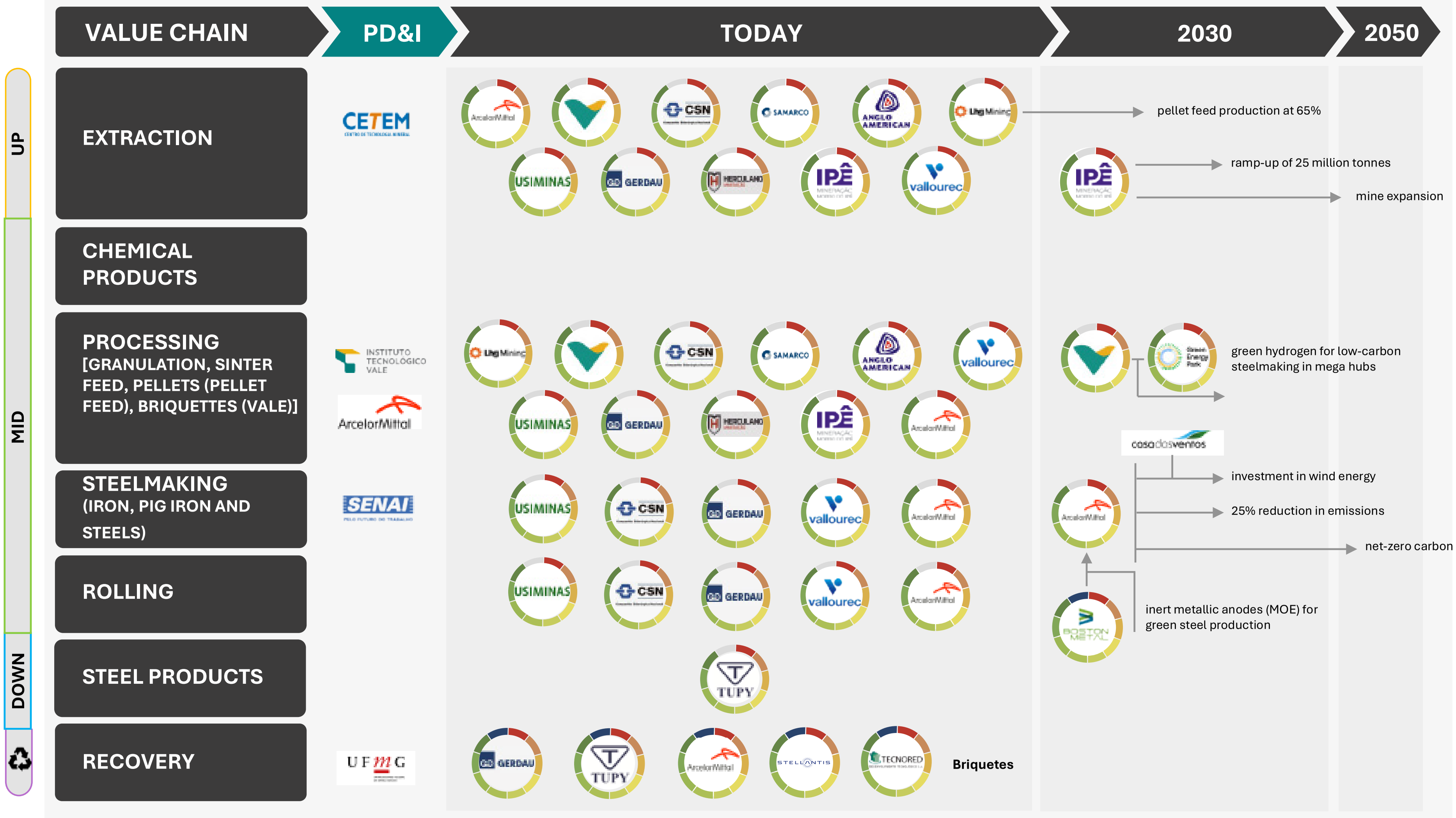


Graph 24. Iron: Export in Net Kg (millions) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.

IRON



https://vale.com/pt/w/parceria-entre-vale-e-green-energy-park-no-brasil-e-incluida-em-lista-prioritaria-da-iniciativa-global-gateway-da-uniao-europeia/-/categories/1968809

PHOSPHATE

- **UPSTREAM** MINING — Phosphate ore
- **MIDSTREAM** CHEMICALS/METALLURGY — Chemicals (oxides, acids, etc.), intermediates for fertilizers and chemical products
- **DOWNSTREAM** FINAL PRODUCTS — Fertilizers, agricultural pesticides and other industrial additives, flame retardants, and components for cells and batteries
- **RECOVERY** RECOVERY — Dephosphorization slags and remineralizers

Overview and demand

Phosphorus is vital for NPK fertilizers, which are essential for Brazilian agricultural productivity, especially in monoculture systems that require increasing application rates. Phosphate is considered a critical mineral due to domestic demand, supply risk, and dependence on phosphate fertilizers. Currently, 70% of demand is met through imports[159]. Phosphorus recycling can be one of the alternatives to external dependence, for example through the use of secondary phosphorus present in animal production waste or in residues from sugarcane processing. Secondary phosphorus could supply up to 20% of Brazil's grain demand by around 2050, with investment in nutrient recovery technologies[160].

The demand for phosphate fertilizers in Brazilian agricultural production is driven by the low availability of phosphorus (P) in soils. Superphosphates (SSP and TSP) and ammonium phosphates (MAP and DAP) are the main products, frequently used in different NPK blends. Brazil's dependence on the import of phosphate rock and phosphate fertilizers is high and has doubled over the last decade, reaching 69% of national consumption (9.03 million tonnes in 2023). Domestic production is concentrated in a few states, derived from alkaline-carbonatite sources (Minas Gerais: Tapira, Salitre, Araxá; Goiás: Catalão; São Paulo: Cajati, Registro; Bahia: Angico dos Dias) and sedimentary sources (Minas Gerais: Arraias, Pratápolis; Mato Grosso do Sul: Bonito).

Mosaic Fertilizantes is the main producer (52%), followed by CMOC (20%), Yara (11%), Itafós (5%), Galvani (4%), Mineração Curimbaba (3%), Grupo Scheffler (2%), EDEM (2%), and Mineração Morro Verde (1%). Despite significant external dependence, Brazil presents promising potential for production expansion, with official reserves estimated at 5.2 billion tonnes (460 Mt of P_2O_5) associated with open-pit magmatic deposits. The current mineable reserve is 2.9 billion tonnes (317 Mt of contained P_2O_5, with an average grade of 10%). The sector comprises 4,331 active mining processes and 18 mines operated by 39 companies.

159 https://www.gov.br/mme/pt-br/assuntos/noticias/fosforo-o-mineral-estrategico-importante-para-seguranca-alimentar-nacional

160 https://www.embrapa.br/busca-de-noticias/-/noticia/33747073/Brazil-adicionou-228-milhoes-de-toneladas-de-fosforo-em-seus-solos-nos-ultimos-50-anos

Figure 62: Phosphate: Reserves by Country

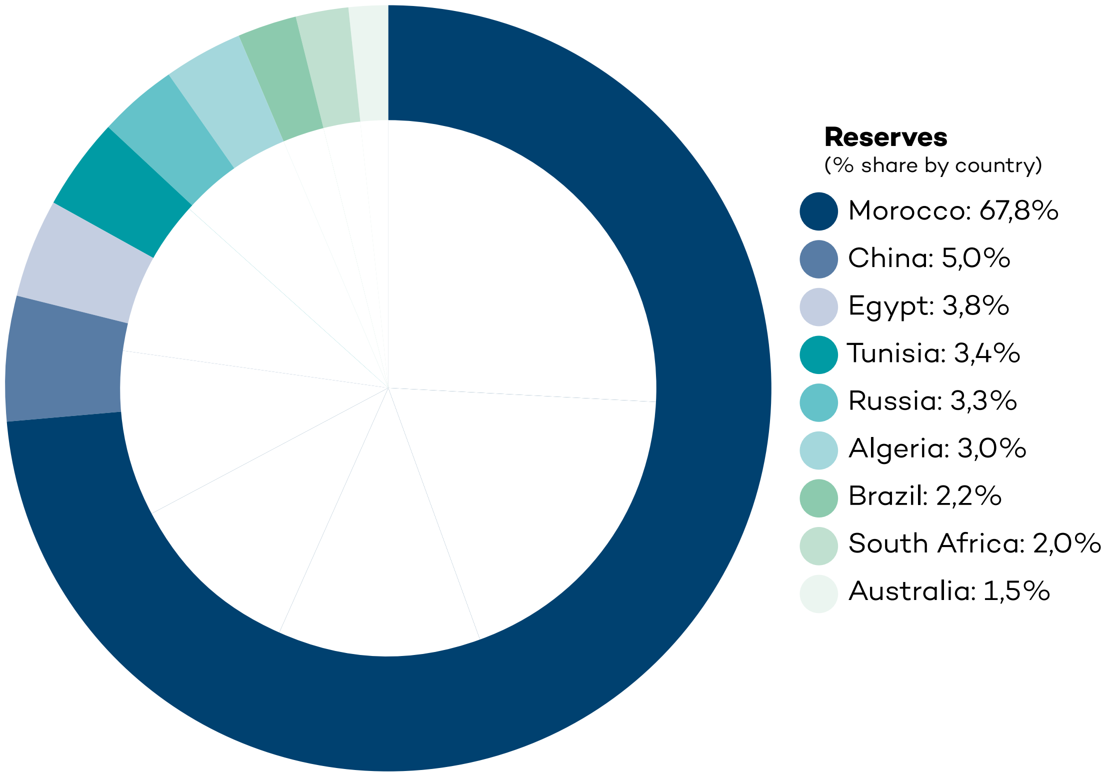
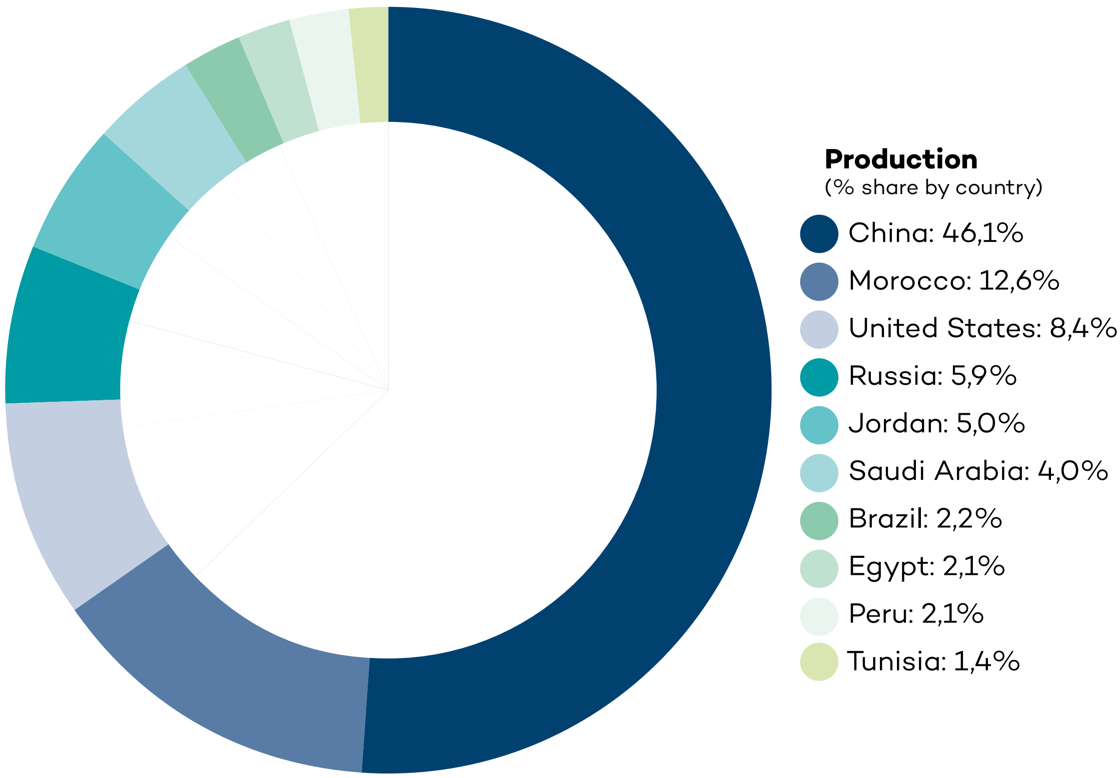


Figure 63: Phosphate: Production by Country



Source: USGS, 2025

Figure 64: Map for Authorization of Phosphate Exploration in Brazil (2025)

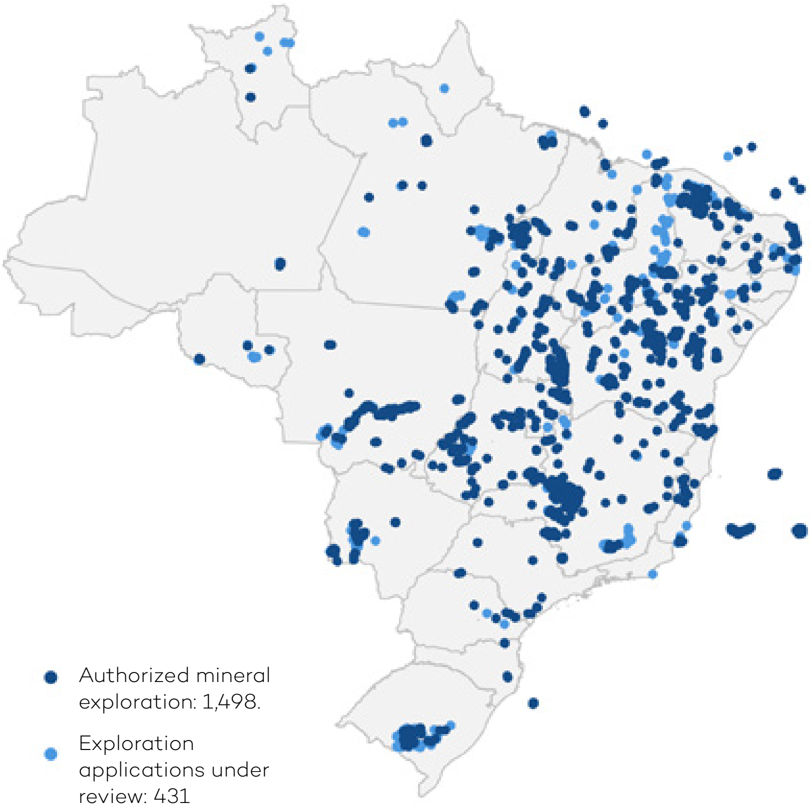
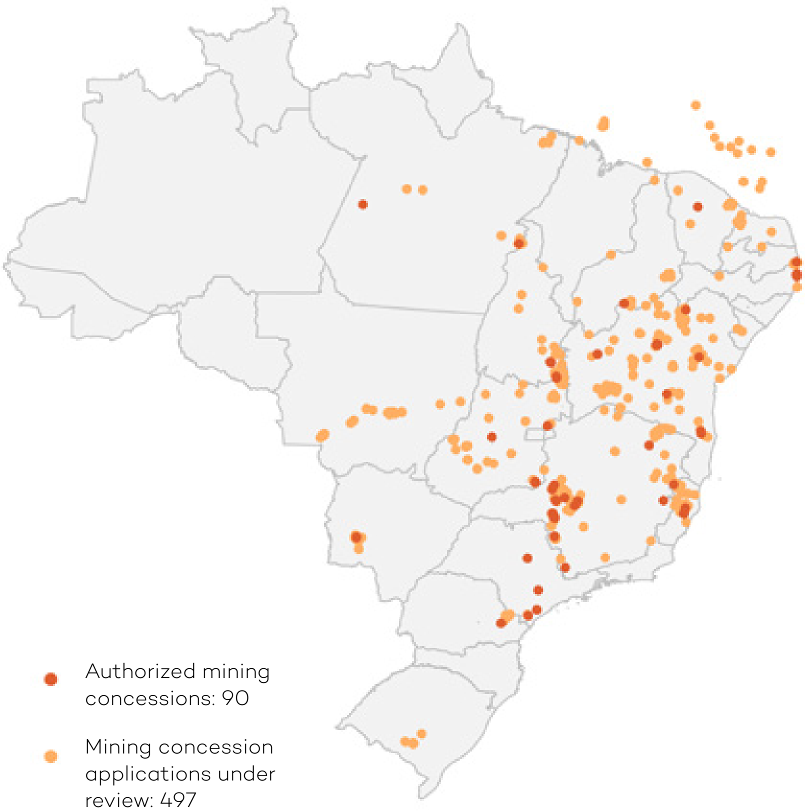


Figure 65: Map for Granting of Phosphate Mining Concessions in Brazil (2025)



Although listed in MME Resolution No. 2 as a strategic mineral, phosphate, as well as potassium, presents conditions that qualify it as a critical mineral due to the risk of supply disruption. High demand from the agricultural sector and insufficient domestic production are examples of criticality factors related to the supply of this mineral.

Best Practices

Brazil can reduce external dependence through the sustainable growth of domestic phosphate rock production, but it must continue investing in installed technology within agro-industrial production, particularly with regard to the training of agronomy professionals dedicated to the fertilizer segment, in order to promote more efficient use of phosphorus and other fertilizers in agriculture.

The increasing use of NPK fertilizers with added technology for controlled nutrient release is a prominent example, currently representing a considerable share of deliveries and a market with more than 200 products registered and/or marketed in Brazil. Another relevant aspect is the development of biological inputs that solubilize nutrients in the soil. The phosphate solubilizer developed by Embrapa[161] within its research network has enabled farmers to achieve savings of more than 10% in fertilizer application.

Within the agro-industrial sector, it is necessary for the country to promote PD&I initiatives and agroecological research networks, which can enhance the competitiveness and resilience of Brazilian agribusiness through more efficient fertilizer use, the development of new technologies adapted to tropical climate and soils, and the reduction of the environmental impact of fertilizer use through alternative sources and other inputs.

Future Outlook

Although the country is not able to fully meet its demand for phosphate fertilizers and their derivatives, new projects and/or the expansion of existing projects may considerably reduce national dependence on external supply. Currently, companies such as Yara (Salitre/MG), Itafos (Santana/PA and Arraias/TO), Aguia Resources (Três Estradas/RS), Fosnor-Galvani (Santa Quitéria/CE and Irecê/BA) and EDEM (Bonito/MS) have planned expansions of operations which, operating jointly, could increase the current installed capacity from 7.9 million t/year to 11.4 million t/year by 2026.

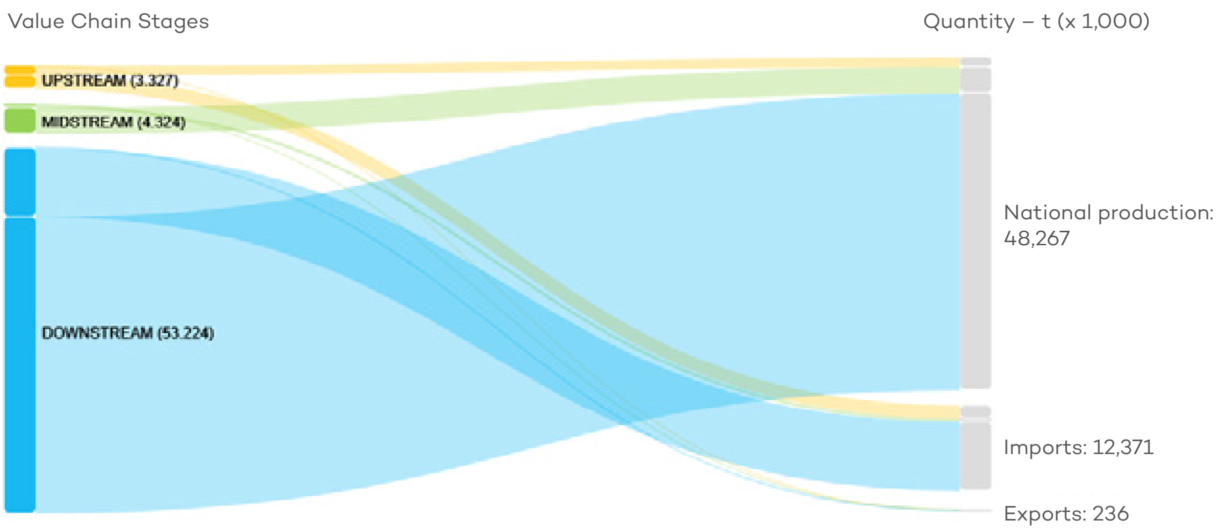
From a strategic perspective, the phosphate fertilizer production chain in Brazil is located relatively close to the Cerrado region, which coincides with the area of expansion of the agricultural frontier, indicating that integration among phosphate, potash and nitrogen producer hubs represents a perspective for the expansion and consolidation of the national fertilizer production chain.

161 https://www.embrapa.br/busca-de-noticias/-/noticia/71715588/primeiro-inoculante-solubilizador-de-fosforo-produzido-no-Brazil-aumenta-produtividade-de-soja-e-milho

Although there is external dependence on sulfur, an essential component of the production chain, the promotion of mineral exploration into new reserves and the assurance of incentives to enable national phosphate rock production, as well as the expansion of production across all links of the value chain, prove to be fundamental mechanisms for the sustainable growth of national fertilizer production, ensuring greater stability for the agro-industrial sector and national food security.

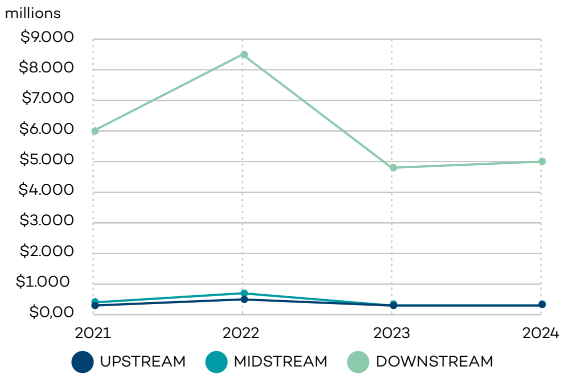
It is necessary to advance beneficiation and logistics processes to reduce costs and compete globally, as well as to advance policies—such as the National Fertilizer Plan—structured to connect mining, agriculture and sustainability, with the objective of reducing criticality attributes.

Figure 66: MFA of imported and exported volumes, in relation to national industrial production data according to the stages of the phosphate value chain for the year 2022.

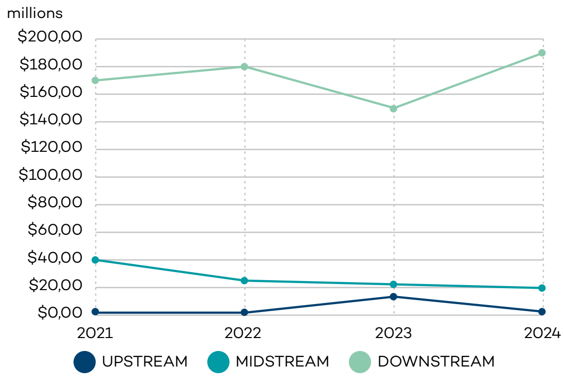


Source: Data obtained from the ComexStat Platform, 2025 (year 2022), and Industrial Production data (SIDRA/IBGE) for 2022.

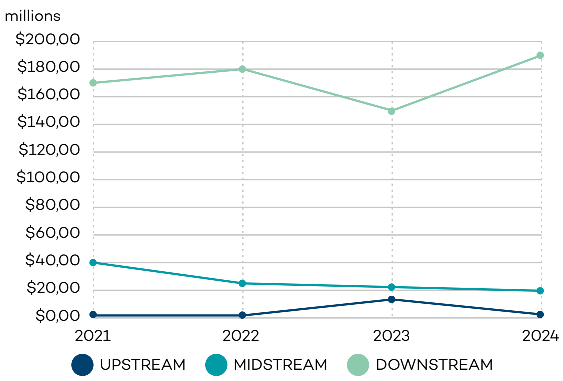
Graph 25. Phosphate: Imports in Value US$ FOB (millions) between 2021 and 2024



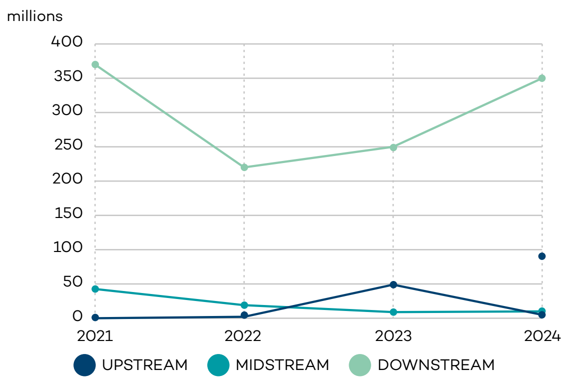
Graph 26. Phosphate: Exports in Value US$ FOB (millions) between 2021 and 2024



Graph 27. Phosphate: Imports in Net Weight Kg (millions) between 2021 and 2024

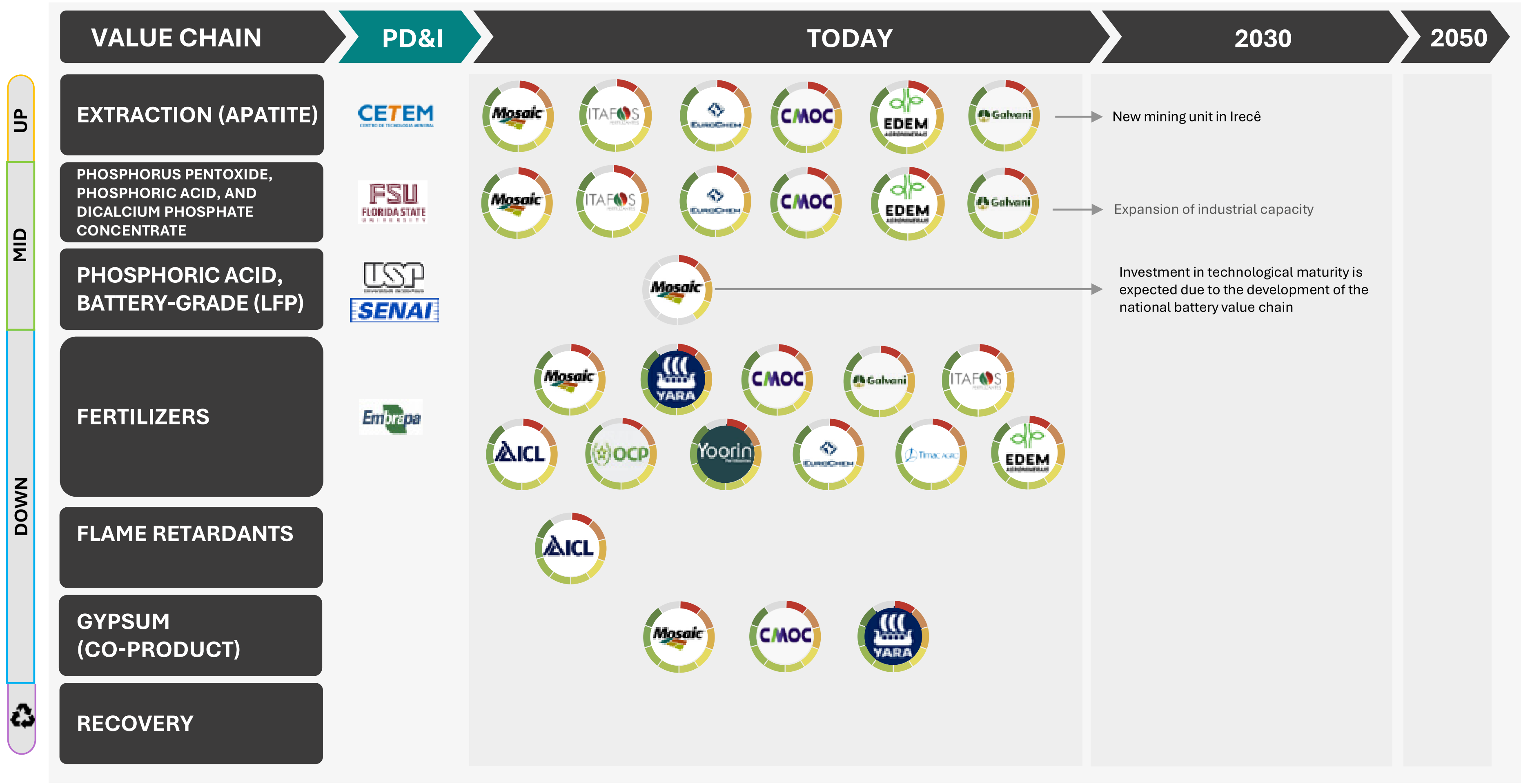


Graph 28. Phosphate: Exports in Net Weight Kg (millions) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.

PHOSPHATE



Sources:
Galvani planeja investir R$ 2,54 bilhões para expandir produção e mineração de fertilizantes
Galvani kicks off plan to invest R$3bn in fertilizers
Galvani aims to increase production in Brazil by 20% in 2025
Página inicial - Projeto Santa Quitéria
Colofanito Uranífero – Museu de Ciências Nucleares
https://www.brasilmineral.com.br/noticias/empresa-de-galvani-adquire-unidade-da-mosaic-em-patos-de-minas-por-us-125-milhoes

CETEM | IBRAM BRAZILIAN MINING

GRAPHITE

UPSTREAM MINING — Natural graphite in powder or flake form

MIDSTREAM CHEMICALS/METALLURGY — Concentrates, artificial graphite, other graphite products, pastes

DOWNTREAM FINAL PRODUCTS — Battery anodes, refractories, lubricants, conductive materials, electrodes,advanced materials and industrial components

RECOVERY RECOVERY — Industrial residues, spent anodes, graphite-containing waste

Overview and demand

Graphite is a soft, flexible mineral with high refractory potential, in addition to being chemically inert and having high thermal and electrical conductivity, as well as natural lubricity and resistance to heat and corrosion. As such, it has diversified application potential in the industrial sector, for example: energy storage devices (batteries and fuel cells), parts and components, metallurgy (carbon additives for steels, carburizers for irons, etc.), refractories, lubricants, polymers (plastics and powders for lubricants), and agriculture (seed and fertilizer lubricants).

Graphite is a common element across different types of batteries and, in the aerospace sector, is applied in spacecraft and aircraft due to its light weight and thermal resistance. It is also applied in conductive paints, anticorrosive coatings, and thermal and acoustic insulation. It is important to understand that Graphite[162] is the non-metallic mineral from which graphene is produced, a carbon sheet with a single layer of atoms arranged in a two-dimensional hexagonal lattice, considered a nanomaterial with important applications in the electronics, biomedicine, and telecommunications industries.

National graphite reserves are concentrated mainly in the states of Minas Gerais, Bahia, and Ceará. Brazil is the third-largest graphite producer and holds the second-largest reserve worldwide. Graphite is the main raw material for graphene, and the main companies operating in the country include Nacional de Grafite Ltda., Graphcoa[163] (Appian), Grafite do Brasil, and Gerdau Graphene. Different products are classified as graphene; however, the technical standard ABNT ISO/TS

21356:2023 establishes the structural characterization of graphene and also defines protocols for determining the number of layers, thereby differentiating the range of products and applications. It is estimated that graphene represents a global market of US$620 million, which could reach approximately US$1.5 billion in 2025[164].

162 https://www.sgb.gov.br/w/mapa-de-favorabilidade-destaca-regioes-estrategicas-para-a-mineracao-de--Graphite

163 https://graphcoa.com/

164 https://www.Brazilmineral.com.br/noticias/abnt-concede-primeira-norma-tecnica-para-grafeno

Figure 67: Graphite: Reserves by Country

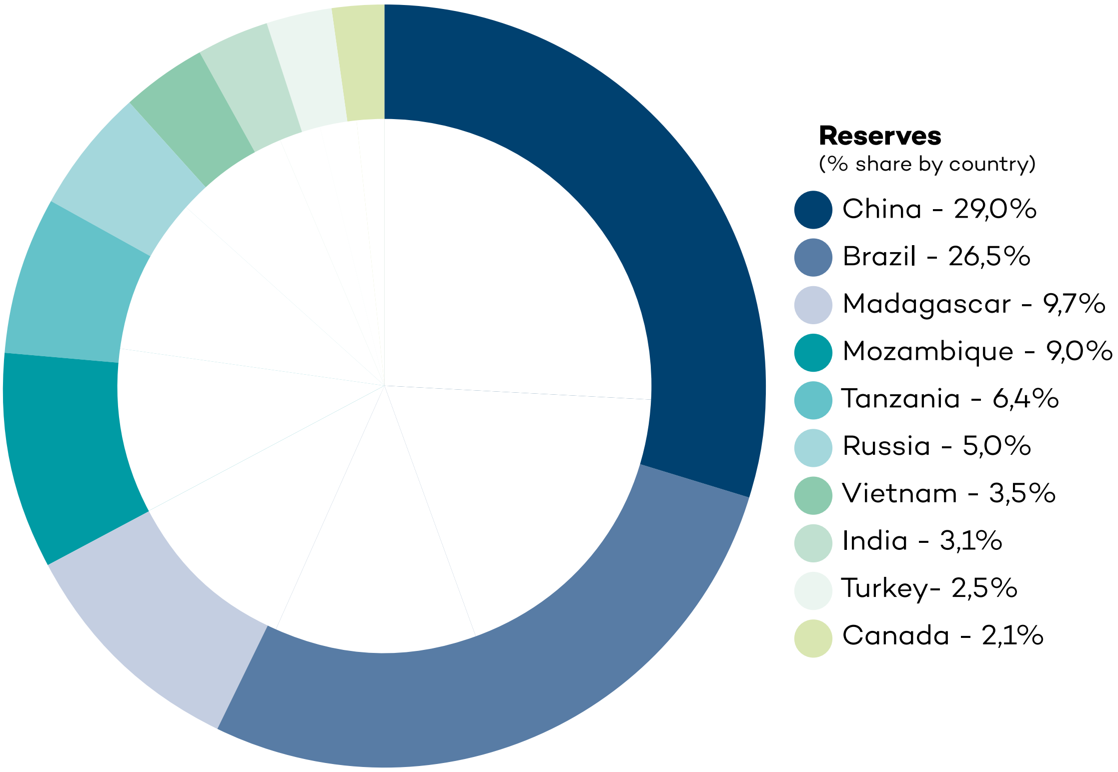
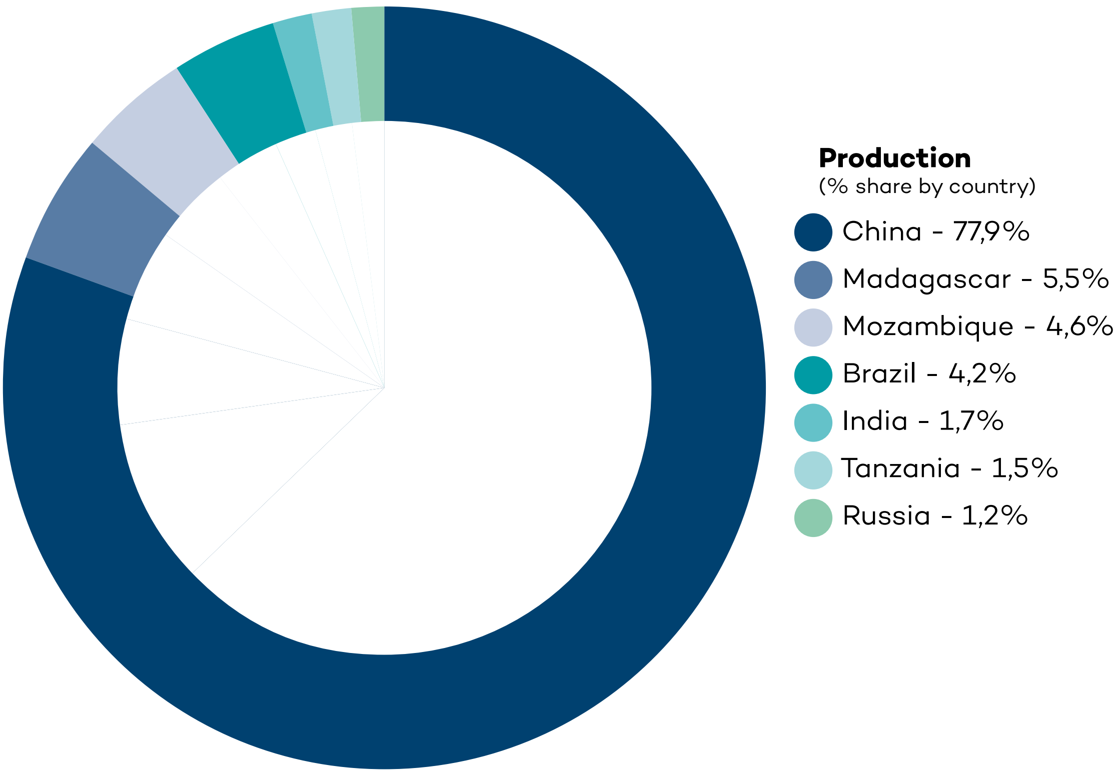


Figure 68: Graphite: Production by Country



Source: USGS, 2025

Figure 69: Map for Authorization of Graphite Exploration in Brazil (2025).

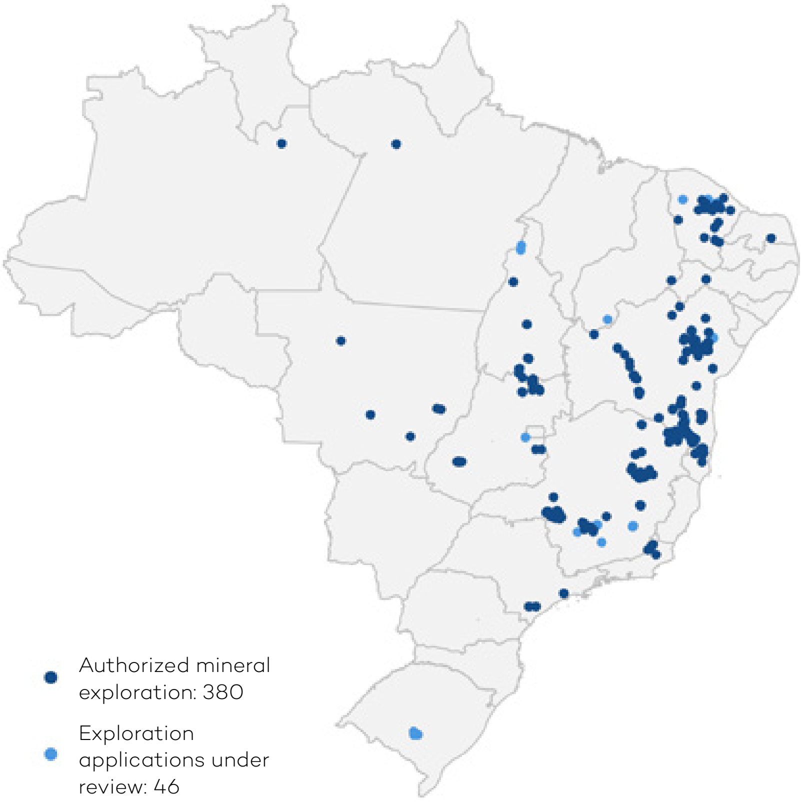


Figure 70: Map for Granting of Graphite Mining Concessions in Brazil (2025)

Best Practices

Nacional de Grafite[165], founded in 1939, operates in the mining and processing of crystalline natural graphite, with a significant diversity of applications across productive sectors and a high level of international market penetration. The company maintains a research and development unit in Itapecerica, Minas Gerais, and annually produces approximately 70 kt of graphite for multiple industrial applications.

