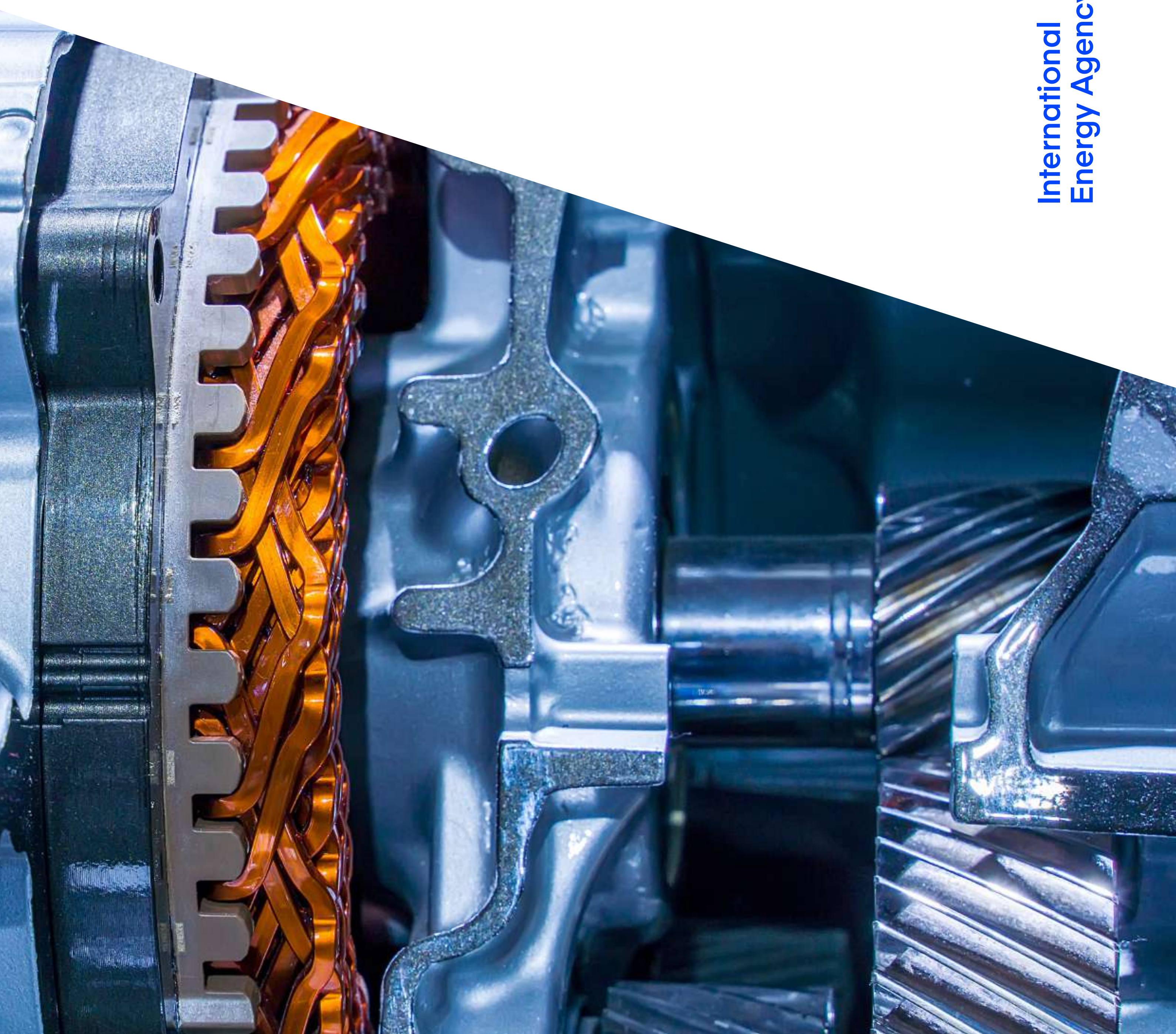
Rare Earth Elements

Pathways to secure and diversified supply chains

International Energy Agency



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Abstract

The critical role of rare earth elements in strategic applications, ranging from energy technologies and advanced electronics to aerospace and defence systems, combined with their highly concentrated supply chains, has elevated their importance in both energy and broader economic security discussions in recent years. This report assesses the current state of the rare earth elements market, examining demand and supply dynamics and key technological developments. It analyses the full value chain from mining to permanent magnet production, evaluates vulnerabilities across supply chains, and highlights the implications of potential supply disruptions. Based on these analyses, the report outlines eight targeted policy recommendations that can pave the way for more secure, diversified and resilient rare earth element supply chains.

The analysis is founded on the work of the IEA Critical Minerals Security Programme and aims to inform the discussions at the G7 meetings under the French Presidency in 2026.

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Executive summary

Rare earth elements have rapidly moved to the forefront of the energy and economic policy agenda

Rare earth elements play a crucial role in a wide range of strategic applications, from energy, transport and artificial intelligence (AI) technologies to aerospace, medical and defence systems. The wide range of applications, combined with highly concentrated supply chains, has elevated their importance in both energy and broader economic security discussions. Though relatively plentiful in the Earth's crust, this set of 17 elements have garnered the label "rare" because economically viable concentrations are uncommon and they are seldom found in pure form. Their chemical similarities make them hard to separate during the extraction process, but their different physical and magnetic properties give individual rare earth elements distinct value for various technological applications.

Permanent magnets represent the fastest-growing and most strategically important applications, accounting for around 95% of total rare earth consumption by value. High-performance neodymium-iron-boron (NdFeB magnets) – primarily composed of neodymium and praseodymium, often with dysprosium and terbium as performance-enhancing additives – are among the strongest permanent magnets in the industry. These magnets underpin a wide range of critical technologies, including electric vehicles (EVs), wind turbines, industrial motors and AI data centres, as well as medical, aerospace and defence applications.

Demand for magnet rare earth elements (neodymium, praseodymium, dysprosium and terbium) has doubled since 2015 and is set to expand further by a third by 2030 under today's policy settings, thanks to growing electrification and the rapid deployment of new energy technologies such as EVs and wind turbines. Growth in automation, robotics and digital technologies plays an increasing role in driving demand beyond 2030, as permanent magnets enable precision motion control, miniaturisation and energy efficiency improvement for these applications.

The supply of magnet rare earths remains among the most geographically concentrated of all critical minerals

The rare earth value chain spans a series of technically demanding stages, each adding distinct value as materials move from geological deposits to refined products and permanent magnets. These stages include extraction, beneficiation, chemical upgrading, separation into oxides, metal refining, alloying and magnet manufacturing. After extraction, ores are crushed and milled to liberate minerals, which are then concentrated. Separation – the technical core of processing – converts mixed rare earth feeds into individual oxides. Refined oxides are then transformed into metals, and then into alloy powders, the primary inputs for magnet production.

Among the strategic minerals analysed by the International Energy Agency (IEA), rare earths exhibit one of the highest levels of geographical concentrations across the value chain. In 2024, the People's Republic of China (hereafter, "China") accounted for 60% of global mined production of magnet rare earths. For refining, the level of concentration is more pronounced, as the country represented 91% of global refined output. Its share is even higher for permanent magnet production. In 2005, China accounted for around 50% of the production of sintered permanent magnets, but its share expanded significantly to reach 94% in 2024. China's extensive magnet production activity generates substantial economies of scale and provides a strong and stable demand base for upstream raw materials.

Export controls announced in 2025 brought the risks of highly concentrated supply chains into sharp reality

In April 2025, China introduced export controls on seven heavy rare earth elements, related compounds and magnets. Export volumes of these rare earth elements and permanent magnets containing them fell sharply in April and May, leaving many automakers in the United States, Europe and beyond struggling to source permanent magnets. Some automakers were forced to cut utilisation rates or even temporarily shut down production. Licences were eventually granted and export volumes recovered in the following months, but a significant premium remained for magnets produced outside China, reflecting an increasingly prominent role of security considerations in sourcing decisions.

In October 2025, China announced major new rare earth export controls, posing significant risks to global economic security. The list of rare earth elements subject to controls was expanded to include five additional elements. Beyond expanded controls on individual elements and processing equipment and technologies, these controls included a new licence requirement covering the trade of any internationally made "parts, components and assemblies" containing Chinese-sourced rare earth materials or produced using Chinese technologies. This new constraint marked a major escalation of scope, with significant potential implications across a wide range of strategic downstream sectors, including energy, transport, defence, aerospace, semiconductors and data centres. In November 2025, these controls were suspended for a year. In January 2026, China tightened export controls on dual-use goods destined for Japan, suggesting that underlying risks to economic security remain.

If these rare earth export controls were implemented in full, the economic value of downstream production at risk would reach USD 6.5 trillion per year for countries outside China. The United States and Europe face the greatest exposure with potential direct economic losses estimated at over USD 1.5 trillion each. The automotive sector is set to face the single greatest impact with over USD 3 trillion in potential direct losses outside China, followed by electronics and other transport (aviation, trucks and trains) sectors. Additional vulnerable sectors include defence and data centres. The impacts of a disruption extend far beyond the loss of direct product sales, given the wide range of high-value services that depend on rare earth-enabled products.

Achieving diversified rare earth supplies requires significant expansion of new capacities, particularly in refining and magnet production

A fundamental starting point for diversifying rare earth supply chains is a clear understanding of demand outside the dominant supplier, both current and future. Without this, it is difficult to take a view on the need for capacity expansion, gauge the scale of required investment, and agree targets or coordinate policy efforts. Under today's policy settings, demand for magnet rare earths outside China is projected to rise by 50% by 2035, with the largest contribution coming from EV deployment. However, existing ex-China capacity across mining, refining and magnet manufacturing falls short of meeting these needs. Even with planned expansions, expected production from existing capacities meets only a fraction of projected needs in 2035: it accounts for about 50% of the demand for mining, 25% for refining and well below 20% for magnets.

Meeting the projected demand outside the dominant supplier from diversified capacities would require significant expansion in mining, refining and magnet production capacity – by a factor of two, four and six respectively, on top of planned expansions from existing projects in the case of full coverage. Several planned projects across the supply chain could help narrow supply gaps if successfully implemented. However, even with these projects, existing and announced capacities in geographically diverse regions would remain insufficient, highlighting the need for additional greenfield developments, particularly in refining and magnet manufacturing.

The project pipeline across different stages of the supply chain is uneven. Existing and announced projects point to a notable expansion of magnet rare earth supply chains outside China in the coming decade. Mining capacity shows the largest potential increase, crossing 50 kilotonnes (kt) of rare earth element content by 2035, led by Australia and the United States, with additional contributions from Brazil, Lao People's Democratic Republic, Tanzania, India and other smaller producers. By contrast, refining and separation capacity amounts to less than 40 kt, with activity concentrated in Malaysia and the United States, followed by Australia, Viet Nam, Japan, the United Kingdom, France and Estonia. Downstream capacity is even more limited: cumulative planned production of metals, alloys and finished magnets from projects announced as of early 2026 amounts to around 18 kt on a rare earth element content basis, representing only about one third of diversified mining capacity. This reflects a relatively modest pipeline led by the United States, and with contributions from Europe, Japan, Korea and Viet Nam.

Magnet production remains the main bottleneck for supply diversification. While resource development is advancing in several regions, the slower build-out of refining and magnet production is a key concern. Without accelerated investment in these parts of the value chain, many regions are likely to remain dependent on the dominant producer for processing and magnet manufacturing even as domestic extraction capacity expands. Constraints are most acute in magnet manufacturing and the "metallisation" stage, where refined rare earth oxides are converted into metallic alloys or powders.

Developing fully diversified rare earth supply chains requires a major increase in investment

Meeting demand for magnet rare earths outside the dominant supplier requires around USD 60 billion of investment over the next decade from both public and private sources. This includes financing for announced projects that have yet to secure funding, as well as additional new capacity needed to close the remaining supply gaps. Refining accounts for nearly half of total investment needs while magnet manufacturing represents around one-third. Although significant, this investment requirement is modest compared with other energy minerals and dwarfed by the USD 6.5 trillion potential economic cost of supply disruptions.

Financing diversified rare earth supply chains is constrained by a combination of structural cost and market factors. Projects outside the dominant supplier face higher capital and operating costs, driven by smaller scale, higher input prices, complex permitting processes and stricter environmental requirements. These challenges are most acute at early project stages, where developers must commit significant capital before revenue certainty is realised. At the same time, downstream customers typically require demonstrated technical feasibility before committing to long-term offtake, creating a structural mismatch between financing needs and demand certainty. By contrast, projects in the leading producing country often benefit from established industrial ecosystems, access to low-cost energy and inputs, skilled labour, vertical integration, shared infrastructure, strong balance sheets, and large domestic offtake bases that provide robust demand signals.

Co-production of various elements further complicates investment decisions. Magnet rare earths are typically co-produced with abundant, lower-value elements such as cerium and lanthanum, creating structural imbalances between supply and demand across individual elements. Without sufficient end-use markets for these co-products, the economics of producing higher-value magnet rare earths can be undermined.

Rare earth supply chains generate various environmental impacts across multiple stages of the supply chains, which persist even after mines are decommissioned. In situ leaching – the dominant extraction method for ionic adsorption clay deposits – produces acidic leachate and radioactive tailings that, if improperly managed, contaminate water bodies, soils and surrounding ecosystems. Processing introduces further pressures through air emissions, toxic sludge and community health impacts from high-intensity chemical operations. Many rare earth containing ores frequently co-occur with thorium and uranium, and extraction activities can concentrate these naturally occurring radioactive materials (NORMs) into tailings and process residues, requiring careful efforts to minimise the environmental impact.

Recycling can offer dual benefits by reducing reliance on mining and strengthening supply chain resilience

Recycling can play a pivotal role in strengthening rare earth supply security by lowering the need for primary supply by up to 35% by 2050. Manufacturing scrap currently accounts for the majority of secondary supply and is heavily concentrated in China where most permanent magnets are produced. However, rapidly growing end-of-life volumes from EV motors, wind turbines and electronic waste offer a major opportunity in regions with higher levels of technology deployment. Europe is particularly well positioned, projected to generate half of global magnet scrap from wind and a quarter from EVs by 2030. Emerging industry players and new technologies are improving the prospects for rare earth magnet recycling, supported by stronger circularity policies and expanding regional magnet manufacturing initiatives.

Pathways to secure and diversified rare earth supply chains

1. Understand rare earth needs and risk exposure. A clear picture of national demand outlooks is crucial to set realistic targets, estimate investment needs and calibrate policy interventions. Data and information gathering through close industry engagement, statistical surveys or trade data is a fundamental step to understanding rare earth needs. Equally important is an assessment of countries' vulnerability to potential disruptions, including a detailed understanding of rare earth use across sectors and the potential economic consequences of supply interruptions.

2. Increase preparedness for potential disruptions and establish a buffer to mitigate short-term supply risks. An effective emergency response ecosystem includes market monitoring to rapidly identify and assess disruptions, clear procedures to enable swift and coordinated actions, regular exercises to strengthen response capacity, and measures capable of delivering meaningful market impacts when disruptions occur. These measures are most effective when developed in close collaboration with international partners. Among emergency preparedness tools, strategic stockpiling can play a critical role by providing a buffer during severe supply disruptions. The net operating cost of a strategic stockpile covering one year of exposed imports of magnet rare earth oxides, metals, alloys and magnets for countries outside China amounts to around USD 200 million, modest relative to the potentially far greater economic consequences of a major supply shock.

3. Adopt a whole supply chain and ecosystem approach. Diversification is not simply a question of developing new projects; there is a much broader ecosystem issue that needs to be addressed for projects to become competitive. Rare earth value chains rely on a range of complex technical processes, requiring specialised equipment, machinery, skills to produce outputs that conform to strict industry specifications. In many cases, there are very few equipment and machinery suppliers outside China, making them much more expensive, and the time required to obtain the equipment can often span several years. Some key equipment bottlenecks include stainless steel cells for separation processes, alloy strip casters, high-efficiency electrolysis cells for metallisation, and magnet production equipment such as alignment pressers and grain boundary diffusion equipment. There are also key knowledge gaps in leaching processes for ionic adsorption clay, equilibrium data for separation, empirical knowledge for industry-specification magnet production. There is an urgent need to address these issues, as export controls are increasingly being applied not only to materials but also to the associated technologies and equipment. The first priority is to address the gap in costs and lead times for equipment and machinery, through supply-side support and demand-side measures (incentives or mandates for diversified sourcing).

4. Strengthen financial and policy support to strategic projects through supply- and demand-side measures. Diversifying rare earths supply chains requires coordinated policy and market mechanisms that reduce investment risk, support project viability and ensure demand for diversified supply. On the supply side, governments can support projects through targeted public finance such as equity, grants, concession loans or loan guarantees. They could also consider complementary measures to reduce price risks (e.g. contracts for differences or price cap-and-floor mechanisms) or provide a degree of volume certainty (e.g. offtake backstops), although these tools need to be designed carefully to balance the impacts on project economics and fiscal costs. On the demand side, governments can help generate predictable demand by introducing policies that encourage or require diversified sourcing, enabling projects to secure long-term offtake agreements and investment. These measures need to be supported by key enablers, including a broader pool of accessible financing, streamlined permitting, international public-private partnerships and enhanced supply chain traceability.

5. Promote supply-side technology innovation. Across mining, separation, refining and magnet production, innovation is increasingly emerging as an essential element for diversification. A number of promising innovation opportunities are emerging, such as smart mining, novel separation and refining technologies, and new recovery pathways from unconventional or secondary sources. However, the transition from laboratory innovation to commercial operation remains a major hurdle. Public support mechanisms – including grants, loan guarantees and support for shared testing facilities – can accelerate commercialisation. International collaboration can also play a role by facilitating knowledge transfer, establishing common standards and supporting workforce development. The recently established IEA Technology Collaboration Programme on Critical Minerals and Materials Recovery provides a platform for countries to identify technology gaps and accelerate the deployment of innovative solutions.

6. Embrace demand-side technology innovation. Demand-side innovation represents a powerful complement to supply-side innovation, providing a pathway to alleviate supply constraints and geopolitical risks. Demand-side innovation can take three distinct forms: reducing the amount of heavy rare earth elements (HREEs) required within existing magnet chemistries; substituting one HREE for another that is less supply-constrained; and developing entirely new technologies that minimise drastically or eliminate rare earth use altogether. Co-ordinated action across the value chain can accelerate both reduction and substitution strategies. Collaboration among end users (such as motor manufacturers), magnet producers and public authorities is particularly effective in overcoming technical barriers. Following the 2010 export controls, Japan implemented demand-side policies in close co-ordination with industry, resulting in 30% lower total rare earth demand compared with 2010 levels, highlighting the substantial potential of targeted demand-side measures.

7. Develop targeted policies to unlock the full potential of recycling. Key measures include boosting collection and sorting, especially for EV motors and wind turbines; harmonising extended producer responsibility schemes; and introducing rare earth-specific recovery and labelling requirements. De-risking investment in recycling infrastructure through grants, feedstock-access programmes and recycled-content incentives is essential to scale emerging recyclers and technologies. Industrial clustering, integration with refining capacity and predictable waste-trade regulations can further strengthen circular supply chains and reinforce long-term resilience.

8. Accelerate efforts to enhance price transparency. Limited price transparency in the rare earth market makes it more difficult for market participants to manage long-term contracts and hedge price risks. Governments can consider starting efforts to enhance price transparency through a range of targeted measures. They can facilitate market development by supporting audited price reporting agencies and increasing liquidity through standardisation. Governments can also draw on complementary data sources, such as trade data. Public purchasing schemes or tender-based mechanisms can also support price discovery.

Diversification cannot be achieved in isolation, calling for strengthened international coordination

Building diversified rare earth supply chains requires a wide array of efforts, including financial capital, access to geological resources, advanced processing and separation technologies, specialised skills, supportive infrastructure, and a robust downstream industrial base. Few regions possess this full suite of capabilities domestically. Many resource-rich regions lack processing capacity or technological expertise, while advanced manufacturing economies often depend on imported concentrates, intermediates or semi-finished components. This uneven distribution of assets, technology and skills implies that no single country or region can develop resilient, end-to-end value chains in isolation. There is significant scope for international collaboration, including cross-border investment, technology partnerships, long-term offtake agreements and co-ordinated policy frameworks to reduce risk and mobilise capital. Such co-operation can help align upstream development with downstream demand, accelerate project timelines and support the emergence of diversified supply networks.

Additionally, efforts to nurture and expand downstream industries – such as EVs, new energy technologies and high-tech manufacturing – outside China can play a critical role in supporting the development of diversified rare earth supply chains. In the absence of parallel growth in downstream capabilities, upstream and midstream projects may face weak or uncertain demand. Strengthening downstream industries can help build a robust demand base, reinforce market confidence and support the long-term competitiveness of emerging supply chains.

Addressing environmental risks in mining and processing rare earths also requires international co-ordination on regulatory standards and support for technological development, particularly as production expands into jurisdictions with varying frameworks. Regulatory standards for NORM management in particular remain fragmented across producing jurisdictions and would benefit from greater international coordination.

As international collaboration is central to build secure and resilient rare earth supply chains, the IEA Critical Minerals Security Programme provides a structured platform to advance co-ordinated policy action, underpinned by data-driven analysis and practical emergency preparedness tools.

Introduction

Rare earth elements have rapidly moved to the forefront of the policy agenda in recent years. Their critical role in strategic applications, ranging from energy technologies and advanced electronics to aerospace and defence systems, combined with highly concentrated supply chains, has elevated their importance in both energy and broader economic security discussions. Following the supply disruption back in 2010, 2025 marked the year when these security risks materialised at scale when export controls introduced by a dominant supplier had material impacts on downstream industries, exposing the vulnerabilities inherent in highly concentrated supply chains.

What makes rare earth elements critical?

Rare earth elements are a set of 17 elements, comprising 15 metallic elements from the lanthanide series and scandium and yttrium. Many of these elements are often found together in known deposits. Though relatively plentiful in the Earth's crust, they have garnered the label "rare" because economically viable concentrations are uncommon and they are seldom found in pure form. Their chemical similarities make them hard to separate during the extraction process, but their different physical and magnetic properties give individual rare earth elements distinct value for various technological applications in their isolated forms. Based on their atomic weight, rare earth elements are usually classified into light rare earths (LREEs) such as lanthanum, cerium, praseodymium, neodymium, samarium and europium; and heavy rare earths (HREEs) such as gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, scandium and yttrium. Since their discovery, these elements have found applications across the breadth of modern economies – from glass and fibre optics to permanent magnets, ceramics, phosphors, pigments, catalysts, lasers, medical and dental equipment (magnetic resonance imaging [MRI], computed tomography scan [CT], X-ray, pacemakers), to sensors and defence and aerospace equipment. Their use in phosphors was the main driver of the industry between the 1990s and the 2000s, transitioning to catalysts between the mid-2000s to mid-2010s. As of the mid-2010s, a single application that is reshaping the industry is their use in permanent magnets.

Magnets containing four rare earths, neodymium, praseodymium, dysprosium and terbium, known as high-performance neodymium-iron-boron (NdFeB magnets), are among the strongest permanent magnets in the industry, able to withstand temperatures as high as 230 ºC. A permanent magnet is a material that produces its own magnetic field indefinitely without the need for an external electric current to maintain its poles. Neodymium and dysprosium can handle a greater saturation magnetisation than more common magnetic elements such as iron, which allows for fabrication of stronger and smaller magnets. Rare earth-based permanent magnets play a very important role in the energy sector, owing to their use in automotive traction motors for conventional cars and electric vehicles (EVs) as well as in wind turbine motors. Their importance, however, extends well beyond the energy sector. They are also essential across the broader economy, with applications in industrial motors, household appliances, artificial intelligence and data centres, aerospace, and defence systems. Electric motors and generators based on rare earth permanent magnets represent the most energy-efficient devices developed so far, leading to energy savings of about 20-40% compared with ordinary motors. In the case of EVs, the addition of small quantities of magnet rare earth elements in a motor can boost efficiency, thereby dramatically reducing the requirements for other critical minerals needed in the battery to power the EV. In the example of wind turbines, the use of permanent magnets makes it possible to eliminate gearboxes, which are among the most frequent sources of mechanical failure.

The importance of rare earths and permanent magnets and the very high level of concentration in their supply chains have drawn global attention as a cornerstone of energy and economic resilience over the past year. Reliance on a small number of suppliers increases vulnerability to shocks and disruptions, making it imperative to advance concrete policy actions to enhance the security and resilience of rare earth supply chains.

The adoption of the Ministerial Declaration Supporting the IEA's Work on Mineral Security at the 2026 International Energy Agency (IEA) Ministerial Meeting is one example highlighting the strategic importance of critical minerals to energy security, economic resilience and emerging technologies. In the Declaration, IEA Ministers endorsed expanded co-operation on emergency preparedness and supply diversification through the IEA's Critical Minerals Security Programme.

Objective of the report

This report assesses the current state of the rare earths market, examining demand and supply dynamics and key technological developments. It analyses the full value chain from mining to magnet production, evaluates vulnerabilities across supply chains, and assesses the implications of potential supply disruptions. The report outlines targeted policy recommendations that can pave the way for more secure, diversified and resilient rare earths supply chains.

Scenarios

The projections in this report are derived from the Global Energy and Climate (GEC) Model, which is a large-scale modelling framework developed at the IEA.

The GEC Model is a simulation model that reflects the real-world interplay among policies, costs and investment choices. None of the scenarios included in this report should be considered a forecast.

Demand projections in this report are based on the Stated Policies Scenario (STEPS), which includes all existing energy policies but also takes account of those policies that have been formally tabled but not yet adopted as well as other official strategy documents that indicate the direction of travel. Supply projections are built using the pipeline of operating and announced mining and refining projects by country. The base case includes production from existing assets and those under construction, along with projects that have a high chance of moving ahead as they have obtained all necessary permits, secured financing and/or established offtake contracts. The report also includes analysis that considers projects at less advanced stages of development but whose realisation could play a central role in global diversification efforts.

Chapter structure

This report is structured into four chapters. Chapter 1 begins with a closer look at rare earth market structure, value chain, demand drivers and supply concentration. Chapter 2 provides analysis on the potential economic implications of supply disruptions. Chapter 3 analyses the pipeline of diversified projects and discusses the opportunities and challenges for creating more diversified supply chains. The final chapter lays out eight key recommendations to build secure and resilient rare earth supply chains.

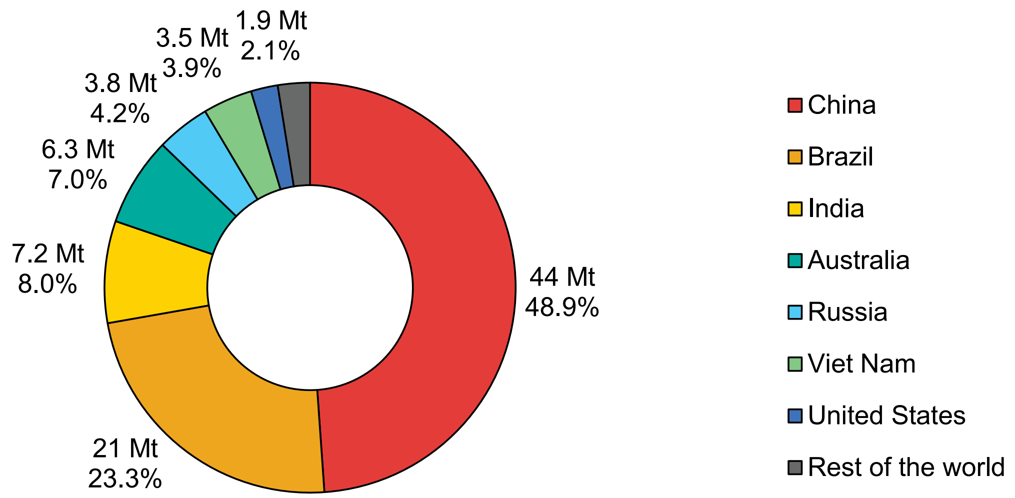
Chapter 1. Market overview

This chapter lays out the status of the rare earths market, covering reserves, market size and applications. The chapter then narrows the scope down to magnet rare earth elements in light of their important role in the energy sector and across a wide range of strategic industries. For magnet rare earths, the chapter describes the value chain from mine to magnets, and analyses demand prospects and the degree of supply chain concentration.

Reserves

Global reserves of rare earth elements (REEs) are geographically widespread but uneven in scale and reporting standards. Most recent estimates from the United States Geological Survey (USGS) indicate that world reserves exceed 90 million tonnes of rare earth oxide equivalent (Mt REO). From a broader geographical perspective, rare earth reserves occur on every continent, but their reported size and classification vary depending on national reporting practices and economic assumptions. The global distribution of rare earth reserves should be understood not as a fixed map of scarcity, but as a snapshot shaped by geology, data availability and the economic criteria applied at the time of reporting.

Geographical distribution of rare earth reserves, 2026



Notes: The figures are estimated in terms of rare earth oxides equivalent and include all rare earth elements. The shares are based on the volume of the reserves that could be economically extracted at the time of determination. Myanmar is excluded from the chart due to lack of reliable data on reserves, but the country is one of the largest mined producers of medium and heavy rare earths.

Sources: US Geological Survey (2026), Mineral Commodity Summaries; Government of India (2026), India's Rare Earth Strategy: Manufacturing, Corridors, and Global Integration.

