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THE RARE EARTH IMPERATIVE

How market dynamics & geopolitics drive diverse investment pathways

CONTENT

AMER HAGE CHAHINE
Partner, Energy, Utilities & Resources (ENUR)
Dubai

TRUNG GHI
Partner, ENUR
Singapore

ILYA EPIKHIN
Principal, ENUR
Dubai

KISEKI HIRAKAWA
Consultant, Growth
Dubai

PETER KAZNACHEEV
Principal, ENUR
Dubai

EXECUTIVE SUMMARY

This report delves into the critical role of rare earth elements (REEs) — the 17 indispensable minerals underpinning modern technology, from smartphones and electric vehicles (EVs) to advanced medical equipment and defense systems. While not geologically rare, their extraction and processing are complex, costly, and, crucially, highly concentrated.

Our analysis underscores a profound market imbalance: China holds a leading position in the global REE landscape, controlling approximately 70% of mining and a staggering 80%-90% of separation and refining capacity, particularly for high-value heavy REEs (HREEs). This high degree of market concentration gives China significant geopolitical leverage and creates price volatility. While this has implications for the viability of non-Chinese producers, it also underscores the importance of diversifying supply sources to enhance global supply chain resilience. Another key challenge is the "balance problem," where the co-production of high-demand magnet elements (neodymium, praseodymium, dysprosium, and terbium, which account for ~90% of market value) leads to an oversupply of less valuable elements like cerium and lanthanum and distorts project economics. The growing demand for REEs is compounding this issue, especially for magnet-critical elements like neodymium-praseodymium (NdPr), which is projected for robust growth (8.4% CAGR for NdPr by 2035), driven by the burgeoning EV, wind turbine, and robotics sectors. This trajectory points toward potential deficits, particularly for dysprosium and terbium, unless new, diversified supply and processing capacities are rapidly developed.

Strategic investment is paramount to respond to the conditions described above. This report identifies three key pathways:

1. **Diversifying primary resource extraction** — prioritizing projects in geopolitically stable regions, with a particular focus on high-value ion adsorption clay (IAC) deposits, which possess favorable HREE content with potentially faster development timelines compared to traditional hard-rock mines.
2. **Strengthening global midstream capacity** — investing in new separation and refining facilities throughout the world, which would enhance the resilience and diversity of these critical stages in the REE value chain. Companies, including Australia's Lynas Rare Earths and the US's MP Materials, are notable pioneers in this effort.
3. **Advancing the circular economy and innovation** — promoting REE recycling from end-of-life products and industrial waste streams (e.g., phosphogypsum) and furthering R&D to identify usage reduction strategies, such as grain boundary diffusion (GBD) in magnet manufacturing, to mitigate demand pressures.

Navigating this evolving landscape requires concerted action from governments, private investors, and industry stakeholders. This includes fostering national champions, supporting technological innovation, streamlining permitting processes, and encouraging international collaboration to build resilient, geographically diverse, and responsible REE value chains. Ultimately, securing a stable supply of these critical rare earth materials is not merely an economic consideration; it is a strategic necessity for technological advancement and a sustainable 21st-century future.

INTRODUCTION

You wake up to the gentle buzz of your smartphone. You flick on your LCD (liquid crystal display) or OLED (organic light-emitting diode) TV to catch up on the latest news. A quick call from a colleague on another continent helps you align the upcoming meeting agenda. You pop in your AirPods, hop into your EV, and drive to the office. Later, you will swing by the medical center for a physical, which includes a computerized tomography (CT) scan with contrast. This is your plan for today. But there is a twist: none of these activities would be possible without the magic of REEs, quietly powering the devices and technologies that surround us.

The world's most powerful magnets are crafted from four REEs: neodymium, praseodymium, dysprosium, and terbium. These elements make your phone vibrate, enhance your sound experience, and help convert the electrical energy in your EV's battery into kinetic energy to turn the wheels. Without europium, yttrium, and terbium, you can forget about the vibrant colors on your TV display. And without erbium-doped amplifiers in long-distance cables, your transcontinental video chat could not connect.

During your CT scan, gadolinium steps in as the contrast agent, giving doctors a crystal-clear image of your blood vessels, helping them spot potential concerns. And that upcoming minimally invasive skin surgery? It is made possible by lasers; specifically, thulium-doped, yttrium-aluminum garnet lasers, which operate at wavelengths perfect for minimally invasive procedures.