The production of high-purity graphite, with a carbon content of 99.99%, is one of the main products of Grafite do Brasil[166], which began its extraction and processing operations of natural crystalline graphite in 2002 in the municipality of Maiquinique, Bahia. The company reports an annual production of around 50 kt of graphite.

The operation of Graphcoa represents one of the four active projects currently in operation in the country, encompassing the production of both concentrates and products for application in refractory, metallurgical, battery, lubricant, polymer, and agricultural additive industries. The company stands out for operating a unit in Itagimirim, Bahia, without the need for tailings dams, employing a filtration system with stacking and compaction of residues. The operation also includes a flotation system for mineral concentration.

UCS Graphene is an EMBRAPII unit located at TecnoUCS in Caxias do Sul, specializing in nanomaterials. The institution works on the development of new applications for graphene, particularly in composites and polymeric materials, as well as on technical regulation and the establishment of quality standards for the market. It also maintains partnerships with suppliers capable of delivering graphene at industrial scale.

Future Outlook

Gerdau Graphene[167] represents one of the leading nanotechnology companies in Brazil, offering industrial application solutions for the chemical, coatings, cement, and lubricant sectors.

The following section presents details of the favorability mapping survey developed by the Geological Survey of Brazil in 2025.

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165 https://www.Graphite.com/aplicacoes

166 https://GraphitedoBrazil.com.br/nossa-empresa

167 https://www2.gerdau.com.br/noticias/gerdau-graphene-lanca-selo-de-autenticidade-da-tecnologia-exclusiva-g2d/

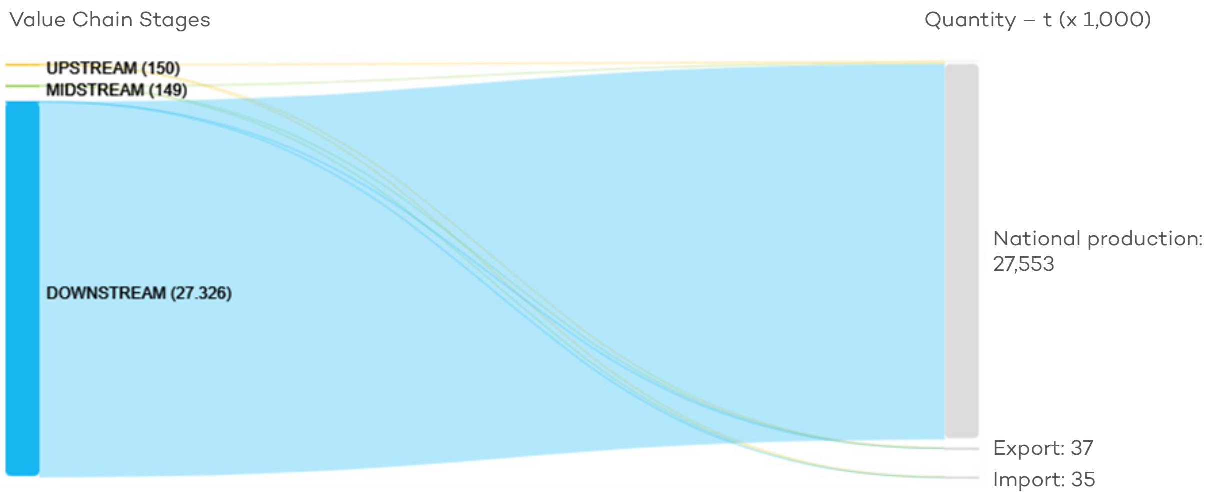
Table 12. Graphite Mines and Deposits.

Nº	Mine / Occurrence	Company	Municipality	Importance Grade	Economic Status
1	Pedra Azul	Nacional de Graphite	Pedra Azul, MG	Deposit	Active Mine
2	Salto da Divisa	Nacional de Graphite	Salto da Divisa, MG	Deposit	Active Mine
3	Maiquinique União Bainana	Graphite do Brazil	Maiquinique, BA	Deposit	Active Mine
4	União Bainana	Graphcoa	Itagimirim, BA	Deposit	Active Mine
5	Mina de Uruaçu	Nacional de Graphite	Pedra Azul, MG	Occurrence	Occurrence
6	Chapada do Barbados	Magnesita Mineração S.A.	Cachoeira de Pajeú, MG	Occurrence	Occurrence
7	Corcovado	Nacional de Graphite	Pedra Azul, MG	Occurrence	Occurrence
8	Corcovado	Nacional de Graphite	Pedra Azul, MG	Occurrence	Occurrence
9	Corcovado	Nacional de Graphite	Pedra Azul, MG	Occurrence	Occurrence
10	Corcovado	Nacional de Graphite	Pedra Azul, MG	Occurrence	Occurrence
11	Fazenda Lameiro	Magnesita Mineração S.A.	Almenara, MG	Occurrence	Occurrence
12	Fazenda Lameiro	Magnesita Mineração S.A.	Almenara, MG	Occurrence	Occurrence
13	São Domingos	Magnesita Mineração S.A.	Bandeira, MG	Occurrence	Occurrence
14	Pedro Perdido	Samaca Irons Ltda	Jordan, MG	Occurrence	Occurrence

Nº	Mine / Occurrence	Company	Municipality	Importance Grade	Economic Status
15	Pedro Perdido	Viva Companhia de Mineração S.A.	Jordan, MG	Occurrence	Occurrence
16	Pedro Perdido	Viva Companhia de Mineração S.A.	Jordan, MG	Occurrence	Occurrence
17	Fazenda Oklahoma	CMG Mineração S.A.	Salto da Divisa, MG	Occurrence	Occurrence
18	Monte Santo Stone	Mineração Taquaral LTDA	Maiquinique, BA	Occurrence	Occurrence

Source: SGB, 2025[168].

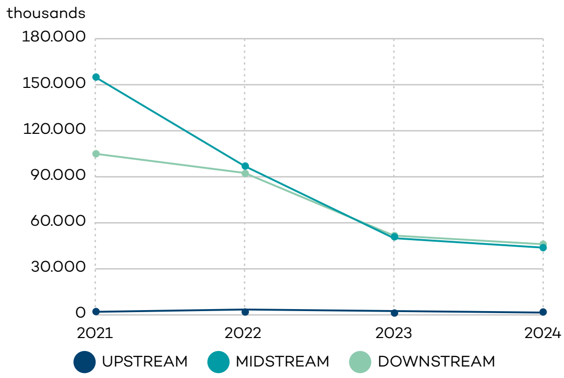
Figure 71: MFA of imported and exported volume in relation to domestic industrial production data according to the stages of the Graphite value chain for the year 2022.



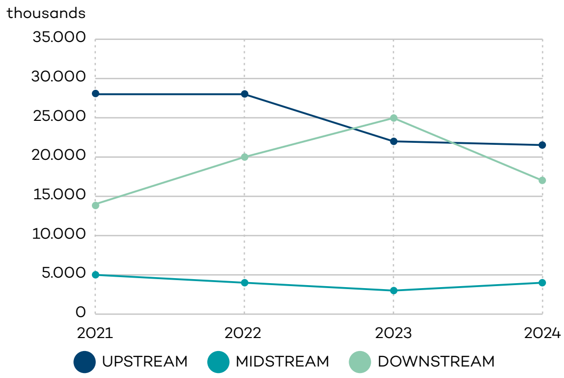
Source: Data obtained from the ComexStat Platform, 2025 (year 2022), and from Industrial Production data (SIDRA/IBGE) of 2022.

168 https://www.sgb.gov.br/documents/d/guest/favorabilidade_Graphite_2025

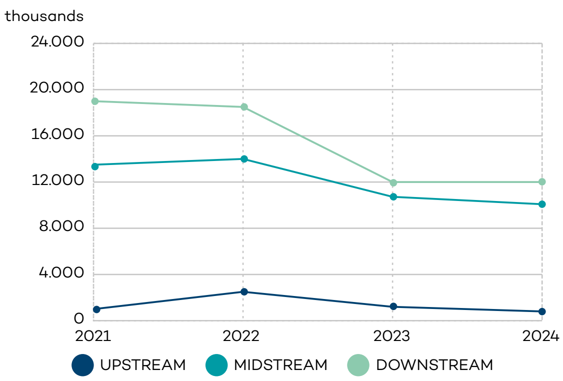
Graph 29. Graphite: Import Value US$ FOB (thousands) between 2021 and 2024



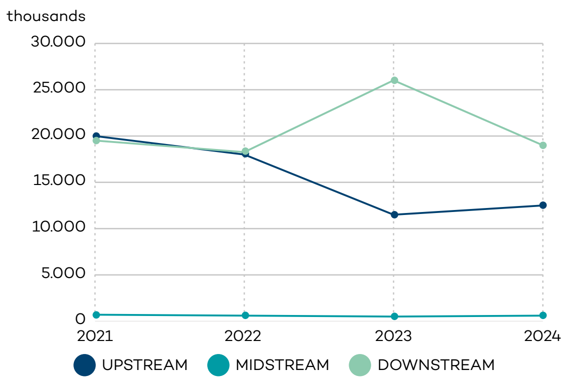
Graph 30. Graphite: Export Value US$ FOB (thousands) between 2021 and 2024



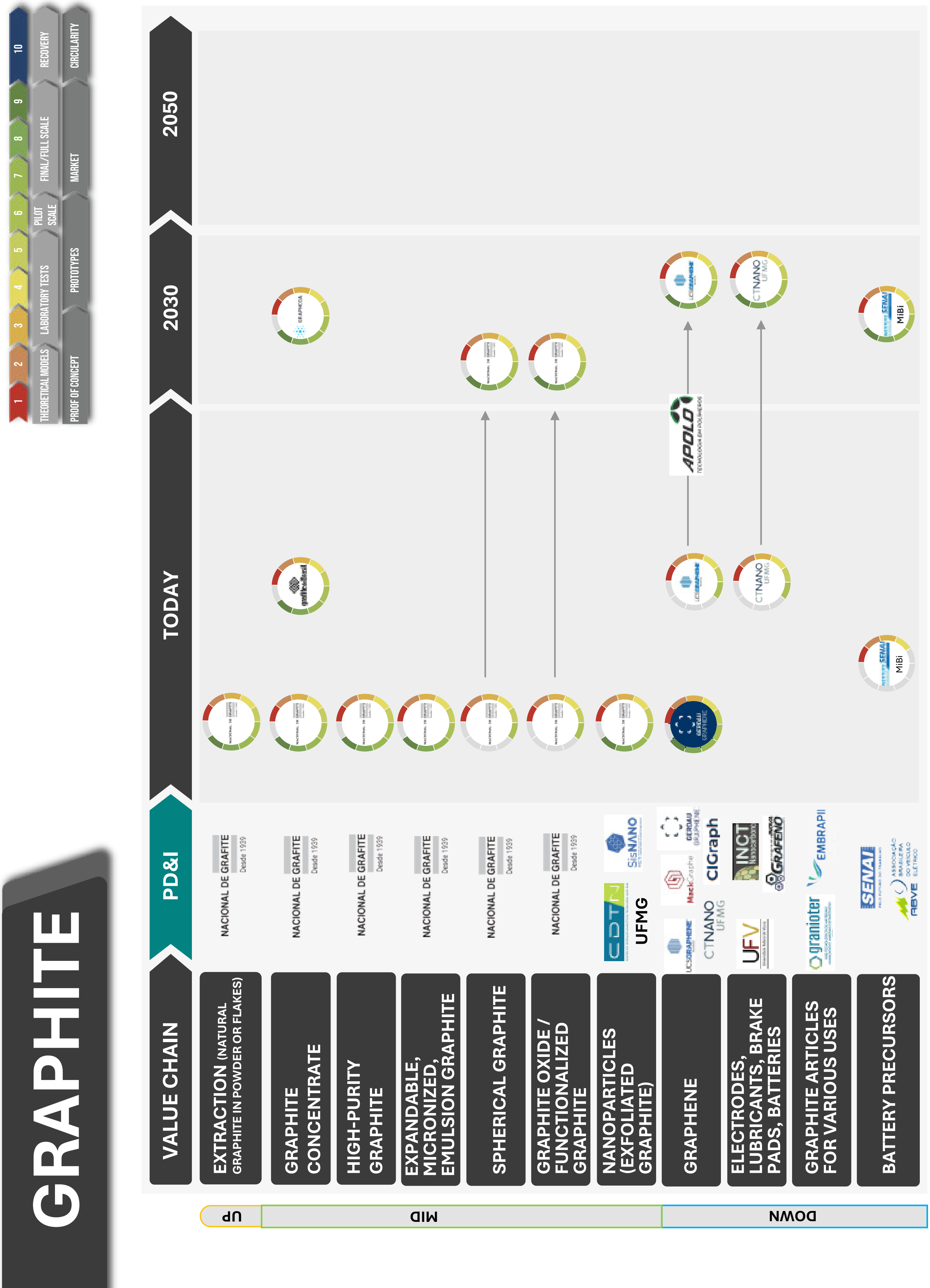
Graph 31. Graphite: Import in Net Kg (thousands) between 2021 and 2024



Graph 32. Graphite: Export in Net Kg (thousands) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.


1
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THEORETICAL MODELS
LABORATORY TESTS
PILOT SCALE
FINAL/FULL SCALE
RECOVERY
PROOF OF CONCEPT
PROTOTYPES
MARKET
CIRCULARITY
GRAPHITE
VALUE CHAIN
PD&I
TODAY
2030
2050
EXTRACTION (NATURAL GRAPHITE IN POWDER OR FLAKES)
GRAPHITE CONCENTRATE
HIGH-PURITY GRAPHITE
EXPANDABLE, MICRONIZED, EMULSION GRAPHITE
SPHERICAL GRAPHITE
GRAPHITE OXIDE / FUNCTIONALIZED GRAPHITE
NANOPARTICLES (EXFOLIATED GRAPHITE)
GRAPHENE
ELECTRODES, LUBRICANTS, BRAKE PADS, BATTERIES
GRAPHITE ARTICLES FOR VARIOUS USES
BATTERY PRECURSORS
NACIONAL DE GRAFITE Desde 1939
UFMG
SisNANO
MackGraphe
CTNANO UFMG
CIGraph
INCT Nanocarbono
UFV
granioter
EMBRAPII
SENAI
ABVE
APOLO TECNOLOGIA EM POLÍMEROS
MiBi
UP
MID
DOWN

Lithium

UPSTREAM MINING — Lithium minerals

MIDSTREAM CHEMICALS/METALLURGY — Chemicals (oxides, hydroxides, carbonates, nitrites and nitrates, sulfates) and concentrates

DOWNSTREAM FINAL PRODUCTS — Components for batteries, battery packs, and motors

RECOVERY RECOVERY — Battery and cell waste and residues

Overview and demand

Lithium has gained relevance in Brazil due to the increase in global demand, with beneficiation carried out by companies such as CBL, AMG, and Sigma Lithium. CBL is the only company advancing in the value chain by producing lithium oxides and carbonates, primarily applied in lubricants. However, the decline in international prices has posed a significant challenge to lithium mineral production.

The Government of Minas Gerais launched a program to promote lithium production in May 2023 at the Nasdaq Stock Exchange in New York. This socio-economic project aims to develop cities in the Northeast and North regions of the state around the lithium value chain, generating jobs and income for local populations. The project seeks to attract multiple actors from the lithium supply chain to the same region, where it will be possible to extract, process, and manufacture products for global markets.

At the time of the launch, Companhia Brasileira de Lítio (CBL) was already operational in the region, and Sigma Lithium was approaching start-up. Other companies, such as Latin Resources, Atlas Lithium, and Lithium Ionic, are implementing exploration programs. In Nazareno, located in the Campo das Vertentes mesoregion, AMG is already producing lithium for export. BNDES approved financing of BRL 486.7 million for Sigma Mining to increase the current production of 270,000 tons/year of lithium concentrate for export by 250,000 tons/year.

Figure 72: Lithium: Reserves by Country

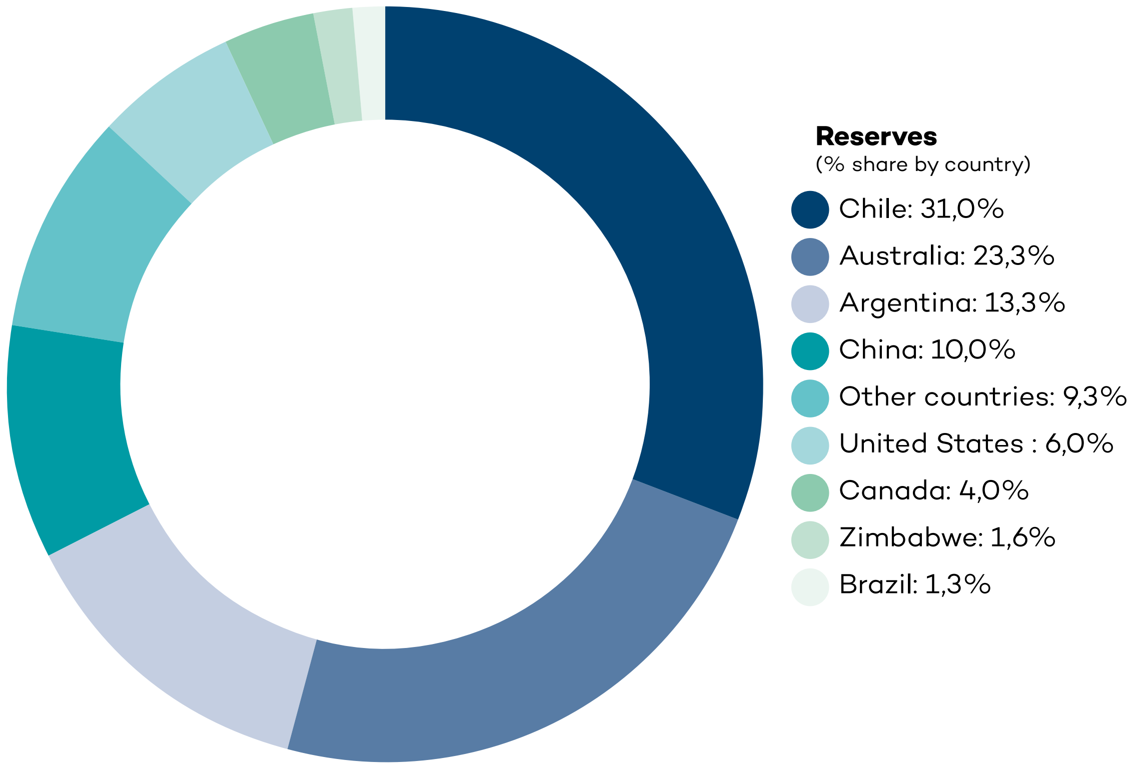
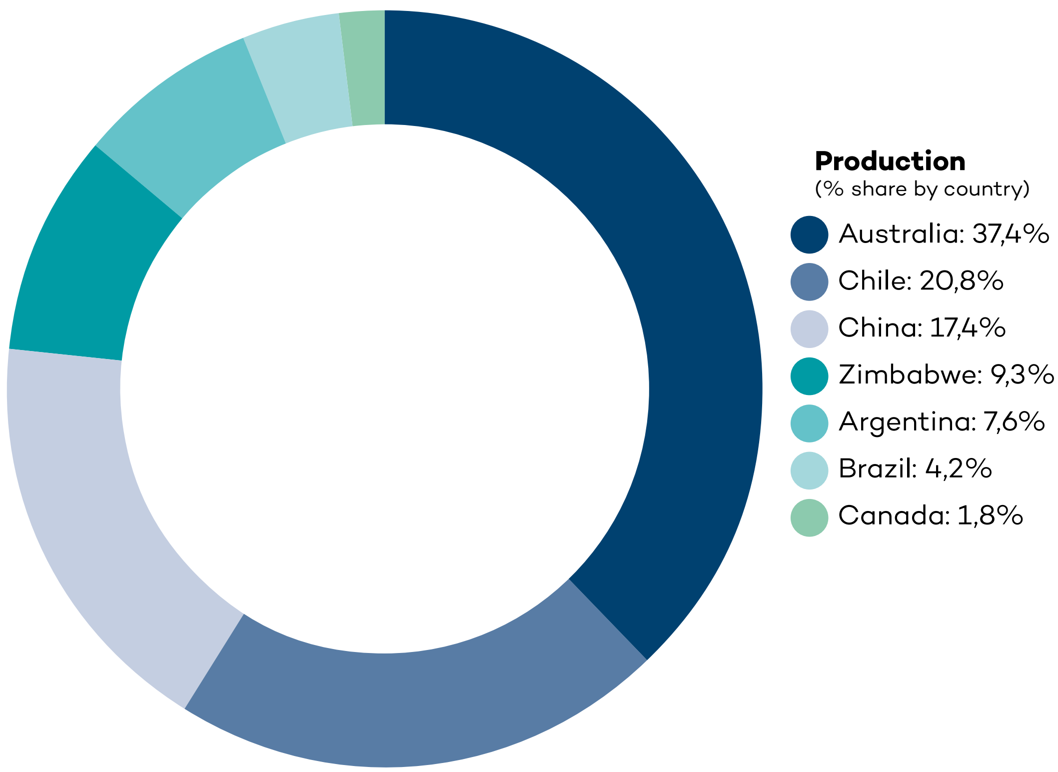


Figure 73: Lithium: Production by Country



Source: USGS, 2025

Figure 74: Map for Lithium Exploration Authorization in Brazil (2025)

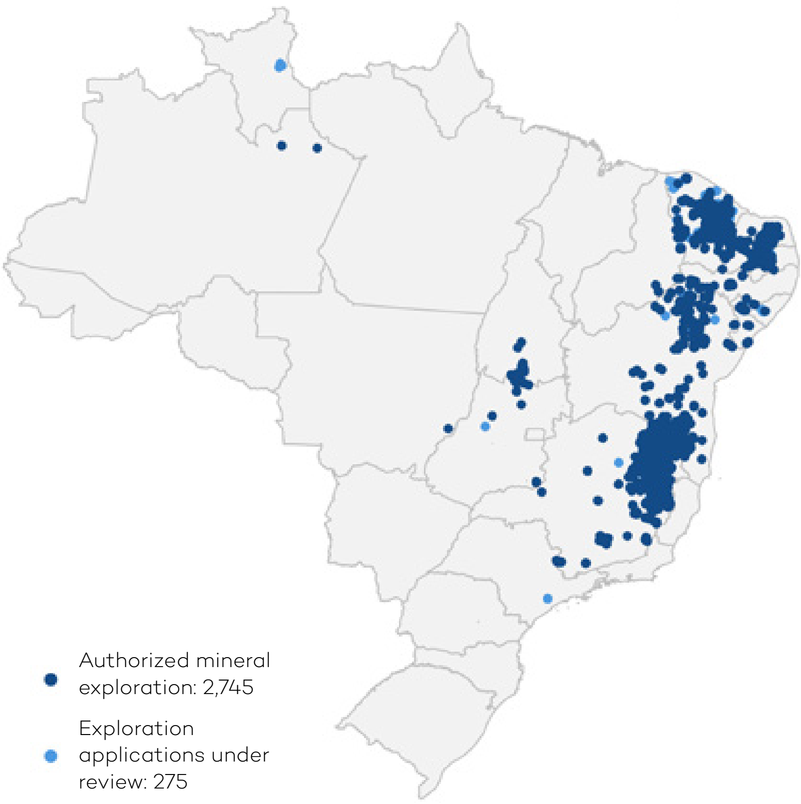


Figure 75: Map for Lithium Mining Concession in Brazil (2025)

Best Practices

The Mining and Energy Committee of the Brazilian Chamber of Deputies approved Bill 2809/23, which establishes a voluntary certification system for "green lithium" in Brazil. Sigma Lithium has been working with this concept since its startup. The Brazilian Lithium Company (CBL) already produces chemical-grade lithium with purity equivalent to battery grade. AMG has developed technology for refining and exporting chemical-grade lithium to Europe.

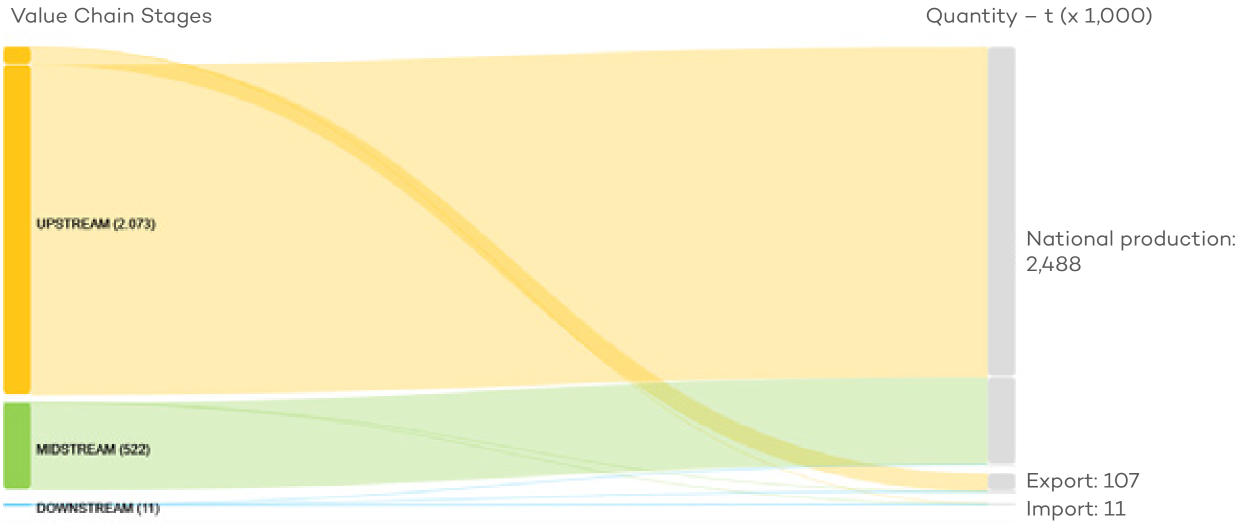
The Lithium Valley (Vale do Lítio) comprises 14 cities: Araçuaí, Capelinha, Coronel Murta, Itaobim, Itinga, Malacacheta, Medina, Minas Novas, Pedra Azul, Virgem da Lapa, Teófilo Otoni, and Turmalina in Northeastern Minas Gerais, and Rubelita and Salinas in Northern Minas. These municipalities host the country's largest lithium reserves. According to the Brazilian Geological Service (SGB[169]), there are 45 deposits in the Lithium Valley with significant economic potential, which could increase the proven mineral reserves in the region by up to 20 times, ensuring supply and boosting regional economic development.

Future Outlook

There are significant potential areas to explore for a lithium R&D network in the Jequitinhonha region and other local development arrangements.

To meet the contribution goals for the energy transition by 2030, it is essential to establish industrial battery units, battery-grade refined lithium production, and bring new lithium mining operations online.

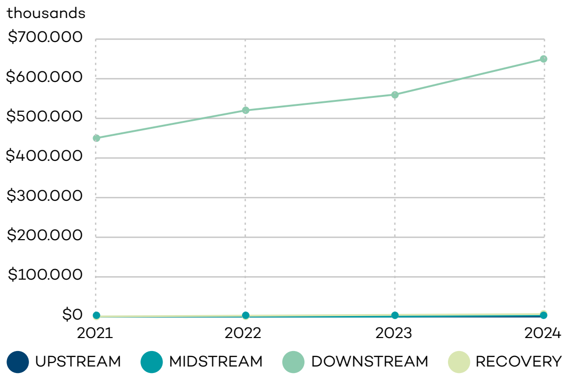
Figure 76: MFA of imported and exported volumes in relation to national industrial production data according to the lithium value chain stages for the year 2022.



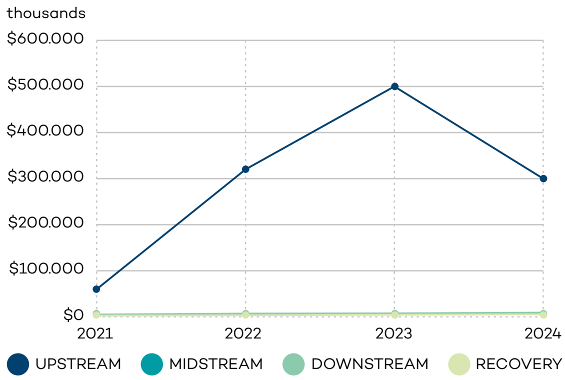
Source: Data obtained from the ComexStat Platform, 2025 (year 2022) and from Industrial Production data (SIDRA/IBGE) for 2022.

169 https://desenvolvimento.mg.gov.br/inicio/noticias/noticia/2160/governo-de-minas-lanca-projeto-lithium--valley-brazil-em-nova-iorque

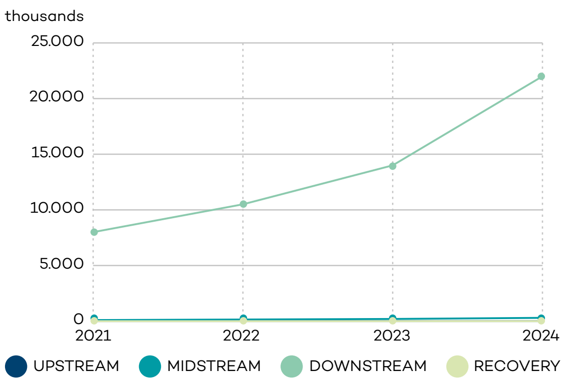
Graph 33. Lithium: Import Value FOB US$ (thousands) between 2021 and 2024



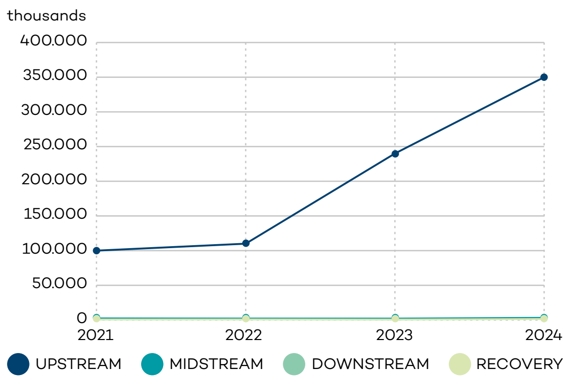
Graph 34. Lithium: Export Value FOB US$ (thousands) between 2021 and 2024



Graph 35. Lithium: Net Import in Kg (thousands) between 2021 and 2024

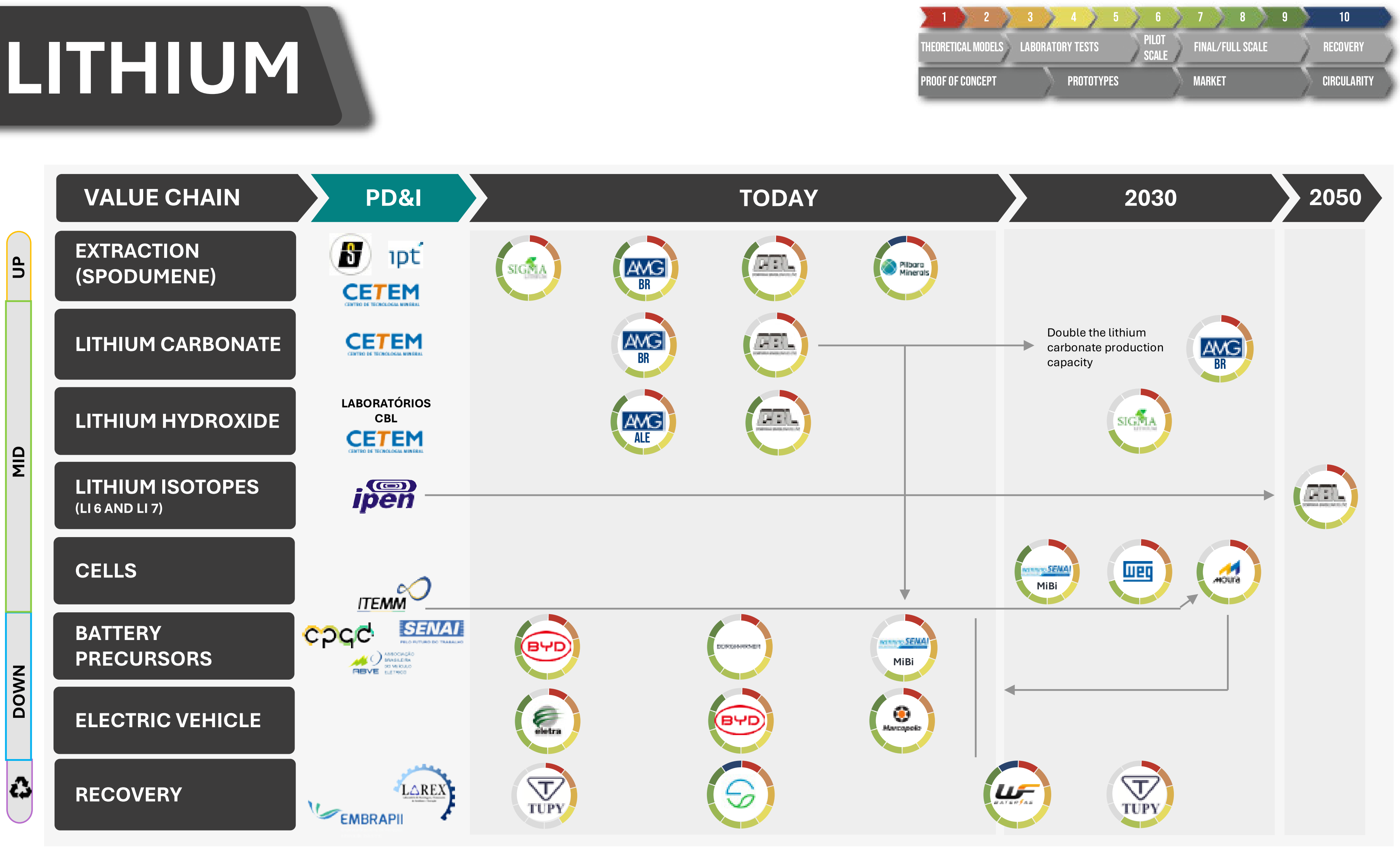


Graph 36. Lithium: Net Export in Kg (thousands) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.

LITHIUM



CETEM | IBRAM BRAZILIAN MINING

MANGANESE

UPSTREAM MINING — Manganese ores

MIDSTREAM CHEMICALS/METALLURGY — Chemicals (oxides, dioxides, chlorides, salts, etc.), concentrates and alloys (ferrosilicon, ferro-manganese, etc.)

DOWNSTREAM FINAL PRODUCTS — Batteries and cells, fungicides

RECOVERY RECOVERY — Manganese waste and residues

Overview and demand

Manganese is an essential element for the production of steel and metallic alloys, with growing demand due to increasing global industrialization. Manganese is frequently associated with iron ore extraction and Brazil's annual manganese production is significant, with highlights in the states of Pará, Minas Gerais, and Mato Grosso do Sul. In 2022, the country produced approximately 559 thousand tons of manganese in contained metal, representing a 6.5% reduction compared to the previous year.

However, there is evidence of illegal manganese extraction in Brazil. The increase in market value has contributed to the rise in occurrences. In 2021, there were approximately 100 illegal manganese mining points in Pará. According to the Brazilian Mineral Yearbook, in 2023, 168 thousand tons of raw manganese and 1.3 million tons of beneficiated manganese were traded[170].

Best Practices

The manganese mineral processing sector has innovations, including new flotation techniques and ore treatment.

Monitoring practices for irregular actions have been conducted through the use of satellite imagery, drone inspections, artificial intelligence, and advanced mineralogical characterization resources.

The ANM has acted jointly with the Federal Police, Navy, and State Finance Departments, in order to implement intelligence-based inspection.