Geographical distribution of reserves

The People's Republic of China (hereafter, "China") holds roughly half of the global reserves at 44 Mt REO, reflecting extensive carbonatite and ion-adsorption clay deposits; Brazil follows with about 21 Mt REO, largely associated with alkaline igneous complexes; India accounts for approximately 7.2 Mt REO, mainly hosted in monazite-bearing coastal and inland deposits; and Australia holds about 6.3 Mt REO, primarily contained within hard-rock alkaline and carbonatite deposits. Additional significant reserves are reported in the Russian Federation (hereafter, "Russia") (around 3.8 Mt REO), Viet Nam (around 3.5 Mt REO), and the United States (around 1.9 Mt REO).

Australia, several African countries and parts of Southeast Asia might hold additional volumes of rare earths, but these occurrences are categorised by the USGS primarily as resources rather than reserves, reflecting uncertainty about long-term economic viability under present conditions. Myanmar is one of the world's largest producers of mined rare earths, but reliable data on its reserves are currently lacking. Reserve estimates are dynamic and may change with market prices, technological developments and updated geological information.

Types of rare earth-containing ores

Rare earth elements naturally occur in a wide variety of mineral ores, though accounting for only a small percentage of the ore's total weight and volume. Over 200 mineral ores are known to contain lanthanides or yttrium as essential components of their crystal structure and chemical composition. However, only a few of these mineral ores are considered economically viable sources of rare earths production. Most commercially operating mines usually extract bastnaesite, monazite and xenotime ore. Ion-adsorption clay deposits have drawn significant interest in recent years due to their higher content of heavy rare earths (HREEs) and potential savings in energy and capital requirements**.**

Light rare earth-containing deposits

Bastnaesite is a carbonate-fluoride based rare earth ore with the composition $(REE)CO_3F$, characterised by a strong enrichment in light rare earths (LREEs) such as cerium (Ce), lanthanum (La), neodymium (Nd) and praseodymium (Pr). Major deposits occur in carbonatite-related systems such as in the world's largest rare earths mine at Bayan Obo in China and at Mountain Pass in the United States. Historically, bastnaesite has been the principal source of LREEs and continues to serve as a key raw material source for the Nd-Pr-based permanent magnet industry.

Monazite is a phosphate-based rare earth ore with composition $(REE)PO_4$ and constitutes a major component of carbonatite-related rare earth deposits. It is characterised by a dominance of LREEs and the presence of radioactive elements, predominantly thorium and some uranium. It can be found in both hard rock and heavy mineral sands (which are sands eroded from source rock) deposits in countries such as India, Australia and Brazil. The Mount Weld deposit in Australia and the Bayan Obo deposit in China are notable examples.

Heavy rare earth-containing deposits

Ion-adsorption clays (IAC), also known as regolith-hosted ionic adsorption deposits (IAD), are deposits which contain rare earth ions (REE^{3+}) adsorbed physically to the clay minerals surface, mainly kaolinite and halloysite. Weathering of igneous rock, primarily granite, that contains specific rare earth-bearing minerals results in their formation. These deposits typically exhibit an enrichment in HREEs, particularly dysprosium and terbium, and are widely reported across southern China – including Jiangxi, Fujian, Guangdong, Guangxi and Yunan – as well as in other countries such as Brazil, Malaysia, Myanmar, Lao People's Democratic Republic (PDR) and Madagascar. Because the rare earth elements occur in an ionically adsorbed state, they can be extracted through low temperature ion-exchange leaching, potentially resulting in notably lower mining and processing costs compared with hard-rock deposits. The scalability of production from IAC deposits remains less certain than other deposit types, but they look increasingly attractive from perspectives of capital intensity, ease of working, carbon intensity and radioactive waste management and could emerge as a major global source of dysprosium and terbium supply.

Xenotime is a phosphate-based rare earth ore with the composition $(REE)PO_4$ and is characterised by high proportions of heavy rare earths (HREE) such as yttrium (Y), ytterbium (Yb), dysprosium (Dy), gadolinium (Gd), erbium (Er) and terbium (Tb). It commonly occurs in coastal heavy mineral sands deposits together with monazite ores such as in the Guangdong province of China. Higher-grade xenotime occurrences have also been reported at sites such as Pitinga in Brazil and Lofdal in Namibia. Xenotime is considered a strategically important mineral ore as it contributes to the supply of dysprosium and terbium, which are essential for enhancing the high-temperature performance of neodymium-iron-boron (NdFeB) permanent magnets.

Prices, market size and applications

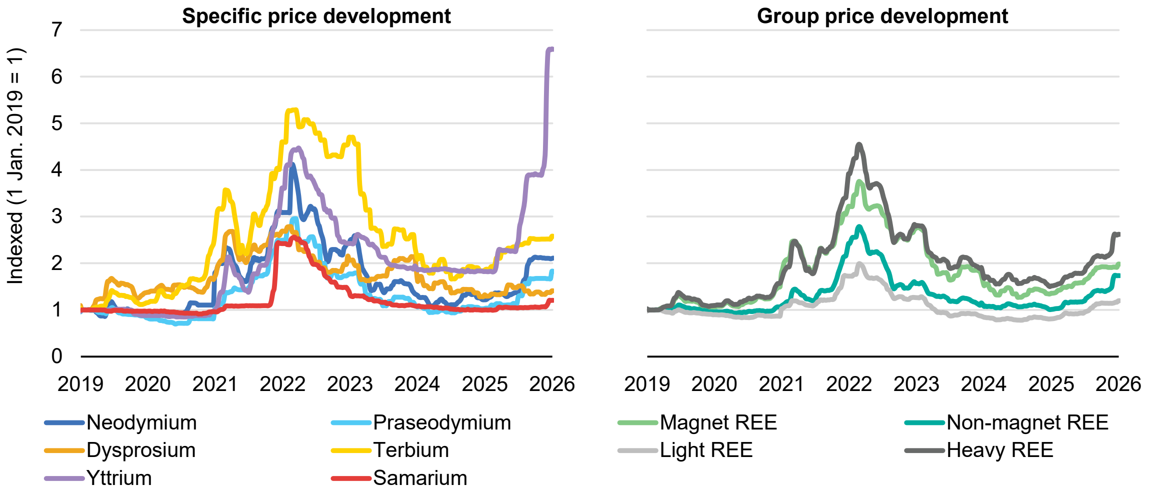
The global rare earth market is modest in size compared with major industrial metal markets but has been growing as demand for electrification and advanced technologies rises. The total market value of these elements is estimated to be around USD 6.4 billion today. Despite their comparatively small market size, their role is disproportionately important as they are essential inputs across modern economies, from energy infrastructure and automotive parts to advanced manufacturing, medical equipment, aerospace, defence and digital technologies. They underpin strategic sectors where few substitutes can deliver comparable levels of performance and efficiency.

Price trends

Rare earth pricing continues to rely largely on assessments published by price-reporting agencies (see “Chapter 3 – Demand and price uncertainties”). Most reference prices are issued by China-based agencies, and these benchmarks remain widely used across the industry despite regional differences in market conditions. Rare earth prices have been highly volatile since 2019, rising through 2021 and peaking in early 2022 at two to four times their 2019 levels. Prices stabilised in 2024 and early 2025 before rising again following China’s export control announcements in April and October. These measures led to prolonged export-licensing delays and tighter availability of high-performance magnets. At the same time, a stronger divergence also emerged between prices in China and the rest of the world. Magnet rare earths (neodymium, praseodymium, dysprosium and terbium) experienced the strongest fluctuations. Prices for lower-value light rare earth oxides such as lanthanum and cerium remained relatively stable, while some heavy rare earth prices rose as much as fivefold in the first half of 2022.

Recent months have also seen a sharp rise in yttrium prices, driven by strong demand growth in high-tech, aerospace, defence, ceramic and other specialised applications, compounded by China’s export controls. Given the extremely small size of the yttrium market, even modest shifts in consumption can have a disproportionate impact on price movements.

Development of Chinese prices for rare earth oxides, 2019-2026



Notes: REE = rare earth elements. Magnet REE = neodymium, praseodymium, dysprosium, terbium. Non-magnet REE = yttrium, samarium, gadolinium, holmium, erbium. Light REE = neodymium, praseodymium, scandium, samarium, cerium, lanthanum, europium. Heavy REE = dysprosium, terbium, yttrium, gadolinium, holmium, erbium. Assessment based on neodymium, praseodymium, dysprosium, terbium, yttrium, samarium, cerium, erbium and lanthanum rare earth oxide 99.5% min FOB China spot prices, and scandium, gadolinium, holmium, and europium rare earth oxide 99% min EXW China. Indexed values were calculated against January 2019.

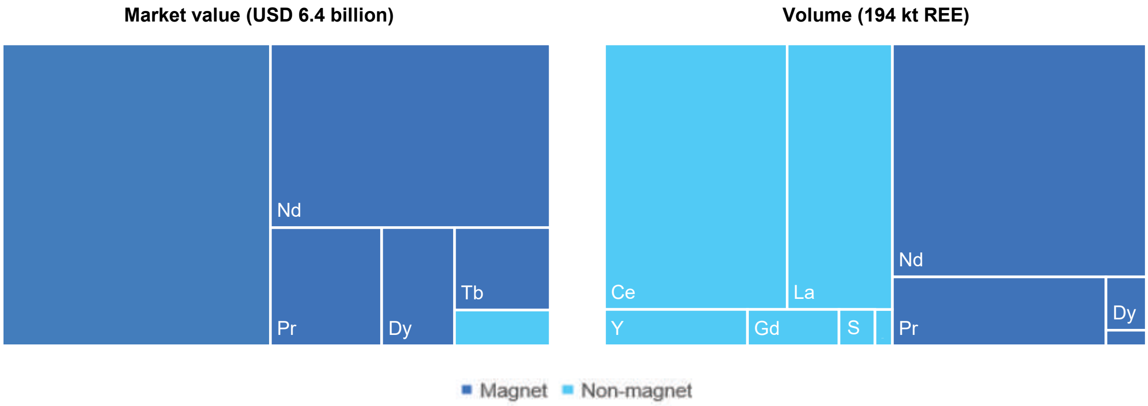
Source: IEA analysis based on KOMIS (2026), Minor Metals

Market size and market value of different elements

The market size and value of individual rare earths vary widely across elements. Light rare earths such as cerium and lanthanum account for almost 50% of volume due to large industrial use across catalysts, glass polishing and ceramics. However, these elements account for only a modest share of total market size given their comparatively low prices. In contrast, magnet rare earths such as neodymium, praseodymium, dysprosium and terbium represent the same market size in tonnage but account for 96% of the total market value. As a result, magnet rare earths have a total market value estimated to be about USD 6.4 billion.

The concentration of value in a small number of rare earth elements plays an important role in shaping market structure. High-value magnet rare earths are produced together with a broader suite of lower-value elements, meaning that the supply of any individual element does not easily adjust to its own price signals. This co-production structure is a defining feature of the rare earth market and contributes to imbalances between supply and demand across different elements, commonly described as the "basket problem."

Market value and volume of rare earths, 2024



Note: kt = kilotonnes.

Although known most for permanent magnets, rare earth elements are crucial to a diverse set of technologies and industrial applications with light and heavy rare earth elements serving different roles. LREEs drive high-volume industrial applications due to their relative abundance and cost-effectiveness. Cerium is used for automotive catalytic converters and petroleum refining catalysts. Lanthanum enables nickel-metal hydride batteries, hydrogen storage systems and specialty optical glass. HREEs typically serve specialised, high-value applications. The display and lighting industry uses HREEs for the following applications: europium produces red emission in screens and fluorescent lamps, terbium enables green phosphors, and yttrium is important for light-emitting diode (LED) and laser technologies. Medical applications rely significantly on HREEs as well, with gadolinium serving as the critical contrast agent for magnetic resonance imaging (MRI) scans and yttrium delivering targeted radiation in cancer treatment. Yttrium also plays an essential role in ceramics and coatings. Telecommunications infrastructure depends on erbium for signal amplification in fibre optic networks and ytterbium for high-power industrial lasers. Collectively, non-magnet applications account for around 50% of global rare earth consumption by volume, with LREEs representing the majority by volume and HREEs used more widely in the electronics and medical sectors.

Permanent magnets represent the fastest-growing and most strategically important applications, accounting for around 96% of the rare earth consumption by value while representing 50% by volume. These applications require both LREEs and HREEs but in different volumes. In the first type of rare earths-based permanent magnets, neodymium (Nd) and praseodymium (Pr) form the magnetic core of NdFeB permanent magnets used most notably in conventional car and electric vehicle (EV) motors and wind turbine generators, but also in a variety of industrial automation systems, aerospace and defence applications. High-performance applications operating at elevated temperatures require small but critical quantities of HREEs as performance additives. Dysprosium and terbium enhance coercivity and enable NdFeB magnets to maintain strength under demanding thermal conditions. At temperatures up to 180º C, NdFeB magnets provide a higher maximum energy product, enabling manufacturers to reduce the size and weight of these magnets – a key advantage in many commercial and transport applications. The second common type of rare earths-based permanent magnets are samarium-cobalt (SmCo) magnets. The global market size of NdFeB magnets is significantly larger than that of SmCo magnets by production volume. While NdFeB magnets account for over 90% of the market share thanks to their lower production cost and versatility in size and shape, SmCo magnets serve certain specialised high-performance applications. SmCo magnets are more resistant to demagnetisation at high temperatures and corrosion compared with NdFeB, making them ideal for high-temperature and less cost-sensitive applications in aerospace and defence where weight is not a core concern.

Properties and applications of rare earths

Light rare earths (LREEs)

Sc*	Scandium	*Soft, reactive*
La	Lanthanum	*Soft, highly reactive*
Ce	Cerium	*Soft, ductile*
Pr	Praseodymium	*Soft, ductile, magnetic*
Nd	Neodymium	*Reactive, hard, malleable*
Pm	Promethium	*Radioactive, rare, reactive*
Sm	Samarium	*Hard, reactive, magnetic*
Eu*	Europium	*Soft, highly reactive*
Gd*	Gadolinium	*Ductile, magnetic*

Heavy rare earths (HREEs)

Tb	Terbium	*Soft, malleable, magnetic*
Dy	Dysprosium	*Soft, strong magnetic*
Ho	Holmium	*Soft, magnetic*
Er	Erbium	*Soft, electro-positive*
Tm	Thulium	*Radioactive, soft, malleable*
Yb	Ytterbium	*Soft, malleable, ductile*
Lu	Lutetium	*Reactive*
Y*	Yttrium	*Soft, reactive*

	LREEs	HREEs	LREE / HREE Split
Permanent magnets	**Nd • Pr • Sm** • SmCo for aerospace and defence • NdPr for EVs, wind turbines, industrial motors, robotics, data centres	**Dy • Tb** • High-temperature resistance • Coercivity enhancement	
Catalysts	**Ce • La** • Catalytic converters • Fluid cracking catalysts • Chemical processing		
Phosphors & displays	**Ce** • Blue phosphors	**Eu • Tb** • Red phosphors (Eu, Y) • Green phosphors (Tb)	
Glass	**Ce • La** • Optical glass polishing • Glass additives • UV absorption	**Er • Y** • Fibre optic cables	
Batteries	**La • Ce • Pr • Nd** • NiMH batteries • Hydrogen storage		
Medical	**La • Ce • Sm • Nd** • Bone regeneration • Wound healing and skin repair	**Gd • Y • Dy • Ho** • MRI, CT, X-rays (Gd) • Radiotherapy (Y) • Dosimeters (Dy)	
Nuclear	**Sm** • Radiation shielding ceramic compositions	**Eu • Gd • Dy** • Nuclear reactor control rods • Nuclear fuel	
Metallurgy	**Ce • La** • Steel additives • Aluminium alloys	**Dy • Tb** • Grain Refinement • Corrosion Resistance	
Ceramics	**La • Pr** • Color control in ceramic glazes • Barium titanate powder doping for electronic applications (La)	**Er • Ho • Y** • Color control in ceramic glazes (Er, Ho) • Ferrites for high-frequency applications (Y)	

* Classification of Sc, Y and Gd varies across sources. Sc is often treated separately due to its distinct geochemical behaviour and supply chains. Y is typically grouped with HREEs based on ionic radius and mineralogical affinity, despite not being a lanthanide. Gd sits at the LREE/HREE boundary and is inconsistently assigned depending on whether atomic number, ionic radius or mineralogical behaviour is used as the basis for classification. Eu sits among LREEs by atomic number but exhibits distinct geochemical behaviour due to its oxidation state and is sometimes grouped with HREEs in applied contexts.

Notes: UV = ultraviolet; NiMH = nickel-metal hydride; CT = computed tomography. The figure illustrates examples of the most common uses of rare earths in the listed applications and is not exhaustive. The LREE/HREE split represents a qualitative estimation based on documented applications in each sector and does not reflect precise consumption data.

Given the substantial share of permanent magnets in total rare earths consumption by value, the importance of rare earths used in magnet applications is particularly pronounced. These include neodymium, praseodymium, dysprosium and terbium for NdFeB magnets and samarium for SmCo magnets. Outweighing the value of the mine-to-magnet value chain by orders of magnitude are the end-use industries relying on the use of permanent magnets – the combined estimated value of these industries in 2025 is placed at USD 6.5 trillion (see Chapter 2).

Unless otherwise specified, the analysis presented in the rest of this report therefore focuses on the four key magnet rare earth elements – neodymium, praseodymium, dysprosium and terbium – given their central role underpinning various strategic industries. The rest of the report uses units in element terms (tonnes REE) rather than oxide terms (tonnes REO)[1], unless otherwise specified.

Rare earth value chain: From mine to magnets

The rare earth value chain encompasses a sequence of technically demanding steps, each adding distinct forms of value as materials move downstream from geological deposits to refined products. While rare earths occur in many mineral ores in varied geological settings as discussed above, the overall transformation follows a consistent structure: extraction, beneficiation, chemical upgrading, separation into oxides, metal refining, alloying and permanent magnet manufacturing.

Upstream beneficiation begins immediately after ore extraction. Hard-rock ores undergo crushing and milling to liberate rare earth minerals from the surrounding gangue, with these comminution steps accounting for a significant share of operational energy demand. Concentration steps then follow, using gravity separation, froth flotation and magnetic separation to produce a mineral concentrate, which reduces the volume of material requiring downstream treatment. Ion-adsorption clay deposits follow a different route: while they do not require mechanical beneficiation, they may undergo attritioning and scrubbing before tank leaching or ion-exchange processing. In regions where heap or in situ leaching is used to extract loosely bound rare earth ions, the method requires strict environmental controls and could pose substantial risks to soil and groundwater quality if regulatory oversight is weak, underscoring the need for robust safeguards.

The next step is chemical upgrading, or group extraction, in which the concentrates are dried, leached and purified to produce mixed rare earth compounds. While mixed rare earth chlorides can be generated at this stage, most commercial flowsheets precipitate mixed rare earth carbonates or oxalates, which

[1] For magnet rare earth elements, 1 REO can be approximately equivalent to 0.86-0.87 REE, although specific conversion factors vary by element.

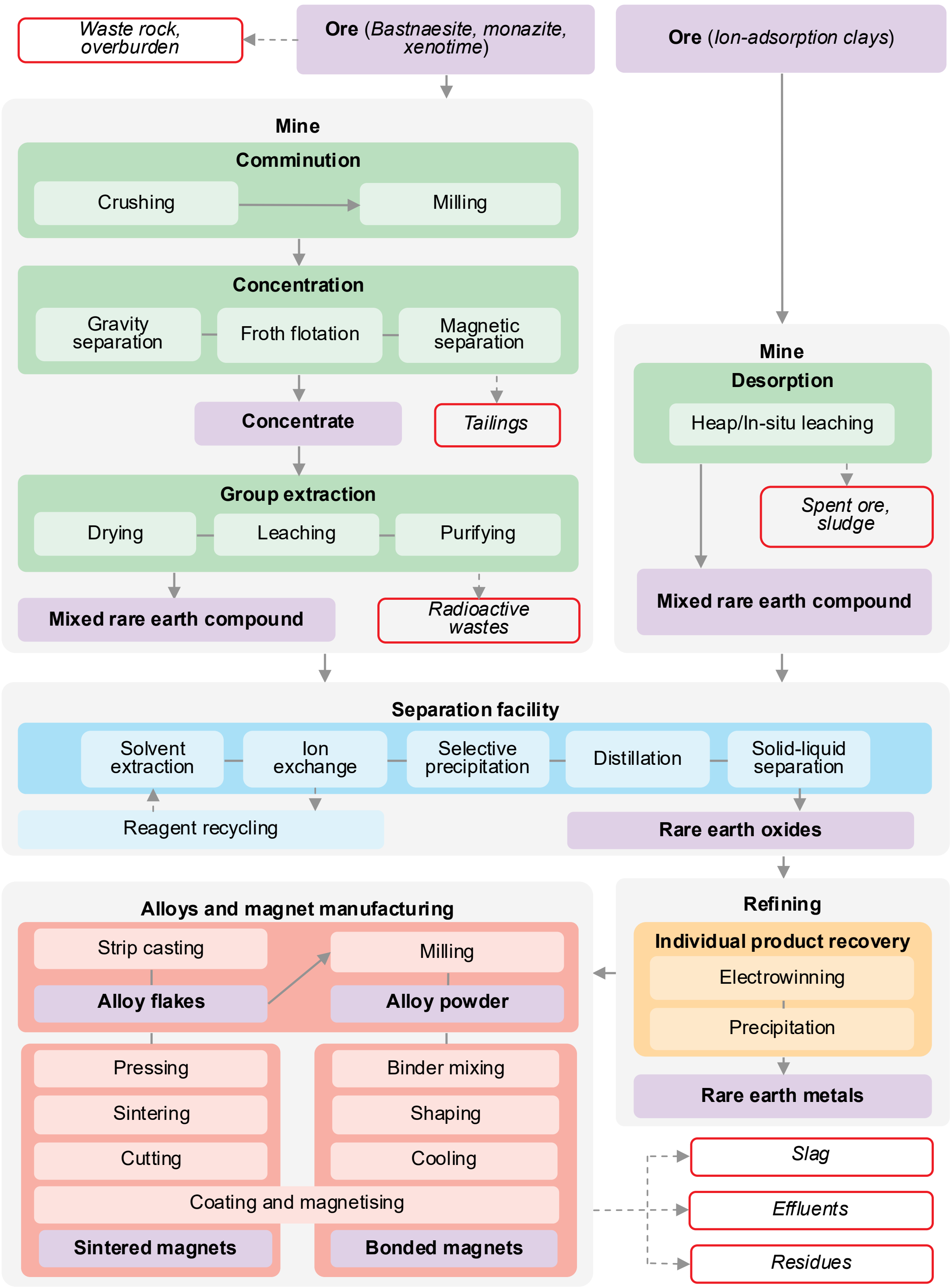
are more stable for handling and transport, particularly for shipment over long distances. This phase marks the transition from physical to chemical processing and depends heavily on reagent supply, water availability and residue management, including the treatment of any radioactive by-products. In hard-rock operations, chemical upgrading typically follows cracking, leaching and impurity removal before precipitation of mixed rare earth carbonates or oxalates. For ion-adsorption clays, pregnant leach solutions undergo impurity removal and are likewise precipitated as mixed carbonates or oxalates, and some variants include additional steps such as lanthanum removal loops.

Separation constitutes the technical core of rare earths processing. Mixed feed streams are processed through large multistage circuits that rely predominantly on liquid-liquid solvent extraction. These circuits may operate in either chloride or nitrate media, with hydrochloric acid widely used in China and nitric acid deployed in facilities such as those in Estonia and France (see Chapter 4). Although solvent extraction involves complex circuit balancing and requires precise control of phase chemistry, it typically handles relatively small solution volumes compared with earlier processing stages. Ion exchange, selective precipitation, distillation and solid-liquid separation may be integrated as complementary steps to achieve the stringent purity specifications required for individual rare earth oxides. Reagent recovery and recycling are integrated to enhance efficiency and limit environmental impacts, while supporting overall operational cost optimisation.

Refined oxides are then converted into metals through molten-salt electrowinning or metallothermic reduction, typically using calcium or lanthanum as reducing agents. Oxides already meet performance needs in catalytic, optical and ceramic applications, but metallic forms are essential for magnet or alloy applications, where very low impurity levels are required. Up to the metal stage, rare earth materials generally follow conventional commodity dynamics; beyond this point, magnet manufacturing becomes highly specialised with products tailored to specific magnetic performance and geometric requirements.

Downstream manufacturing converts metals into function materials. Strip casting produces alloy flakes, which are milled into alloy powders for further processing. These alloy powders serve as primary feedstock for permanent magnet production, where controlled properties enable the formation of the fine microstructures required for high-performance magnets. Two main categories of permanent magnet designs dominate: sintered magnets (used in EV and wind turbine motors), made through pressing, sintering, machining, coating and final magnetisation under controlled thermal conditions; and bonded magnets (used in appliances and smaller devices), formed by blending alloy powders with polymer binders and shaping them into complex geometries. Sintered magnets currently dominate the market and exhibit the highest performance, maximum coercivity and conformity to shape specifications. Bonded magnets are smaller and more cost-competitive, enabling the production of intricate shapes. These final manufacturing steps also generate slag, effluents and solid residues, which require appropriate handling, treatment and disposal. At this stage, the highest concentration of value addition in the rare earth supply chain is realised, linking upstream mineral production to critical end-use applications.

Illustrative mine-to-magnet value chain



Notes: This figure illustrates a simplified, generalised flowsheet and does not capture the full complexity of real-world circuits, which are typically customised for specific ores. Recycling process is not covered by the processes outlined here.

Risks associated with mining and processing rare earths

Mining and processing together constitute the most environmentally intensive stages of the rare earth supply chain, although the severity of impacts varies by deposit type, extraction technology and the regulatory environment in which production takes place. In the mining stage, the co-occurrence of rare earth ores with thorium and uranium produces tailings and waste rock with enhanced concentrations of naturally occurring radioactive materials (NORMs) requiring long-term management, while acid mine drainage (where sulphide minerals are present) and acidic leachate from in situ leaching mobilise metals and rare earths into surface and groundwater systems over extended periods. The processing and refining stage is characterised by high chemical and energy intensity, generating waste-water streams containing acids, bases, organic solvents, ammonium, sulphate, metals and radionuclides, alongside air emissions of dust, acid gases and solvent vapours. Life-cycle assessments specifically identify the separation and refining stages as major contributors to cumulative energy demand and greenhouse gas emissions across the entire rare earths supply chain. These documented risks across both production stages have prompted regulatory and technical responses aimed at environmental control, worker protection and mine closure planning. Potential mitigation approaches are explored in Chapter 3.

Demand prospects for magnet rare earths

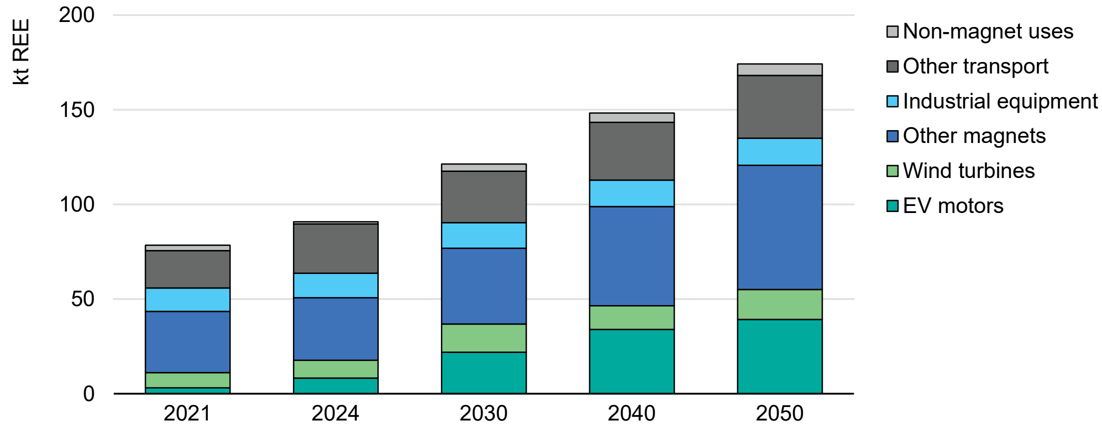
Two decades ago, the most common uses for magnet rare earths (neodymium, praseodymium, dysprosium and terbium) were – in much smaller volumes compared with today's EV motors – for small magnet components such as sensors, speakers, and actuators in conventional cars and other transport modes, as well as for small household appliances, consumer electronics and ceramics.

With record growth over the past ten years in electrification of end uses and industrial processes and the rapid deployment of new energy technologies such as EVs and wind turbines, whose powerful motors rely heavily on permanent magnets, demand for magnet rare earths has doubled since 2015. The two heavy magnet rare earth elements, dysprosium and terbium, continue to play small but significant roles in phosphors, displays, medical equipment, nuclear reactors and metallurgy, but the strongest driver for their demand growth has been their use as additives to enhance the performance of modern permanent magnets.