REEs ARE UNSUNG HEROES, QUIETLY SHAPING OUR HIGH-TECH LIVES

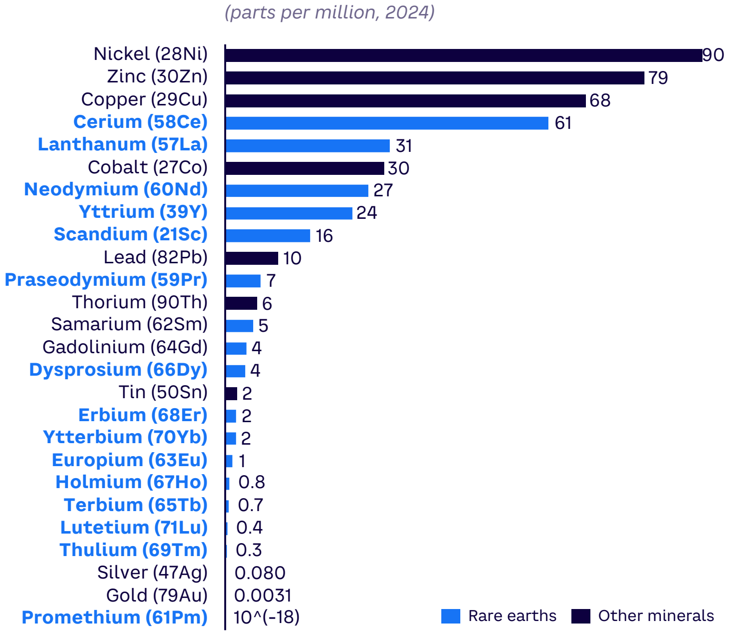
This is just a snapshot of a day in the life of a modern citizen. As you can see, REEs are unsung heroes, quietly shaping our high-tech lives. The increasing ubiquity of these technologies signals a growing, and often underappreciated, demand, making a deeper understanding of the REE sector more critical than ever for both strategic planning and investment.

This report offers a unique value proposition. We synthesize information from disparate sources: geological surveys, market analyses, geopolitical reports, and company filings to provide a holistic, investor-focused introduction to the REE sector, which can serve as a starting point for private and public sector decision makers alike. Our aim is not just to explain REEs, but to identify actionable investment opportunities in a world increasingly dependent on these critical materials. Understanding the forces shaping tomorrow's REE landscape is paramount for strategic investment and securing a technologically advanced, sustainable future.

1. THE INTRINSIC VALUE & PROPERTIES OF REEs

The domain of critical materials has garnered attention in recent years, with REEs standing prominently at the forefront of strategic discourse. This group of 17 chemically similar metallic elements, comprised of 15 lanthanides, plus scandium and yttrium, is not merely an esoteric entry on the periodic table; it constitutes indispensable components underpinning a vast spectrum of modern technologies. REEs' unique physicochemical properties, derived largely from their electronic structures, make them critical in applications ranging from consumer electronics and medical devices to advanced defense systems and the growing green energy sector. This irreplaceability, coupled with a complex supply chain, underscores why now is an opportune moment to consider strategic investments and intervention in this vital sector.

Figure 1. Crustal abundance of REEs



Source: Arthur D. Little; Chen, Ping et al. "Global Rare Earth Element Resources: A Concise Review." *Applied Geochemistry*, Vol. 175, November 2024

FUNDAMENTAL GEOCHEMICAL & PHYSICAL PROPERTIES

Counterintuitively, many REEs are relatively abundant in the Earth's crust (see Figure 1), with cerium, for example, being more plentiful than copper. However, their widespread low concentration makes it difficult to identify economically viable deposits. This leads to complex and costly extraction processes, creating potential vulnerabilities and opportunities for mining companies and businesses reliant on REEs.

The strategic value of REEs stems directly from their unique and potent magnetic and optical properties, which are essential for a range of advanced applications. These properties enable the production of high-performance permanent magnets crucial for converting electric into kinetic energy and vice versa in EVs, wind turbines, and consumer electronics, as well as specialized lasers, lighting, displays, polishing compounds, and catalysts for the oil & gas and automotive sectors.

These distinctive characteristics arise from the specific atomic structure of REEs (their 4f electron orbitals). From a practical standpoint, this means they can create the most powerful and stable localized magnetic moments and allow magnets to operate at higher temperatures and under pressure.

Geologically, the similar chemical nature of REEs (including their common +3 oxidation state and comparable ionic radii) means they often occur together in mineral deposits, though they are also highly reactive metals, particularly with oxygen and moisture, which adds complexity to their processing.