170 https://www.gov.br/anm/pt-br/assuntos/economia-mineral/publicacoes/anuario-mineral/anuario-mineral--Brazileiro/anuario-mineral-Brazileiro-principais-substancias-metalicas-2024

Figure 78: Magnesium: Reserves by Country

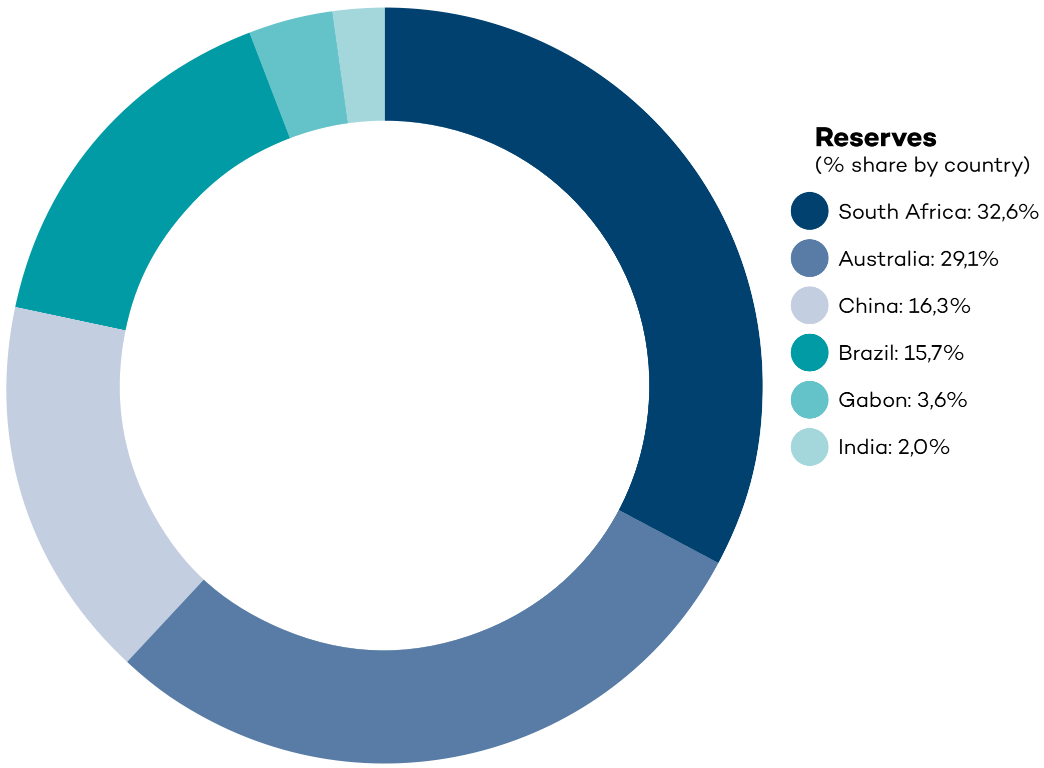
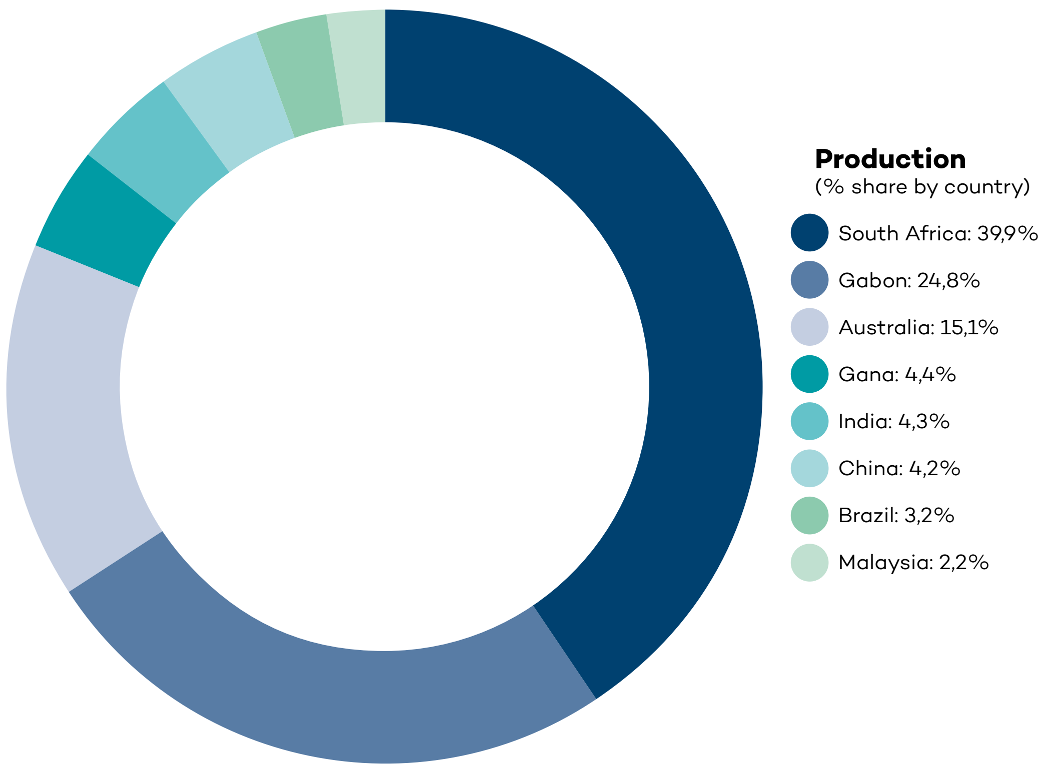


Figure 79: Magnesium: Production by Country



Source: USGS, 2025

Figure 80: Map for Manganese Exploration Authorization in Brazil (2025)

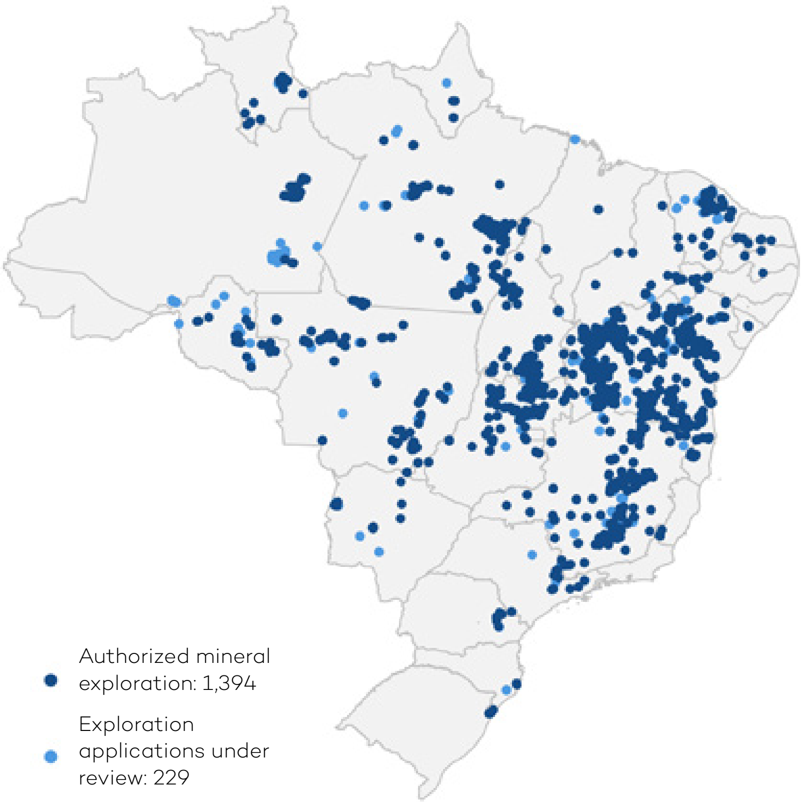


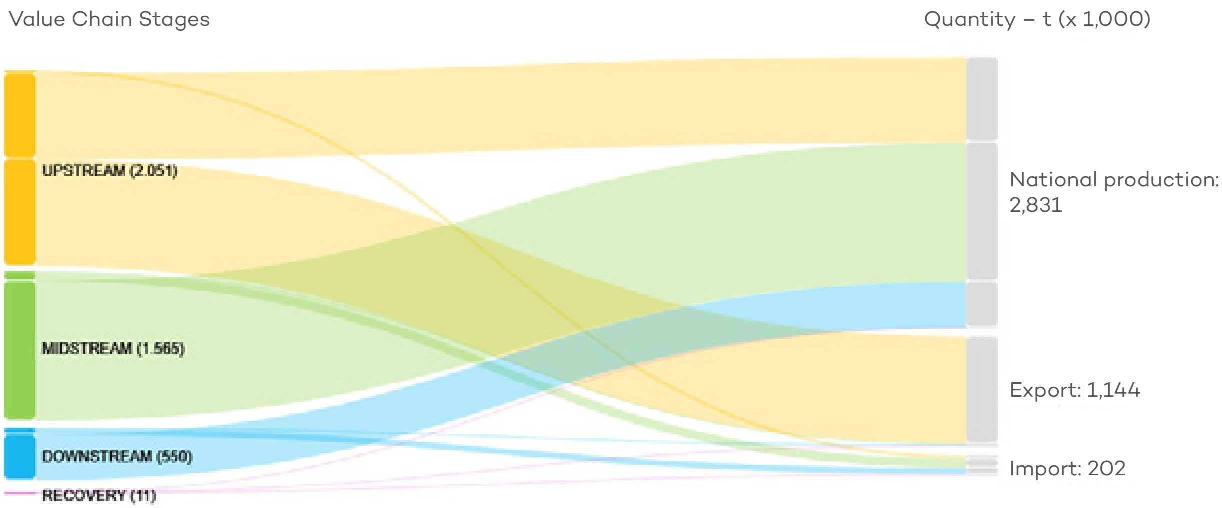
Figure 81: Map for Manganese Mining Concession in Brazil (2025)

Future Outlook

International data (GlobalData) reveal that annual manganese production in Brazil decreased from 1.54 Mt in 2011 to 0.98 Mt in 2024. Companies operating in the iron ore extraction sector have discontinued their manganese operations. A recent study conducted by the Brazilian Geological Survey (Uchôa Filho *et al.*, 2025[171]) provides evidence that manganese deposits in both Brazil and Africa are an important alternative source of cobalt. These same authors state that significant manganese deposits are present in the Amazon Craton region, with the Serra do Navio (Amapá) deposit and the Carajás mineral province being the most prominent. With its potential application in aluminum alloys and battery manufacturing, manganese qualifies as an important mineral for the energy transition.

Through Invest Minas, Boston Metal mining company and the government of Minas Gerais invested BRL 5.18 million for the construction of a pilot green ferro-manganese production unit in (MG[172]), with a forecasted creation of 350 direct jobs.

Figure 82 MFA of imported and exported volume relative to national industrial production data according to the stages of the Manganese value chain for the year 2022.

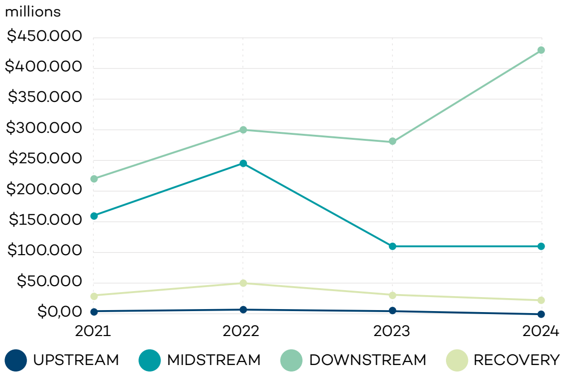


Source: Data obtained from the ComexStat Platform, 2025 (year 2022) and from Industrial Production data (SIDRA/IBGE) for 2022.

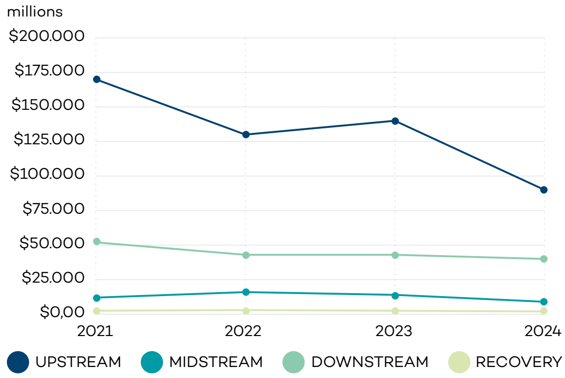
171 https://www.sciencedirect.com/science/article/pii/S1674987125000350

172 https://www.agenciaminas.mg.gov.br/noticia/empresa-atraida-pelo-governo-de-minas-preve-mais-uma--planta-piloto-de-manganes-verde-em-operacao-ate-o-fim-de-2025

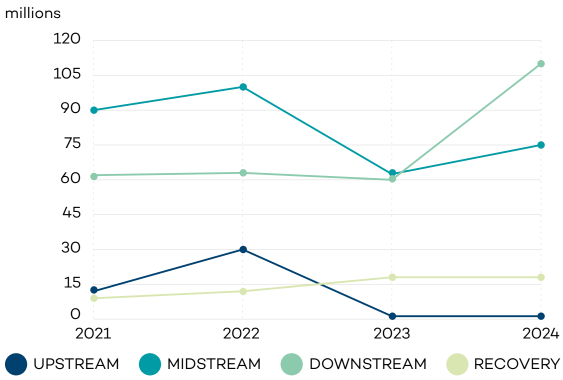
Graph 37. Manganese: Import in Value US$ FOB (millions) between 2021 and 2024



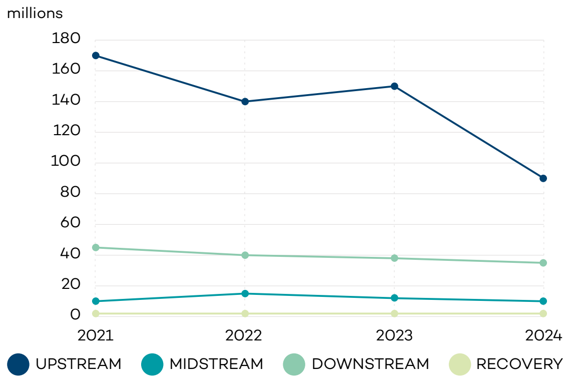
Graph 38. Manganese: Export in Value US$ FOB (millions) between 2021 and 2024



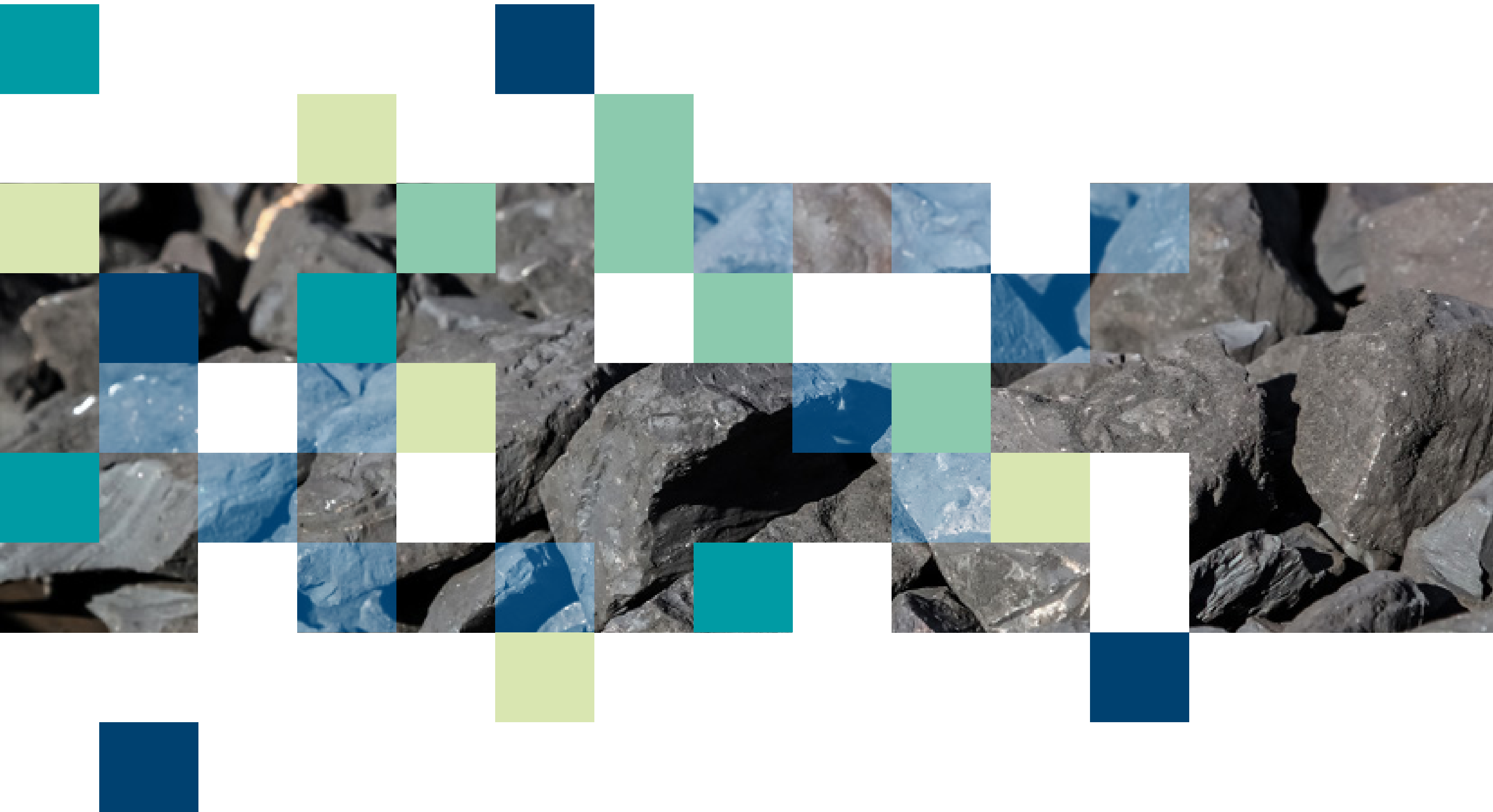
Graph 39. Manganese: Import in Net Kg (millions) between 2021 and 2024



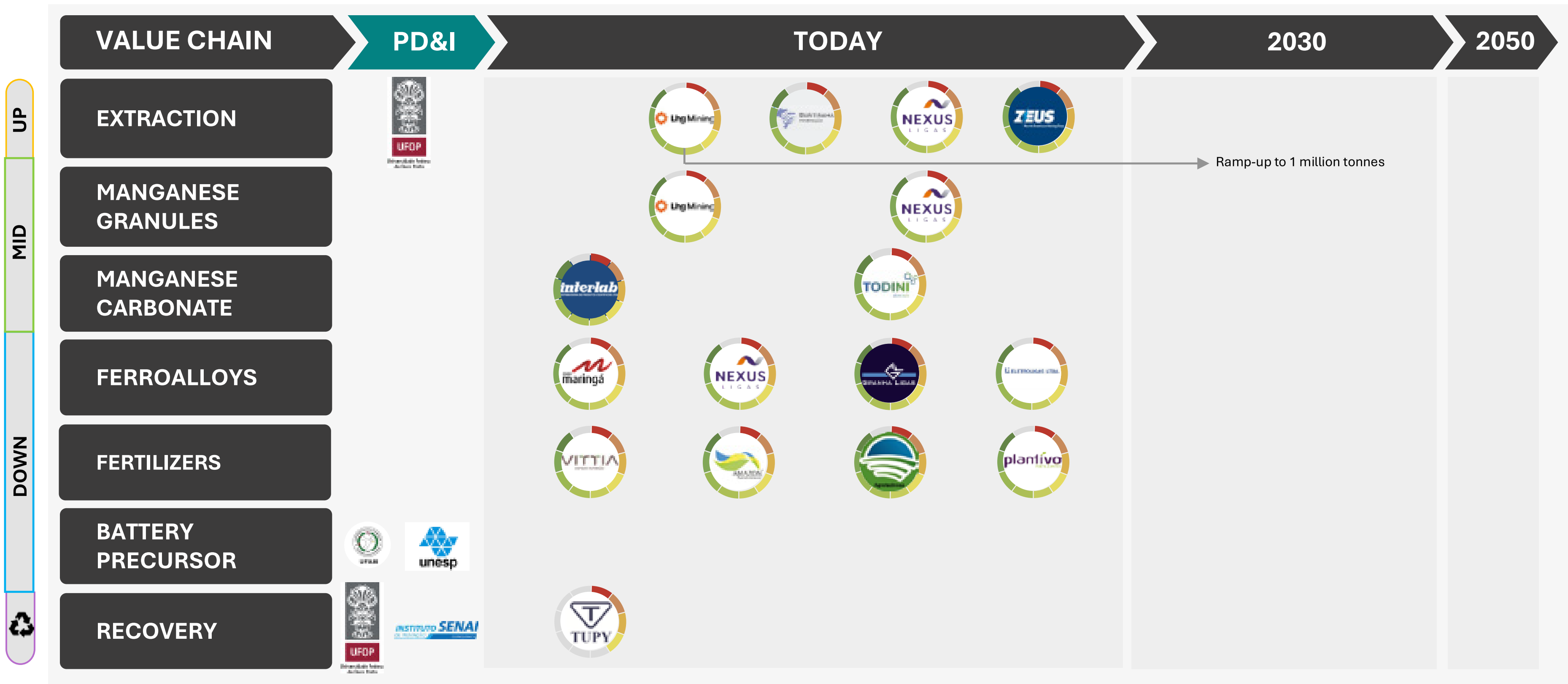
Graph 40. Manganese: Export in Net Kg (millions) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.



MANGANESE



Source:
https://www.fastmarkets.com/insights/brazils-cbmm-niobium-batteries-2030 https://niobium.tech/en/search?pagenumber=1
https://acobrasil.org.br/site/wp-content/uploads/2023/07/AcoBrasil_Anuario_2023.pdf

CETEM | IBRAM BRAZILIAN MINING

NIOBIUM[173]

UPSTREAM MINING — Niobium ores

MIDSTREAM CHEMICALS/METALLURGY — Chemicals (oxides), concentrates, and non-ferrous metallurgy and their alloys, FeNb

DOWNSTREAM FINAL PRODUCTS — Sheets, nanocrystalline material, and components for batteries and automotive vehicles

Overview and demand

Niobium is an element with a wide range of applications, from alloy compositions and steel formulations to aerospace technologies. Holding over 95% of the world's niobium reserves, Brazil also leads in the production of niobium oxides and FeNb, actively developing technologies for niobium applications in technologically relevant processes. Companhia Brasileira de Metalurgia e Mineração (CBMM), headquartered in Araxá (MG), is the market leader, with operations on other continents as well. The company has facilities in South America, North America, Europe, and Asia, with well-established commercial relations with China. CBMM has Asian capital and generates approximately US$400 million in revenue, serving the battery, aerospace, and medical sectors.

The development of applications for niobium and its products should be encouraged through partnerships between companies and research centers, including programs such as those offered by Embrapii.

Best Practices

The company has more than 40 projects focused exclusively on developing technological solutions for batteries. The aim of these projects is to accelerate the development of new niobium applications. In a partnership established between Toshiba and Volkswagen, the company was responsible for launching a super-fast charging e-bus that uses a lithium-ion battery containing niobium instead of graphite, enabling a recharge time of less than 10 minutes. The process eliminates the risk of explosion and offers durability up to three times greater than previous solutions.

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173 Os dados referentes a extração de Niobium seguem agrupados nas subclasses de produção industrial (prodlist/IBGE) e dos códigos NCM e HS como "minérios de Niobium, tantalum ou vanadium", o que impede o levantamento dos dados de produção e fluxos comerciais na etapa do upstream. O mesmo ocorre com os "produtos" à base de Niobium, que comporiam o downstream. São ligas e multimatérias, geralmente englobadas em subclasses em conjunto com "gálio, hafnio, índio, renio e tálio", o que impedem uma análise da totalidade do volume negociado na cadeia. O FeNb é a liga da cadeia de valor mais comercializado. Sua relevância a alça a nível de produto Brazileiro e pauta das exportações. O Brazil exportou em 2023 86 mil toneladas, muito acima do Canada, o segundo maior exportador, com 9,5 mil toneladas, seguido de Singapura (8,5 mil toneladas), União Européia (1,8 mil toneladas) e Países Baixos (1,3 mil toneladas).

Figure 83: Niobium: Reserves by Country

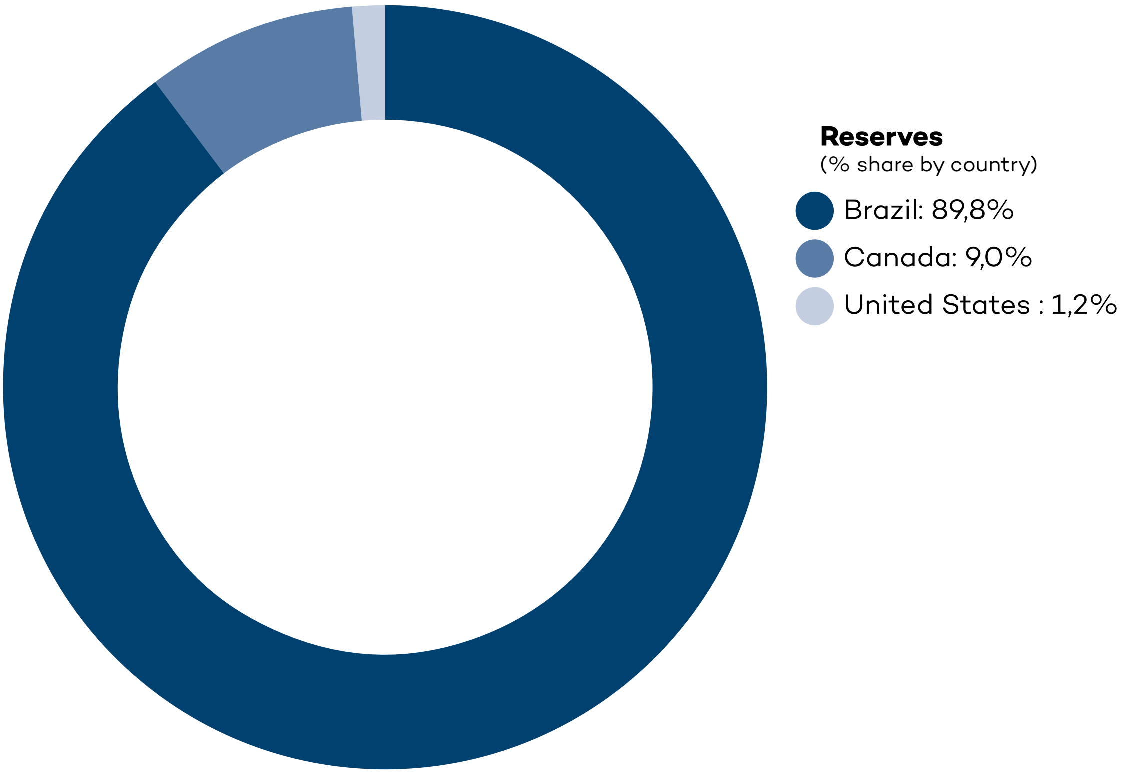
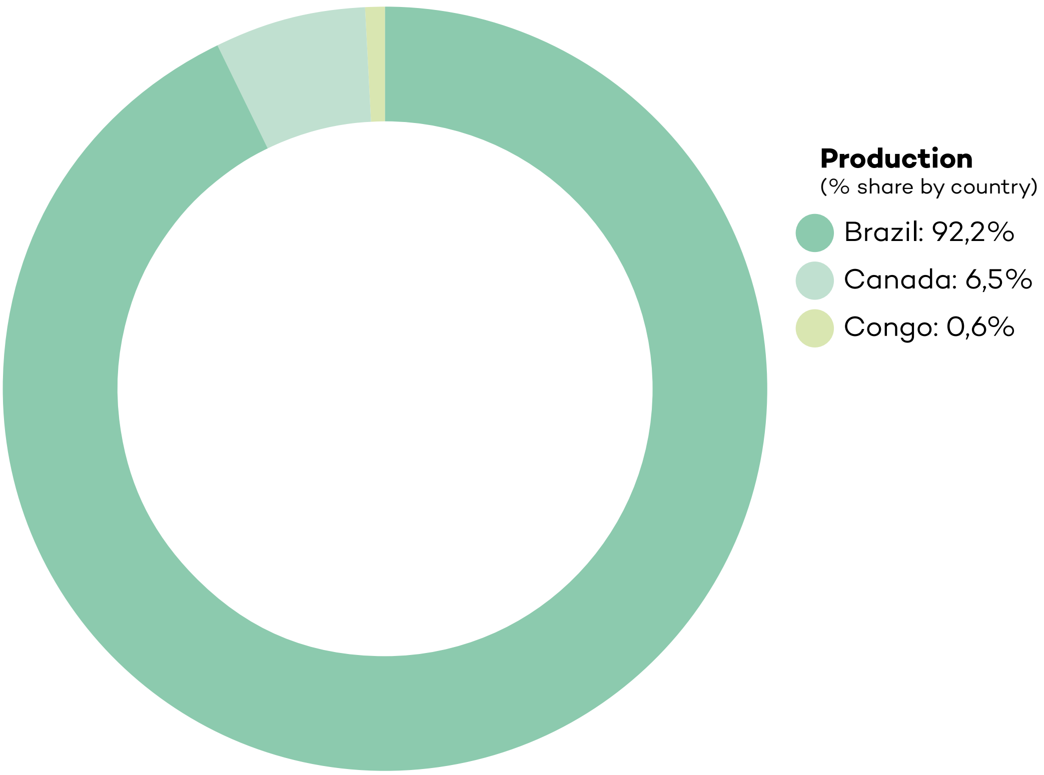


Figure 84: Niobium: Production by Country



Source: USGS, 2025

Figure 85: Map for Niobium Exploration Authorization in Brazil (2025)

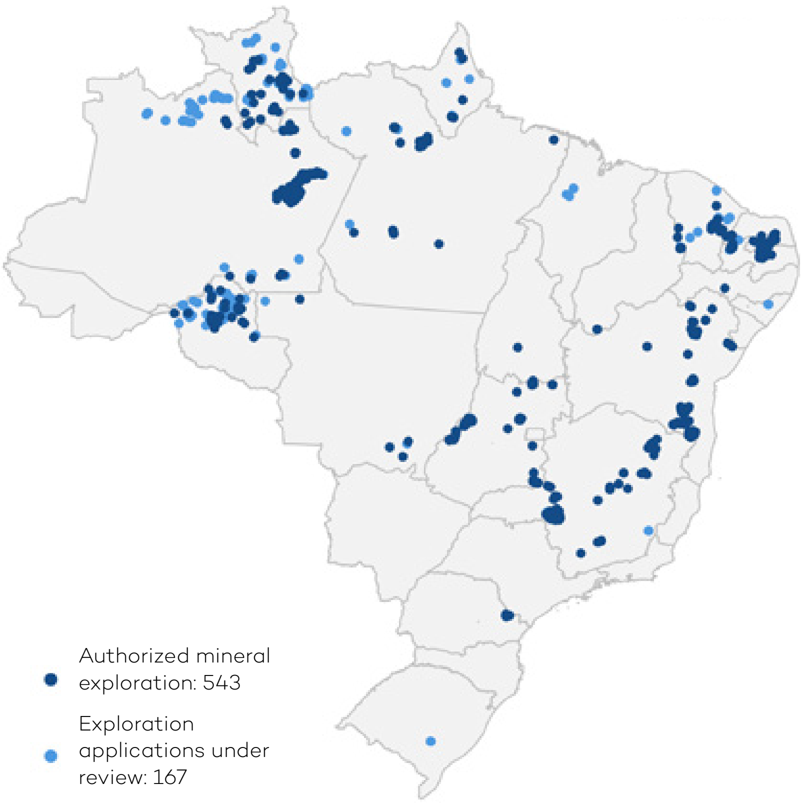


Figure 86: Map for Niobium Mining Concession in Brazil (2025)

CBMM, the largest national producer, recorded an annual production of approximately 150,000 tons of niobium products in 2024, with an average niobium oxide content of 2.6%. In the same year, CBMM sold 11,000 tons of FeNb. CBMM invests heavily in R&D, with a budget of BRL 250 million in 2024, of which BRL 80 million was exclusively allocated to the development of innovations for the battery sector.

CMOC, a Chinese-capital company located in Goiás, reached a production record of 10,024 tons of niobium in 2024. The company extracts niobium at its Catalão (GO) unit and processes it at the Ouvidor (GO) plant, where ferro-niobium alloys and phosphates are produced.

A brief analysis of patent applications related to Niobium[174] reveals more than 100,000 patents involving niobium-containing products and processes. The patents are primarily filed by companies such as Intel, Toshiba, Fuji, Posco, and Samsung, from various countries, demonstrating a diversity of applications without concentration of innovation.

Future Outlook

In 2024, CBMM inaugurated the world's largest niobium-based anode factory in Minas Gerais, with a production capacity of up to 2,000 tons by 2027[175], scalable to 20,000 tons by 2030[176].

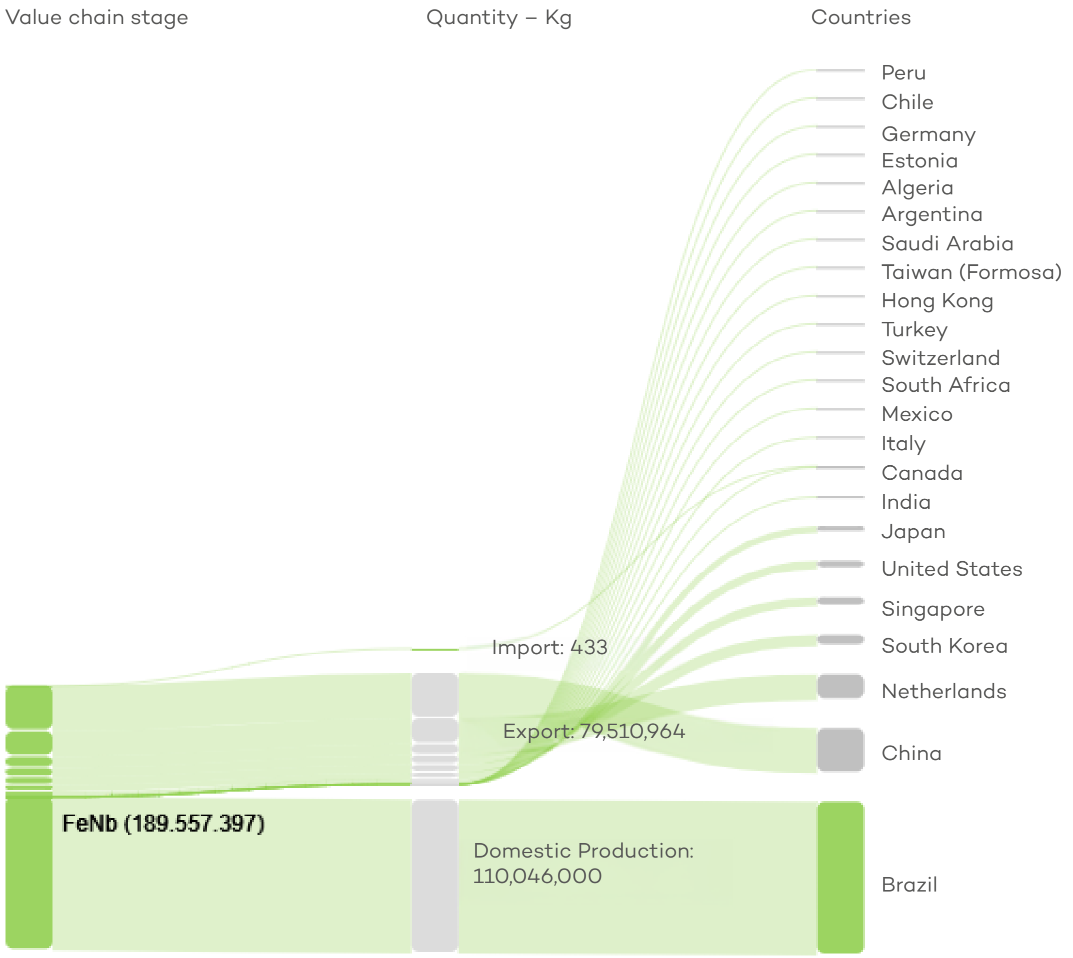
The development of technological solutions for the energy transition based on niobium represents a significant reduction in the criticality of this mineral, while niobium increases the level of criticality in most industrialized countries. In other words, the diversity of niobium applications, supported by reserves with long-term exploitation potential, substantially reduces the degree of uncertainty that has driven conflicts over critical and strategic minerals and influenced geopolitical disputes.

174 https://patents.google.com/?q=(niobium)&oq=(niobium)

175 https://clickpetroleoegas.com.br/cbmm-inaugura-a-maior-fabrica-de-anodo-a-base-de-niobio-do-World--em-minas-gerais-capacidade-de-2-mil-toneladas-ate-2027/

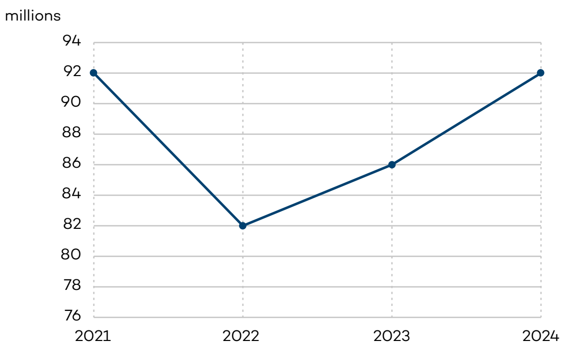
176 https://clickpetroleoegas.com.br/cbmm-inaugura-a-maior-fabrica-de-anodo-a-base-de-niobio-do-World--em-minas-gerais-capacidade-de-2-mil-toneladas-ate-2027/

Figure 87: MFA of imported, exported, and domestically produced FeNb volumes for the year 2022.

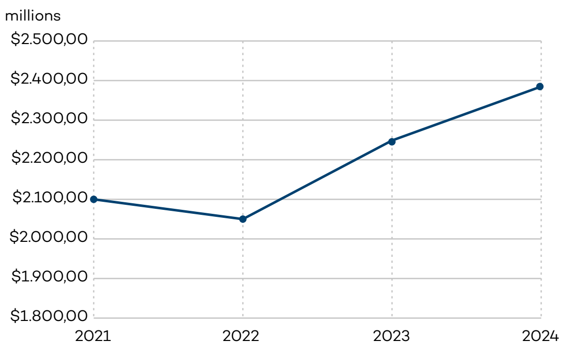


Source: Data obtained from the ComexStat Platform, 2025 (year 2022), and Industrial Production data (SIDRA/IBGE) for 2022.

Graph 41. FeNb: Export in Net Kg (millions) between 2021 and 2024

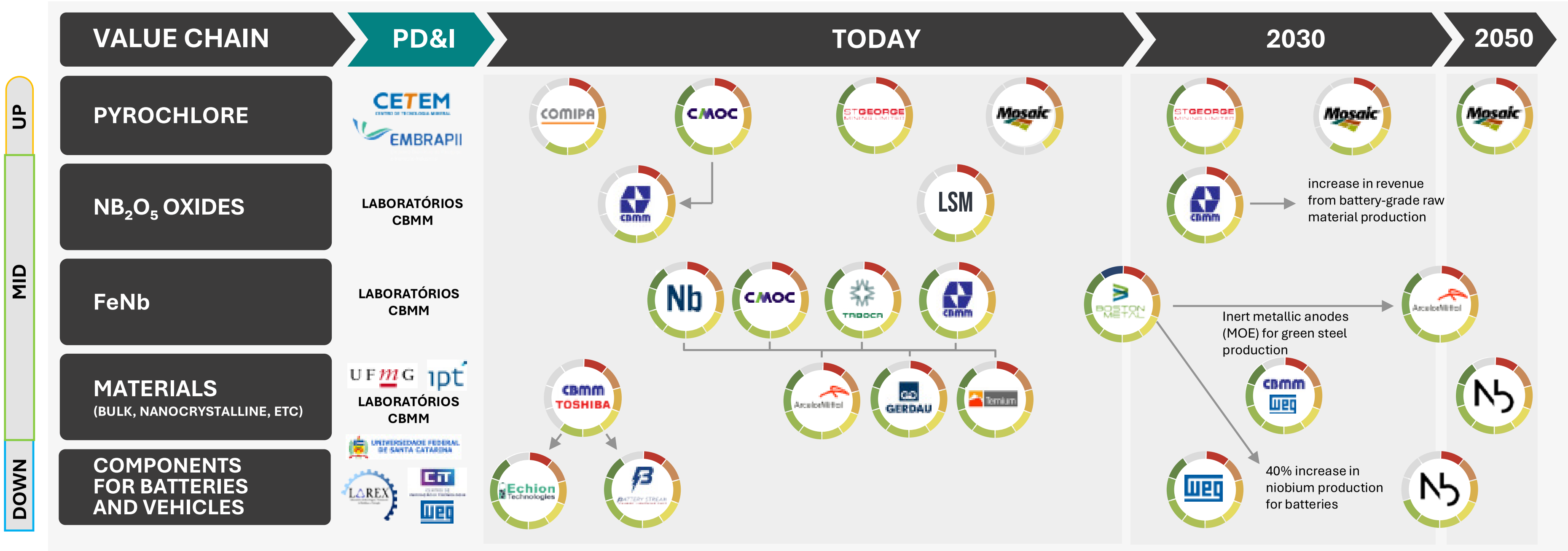


Graph 42. FeNb: Export in Value US$ FOB (millions) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.