One of the most prominent sources of demand for magnet rare earths is the production of permanent magnets for electric motors and generators. NdFeB magnets enable high-efficiency, high-power and compact motor designs, with each EV traction motor requiring approximately 2 kilogrammes (kg) to 4 kg of these magnets (compared with only a few hundred grammes in conventional cars). Even the addition of small quantities (1 kg to 2 kg) of magnet rare earths in a motor can dramatically reduce the requirements for other critical minerals (60 kg to 80 kg of lithium, nickel, cobalt) needed for an EV. As global EV sales grew at an annual average rate of 50% since 2014 – from only 300 000 units to over 17 million units in 2024 – EVs have emerged as one of the strongest drivers of demand growth for magnet rare earths, increasing their share of demand from under 1% in 2015 to 9% today.

Global demand for magnet rare earths is set to expand by a third between 2024 and 2030, crossing 120 kt, and by over 90% to 2050, reaching 175 kt under today's policy settings. EV motors significantly increase their contribution to demand growth, doubling their current share to reach 18% of demand by 2030. Driven by sustained growth in deployment of EVs, wind generation, industrial motors, automation, and other applications in transport, appliances and electronics, permanent magnets, though of various sizes and performance specifications depending on the use, account for a majority of magnet rare earth demand throughout the projection period. Emerging growth in automation, robotics and digital technologies plays a larger role in driving total demand beyond 2030, as permanent magnets enable precision motion control, miniaturisation (small motors with high power) and energy efficiency for these applications. Other non-magnet uses such as in ceramics, phosphors, displays, medical equipment and nuclear reactors make up the remaining demand.

Magnet rare earth demand by sector in the Stated Policies Scenario, 2021-2050



Note: The figures are for magnet rare earths (neodymium, praseodymium, dysprosium, terbium) only.

As the largest producer of NdFeB permanent magnets and EVs, China is currently the largest demand centre for magnet rare earths. Compared with two decades ago, when it accounted for around 50% of the production of sintered magnets (most commonly used in EVs and wind turbines) and around 45% of the production of bonded magnets (used in appliances and electronics), its share in the production of these magnets expanded massively to reach 94% and 80%

respectively in 2024. Japan, which accounted for nearly half the global production of sintered permanent magnets in 2005, remained the second-largest producer as of 2024 even though its share had fallen to around 5% of global production. While China dominates production for the entire range of permanent magnets ranging from very small applications to high-performance magnets, Japan primarily focuses on the production of advanced and high-performance magnets.

In 2024, China accounted for nearly 60% of the global demand for magnet rare earths. This share falls to around 50% by 2050 as other players enter the permanent magnet manufacturing sector and demand from other uses also grows in many regions. Some of the largest magnet manufacturing projects added globally in the coming decade are still in China, but the United States, the European Union, Japan and Korea make significant strides in magnet production capacity in the coming years, thanks to strong policy actions. Beyond magnets and automotive, China is also home to other major industries that use magnet rare earths, such as ceramics, electronic displays, medical devices and nuclear reactors.

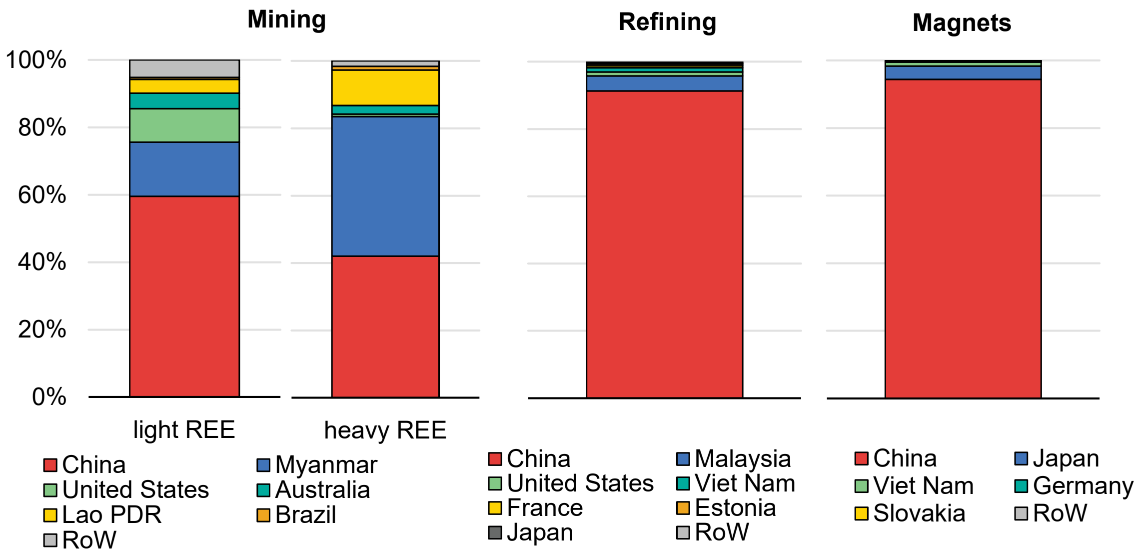
Production and supply chain concentration

Global rare earth markets have been well-supplied in the last decade, as supply has continued to outpace demand growth, despite a slowdown in China's production quota growth in 2024. However, the announcement of export controls (see Chapter 2) from China in April and October 2025 and sustained social and governance challenges in Myanmar have emerged as tangible risks to the reliable supply of these minerals.

The supply of magnet rare earths remains among the least geographically diversified of all critical minerals. In 2024, the share of the top three producers for mining stood at 86%, of which China alone accounted for 60% of global mined production. In the rest of the world, Mountain Pass (MP Materials) in the United States and Mount Weld (Lynas) in Australia are leading mine production sites.

For refining, the top three countries controlled the lion’s share (97%) of the refined output in 2024, with China’s dominance even more pronounced than in mining as it single-handedly represented 91% of the refined output. In the rest of the world, refineries owned by Lynas in Malaysia, MP Materials in the United States, Viet Nam Rare Earth JSC (VTRE) in Viet Nam, Solvay in France and Neo Performance Materials in Estonia (Silmet) are the notable industrial-scale producers.

Share of global supply of magnet rare earths and magnet manufacturing, 2024



Notes: REE= rare earth element. RoW = rest of world. The figures are for magnet rare earths (neodymium, praseodymium, dysprosium, terbium) only.

When looking only at the heavy magnet rare earths, which are under Chinese export controls and are generally more expensive than LREEs, the supply picture looks somewhat different. Myanmar accounted for over 40% of total mined dysprosium and terbium production in 2024 although the sector remains largely informal and underreported within the country. For decades, the country has been exporting raw materials from its Kachin State region across the border to China for processing and refining until local governance issues led to border closures at the end of 2024, followed by gradual reopening in 2025. Together, Myanmar and China are responsible for around 83% of the global mined heavy magnet rare earth supply today, notably higher than 76% of the light magnet rare earth supply.

Thanks to its dominance in processing and refining as well as in end-use industries such as automotive and energy technology manufacturing, China is the largest producer of permanent magnets. For magnets that use rare earths placed under export controls, i.e. dysprosium and terbium (NdFeB magnets), China’s share of global production in 2024 stood at around 94%. There are several planned projects for permanent magnet manufacturing in diversified regions set to start production this decade, but their success will depend on securing reliable and affordable supplies of raw materials. Chapter 3 expands on the analysis of magnet rare earth supply and permanent magnet production, focusing on projects in the pipeline that hold significant potential to support diversification efforts. China’s extensive magnet production activity not only delivers substantial economies of scale but also is supported by a significant network of equipment suppliers – including industrial furnaces, grinders and presses – that underpin the magnet manufacturing process. This combination of scale, technical capability and supplier ecosystem highlights the structural complexity of the permanent magnet value chain. Chapter 4 discusses these bottlenecks for diversification in more detail.

The influence of regulations on the rare earths industry in China

China plays a big role in the rare earth market, which has evolved significantly since the 2000s. Through policy and regulations, the country transformed its rare earth industry to a high-value ecosystem.

Central to China's deliberate policy choices was a rare earth mining quota management system established in 2006 to balance economic development with resource conservation. What began as a protective extraction measure for ion-adsorption HREE deposits was later expanded to cover all rare earth elements. The quota system evolved into a dual-track mechanism in 2009, when the Ministry of Industry and Information Technology (MIIT) allocated quotas directly to key enterprises, while the Ministry of Natural Resources regulated the proportion between rock-type light rare earth and ion-adsorption heavy rare earth extraction. In 2012, MIIT established a dual-control system governing both mineral products and smelting and separation products. These quotas are strictly implemented through satellite aerial photography, video surveillance, regular inspections, monthly reporting, invoice monitoring and hotlines.

This quota framework enabled state-led consolidation to achieve more co-ordinated resource management and strategic planning. Quotas that were initially distributed among multiple enterprises were gradually concentrated among six major state-owned rare earth groups after 2016. By February 2024, China Rare Earth Group (created through a merger of state-owned rare earth companies) had been allocated all ion-adsorption (medium-heavy) rare earth extraction quotas, while light rare earth extraction quotas were divided between China Rare Earth Group and Northern Rare Earth Group. Moreover, the 2026 launch of the Baotou Rare Earth Price Index by the Baotou Rare Earth Products Exchange (replacing incumbent listing prices of the Northern Rare Earth Group) allows further industry oversight by functioning as a state-backed pricing mechanism for mainstream rare earth products such as lanthanum, cerium, praseodymium and neodymium.

Beyond this system, the government provides substantial support through long-standing incentives including below-market energy rates, preferential land access, and research and development grants, consistent with its broader New Quality Productive Forces agenda – a policy term that emphasises innovation-driven growth. Efforts for technological modernisation are also supported, for example through the deployment of intelligent computing centres and artificial intelligencepowered remote mining systems at major sites such as Bayan Obo, optimising extraction rates and enhancing operational efficiency.

In 2025, China implemented a national tracking system which mandated all rare earths product flows to be logged into a centralised state database to enhance traceability throughout the supply chain. The system ensures environmental compliance by accounting for all rare earth elements produced to eliminate illegal mining operations that have historically been environmentally damaging. Complementarily, China introduced export controls on certain medium and heavy rare earth items in 2025 requiring licences for certain strategic elements including gadolinium, samarium, terbium and yttrium. These regulations assert extraterritorial reach, with China claiming jurisdiction over foreign products containing more than 0.1% Chinese-sourced rare earths or utilising Chinese proprietary processing technology (see Chapter 2).

Environmental considerations also shape China's rare earth strategy, where the country has prioritised "Zero Liquid Discharge" and bio-leaching technologies as part of its 2026 circular economy objectives. This is particularly applied to the recycling of magnets to recover neodymium and dysprosium.

China's strategic policy choices aimed at capturing greater value from domestic mineral resources – while establishing a specialisation in mining and refining technology – allowed the country to secure a central role in the global rare earth supply chain.

Chapter 2. The strategic importance of rare earths for economic security

It is difficult to overstate the importance of rare earth elements to energy, national and economic security around the world. With applications in strategic sectors including energy, automotive, semiconductors, aerospace, industrial motors, artificial intelligence (AI) and defence, rare earths are fundamental to a wide range of many of the leading modern technologies the world relies on. Rare earth permanent magnets are one of the most important components to the production of the best performance motors that are used for many applications such as cars, data centres and defence systems. However, their supply is highly concentrated in a single country, China, leaving many strategic sectors vulnerable to potential disruptions, notably from export controls.

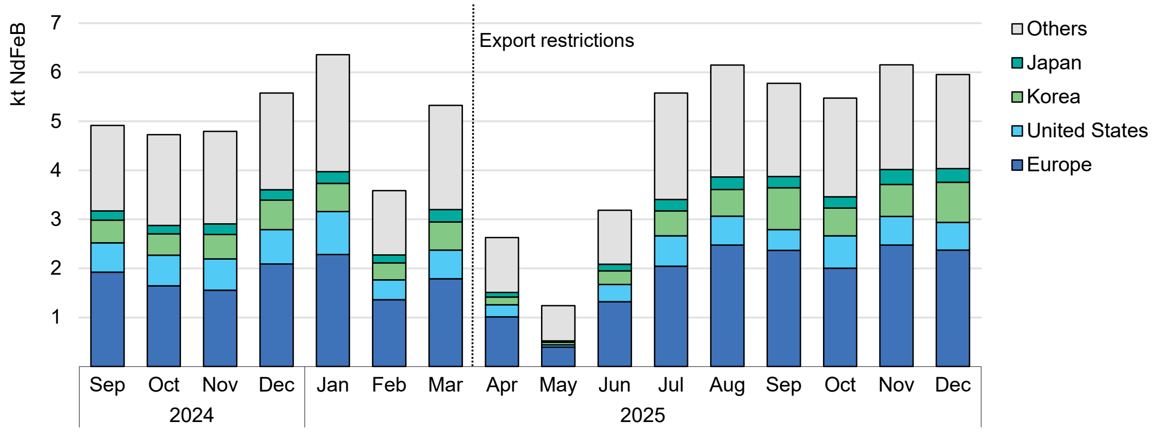
Recent export controls and market developments

In 2010, China implemented rare earth controls using quotas and licensing, causing global supply shock and temporary rare earth price spike as much as ten times. These controls were eventually ruled non-compliant with the World Trade Organization (WTO), leading to their removal. In 2025, significantly strengthened and expanded rare earth export controls from China re-emerged, bringing major new risks to global supply chains and economies.

April rare earth export controls

The impact became especially visible in 2025, when the Chinese government introduced export controls on seven heavy rare earth elements – samarium, gadolinium, terbium, dysprosium, lutetium, scandium and yttrium – together with all related compounds, metals and magnets on 4 April 2025. Export volumes from China dropped sharply in April and May, leaving many automakers in the United States, Europe and beyond struggling to source permanent magnets. Some were forced to reduce utilisation rates or temporarily shut down production lines. Exports of dysprosium and terbium oxides and metals were also affected by the restriction, dropping in May to then slowly recover in the following months, impacting the supply of feedstocks for magnet manufacturing outside of China.

Exports of rare earth magnets from China, September 2024 to December 2025



Note: kt = kilotonnes; NdFeB = neodymium iron boron magnets

Even after trade volumes recovered, a significant premium for magnets from outside China remained, indicating a growing appetite among companies to secure non-Chinese magnet supply, reflecting a strategic shift where security of supply considerations play an increasingly prominent role in sourcing decisions.

October rare earth export controls

In October 2025, the export controls on rare earths were significantly escalated. On 9 October 2025, the Ministry of Commerce of China announced further export controls on rare earth elements and related products, equipment and technologies. The new controls required foreign companies to obtain a licence from China to export “parts, components and assemblies” containing Chinese-sourced rare earth materials or produced using Chinese rare earth technologies. The rule was applied with immediate effect to products made in China. However, from 1 December 2025, the controls were to be escalated to include "internationally made" products containing Chinese-sourced materials or manufactured using Chinese technologies, even if they are traded domestically.

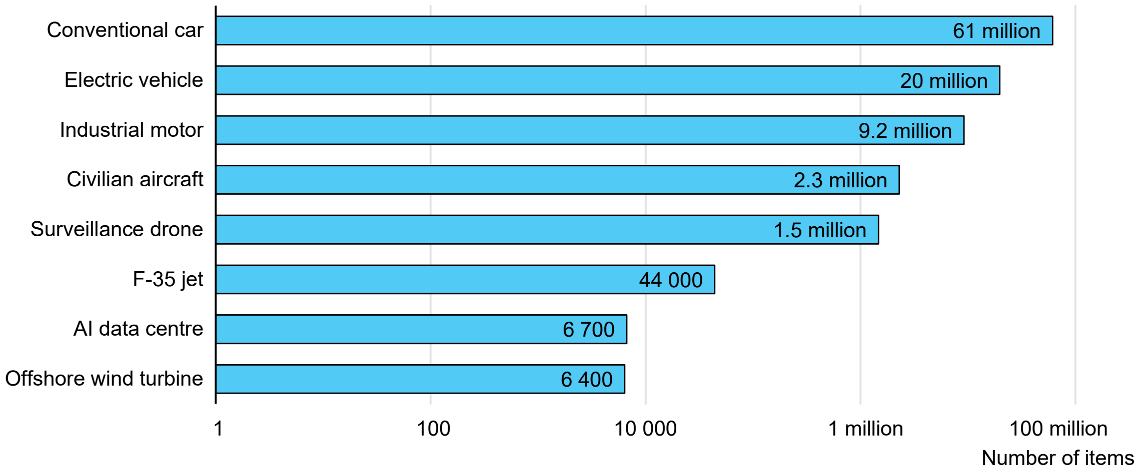
The inclusion of “internationally made”, “parts, components and assemblies”, beyond the previous isolated controls on select rare earth magnets and materials, marked a major escalation and considerable expansion of the scope of export controls. A wide range strategic sectors across the world rely on products and components containing controlled Chinese rare earth elements.

Moreover, the list of rare earth elements subject to controls was also expanded to include five additional elements – holmium, erbium, thulium, europium and ytterbium – on top of the seven elements initially restricted in April. The inclusion of holmium was particularly significant, as many permanent magnet makers had been revising their approach to replace the previously restricted rare earths with holmium since April 2025. New controls were also announced on a wide range of equipment for processing rare earths, including for milling, separation and refining, which were supposed to be effective from 8 November.

Nevertheless, in November 2025, China announced a one-year suspension of export restrictions introduced in October 2025, providing relief to the market. However, the underlying risks and potential for future implementation remains. Recently, in January 2026, China tightened export controls on dual-use goods destined for Japan. Although China did not specify the products affected, rare earths are included on China's dual-use control list, giving the government the ability to effectively suspend their export if deemed necessary. These developments underscore the growing prominence of supply chain risks exposed by recent export controls.

If the October export controls had been fully enacted, the consequences for many key strategic sectors would have been far-reaching. Rare earth magnets are used in a multitude of items across various industries. The amount of material per item can be small, but frequently it is very difficult to substitute, and its inclusion is essential for achieving high performance. In 2025, China exported 57 kt of rare earth magnets, which are enough to manufacture components used in over 61 million conventional cars, 9 million industrial motors, 44 000 military jets, 6 700 AI data centres or 6 400 offshore wind turbines. Prolonged delays or denials in licensing approvals could threaten revenues, competitiveness and employment for strategic global value chains.

Number of items containing an amount of rare earths equivalent to China's rare earth magnet export volumes, 2025



Potential economic impacts of supply disruptions

Major impacts were already felt from targeted and specific rare earth export restrictions in April. However, the announced controls in October 2025 were much larger in scope, with major potential impact. Understanding what the economic impact would be on importing countries if these suspended export controls were fully implemented has become a key question to understand critical economic vulnerabilities and exposure. We assessed the economic value of downstream production at risk for countries if these currently suspended export controls are fully implemented.

Economic impact assessment methodology

The economic value of downstream production at risk from a supply disruption was estimated based on the suspended October export controls, as if they were implemented in full. If the controls were implemented, companies must obtain a licence from China to export any domestic or internationally made "parts, components and assemblies" containing China-sourced rare earth materials or produced using Chinese rare earth technologies. In a scenario that the relevant licences are not granted, the production and trade of final end-use products containing Chinese rare earth elements would be severely constrained. As a result, downstream manufacturers would face economic losses stemming from their inability to sell and export affected products.

To estimate the economic value of downstream production at risk outside of China from full export controls, the assessment first utilises rare earth magnet demand data in end-use products (both NdFeB and samarium-cobalt [SmCo]) across these economies. This data is then combined with our database of rare earth intensities for downstream products in each sector to determine the number of magnet-dependent products. These sales numbers are then combined with product price information to calculate exposed revenue if licences are not granted, thereby quantifying the economic value of downstream production at risk from their loss of sales. The 24 specific product categories were analysed. Independent product sales data are also used to validate the estimates derived from rare earth intensities. The resulting economic value of downstream production at risk by product are then aggregated by region and by sector.

End-use product categories that are considered in the economic impact assessment

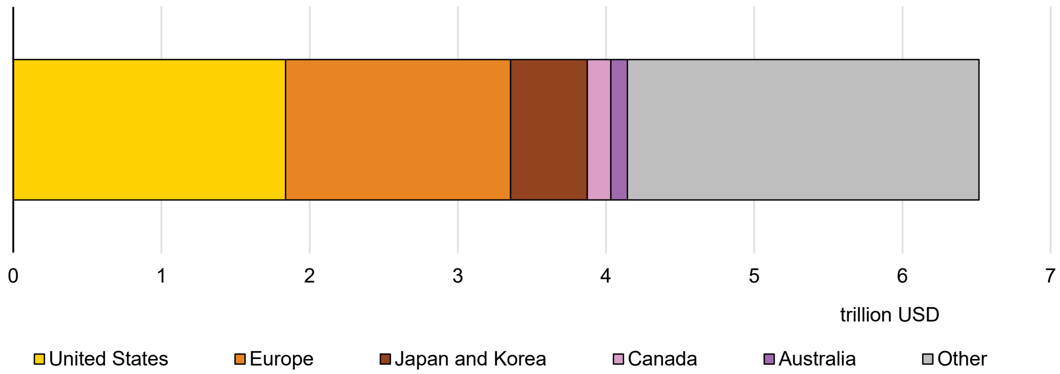
Sector	Product category				
Automotive	Conventional cars	Electric cars	Hybrid cars		
Aviation, trucks and trains	Trucks and buses	Narrow-body aircraft	Wide-body aircraft	Regional aircraft	Trains
Defence	Fighter jets	Ships and submarines	Tanks	Missiles	Defence drones
Portable electronics	Smartphones	Laptops	Portable HDDs	Speakers	Commercial drones
Data centre servers	Data centre HDDs	Cooling fans			
Wind	Onshore wind turbines	Offshore wind turbines			
Industrial	Electric motors/pumps	Robotics			

Note: HDDs = hard disk drives.

Results

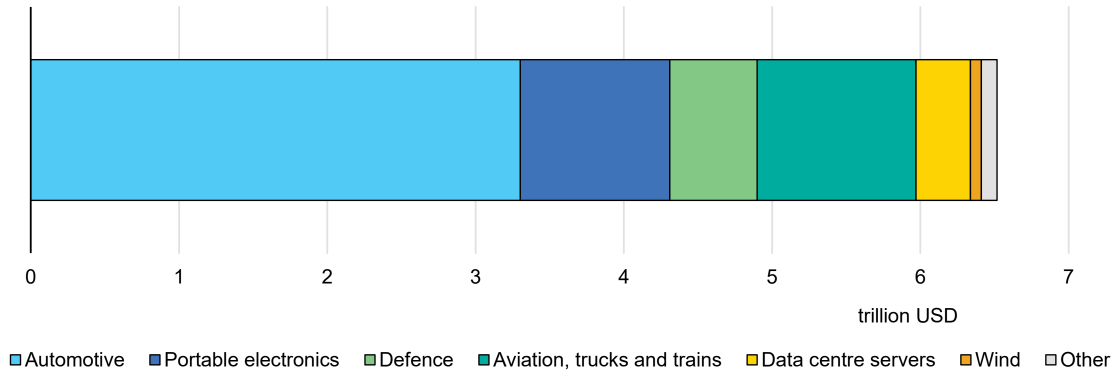
If the rare earth export controls are implemented in full, the economic value of downstream production at risk would reach USD 6.5 trillion per year for countries outside of China, with USD 4.2 trillion for IEA countries. For context, the economic value of downstream production at risk to countries outside China amounts to almost 10% of their combined annual gross domestic product (GDP).

Economic value of downstream production at risk from full export controls by region, 2025



The United States and Europe face the largest potential economic value at risk with over USD 1.5 trillion of direct economic losses each. Japan and Korea together face over USD 500 billion of potential economics losses, underlining the severity of the impact these controls could have on major economies if fully implemented.

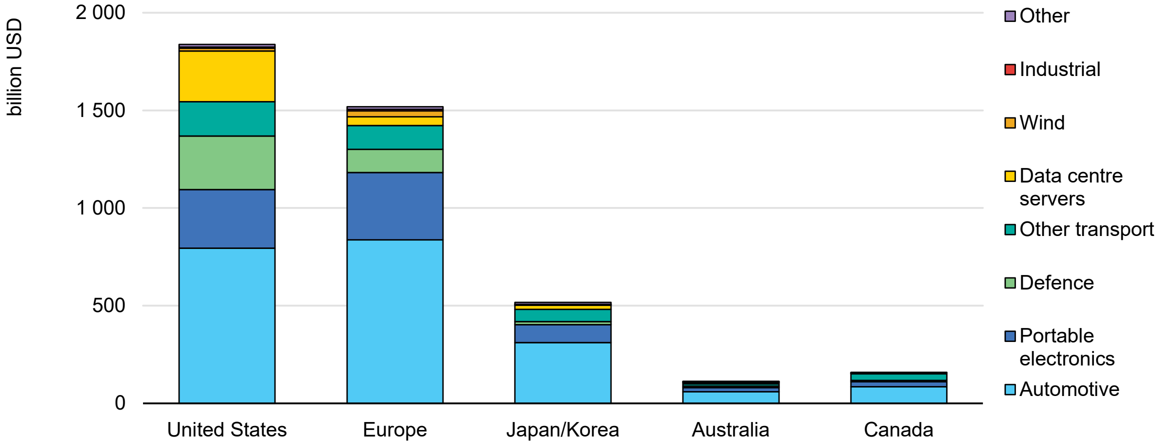
Economic value of downstream production at risk from full export controls by sector, 2025



In terms of sectoral exposure, the automotive sector is the source of greatest economic value of downstream production at risk with over USD 3 trillion of direct losses alone for countries outside China, followed by portable electronics and the other transport (aviation, trucks and trains) sector, with over USD 1 billion of losses each. These three sectors together are responsible for almost 85% of economic value of downstream production at risk, demonstrating their economic importance and vulnerability. There are also almost USD 600 billion of losses in the defence sector and over USD 350 billion of losses for the data centre sector.

Automotive is the leading domestic loss sector for all major economies – over 40% for the United States and over 50% for the others – but vulnerabilities in other sectors vary considerably by region. The United States is more exposed to data centre servers and defence (15% of losses each), while Europe, Japan and Korea have high exposure to electronics (around 20% of losses). Data centres currently represent a smaller source of economic exposure for countries outside the United States, but their significance could increase over time as new facilities are deployed more widely across other economies.

Economic value of downstream production at risk from full export controls by key region, 2025



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Indirect economic impacts

The impacts of a disruption extend far beyond the loss of direct product sales in practice. There are a wide range of high-value services which depend on the sales of the rare earth-dependent products. For example, internet communication, AI services, websites and e-commerce, fintech, and cloud computing services are high-value, rapidly expanding services used across global sectors, and all rely on data centre servers to operate. If data centre servers cannot be traded due to rare earth export controls, there will be a major economic multiplier effect significantly beyond the loss from data centre sales. The same is true for the plethora of high-value services which depend on industrial motors containing rare earths, for example automated and advanced manufacturing, robotics, or applications in energy, mining, and oil and gas production. Therefore, there is a cascade economic effect from the inability to trade rare earth-dependent products. A prolonged disruption of the trade of these products would involve a significant economic multiplier for the loss of these high-value associated services, with the risk of potential economic standstill in major sectors. This would likely lead to economic losses several times larger than the direct economic losses estimated in this analysis.

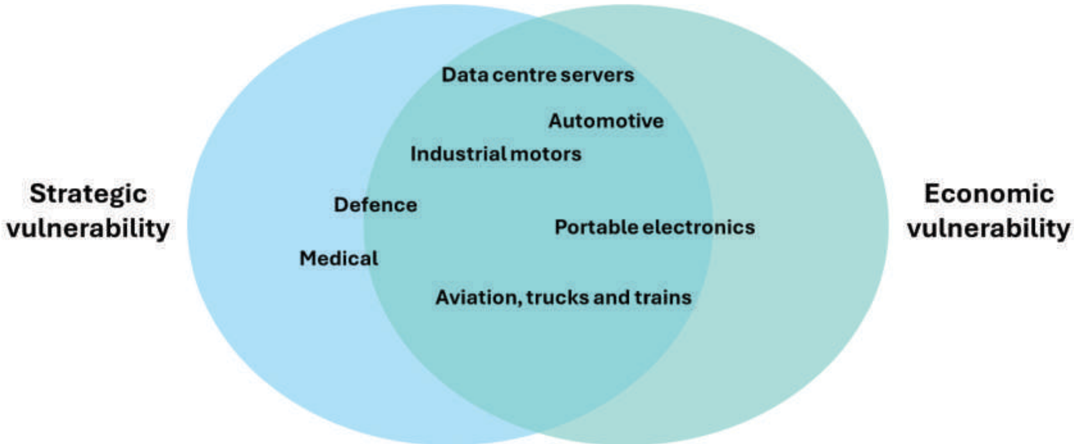
Rare earth-dependent product	High-value associated services
Data centre servers	AI services, cloud computing, data analytics, fintech, cybersecurity, content delivery, e-commerce, streaming services, communication etc.
Aviation, trucks and trains	Passenger transport and tourism, business travel, logistics, e-commerce, freight, tourism etc.
Portable electronics	Professional services, mobile communications, internet services, digital media, software and applications, social networks, financial technology and payments etc.

Rare earth-dependent product	High-value associated services
Industrial motors	Manufacturing, automated manufacturing, robotics, energy services, mining, oil and gas etc.
Automotive	Transport and mobility services, logistics, leasing, financing and insurance services etc.

Strategic impacts

Some sectors may have lower economic impact for some regions, but they can still pose major strategic vulnerabilities, for example defence or medical applications that rely heavily on rare earths. Future economic and strategic value is also a key consideration, even where current exposure appears modest today. For example, data centre servers, which are critical for AI development, underpin a sector widely regarded as one of the most strategically and economically significant for the future.