NIOBIUM



Source:
https://www.fastmarkets.com/insights/brazils-cbmm-niobium-batteries-2030 https://niobium.tech/en/search?pagenumber=1
https://acobrasil.org.br/site/wp-content/uploads/2023/07/AcoBrasil_Anuario_2023.pdf

CETEM | IBRAM BRAZILIAN MINING

NICKEL

UPSTREAM MINING — Nickel ores

MIDSTREAM CHEMICALS/METALLURGY — Chemicals (oxides, hydroxides, sulfates, chlorides), concentrates and alloys, mattes, sinters

DOWNTREAM FINAL PRODUCTS — Parts, accessories, artifacts and components for batteries and motors

RECOVERY RECOVERY — Waste and residues

Overview and demand

Nickel is a highly versatile mineral with key characteristics including corrosion resistance, high-temperature resistance, malleability and ductility, magnetic properties, good thermal and electrical conductivity, and chemical stability.

Brazil ranks 10th globally in nickel reserves, with prominent states including Goiás, Minas Gerais, and Pará. Major companies operating in the country include Vale, Anglo American, and Horizonte Minerals[177].

Main applications:

- **Stainless steel:** Nickel is widely used in stainless steel production, essential for construction, transportation, and household appliances.
- **Batteries:** A key component in rechargeable batteries such as nickel-cadmium (NiCd) and nickel-metal hydride (NiMH), as well as in electric vehicle batteries. Battery types using cadmium include NMC, NiCd, NiMH, and NCA.
- **Metal alloys:** Nickel is used in special alloys like Inconel and Monel, which are corrosion- and high-temperature-resistant, applied in aircraft turbines and nuclear reactors.
- **Electroplating:** Used to coat other metals, protecting them from corrosion and wear.
- **Catalysts:** Nickel powder is employed as a catalyst in industrial processes, such as the hydrogenation of vegetable oils.
- **Coins:** Historically, nickel has been used in coin production due to its durability.

177 https://cidadeseminerais.com.br/geral/exploracao-e-producao-de-niquel-no-Brazil/

The main challenges for Brazil's nickel production specialization and advancement are international competition and sustainable mining challenges.

Anglo American, operating in Goiás with the Barro Alto and Niquelândia mines and future projects in Mato Grosso, announced the sale of its ferro-nickel operational assets, expected to close in Q3 2025[178], to MMG Singapore Resources, a subsidiary of China Minmetals. The deal includes future development projects in Morro sem Boné (MT) and Jacaré (PA), with exploration potential of 65 million tons and 365 million tons, respectively. This transaction is part of a corporate restructuring mechanism, as Anglo American exits diamond, platinum, nickel, and coal mining to focus on copper, iron ore, and fertilizers.

The main large-scale companies processing nickel in Brazil are Mineração Onça Puma (Vale), Anglo American Nickel (Barro Alto/Codemin), and Atlantic Nickel.

Table 13. Main companies involved in nickel processing in Brazil.

Company	Project/State	Status	Type	Notes
Vale Base Metals	Onça Puma/ PA	Active	Lateriti c	RKEF route
Atlantic Nickel / CBPM	Santa Rita / BA	Active	Sulfide	Nickel concentrate
Anglo American	Barro Alto / GO	Active	Lateriti c	Lateritic
Centaurus	Niquelândia/ GO	Active	Lateriti c	Under implementation
Brazilian Nickel Ltda	Jaguar / PA	Under implementation	Sulfide	Heap leaching and mixed hydroxide precipitate (MHP)
Brazilian Nickel Ltda	Piauí Nickel/ PI	Under implementation	Lateriti c	Heap leaching and mixed hydroxide precipitate (MHP)

178 https://valor.globo.com/empresas/noticia/2025/02/18/anglo-american-vende-operaes-de-nquel-no-Brazil--por-at-us-500-milhes.ghtml

Figure 88: Nickel: Reserves by Country

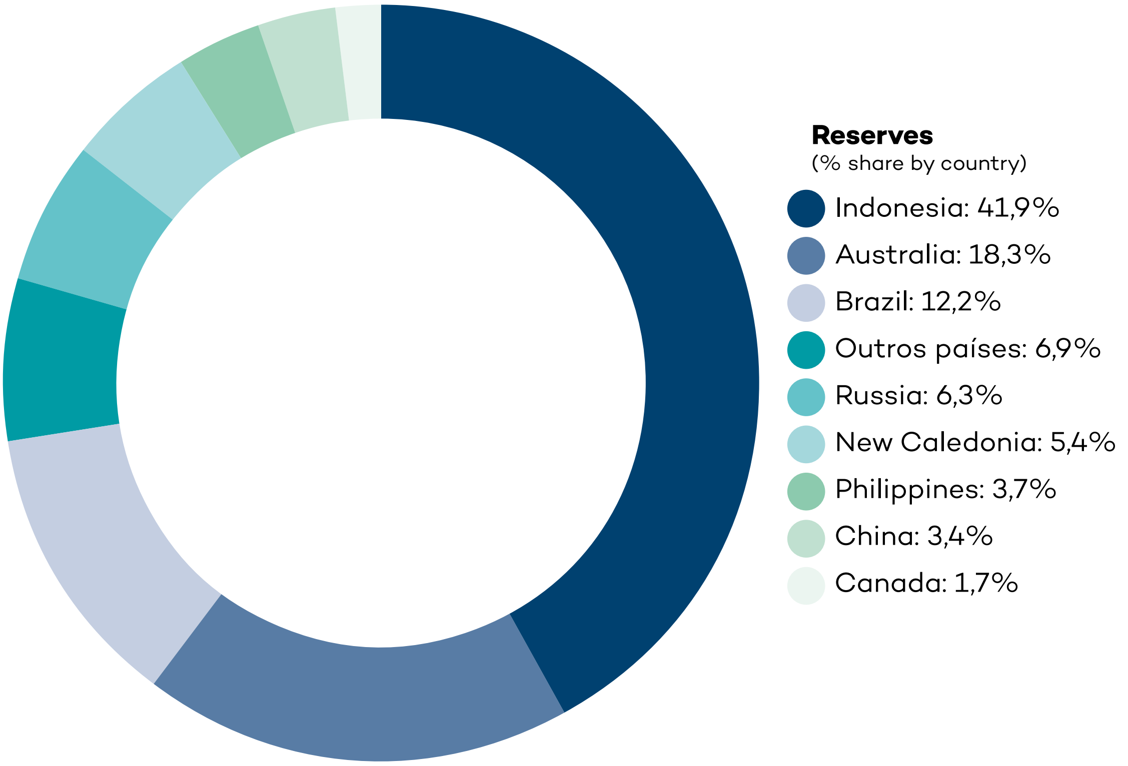
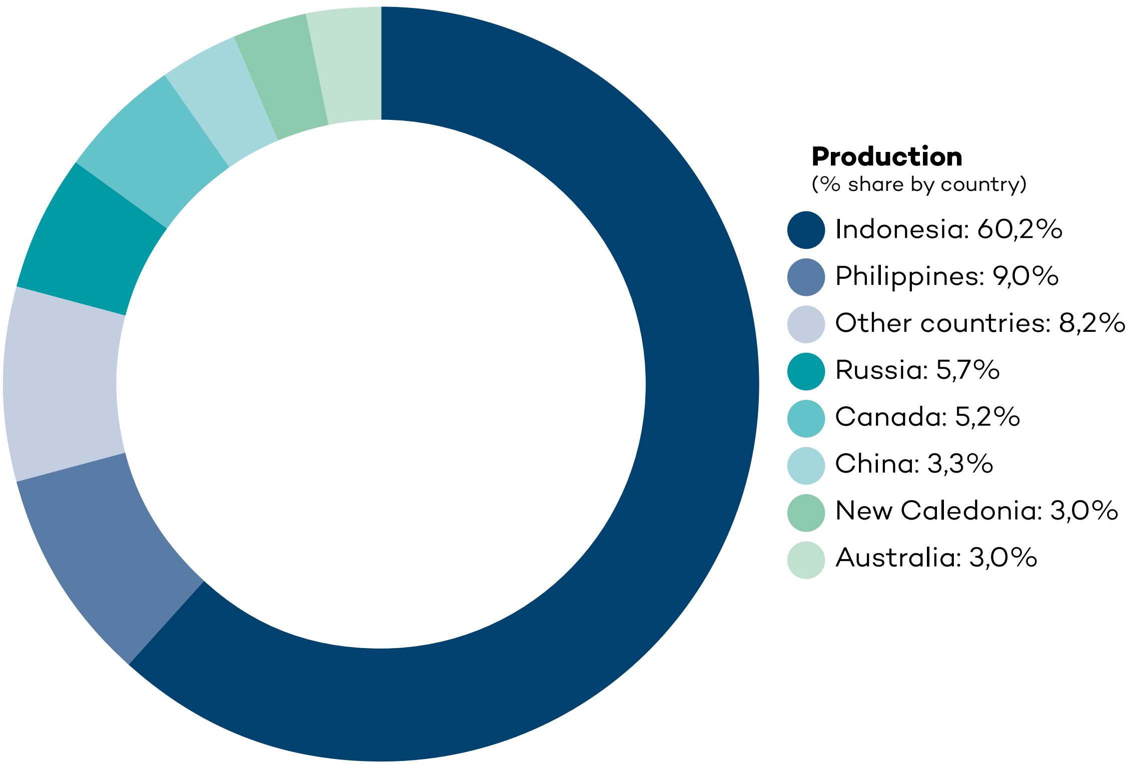


Figure 89: Nickel: Production by Country



Source: USGS, 2025

Figure 90: Map for Authorization of Nickel Exploration in Brazil (2025)

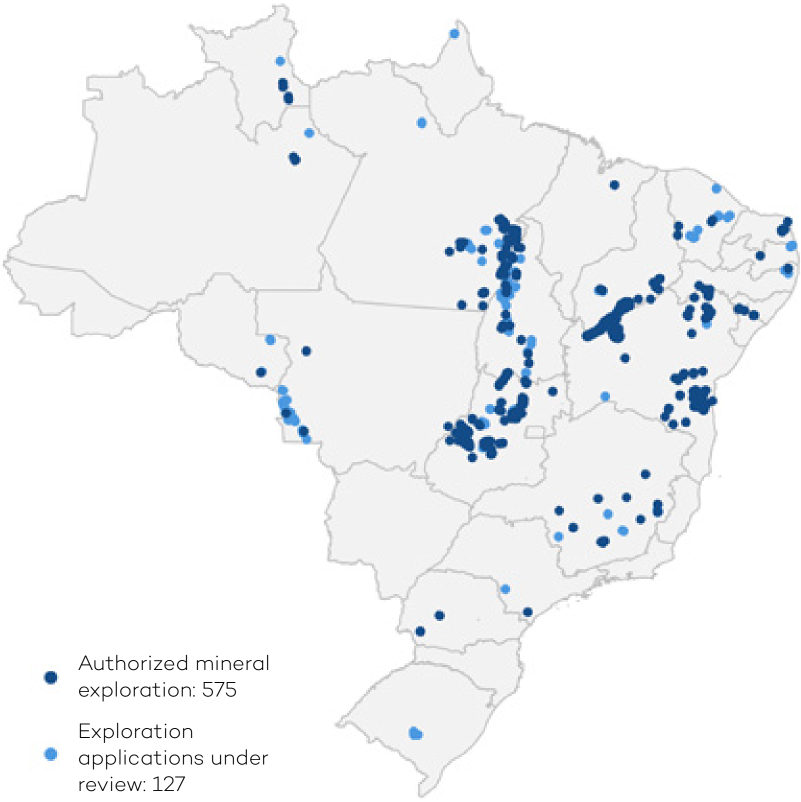


Figure 91: Map for Granting of Nickel Mining Concessions in Brazil (2025)

Best Practices

With the start of small-scale nickel and cobalt production in 2022[179], Brazilian Nickel has directed investments to the Piauí Nickel Project in Northeast Brazil, with expected production in 2028, supported by debt management and financial backing from its main investor, TechMet. Under these conditions, projects such as this may benefit from the use of incentivized debentures and investments such as those made available by BNDES in 2025.

In the first quarter of 2025, Anglo American recorded nickel production of 9.8 tonnes, with a projection to close the year with total production of 39 tonnes[180], maintaining the same production level as the previous year at the Barro Alto and Niquelândia mines.

Nickel production by Vale Base Metals[181] takes place at the Onça Puma Mine, located in Ourilândia do Norte, in the state of Pará. The company's investments in the capture system of the plant's tailings dam, which receives industrial drainage and treated effluents, enabled 97.8% of the unit's water demand to be met through reuse practices in 2024. The company is also conducting research into the use of biomass as a substitute for coal in the calcination stage.

Vale Base Metals signed a commercial, non-binding memorandum of understanding for slag off-take with BluestOne, a leading Brazilian company that transforms waste into agricultural products, to supply up to 50,000 tonnes per year of refinery slag from its Onça Puma mine in Brazil over the next 10 years. Within two years, BluestOne will begin construction of a plant near Onça Puma to process slag products, providing a solution to improve mineral fertilizers with low usage in the agricultural sector.

Under the terms of the agreement, both companies also agreed to work together to explore additional circular economy opportunities to treat and reuse more waste from Onça Puma, as well as from other Vale Base Metals operations worldwide. This potentially includes strengthening BluestOne's production of recycled nickel recovered from waste streams globally.

179 https://www.mining.com/brazilian-nickel-advances-project-financing-with-loi-for-550m/

180 https://mineraBrazil.com.br/anglo-american-registra-recorde-de-producao-de-minerio-de-Iron-e-alta-no-niquel-no-1o-trimestre/2025/04/25/

181 Interview with Vale Base Metals conducted on May 16, 2025, and https://www.gov.br/mme/pt-br/assuntos/secretarias/geologia-mineracao-e-transformacao-mineral/seminario-sobre-mineracao-e-transformacao-mineral-de-minerais-estrategicos-para-a-transicao-energetica/4-1-vale-bm_mme_forum_feb2024_jlm_final_short.pdf

Future Outlook

Although the battery value chain exerts influence and increases international demand for nickel, market value levels and the lack of national infrastructure for processing more advanced products along the value chain, such as battery precursors, hinder short-term investments. However, the consolidation of Brazilian industrial policy programs and new geopolitical configurations may help change this trajectory and enable densification of the nickel production chain in the medium and long term.

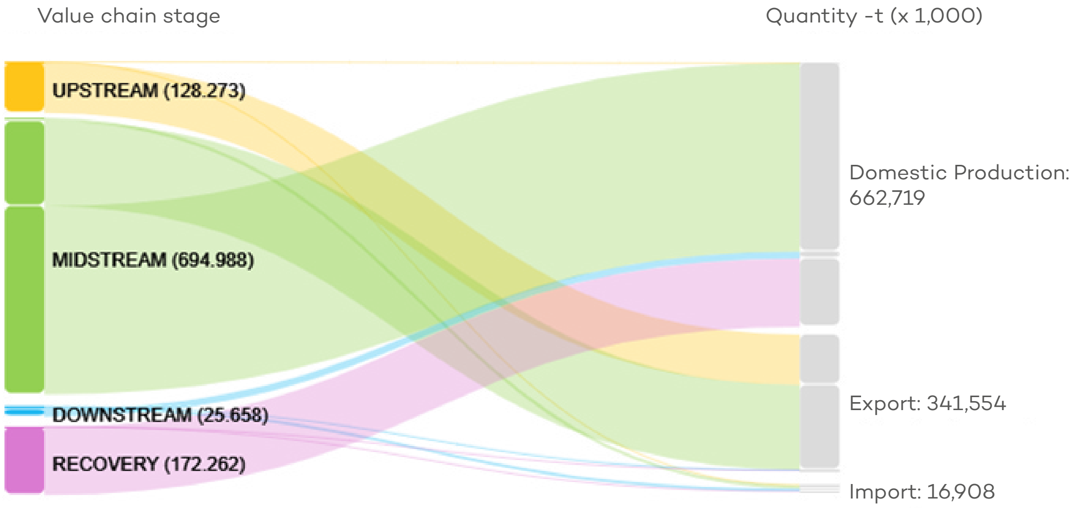
Investments in this direction would begin with the consolidation of smelting processes in Brazil. The lack of this processing stage in the country has already been identified for different minerals and, considering the competitiveness provided by the national energy matrix, this would constitute an important strategic pathway. Indonesia is responsible for more than 50% of global nickel supply[182] and is seeking to reduce production costs.

Anglo American, which operates in Goiás with the Barro Alto and Niquelândia mines and has future projects in Mato Grosso, announced the sale of its ferronickel operating assets, expected to be concluded in the third quarter of 2025, to MMG Singapore Resources, a subsidiary of China Minmetals. The transaction involves future development projects at Morro Sem Boné (MT) and Jacaré (PA), with exploration potential of 65 Mt and 365 Mt, respectively. The transaction is part of a corporate restructuring mechanism. The company, which is exiting mining activities in the diamond, platinum, nickel, and coal sectors, announced its focus on copper production, in addition to iron ore and fertilizers.

The Onça Puma Mine, operated by Vale Base Metals, is undergoing an expansion project with the installation of a new 85-megawatt furnace, with estimated investment of US$ 560 million. The project is expected to add an additional 15 thousand tonnes per year of nickel contained in ferronickel from the second half of 2025 onward.

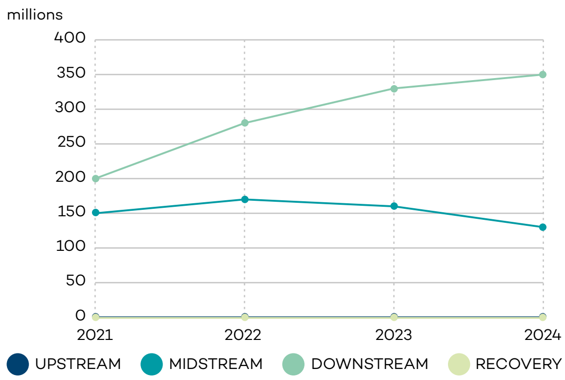
182 https://www.infomoney.com.br/business/stellantis-e-vale-discutem-investimento-em-fundicao-de-niquel--na-indonesia-diz-ft/

Figure 92: MFA of imported and exported volumes, in relation to national industrial production data, according to the stages of the nickel value chain for the year 2022.

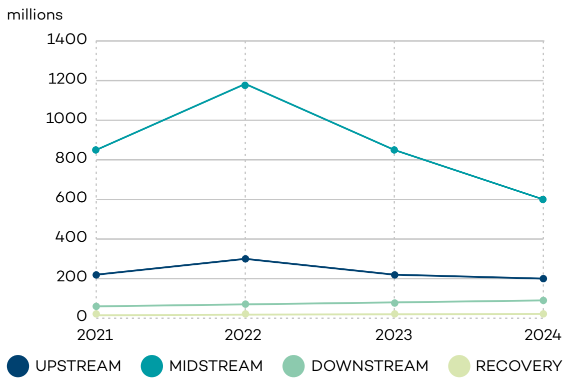


Source: Data obtained from the ComexStat Platform, 2025 (year 2022), and from Industrial Production data (SIDRA/IBGE) for 2022.

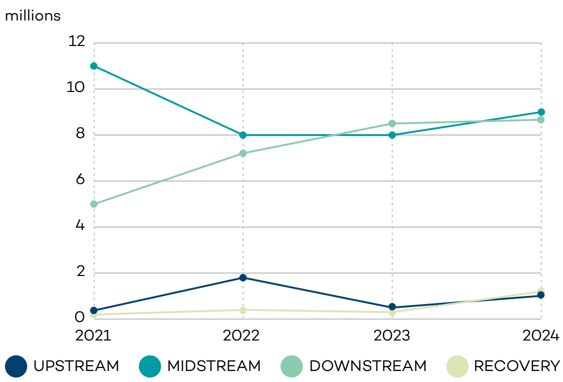
Graph 41. Nickel: Imports in Value, US$ FOB (millions), between 2021 and 2024



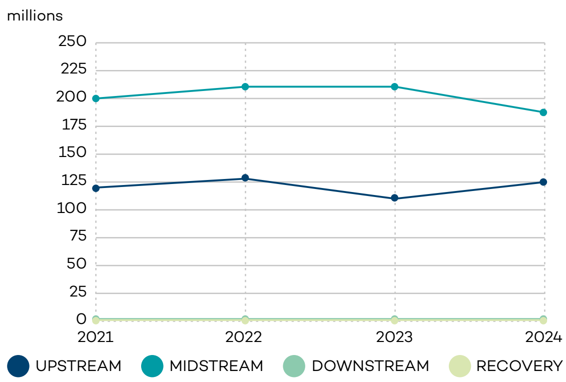
Graph 42. Nickel: Exports in Value, US$ FOB (millions), between 2021 and 2024



Graph 43. Nickel: Imports in Net Weight (millions of kg) between 2021 and 2024

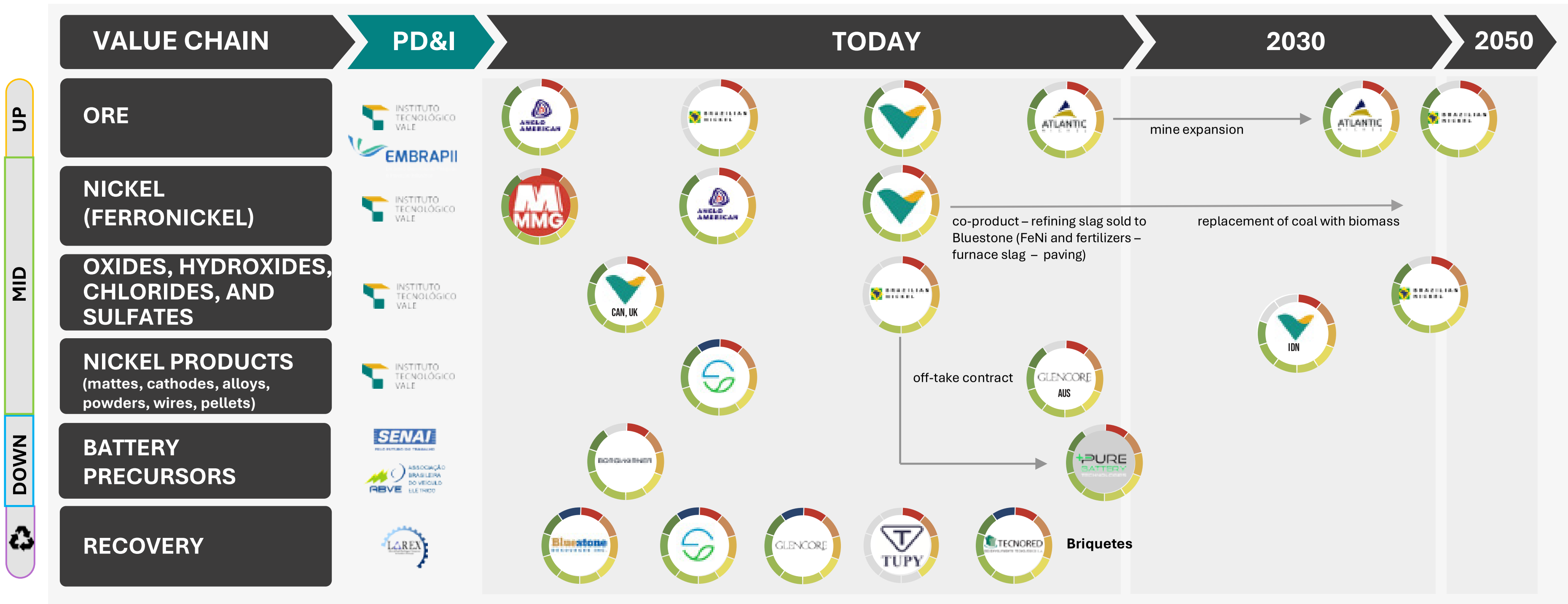


Graph 44. Nickel: Exports in Net Weight (millions of kg), between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.

NICKEL



Source:
https://exame.com/negocios/aposta-num-niobio-multiuso-faz-cbmm-faturar-r-11-bi-em-2021/
https://europe.autonews.com/suppliers/vws-powerco-stellantis-glencore-back-1b-mine-deal-brazil
https://www.brasilmineral.com.br/noticias/jervois-mining-tera-us-70-milhoes-para-reativar-refinaria-no-brasil

Gold

UPSTREAM
MINING
Gold and bullion in crude forms

MIDSTREAM
CHEMICALS/METALLURGY
Chemicals (sulfides and other compounds) and gold in crude forms, in powder or other semi-manufactured forms

DOWNTREAM
FINAL PRODUCTS
Gold in bars, wires, bullion and solid-section profiles

RECOVERY
RECOVERY
Ashes, waste, and residues (gold-plated or gold-coated metals)

Overview and demand

Gold has played a fundamental role throughout history and is recognized as one of the most versatile minerals. Its use is widespread across several segments of society, including as a store of value in the financial sector, as well as in fashion, jewelry, design, and biomedical applications. Gold is also present in the electronics industry, for example in mobile phone chips and computer processors, in satellites, and in the automotive industry, among others[183].

According to data from the United States Geological Survey (USGS), global gold reserves totaled approximately 59 thousand tonnes in 2023. The distribution among the main reserve-holding countries is as follows: Australia (12,000 tonnes), Russia (11,100 tonnes), South Africa (5,000 tonnes), the United States (3,000 tonnes), China (3,000 tonnes), and other countries (22,400 tonnes)[184].

Brazil is one of the world's largest gold producers, with major production centers in the Quadrilátero Ferrífero in the state of Minas Gerais, Carajás in Pará, Itapicuru and Jacobina in Bahia, and Crixás in Goiás. Its proved and probable reserves, estimated in 2023 according to data from the National Mining Agency (ANM), totaled approximately 2,500 tonnes of contained gold. In the same year, national gold production reached 81.5 tonnes[185], representing a decline of −9.6% compared to the previous year (90 t in 2022). Industrial production accounted for 82.7% of total output, recording an increase of 3.4% compared to the previous year. Artisanal production from small-scale mining showed a sharp decline in 2023, totaling approximately 14 tonnes. A possible contributing factor was the invalidation of the presumption of good faith, which began to require the issuance of an electronic invoice and the registration of the first buyer as a mechanism to ensure traceability throughout the production chain.

183 IBRAM - Brazilian Mining: https://ibram.org.br/noticia/Gold-e-um-minerio-essencial-para-sociedade/

184 ANM – Agência Nacional de Mineração. Sumário Mineral Brazileiro 2024, ano base 2023. https://www.gov.br/anm/pt-br/assuntos/economia-mineral/publicacoes/sumario-mineral/sumario-mineral-Brazileiro-2024/Gold-2024-ano-base-2023.pdf

185 https://www.gov.br/anm/pt-br/assuntos/economia-mineral/publicacoes/sumario-mineral/sumario-mineral-Brazileiro-2024/Gold-2024-ano-base-2023.pdf

Figure 93: Gold: Reserves by Country

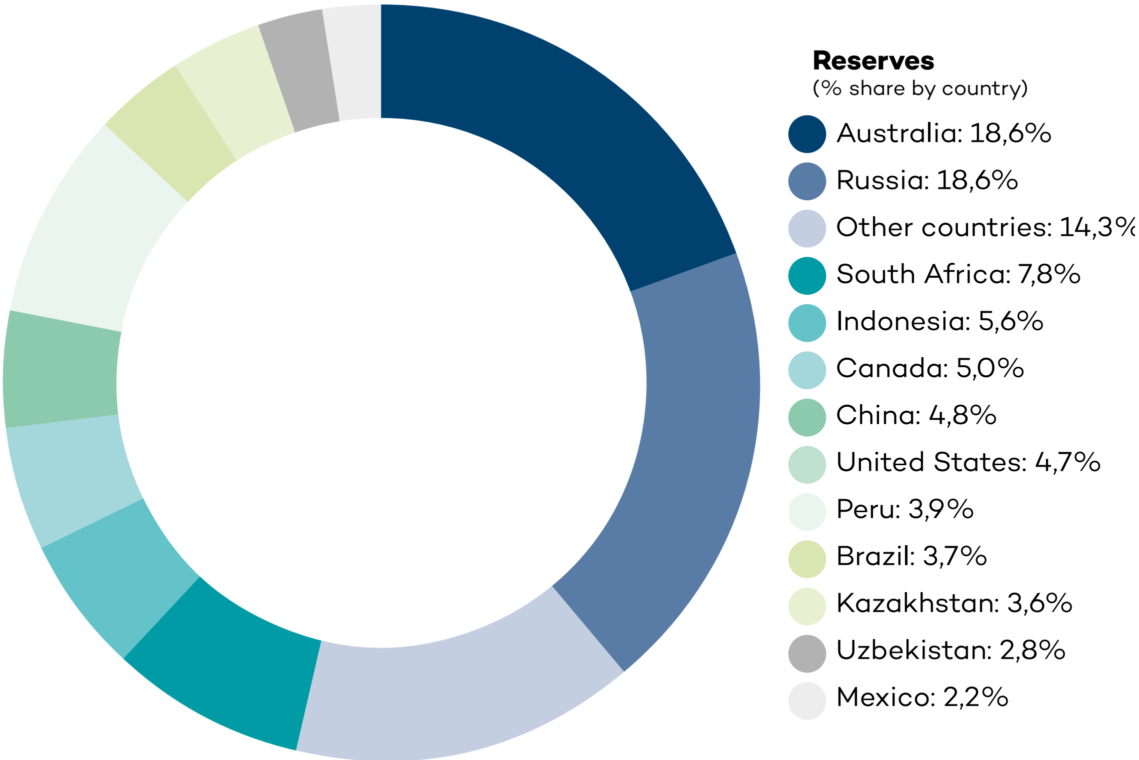
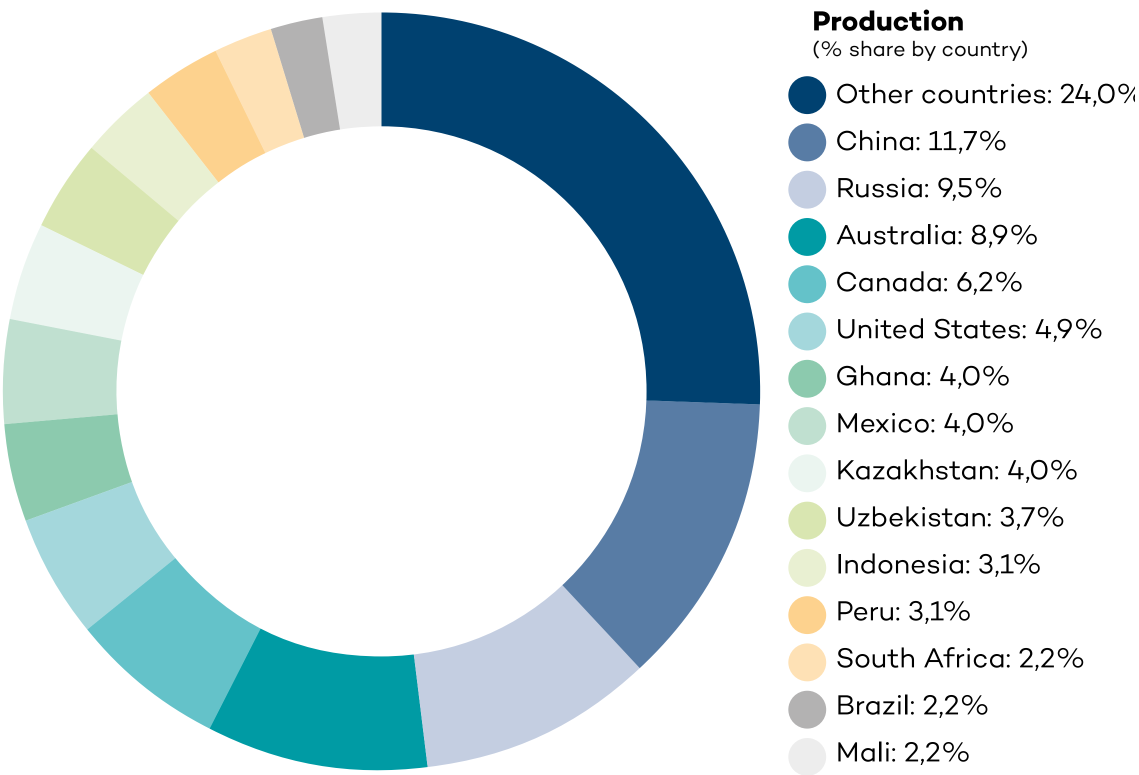


Figure 94: Gold: Production by Country



Source: USGS, 2025

Figure 95: Map for Authorization of Gold Exploration in Brazil (2025)

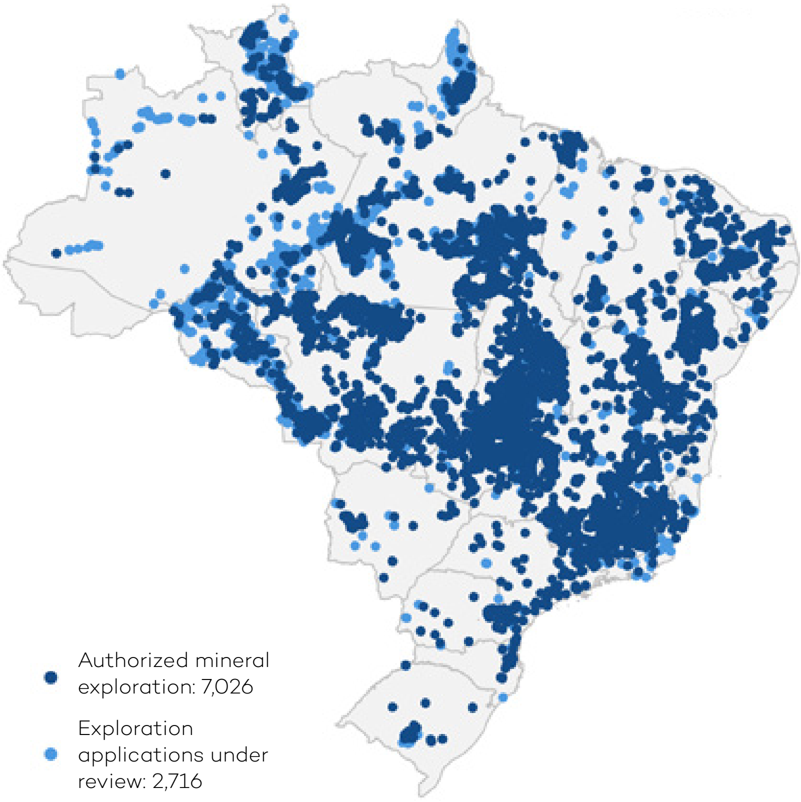


Figure 96: Map for Authorized Gold Mining Concessions in Brazil ((2025)

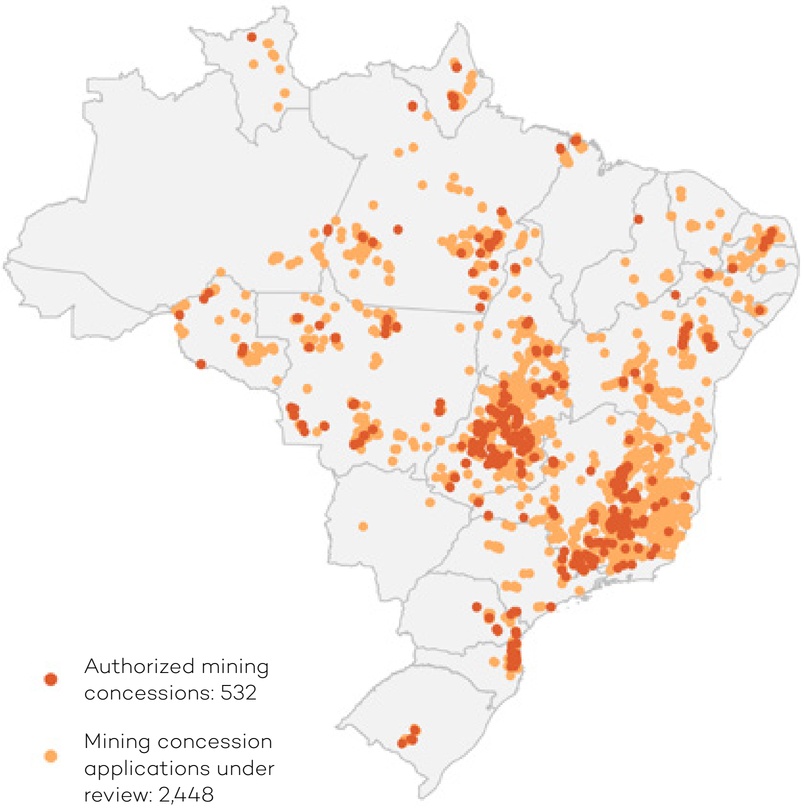
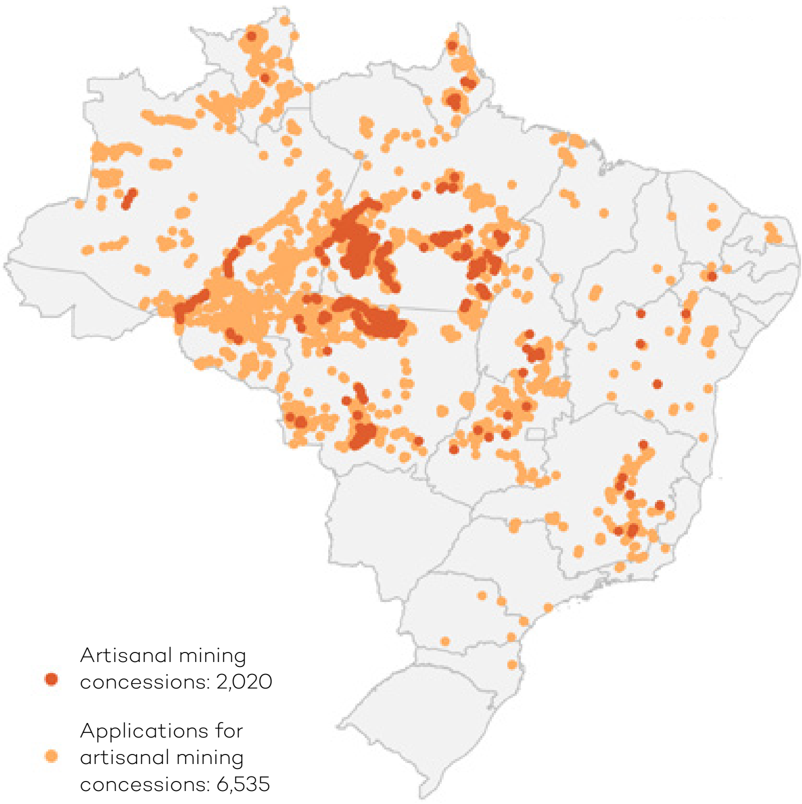


Figure 97: Mapa para Concessão de Lavra garimpeira de **Gold no Brazil** (2025)



Despite the economic relevance of gold, mining faces significant challenges in Brazil, especially those related to the advance of illegal artisanal mining. Clandestine extraction in the Amazon region stands out, as it fuels several criminal activities in the territory. The illicit commercialization of this metal, often destined for international markets, causes severe socio-environmental impacts, such as river contamination, illegal exploitation of valuable timber, invasion and exploitation of indigenous lands and peoples, in addition to strengthening drug trafficking networks[186.]

In a study conducted by Instituto Escolhas[187], the 50 largest companies that collect CFEM on gold are presented, among which are listed Kinross S/A (R$ 17 million), Anglogold S/A (R$ 11 million), F D Gold Ltda. (R$ 7.4 million), Jacobina Mineração Ltda. (R$ 6 million), and Mineração Aurizona S/A (R$ 4.6 million). According to ANM data, in 2024 more than R$ 407 million were collected in CFEM from gold extraction in Brazil[188].

186 IBRAM - Instituto Brasileiro de Mineração. International Conference on the Amazon and New Economies, Belém, PA, 2024 - https://amazoniaenovaseconomias.com.br/wp-content/uploads/2025/02/Conferencia-Amazonia_PORT_WEB.pdf

187 https://escolhas.org/wp-content/uploads/2020/05/TD_04_GARIMPO_A-NOVA-CORRIDA-DO-Gold-NA--AMAZONIA_maio_2020.pdf

188 https://revistamineracao.com.br/2025/02/06/mineracao-recolhe-r-934-bilhoes-em-impostos-e-tributos--em-2024/

Best Practices

Industrial gold mining has incorporated important advances to minimize environmental impacts, safeguard human health, and maximize extraction efficiency. In this context, Brazil faces the challenge of modernizing its extractive methods to meet the growing demand for sustainable practices. Activities related to illegal artisanal mining must be strongly combated. Actions aimed at legalizing non-compliant artisanal mining operations and reducing environmental enforcement, especially in the Amazon, represent a significant risk and require effective measures.

Contemporary sustainable gold mining techniques focus on three fundamental principles: efficiency in mineral recovery; minimization of environmental impacts; and social responsibility.[189,190]. O Instituto Escolhas[191] has developed important studies aimed at analyzing the impacts of illegal artisanal mining, highlighting in 2024 the inconsistency between gold export volumes and mercury imports—an important indicator of illegal practices in the sector.

IBRAM and USP established an agreement to strengthen the fight against illegal gold in Brazil. The Research Center for Responsible Mining at USP (NAP.Mineração) organized the Responsible Gold Purchasing Platform (PCRO) with the support of IBRAM, WWF Brazil, and Instituto Igarapé (2023[192]).

In 2024, the federal government carried out approximately 3,500 operations to combat illegal artisanal mining and protect the Yanomami Indigenous Land (TIY) in the states of Roraima and Amazonas. These operations resulted in a 96% reduction in the opening of new artisanal mining sites compared to 2022, the seizure of approximately 30 kilograms of gold valued at more than R$ 13 million, and the seizure of 103 kilograms of mercury valued at R$ 309 thousand[193].

Thus, studies on potential impacts on human and environmental health resulting from gold extraction are underway. CETEM, with the support of Ibama and ICMBio, is developing the Monitora Y Project[194], whose purpose is to analyze the presence of metals—including mercury—agrochemicals, PAHs, and BTEX in fish and water resources in Roraima. In this way, potential impacts on local populations, whether indigenous or not, will be assessed.

189 Serpa, Audesio. Sustainable Gold Mining Techniques: Methods, Advances, and Challenges - https://reidoGold.com/ideias-de-garimpo-de-Gold/

190 ICMM - International Council on Mining and Metal. Equivalency Benchmark of ICMM's Mining Principles and the World Gold Council's Responsible Gold Mining Principles, 2019 - https://www.icmm.com/website/publications/pdfs/mining-principles/equivalency/equivalency_icmm-rgmp_update.pdf

191 https://escolhas.org/publicacoes/estudos/

192 Responsible Gold Purchasing Platform - https://repositorio.usp.br/item/003144914

193 https://www.gov.br/funai/pt-br/assuntos/noticias/2024/com-mais-de-3-mil-operacoes-em-2024-governo-federal-impoe-prejuizo-de-r-267-milhoes-ao-garimpo-na-terra-indigena-yanomami

194 Monitora Y Project, coordinated by researcher Zuleica Castilhos (CETEM) - https://www.gov.br/cetem/pt-br/assuntos/noticias/projeto-monitora-y-equipe-do-cetem-e-parceiros-realizam-trabalho-de-campo-em-roraima

The Minamata Convention, to which Brazil is a signatory, has a report presented by the Ministry of the Environment (MMA) in 2024[195] addressing the inventory of mercury emissions and releases from Artisanal and Small-Scale Gold Mining (ASGM) in Brazil. The topic is scheduled to be addressed at COP 30 in Belém (PA) in 2025 and involves actions by competent institutions together with UNEP[196].

Future Outlook

The future of gold mining requires the adoption of innovative technologies and practices that minimize environmental impacts and promote social and economic sustainability. Investments in research and development, combined with strengthened integration with local communities, are essential for building a responsible mining model[197].

Additionally, there is a strategic need to improve inspection systems to combat illegal practices and ensure that economic growth is aligned with the preservation of Brazil's natural heritage. The formalization of artisanal mining, with incentives for good practices, also emerges as a priority for strengthening the sector.

At the global level, there is a growing trend toward stricter environmental and social requirements throughout the gold supply chain. International initiatives such as the Responsible Gold Mining Principles (ICMM) and the adoption of new certifications are expected to gain relevance, establishing new standards of responsibility for the market.

Brazil, with its vast gold reserves, is in a privileged position to benefit from this new context; however, it must align its production with internationally required environmental, social, and governance standards.

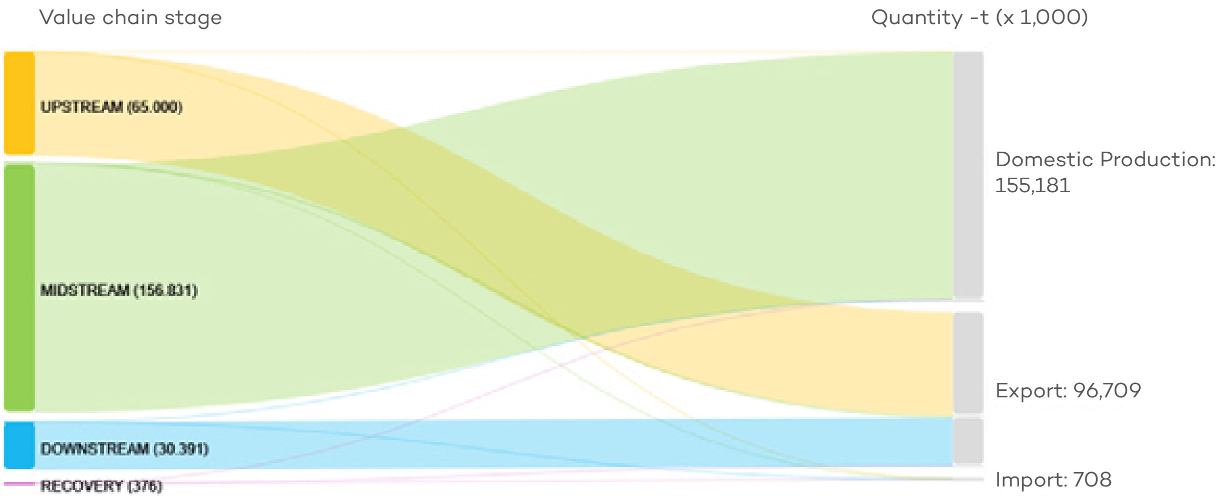
Moreover, new applications for gold are being demanded, driven by technological advances, such as the use of gold nanoparticles in medical treatments and applications in energy storage technologies. These transformations point toward a gold mining industry that not only drives economic growth but also contributes to the protection of strategic ecosystems and the advancement of sustainable technologies in Brazil and worldwide.

195 Initial Assessment Project of the Minamata Convention on Mercury. https://www.gov.br/mma/pt-br/assuntos/meio-ambiente-urbano-recursos-hidricos-qualidade-ambiental/seguranca-quimica/convencao-de-minamata-sobre-mercurio/relatorio-final-projeto-avaliacao-inicial-da-convencao-de-minamata-sobre-mercurio.pdf

196 https://wedocs.unep.org/bitstream/handle/20.500.11822/47571/BRSCOPs_Mercury-side-event.pdf?sequence=1&isAllowed=y

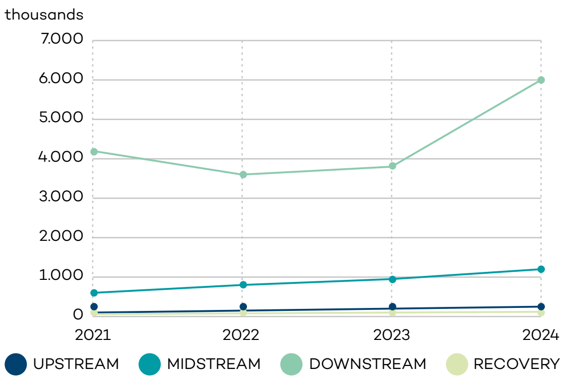
197 WGC – World Gold Council. Responsible Gold Mining Principles, London, 2019. https://www.gold.org/download/file/14263/Responsible-Gold-Mining-Principles-August-2019-ps.pdf

Figure 98: MFA of imported and exported volume, in relation to national industrial production data according to the stages of the gold value chain for the year 2022.

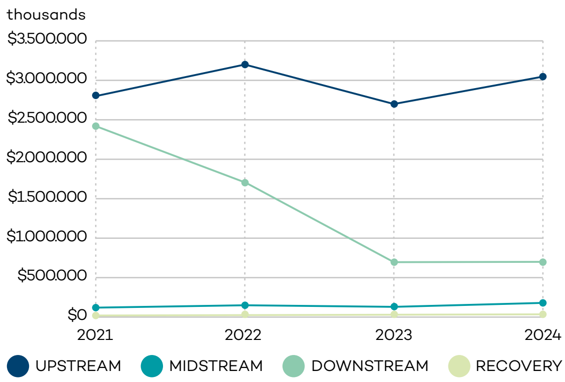


Source: Data obtained from the ComexStat Platform, 2025 (base year 2022), and from Industrial Production data (SIDRA/IBGE) for 2022.

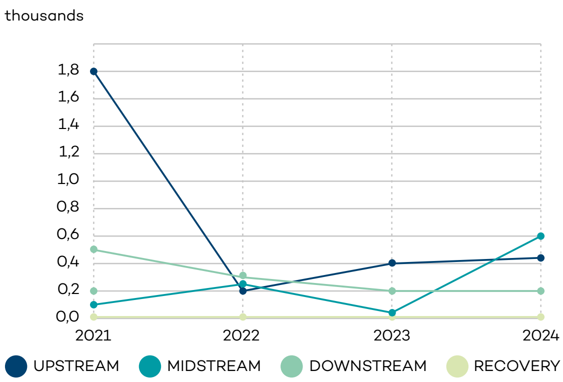
Graph 45. Gold: Imports in Value US$ FOB (thousands) between 2021 and 2024



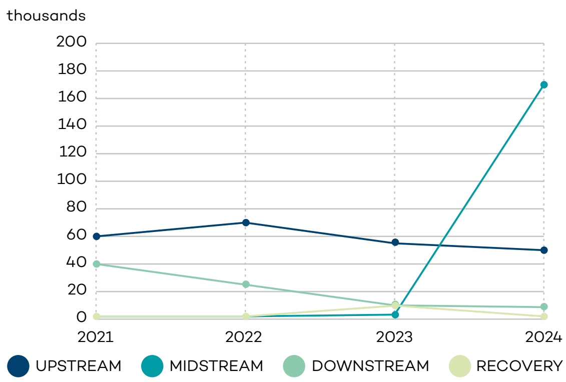
Graph 46. Gold: Exports in Value US$ FOB (thousands) between 2021 and 2024



Graph 47. Gold: Imports in Net Weight (millions of kg) between 2021 and 2024

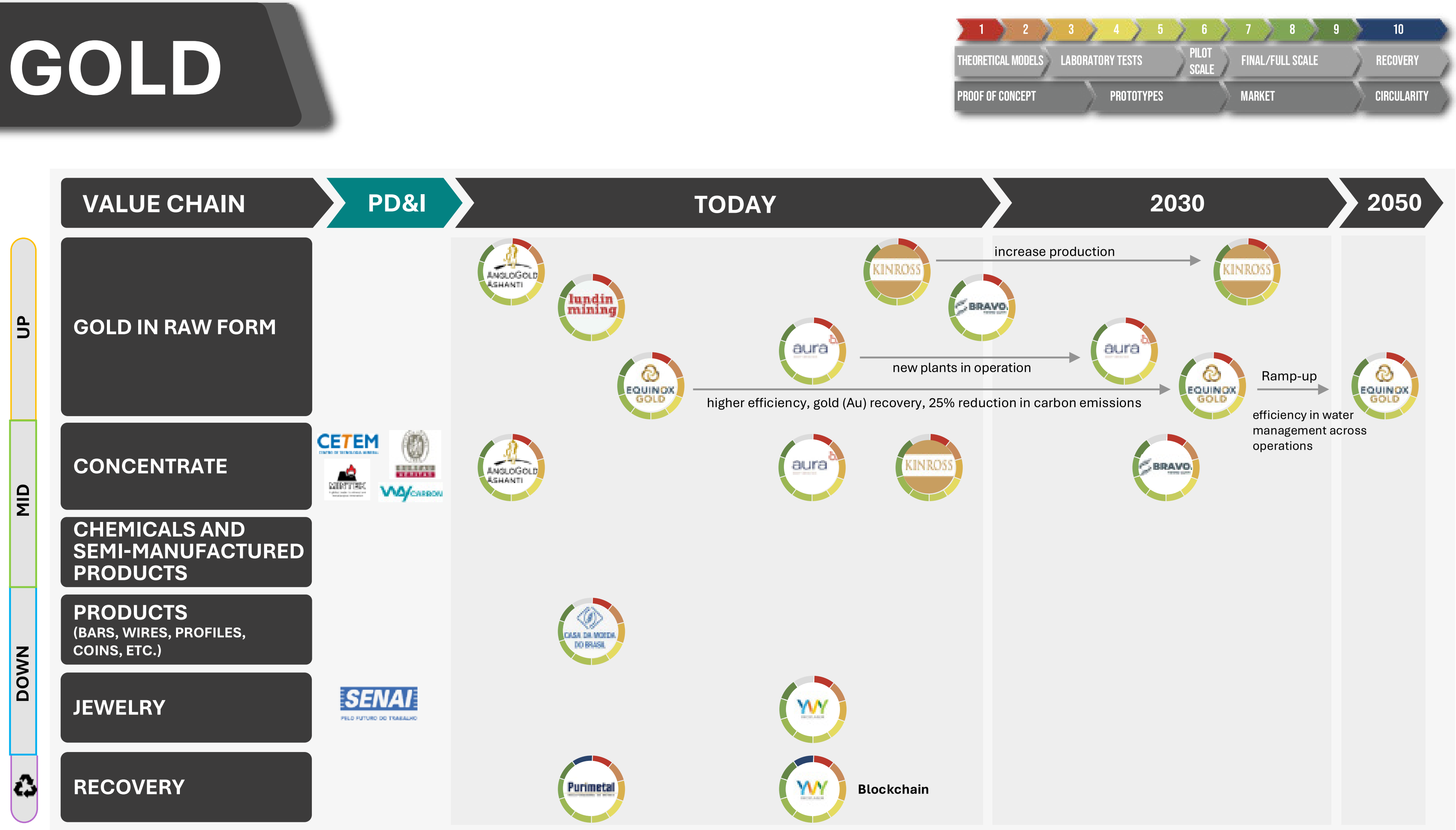


Graph 48. Gold: Exports in Net Weight (millions of kg), between 2021 and 2024



Source: Dados obtidos a partir da Plataforma ComexStat, 2025.

GOLD


1 2 3 4 5 6 7 8 9 10
THEORETICAL MODELS
LABORATORY TESTS
PILOT SCALE
FINAL/FULL SCALE
RECOVERY
PROOF OF CONCEPT
PROTOTYPES
MARKET
CIRCULARITY
VALUE CHAIN
PD&I
TODAY
2030
2050
UP
MID
DOWN
GOLD IN RAW FORM
CONCENTRATE
CHEMICALS AND SEMI-MANUFACTURED PRODUCTS
PRODUCTS (BARS, WIRES, PROFILES, COINS, ETC.)
JEWELRY
RECOVERY
increase production
new plants in operation
higher efficiency, gold (Au) recovery, 25% reduction in carbon emissions
Ramp-up
efficiency in water management across operations
Blockchain

PLATINOIDS

UPSTREAM MINING — Platinum and platinum-group minerals in raw form or powder

DOWNTREAM FINAL PRODUCTS — Works and products containing platinum

MIDSTREAM CHEMICALS/METALLURGY — Chemicals, concentrates, platinum compounds, powders and alloys

RECOVERY RECUPERAÇÃO — Wastes, residues (plated or coated metals) and ashes

Overview and demand

Platinum group metals (PGMs) are found in significant reserves in

South Africa (63 Mt) and Russia (16 Mt), which are also the main producers, along with Zimbabwe, the United States, and Canada. It is estimated that in 2024 a total of 120 tonnes of platinum and palladium were recycled worldwide from scrap, with 45 tonnes recovered from automotive catalysts in the United States alone[198].

Brazil does not yet have production of platinum group metals. Mineral exploration, including drilling campaigns, has been conducted by the companies Valore Metals and South Atlantic Gold in the state of Ceará[199]. Acting jointly in the Pedra Branca Project (CE), the companies are leading prospecting efforts and investments aimed at the extraction of platinum and palladium in Brazil. The project is still advancing toward the environmental licensing stage following confirmation of its economic viability.

Rhodium, another element of the platinum group, is the most valuable metal in the world and is not extracted from primary mines, but rather obtained as a by-product of the mining of other metals, such as platinum and nickel. Brazil currently does not have significant production of any of the platinum group elements.

198 https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-platinum-group.pdf

199 https://diariodonordeste.verdesmares.com.br/opiniao/colunistas/ingrid-coelho/mineradora-canadense-investe-r-35-milhoes-no-ce-para-exploracao-de-materia-prima-de-carros-hibridos-1.3511553

Figure 98. Platinoids: Reserves by Country

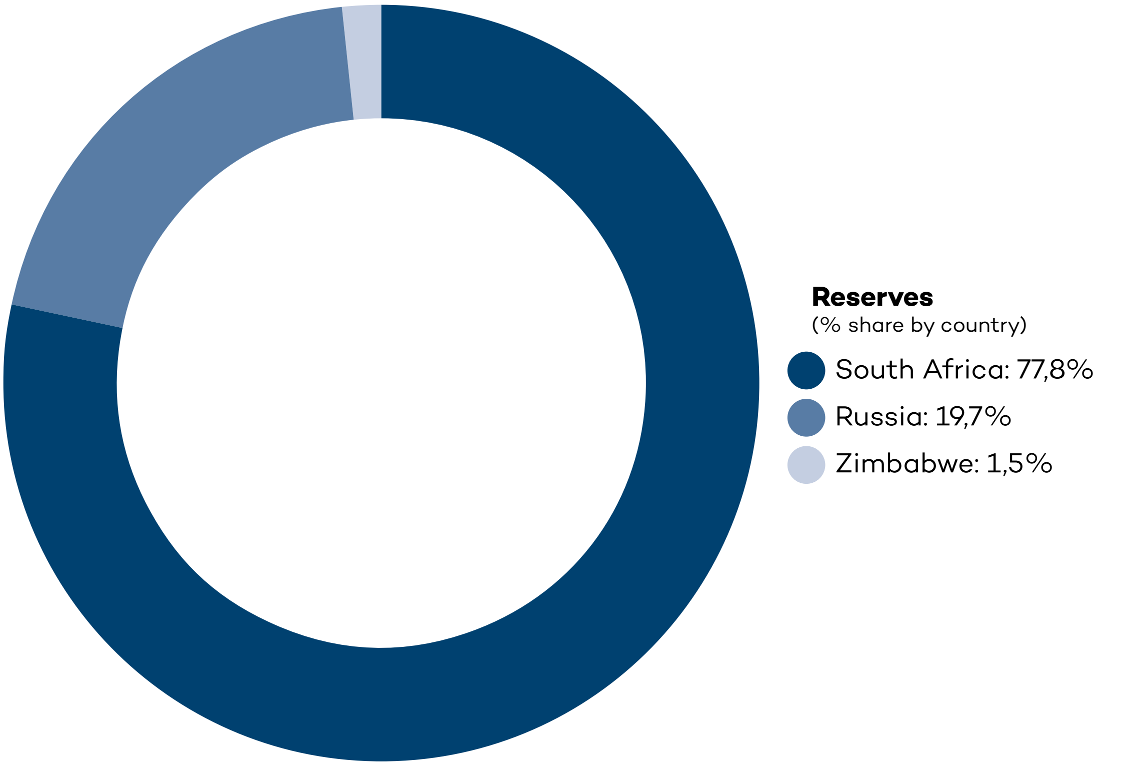
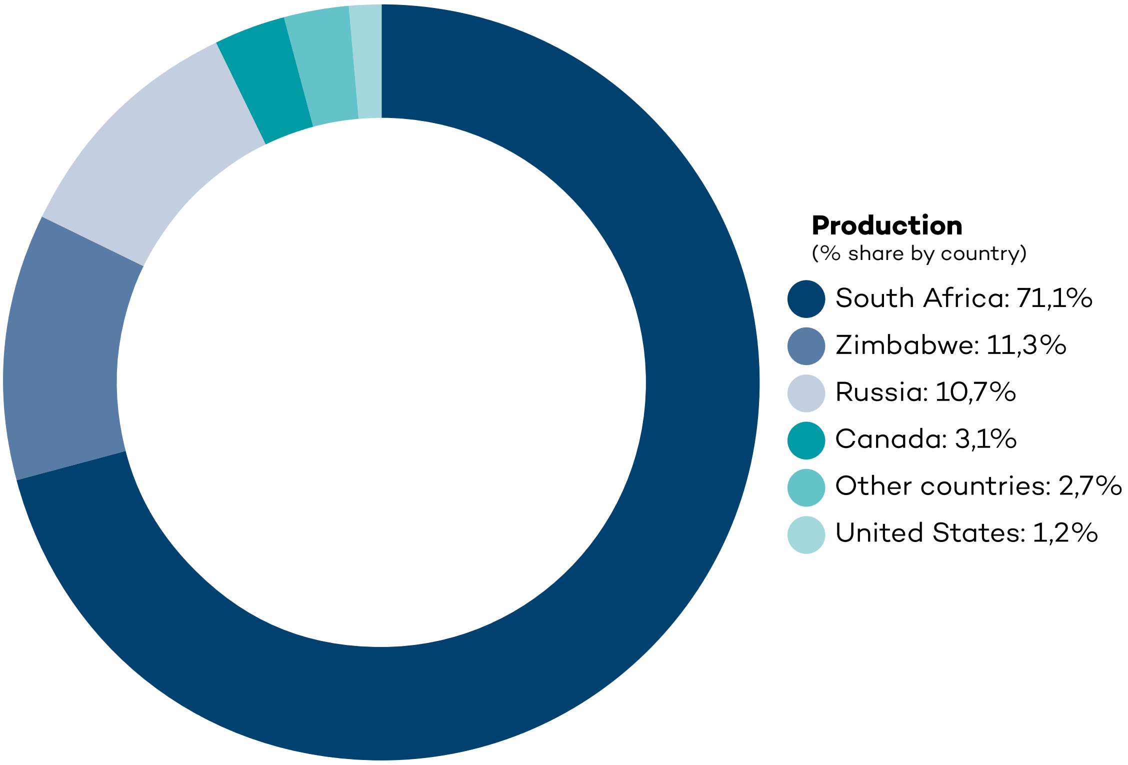


Figure 99. Platinoids: Production by Country



Source: USGS, 2025

Best Practices

Bravo Mining obtained the preliminary license for the Luanga mine, which hosts deposits of palladium, platinum, rhodium, gold, copper, and nickel in the Carajás Mineral Province (PA). The company's recognized socio-environmental performance is reflected in actions such as the hiring of local human resources and the planting of more than 30,000 trees in the project's surroundings over a two-year period[200].

BASF has developed a technology that allows the partial substitution of palladium, which is more expensive, by platinum in automotive catalysts, thereby increasing demand for platinum[201].

Future Outlook

The Pedra Branca project, covering the municipalities of Pedra Branca, Boa Viagem, Mombaça, and Tauá in the state of Ceará, has the potential to become the first project in Latin America to produce palladium and platinum on an industrial scale. The integration of projects between the two companies may represent an important opportunity for the maturation of the value chain, particularly for the production of electrolyzers and automotive catalysts.

Bravo Mining[202] obtained a preliminary license in 2025 from SEMAS (the environmental agency of the state of Pará) for its palladium, platinum, rhodium, gold, and nickel deposit at Luanga, located in the Carajás Mineral Province, State of Pará. Despite being at a preliminary stage, the prospects for exploitation are positive.

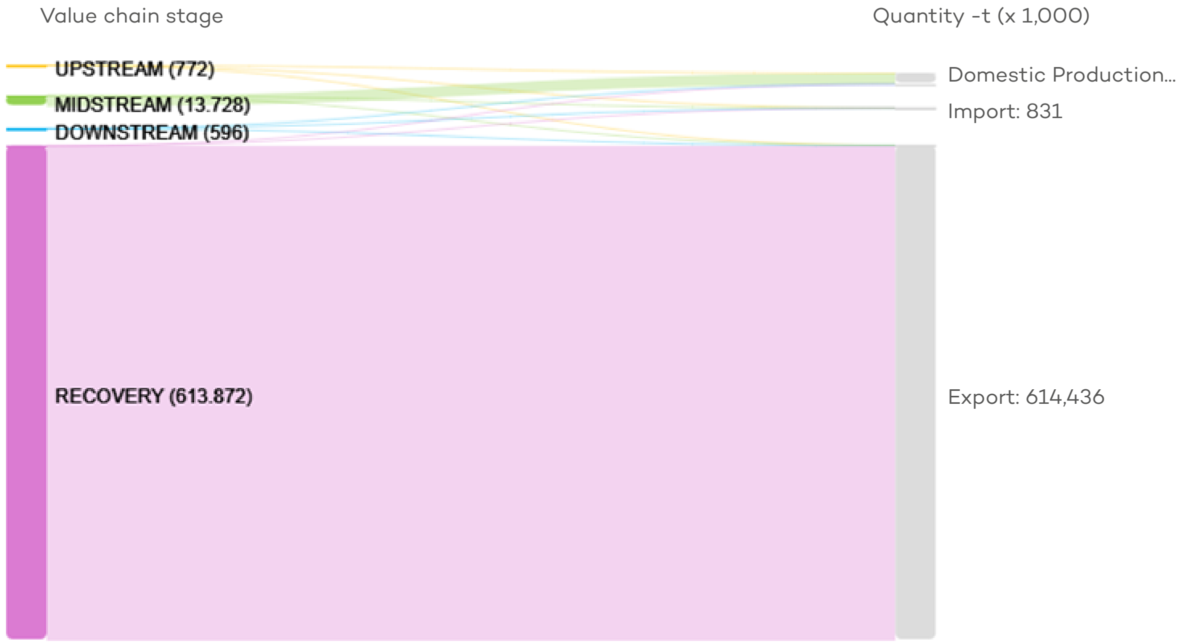
The Carajás Mining Province is an area with strong mineral endowment and a pro-mining jurisdiction, and the Luanga Project benefits from being located near operating mines and an experienced mining workforce, with access and proximity to existing infrastructure, including roads, railways, ports, and power from the hydroelectric grid.

200 https://www.Brazilmineral.com.br/noticias/bravo-mining-obtem-licenca-preliminar-para-o-projeto-luanga--no-para

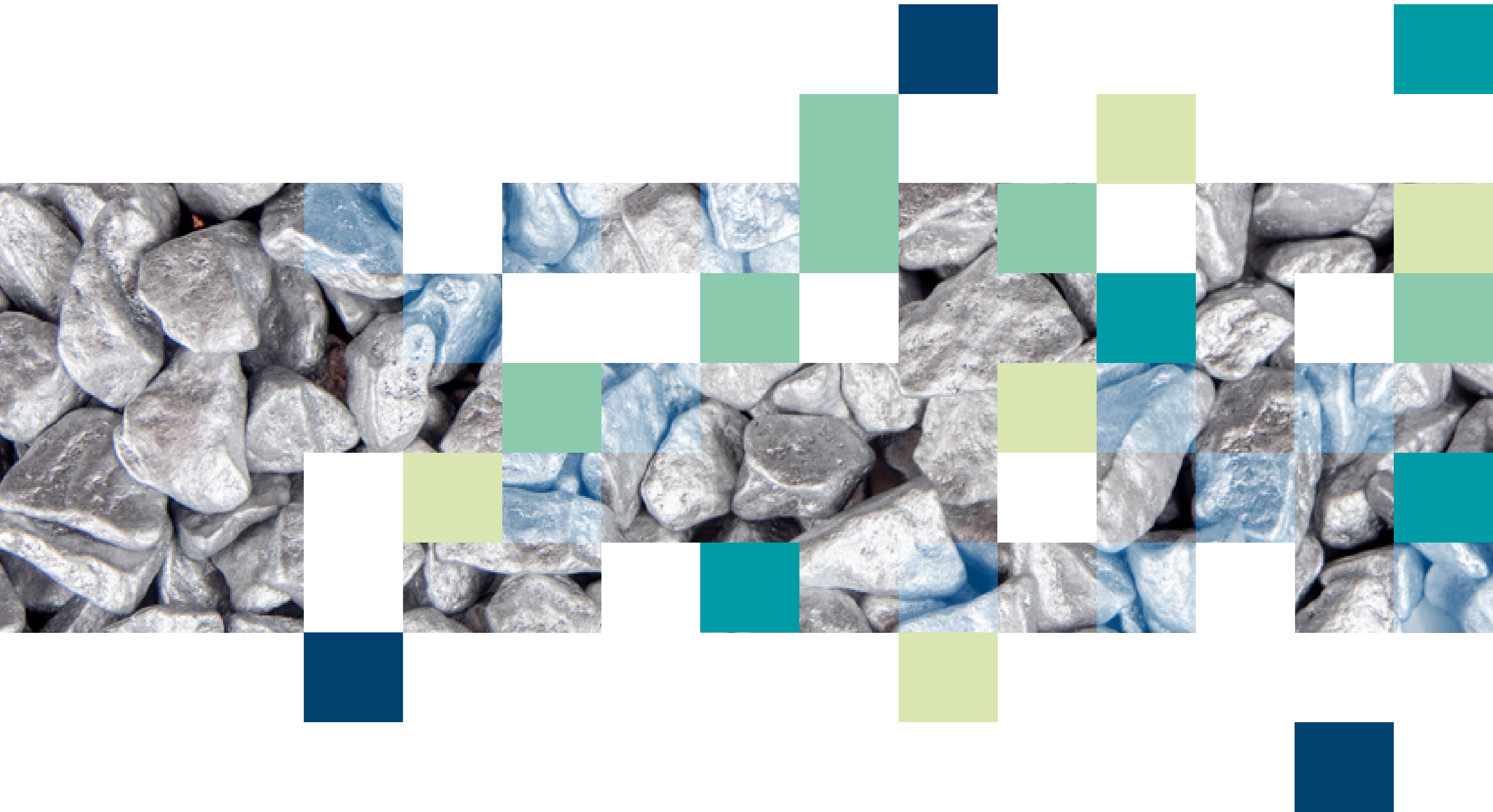
201 https://www.infomoney.com.br/mercados/maior-mineradora-global-de-Platinum-preve-mais-valorizacao--do-metal/#:~:text=Uma%20nova%20tecnologia%20desenvolvida%20pela,300.000%20on%C3%A7as%20por%20ano%2C%20disse.

202 https://www.Brazilmineral.com.br/noticias/bravo-mining-obtem-licenca-preliminar-para-o-projeto-luanga--no-para

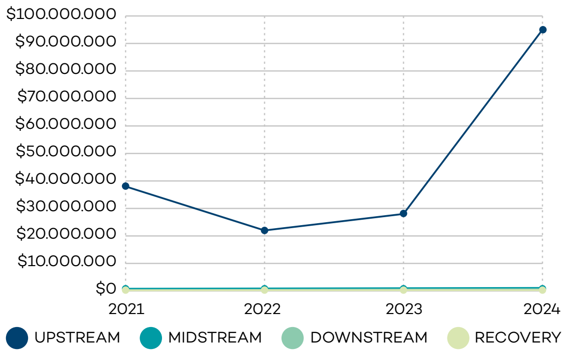
Figure 99: MFA of imported and exported volumes, in relation to national industrial production data, according to the stages of the Platinum Group Metals value chain for the year 2022, with the main waste export flows.



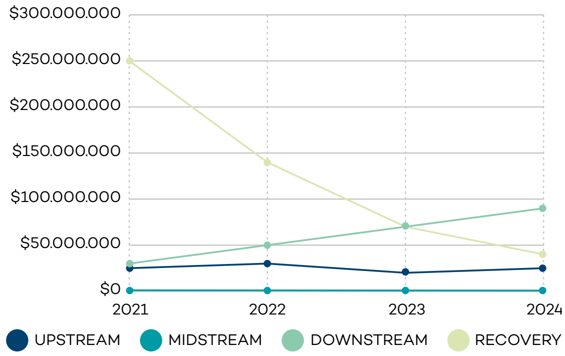
Source: Data obtained from the ComexStat Platform, 2025 (year 2022), and from Industrial Production data (SIDRA/IBGE) for 2022.



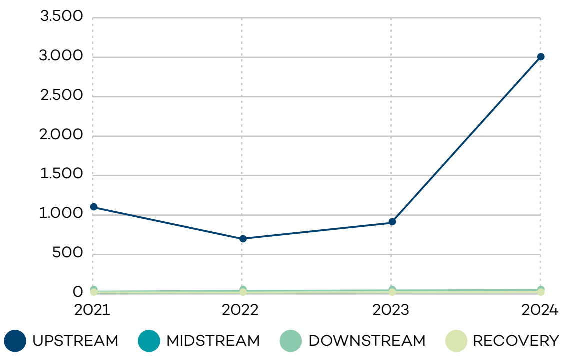
Graph 49. Platinum Group: Imports in FOB Value (US$) between 2021 and 2024



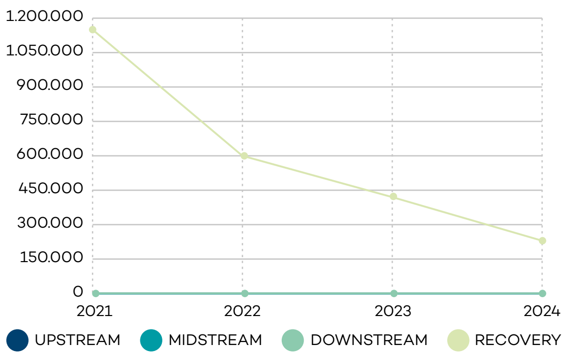
Graph 50. Grupo de Platinum: Exports in FOB Value (US$) between 2021 and 2024



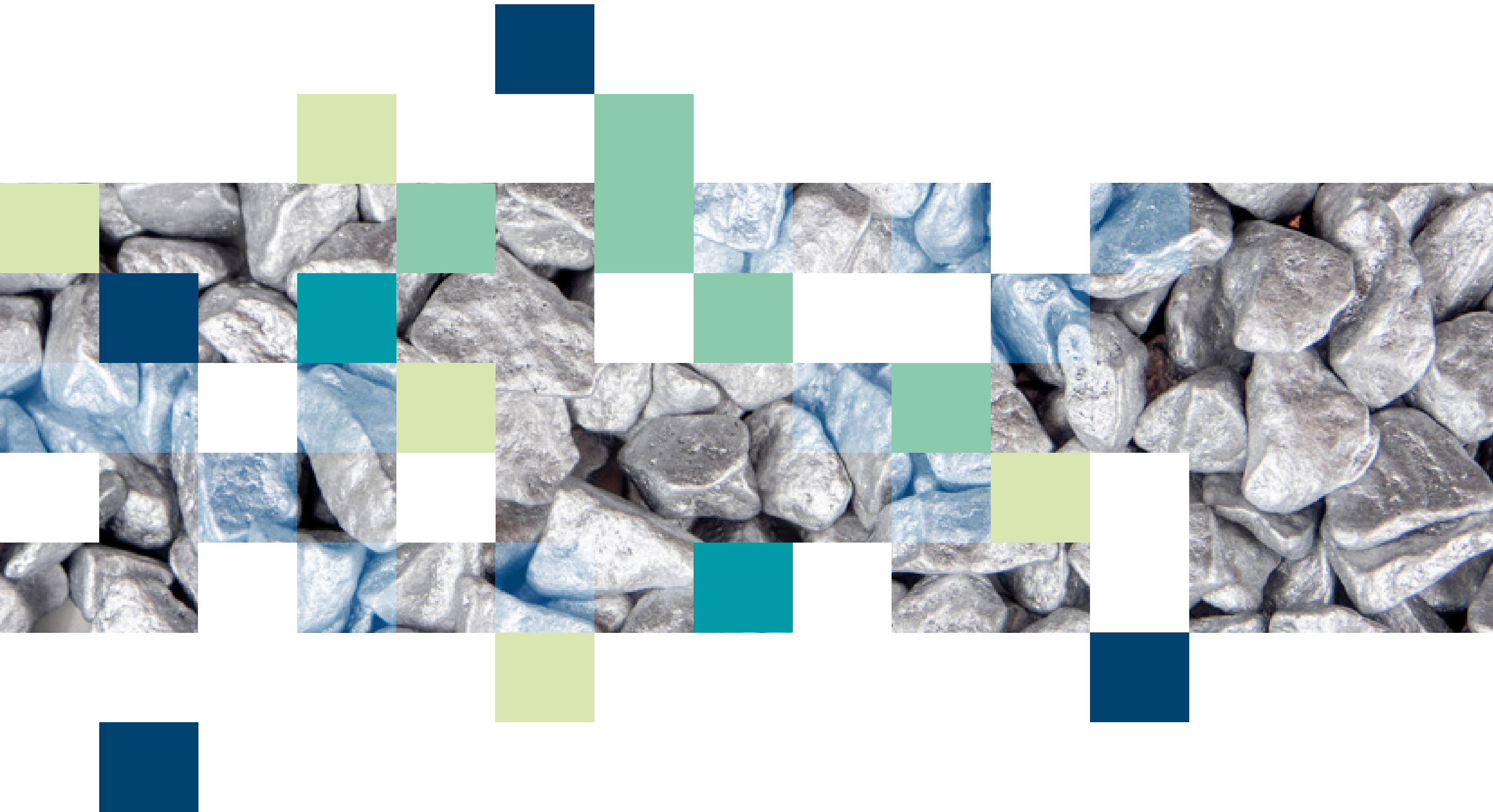
Graph 51. Platinum Group: Imports in Net Weight (kg) between 2021 and 2024



Graph 52. Platinum Group: Exports in Net Weight (kg) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.