Economic and strategic vulnerabilities of rare earth-dependent sectors



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The high risks associated with supply concentration and tensions in rare earth trade, together with the outsized economic impact of potential disruptions, call for urgent actions to increase resilience and diversification of rare earth supply chains. Short-term preparedness to potential shocks is key to defend strategic sectors, while more diversified supply chains are built. Chapter 4 will include possible measures to increase resilience and limit economic impacts by establishing comprehensive emergency preparedness systems, including market monitoring, dialogue with industry, emergency measures such as stockpiling, and emergency response exercises.

Chapter 3. Opportunities and challenges for diversification

While emergency response measures play an important role in addressing the impacts of geopolitical developments on prices and supply, ensuring the fundamental resilience of supply chains requires parallel efforts on diversification through strong international partnerships.

Diversification in the rare earths market has been limited by several factors. In the upstream segment, only a handful of mines outside the People's Republic of China (hereafter, "China") and Myanmar are operating at scale, and newly announced projects typically have long lead times, averaging around eight years. Refining development is even more nascent, with only a few industrial-scale facilities operating outside China today – in Malaysia, the United States and Estonia, although several projects are currently under development across various regions. However, planned capacity for permanent magnet manufacturing outside China is notably lower than for mining and refining, posing a key source of concern.

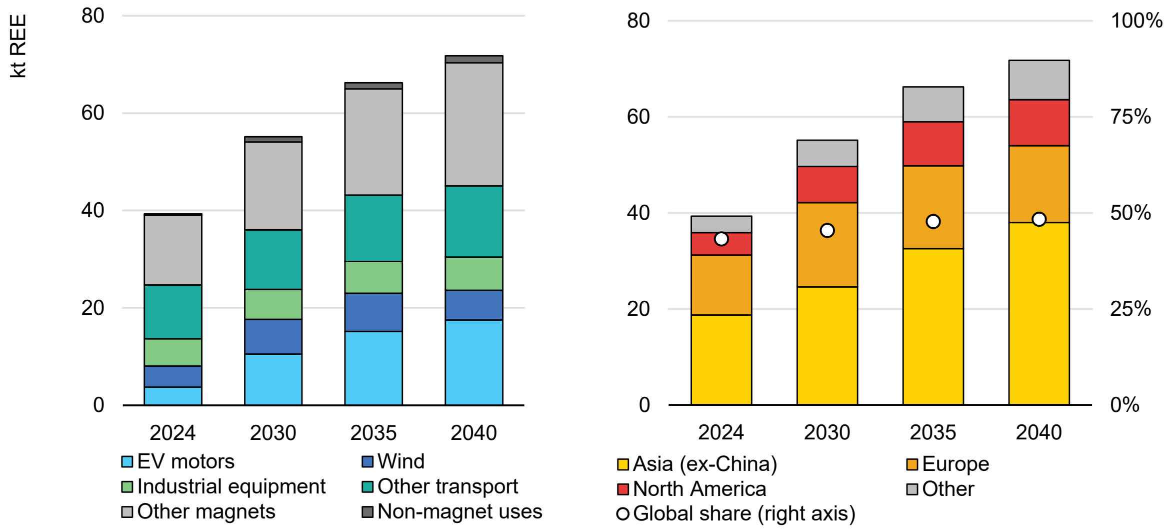
This chapter lays out the global picture for magnet rare earth element (REE) demand and supply, particularly in the context of regions outside the largest supplier, to understand where the gaps lie, what is required to close them and the challenges that could hinder these efforts.

Needs for diversified rare earth supplies

Demand for magnet rare earths outside China rises steadily through to 2040, driven primarily by the rapid expansion of electrification, energy and automation technologies. It increases from around 40 kilotonnes (kt) today to around 70 kt by 2040 under today's policy settings, with the largest contribution coming from electric vehicle (EV) deployment, in both advanced economies and emerging market and developing economies. Major original equipment manufacturers (OEMs) expanding production across Japan, Korea, North America, Europe and India rely on magnet rare earths most prominently for EV traction motors, but also for many smaller magnetic components (actuators, speakers, sensors) for conventional cars and all types of vehicles. Wind power is also a source of demand growth. Despite some headwinds, turbine installations continue to expand and shift towards larger, permanent-magnet-based designs for offshore installations. Industrial motors and equipment and other transport applications account for the remaining contributions.

Energy applications increase their contributions over time. By the mid-2030s, EV motors account for the single largest share of demand, reflecting both higher vehicle sales and the trends favouring larger vehicles in many regions. Wind power demand also grows this decade, supported by offshore expansion and repowering of onshore fleets. At the same time, a wide range of appliances and consumer electronics continues to rely on permanent magnets. Emerging growth in automation, robotics and digital technologies plays a larger role in driving total demand beyond 2030, as permanent magnets enable precision motion control, miniaturisation (small motors with high power) and energy efficiency for these applications.

Magnet rare earths demand outlook outside of dominant supplier, 2024-2040



Note: The figures are for magnet rare earths only (neodymium, praseodymium, terbium and dysprosium).

Regionally, Asia remains the dominant centre of demand outside China, accounting for roughly half of global consumption throughout the outlook period, supported by large manufacturing bases in Japan and Korea. Europe and North America register notable increases, reflecting strong policy support for electrification and renewed ambitions to scale up domestic manufacturing for high-tech supply chains. Nevertheless, the global share of demand outside China expands only gradually from just over 40% today to nearly half of global demand by 2040, indicating that China continues to play a central role in magnet rare earth consumption.

How do projections vary by scenario?

The demand projections in this report are based on the Stated Policies Scenario (STEPS), which reflects today's policy settings based on existing and announced policies. However, the outlook for rare earth demand and supply varies across International Energy Agency (IEA) scenarios.

STEPS assumes the deployment of EVs, offshore wind, robotics and advanced manufacturing in line with current policy commitments, alongside a specific mix of car sizes, wind turbine types, motor technologies and a particular pace of improvement in material efficiency. However, in a scenario that considers a snapshot of policies and regulations that are already in place, such as in the Current Policies Scenario, demand for rare earths is notably lower owing to the slower speed at which new energy technologies can be deployed in the energy system. Conversely, in a scenario that reflects higher ambitions to reduce emissions, such as in the Announced Pledges Scenario or the Net Zero Emissions by 2050 Scenario, demand is higher due to the faster uptake of energy technologies. Beyond scenario differences, assumptions about technological evolution also play a role. For example, faster progress in alternative motor designs or magnet-lean engineering could reduce demand further.

Beyond demand projections, recycling can also contribute to supply-demand balances, though volumes currently remain very low. The availability of recyclable feedstock varies across scenarios, reflecting differing levels of technology deployment. Other important factors include the strength of end-of-life collection frameworks and recycling design requirements; the pace of technological progress in recovering rare earths from complex or small products such as consumer electronics; regulatory measures such as recycled content requirements or controls on magnet scrap exports; and the geography of magnet manufacturing, which determines where recycling feedstock arises.

Multiple scenarios and technology cases for critical minerals, including rare earths, are available through the Critical Minerals Data Explorer, which allows users to explore how different assumptions affect demand and supply outcomes for key minerals and demand by technology over time.

Diversified supply project pipelines

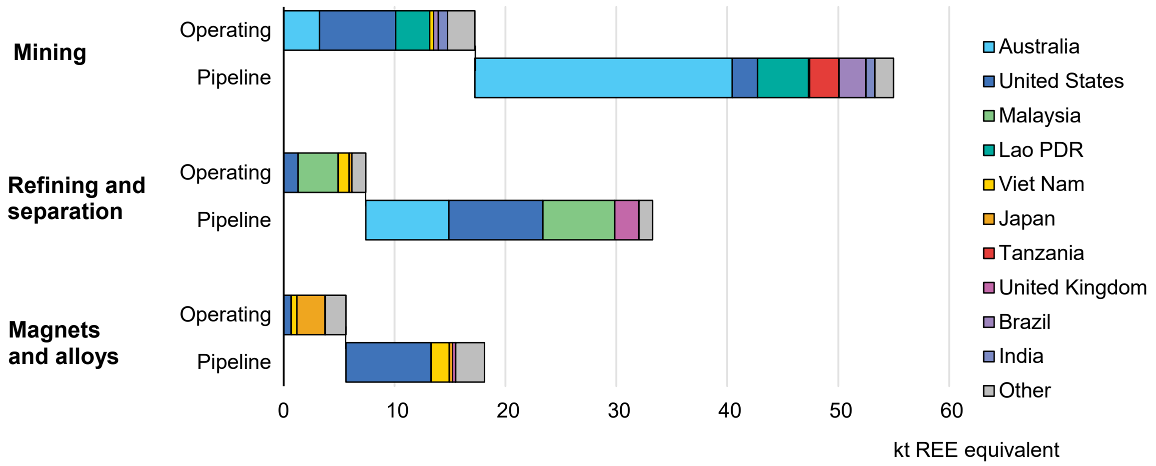
While today's rare earth supply chains are highly concentrated in China, a number of projects across the value chain are currently starting operations or under development in various regions. However, there is a visible mismatch in the scale of project pipeline across the supply chain. Planned capacity for diversified projects narrows progressively from mining to refining to magnet manufacturing, posing a key source of concern. Several new magnet manufacturing plants began operations in 2025, notably in the United States (MP Materials) and Estonia (Neo Performance Materials), while other projects are accelerating in the United States, Japan, Korea, Viet Nam and Germany. Continued efforts through targeted policy support and strategic partnerships will nonetheless be essential to bring more projects online.

Type and location

Existing and announced projects in geographically diverse regions point to a substantial expansion of magnet rare earth supply chains outside China within the decade, although progress remains uneven across the value chain. Mining capacity shows the largest potential increase, crossing 50 kt of REEs by 2035, led by Australia and the United States, with additional contributions from Brazil, Lao People's Democratic Republic (PDR), Tanzania, India and other smaller producers. By contrast, refining and separation capacity – an essential but technically complex step – amounts to less than 40 kt, with activity concentrated in Malaysia and the United States, followed by Australia, Viet Nam, Japan, the United Kingdom, France and Estonia. Downstream capacity is more limited: cumulative planned production of metals, alloys and finished magnets from projects announced as of early 2026 amounts to around 57 kt of neodymium-iron-boron (NdFeB) in 2035, equivalent to 18 kt of magnet rare earth content, significantly less than diversified rare earth refining capacities. This reflects a relatively modest pipeline led by the United States, and with notable contributions from Europe and parts of Asia including Japan, Korea and Viet Nam.

This pronounced tapering from upstream mining to downstream magnet manufacturing highlights the difficulty in establishing entire supply chains outside China. While resource development is advancing in several regions, the comparatively slower build-out of refining and magnet production suggests that critical midstream and downstream stages could remain bottlenecks. Without accelerated investment in these parts of the value chain, many regions may continue to depend on external processing and manufacturing even as domestic extraction capacity expands.

Estimated 2035 production from currently operating and planned projects for magnet rare earth mining, refining and magnet manufacturing in diversified regions

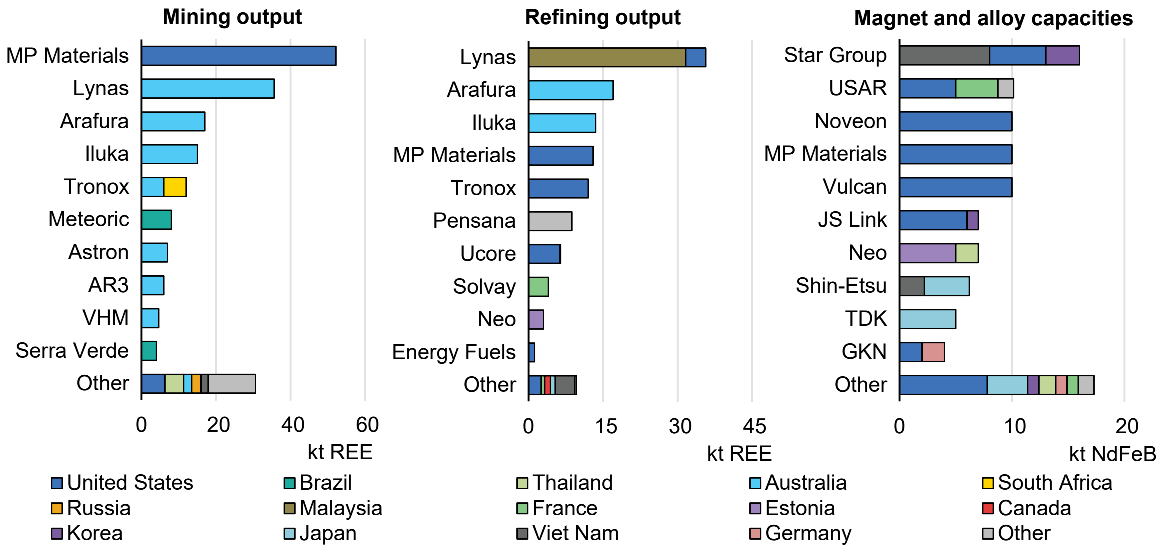


Notes: Lao PDR = Lao People's Democratic Republic. The figures are for magnet rare earths only (neodymium, praseodymium, terbium and dysprosium). The magnet values reflect the contained volume of rare earths (in kt REE) in permanent magnets manufactured (kt NdFeB).

Companies and ownership

Based on company ownership across existing operations and the announced project pipeline, a relatively small group of companies play an important role in producing volumes in geographically diverse regions, outside China and Myanmar. In mining, existing and planned projects indicate that today's established producers play a central role even in 2035, led by MP Materials in the United States and Lynas Rare Earths in Australia, followed by companies such as Arafura Rare Earths, Iluka Resources, Tronox and Meteoric Resources. In refining and separation, firms with advanced chemical processing expertise are prominent, with Lynas Rare Earths (at its refinery in Malaysia) and MP Materials currently operating the two largest facilities outside China, and Arafura Rare Earths, Iluka Resources, Tronox and Pensana becoming important contributors by 2035. Neo Performance Materials (in Estonia), Energy Fuels, Solvay and Carester are other specialised chemical processors supporting diversified supply. Downstream magnet and alloy manufacturing is characterised by a more technologically specialised set of companies, led by firms from Japan (Shin-Etsu, TDK, Daido and Proterial), Korea (Star Group) and North America (Noveon Magnetics, USA Rare Earths, MP Materials, Vulcan Elements, Neo Performance Materials).

Estimated 2035 production for rare earth elements in diversified regions by company and ownership



Notes: REE = rare earth elements, NdFeB = neodymium iron boron magnets; Lynas = Lynas Rare Earths Limited; Arafura = Arafura Rare Earths; Iluka = Iluka Resources; Meteoric = Meteoric Resources; AR3 = Australian Rare Earths; Serra Verde = Serra Verde Mineração; Ucore = Ucore Rare Metals; USAR = USA Rare Earth; Noveon = Noveon Magnetics; Vulcan = Vulcan Elements; Neo = Neo Performance Materials; Shin-Etsu = Shin-Etsu Chemicals; TDK = TDK Corporation; GKN = GKN Powder Metallurgy. The Pensana project is considered to be based in the United Kingdom as of 2025. The production figures for mining and refining include all rare earths produced by the projects in element equivalent terms.

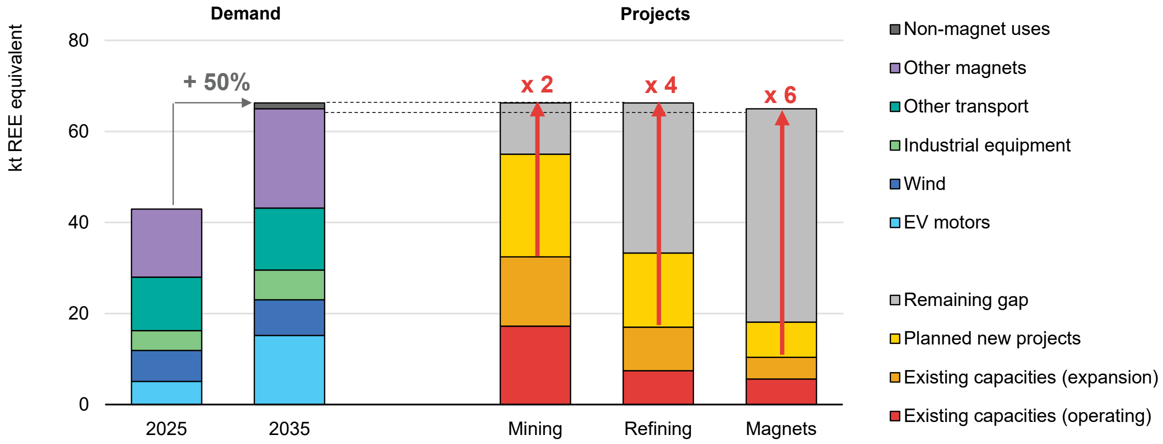
Supply and demand balances outside the top producer

Demand for magnet rare earth elements in regions outside the dominant suppliers is set to grow by 50% over the next decade, led by EV motors and high-tech applications. However, existing production capacity outside China and Myanmar remains highly limited across the value chain, exposing key strategic sectors to significant supply risks. Production from current capacities in regions outside China and Myanmar account for only 45% of mining, 20% of refining and 14% of magnet demand in these regions. Including their planned expansions, they account for about 50% of the demand for mining, 25% for refining and well below 20% for magnets in 2035.

Meeting the projected demand outside the dominant suppliers fully from diversified capacities necessitates the development of additional projects expanding mining, refining and magnet manufacturing capacity by factors of two, four and six respectively, on top of planned expansions from existing projects. With growing security risks, a number of new projects have been announced across the supply chain, which could help narrow the supply gaps if successfully implemented, although these projects need to address financing, technical and operational challenges.

Nonetheless, existing and announced projects in geographically diverse regions are still insufficient to fully cover projected demand in these regions, requiring the development of new greenfield projects across the supply chain, with a particularly strong need for refining and magnet manufacturing. Magnet production is the strongest bottleneck for supply diversification. Production of magnets outside China is highly limited. While several plants have begun construction or are ramping up and around 14 additional greenfield projects have been announced outside the top producing country, expected production remains far below the need in these regions.

Magnet rare earth demand and production from existing and announced mining, refining and magnet projects in diversified regions, 2035



Notes: REE = rare earth elements. Recycling has the potential to reduce the remaining gaps. The figures are for magnet rare earths only (neodymium, praseodymium, terbium and dysprosium).

A key constraint on magnet supply diversification is that many announced projects do not yet plan to operate across all stages of magnet manufacturing, from refined oxides to finished magnets. In particular, the “metallisation” stage, where refined rare earth oxides are converted into metallic alloys or powders, remains a critical bottleneck. While this step requires specific expertise that remains concentrated among a limited number of players, some companies are developing dedicated metallisation facilities, either in-house, such as US-based Phoenix Tailings, or through partnerships and acquisitions. One example is a British company, Less Common Metals, which is expected to develop a metallisation plant in France as part of the industrial ecosystem in Lacq. The company has also been recently acquired by USA Rare Earths, which also aims to expand magnet capacities in the United States.

Estimated production for selected rare earths projects outside China

Project	Country	Ownership	Estimated production in 2035 (t REE)
Mining			
Brownfield projects (planned expansion)			**Planned addition**
Mount Weld	Australia	Lynas (AU)	21 300
Mountain Pass	United States	MP Materials (US)	11 000
Orissa	India	India Rare Earth Limited (IN)	2 000
Greenfield projects			
Nolans	Australia	Arafura (AU)	17 000
Eneabba	Australia	Iluka Resources	8 000
Caldeira	Brazil	Meteoric Resources (AU)	8 000
Donald	Australia	Astron (AU)	7 000
Strange Lake	Canada	Torngat Metals (CA)	2 750
Refining			
Brownfield projects (planned expansion)			**Planned addition**
Balok	Malaysia	Lynas (AU)	17 200
Mountain Pass	United States	MP Materials (US)	5 250
La Rochelle	France	Solvay (BE)	2 000
Silmet	Estonia	Neo Performance Materials (CA)	500
Greenfield projects			
Nolans	Australia	Arafura (AU)	17 000
Eneabba	Australia	Iluka Resources (AU)	13 500
Hamilton	United States	Tronox (US)	12 000
Louisiana SMC	United States	Ucore Rare Metals (CA)	6 300
Long Mott	United States	Lynas (AU)	4 000
Magnet and alloy manufacturing			
Brownfield projects (planned expansion)			**Planned addition**
San Marcos	United States	Noveon Magnetics (US)	5 600
Que Son	Viet Nam	Star Group (KR)	4 900
Narva	Estonia	Neo Performance Materials (CA)	2 800
Exeter	United States	Phoenix Tailings (US)	1 750
Ellesmere	United Kingdom	USA Rare Earth (US)	900
Greenfield projects			
Polaris	United States	Vulcan Elements (US)	7 000
10X	United States	MP Materials (US)	4 900
Stillwater	United States	USA Rare Earth (US)	3 500
Lacq	France	USA Rare Earth (US)	2 650
Independence	United States	MP Materials (US)	2 100

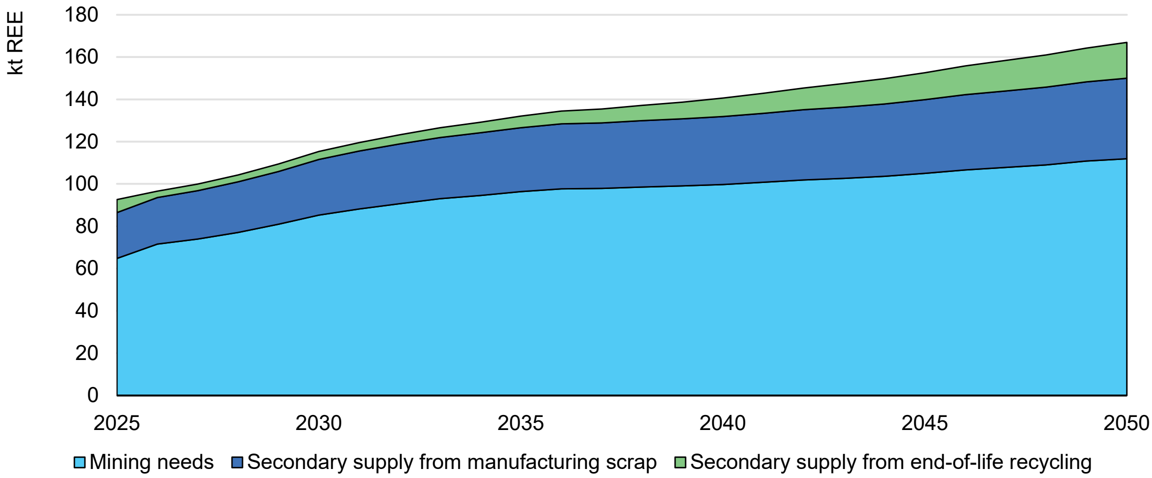
Notes: t = tonnes; REE = rare earth element; AU = Australia; BE = Belgium; CA = Canada; IN = India; KR = Korea; US = United States. Myanmar- and China-owned projects are excluded from the table. Projects shown in this table were selected by expansion size for brownfield projects, and total size for greenfield projects. The figures for mining and refining represent total rare earths. The magnet values reflect the contained volume of rare earths (in kt REE) in permanent magnets manufactured (kt NdFeB). The projects listed represent a selection of the planned brownfield and greenfield projects. Production figures for brownfield projects and expansions represent the additional output between today and 2035.

Sources: IEA analysis based on Wood Mackenzie, company reports and press research.

Opportunities for recycling

With the right policy framework, recycling can contribute to reducing overall rare earth mining needs, offering substantial economic and sustainability benefits. While not able to meet the totality of the demand for magnets, secondary supply has potential to lower mining requirements by 35% in 2050 – 25% from manufacturing scrap and 10% from the recycling of end-of life products.

Recycling volumes and mining requirements for magnet rare earth elements



Notes: REE = rare earth element. The figures are for magnet REEs only (neodymium, praseodymium, terbium and dysprosium).

Dedicated policies are essential to unlock the full potential of secondary rare earth supply, as each source of feedstock presents distinct challenges and opportunities. Today, secondary supply is dominated by manufacturing scrap, which accounts for close to 75% of total secondary volumes. However, industrial scrap is generated where magnets are produced, 94% of which occurs in China, limiting its contribution to supply diversity.

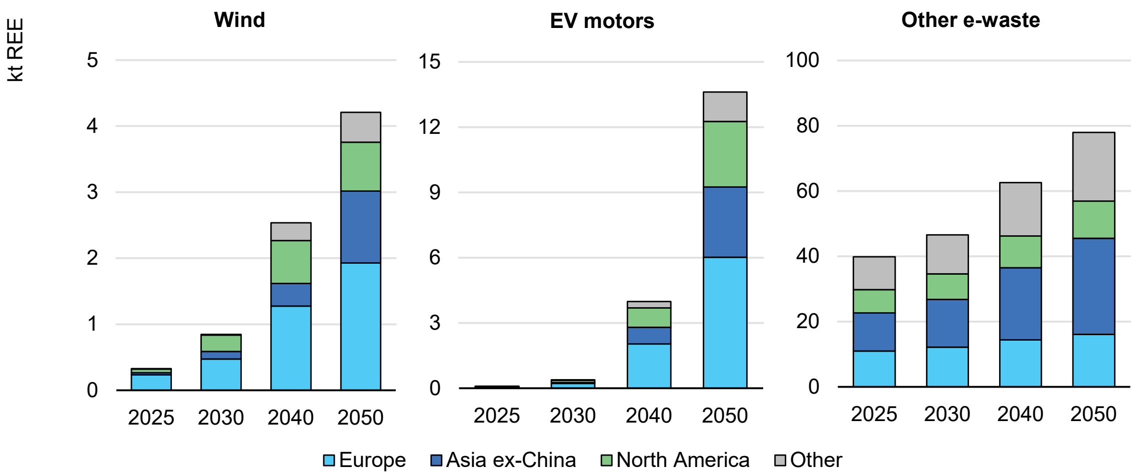
End-of-life products represent a growing opportunity for recycling and diversification. Total available feedstock is expected to grow by 50% by 2035.

- Wind turbines are a relatively small but rapidly expanding source of secondary rare earth supplies. Their large magnet sizes make recycling particularly competitive, and feedstock available outside China is projected to increase twelve-fold by 2050, reaching 2 500 tonnes in 2040 and 4 000 tonnes in 2050.
- EV motors, which are poised for even faster growth, reach 4 000 tonnes by 2040 and beyond 12 000 tonnes in 2050 outside China.
- Other electronic and electrical waste streams already contain around 50 kt of rare earths today. Despite this sizeable resource, recycling rates remain very low due to technical barriers, such as dispersed materials and small magnet sizes, as well

as limited economic and regulatory incentives. This can lead to challenges in disassembling magnets from products, distinguishing rare earth-containing magnets from other types of magnets, and managing various magnet specifications, including size and elemental composition, within recycling processes.

Harnessing the potential from these end-of-life products can make a significant contribution to diversifying rare earth supply chains. Europe is well placed to capture this emerging opportunity: by 2030, the region is set to generate about 50% of global end-of-life magnet feedstocks from wind turbines and 25% from EV motors. End-of-life feedstocks from other technologies are more widely distributed, creating opportunities for many regions to utilise these resources. Realising this potential will require robust collection systems, particularly in emerging market and developing economies, where today's frameworks remain limited.

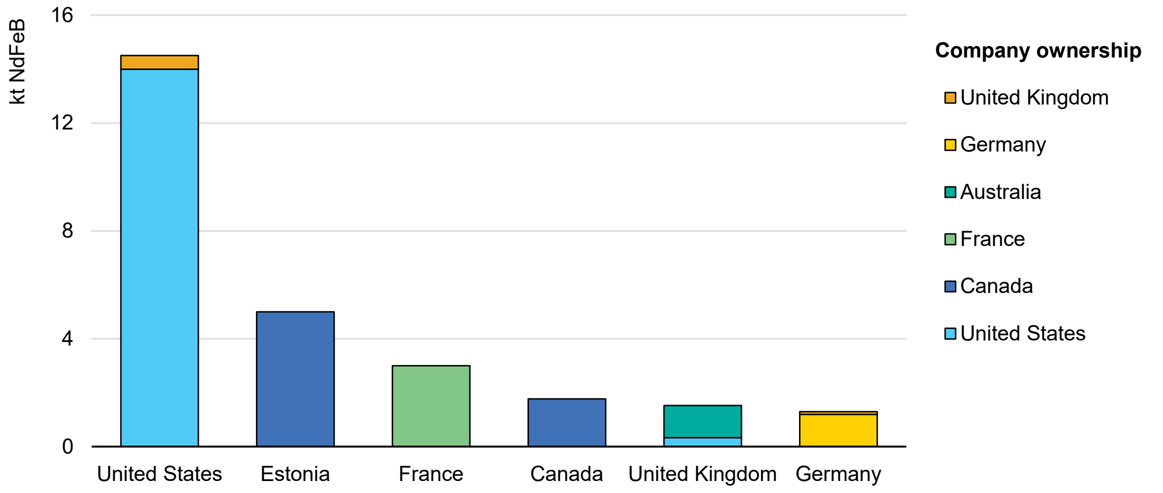
Availability of end-of-life magnet rare earth feedstocks outside China by type and region



Notes: REE = rare earth elements. The figures are for magnet REE only (neodymium, praseodymium, terbium and dysprosium).