PGM

Sources:
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https://www.brasilmineral.com.br/noticias/valore-investe-em-platina-e-paladio-no-ceara

CETEM | IBRAM BRAZILIAN MINING

POTASSIUM

UPSTREAM MINING — Carnallite and other potassium salts; Potassium chloride

MIDSTREAM CHEMICALS/METALLURGY — Chemicals (hydroxides, chlorides, sulfates, carbonates, salts)

DOWNSTREAM FINAL PRODUCTS — Fertilizers

RECOVERY RECOVERY — Remineralizers

Overview and demand

Potassium is a generic term for potassium-bearing minerals (K_2O or KCl), whether ores or refined products. Potassium is an essential nutrient for food production, promoting plant strengthening and increasing resistance to pests, which results in higher yields and improved crop quality. Demand in Brazil is growing, driven by the fact that the country is one of the world's largest grain producers, with potassium being the most widely applied nutrient in national agriculture (38%).

Found mainly in potassium salts, its primary agronomic use is in the form of potassium chloride (KCl), of which Brazil is highly dependent on imports (over 95%), ranking as the world's largest importer.

The country has significant potassium reserves, represented by sylvinite deposits – KCl (in Sergipe: Taquari, Vassouras, and Santa Rosa de Lima; and in Amazonas: Itacoatiara, Nova Olinda do Norte, and Autazes, a project of Potássio do Brasil Ltda.) and carnallite – $KCl \cdot MgCl_2 \cdot 6(H_2O)$ (in Rosário do Catete, Sergipe, operated by Mosaic Fertilizantes). Despite having only one active mine with production capacity below 500 thousand t/year, Brazil holds indicated reserves on the order of 12 billion tonnes of potassium ore, of which 2.5 billion tonnes are KCl (grade 8.3%), representing about 3% of global reserves.

As with phosphate, potassium presents a criticality pattern related to import dependence. Therefore, despite being included in the list of strategic minerals under MME Resolution No. 2 of 2021, phosphate could be included in a list of critical minerals, together with potassium.

Figure 100: Potassium: Reserves by Country (minerals)

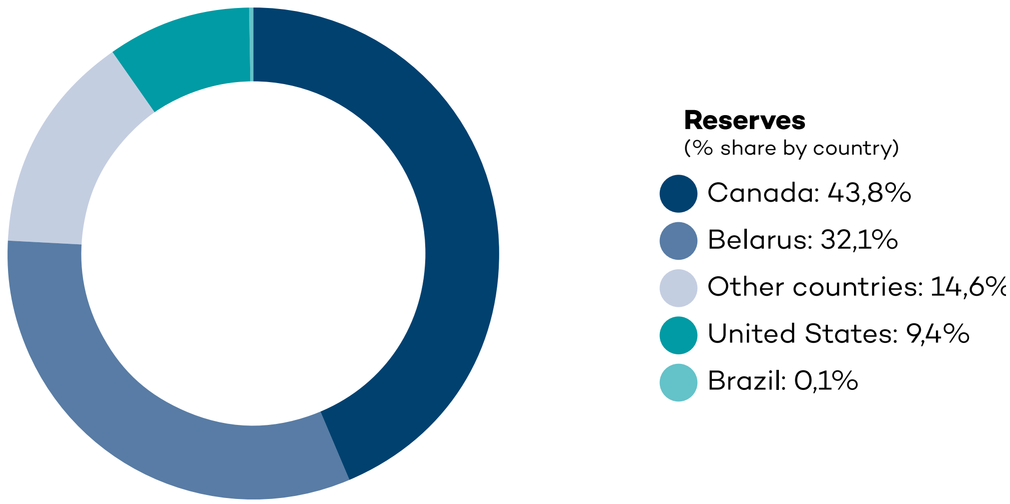


Figure 101: Potassium: Reserves by Country (K_2O equivalent)

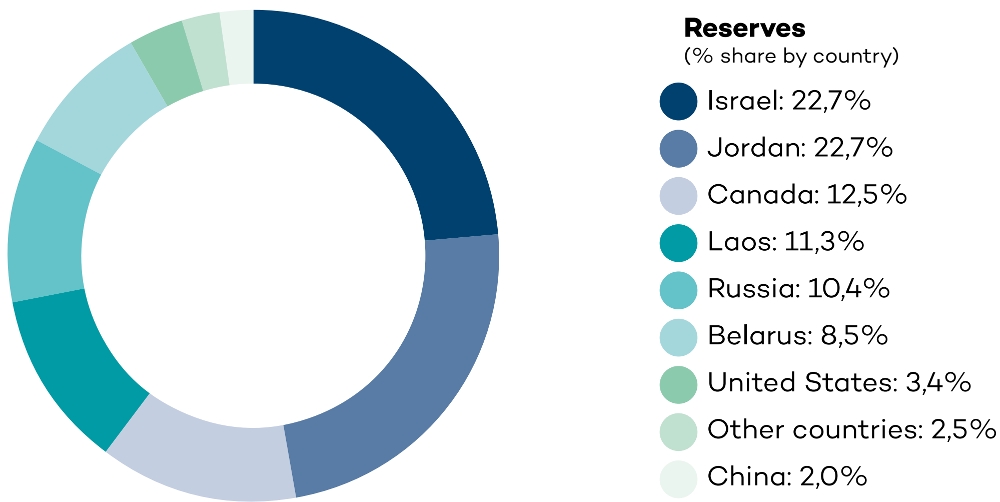
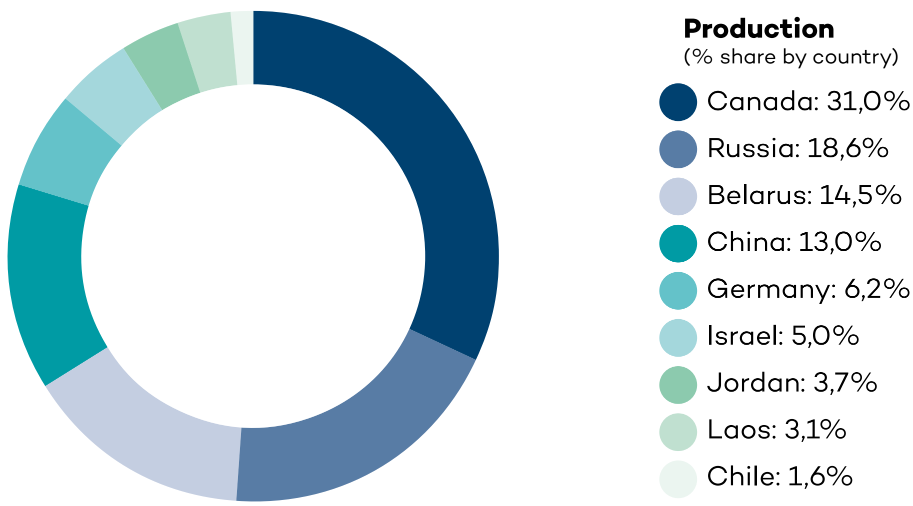


Figure 102: Potassium: Production by Country



Source: USGS, 2025

Figure 103: Map for Authorization of Potash Exploration in Brazil (2025)

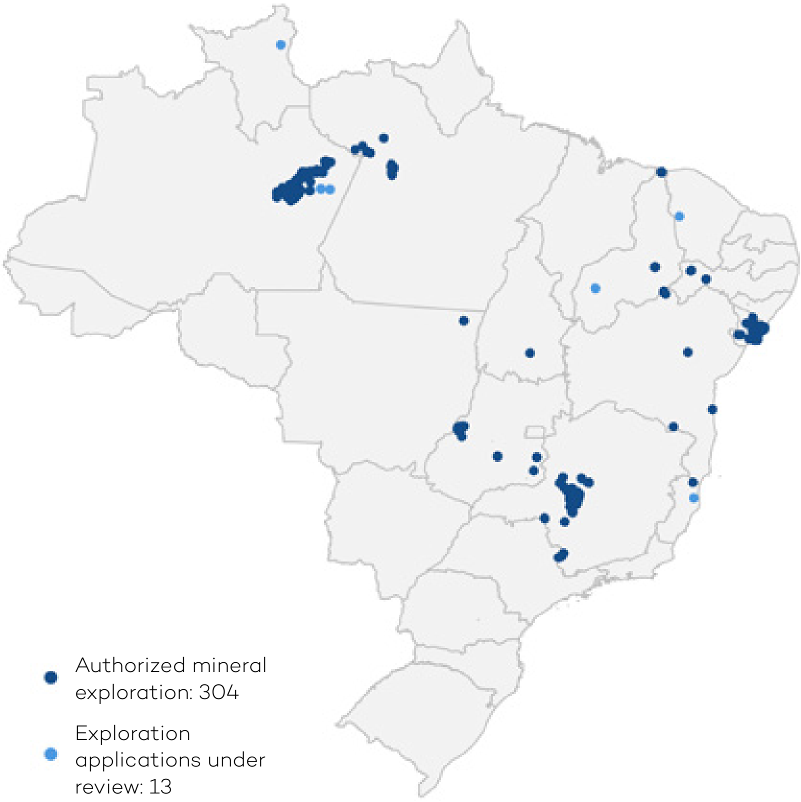


Figure 104: Map for Authorized Potash Mining Concessions in Brazil (2025)

Best Practices

In the agro-industrial sector, Brazil needs to prioritize initiatives that encourage domestic potash production in a sustainable manner and integrated with efficient logistics infrastructure. Several key points reveal challenges and opportunities for the expansion of this value chain: (i) proximity of potassic rock deposits to major demand centers and/or logistics outflow infrastructure; (ii) prospects for integration among phosphate, potash, and nitrogen production hubs; (iii) potential for potash recovery and recycling, highlighted by R&D&I initiatives within agroecological research networks; and (iv) the need for a regulatory framework that provides legal certainty for public and private investors. In addition, the recovery and recycling of residues—practices well established in other countries but still incipient in Brazil—represent a promising alternative pathway. Public incentive policies, recycling programs, tax reductions for recycling companies, and attractive financing lines can significantly strengthen domestic production.

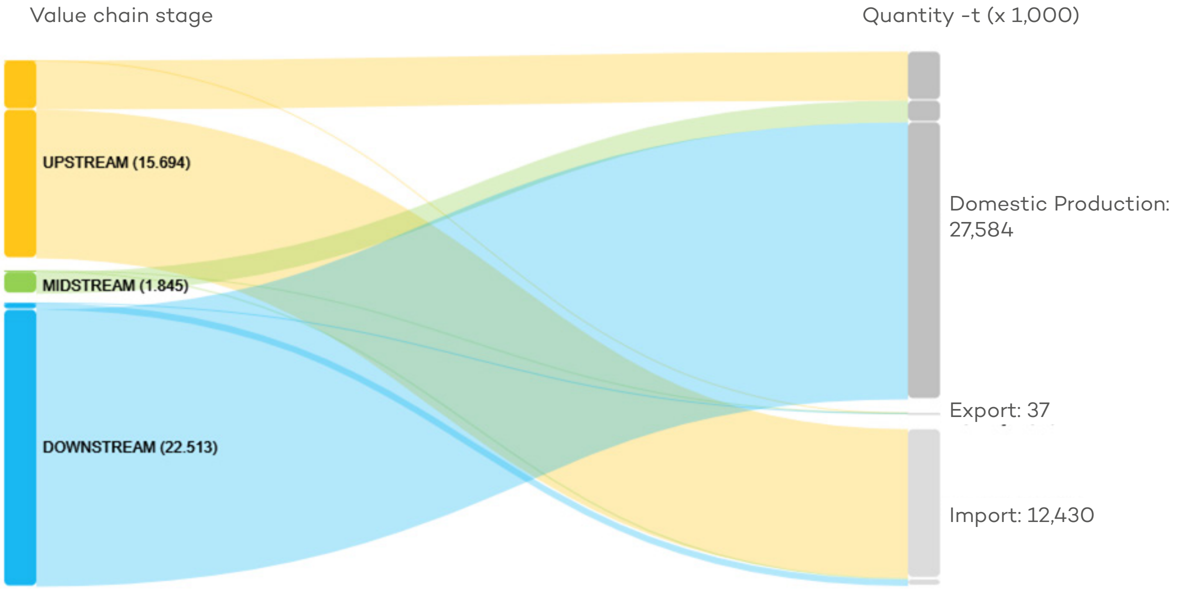
Potássio do Brasil Ltda., a subsidiary of the Canadian group Brazil Potash Corp., obtained licensing for the implementation of potash production activities under the Autazes Potash Project, with an estimated capacity of 2.2 million tonnes per year of potassium chloride. Extraction will be carried out by underground mining, using the room-and-pillar method, accessing the mining area through two shafts of approximately 900 meters in depth. Construction is estimated to take about 5 years, with an operational life of 23 years. In the first phase of the project, the company aims to supply approximately 20% of annual domestic demand.

Future Outlook

The continued expansion of agriculture projects an alarming dependence on potash imports, potentially reaching 97%, placing Brazil in a position of economic vulnerability. To reverse this scenario, the future vision is clear: invest in the sustainable growth of domestic fertilizer production. This entails leveraging the production of potassium chloride (KCl) from evaporite deposits and the domestic production of potassium oxide (K_2O) through the exploitation of silicate rocks and the recycling of residual mineral and organomineral sources. The success of this endeavor requires the mobilization of joint efforts by the public and private sectors.

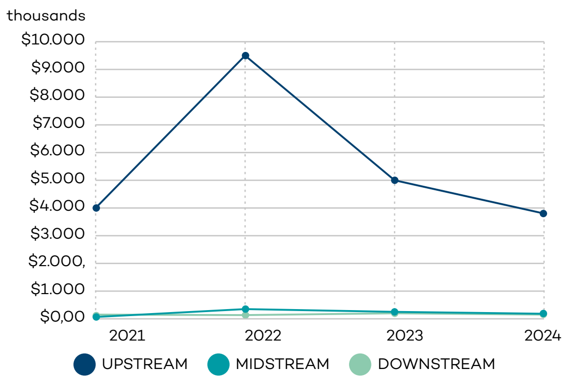
The National Fertilizers Plan (PNF 2050) sets an ambitious goal: to increase domestic potash production to 3.8 million tonnes per year by 2030 and, consequently, reduce import dependence from 85% to 45% by 2050 (8.9 million tonnes/year). Currently, three projects stand out in the national present and future landscape: the Autazes project, by Potássio do Brasil, located in Autazes (AM), with potential annual production of 2.2 million tonnes of potassium chloride; the South Atlantic Potash project, in the state of Sergipe, which, although still in the exploration phase, encompasses an extensive area with potential for the exploitation of potassium and sodium chloride; and the Mosaic Fertilizantes project, in Rosário do Catete (SE), which exploits the mineral carnallite with a capacity below 500 thousand tonnes per year.

Figure 105: MFA of imported and exported volumes, in relation to national industrial production data according to the stages of the Potash value chain for the year 2022.

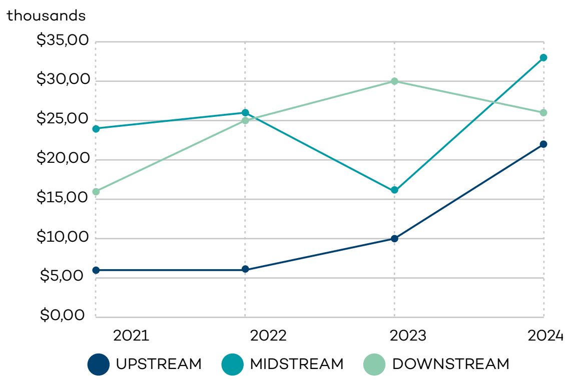


Source: Data obtained from the ComexStat Platform, 2025 (year 2022), and from Industrial Production data (SIDRA/IBGE) for 2022.

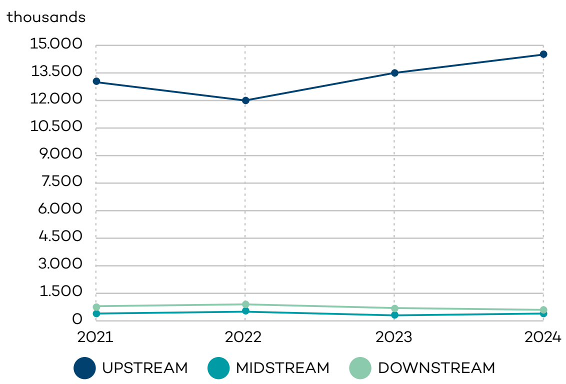
Graph 53. Potassium: Imports in Value US$ FOB (thousands) between 2021 and 2024



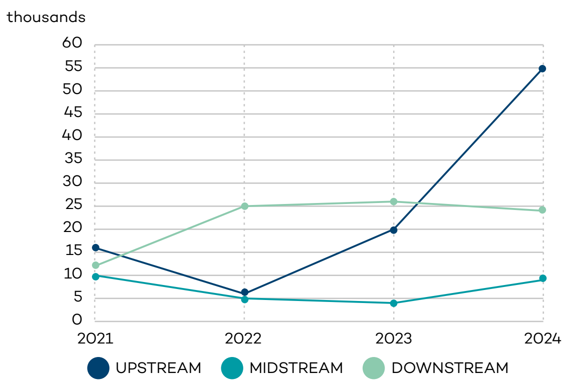
Graph 54. Potassium: Exports in Value US$ FOB (thousands) between 2021 and 2024



Graph 55. Potassium: Imports in Net Weight (millions of kg) between 2021 and 2024

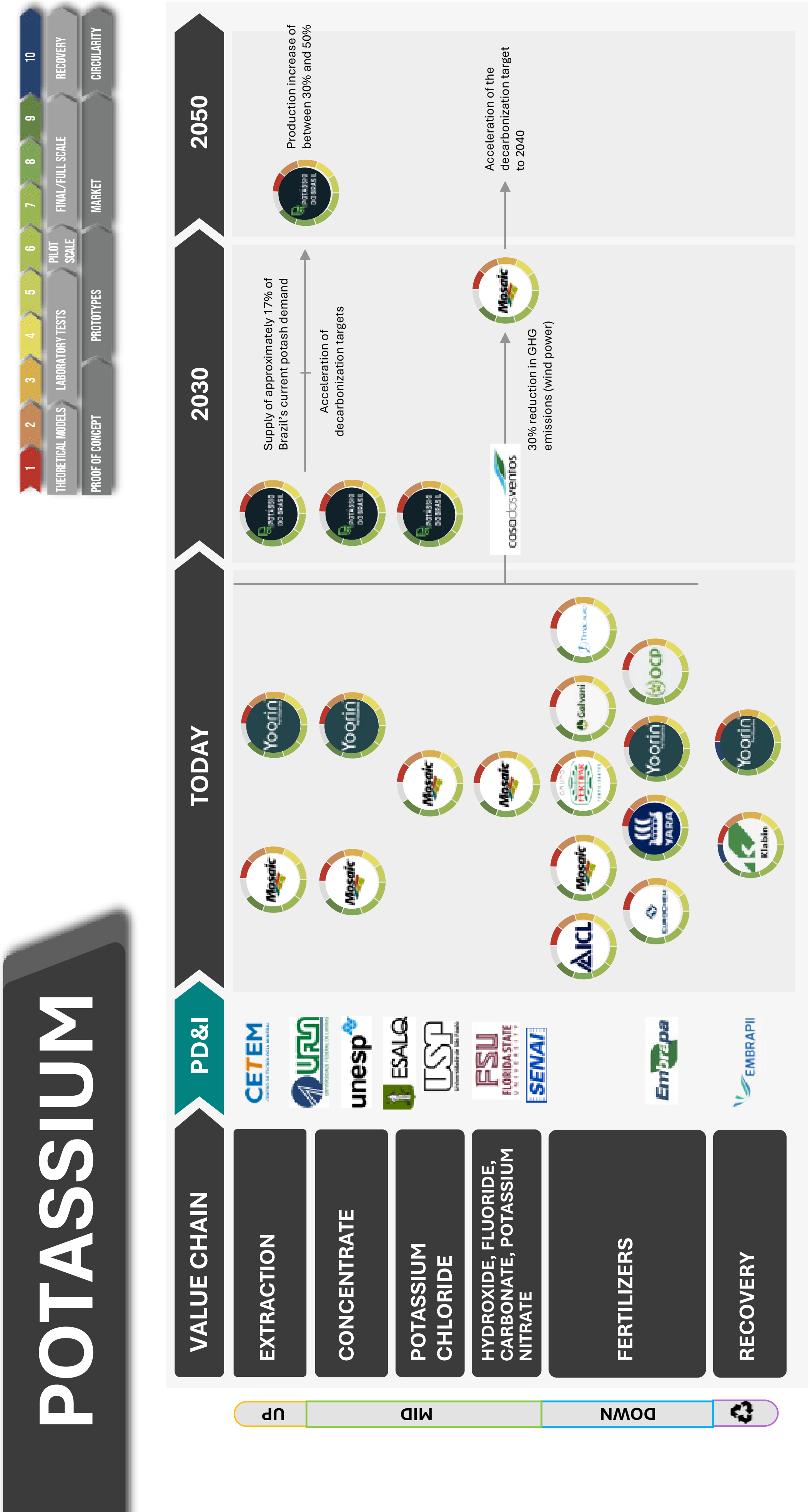


Graph 56. Potassium: Exports in Net Weight (millions of kg), between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.

Inserir imagem Roadmap que está no pptx



https://mosaicco.com.br/Article/Mosaic-antecipa-o-in%C3%ADcio-do-fornecimento-de-energia-e%C3%B3lica-com-a-Casa-dos-Ventos-e-acelera-estrat%C3%A9gia-de-descarboniza%C3%A7%C3%A3o-da-empresa.

https://brazilpotash.com/wp-content/uploads/2024/04/PdB-Apresentacao-Institucional-para-Investidores-ABR.2024.pdf

SILICON

UPSTREAM MINING — Silicon ores (quartz, sand)

MIDSTREAM CHEMICALS/METALLURGY — Chemicals (oxides, carbides, etc.) and alloys, filaments, other compositions

DOWNSTREAM FINAL PRODUCTS — Glass and its parts, accessories, artifacts, products, silicone, fabrics, papers, piezoelectric materials, precursors for photovoltaic cells

RECOVERY RECOVERY — Cullet, fragments, and other glass waste and residues

Overview and demand

Silicon is one of the most abundant minerals in the Earth's crust and has significant application potential in the energy transition, particularly in the production of

solar-grade silicon used in the manufacture of glass, ceramics, photovoltaic panels, biomedical applications, as well as semiconductors and agriculture. Among its main characteristics, its ability to conduct electricity under certain conditions stands out, making it essential for the production of electronic chips. Brazil's main quartz reserves are located in Cristalina (Goiás), as well as in the states of Minas Gerais and Bahia. The scarcity of mines in other countries is already a reality, qualifying this mineral as globally critical. Silicon is widely used in Brazilian agriculture, especially as a beneficial element for crop management. It can be found in minerals such as quartz and silicates, as well as in plant residues such as rice husks and sugarcane bagasse. These materials are frequently used to improve soil properties and increase agricultural productivity[203].

According to data from CETEM[204], although Brazil holds 4.3% of global silicon production, it has not yet achieved the metallurgical (99.9%) or chemical (99.999%) purity levels required for the production of, for example, semiconductors, solar panels, or certain aluminum alloys. As such, there is a clear demand for the development of technological purification routes.

With the growing demand for artificial intelligence across sectors such as healthcare, industrial automation, and autonomous mobility, the development of silicon-based materials and technologies remains a strategic priority[205].

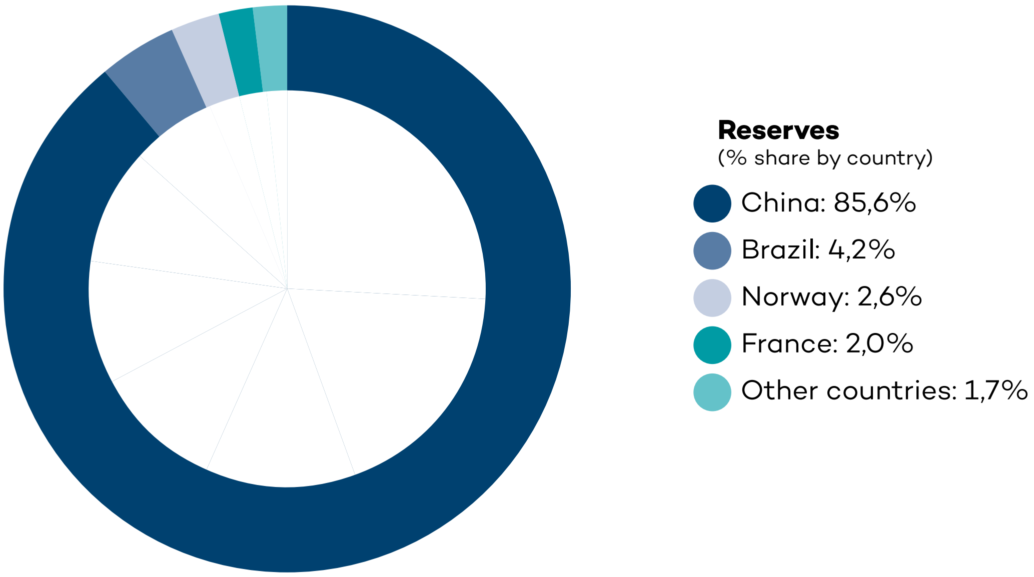
The production of photovoltaic silicon is directly linked to the growth of solar energy in Brazil. The purification process required for photovoltaic-grade silicon demands high-cost industrial plants and advanced technology, in addition to high energy

203 https://Brazilescola.uol.com.br/quimica/silicio.htm

204 https://www.gov.br/mcti/pt-br/acompanhe-o-mcti/noticias/2024/08/minerais-estrategicos-sao-destaca-dos-no-contexto-de-um-projeto-nacional

205 https://revistapesquisa.fapesp.br/wp-content/uploads/2002/04/72-inform%C3%A1tica.pdf consumption. Although Brazil is one of the largest producers of metallic silicon, it still faces significant challenges in positioning itself as a leader in the production of photovoltaic silicon.

Figure 106: Silicon: Global Production



Source: USGS, 2025

Figure 107: Map of Authorized Silicon Mining Concessions in Brazil (2025)

Best Practices

RIMA is the largest Brazilian producer of metallic silicon and ferroalloys. The company uses renewable charcoal in its production process. The Brazilian Association of Ferroalloy and Metallic Silicon Producers (ABRAFE) brings together the main industrial groups in the sector, representing approximately 75% of national production. Minas Ligas produces ferrosilicon (FeSi) with 75% purity grades.

Investment in R&D&I has been driven by initiatives from companies such as BYD, which operates a specialized laboratory in Campinas (São Paulo), as well as Tecnometal and Liasa, which invest in improving product quality. With an investment of BRL 65 million in research, BYD is studying the photovoltaic module production cycle, including the use of silicon as an essential raw material.

Future Outlook

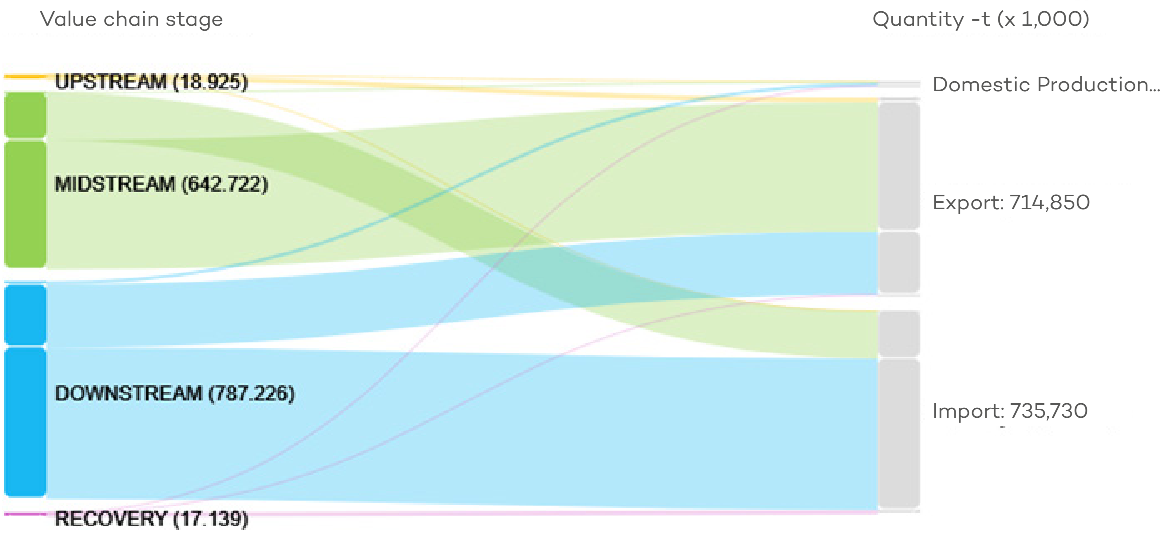
As an energy-intensive industry, silicon refining for applications in energy transition technologies would benefit significantly from Brazil's national energy matrix, resulting in production costs substantially lower than those observed in other countries.

Despite the availability of mineral reserves of silicon ore (silica), purification is largely carried out abroad, and photovoltaic modules are predominantly imported as finished products, with high added value concentrated in the assembly of photovoltaic panels.

Production costs in the sector benefit from the green energy matrix and the availability of natural reserves. Combined with high solar irradiation across much of the country, these factors represent important drivers to justify incentives for densifying the value chain toward the production of high-efficiency and sustainable photovoltaic panels.

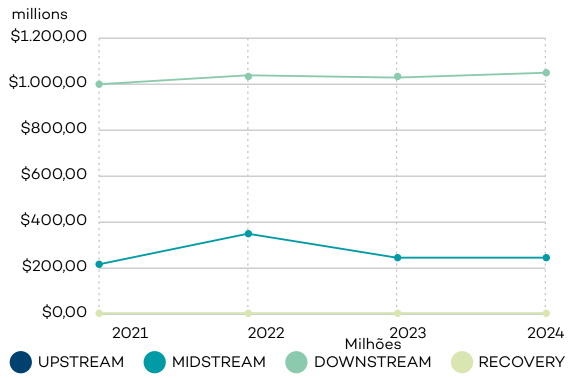
One way to invest in the specialization of the silicon value chain is through the effective allocation of royalties from mining activities, which by law are earmarked for R&D&I activities. In 2024, these resources would amount to an estimated investment of BRL 7.1 billion.

Figure 108: MFA of imported and exported volumes in relation to national industrial production data according to the stages of the silicon value chain for the year 2022

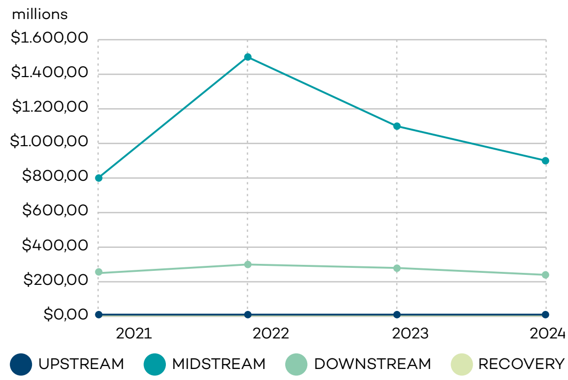


Source: Data obtained from the ComexStat Platform, 2025 (reference year: 2022), and from Industrial Production data (SIDRA/IBGE) for 2022.

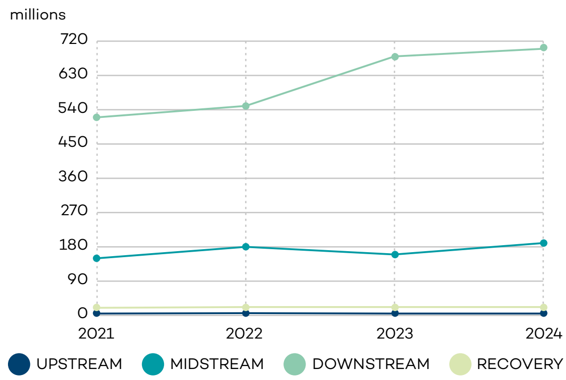
Graph 57. Silicon: Imports in Value, US$ FOB (millions), between 2021 and 2024



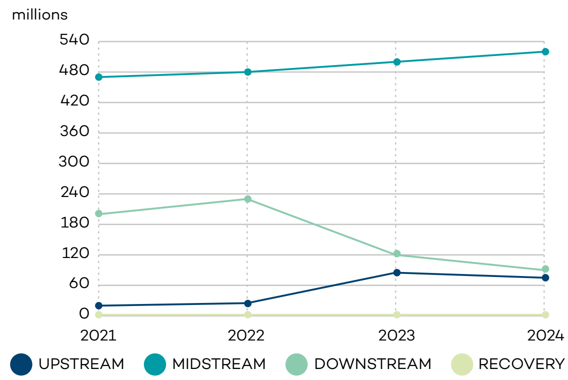
Graph 58. Silicon: Exports in Value, US$ FOB (millions), between 2021 and 2024



Graph 59. Silicon: Imports in Net Weight (millions of kg), between 2021 and 2024

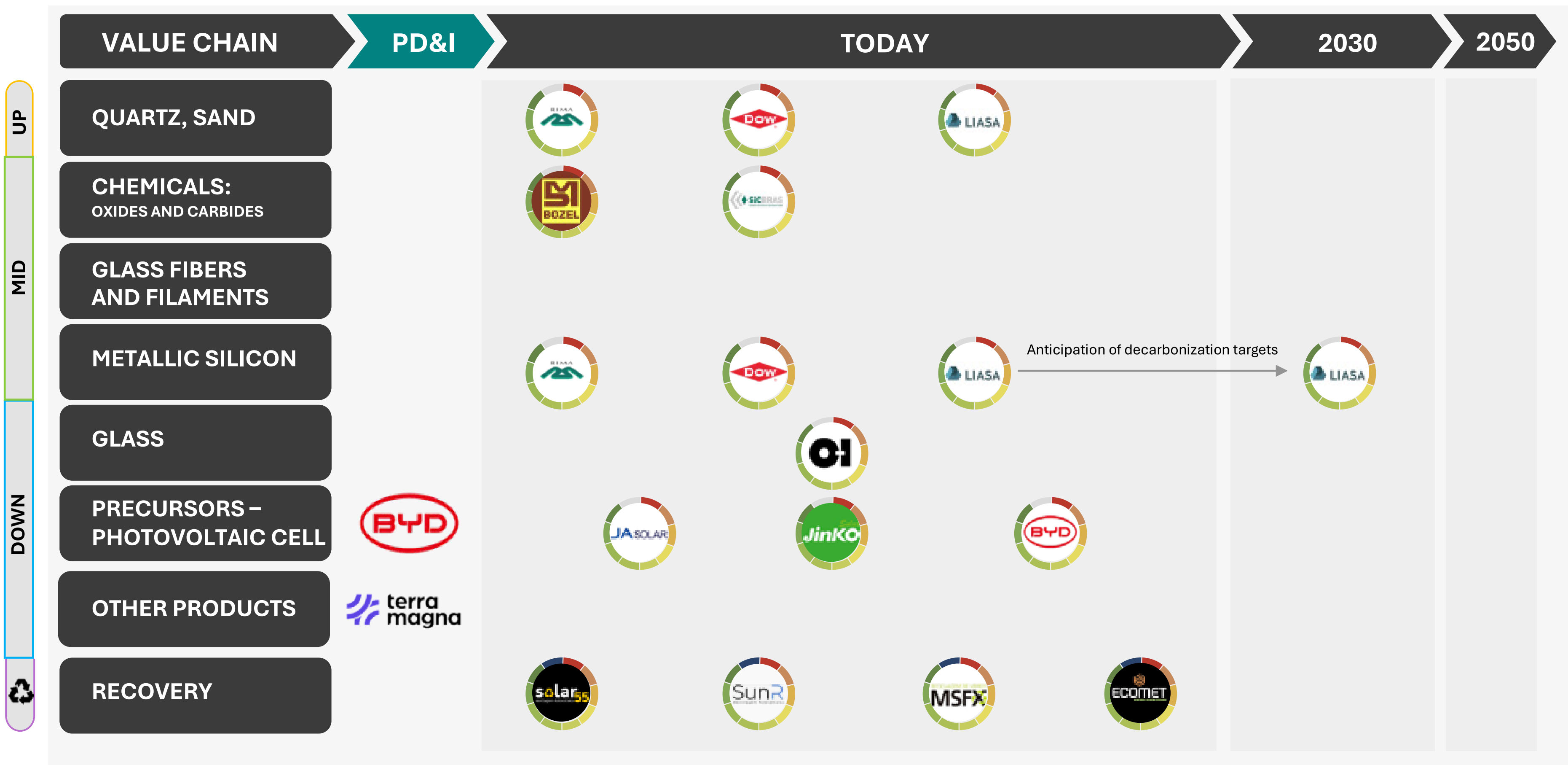


Graph 60. Silicon: Exports in Net Weight (millions of kg), between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.

SILICON



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https://terramagna.com.br/blog/silicio/
https://revistapesquisa.fapesp.br/silicio-brasileiro-para-celulas-solares/#:~:text=A%20empresa%20Tecnometal%2C%20de%20Campinas,tamb%C3%A9m%20%C3%A9%20parceira%20da%20pesquisa.
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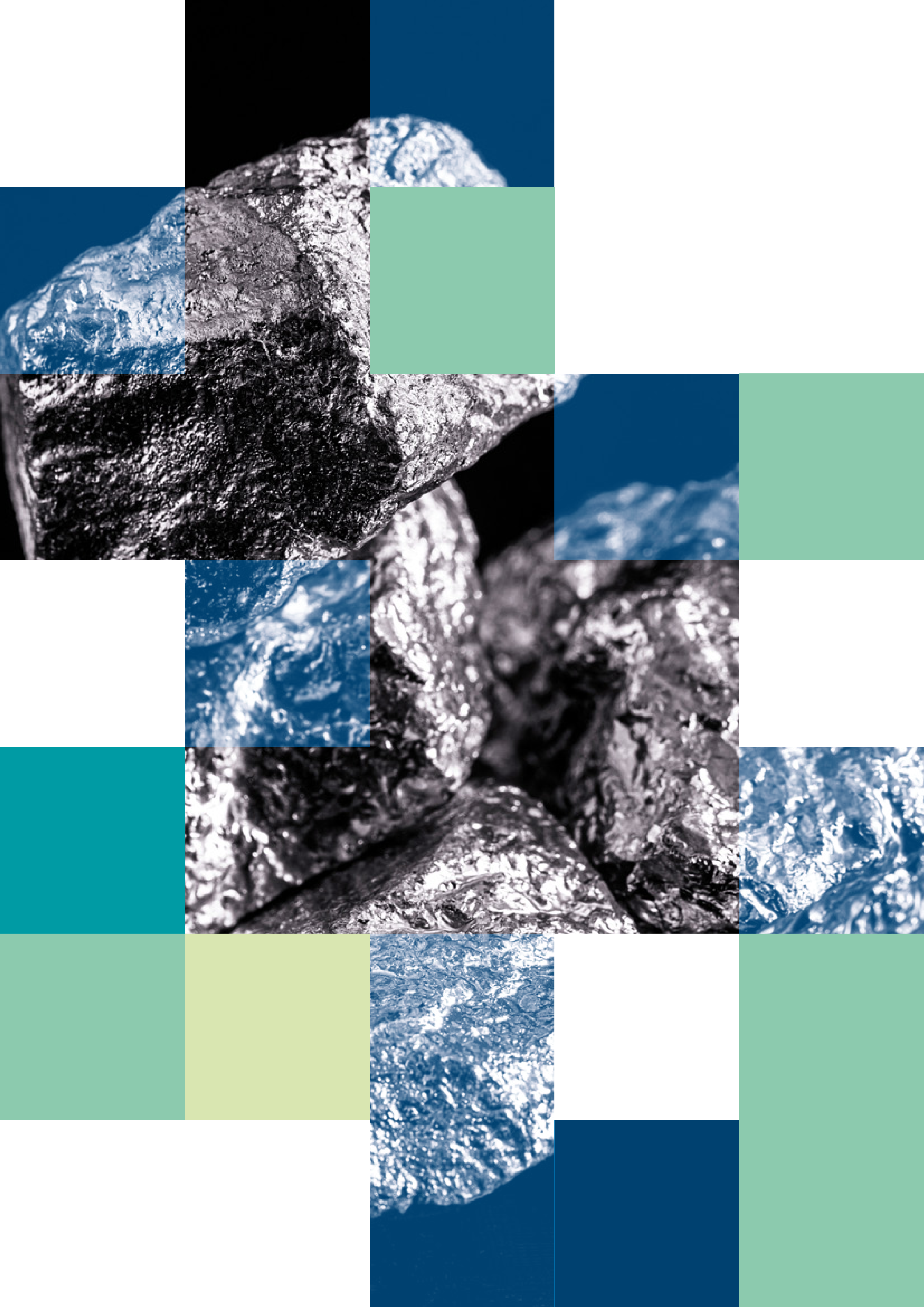


Tantalum

- **UPSTREAM** MINING — Tantalum ores
- **MIDSTREAM** CHEMICALS/METALLURGY — Chemicals, concentrates, sinter, powders, and bars
- **DOWNSTREAM** FINAL PRODUCTS — Capacitors and condensers
- **RECOVERY** RECOVERY — Scrap and waste

Overview and demand

Tantalum (symbol Ta and atomic number 73) belongs to the group of ferrous metals, that is, those that commonly form alloys with iron as the main component. Although most of the world's production comes from Africa, Brazil holds significant tantalum reserves, particularly in the states of Minas Gerais, Paraíba, and Rio Grande do Norte[206]. The largest global reserves are located in the Democratic Republic of the Congo (240,000 t), Australia (110,000 t), and Brazil (40,000 t) (USGS, 2025).

This mineral is widely used in the manufacture of superalloys and electronic components, especially electronic capacitors, due to its high corrosion resistance and excellent electrical conductivity. In Brazil, AMG, located in the state of Minas Gerais, is one of the few companies that has conducted in-depth studies of its reserves, identifying the largest volume of Ta_2O_5 in the country[207].

Global production is concentrated in countries such as Rwanda, the Democratic Republic of the Congo, Brazil, and Australia. The Asia-Pacific region is the largest consumer, with China and South Korea standing out. In 2024, the global tantalum market is estimated at 2.46 thousand tonnes, with projected growth to 3.18 thousand tonnes by 2029, at a compound annual growth rate (CAGR) of 5.26%[208].

Brazil is one of the main producers of tantalum ore (tantalite), from which tantalum is extracted. National production is significant but faces challenges related to sustainability and supply chain transparency. The mining company Taboca produces tantalum and niobium as by-products of tin mining operations in the states of Amazonas and São Paulo, as well as from tailings generated by mineral processing activities.

206 https://www.fortunebusinessinsights.com/pt/tantalum-market-110104

207 https://www.gov.br/mme/pt-br/assuntos/secretarias/geologia-mineracao-e-transformacao-mineral/relatorios-de-apoio-ao-pnm-2030-projeto-estal-1/a-mineracao-Brazileira/documentos/p19_rt29_perfil_da_mineraxo_da_tantalita.pdf

208 http://recursomineralmg.codemge.com.br/substancias-minerais/tantalo/

Figure 109: Tantalum: Reserves by Country

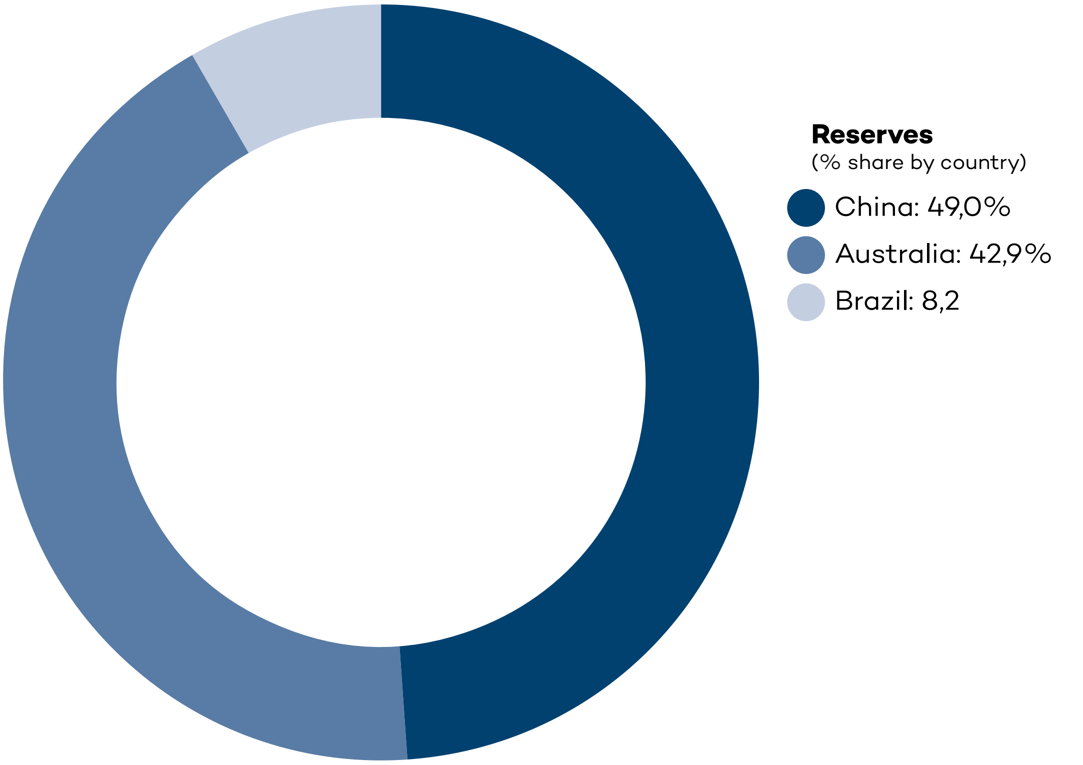
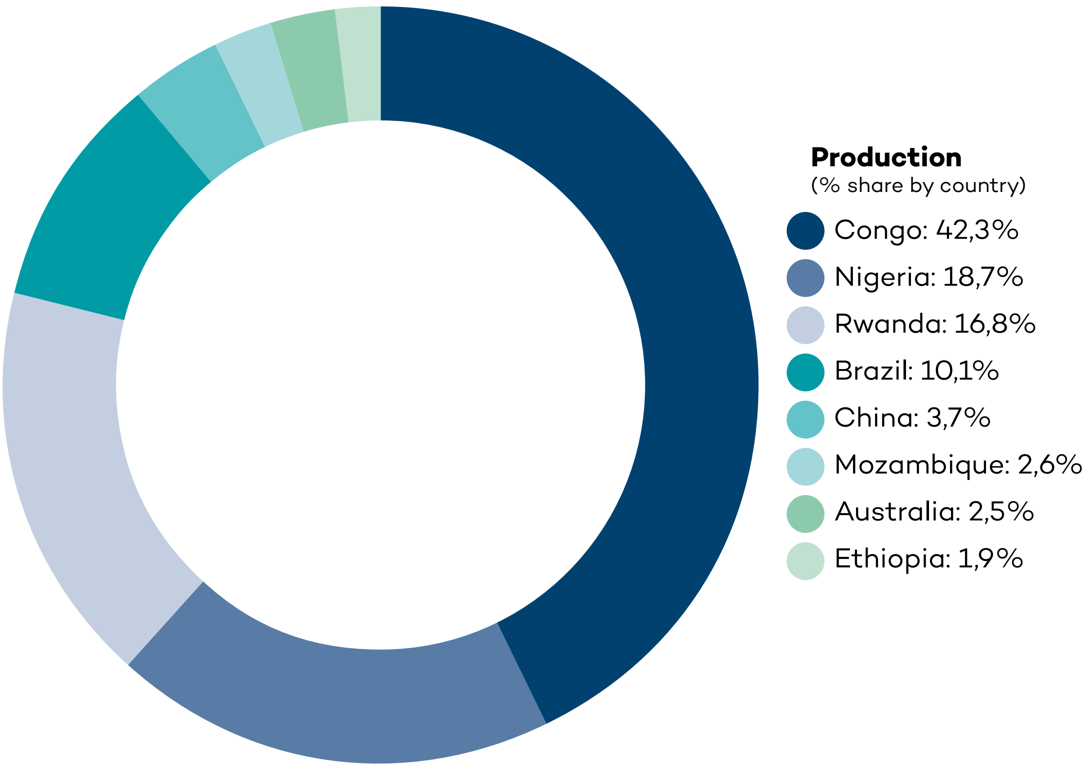


Figure 110: Tantalum: Production by Country



Source: USGS, 2025

Figure 111: Map for Authorization of Tantalum Exploration in Brazil (2025)

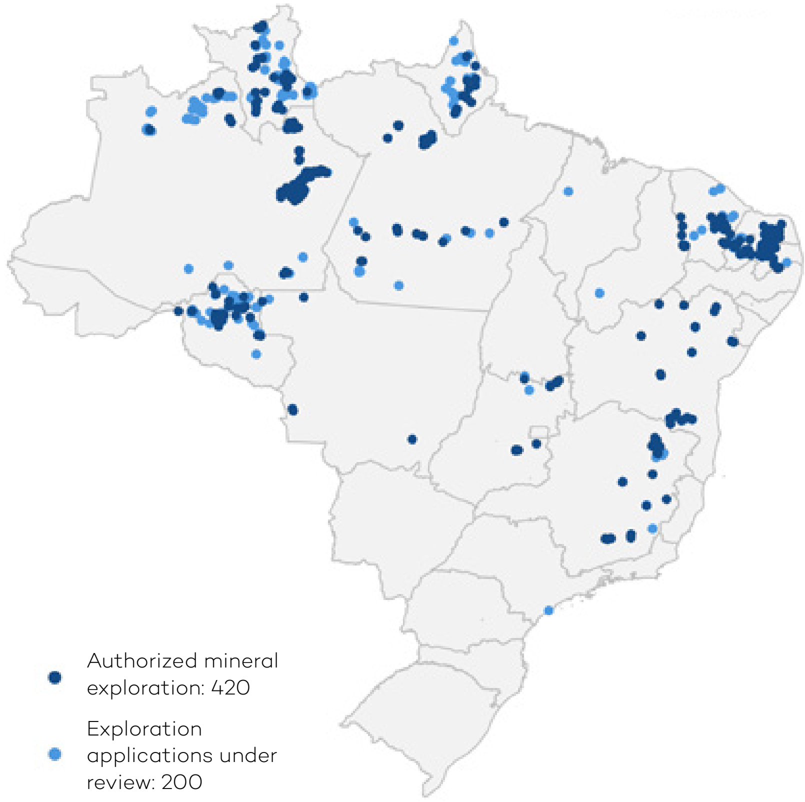


Figure 112: Map for Authorized Tantalum Mining Concessions in Brazil (2025)

Best Practices

Tantalum is a rare and strategic metal, widely used in technology and medicine due to its unique properties, such as high corrosion resistance, excellent electrical conductivity, and biocompatibility. It is extensively applied in prostheses and implantable devices, as well as in high-performance capacitors for compact and efficient electronics like smartphones and laptops[209].

The innovative Molten Oxide Electrolysis (MOE) process, used by Boston Metals[210] for selective tantalum and niobium recovery, is a disruptive technology with low carbon emissions. The process is modular and scalable according to projected production volume; increasing capacity simply requires adding new cells to the process.

Boston Metal Brazil operates in the recovery stage of the tantalum value chain using mining tailings. Besides contributing to sector decarbonization, its facility in Coronel Xavier Chaves (MG) employs molten oxide electrolysis technology with low CO_2 emissions, promoting circular economy practices in mineral processing.

A Primo Metais[211] is a Brazilian company specialized in purchasing and processing high-performance metal scrap, including tantalum. With over 20 years of experience, it excels in industrial waste management and proper material disposal, promoting sustainable practices while respecting the environment.

The tantalum processed by Primo Metais is known for its high corrosion and oxidation resistance, as well as extreme hardness and durability, making it widely used in electronics, aerospace, and medical industries.

A Recintech[212] specializes in water treatment and purification solutions using advanced technologies like ion exchange and activated carbon. Although not directly involved with tantalum, its expertise in ion exchange resins can be relevant for industrial processes involving rare and high-performance metals such as tantalum.

209 https://www.igneabr.com.br/noticias/informativos/o-minerio-de-tantalo-do-Brazil-um-potencial-para-a-industria-de-capacitores/

210 https://www.bostonmetal.com/news/zero-co2-steel-by-molten-oxide-electrolysis-a-path-to-100-global--steel-decarbonization/

211 https://primometais.com.br/tantalo/

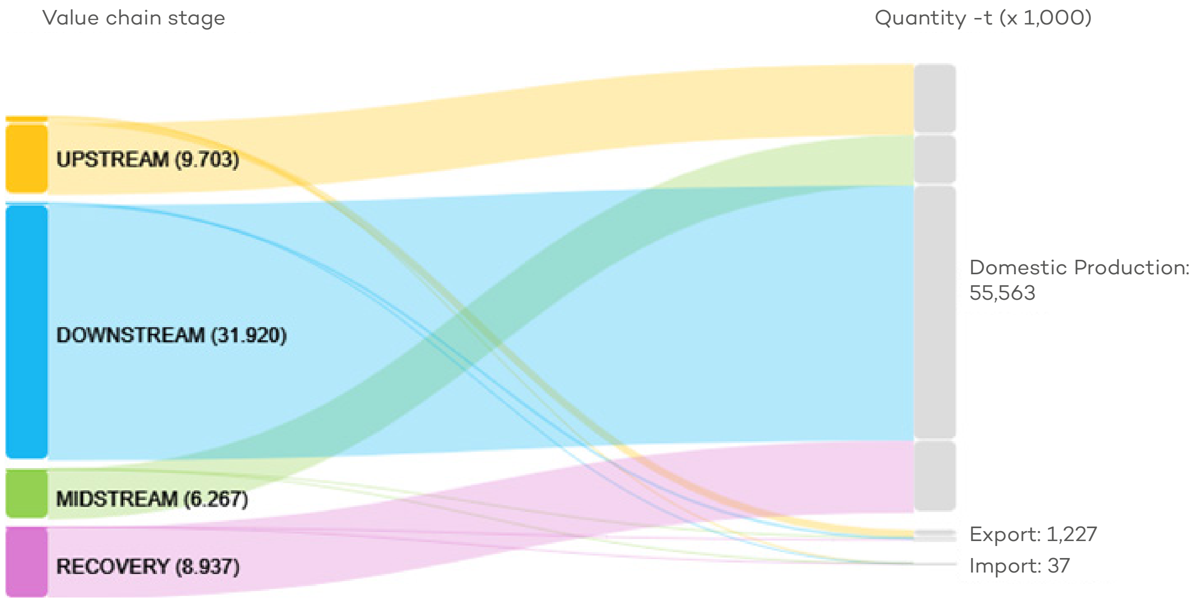
212 https://www.resintech.com/applications/reducao-de-tantalo/?lang=pt-br

Future Outlook

The tantalum market shows a promising future, driven by growing demand in the electronics, aerospace, and medical sectors. A notable trend is the replacement of solid capacitors with tantalum polymer capacitors, which offer greater efficiency.

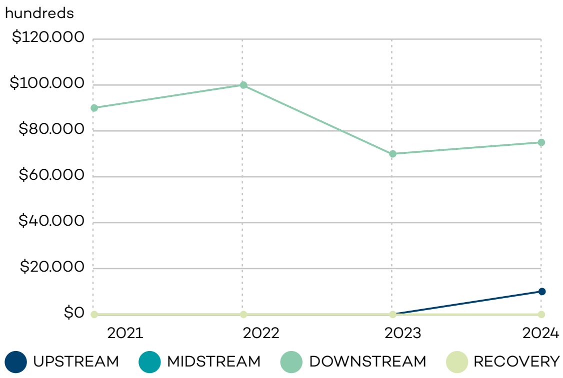
International regulations, such as the EU Conflict Minerals Regulation, are fostering more ethical and sustainable practices across the supply chain.

Figure 113: MFA of imported and exported volumes relative to national industrial production data according to the stages of the Tantalum value chain for the year 2022.

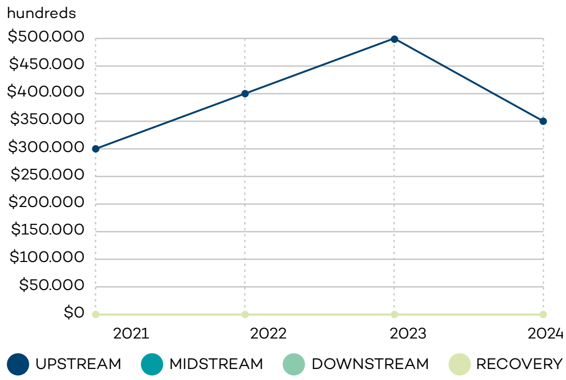


Source: Data obtained from the ComexStat Platform, 2025 (for the year 2022) and from Industrial Production data (SIDRA/IBGE) of 2022.

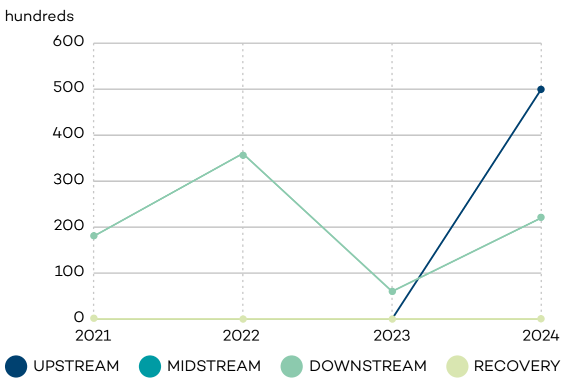
Graph 61. Tantalum: Import Value in US$ FOB (hundreds) between 2021 and 2024



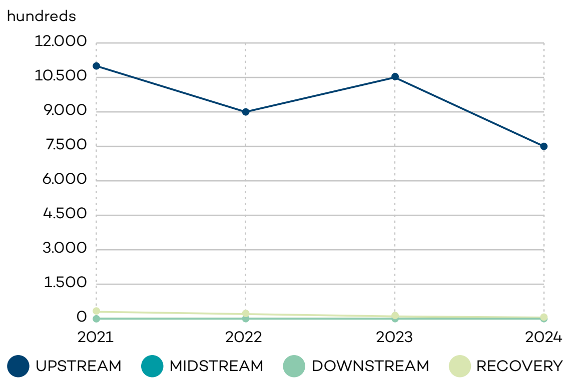
Graph 62. Tantalum: Export Value in US$ FOB (hundreds) between 2021 and 2024



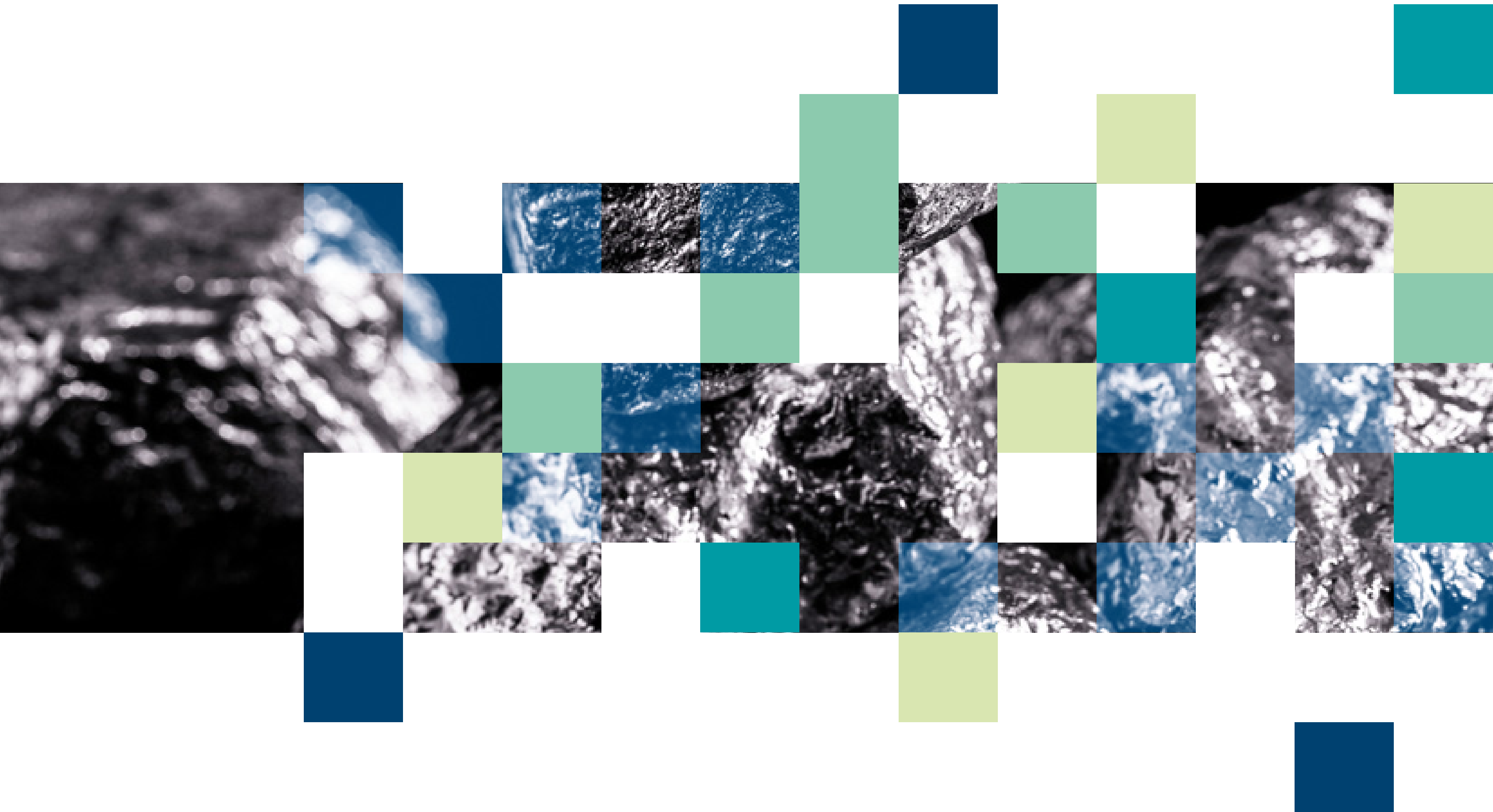
Graph 63. Tantalum: Import in Net Kg (hundreds) between 2021 and 2024



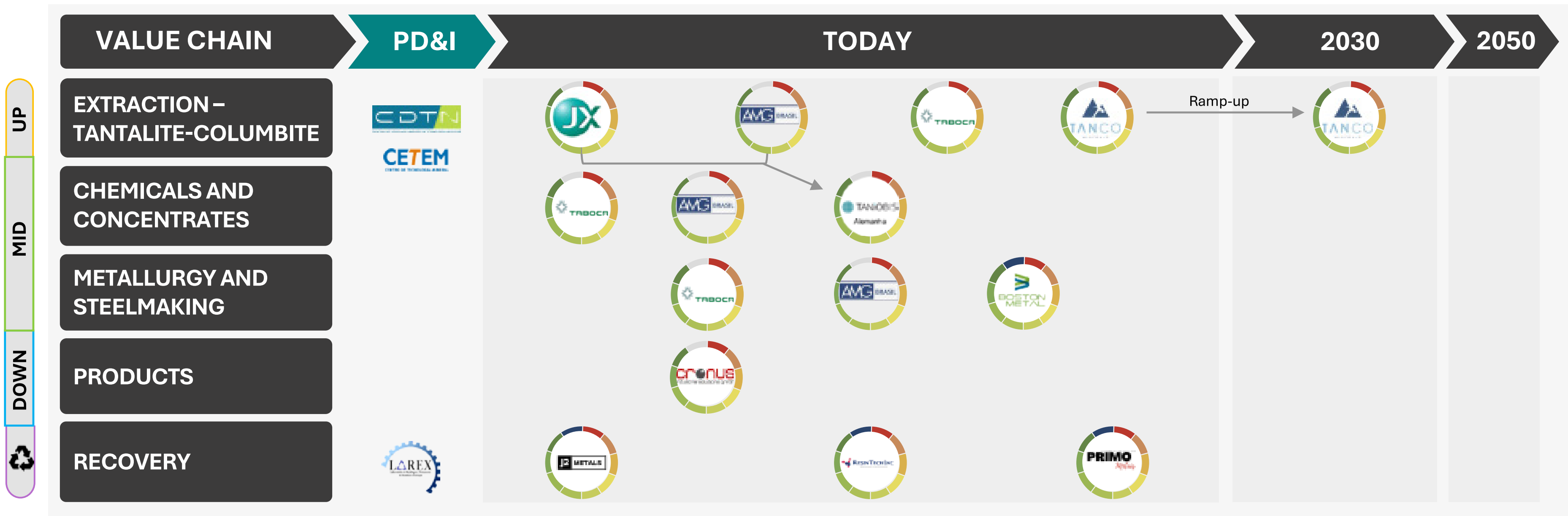
Graph 64. Tantalum: Export in Net Kg (hundreds) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.



TANTALUM



Sources:
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https://www.brasilmineral.com.br/noticias/investimento-de-r-500-milhoes-para-recuperar-metais-de-rejeitos-em-mg

TITANIUM

UPSTREAM MINING — Titanium ores

MIDSTREAM CHEMICALS/METALLURGY — Chemicals (oxides, salts), powders, and alloys

DOWNTREAM FINAL PRODUCTS — Works and products (pigments, wires, rods, etc.)

RECOVERY RECOVERY — Waste, residues, and ashes

Overview and demand

Titanium is part of the ferrous metals group, meaning it commonly forms alloys with iron as the main component. It is considered the 9th most abundant element in the Earth's crust (average 0.4–0.6%), mainly occurring in minerals such as ilmenite ($FeTiO_3$) and rutile (TiO_2), which are the main sources for titanium deposits. China (34%), Mozambique (17.5%), and South Africa (12%) are the largest producers of TiO_2 concentrates (ilmenite + rutile)[213], while the largest reserves are found in Australia, China, Norway, and South Africa[214]. Titanium has a relatively low density of 4.5 g/cm^3, making it light compared to many other metals, and a high melting point of 1,668°C, allowing it to maintain structural integrity at high temperatures. It is highly resistant to corrosion, strong in tensile strength, fatigue-resistant, tough, wear-resistant, and moderately ductile, meaning it can be drawn into wires or hammered into thin sheets without breaking. Titanium is also **biocompatible**, i.e., non-toxic to living tissues[215].

Its industrial applications include: aircraft components (engines, fuselages, landing gear, missiles) for aerospace; components for chemical and petrochemical industries; energy plants, offshore oil and gas platforms, and desalination plants; engine and exhaust components for the automotive industry; medical implants and instruments; electronics (smartphones, laptops, tablets); and pigments and paints.

213 El Khalloufi, M., Drevelle, O., Soucy, G. 2021. Titanium: An Overview of Resources and Production Methods. Minerals, 11, 1425. https://doi.org/10.3390/min11121425 https://www.mdpi.com/journal/minerals.

214 Buesa, A., Georgitzikis, K., Jakimów, M., Piñero, P., Maury, T., Latunussa, C., Pedauga, L., Samokhalov, V., Baldassarre, B., Mathieux, F., Rueda-Cantuche, J.M., Bilous, A., Notom, P., Tercero, L. 2025. Titanium metal in the EU: Strategic relevance and circularity potential. Publications Office of the European Union, Luxembourg, 2025, doi: 10.2760/5871804, JRC137082.

215 https://pt.geologyscience.com/minerais-de-min%C3%A9rio/min%C3%A9rio-de-tit%C3%A2nio/

Figure 114: Titanium: Reserves by Country (Ilmenite)

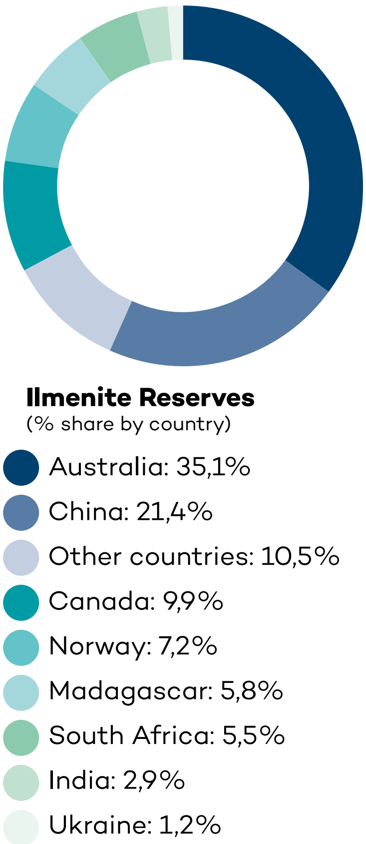


Figure 115: Titanium: Reserves by Country (Rutilo)

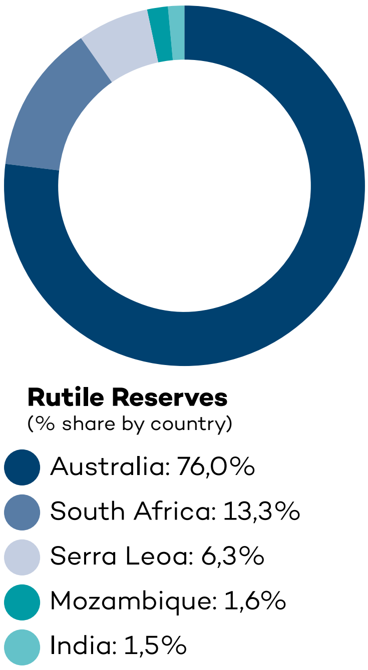


Figure 116: Titanium: Production by Country (Ilmenita)

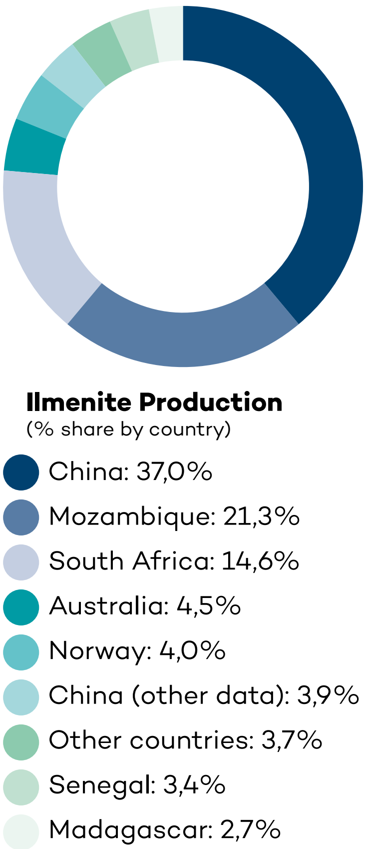
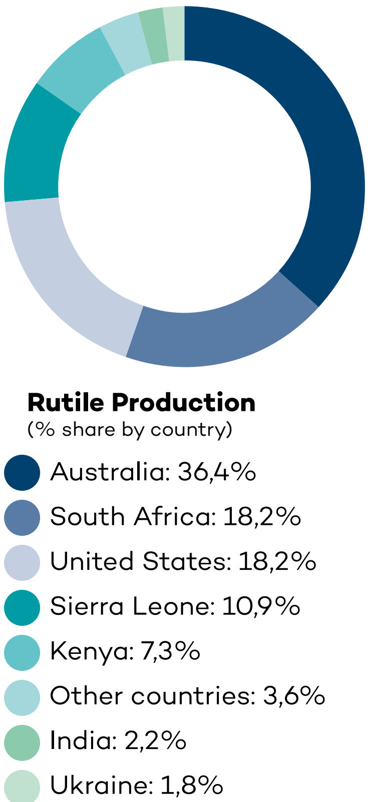


Figure 117: Titanium: Production by Country (Rutilo)



Source: USGS, 2025

Figure 118: Map for Titanium Exploration Authorization in Brazil (2025)

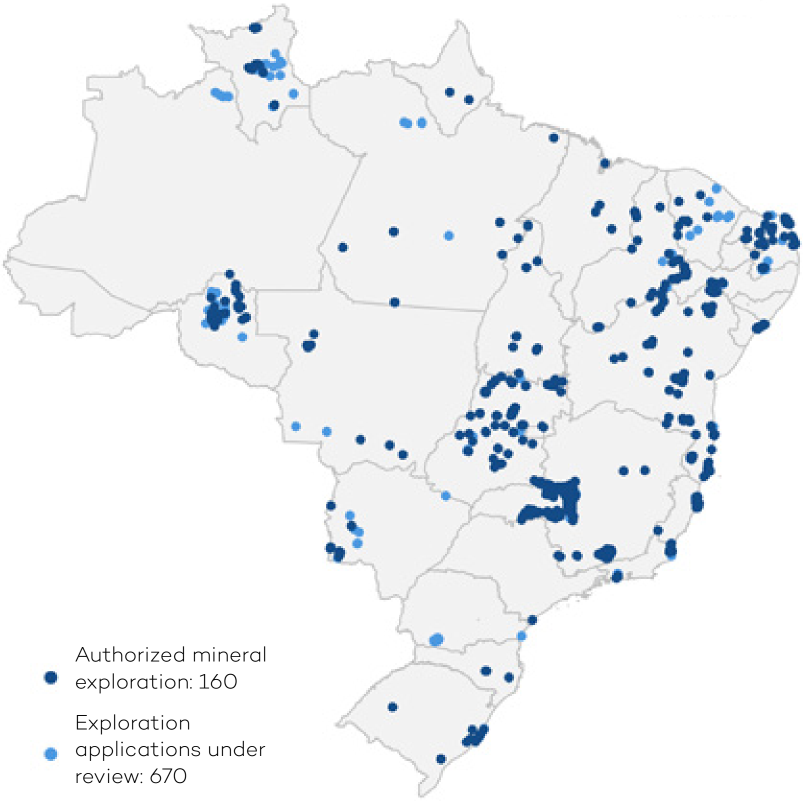


Figure 119: Map for Authorized Titanium Mining Concessions in Brazil (2025)

Titanium no Brazil

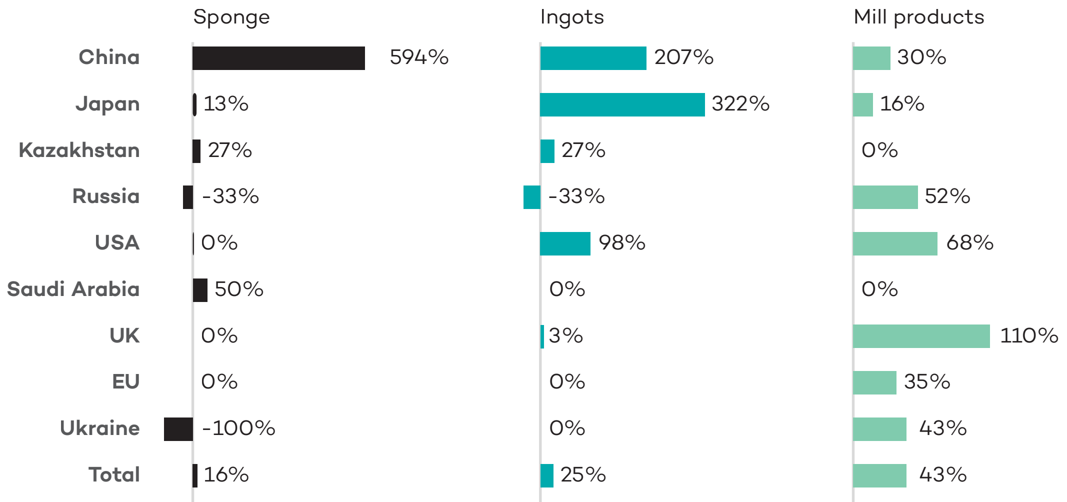
Brazil does not have significant production or reserves of TiO_2 concentrates. Currently, there is only one mine in operation, Maracás Menchen, operated by Largo Inc. in southern Bahia. The mine primarily produces vanadium through the extraction of vanadium-bearing magnetite (Fe_3O_4) concentrates, but it also produces TiO_2 through ilmenite recovery (estimated 25,000 to 35,000 tons in 2025) as a byproduct. The Ti–V ore mined at Maracás Menchen has estimated reserves of 101 Mt @ 0.56% V_2O_5 and 7.52% TiO_2. The beneficiation of this ore results in 20 Mt of magnetic concentrate, from which 435 Kt of V_2O_5 and 7 Kt of TiO_2 are recovered.

Future Outlook

The global demand for titanium is expected to continue growing in the coming years, with 85% of products directed to the civil and aerospace aviation industries, defense, and the chemical sector.

The main global players in the supply–demand–market relationship are the United States (major suppliers of titanium to the EU), China (largest reserves and production), Russia (largest supplier of titanium to the aerospace sector, but also an importer of the metal), Kazakhstan, Japan, and Saudi Arabia (important suppliers of manufactured products), and Ukraine (main supplier of titanium to the EU). The Russia–Ukraine conflict is expected to disrupt the titanium supply chain, forcing a repositioning of market relationships among producers, suppliers, and consumers: the decrease in metal exports from Ukraine to the EU is offset by Kazakhstan, Japan, and Saudi Arabia redirecting their exports to the EU, USA, and South Korea, while the decrease in Russian exports of sponge ingots and alloys is compensated by the USA and Kazakhstan (Fig. 86).