New industrial players and research and development activity are increasing the prospects for rare earth recycling capabilities, driven by technological innovation and growing expectations for future market opportunities. A large number of projects have been announced in North America, with projects developed by companies such as Noveon, ReElement, MP Materials and Element USA in the United States. Europe also hosts a number of projects, where two factories recently opened in France and the United Kingdom using novel hydrogen processing technologies. Other key actors include Cyclic materials in Canada, NeoPerformance Materials in Estonia, Caremag and Orano in France, Heraeus Remloy in Germany, and Ionic Rare Earths in the United Kingdom.

Announced rare earth permanent magnet recycling capacity outside China by location and country ownership, 2035



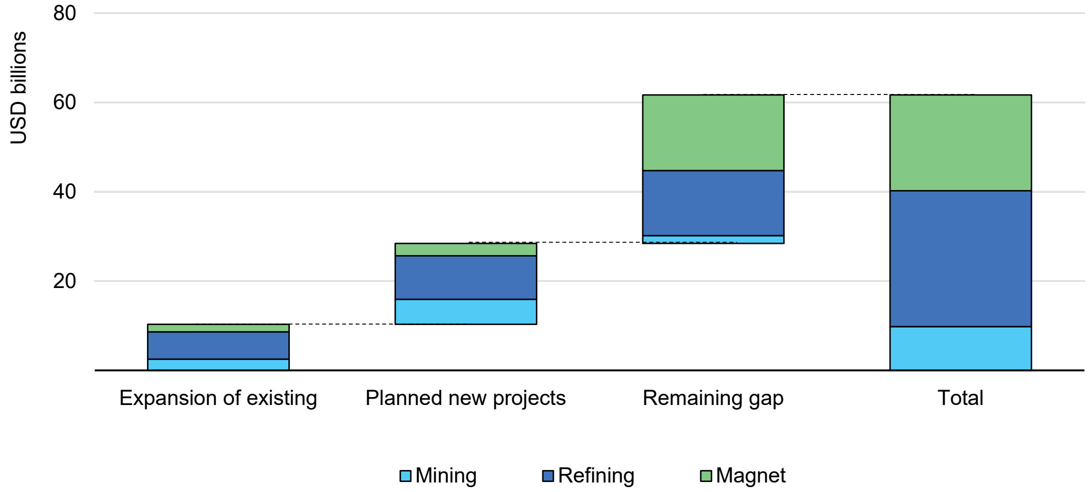
Notes: NdFeB = neodymium-iron-boron magnets. Capacities are reported as the mass of input feedstock facilities can process, in kt of end-of-life magnets and scrap.

Investment

Developing a secure supply chain for magnet rare earths will require sustained investment in both new and announced capacities. Meeting projected demand in regions outside the top supplier requires an estimated USD 60 billion in investment across mining, refining and magnet manufacturing facilities over the next decade (USD 6 billion per year). At USD 30 billion, refining requires the largest amount of investment, followed by USD 21 billion for refining. This includes funding for announced projects that have not yet secured financing, as well as new projects that will be required to close the remaining supply gap.

While sizeable, this amount remains relatively modest compared with the investment required in other energy mineral supply chains – meeting the rising demand for copper, nickel, lithium and cobalt requires around USD 800 billion of capital expenditures to 2035. The scale also remains modest in comparison with the huge direct economic impact USD 6.5 trillion, which could arise due to high supply concentration.

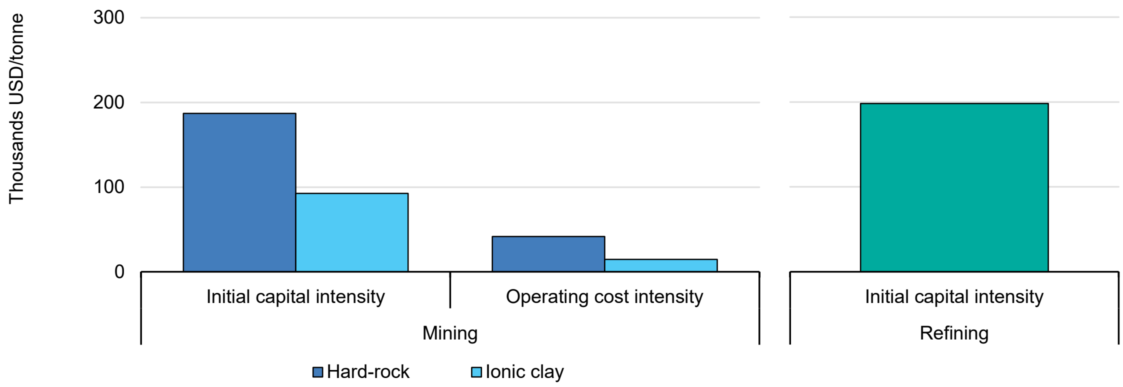
Investment requirements to 2035 in magnet rare earth supply chains to meet projected demand in diversified regions



Note: Investment requirements are estimated by multiplying the gap between projected supply and primary supply requirements by capital intensity.

Despite relatively lower overall scale compared with other minerals, individual rare earth mining and refining projects still involve high capital costs, ranging from tens of millions to more than USD 1 billion. Capital intensities sit at around USD 100 000 per tonne for mining and USD 200 000 per tonne for refining, far more than almost any other energy mineral. These high costs reflect that rare earth projects are structurally more expensive, especially at the refining stage, due to complex processes involved, including beneficiation, chemical leaching, multistage separation, and high energy and reagent requirements.

Mining and refining capital intensities of rare earth projects



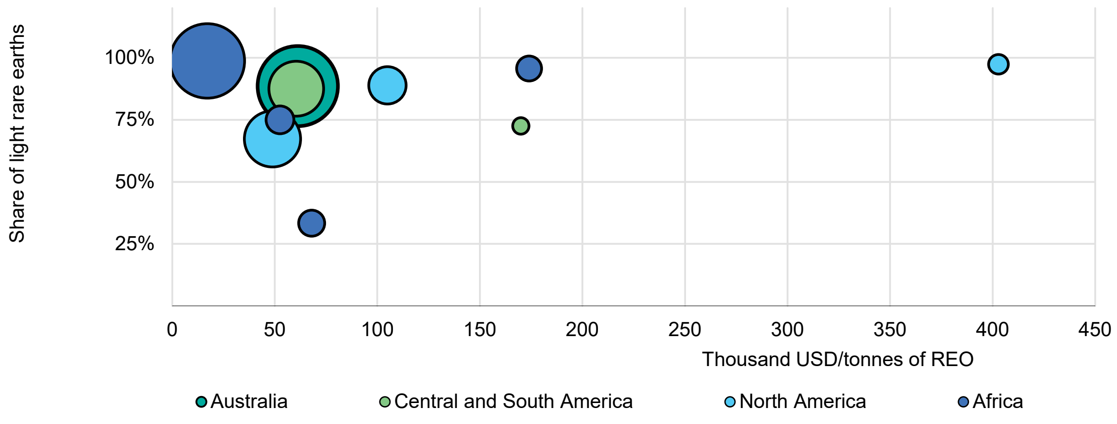
Note: This analysis considers capital intensity for rare earth projects without distinction between different rare earth elements.

Costs vary widely across projects due to geological, technical and locational factors such as deposit type, ore grade, recovery rates and the mix of light versus heavy rare earths (HREEs). One of the biggest structural cost differentiators is the type of deposit. Hard-rock projects have nearly double the capital intensity and triple the operating costs of ionic clays, largely because they rely on more energy- and reagent-intensive processing. Ionic clays, by contrast, benefit from naturally "pre-weathered" host rock that is easier to leach, although they often have lower grades, lower recovery and more environmental risks.

The composition of the deposit also matters. Projects aiming to perform full heavy rare earth separation on-site face significantly higher capital requirements, as HREE separation requires significantly more specialised equipment and solvent-extraction stages – in some cases up to 40 times more stages than for light rare earth separation. Many heavy-rich deposits, particularly ionic clays, could use alternative processing routes such as producing a mixed concentrate and sending it to centralised separation facilities, which reduces the capital intensity at the mine site.

Beyond geology and metallurgy, regional differences are also stark, particularly in operating cost. For example, crack-leach operating costs outside China can be anywhere from 2.5 times to 10 times more expensive than in China, largely due to stricter environmental controls, more expensive chemical inputs, energy prices and the management of radioactive by-products.

Variations across capital intensities for selected rare earth projects by the composition of light and heavy rare earths



Notes: REO = rare earth oxides. The projects include both historical operations and planned developments, based on company documents.
Source: IEA analysis based on company documents.

Key challenges in advancing diversification

Economics and investment

Challenges obtaining financing and reaching economic viability remain one of the central constraints to diversifying rare earths supply chains, arising from a combination of structural cost and market factors. Projects in geographically diverse regions typically face higher upfront capital requirements due to smaller economies of scale, higher labour and energy costs, and limited availability of reagents. Stricter environmental requirements can also increase the cost. These pressures are reinforced by geological factors such as low ore grades and complex recovery processes, which can push production costs above those of established competitors.

Financing challenges remain particularly difficult at the early stages. Spending before the final investment decision must cover geological studies, pilot testing, environmental permitting and community engagement, often long before any revenue certainty exists. While offtake agreements are not always required during exploration or early feasibility work, they typically become critical at the final investment decision. Downstream customers, especially in sectors where safety standards are stringent, typically require lengthy qualification periods that demonstrate technical feasibility, as well as piloting before committing to long-term supply contracts. This creates a structural sequencing challenge: developers need assured demand to raise capital, while end users often need demonstrated technical performance before offering commercial commitments.

Demand outside China also remains limited relative to China's large, integrated domestic ecosystem, making diversified producers highly sensitive to shifts in demand. This is especially true for co-products of magnet rare earths such as cerium and lanthanum, which must be placed in non-magnet applications to avoid undermining the economics of magnet-grade elements. At the same time, many buyers continue to favour lower-cost Chinese material, reflecting competitive pressures and the absence of frameworks that incentivise diversified sourcing.

Many of the rare earth mining projects are owned by smaller mining companies with limited access to balance-sheet financing, leaving them reliant on external equity or debt financing to fund development. Yet the combination of high capital costs and relatively modest project scale can deter large institutional investors, making capital raising difficult. High price volatility and the absence of transparent benchmark prices further complicate cash-flow projections, raising the cost of capital and delaying final investment decisions.

These challenges are amplified in diversified regions. Projects in the top producer often benefit from long-established industrial ecosystems, integrated processing capacity, shared infrastructure, ample financial buffers and large, established domestic offtake bases that provide robust demand signals. There is also relatively easy access to low-cost energy, reagents and skilled workers, which reduces both capital and operating costs. By contrast, projects in diversified regions face higher input costs, more complex permitting requirements and fragmented supply chains, raising development risk.

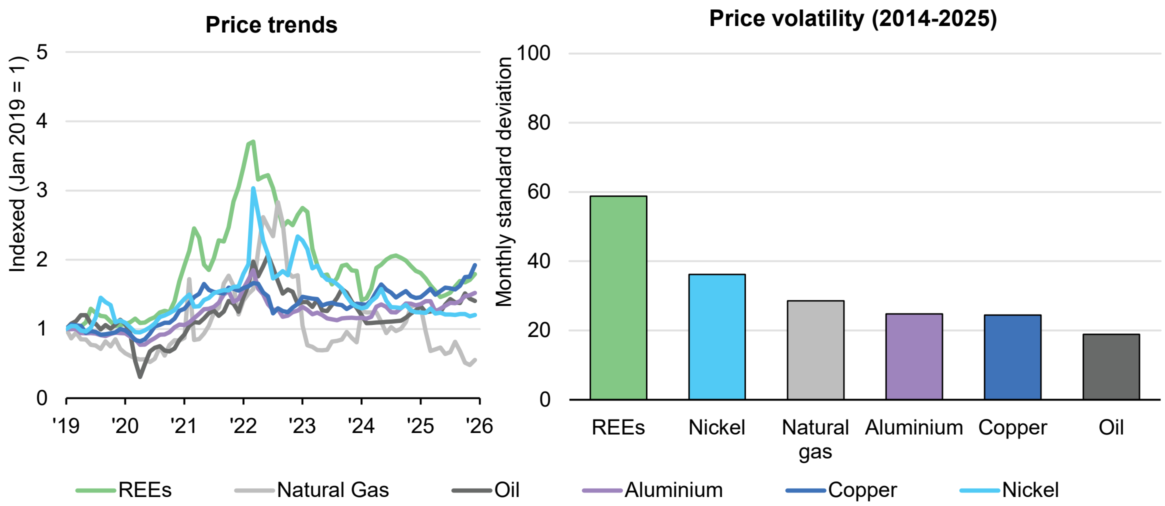
Project-level constraints are compounded by broader market characteristics. The global market is relatively small, meaning that even a limited number of new entrants could materially affect supply-demand balances, increasing the risk of oversupply and price downturns. Combined with the limited scale of downstream manufacturing base in regions outside China, this raises the cost of capital for developers and complicates cash-flow projections. Long development timelines and extended ramp-up periods can further lengthen payback horizons, reducing project attractiveness.

Demand and price uncertainties

Rare earth markets have experienced two major price spikes: the 2010-2011 crisis, driven by China's export restrictions, and another in 2022, caused by tight market conditions. These sharp spikes mean that average monthly price volatility over the past decade was roughly twice that of natural gas and three times that of crude oil, placing rare earths as the third most volatile among 20 strategic energy-related minerals tracked by the IEA, surpassed only by lithium and gallium.

Price uncertainty is amplified by the relatively small size of the market and its increased fragmentation across multiple specifications, grades and oxides, which structurally limits transaction liquidity. Most transactions are conducted over the counter, with price discovery largely dependent on thin spot markets, primarily centred in China.

Price developments (left) and monthly price volatility (right) for rare earths and other selected commodities



Notes: REEs = rare earth elements. Assessment based on neodymium, praseodymium, dysprosium and terbium rare earth oxide 99.5% minimum free on board (FOB) China spot prices, Brent crude spot price FOB (oil), and Henry Hub natural gas spot price. Volatility values were calculated from 2014 to 2025.

Source: IEA analysis based on KOMIS (2026), Minor Metals, US Energy Information Administration (2026), Henry Hub Natural Gas Spot Price, S&P Global and Bloomberg.

Outside China, price discovery is hindered by an overall lack of liquidity. Export controls and trade restrictions have further strained market dynamics. Following the export restrictions in April 2025, prices quoted outside China have frequently diverged from Shanghai benchmark prices, while extraterritorial regulations constrain the resale and redistribution of rare earth products by importers, further impeding the development of liquid markets outside China.

This market structure makes it difficult to develop key financial tools that are commonly used to hedge risks in other commodity markets. The lack of reliable spot market prices, particularly outside China, complicates the creation of long-term supply contracts and offtake agreements, which are critical for project developers seeking to hedge risks. The absence of a futures market complicates risk management for refiners, recyclers and magnet manufacturers, who would typically use these tools in other more established commodity markets.

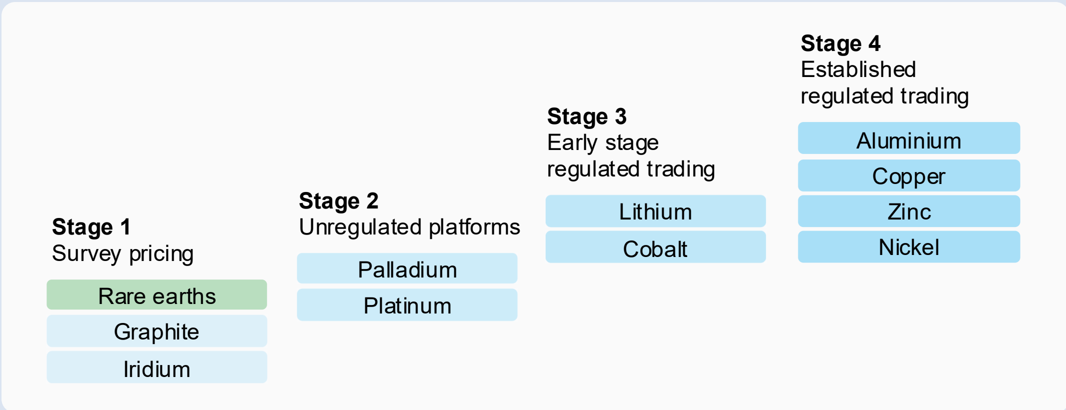
Demand uncertainty is another factor that hampers investment decisions. The outlook for rare earth demand remains uncertain, shaped by factors such as the pace of downstream technology deployment and broader technological evolution. While many regions are developing manufacturing capacity for EVs, wind power, artificial intelligence (AI) data centres and other strategic sectors that rely on rare earth magnets, the pace of this expansion is uncertain, complicating investment decisions for upstream supply chains. The lack of incentives for existing consumers to source from diversified suppliers further exacerbates these challenges.

Rare earth markets are among the least liquid and most concentrated of commodity markets

Price discovery and thus transparency takes different forms depending on market maturity. Maturity varies depending on the level of liquidity, which itself depends not only on the size of the market, but also on the degree of commoditisation, the level of fragmentation and the number and diversity of participants. When markets are mature, there is a clear "spot" price, corresponding to immediate delivery, as well as a forward price curve, which reflects market information on prices for delivery months or years into the future.

Higher levels of market maturity deliver two principal advantages. First, they enhance the clarity and reliability of price signals, thereby supporting short-term operational decisions by merchants, processors and refiners, while also informing medium- and long-term investment planning and procurement and offtake strategies. Second, greater maturity underpins the development of financial instruments that enable refiners and recyclers and downstream consumers to manage and hedge price risk more effectively.

Market maturity for selected minerals



For rare earths, the market is mostly operating under stage-1 survey-based pricing, where market participants rely on price reporting agencies (PRAs). Currently, the main reference prices are those that are published by China-based agencies, notably Asian Metal. Despite PRAs outside of China, mostly audited against International Organization of Securities Commissions (IOSCO) Principles, starting to report on rare earths in recent years, these are still not yet widely utilised.

Liquidity in rare earth markets is structurally constrained. Market size remains modest relative to most other bulk commodities, limiting the depth and breadth of trading activity. Moreover, rare earths are not traded as standardised commodities. They encompass 17 distinct and often intermixed elements marketed in a wide range of forms – including concentrates, oxides, carbonates, other chemical compounds, swarf, powders, metals, alloys and magnets – each with varying specifications and grades.

Market fragmentation is further reinforced by high levels of supply concentration and the presence of trade restrictions. Volumes traded outside the leading producing country account for only a limited share of the market. In addition, resale and re-export of material originating from the dominant supplier are subject to regulatory constraints, further reducing secondary market liquidity and price transparency.

Technology, ecosystem and skills

Rare earth processing and magnet manufacturing rely on highly specialised technology and equipment. Chinese export controls on technology and equipment announced in December 2023 span nearly the entire supply chain from extraction including ionic leaching – which is increasingly used to extract HREEs from ionic clay deposits – to separation and processing, strip casting for metal/alloy production, and magnet-making equipment (decrepitation, alignment pressers, coating) for both NdFeB and samarium-cobalt (SmCo) permanent magnets. This creates significant barriers for new entrants trying to build capacity in geographically diverse regions, which will require innovation and international co-operation to overcome.

There is also a shortage of skilled workforce across all countries outside of the dominant producer. Rare earth separation and refining and magnet manufacturing are technically demanding, requiring a workforce with specific expertise that is relevant for each step of the supply chain. Building this talent base takes time and requires dedicated investments in training and skill transfer.

Environmental impacts and waste handling

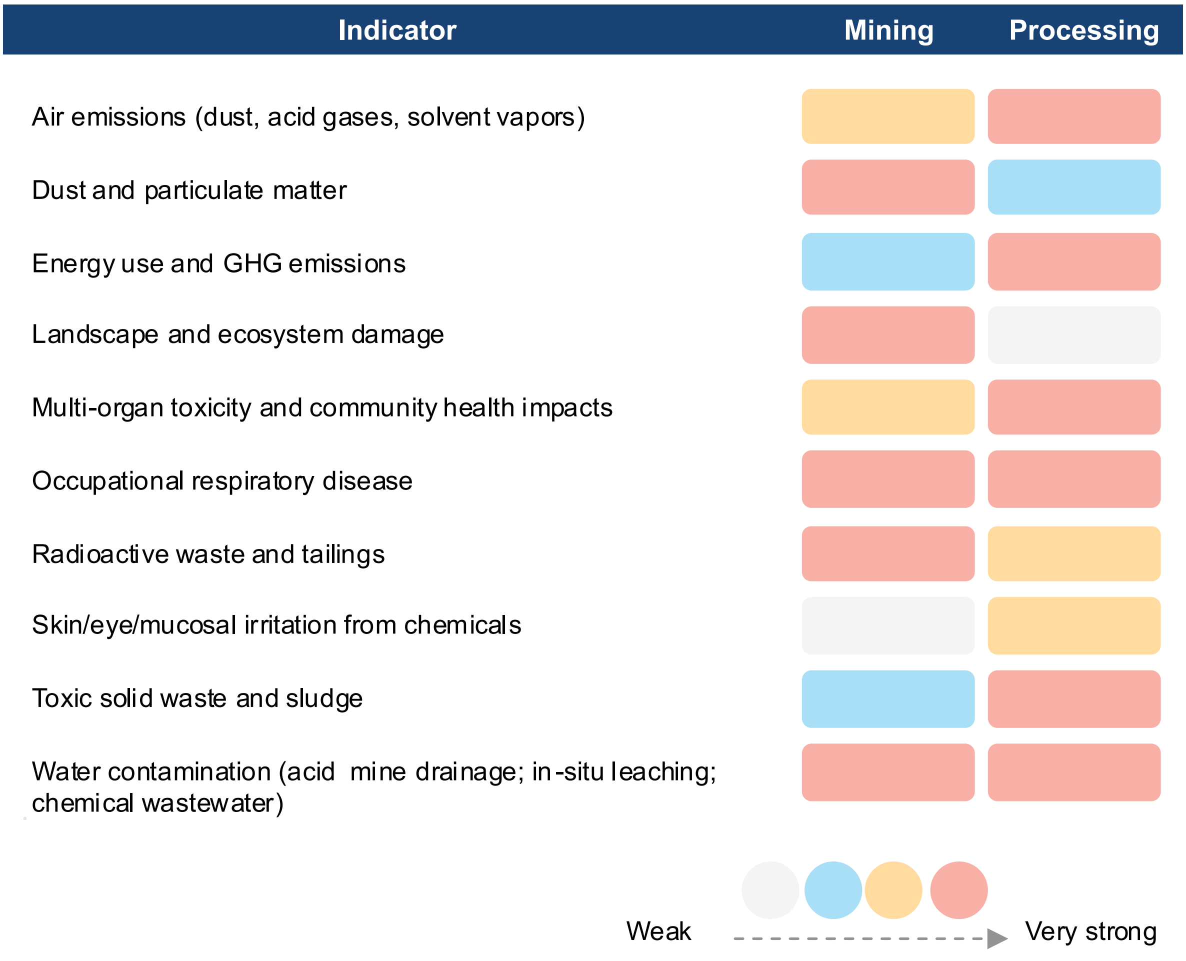
Rare earth supply chains generate various environmental burdens across multiple stages of the supply chains, with impacts persisting even after mines are decommissioned. The nature and severity of impacts vary by deposit type, mineral type, extraction technology and the regulatory environment in which production takes place. Comprehensive data on their full environmental footprint remains limited – illegal mining operations, particularly of ion adsorption clay deposits, represent a particular blind spot. Despite this, some life-cycle assessment studies provide useful background in understanding impacts across different sites.

Mining and processing

In the mining stage, extraction of rare earths can create environmental and health risks through dust emissions, water contamination and radioactive waste. Dust and particulate matter emissions from blasting, hauling and ore handling may disperse into surrounding agricultural and residential areas. Water contamination occurs primarily through acidic leachate from in situ leaching with ammonium sulphate, and in some deposit types through acid mine drainage from sulphide oxidation, mobilising metals and rare earth elements into surface and groundwater systems over extended periods. Open-pit operations result in landscape and ecosystem damage through habitat loss, altered drainage patterns and land degradation. Occupational respiratory disease is also consistently documented among workers exposed to rare earth-containing and silica-rich dust during mining and crushing operations.

In the processing and refining stage, high chemical and energy intensity of operations generate substantial volumes of hazardous waste and emissions. Water contamination from processing involves waste-water streams containing high concentrations of acids, bases, organic solvents, ammonium sulphate, metals and naturally occurring radioactive materials (NORMs). Air emissions from processing plants include dust, acid gases and solvent vapours. Life-cycle assessments identify the separation and refining stages as major contributors to cumulative energy demand and greenhouse gas emissions in the rare earth supply chains. Multi-organ toxicity has also been observed in workers and communities near processing facilities alongside occupational respiratory diseases from inhalation of dust and fumes. Case studies of several processing sites document local environmental degradation.

Environmental impacts of mining and processing of rare earth elements



Notes: GHG = greenhouse gas. Indicators listed are not exhaustive and represent the most studied and cited impacts in academic studies.

Sources: IEA analysis based on AfDB and IGF, Critical Mineral Insights - Rare Earth Elements; Han et al., (2025), Environmental impacts of rare earth elements mining and strategies for sustainable management: A comprehensive review; Fan et al. (2022), Contamination, source identification, ecological and human health risks assessment of potentially toxic-elements in soils of typical rare-earth mining areas; US EPA (2012), Rare Earth Elements: A Review of Production, Processing, Recycling, and Associated Environmental Issues.

Chemical contamination from in situ leaching

Chemical emissions represent the most significant environmental impact across the rare earth production process. In situ leaching is the dominant extraction method for ion adsorption clay deposits, primarily in southern China and Myanmar. The process involves injecting chemical reagents – typically ammonium sulphate or magnesium sulphate – directly into ore bodies to dissolve and extract rare earth ions, which are then pumped to the surface as a solution for further processing. Without proper soil and water management, this method risks contaminating groundwater and surface water with heavy metals, ammonium and sulphate at concentrations that can exceed regulatory thresholds.

Mitigation measures include recycling ammonium sulphate to significantly reduce chemical emissions, as well as emerging alternatives such as optimised reagent formulations and bioleaching. In contrast to hard rock deposits, ionic clay deposits can be processed without acids, using salt-based leaching reagents instead. Newer projects outside Asia, such as Serra Verde in Brazil, are demonstrating this at scale, producing a mixed rare earth concentrate for downstream processing. Regulatory tools such as mandatory waste treatment within industrial complexes before discharge, as applied in China, can also reduce the risk of wider environmental contamination.

Radioactive waste from ore processing

Rare earth ores frequently co-occur with thorium and uranium. Extraction and processing concentrate these naturally occurring radioactive materials (NORMs into tailings and process residues (a process that produces what is sometimes termed technologically enhanced NORM or TENORM) creating radioactive waste streams that persist long after active mining operations cease. Monazite-rich deposits in particular produce radioactive tailings that require long-term containment, monitoring and management of legacy sites. Regulatory standards for NORMs differ across jurisdictions, and inadequately managed tailings sites may pose ongoing risks to the environment and public health, particularly where containment failures allow NORM migration into surrounding soils and water systems.

Developing and strictly implementing radiological standards for NORM management is a foundational measure, as is mandating engineered liner systems to prevent radioactive material from leaching into surrounding soils and water. In countries where no national NORM framework exists, sub-national authorities could fill in this gap through permitting conditions. For example, California limits discharge for tailings waste solids and waste water and requires liner systems and groundwater monitoring in the Mountain Pass Mine.

Countries with rare earth resources or processing ambitions may lack dedicated radioactive waste disposal infrastructure, meaning that NORM standards and engineered containment requirements cannot be effectively implemented without first establishing licensed disposal sites. As such, even where regulatory frameworks exist, classification choices can create their own constraints. In Brazil, for instance, classifying NORM waste as radioactive waste means that disposal falls exclusively under the national nuclear commission, leaving export as the only currently available disposal route.

As for technological advances, thorium recovered from rare earth processing has potential applications in nuclear energy through the thorium fuel cycle. Emerging processing technologies such as electrosorption are also being explored for more selective separation of thorium from rare earth process streams, which could reduce the radioactive burden of tailings and residues, though these remain at the pre-commercial stage.

Energy consumption during metal refining

Beneficiation – which involves crushing, grinding and magnetic sorting – is highly energy intensive. Molten salt electrolysis, the dominant method in China, operates at temperatures between 427 °C and 870 °C and remains particularly energy intensive due to fluoride use and batch processing constraints. Energy requirements also vary significantly by element, with heavy rare earth elements such as dysprosium demanding considerably more energy to purify than light rare earths.

Mitigation options include shifting to lower-emissions electricity sources, improving separation efficiency through advances in ionic liquid extraction and membrane technologies, and implementing exhaust gas cleaning and recycling of used electrolytes. Automated process control and dust filtration can further reduce emissions and material waste during refining.

Current policy measures along the supply chain

Since 2024, governments have rapidly deployed a range of policy instruments to reduce vulnerabilities in the rare earth supply chain, spanning trade, project financing, research and development, and international partnerships. These have been driven by tightening export controls and growing recognition that supply chain resilience requires policy action throughout the value chain beyond the point of extraction.