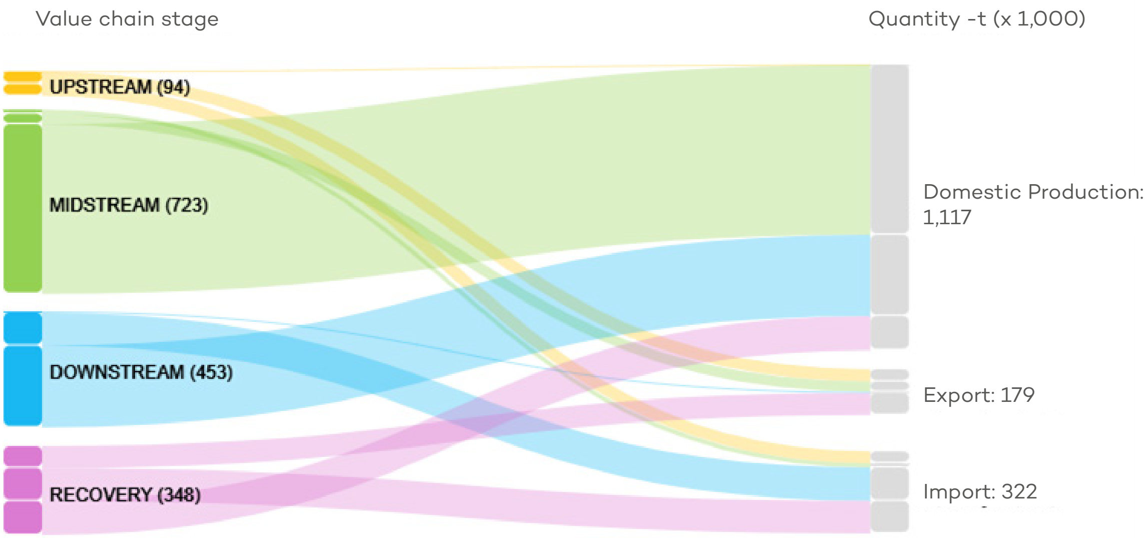
Figure 120: Variation (in %) of global exports of various types of titanium products following Russia's invasion of Ukraine.



Source: Buesa, *et al.*, 2025.

Brazil is currently outside the core group of major TiO2 concentrate producers, as well as among the largest holders of reserves. However, there is geological potential for the country to increase its reserves and production, depending on legal agility, availability of capital for ongoing projects, and the adoption of sustainable practices. Currently, the ANM has registered 1,278 titanium processes in the research authorization phase, involving 346 companies, and 221 processes in various stages of mining rights and concessions, involving 113 companies[216]. The difference between the data on the Mining Concessions Map and Exploration Authorizations is due to the existence of other types of mining titles.

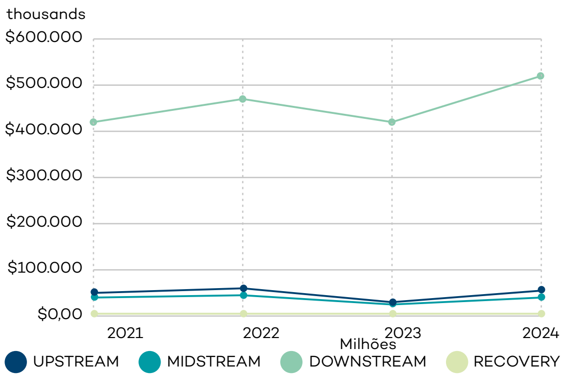
Figure 121: MFA de volume importado e exportado, em relação aos dados de produção industrial nacional segundo as etapas da cadeia de valor do Titanium para o ano de 2022.



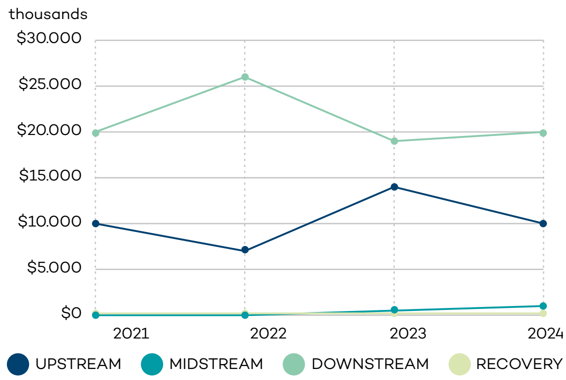
Source: Data obtained from the ComexStat Platform, 2025 (year 2022) and from Industrial Production data (SIDRA/IBGE) for 2022.

216 Interactive Brazilian Mineral Yearbook. National Mining Agency (ANM).

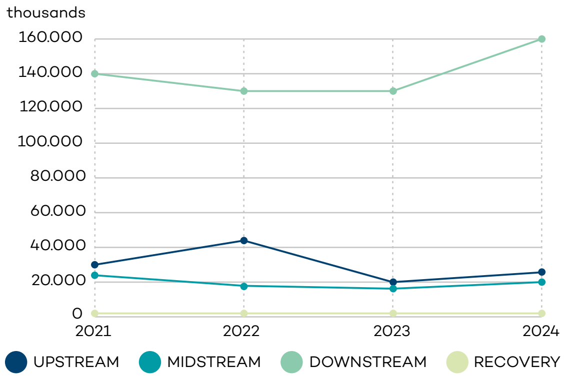
Graph 69. Titanium: Imports in Value US$ FOB (thousands) between 2021 and 2024



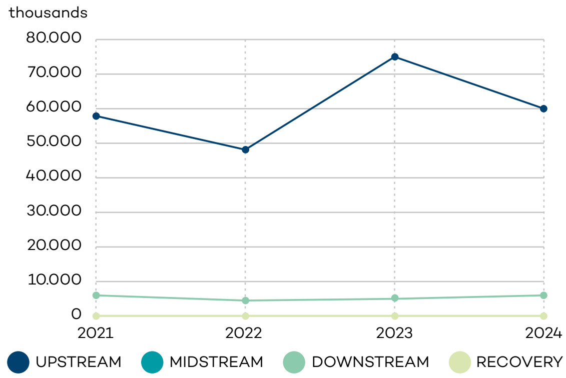
Graph 70. Titanium: Exports in Value US$ FOB (thousands) between 2021 and 2024



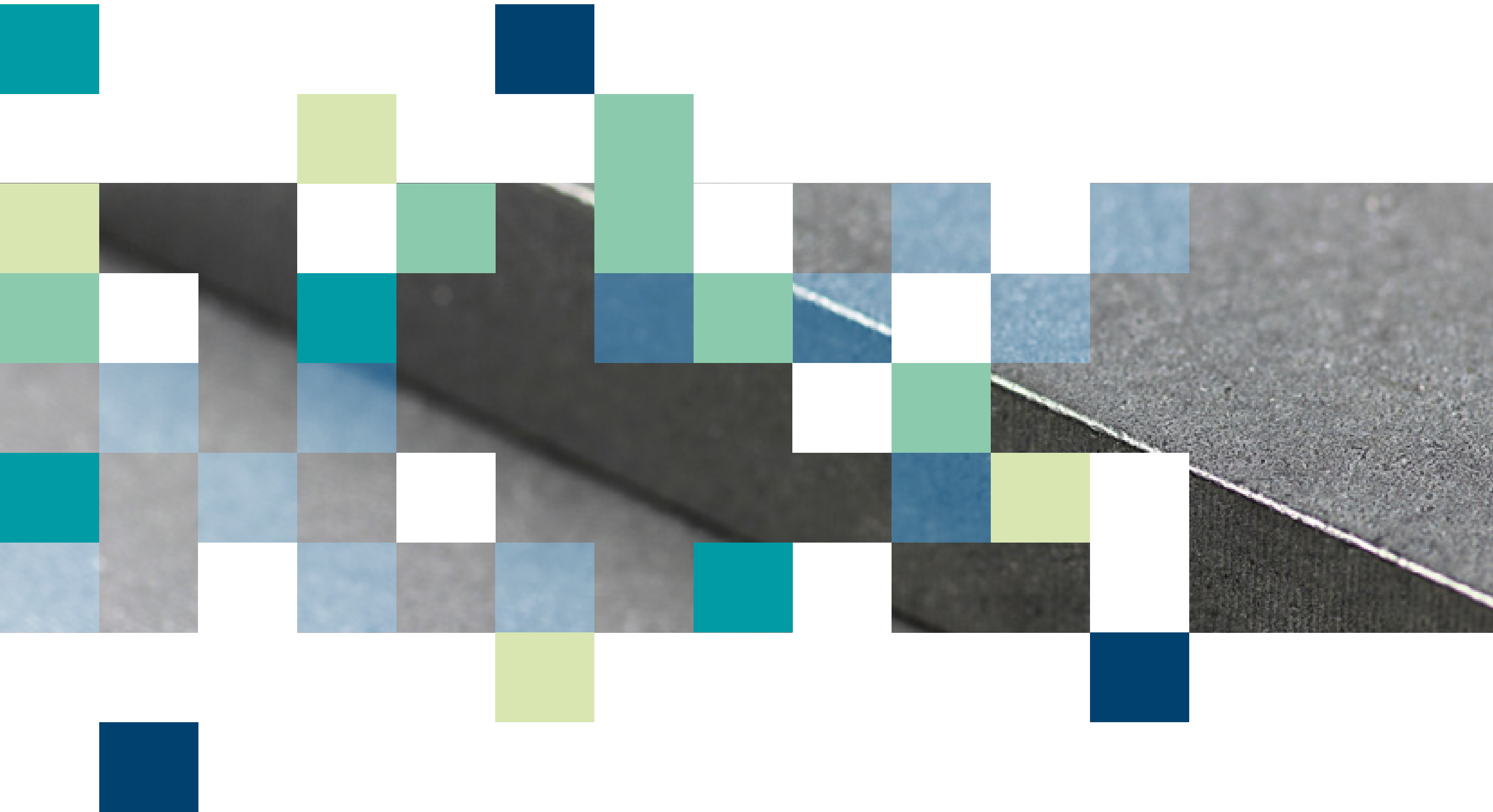
Graph 71. Titanium: Imports in Net Kg (thousands) between 2021 and 2024



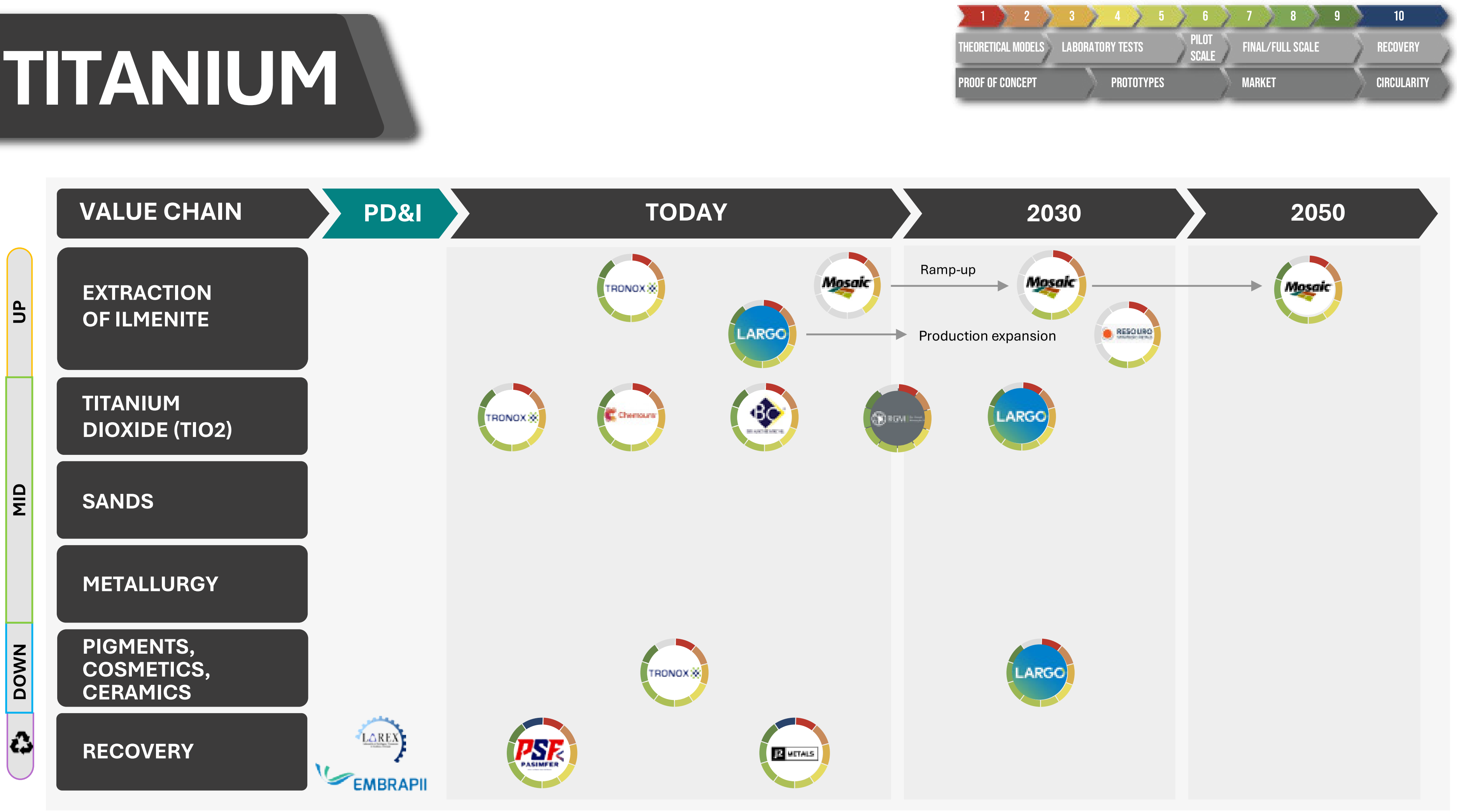
Graph 72. Titanium: Exports in Net Kg (thousands) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025



TITANIUM



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CETEM | IBRAM BRAZILIAN MINING

Zinc

UPSTREAM MINING — Zinc ores

MIDSTREAM CHEMICALS/METALLURGY — Chemicals (oxides, chlorides, sulfates, salts, etc.), concentrates, additives, and alloys

DOWNSTREAM FINAL PRODUCTS — Works, artifacts, products (components for batteries and cells)

RECOVERY RECOVERY — Waste, residues, and ashes

Overview and demand

Zinc (Zn) is considered a base metal of great importance to humanity due to its ability to combine with other metals, enabling the production of various metal alloys, and its high malleability, which facilitates shaping for different applications. These attributes make zinc a strategic element for multiple sectors of the economy.

Although it ranks 24th among the most abundant elements in the Earth's crust, zinc is not found in its free metallic form, as occurs with copper (Cu). In general, it occurs combined with other elements, predominantly in minerals such as sulfides (sphalerite), oxides (zincite and franklinite), and silicates (willemita)[217].

These characteristics make zinc one of the most widely used metals in the world, primarily known for its application in galvanization—a process that protects steel against corrosion—as well as in the production of metal alloys (such as brass), chemicals, batteries, fertilizers, and the healthcare sector.

In 2023, according to the International Lead and Zinc Study Group (ILZSG)[218], global zinc concentrate production (contained metal) reached 12.2 million tonnes (Mt), representing a 2.0% decrease compared to the previous year. During the same period, global primary zinc metal production was 12.1 Mt, while secondary (recycled) zinc metal production reached 1.8 Mt[219].

Global refined zinc consumption totaled 13.6 Mt in 2023, showing a 1.0% increase compared to 2022. The main consuming countries were China (7.0 Mt), the United States (0.9 Mt), and India (0.7 Mt).

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217 MME - Ministry of Mines and Energy. Zinc Profile – Development of Studies for the Elaboration of the Duodecennial Plan (2010–2030) of Geology, Mining, and Mineral Transformation, Product 39 – Zinc Chain. Brasília, 2009.

218 ILZSG - International Lead and Zinc Study Group - https://www.ilzsg.org/

219 ANM – National Mining Agency. Brazilian Mineral Summary 2024, base year 2023. https://www.gov.br/anm/pt-br/assuntos/economia-mineral/publicacoes/sumario-mineral/sumario-mineral-Brazileiro-2024/Gold--2024-ano-base-2023.pdf.

Regarding mineral reserves, data from the United States Geological Survey217[220] indicate that global zinc reserves (contained) totaled 224.8 Mt, primarily distributed among Australia (66 Mt), China (44 Mt), Russia (25 Mt), Peru (21 Mt), Mexico (14 Mt), and other countries (53.0 Mt).

Brazil's national zinc concentrate production in 2023 was 504.7 thousand tonnes (kt) of zinc concentrate, with 194.1 kt of contained metal, ranking the country as the 13th largest global producer, representing 1.6% of global production, and the third largest producer in Latin America, with significant operations in Minas Gerais, Mato Grosso, and Rondônia.

In terms of consumption, Brazil recorded 209.4 kt of refined zinc, equivalent to 1.5% of global consumption, ranking 12th among global consumers, although reflecting a 3.5% decrease compared to 2022. As for national reserves, Brazil's proved and probable zinc reserves (contained) were estimated at 3.7 Mt, corresponding to 1.7% of global reserves, representing an 18.0% increase compared to the previous year.

The global zinc market, estimated at 13.58 million tonnes in 2024, is expected to reach 14.68 million tonnes by 2029, with a compound annual growth rate (CAGR) of over 1.5% during the period. After the negative impacts of the COVID-19 pandemic, which caused production interruptions and price fluctuations, the market recovered, driven by the resumption of construction and electronics industries.

Currently, demand is mainly supported by the application of zinc in the construction, electronics, and automotive sectors, despite challenges posed by environmental regulations and competition from other metals[221].

220 United States Geological Survey (USGS). Mineral Commodity Summaries 2024. Reston, Virginia: U.S. Department of the Interior, U.S. Geological Survey, 2024 - https://pubs.usgs.gov.

221 Mordor Intelligence. Mercado Zinc - Crescimento, tendências, impacto COVID-19 e previsões (2024-2029) - https://www.mordorintelligence.com/pt/industry-reports/zinc-market

Figure 122: Zinc: Reserves by Country

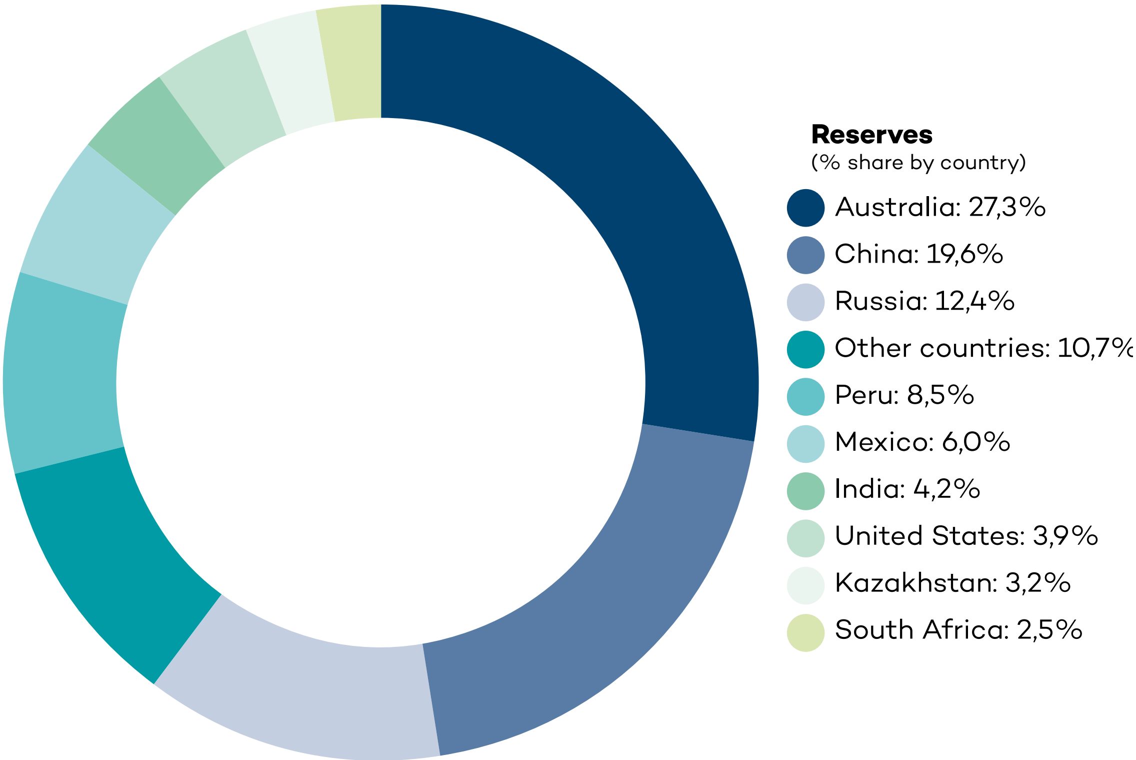
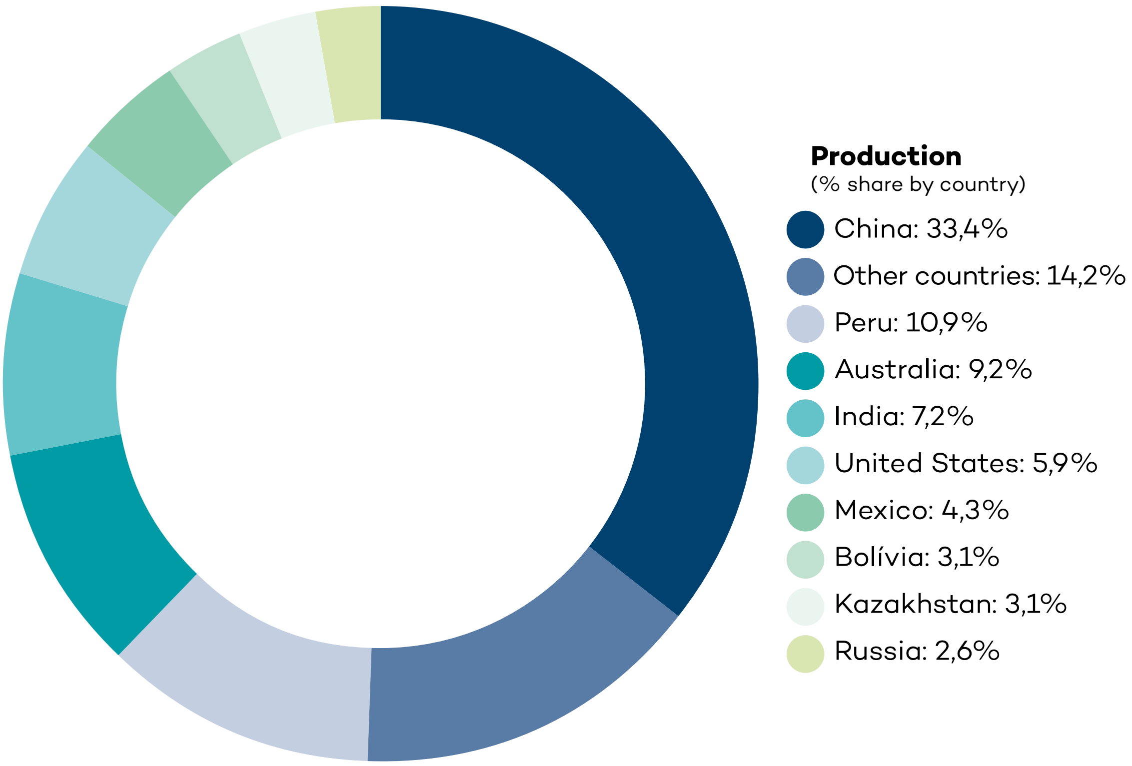


Figure 123: Zinc: Production by Country



Source: USGS, 2025

Figure 124: Map for Zinc Exploration Authorization in Brazil (2025)

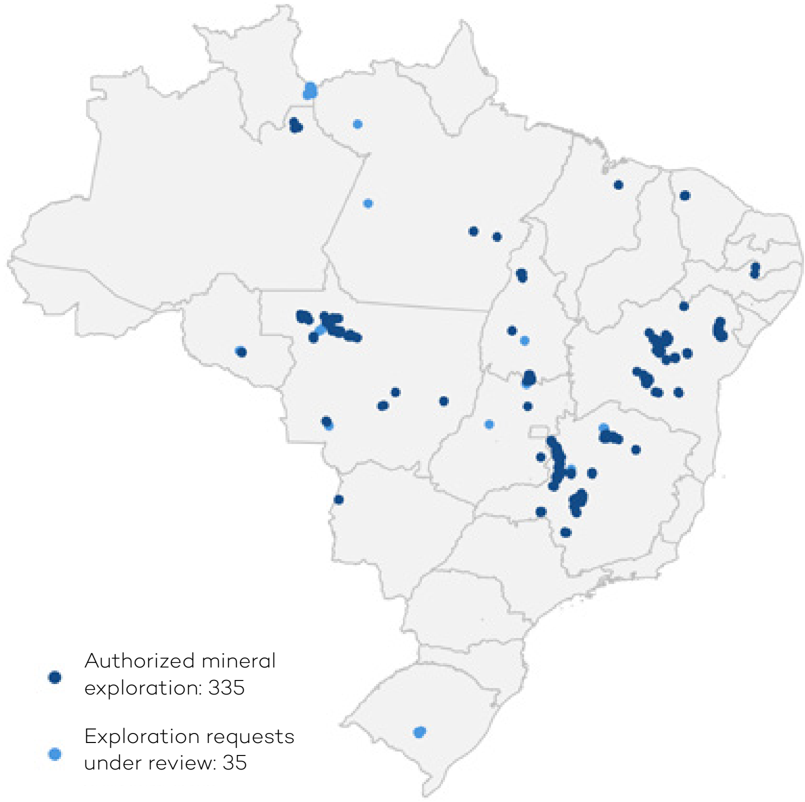


Figure 125: Map for Authorized Zinc Mining Concessions in Brazil (2025)

Best Practices

The zinc mining industry has evolved to incorporate practices aimed at promoting greater operational efficiency, environmental sustainability, and social responsibility, in order to meet the demands of a globalized market and ensure the sector's competitiveness.

Modern practices in zinc mining and processing focus on sustainability, technological innovation, and efficiency, highlighting:

- **Zinc recycling:** Approximately 30% of the zinc consumed globally comes from recycling, with increasing recovery from metallic waste. The incorporation of advanced materials and the development of emerging technologies have expanded opportunities for sustainable growth in the sector.

- **Improved energy efficiency:** Mining operations have been adopting more efficient flotation processes and strategies to reduce energy consumption in smelting.

- **Technological advances:** The application of automation, remote sensing, digitization, and advanced control systems has enabled more efficient extraction and processing of ores, while increasing safety and reducing environmental impacts.

- **Sulfur capture and reuse technologies:** In zinc processing, sulfur is captured and converted into sulfuric acid, significantly reducing pollutant emissions.

- **Decarbonization technologies:** The growing use of renewable energy in operations and the development of carbon capture and storage solutions align the sector with global climate change mitigation trends.

- **Use of artificial intelligence and big data:** Predictive analytics are employed to optimize extraction processes, reduce operational losses, and enhance operational safety.

Compliance with increasingly strict environmental regulations drives the sector to prioritize investments in clean technologies, proper waste management, rehabilitation of degraded areas, and continuous monitoring of water and air quality. In this context, adopting environmental and sustainable practices has become a strategic priority. There is growing demand for responsible mining processes that reconcile biodiversity conservation with strong relationships with local communities, ensuring the maintenance of a social license to operate.

Additionally, effective supply chain management, adherence to occupational health and safety best practices, and diversification of zinc applications are essential factors for sector competitiveness. The expansion of markets for recycled zinc, the use of advanced materials, and the development of new technologies reinforce the industry's positioning toward sustainable growth.

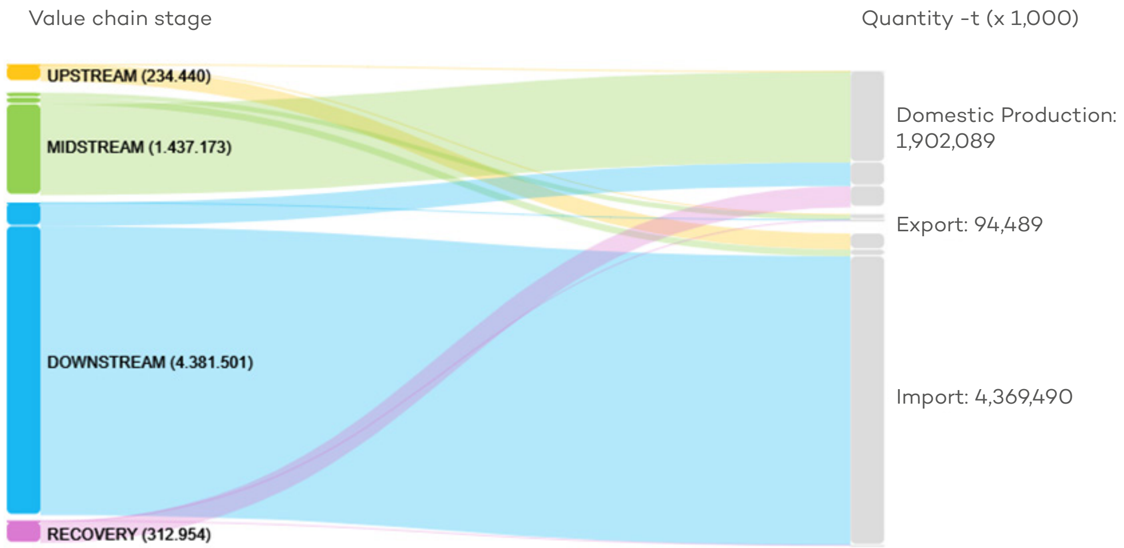
Future Outlook

Increasing urbanization, industrial development, and the rising use of zinc in emerging technologies, such as zinc-based batteries, indicate new opportunities for global market growth. The Asia-Pacific region leads global consumption, with China, India, and Japan as key players. The incorporation of zinc in structural elements and metallic coatings in construction, due to its corrosion resistance, durability, and aesthetic appeal, underscores its importance in urban and residential infrastructure projects. Globally, the construction industry is expected to continue growing over the next 15 years, consolidating the sector as the main driver of zinc market expansion in the medium and long term.

With the growth of renewable energy industries and the pursuit of more sustainable energy storage technologies, a significant increase in zinc demand is expected in the coming years. Zinc is also the subject of intensive research for the development of zinc-air and zinc-ion batteries, lower-cost alternatives with greater durability and lower environmental impact compared to lithium-ion batteries[222].

In addition, carbon-neutral mining practices and greater incorporation of recycled zinc are expected to become standard requirements for market participants. Brazil, with its significant reserves and an adapting regulatory environment, has the opportunity to expand its participation in this new scenario, aligning with global best practices.

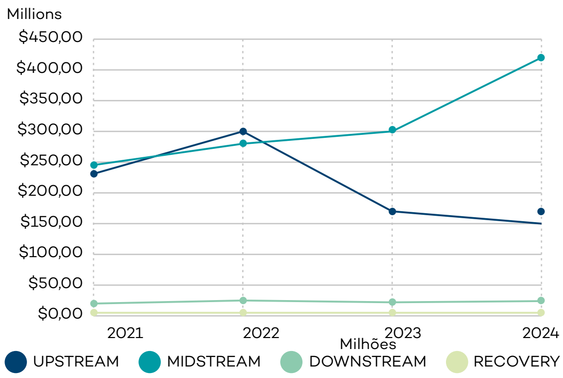
Figure 126: MFA de volume importado e exportado, em relação aos dados de produção industrial nacional segundo as etapas da cadeia de valor do Zinc para o ano de 2022.



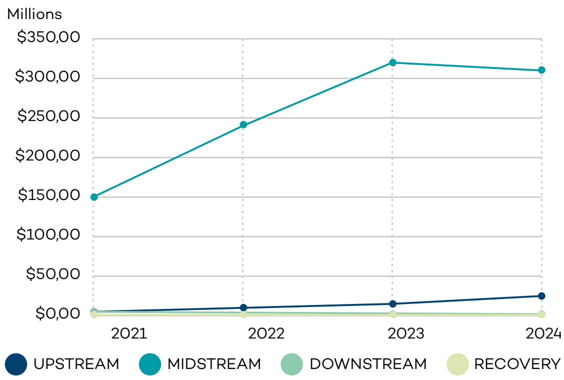
Source: Data obtained from the ComexStat Platform, 2025 (year 2022) and from Industrial Production data (SIDRA/IBGE) of 2022.

222 Tang, L.; Peng, H.; Kang, J.; Chen, H.; Zhang, M.; Liu, Y.; Kim, D. H.; Liu, Y.; Lin, Z. Zn-based batteries for sustainable energy storage: strategies and mechanisms. Chem. Soc. Rev. 2024, 53, 4877–4925. DOI:10.1039/D3CS00295K.

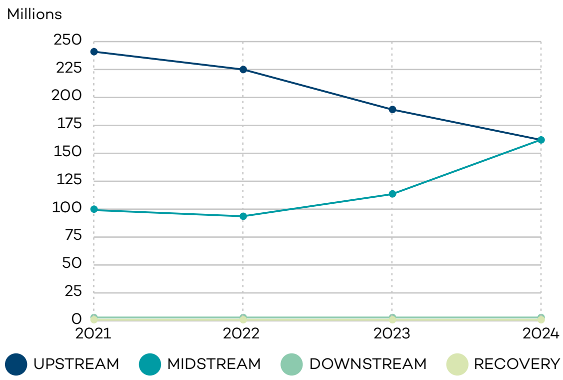
Graph 73. Zinc: Import in US$ FOB value (millions) between 2021 and



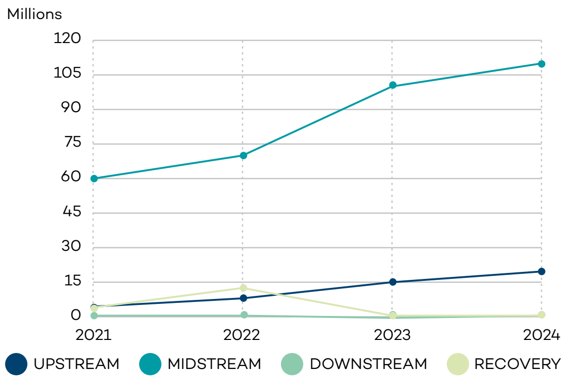
Graph 74. Zinc: Export in US$ FOB value (millions) between 2021 and 2024



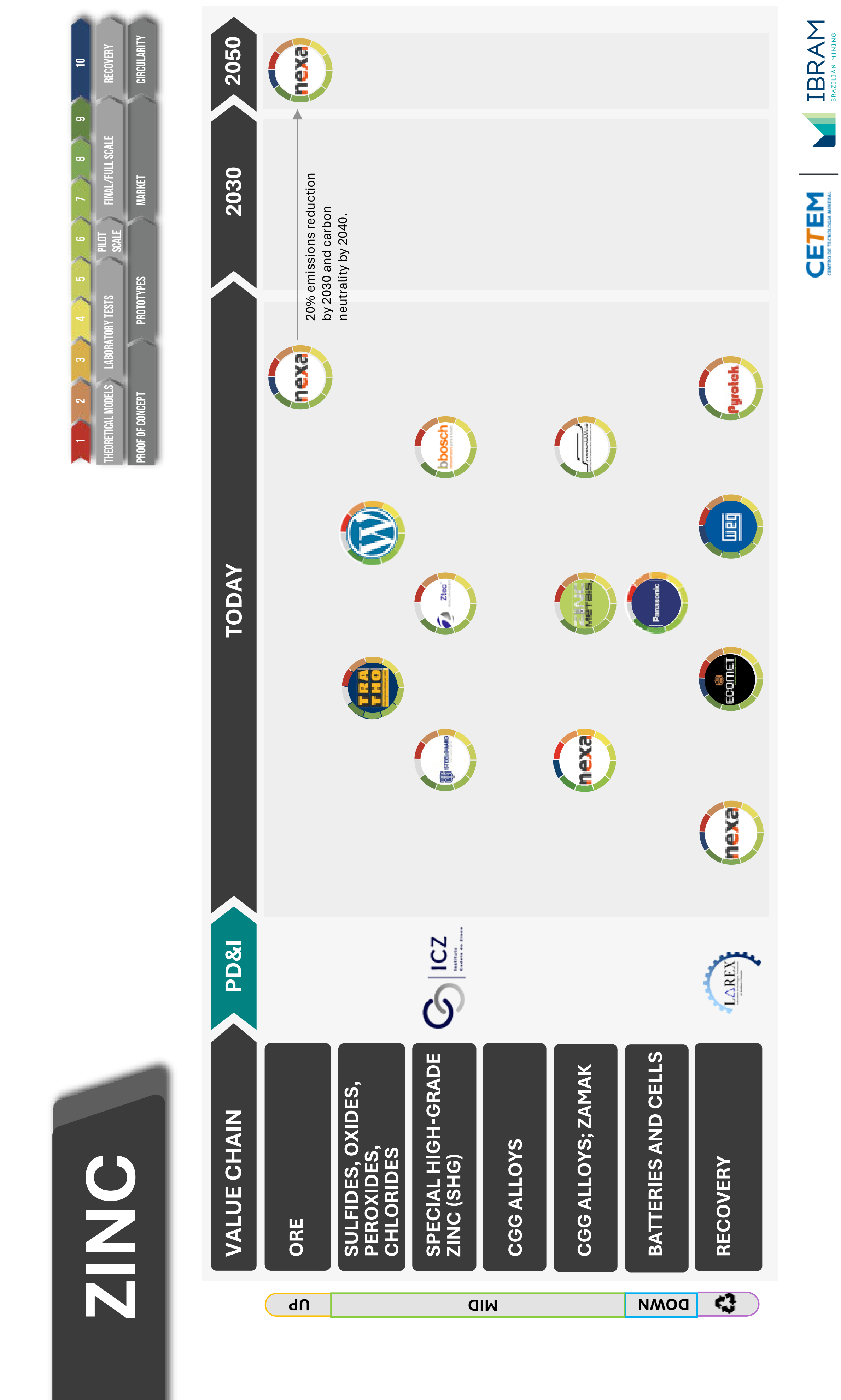
Graph 75. Zinc: Import in net kg (millions) between 2021 and 2024



Graph 76. Zinc: Export in net kg (millions) between 2021 and 2024



Source: Data obtained from the ComexStat Platform, 2025.


ZINC
1
2
3
4
5
6
7
8
9
10
THEORETICAL MODELS
LABORATORY TESTS
PILOT SCALE
FINAL/FULL SCALE
RECOVERY
PROOF OF CONCEPT
PROTOTYPES
MARKET
CIRCULARITY
VALUE CHAIN
PD&I
TODAY
2030
2050
ORE
SULFIDES, OXIDES, PEROXIDES, CHLORIDES
SPECIAL HIGH-GRADE ZINC (SHG)
CGG ALLOYS
CGG ALLOYS; ZAMAK
BATTERIES AND CELLS
RECOVERY
20% emissions reduction by 2030 and carbon neutrality by 2040.
UP
MID
DOWN

IBRAM
BRAZILIAN MINING

IBRAM
BRAZILIAN MINING

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