Financing has been the most utilised policy response, with governments stepping in where private capital is lacking. Australia's AUD 1.65 billion (Australian dollars) loan (increased from AUD 1.25 billion in 2022) to Iluka Resources for the Eneabba rare earths refinery is one example, as well as the United States' (US)

USD 150 million loan to MP Materials for its plan to expand heavy rare earth separation capabilities. Additional actions from the Australian government are expected, partly linked to the country's Critical Minerals Strategic Reserve initiative. The United States International Development Finance Corporation has also been active, including through the Critical Minerals Consortium, which is backed by USD 600 million in funding. Export credit agencies have started to finance projects as well, including Export Development Canada's letter of interest to support a Viridis mining project in Brazil for CAD 100 million (Canadian dollars) in debt financing.

Research, development and innovation along the supply chain has also made significant funding, including the US Department of Energy National Energy Technology Laboratory's letter of intent with USA Rare Earth to develop digital twin technology for heavy rare earth separation at the company's Wheat Ridge laboratory and Round Top deposit.

Select government-supported rare earths projects

Project	Location	Government agency	Amount and type of support	Focus
Caldeira (Meteoric)	Brazil, Minas Gerais	US EXIM	USD 250 million letter of interest	Mining
Caremag (Carester)	France, Lacq	SGI (France 2030)	EUR 106 million grant + up to 45% tax credits on equipment	Processing / recycling
The Donald Project (Vital Metals / Energy Fuels)	Australia	EFA	Up to AUD 80 million (conditional letter of support)	Mining to processing
Dong Pao Processing (Viet Nam Rare Earth)	Viet Nam	MOIT	Undisclosed	Processing
Eneabba Refinery (Iluka Resources)	Australia, Eneabba (Western Australia)	DISR	AUD 1.65 billion (concessional loan)	Processing / refining
Lynas Texas (Lynas Rare Earths)	United States, Texas	US DoD	USD 288 million (grant)	Separation
Multiple projects — 27 projects (various)	Brazil, various	BNDES / Finep	BRL 5 billion funding envelope	Multiple stages
Serra Verde (Serra Verde)	Brazil, Goiás (Minaçu)	US DFC	BRL 565 million financing package with option to acquire equity stake	Mining / processing

Project	Location	Government agency	Amount and type of support	Focus
Vital Metals processing facility	Canada, Saskatchewan	Saskatchewan Province	Part of CAD 7.5 million+ (provincial funding)	Processing to magnets
Strange Lake (Torngat Metals)	Canada	EDC	CAD 10 million	Infrastructure
Round Top (USA Rare Earth)	United States, Oklahoma / Texas	US DoC	USD 277 million funding + USD 1.3 billion loan	Mining to magnets
Vulcan Elements Magnet Facility (Vulcan Elements)	United States, Benson (North Carolina)	US DoD / US DoC	USD 620 million direct loan + USD 50 million incentives	Processing to magnets

Notes: The list above is not exhaustive. BNDES = Brazilian Development Bank; DoC = Department of Commerce (United States); DoD = Department of Defense (United States); DFC = Development Finance Corporation; EDC = Export Development Canada; EFA = Export Finance Australia; EXIM = Export-Import Bank of the United States; Finep = Brazilian Funding Authority for Studies and Projects; MOIT = Ministry of Industry and Trade (Viet Nam); SGI = General Secretariat for Investment (France, France 2030 programme); DISR = Department of Industry, Science and Resources (Australia); BRL = Brazilian real.

Geological exploration has been a way for countries to expand their domestic resource base. India's Atomic Minerals Directorate, for example, has been conducting systematic rare earths exploration and targeting monazite and xenotime deposits. Between 2021 and 2024, the Geological Survey of India launched 368 critical mineral exploration projects which include rare earths with a further 195 projects initiated from 2024 to 2025. These efforts were complemented by the 2026 Union Budget, which introduced dedicated rare earth industrial corridors in Andhra Pradesh, Kerala and Odisha, designed to bundle extraction, processing and value-added manufacturing into a coherent development strategy for electronics and defence supply chains.

Recycling is also a parallel priority for countries. India's incentive scheme to promote critical minerals recycling sets aside INR 1 500 (Indian rupees) crore (approx. EUR 145 million) to provide financial incentives for the development of recycling capacity for the separation and production of critical minerals from secondary sources. The European Union (EU) Critical Raw Materials Act introduces a suite of measures aimed at strengthening rare earth recycling across the region, including requirements for rare earth content labelling and minimum recycled content obligations, with implementation scheduled between 2028 and 2032. In parallel, under the RESourceEU Action Plan, the European Commission is expected to put forward a proposal by the second quarter of 2026 to restrict exports of permanent magnet scrap and waste from EU countries.

International partnerships have increasingly become a cornerstone in many countries' efforts for secure rare earth supply chains. The United States has signed many bilateral agreements since 2025, including a framework with

Australia specifically focused on securing supply in the mining and processing of critical minerals and rare earths, and more recently a strategic co-operation framework with Saudi Arabia. Lastly, the IEA Critical Minerals Security Programme was established in 2022 for governments to strengthen mineral security and serves as an avenue for partnerships and collaboration. In addition, a growing number of governments are making collaborative efforts to develop supply chains from mining to magnet manufacturing, from joint ventures between state-backed entities and mining companies to government-facilitated offtake agreements, to equity investments by national resource agencies in foreign operations. These examples point to an emerging approach in which governments are extending more direct support to the supply chain, in addition to creating enabling policy environments.

Examples of cross-border public-private partnerships and instruments

Fast impact / Low enforceability → Slow impact / High enforceability

MOU	LOI	Offtake agreement	Equity investment	Joint venture
Signatory alongside private parties; lends political weight and opens financing pathways	Signatory or facilitator; reduces counterparty risk and can unlock financing	Co-financier or guarantor of supply; underwrites project economics	State entity takes direct stake, sharing risk and signaling long-term policy commitment	Public entity as co-owner; combines resources and shares risk across jurisdictions
EXAMPLE	**EXAMPLE**	**EXAMPLE**	**EXAMPLE**	**EXAMPLE**
JOGMEC and ECERDC Malaysia signed an MOU of co-operation on rare earth exploration/ development at Khalzan Buregtei and other projects.	Saskatchewan Research Council and Hung Thing Group (Viet nam) signed a 5-year agreement in principle to supply 3 000 t/y REC to a provincially funded facility, enabling ~400 t/y rare earth metal output from 2025	Frontier Rare Earths' Zandkopsdrift offtake with Carester was underpinned by USD 20 million equity from South Africa's Industrial Development Corporation to fund definitive feasibility study.	JARE (Japanese government-backed vehicle) provided ~AUD 200 m equity/loan investment to Lynas rare earths to ensure the material flow of rare earth ore in Australia, refining in Malaysia, and manufacturing in Japan.	JOGMEC invested USD 17 million for 40% stake in Namibia Critical Metals' dysprosium /terbium-rich Lofdal HREE project with option to fully fund.

Notes: JOGMEC = Japan Organization for Metals and Energy Security; ECERDC = East Coast Economic Region Development Council; MOU = memorandum of understanding; LOI = letter of intent; t/y = tonnes per year; REC = rare earths concentrate; JARE = Japan Australia Rare Earths. Beyond these traditional examples, governments and multilateral bodies are also exploring more innovative financing and trade mechanisms (including blended finance structures, strategic reserves and co-ordinated procurement arrangements) examined in Chapter 4.

Chapter 4. Pathways to secure and diversified rare earth supply chains

Building secure and diversified rare earth supply chains requires a broad range of policy actions spanning financing, technology development, ecosystem building and emergency preparedness, supported by strong international collaboration. This chapter presents eight key recommendations for policy makers.

1. Understand rare earth needs and risk exposure

A fundamental starting point for rare earth element (REE) supply chain diversification is a clear understanding of national demand outlooks and exposure to supply risks. While many countries are introducing or exploring policy instruments and financial support mechanisms for individual projects, these efforts are most effective when guided by a comprehensive assessment of future rare earth and magnet requirements. Understanding the future needs is often an overlooked element in policy discussions for REEs. Unlike bulk commodities, for which future demand is generally well documented, obtaining reliable information on national rare earth and magnet requirements is often challenging. Yet such analysis is essential to define realistic capacity targets, estimate the scale of investment required, calibrate policy instruments to minimise fiscal burdens and identify priority segments across the value chain. This ensures that policy interventions are proportionate to strategic and security objectives. Without this strategic perspective, project-level support risks becoming fragmented and may fail to address critical bottlenecks, particularly in refining, alloy production and magnet manufacturing.

Equally important is assessing countries' vulnerability to potential supply disruptions. This requires a detailed understanding of rare earth use across downstream sectors, including energy technologies, automotive, electronics, defence and medical applications as well as an evaluation of the potential economic and strategic consequences of supply interruptions. Yet in many industries, manufacturers often lack a precise assessment of the rare earths embedded in their products and the associated supply chain vulnerabilities. Strengthening this understanding is essential to identify which industries are most exposed and to gauge the scale of potential economic losses, thereby enabling governments to prioritise policy interventions, design effective emergency response measures, and align diversification efforts with national industrial and security objectives.

The International Energy Agency (IEA) estimates that the need for rare earth magnets in regions outside the People's Republic of China (hereafter, "China") is set to grow by 50% between today and 2035, led by electric vehicle (EV) motors (see Chapter 3). Because countries have different downstream industrial structures, the scale of rare earth demand and its growth prospects vary markedly by region, underscoring the importance of developing a clear understanding of country-specific needs. The IEA also estimates that around USD 6.5 trillion of potential economic losses could occur across strategic industries in rare earth-importing regions in case of major disruptions (see Chapter 2). The scope and severity of these impacts, however, vary depending on each country's industrial footprint. Despite the crucial importance of data for assessing demand and risk exposure, there is limited availability and transparency of demand data along the value chain.

Similar to the approach to collect energy statistics, there are multiple ways for governments to gather information on rare earth demand and trade, such as through surveys, administrative data sources or modelling. Surveys, voluntary or mandatory, are performed either by enumerating all relevant stakeholders (census) or selecting a subset of representative stakeholders, with a predetermined frequency. Surveys can also be used to improve short-term emergency preparedness. The IEA oil emergency data architecture, for example, includes multiple statistical surveys that allow for both short-term reactivity in case of crisis and strategic planning for long-term energy security. Administrative data sources can also be utilised; they provide data originally created for other purposes, such as customs records, tax collections and management of support tools. While these sources might have limitations in scope, they offer several advantages such as lower cost and reporting burden and regular updates. Modelling can complement surveys and administrative data and can also be used to estimate future demand.

Trade data are among the most powerful administrative data sources, allowing the detailed tracking of material flows across supply chains. A Harmonised System (HS) of codes for traded materials is recognised internationally and can be used to identify and trace numerous commodities. These six-digit codes provide the most complete open-source information about global trade flows of critical minerals, but they have some important limitations for REEs. Seventeen rare earths are grouped under a few broad codes, without distinctions between individual elements, and mined and refined materials are frequently combined in the same category. Some national or regional trade code systems offer a more granular approach, complementing the HS system with national subheadings that involve eight-digit or longer commodity codes for custom declarations. In recent years, particularly in the wake of export controls, several countries refined these codes to improve the tracking of trade flows and the assessment of supply disruptions by separating codes for specific REEs or making distinctions among oxides, metals, compounds, alloys and magnets.

Tariff codes for magnet rare earth material in China, the European Union and the United States

Rare earth are earth compounds (284690.XXYY)

	Neodymium	Dysprosium	Praseodymium	Terbium
CN	Neodymium oxide (.13)	Dysprosium oxide (.15)	Praseodymium oxide (.17)	Terbium oxide (.16)
EU	Compounds of neodymium (.5040)	Compounds of dysprosium (.6025)	Compounds of praseodymium (.5030)	Compounds of terbium (.6020)
US	Mixtures of rare earth oxides or chlorides, other than cerium (.20)			

Rare earth metals (280530.XXYY)

	Neodymium	Dysprosium	Praseodymium	Terbium
CN	Neodymium metal (.11)	Dysprosium metal (.12)	Praseodymium metal (.16)	Terbium metal (.13)
EU	Containing both neodymium and dysprosium (.10.30)			
EU	Containing neodymium (.1040)	Containing dysprosium (.1050)		
EU	Neodymium by weight >95% (.2940)	Dysprosium by weight >95% (.3125)	Praseodymium by weight >95% (.2930)	Terbium by weight >95% (.3120)
US	Neodymium metal (.0020)		Praseodymium metal (.0015)	

Rare earth ferroalloys (720299.XX)

CN	NeFeB strip casing alloy (.11)	NeFeB bonded magnetic powder (.12)	NdFeB lump (.19)

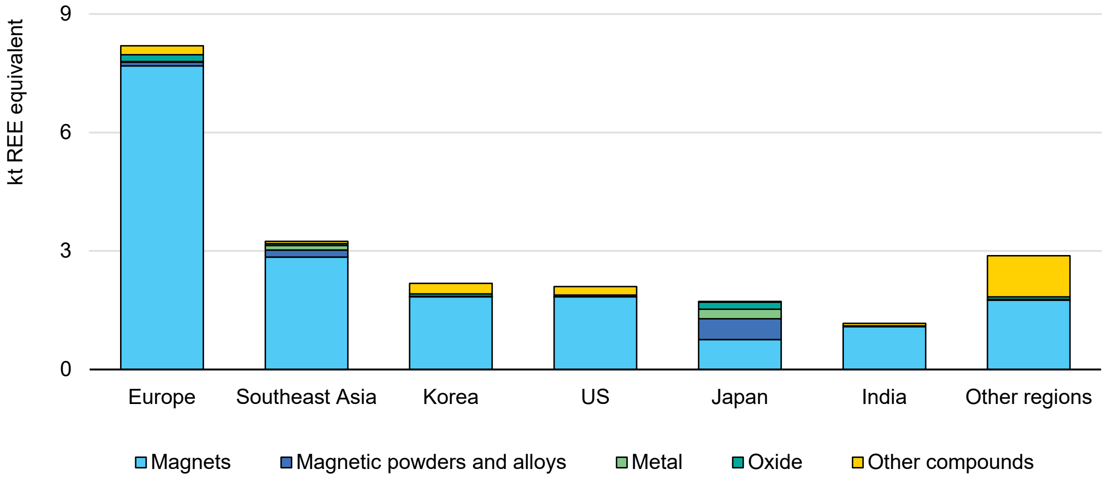
Rare earth magnets (850511.XXYY)

CN & EU	Rare earth magnets (.10)
US	Sintered NdFeB (.0070)
US	Sintered samarium cobalt (.0050)

Note: NdFeB = neodymium-iron-boron.

Sources: IEA analysis based on European Commission (2026) TARIC Consultation, United States International Trade Commission (2026) Harmonized Tariff Schedule

China exports of magnet rare earth elements to selected regions by material type, 2025



Notes: kt = kilotonnes. The figure shows 2025 total exports from China to selected regions of rare earth materials in kt REE equivalent.

Administrative data collection could also leverage fiscal instruments. In other sectors, data are gathered in conjunction with the collection of excise duties or when deploying support tools such as feed-in tariffs, tax credits or contracts for difference, or when facilitating offtake agreements. The inclusion of collection clauses when setting up new fiscal tools in the critical minerals sector would provide governments additional useful information streams. Consumer information and environmental disclosures can also support data collection efforts. These can involve disclosures of rare earth content in product for recycling purposes (see Recommendation 7) as well as requirements embedded in environmental impact assessments for certain products. Another example of administrative data gathering is Euratom Supply Agency (ESA)'s oversight of uranium contracts for assessing supply risks. Strategic stockpiling systems can also offer options to gather information, for instance through the monitoring of stock rotation, which provides continuous feedback on market development (see Recommendation 2). Close engagement with industry is always a key factor when developing data monitoring systems, and any such system needs to put dialogue with industry at the centre of data collection efforts.

To enhance transparency in rare earth markets and improve understanding of demand and exposure to shocks, countries could consider several measures. They can assess future rare earth demand based on the expected deployment of technologies that use rare earths and the domestic industrial footprint. They can also explore the possibility of establishing statistical data collections in collaboration with relevant domestic stakeholders, such as suppliers or consumers of rare earth products. Since trade flows provide the most relevant indication of supply exposure to shocks, countries can leverage disaggregated customs data by working with customs administrations, improving harmonisation of codes, and setting up systems for regular and automated data collection. Additionally, other administrative data sources can be explored, such as data collection linked to the implementation of policy tools or rare earth content disclosures, while ensuring that the additional burden on companies and administrations is minimised.

2. Increase preparedness for potential disruptions and establish a buffer to mitigate short-term supply risks

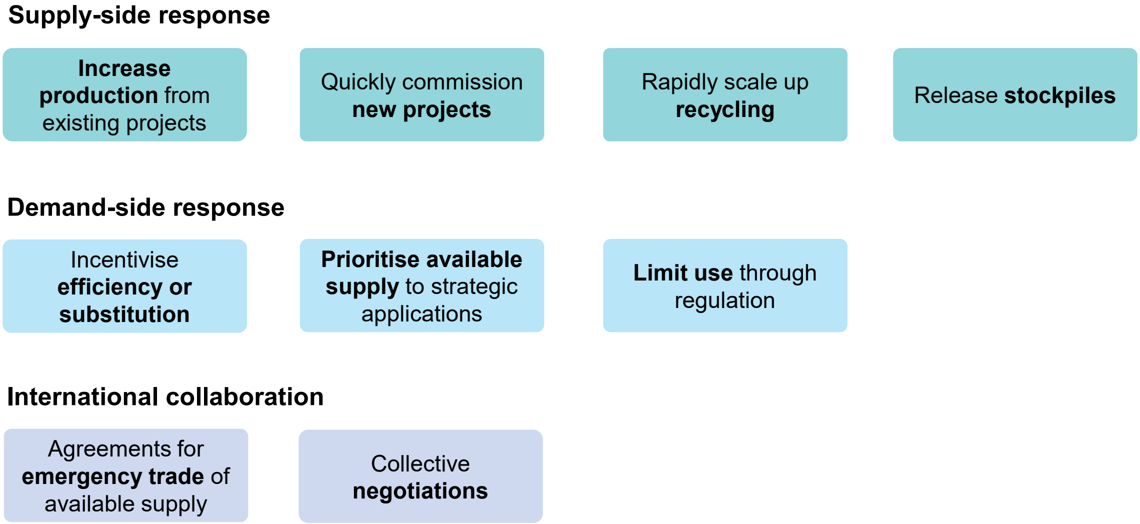
While supply diversification is the fundamental way to improve supply chain resilience, it is essential to plan short-term emergency response measures to safeguard countries from sudden supply shocks and disruptions.

Emergency preparedness and response can be increased through regular emergency response exercises (or table-top exercises) and market disruption monitoring. Table-top exercises simulate a realistic supply disruption and help countries develop coordinated response measures. These exercises offer opportunities to improve common understanding of domestic and global risk exposure, test emergency procedures, and coordinate management and exchange of available supply. The process of simulating supply disruptions through exercises may also help build domestic data gathering capabilities and strengthen emergency response capacity. The IEA organises regular exercises as part of its Critical Minerals Security Programme to enhance emergency resilience at a global level. Additionally, domestic exercises could also be useful to identify domestic priorities and bottlenecks. Close collaboration with impacted downstream sectors is crucial for actionable outcomes.

Emergency response procedures could be established, involving steps for data monitoring, impact assessments and stakeholder consultations. Management of emergency response should also include a database of relevant contacts to be used to quickly gather the key stakeholders.

At the centre of emergency preparedness, response measures provide relief to disrupted supply chains, acting on the supply and/or demand side. On the supply side, unlocking spare production capacity and commissioning new projects in an accelerated time frame can help make up for the lost supply in the event of a disruption. For countries with existing stockpiling systems, the release of stockpiled material is also a key option providing a temporary buffer. On the demand side, temporary allocation of available demand to strategic industries, incentives for efficiency, substitution and rationing could also help withstand supply shortages.

Possible emergency response measures



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Redirection of available supply to priority industries could help reduce the economic impact of disruptions, but countries would need to conduct a prioritisation exercise ahead of a crisis. Many countries have experience in conducting a similar exercise for the oil sector, but different industry structure and user profiles should be taken into account.

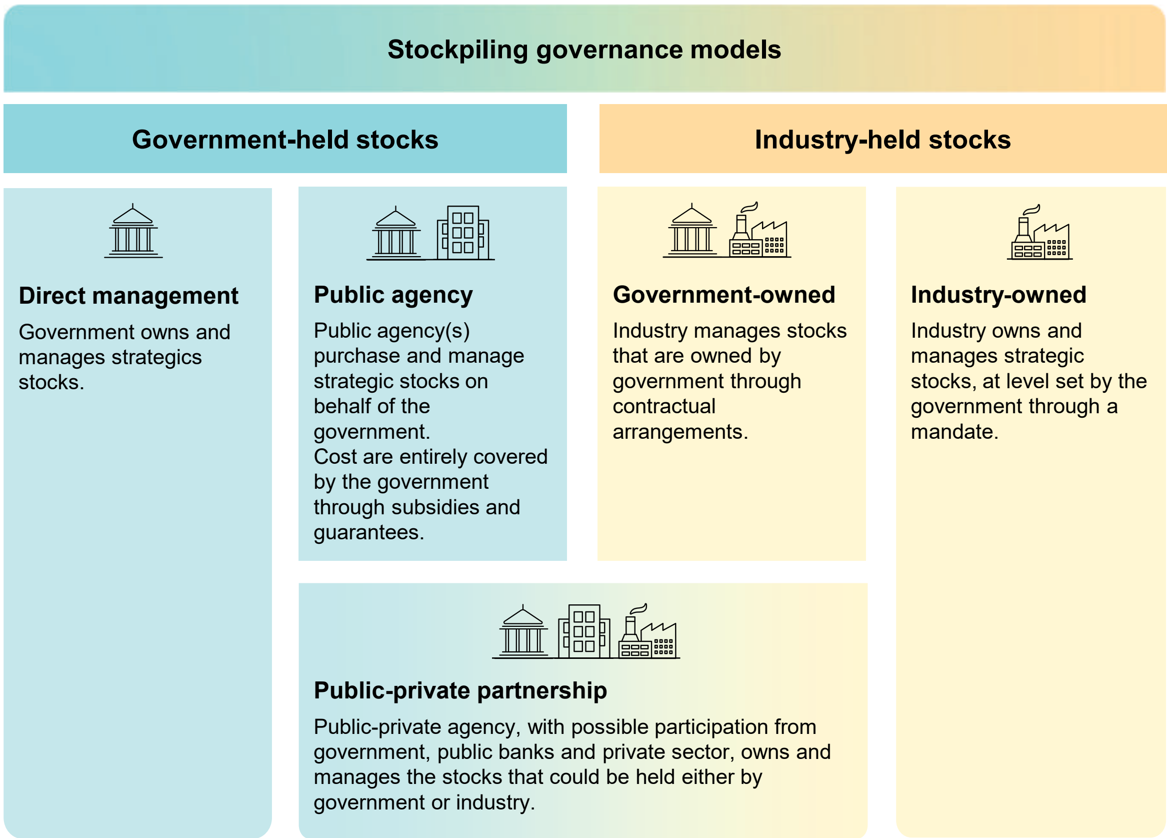
International collaboration can also provide paths to withstand supply disruptions and increase the collective ability to respond to supply shocks. For example, international agreements between countries that would be able to supply feedstocks of rare earth oxides and metals and those with domestic magnet manufacturing would be instrumental not to halt production and trade flows. These feedstocks could come from mining, refining and recycling projects in partner countries or from stockpiles if available. International partnerships can also strengthen negotiating power in possible trade agreements, if the disruption is caused by trade restrictions.

Strategic stocks can provide a supply buffer in case of disruptions

Strategic stockpiles of critical minerals – held specifically for emergency purposes with the involvement of the government – can play an important role in providing emergency supply in case of sudden severe supply disruptions. Even when they are not used, they send a signal to markets that sudden supply shocks or export restrictions need not immediately cripple the system. Some countries such as Japan, Korea and the United States hold strategic stockpiles of critical minerals that have protected industries during past supply disruptions.

Strategic stockpiling systems can follow a spectrum of governance models that could be grouped into two broad categories based on where the minerals are physically stored: "government-held" or "industry-held", each with two main options. For government-held (centralised) stockpiling models, the government owns and manages the stockpile, either directly or through a public agency acting on its behalf. Industry-held (decentralised) models require companies to store strategic stocks in addition to their existing commercial inventories. A public-private partnership owning and managing the stocks could also be set up, combining some advantages of government-held stocks (such as lower financing cost) and some of industry-held stocks (such as a close relationship with private companies that ultimately used the materials).

Possible stockpiling governance models



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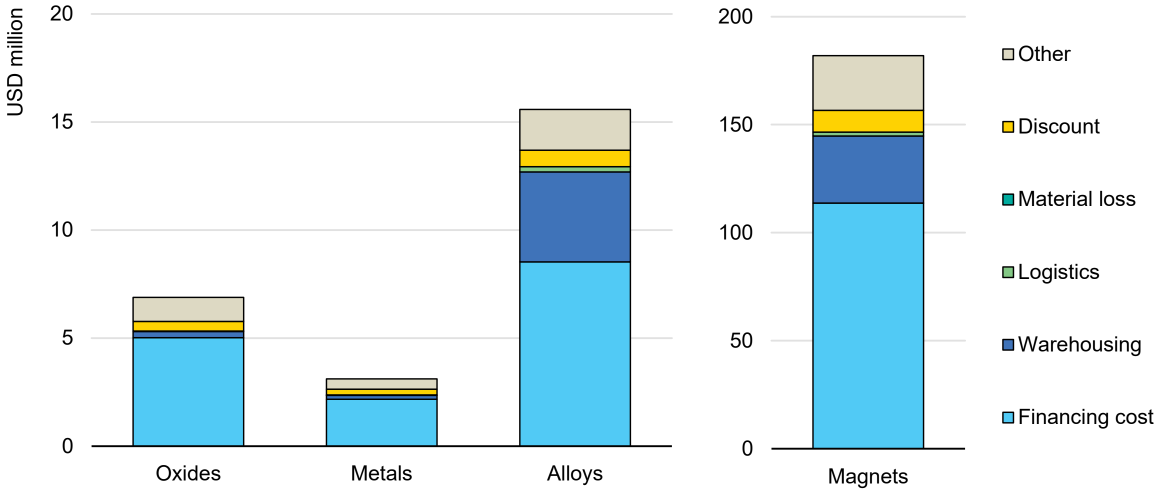
The appropriate stockpiling governance model varies considerably by material and depending on domestic context and supply chain structures. Within the rare earth elements value chain, the storage of more upstream materials such as rare earth oxides or metals – which could be used by multiple downstream magnet manufacturers – could benefit from stronger involvement of the government and centralised stockpiling. When stockpiling materials that are closer to downstream products, such as rare earth permanent magnets, industry-held models are often better suited as each company can store the specific materials they need and perform stock rotation more efficiently.

The choice of the type of rare earth material to be stockpiled should be based on the domestic industry structure and actual exposure. The stockpiled materials should be those that are imported and risk to be disrupted in case of supply shocks and need to be rapidly deployable. For example, if there are no domestic magnet manufacturing facilities, it would be beneficial to directly stockpile the permanent magnets required domestically. If stockpiling material that cannot be directly used domestically, international agreements with partner countries hosting relevant processing facilities could provide a viable alternative.

The total cost of stockpiling comprises both the initial purchase cost and the operating cost. However, the investment to purchase the material is transformed into an asset that is later sold, either for stock rotation or for a stock release. The real cost is therefore the operating cost of stockpiling, which comprises financing cost, warehousing cost, the cost of logistics, material losses and discount. The discount cost is associated with the need to refresh stocks – selling them at a discount – before they reach shelf life.

Strategic stocks are typically built to cover a specified number of days of exposed imports – those coming from the dominant supplier – of materials used as input to domestic manufacturing. The total operating cost of a strategic stockpile covering one year of exposed imports for countries outside of China ranges from around USD 3 million per year for magnet rare earth metals to USD 180 million when stockpiling rare earth magnets, using an industry-held government-owned stockpiling model. The cost of the initial purchase of all materials would be over USD 2.5 billion. For comparison, the direct economic impact if the export controls announced in October 2025 were implemented is estimated to be USD 6.5 trillion.

Operating cost of stockpiling magnet rare earth materials to cover one year of exposed imports for countries outside of China



Notes: Operating cost of stockpiling for an industry-held, government-owned stockpiling model. Based on exposed imports from the dominant supplier in 2025.

While the objective of stockpiles is to strengthen the security of domestic supply, coordination with international partners can help achieve greater security more efficiently and faster. Aligning on the timing of stockpile purchases and establishing principles for releases can help ensure that markets are not distorted. When procuring stocks, countries could also agree to support strategic projects that would increase global diversification or consider aggregating demand. When compatible with domestic policies, countries might co-locate stocks for greater efficiency, particularly for low-volume materials, or reserve production in countries with production infrastructure for emergency use. Close dialogue among partners also facilitates the transfer of knowledge on efficient stockpile management.

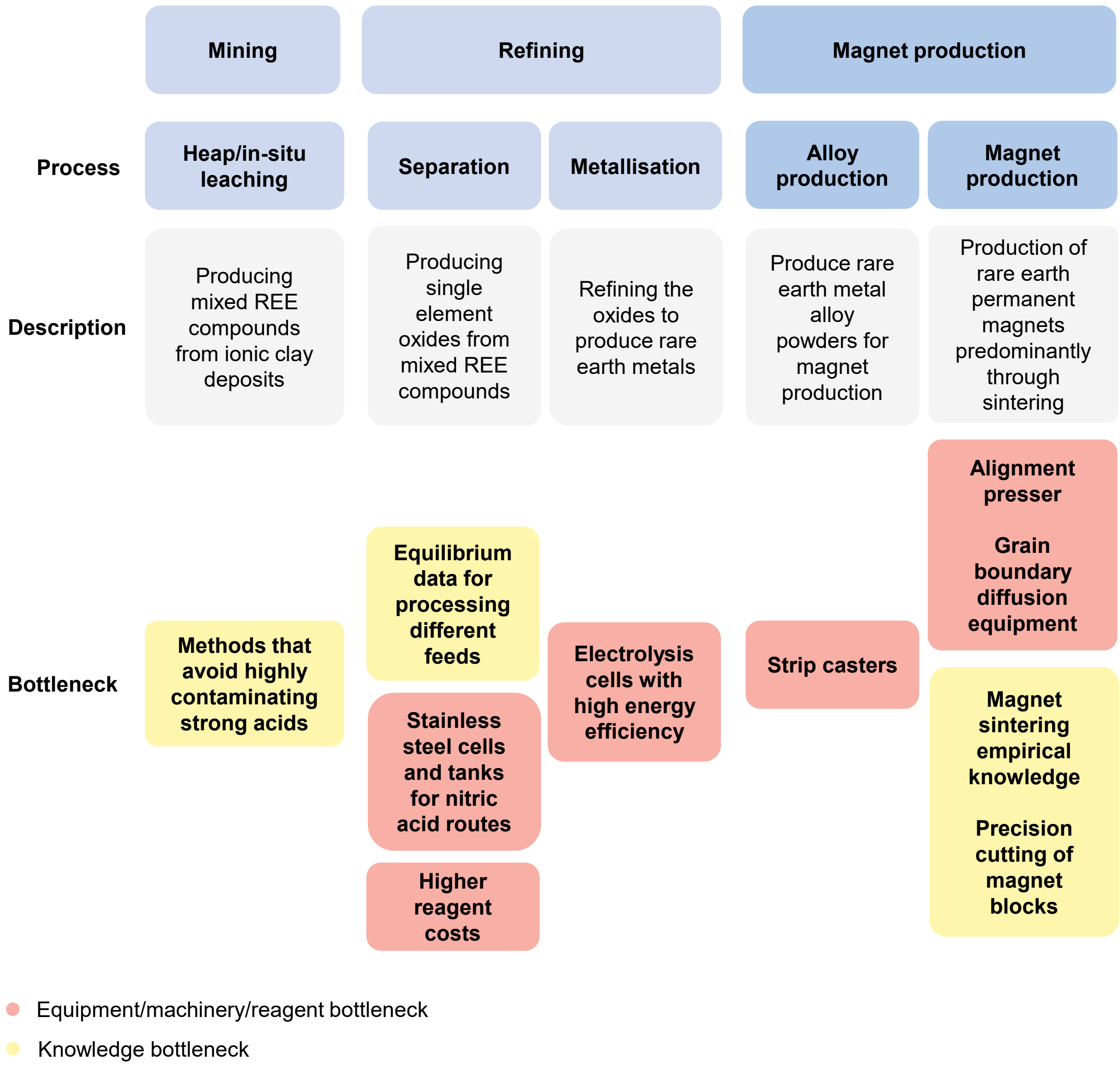
To increase emergency preparedness and establish a cushion to mitigate short-term supply risks, countries can consider developing emergency response procedures that outline steps to be followed in the event of supply disruptions, including impact assessment protocols and a database of emergency contacts. Organising emergency response exercises involving policy makers and stakeholders that could affected by supply disruptions can help coordinate efforts and refine response tools. Countries can also prepare response measures to provide relief during supply disruptions through supply- or demand-side interventions and international collaboration. Finally, developing or expanding domestic stockpiles of rare earth materials that can be rapidly deployed in the event of a disruption, while leveraging international collaboration to optimise multiple domestic systems where compatible with domestic policies, can further strengthen resilience.

3. Adopt a whole supply chain and ecosystem approach

The rare earth project pipeline clearly shows that efforts for diversification must extend well beyond mining. While there has been a marked increase in rare earth mining project announcements and developments in diversified regions in recent years, the pipeline for separation and refining, alloy production, and magnet manufacturing is much narrower and insufficient to meet projected industrial requirements outside China. As highlighted in Chapter 3, the gap for alloy and magnet production is particularly stark, making it a critical bottleneck. Substantial additional investment and project development will be required in the midstream and downstream to close this gap. Most strategic end-use applications of rare earths rely on permanent magnets, thus, no matter how extensive diversified mines are developed, without refining and magnet production capability, this output cannot be effectively utilised in critical strategic downstream sectors.

However, this is not simply a question of developing new projects; there is a much broader ecosystem issue that needs to be addressed. Rare earth refining and magnet production relies on a multitude of complex technical production processes, requiring specialised equipment, machinery, and skills and training to produce magnets conforming to strict industry specifications. There are very few suppliers of rare earth refining and magnet production equipment and machinery outside of China and the time required to obtain the equipment can often span several years. There is an urgent need to nurture this industry in parallel to developing projects. China's 2023 export controls, which covered a wide range of rare earth processing equipment and technologies, highlighted the importance of addressing this issue.

Bottlenecks for creating diversified rare earth supply chains



Mining: While mining technology and equipment is not the biggest bottleneck, there is a lack of processes to extract heavy rare earths from ionic adsorption clay (IAC) deposits without using acid leaching as done in China and Myanmar.

Countries such as Malaysia and Brazil that are developing their IAC deposits can explore alternative technologies using weaker pH acids.

Separation: There is a significant gap in knowledge and data on equilibrium for solvent extraction used for rare earths separation, which is a complex process due to the similar chemical properties of many rare earth elements found together. This concern is particularly relevant for mixed feeds such as monazite and bastnaesite. Another issue at the separation stage is that China predominantly uses chloride routes (hydrochloric acid) that require polyvinyl chloride (PVC) tanks and cells, whereas most suppliers outside China have favoured the nitric route (nitric acid) which requires stainless steel tanks and cells that are more expensive to produce. The nitric acid route also requires very strong waste-water management systems and land-use planning regulations, and there is limited experience in tackling this issue systematically outside China and Japan.

Aside from machinery and equipment, reagents could also be a bottleneck for diversified projects as they account for 15-25% of conversion costs depending on the route (chloride or nitric) used, and the acids are usually sold at lower prices in China than most other regions.

Alloying, metallisation and magnet manufacturing: The priority areas where there is a stark deficiency of competitive equipment and machinery that meet industry specifications are alloy production, metallisation and magnet production. Equipment for these supply chain steps outside of China could be 5-12 times more expensive and often have two to three times longer lead times than those from China. The increased costs and lead times are due to the limited equipment manufacturers outside China, who typically produce this equipment for other applications and have not optimised it for rare earth processing, which often requires some resizing and re-specification. Moreover, they have not yet achieved economies of scale, have not secured long-term established customers, and need time to customise and ramp up production. In some cases, there is only a single supplier of equipment and machinery outside China, meaning a competitive landscape for efficient scaling does not exist.

For metallisation, in particular for light rare earth metals, there is a bottleneck for the design of energy-efficient equipment for the electrolysis step. Light rare earth metals typically use molten salt electrolysis, and in order to have competitive costs, the design of the electrolysis cells must be highly energy efficient. This is because energy is one of the largest cost factors in the metal conversion process. The design of highly energy-efficient electrolysis equipment remains closely held and is not widely available outside China. For heavy rare earth metals, vacuum induction chambers are used for calcination/reduction. This equipment is made by very few producers and needs to be highly customised for scaling the metals to size. Therefore, the design and development of energy-efficient electrolysis cells and vacuum chambers needs to be a priority in order to reach viable, economically competitive metallisation to support diversified projects.

In the production of alloys, a key process is strip casting to produce the rare earth alloy with additives such as iron, gallium or zirconium (which make up less than 1% of the alloy by weight). Strip casters are another key equipment with few suppliers available outside China. Jet milling equipment, used to produce alloy powder, has suppliers outside China but is more expensive.

However, some of the most critical equipment challenges are in magnet production. In the production of sintered magnets, the availability and quality of alignment pressers is a source of concern. There are a few suppliers outside China, but their pressers could be around ten times more expensive, and the technology and design are notably less advanced. Finally, the technology for grain boundary diffusion processes, used to apply heavy rare earth molecules as a coating to the magnets, is subject to Chinese technology and equipment export controls. There is currently a single equipment supplier outside China where the equipment is around 12 times more expensive and has a longer lead time. Grain boundary diffusion is also a highly patented process with a lot of litigation disputes already ongoing, providing another barrier to successful development for emerging producers.

Beyond equipment and machinery, there are several areas with skill and knowledge bottlenecks. In the separation process, there is a considerable lack of equilibrium data for processing various feeds. The same is true for sintering furnaces for magnet production, where there are major empirical and heuristic knowledge gaps in the protocols to produce sintered magnets with required specifications. This also extends to the high precision cutting of the magnet blocks, where, while the equipment needed exists outside China, the limitations exist in process knowledge to achieve results at scale and speed. These are areas which require training, practice and time to hone the technique and build a skilled workforce.

The gaps in costs and lead times that we observe today are a function of the high levels of supply chain concentration and the lack of major industrial bases outside China. As efforts to diversify rare earth supplies ramp up, there is potential for competitive markets for equipment and machinery to emerge. To develop a successful rare earths ecosystem in diversified regions, the first and highest priority is to address the gap in equipment costs and lead times. Providing targeted subsidies and incentives to existing and emerging equipment/machinery producers can be effective in reducing both lead times and equipment and machinery costs through economies of scale. Building a consortium of domestic or international equipment producers to coordinate production of components and equipment can also realise scale advantages more effectively.

Second, providing financial support both at direct capital cost and operating cost levels or through other de-risking measures, such as loan guarantees or lowered interest rates, can help diversified rare earth magnet, metal and equipment producers. These measures strengthen the business case for producers, incentivising private investment. Unlocking private investment can accelerate the development of diversified rare earth magnet expertise, which is crucial to building a successful rare earth ecosystem.

Finally, it is also critical to simultaneously stimulate demand, for example through introducing incentives or mandates to use magnets produced using a fraction of material, processing and equipment originating from diverse sources. Facilitating coordination among diversified players and countries is also important to negotiate more effectively in the event any export controls are enacted. Coordination among key diversified players acting as a group can be important for patent negotiations in the event of patent disputes. The industry can also benefit from looking to battery markets and the ongoing attempts to develop a successful diversified lithium iron phosphate (LFP) supply chain, which also faces considerable equipment, technology, knowledge and patent barriers.

4. Strengthen financial and policy support to strategic projects through supply- and demand-side measures

Building an ecosystem of diversified rare earths supply chains requires a coordinated suite of policies that address investment and operating risks, while balancing incentives for both supply- and demand-side development. No single instrument will be sufficient on its own; rather, measures need to reinforce each other to shift supply chains in a meaningful way. Both supply and demand stimulation measures can be deployed concurrently, supported by cross-cutting enabling measures. This approach can help advance strategic diversified projects while ensuring sufficient demand for these alternative sources.

Supply stimulation

Developing diversified rare earths supply requires both creating market conditions that attract investment into new production in diversified regions and supporting projects by reducing price and volume uncertainties, thereby helping to secure financing and maintain operational viability.

Supply-side measures can include direct support measures such as capital expenditure financing which tackles the large upfront costs of building mines, refineries and processing plants. This support can take the form of direct loans or grants, providing access to capital at concessional rates. It can also include direct equity investment, which may reduce the cost of debt and equity financing on projects by lowering risk. Tax credits and reduced mineral royalties can also improve the economic viability of projects. Risk mitigation tools can also help "crowd in" private investment rather than directly financing projects. These include backstops for private lenders and insurance products not readily available from commercial insurers.

While direct support measures are crucial, there is a growing recognition that additional market mechanisms may be required to support the economically sustainable operation of the facilities and create a diversified market. These can create greater predictability and stability for investors and markets by reshaping how minerals are priced, traded and procured, thereby creating a more self-sustaining market for diversified supply chains.

Price-based mechanisms

One way to stimulate supply is to use price-based mechanisms that are designed to maintain stability in commodity prices by ensuring that prices remain above a predetermined threshold, which can help mitigate price volatility risks.

This can be operationalised through several methods. For example, a contract for difference (CfD) is a contractual agreement between an operator and a public entity that stabilises project revenue by setting a fixed “strike price” for the operator’s output. The operator sells its product in the market but then settles with the public entity the difference between the strike price and a “reference price”, normally set based on a published market price. If the reference price falls below the strike price, the public entity pays the difference to the operator (i.e. a “top-up”), whereas if the reference price goes above the strike price, the producer pays back the difference to the public entity (i.e. a repayment). CfDs allow operators to receive a stable revenue for their output (ensuring continued operational viability). CfDs have been used heavily in European renewable electricity markets, where 33% to 50% of new offshore wind capacity has been financed through CfDs since the late 2000s.

Using CfDs requires several operational considerations. The most fundamental is the determination of the appropriate strike price, which forms the core of the mechanism. Effective operation depends on setting a price threshold that provides sufficient certainty for investment while still sending adequate market signals. If the threshold is set too low or high, it may fail to support investment decisions or impose too high a fiscal burden.

Price caps and floors can serve as a variation of CfDs using two different strike prices – cap and floor prices – to reduce revenue volatility for producers. If the market price falls below the floor price, a government compensates the difference. Conversely, if the market price rises above the cap price, the producer pays back the difference. This two-sided mechanism stabilises revenues within an agreed band, improving investment certainty while limiting excessive gains or losses for either party.

The strike prices can be determined in several ways, including by using the weighted average of relevant sector prices over a defined period (ranging from days to years) or through a competitive bid process. Schemes should ensure that strike prices are flexible to allow adjustments that reflect evolving market conditions. Another key design element is the duration of CfDs or price cap-and-floor schemes: in the power generation sector, CfDs have typically stretched from 10 to 15 years. Lastly, a further policy decision needs to be made regarding how to allocate contracts between operators. Contract allocation can be done directly (e.g. through bilateral negotiation) or through competitive auctions. Under an auction-based approach, a budget or capacity target is normally set in advance, and the government then accepts strike price bids submitted by operators sequentially (from the lowest to the highest strike price) until the budget runs out. Competitive allocations such as tender-based schemes or auctions can allocate support and industrial rights competitively, covering concessions, permits, access to infrastructure, or public financial support, rather than relying on first-mover advantage. This can enable governments to select projects based on cost and strategic criteria, improving competitiveness and reducing finance risk for projects in diversified regions.

Volume mechanisms

In addition to price, predictable and reasonable quantities are important for investment decisions. Offtake agreements are widely used during project development to provide some degree of revenue certainty once operations begin. These agreements help projects secure equity or loans from financial institutions.

Governments could play a meaningful role in offtake agreement, both directly and indirectly. Recent examples include the US Department of War at MP Materials and the government of Canada with Nouveau Monde Graphite. Governments can also support industry-negotiated offtake or take-or-pay arrangements, as already occurs in the electricity sector. However, they must carefully assess which products are suitable for direct government offtake. Offtake backstops can be another mechanism whereby governments guarantee a minimum volume as a buyer of last resort, if commercial demand falls short. By providing confidence that output will have a reliable market, they can help catalyse new capacity while allowing governments to build strategic stockpiles or support downstream industries if needed.

Demand stimulation

While it is important to get projects in diversified regions up and running, parallel efforts are needed to incentivise buyers to procure materials from these projects. These diversified products typically face higher costs than incumbents due to smaller project scales, less advanced infrastructure, more stringent regulatory requirements, expensive or inaccessible equipment, and higher energy, labour and transport costs.

In markets where prices are set by the lowest-cost producers, manufacturers or downstream users have limited incentives to switch suppliers without policy intervention. Without mechanisms to generate predictable demand for diversified supply, diversified projects may struggle to secure long-term offtake agreements and investment, reinforcing existing concentration patterns. Demand-side tools are therefore essential complements to supply-side measures.

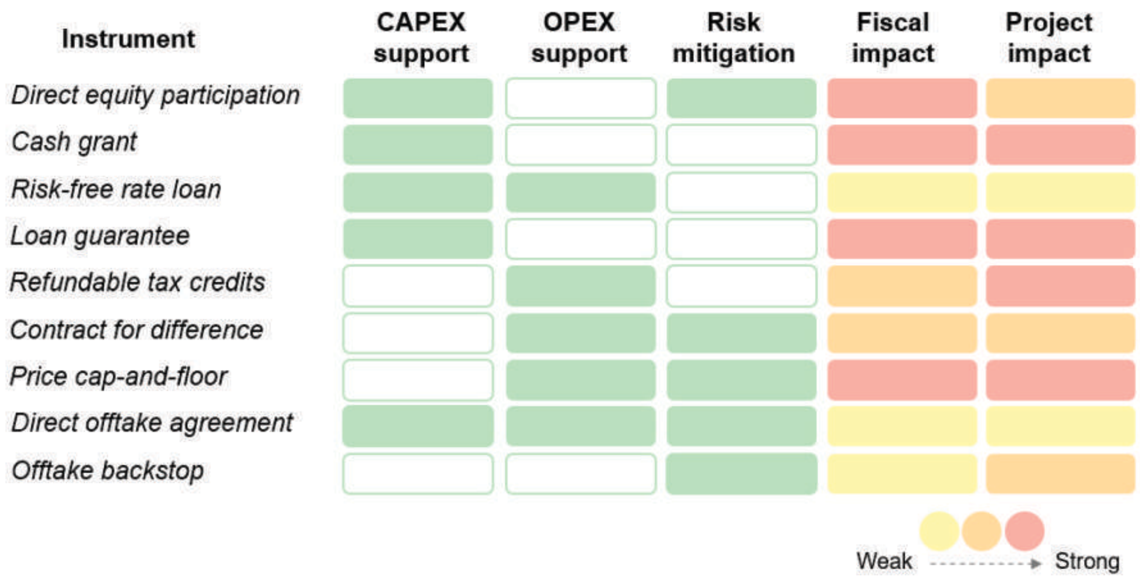
Diversified sourcing obligations

Diversified sourcing obligations are one approach to ensuring demand for diversified supplies as they can require or encourage manufacturers to source a minimum percentage of their inputs from suppliers outside the dominant producer. They can be implemented through direct regulations on products sold locally (e.g. requiring that a minimum percentage of domestically sold batteries or cars incorporate local inputs) or through fiscal incentives (e.g. offering a tax credit or deduction conditional on a minimum percentage of inputs being sourced locally). One example is the US Inflation Reduction Act, which until 2025 offered a USD 7 500 consumer tax credit for battery-powered electric vehicles, conditional on a certain baseline percentage of the battery's minerals being extracted or processed in the United States or in a US free trade partner. The level of sourcing obligations needs to be carefully assessed based on the review of projected capacity expansion from domestic and other diversified sources.

Considerations

Strategic intent from deploying policy tools must also be balanced with the impact on project economics, market fundamentals and government cost to ensure that there is not a long-term impact on competitivity or excessive government exposure to fiscal costs or downside risk.

Policy tools and relative impacts on project profitability and government cost



Notes: Instruments listed are not exhaustive. The above assessment varies depending on the specific projects and contractual agreements.

Cross-cutting enabling measures

Accessible financial instruments

Capital intensity, long lead times and highly specialised processing technology have made it difficult for export credit agencies and development finance institutions to lend to rare earth projects under standard lending criteria. To make financing instruments more accessible to these projects, policy makers could establish dedicated rare earth funding windows (or those for strategic minor metals) within existing institutions or facilities with tailored terms that reflect the strategic and commercial realities of these projects. This includes longer repayment horizons, lower collateral thresholds, and co-financing for separation and processing infrastructure. For instance, Australia's AUD 5 billion Critical Minerals Facility, managed by Export Finance Australia, provided a AUD 1.65 billion loan package to the Eneabba project, supporting the country's first integrated rare earths refinery to produce separated rare earth oxides.

Governments may also leverage existing strategic mineral partnerships and trade agreements with emerging markets and developing economies that hold rare earth resources or potential for developing refining capacity through financing commitments to allow such countries to gain access to capital markets.

Regulatory and permitting reforms

Rare earth projects face a particularly complex permitting environment given the radioactive by-products associated with processing, which trigger regulatory layers beyond standard mining approvals. Governments can reduce these barriers by developing rare earth-specific permitting pathways with clear statutory timelines including pre-approved disposal pathways for naturally occurring radioactive material (NORM) waste and accelerating the licensing of tailings facilities. Frequently, uncertainty around waste handling, rather than the mining permit itself, stalls rare earth project approvals.

The United States' FAST-41 framework offers a useful model by requiring federal agencies to coordinate on a single permitting timetable and empowering the Permitting Council to resolve interagency disputes and enforce scheduling discipline. It reduces the open-ended delays that have historically deterred investment in long-lead rare earth projects, and its recent application to heavy rare earth exploration projects such as Sheep Creek in Montana signals its potential as a procedural tool for accelerating rare earth project approvals.

At the international level, harmonising NORM management across jurisdictions (including for countries that must export radioactive waste due to limited domestic disposal infrastructure) is a recognised challenge. Significant gaps remain, particularly for emerging rare earth producers that may lack both the regulatory frameworks and the disposal infrastructure needed to manage NORM residues. The International Atomic Energy Agency coordinates ongoing work in this area, providing guidance that countries can draw on when developing or strengthening national frameworks.

Cross-border public-private partnerships

Because rare earth supply chains outside China are geographically separated, with mining, refining and manufacturing usually found in different regions, international public-private partnerships are both valuable and necessary to ensure accelerated progress on diversification. Governments can enable cross-border rare earth ecosystems by acting as conveners and guarantors, bringing together mining companies in resource-rich countries with separation technology providers and downstream manufacturers and aligning financing instruments behind these partnerships.

Two recent examples illustrate this. The Frontier-Carester partnership at Zandkopsdrift in South Africa combines South Africa's Industrial Development Corporation committing USD 20 million to fund a definitive feasibility study for a deposit holding approximately 750 000 tonnes of total rare earth oxides with France-based Carester providing proprietary separation technology. This structure pairs public financing for upstream development with private technology transfer for midstream processing, and positions South Africa as a non-incumbent supplier of rare earths for European supply chains. The Maaden-MP Materials joint venture goes further along the chain, with Saudi Arabia's state mining company holding majority equity in a refining and separation facility that will process both domestic and imported feedstock from the United States and allied buyers, and the US Department of War providing non-recourse financing and MP Materials contributing separation and marketing expertise.

Regional processing partnerships can also help distribute the radioactive waste management burden – a shared separation facility serving multiple producer countries within the same region can achieve the scale needed to invest in certified NORM disposal infrastructure. This may be constrained by the Basel Convention's restrictions on the transboundary movement of hazardous waste, making such arrangements more feasible within countries with compatible regulatory frameworks and existing trade relationships and requiring bilateral or regional waste management agreements to be in place as a precondition.

5. Promote supply-side technology innovation

Supply-side innovation is a critical enabler of efforts to diversify rare earth supply chains as new entrants face substantial technical, economic and environmental barriers across mining, separation and refining. So far, innovation in the upstream and midstream has been slow, but it is increasingly emerging as an essential element for diversification. Without innovation, closing existing technology gaps in diversified regions and ensuring the competitiveness of new projects will be highly challenging. Many deposits outside established producing regions differ in geology, scale and composition, making conventional extraction routes less effective or more costly. Innovation can help overcome these constraints by enabling the development of a wider range of resources, lowering environmental risks and reducing capital intensity. Separation and refining are technically demanding processes, and innovation in these areas could deliver significant benefits for energy and reagent consumption, waste management, and emissions.

Innovation in mining

Most hard-rock rare earth mining operations rely on conventional extraction techniques, including open-pit, placer (dredging) and underground mining. These extraction routes are gradually benefiting from modern technological innovations. The adoption of smart mining platforms and digital twins is also helping optimise these traditional extraction processes, maximising resource recovery while minimising safety risks. Nonetheless, extraction of IAC deposits – a major potential source of heavy rare earths – currently relies on in situ leaching using ammonium sulphate solutions. While effective, this method poses environmental risks, including groundwater contamination and soil degradation due to ammonia nitrogen residues. These impacts can constrain development in regions with strict environmental regulations or limited water resources.

Bioleaching represents a promising alternative that could enable production in such contexts. Widely used in copper mining, bioleaching employs microorganisms to solubilise metals from ores, reducing the need for aggressive chemical reagents. This approach is particularly attractive for low-grade or geochemically complex deposits that are common outside established producing regions. By lowering chemical use and potentially reducing waste generation, bioleaching could make previously marginal resources both economically and environmentally viable. However, applying bioleaching to rare earths presents specific challenges and will require significant research and development (R&D) efforts to be deployable at scale within the near future. Suitable microbial strains vary depending on mineral composition, which differs significantly across deposits. Achieving stable operation, competitive recovery rates and acceptable processing times remains difficult. Continued research into microbial selection, process optimisation and scale-up is therefore essential for widespread adoption.

Other mining innovations – including improved ore characterisation, targeted leaching techniques, reduced water consumption and technologies enabling co-recovery of by-products – can further enhance project viability. These advances can be particularly important for smaller deposits, where maximising resource utilisation is key to economic success.

Novel rare earth separation and refining technologies

Refining and separation are regarded as among the most value-intensive and technologically demanding stages. For permanent magnet applications, high-purity separation is essential and requires large-scale continuous operations and precise chemical control. Currently, these separation requirements are primarily addressed through solvent extraction (SX), which separates rare earth ions through multistage liquid-liquid extraction. Because rare earths have very similar chemical properties, dozens to hundreds of stages are required, involving repeated extraction, scrubbing and stripping. This results in large, complex facilities; high capital and operating costs; and environmental compliance challenges linked to extensive solvent use.

To mitigate these limitations and enhance efficiency, efforts are under way to improve equipment configuration and operating methods while retaining the core SX framework. For example, Ucore's RapidSX is a process intensification technology that replaces conventional large mixer-settler arrays with column-based contactors, aimed at increasing process speed and operational efficiency.

In parallel, efforts are under way to simplify overall processing by more precisely controlling chemical conditions during the separation stage. Selective precipitation, crystallisation and dissolution techniques can be used to pre-simplify mixed solutions by removing certain elements in advance. Although rare earth elements are chemically similar, small differences in solubility and complexation behaviour allow selective separation of specific elements or element groups through careful adjustment of parameters such as pH and temperature. Such pretreatment steps can reduce the separation burden required in subsequent SX stages.

Within the SX process itself, ongoing efforts aim to improve extractant performance in order to enhance separation selectivity. Syensqo's CYANEX series is a commercially utilised line of SX reagents applied in various metal separation processes, including rare earths. More recently, nitrogen-containing N-heterocyclic high-selectivity extractants have been investigated, with particular focus on improving the efficiency of heavy rare earth separation. Increased extractant selectivity can reduce the number of stages required to achieve a given separation level, thereby lowering solvent consumption and plant scale, and potentially improving overall process economics.

In addition, technologies seeking to replace the solvent extraction structure altogether are emerging. ReElement Technologies is developing a rare earth separation process based on ligand-assisted displacement (LAD) chromatography, which employs solid-phase resin columns to sequentially separate ions instead of traditional liquid-liquid solvent extraction. Aclara Resources has recently inaugurated a pilot plant in Virginia to validate its proprietary rare earth separation technology using high purity mixed rare earth carbonates, with high concentration of heavy rare earths, that will be sourced from ionic clay deposits in Brazil and Chile. They have partnered with Argonne National Laboratory which is supporting the pilot through the development of advanced digital tools and artificial intelligence (AI) models to optimise rare earth separation processes. Rare Earth Salts has also announced the development of a proprietary separation technology distinct from conventional solvent extraction processes.

Enabling new recovery pathways

Unconventional or secondary sources, including industrial residues, mine tailings and end-of-life products, have potential to support diversification. Innovations that improve tolerance to impurities or enable flexible feedstock processing can expand the range of materials that can be economically refined. This is particularly relevant for countries lacking large high-grade deposits but possessing significant secondary resources. Digital technologies and advanced process control systems can further enhance efficiency and reliability, helping new facilities achieve stable operation more quickly. Standardised modular designs may reduce construction timelines and facilitate replication across different locations.

Supply-side innovation through the IEA Technology Collaboration Programme on Critical Minerals and Materials Recovery

The Technology Collaboration Programme on Critical Minerals and Materials Recovery (CMMR TCP) was established at the IEA in December 2025, sponsored by the governments of Canada (CanmetMINING) and the United States (Department of Energy). Technology Collaboration Programmes (TCPs) are international cooperation mechanisms operating under a common IEA framework that enable countries to jointly carry out research, development, demonstration and knowledge-sharing activities in priority technology areas. A broad range of stakeholders – including government agencies, national laboratories, universities and research institutions – contribute to TCP activities through collaborative tasks and technical work.

The CMMR TCP aims to advance technology innovation on the supply side of critical mineral value chains, with a particular focus on the responsible recovery of critical minerals and materials from secondary and unconventional sources, including mining waste, tailings and by-products from past and current operations. Through collaborative tasks on knowledge sharing, data pooling, technology assessment and test beds, the TCP provides a platform for participating countries to identify technology gaps, assess emerging recovery methods and accelerate the deployment of innovative solutions that can strengthen supply security and improve environmental performance.

While a number of promising innovation opportunities exist, the transition from laboratory innovation to commercial operation remains a major hurdle. Pilot and demonstration plants are capital-intensive and carry significant technical risk, which private investors may be reluctant to assume. Public support mechanisms – including grants, concessional finance, loan guarantees and support for shared testing facilities – can accelerate commercialisation. International collaboration can also play a role by facilitating knowledge transfer, establishing common standards and supporting workforce development. Overall, focusing more on technologies that can boost diversified supplies for heavy rare earths could be a strategy that will have more profound impacts on security.

6. Embrace demand-side technology innovation

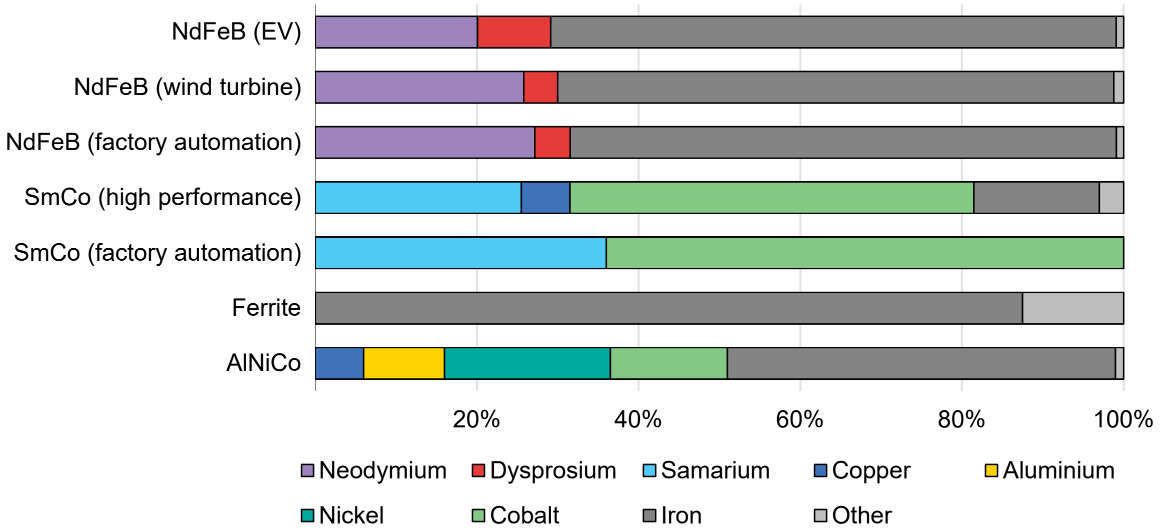
Demand-side innovation represents a powerful complement to supply-side diversification, providing a pathway to alleviate supply constraints and geopolitical risks. Demand-side innovation can take three distinct forms: reducing the amount of heavy rare earth elements (HREEs) required within existing magnet chemistries; substituting one HREE for another that is less supply-constrained; and developing entirely new technologies that minimise drastically or eliminate rare earth use altogether.

Neodymium-iron-boron (NdFeB) magnets deliver the highest magnetic performance currently available and are indispensable in many strategic applications. Their performance can be enhanced through the addition of HREEs – notably dysprosium and terbium – which improve coercivity and high-temperature stability. However, while supply chains for light rare earth elements (LREEs) are gradually diversifying, HREE production remains overwhelmingly concentrated in China and Myanmar. This structural imbalance heightens vulnerability to supply disruptions and export restrictions.

One major avenue of innovation therefore focuses on reducing HREE intensity within NdFeB magnets without sacrificing performance. Manufacturers are improving grain boundary engineering, motor cooling and system design to achieve equivalent functionality with less dysprosium or terbium. The HREE content of magnets varies significantly by application: high-performance EV traction motors contain around 8.5-11% of HREEs by weight of the magnet, while magnets used in industrial motors and wind turbines typically have slightly lower ratios of heavy to light rare earths. Continued improvements in materials science and engineering can lower these requirements, thereby reducing exposure to constrained supply.

In the wind sector, manufacturers are pursuing both technological and supply-chain strategies to limit rare earth use. Turbine drivetrain design plays a major role: geared drivetrains require substantially less rare earth material than gearless direct-drive systems. According to Vestas, geared turbine designs can use up to ten times less rare earth material than direct-drive configurations, and newer turbine platforms have further reduced rare earth intensity per megawatt.

Indicative elemental composition of different types of magnets



Notes: AlNiCo = aluminium nickel cobalt magnets; SmCo = samarium cobalt magnets; NdFeB = neodymium iron boron magnets

A related strategy involves substituting one rare earth element for another that is less scarce or less geopolitically concentrated. For example, magnet manufacturers started replacing dysprosium or terbium with alternative elements such as gadolinium or holmium after the announcement of the April 2025 export controls. While such substitutions do not eliminate dependence on rare earths, they could reduce pressure on the most constrained segments of the supply chain.

Coordinated action across the value chain can accelerate both reduction and substitution strategies. Collaboration among motor manufacturers, magnet producers and public authorities is particularly effective in overcoming technical barriers and scaling innovation. Following the rare earth supply shock of 2010, for example, Japan implemented government-supported programmes to redesign motors for vehicles, industrial equipment and hard disk drives. Even though demand has risen again in recent years due to growing magnet applications, overall rare earth demand in Japan has reduced significantly in the years following the implementation of these measures. Currently, total rare earth demand, including heavy rare earths, is nearly 30% below the levels in 2010, indicating that substantial reductions have been achieved, and demonstrating the impact of targeted demand-side measures.

A more transformative pathway is the development of technologies that substitute rare earth-based magnets entirely. Mature alternatives such as ferrite and aluminium–nickel–cobalt (AlNiCo) magnets contain little or no rare earth content and are already widely used where performance requirements are lower. These materials, based on abundant iron alloys or ceramic oxides, can replace NdFeB magnets in applications such as speakers, sensors and lower-power motors, thereby reducing overall rare earth demand and material costs.

Emerging rare earth-free technologies are also progressing towards commercialisation. In the United States, Niron Magnetics has begun construction of a permanent magnet manufacturing facility in Minnesota based on iron nitride (FeN) technology with no rare earth elements, aiming to serve the automotive and electronics sectors. In parallel, research programmes are developing electric motors that avoid permanent magnets altogether by using alternative electromagnetic designs based on widely available materials such as iron and aluminium. Although many of these technologies remain at demonstration or early commercial stages, they illustrate a growing strategic shift towards reducing dependence on critical minerals.

A wider range of alternative materials and magnet concepts – including iron cobalt (FeCo) composites, hexaferrite nanostructures, artificial intelligence (AI)-designed materials and bonded hybrid magnets – are at varying stages of maturity. These approaches aim to balance performance, cost and material availability, but most involve trade-offs in magnetic strength, thermal stability, manufacturability or durability, and none yet provide a universal drop-in replacement across all high-performance applications. Dedicated research, pilot production and testing are required before they can compete at scale with established NdFeB technologies.

Summary of alternative technologies that reduce, substitute or avoid rare earth use

Technology	REE use	Performance	Applications	Advantages	Shortcomings
Ferrite	None	Mature, low cost, energy product (BH_{max}) ~3-5 MGOe	Small motors, sensors, speakers, appliances	Abundant, highly scalable, no rare earth dependency	Very low magnetic strength (~1/10 NdFeB); poor high-temp performance; heavy and brittle; inefficient for compact motors
AlNiCo	None/ minimal	Moderate strength (~5-9 MGOe); excellent temperature stability	Niche motors, instruments, high-temperature environments	Proven, recyclable, less critical material risk	Lower coercivity; cobalt cost volatility; bulky design; complex magnetisation requirements
Heavy REE low/free NdFeB	Light REE (Nd/Pr), minimal Dy/Tb	High performance (~30-45 MGOe); pilot-commercial scale	EVs, wind turbines, robotics	Major step towards HREE independence; retains most performance	Major step towards HREE independence; retains most performance
Iron nitride (FeN)	None	Lab to pilot stage; high theoretical BH_{max} (~35-40 MGOe)	EVs, motors, wind (in R&D)	Potential true REE-free alternative; sustainable	Thermal stability limited; nitrogen loss risk; scalability and durability unproven; small-scale production
FeCo /hexaferrite composites, nanowire hybrids	None	Emerging; performance 1.2-1.5× ferrite (~5–8 MGOe)	Mid-performance motors, electronics	Compromise between abundant resources and performance	Below NdFeB strength; complex manufacturing; anisotropy control difficult; long-term reliability unproven

Technology	REE use	Performance	Applications	Advantages	Shortcomings
Bonded/ hybrid magnets (ferrite + polymer/soft magnetic inclusions)	None/ minimal	Flexible manufacturing, corrosion resistant	Sensors, actuators, e-bikes	Good processability, low weight	Lower flux density (~30-50% of NdFeB); polymer limits temperature; possible mechanical degradation
AI-designed materials	None/ minimal	Discovery stage; modelled ~20% cost of NdFeB	Early R&D/ prototypes	Novel route using abundant elements; low carbon footprint	Unverified large-scale synthesis; unknown durability; needs validation for multiple geometries

Notes: BH_{max} = Maximum Energy Product, it represents the magnetic energy density established in the space between the two magnetic poles of the magnet; MGOe = Mega Gauss Oersteds, it is the unit use to measure the BHmax

For new solutions to achieve widespread adoption, they must offer a competitive combination of performance, cost and manufacturability without introducing new supply constraints elsewhere in the value chain. Innovations that merely shift dependency from rare earths to other scarce or geopolitically concentrated materials would provide limited systemic benefit. Priority should therefore be given to technologies based on abundant inputs, scalable production processes and compatibility with existing industrial systems. The example of Japan highlighted above demonstrates the significant impact that coordination among producers and consumers can have in achieving meaningful improvements in material efficiency through innovation. Governments can signal strong support for research, development and commercialisation across various demand-side innovation pathways by allocating finances to R&D efforts as a key lever for strengthening long-term resilience.

7. Develop targeted policies to unlock the full potential of recycling

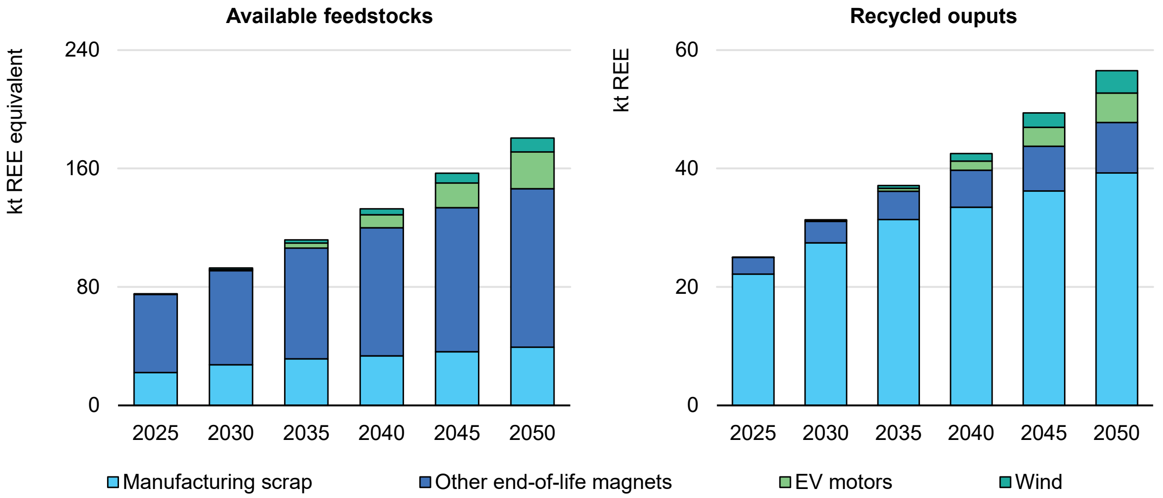
Recycling has the potential to enhance the security of rare earth supply, with secondary sources projected to reduce mining requirements by 35% by 2050 if supported by the right policy framework (see Chapter 3). Manufacturing scrap currently accounts for close to 75% of secondary supply and is heavily concentrated geographically where permanent magnets are produced. While currently small, end-of-life feedstocks are expected to grow by 50% by 2035 and are more widely distributed geographically than today's manufacturing scrap, creating strategic opportunities for regions outside China to strengthen supply security.

While some policies have already defined critical mineral recycling targets, such as the 25% goal under the European Union Critical Raw Materials Act (CRMA), realising this will require targeted actions. Unlocking the full potential of secondary supply depends on policies dedicated to increasing collection, sorting and recycling rates; de-risking investments; and promoting ecosystem development.

From feedstocks to recycled materials: Tackling challenges to collection, sorting and recycling

Rare earth recycling remains constrained by low collection rates, weak economics and the limited availability of feedstock. Collection rates remain low for many waste streams, particularly for electronic waste. These constraints are, however, less pronounced for certain emerging secondary supply streams. Products containing larger magnets or those subject to dedicated end-of-life management systems – notably EV motors and wind turbines – present more favourable recovery conditions. As deployment of these technologies accelerates, they offer growing opportunities for recycling. Their relatively long lifetimes also provide greater visibility on future feedstock availability, which can support investment planning and capacity development.

Global end-of-life feedstock and secondary supply output of magnet rare earth elements



IEA. CC BY 4.0.

Note: The figures are for magnet REE only (neodymium, praseodymium, terbium and dysprosium).

Strengthening and harmonising extended producer responsibility schemes can be an important first step, making producers contribute to meeting collection and recovery targets. Recycling rates for e-waste vary significantly across regions – 55% in Germany, 50% in the United States and Korea, 40% in Italy, 23% reported in Japan, and less than 3% in Central and South America and in Southeast Asia.

This variation suggests that well-designed policy frameworks can improve outcomes, although implementation remains uneven.

Second, setting collection and recycling targets specific to rare earths could be considered. After their collection, end-of-life products must also be processed in ways that allow magnets to be effectively extracted. In many applications, permanent magnets are embedded in complex, multi-material products. Their small size and integration into larger assemblies make them difficult to identify and recover under conventional recycling systems. Existing circular economy policies have primarily focused on waste management and reducing demand for primary raw materials and sometimes do not specifically target critical minerals: recycling obligations are often defined on a weight basis, without material-specific recovery requirements. As a result, operators tend to prioritise bulk materials or precious metals that contribute most to meeting legal targets or economic interests, while recovery of REEs remains limited. The European Union battery regulation, which includes a 90% recovery target for cobalt, copper and nickel and a 50% lithium recycling target by 2028 for battery recyclers, can be an example of such material-specific policy. As a second example, some public tenders for offshore wind in Europe now include up to 75% recycling targets for the magnets in wind turbine generators.

Third, mandating rare earth content disclosure in relevant products could be considered to improve traceability and sorting efficiency. The absence of clear data on composition complicates sorting and dismantling and reduces process efficiency. The lack of data also makes it difficult to forecast future secondary supply. Such product labelling obligation, including weight, location and chemical composition of permanent magnets, is planned to enter into force by end of 2028 in the European Union. A related challenge is the lack of incentives promoting design for recyclability, particularly for products where magnet removal is technically challenging.

Beyond improvements in product-level design and labelling, enhanced data sharing is critical to strengthening circularity. Additional efforts are needed to support the traceability of materials in waste and scrap streams, particularly in international trade. The absence of dedicated trade codes (six-digit HS codes) for magnet waste hampers systematic monitoring, resulting in gaps in understanding secondary rare material trade and flows.

De-risking investments in recycling infrastructure

Recycling facilities face challenging economic conditions. Business models are exposed to high capital costs, technological risk, volume risk and uncertain margins, while operating at smaller scale and with less established supply chains. Recyclers, who secure feedstock at market prices while competing directly with primary producers on sales, are exposed to three sources of volatility: i) feedstock costs; ii) uncertainty over the resale value of recovered materials; and iii) shifting competitiveness relative to primary supply. Price volatility can also further amplify the risks for recyclers.

Supporting early-stage recyclers through grants and feedstock access programmes can help overcome the current scarcity of end-of-life materials. To this end, the European Union (EU), the US Department of Energy and Japan have developed programmes to support innovative recycling companies. In February 2026, Japan announced new subsidies towards rare earth recycling facilities. Dedicated action may be needed to help companies source emerging feedstock types: although deployment of EV motors and wind turbines is accelerating, only limited volumes have yet reached end of life, which means available material is insufficient to support large-scale operations, creating competition among start-ups and pilot projects for limited supply.

Encouraging the adoption of recycled rare earths through policy incentives such as procurement rules or eco-design requirements can play a role. Uncertainty of demand for secondary materials, caused by the limited visibility on manufacturers' willingness to incorporate recycled content, is a key barrier to investment in recycling facilities. Policy tools such as eco-design requirements or recycled content targets can provide demand signals for secondary materials, provided that targets are realistic and aligned with expected material availability. A key example is the EU CRMA plan for mandatory recycled content disclosures by 2027 for magnets of over 200 grammes and mandatory minimum recycled content shares by 2032.

Ecosystem strategies to recycling: Synergies among refineries, magnet makers and recycling technologies

Industrial clustering that links recycling facilities with magnet manufacturers can help close the loop. Waste streams and magnet manufacturing are frequently geographically separated, with over 30% of available end-of-life feedstocks entering the market in Europe and North America, but where magnet manufacturing in these regions is currently limited. Proximity to magnet manufacturing capacity is particularly important to access swarf and scrap generated during magnet production, which account for the majority of today's available feedstock. As countries in geographically diverse regions begin developing magnet manufacturing facilities, investment in recycling facilities can be aligned with these expansion plans to strengthen supply security and improve material circularity.

Governments can also aim to support integrated ecosystems that include a diverse range of refining and recycling infrastructure. In some cases, magnet powders can be directly reprocessed into new magnets through so-called short-loop recycling, reducing processing steps and energy use. However, the production of new magnets often also requires fresh alloys and separated oxides, underscoring the need for long-loop recycling capacities. This involves chemical separation, solvent extraction and metallisation – processes that closely overlap with conventional rare earth refining. As a result, co-locating or integrating recycling with refining facilities can create technological synergies, lower capital costs and improve operational efficiency.

Finally, ensuring predictable regulations applicable to waste management and trade can facilitate investments. Divergent rules governing electronic waste and other secondary feedstocks across jurisdictions create complexity for operators seeking to source material internationally.

8. Accelerate efforts to enhance price transparency

Why does price transparency matter?

One of the essential features of a well-functioning market is transparency in pricing, which enables reliable spot prices for buyers and sellers, as well as the development of a forward price curve. The absence of such transparency in rare earth markets hampers the creation of key financial tools that are commonly used to manage risk in other commodity sectors. In particular, the absence of reliable spot market prices, particularly outside China, complicates the negotiation of long-term supply contracts and offtake agreements that project developers rely on to hedge volume risks. Against the backdrop of rising trade restrictions, price transparency becomes increasingly critical to identify potential market distortions and economic coercion, including measures affecting specific companies or segments of the market.

The lack of reliable information on transaction prices constrains market participants' ability to hedge risks effectively, plan production and manage procurement. Access to this information enables both producers and consumers to plan ahead: producers can assess whether to expand or reduce production capacity, while consumers can better gauge supply availability and the ease or difficulty of securing materials.

Measures towards increased price transparency of rare earth markets

Policy efforts aimed at enhancing price transparency need to reflect the structural constraints associated with limited market liquidity of rare earths. In such conditions, the development of instruments commonly observed in more mature commodity markets – including sophisticated derivatives or large-scale private trading platforms – is likely to remain limited.

Governments can nevertheless consider starting efforts through a range of targeted measures, which can be grouped under three categories: i) measures to facilitate market development; ii) establishing active mechanisms where market tools remain underdeveloped; and iii) gathering prices through complementary data sources.

Potential measures for enhanced price transparency in markets with limited liquidity

Markets for critical minerals have reached varied maturity levels

Market development facilitation
- Supporting audited price reporting agencies
- Increased liquidity through standardisation
- Supporting open and non-discriminatory trade

Alternative or public mechanisms
- Market-making mechanisms
- Direct market participation, such as for stockpiling purposes
- Grouped purchasing

Alternative data sources
- Dialogue and surveys of industry
- Analysis of administrative data (such as trade data)
- Oversight of supply contracts

First, actions to facilitate market development can include:

- **Enhancing existing transparency tools** by promoting the use of established platforms and market arrangements in more mature commodity markets, and by supporting price reporting agencies that adhere to internationally recognised standards. For example, conditions for financial support (e.g. government offtake, bids for price floor) can be linked to price indices that are developed and governed in accordance with recognised standards, such as the International Organization of Securities Commissions.
- **Strengthening market liquidity** by encouraging greater standardisation of products (such as magnet specifications within specific industries). Initiatives to promote standardisation and reporting practices should have close industry engagement to ensure technical feasibility and interoperability.
- **Pursuing efforts aimed at limiting the impact of extraterritorial measures** that may constrain the open and non-discriminatory sale of these commodities.

Second, several more active mechanisms that involve stronger government interventions also exist, each with different advantages and disadvantages:

- **Participating directly in the market,** notably through coordinated purchasing schemes or strategic stockpiling (see Recommendation 2), which can also provide public authorities with first-hand information on prevailing transaction prices and volumes.
- **Price-based mechanisms**, such as price cap and floor, can provide some avenues for increasing market transparency as they can contribute to price discovery under certain conditions. When they are allocated through competitive processes, such as public tenders or auctions, the bidding behaviour of market participants reveals information about their cost structures, price expectations and risk assessments. The resulting strike price can serve as a reference point for the broader market, especially where transparent benchmark prices are otherwise limited. By providing actors with some form of price certainty, these can also lessen the immediate need for deep secondary markets or sophisticated hedging instruments.
- **Engaging in market-making mechanisms**, which provide a reliable buyer or seller of last resort for strategic volumes through a public or public-backed entity that commits to buying and/or selling products at transparent terms to provide liquidity or price stability. There are multiple ways of operationalising this, for example through national agencies, multilateral platforms, public-private partnerships or special-purpose vehicles. A market maker increases confidence in the ability of players within the market to transact at transparent, stable prices.

These direct measures require careful handling of financial risks, clear strategies for phase-in and -out, and strong industry engagement. Governments should design and implement them so that they improve transparency and liquidity without distorting prices or crowding out private actors, supported by clear governance and transparent mandates.

Finally, governments may wish to leverage alternative data sources such as industry surveys, administrative data sources or contract oversight (see Recommendation 1). For example, existing data sources such as trade data, customs fillings and value-added tax (VAT) records can allow for inference of implicit transaction prices. Contract oversight, such as in the case of Euratom in the uranium sector, involves a public agency having access to supply contracts and publishing aggregate price information for public reference.

These data collection actions must strike an appropriate balance between transparency objectives and the protection of commercially sensitive information, including identification of what would be publicised at what level of aggregation for best use to the wider public. Overall, actions should remain consistent with international trade and competition obligations and, where possible, be coordinated with like-minded partners to avoid further market fragmentation.

Potential for strengthened international coordination across the supply chain

Building diversified rare earth supply chains requires a wide array of efforts, including substantial financial capital, access to geological resources, advanced processing and separation technologies, specialised skills, supportive infrastructure, and a robust downstream industrial base capable of converting refined materials into high-value components and equipment. Few regions possess this full suite of capabilities domestically. Many resource-rich regions lack processing capacity or technological expertise, while advanced manufacturing economies often depend on imported concentrates and intermediates or semi-finished components such as alloys or magnets. This uneven distribution of assets, technology and skills implies that no single country or region can efficiently develop resilient, end-to-end value chains in isolation. There is significant scope for international collaboration, including cross-border investment, technology partnerships, long-term offtake agreements and coordinated policy frameworks to reduce risk and mobilise capital. Such cooperation can help align upstream development with downstream demand, accelerate project timelines, and support the emergence of diversified supply networks.

Cooperation between different supply chain actors

In a market characterised by relatively small volumes but high concentration and risk, international collaboration can provide the scale of supply, demand and financial support that is needed to help and realise projects. Additionally, in case of disruptions, cross-border partnerships can also provide the feedstocks required by magnet manufacturers – coming from refining projects or existing stockpiles – or pool scrap from multiple countries to be transformed in refining facilities and provide additional supply for a multilateral group. If disruptions are caused by trade restrictions, multilateral engagement also brings higher leverage when negotiating with dominant suppliers.

Targeted policy and financing efforts

Governments can strengthen collaboration across the value chain by using co-investment, joint ventures and offtake agreements to better align incentives between upstream and downstream actors. Public participation can help share risk, attract private capital and support coordinated development of supply chains. Policy tools can also be deployed to support supply and stimulate demand. Aligning the use of these tools across jurisdictions, for example by harmonising eligibility criteria, standards and financial de-risking instruments, as well as by pooling funding or coordinating strategic investments to meet collective needs, can reduce fragmentation and help prevent overinvestment in any single segment of the value chain.

Harmonisation of magnet performance standards

Harmonisation of magnet performance standards can reduce fragmentation across markets and enable manufacturers to scale production of rare earth permanent magnets. At present, differing national and industry specifications for properties such as coercivity, thermal stability, corrosion resistance and testing protocols create barriers to trade and slow qualification of new suppliers. Greater alignment on harmonised standards and performance benchmarks would lower certification costs, facilitate interoperability across global value chains and accelerate the entry of alternative producers without compromising safety or performance.

Incentivise downstream manufacturing and stimulate end-use demand

For supply projects to be commercially viable, a strong and growing demand base is essential. Efforts to nurture and expand downstream industries – such as EVs, new energy technologies and high-tech manufacturing – outside China can play a critical role in supporting the development of diversified rare earth supply. In the absence of parallel growth in downstream capabilities in diversified regions, upstream and midstream projects may face weak or uncertain offtake, limiting investment and increasing exposure to price volatility. Policy measures to encourage the development of strategic downstream industries in energy, automotive and high tech are crucial to underpin long-term contracts and financing decisions. Countries with established manufacturing bases can also strengthen partnerships with regions that have significant end-use demand, reinforcing market confidence, enabling economies of scale and supporting the long-term competitiveness of emerging supply chains.

The IEA Critical Minerals Security Programme

As international collaboration is central to build secure and resilient rare earth supply chains, the IEA Critical Minerals Security Programme (CMSP) provides a structured platform to advance coordinated policy action, underpinned by data-driven analysis and practical preparedness tools.

The CMSP supports countries in strengthening their ability to anticipate and respond to supply disruptions while accelerating broader efforts to diversify supply chains. Regular Table-Top Exercises simulate realistic disruption scenarios and enable countries to test emergency procedures, identify priority response measures and reinforce emergency response procedures. Complementing these emergency preparedness efforts, diversification workshops bring together countries to assess strategic project opportunities, explore potential partnerships, and evaluate policy instruments that can unlock new and diverse supply sources, supported by the Critical Minerals Information Dashboard, which provides project information and essential market insights to guide effective decision-making. Activities and tools of the CMSP can be leveraged to achieve and implement the international collaboration objectives to build secure and diversified rare earth supply chains.

Annex

Abbreviations and acronyms

AI	artificial intelligence
AUD	Australian dollar
CAD	Canadian dollar
BRL	Brazilian real
Ce	cerium
CfD	contract for difference
CMMR TCP	Technology Collaboration Programme on Critical Minerals and Materials Recovery
CMSP	Critical Minerals Security Programme
CRMA	Critical Raw Materials Act
CT	computed tomography
Dy	dysprosium
Er	erbium
ESA	Euratom Supply Agency
EU	European Union
EV	electric vehicle
FeCo	iron-cobalt
FeN	iron-nitride
Gd	gadolinium
GDP	gross domestic product
GEC Model	Global Energy and Climate Model
HREE	heavy rare earth element
HS	Harmonised System
IAC	ionic adsorption clay
IAD	ionic adsorption deposits
IEA	International Energy Agency
IOSCO	International Organization of Securities Commissions
La	lanthanum
LED	light-emitting diode
LFP	lithium-iron-phosphate
LREE	light rare earth element
MIIT	Ministry of Industry and Information Technology
MRI	magnetic resonance imaging
Nd	neodymium
NdFeB	neodymium-iron-boron
NORM	naturally occurring radioactive material
PRA	price reporting agency
Pr	praseodymium

PVC	polyvinyl chloride
R&D	research and development
REE	rare earth element
REO	rare earth oxide
Sm	samarium
SmCo	samarium-cobalt
STEPS	Stated Policies Scenario
SX	solvent extraction
Tb	terbium
TCP	Technology Collaboration Programme
US	United States
USGS	United States Geological Survey
VAT	value-added tax
WTO	World Trade Organization
Y	yttrium
Yb	ytterbium

Glossary

kg	kilogrammes
kt	kilotonnes
kt REE	kilotonnes of rare earth element content
Mt REO	million tonnes of rare earth-oxide equivalent
GtCO2/yr	gigatonnes of carbon dioxide per year

See the IEA glossary for a further explanation of many of the terms used in this report.

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