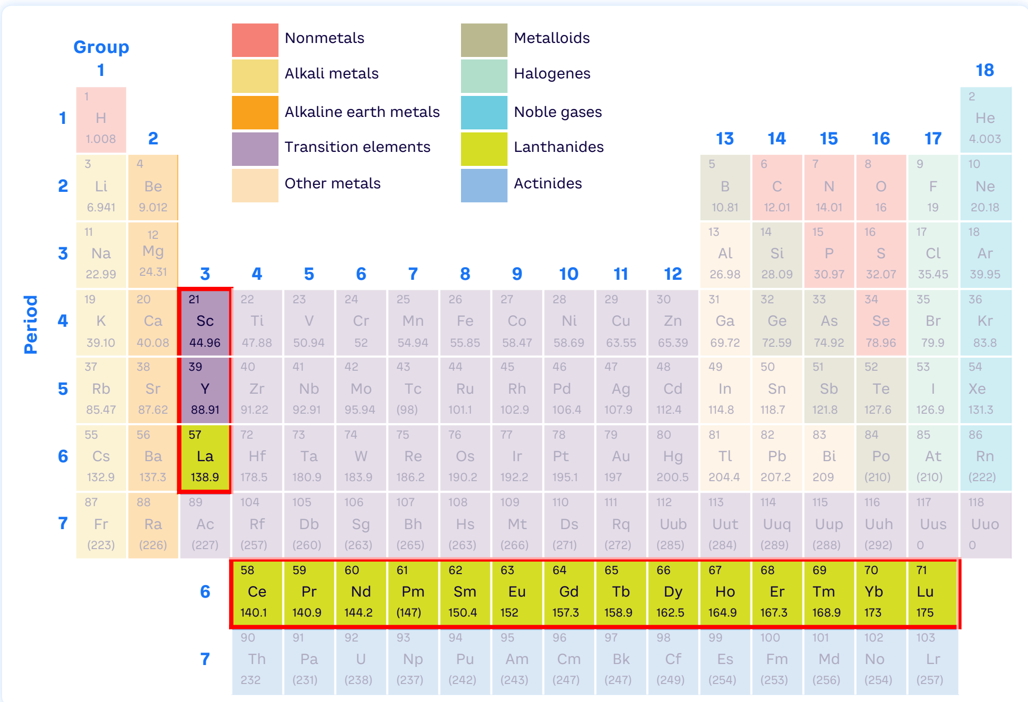
DISTINGUISHING BETWEEN LREEs, HREEs & SCANDIUM

Figure 2 shows distinctions within the REE group based on atomic weight and properties:

- **Light rare earth elements (LREEs).** These include elements from lanthanum (57) to gadolinium (64) and are more abundant and less expensive than HREEs, except for neodymium and praseodymium, which are pricier due to their use in permanent magnets. LREEs are characterized by unpaired 4f electrons.
- **HREEs.** This group spans from terbium (65) to lutetium (71) and includes yttrium (39), due to its similar properties. HREEs usually have paired 4f electrons, are less abundant than LREEs, and are more valuable, as dysprosium and terbium are crucial for enhancing NdFeB magnets' performance. Their scarcity makes them key for investment in resource exploration.
- **Scandium.** Scandium (21) is distinct from LREEs and HREEs, with a smaller ionic radius and unique applications, primarily in high-strength aluminum alloys for aerospace. It is best viewed as a unique member of the broader REE family; it is related mainly due to its appearance in the same deposits.

REEs' UNIQUE PHYSICOCHEMICAL PROPERTIES MAKE THEM CRITICAL IN APPLICATIONS

Figure 2. How 17 REEs appear in the periodic table



Source: Arthur D. Little

APPLICATIONS FOR THE 17 REEs

The 17 REEs each occupy a distinct and frequently irreplaceable technical niche (see Figure 3). This specialization is critical across numerous high-value sectors, with specific REEs underpinning key technological advancements.

High-performance magnets

- **Neodymium (Nd)** and **praseodymium (Pr)**, often with **dysprosium (Dy)** and **terbium (Tb)** to enhance high-temperature stability, are the driving force behind **NdFeB (neodymium-iron-boron)** permanent magnets. These magnets are at the heart of EV motors, wind turbine generators, robotics, and a myriad of consumer electronics.
- **Samarium (Sm)** is essential for **samarium-cobalt (SmCo)** magnets, which are preferred for demanding aerospace and nuclear-control applications.

Catalysis & industrial processes

- **Cerium (Ce)** and **lanthanum (La)** are foundational to high-volume chemical markets. Cerium serves as a workhorse in glass-polishing powders and three-way auto-exhaust catalysts. Lanthanum is dominant in fluid-cracking catalysts for petroleum refining and in **mischmetal** alloys, used in NiMH (nickel-metal-hydride) batteries.

> **REE naming**
>
> Interestingly, the names of eight REEs trace their origins to Scandinavia — particularly Sweden. Elements such as scandium and thulium reflect the region's ancient name, while holmium derives from the Latin name for Stockholm. Four others — yttrium, ytterbium, erbium, and terbium — are all named after the Swedish village of Ytterby, where they were first discovered. Many of these elements were identified in the mineral gadolinite, itself named after Finnish chemist Johan Gadolin, whose work in Ytterby also inspired the naming of gadolinium.

Lighting, displays & optics

- **Europium (Eu), terbium,** and **yttrium (Y),** coupled with gallium (outside of REE domain), form the crucial red-green-blue phosphor triad that illuminates fluorescent lamps, LEDs, and flat-panel displays.
- **Erbium (Er), ytterbium (Yb), holmium (Ho),** and **thulium (Tm)** enable critical components like fiber-optic amplifiers and specialized laser crystals.

Medical & emerging technologies

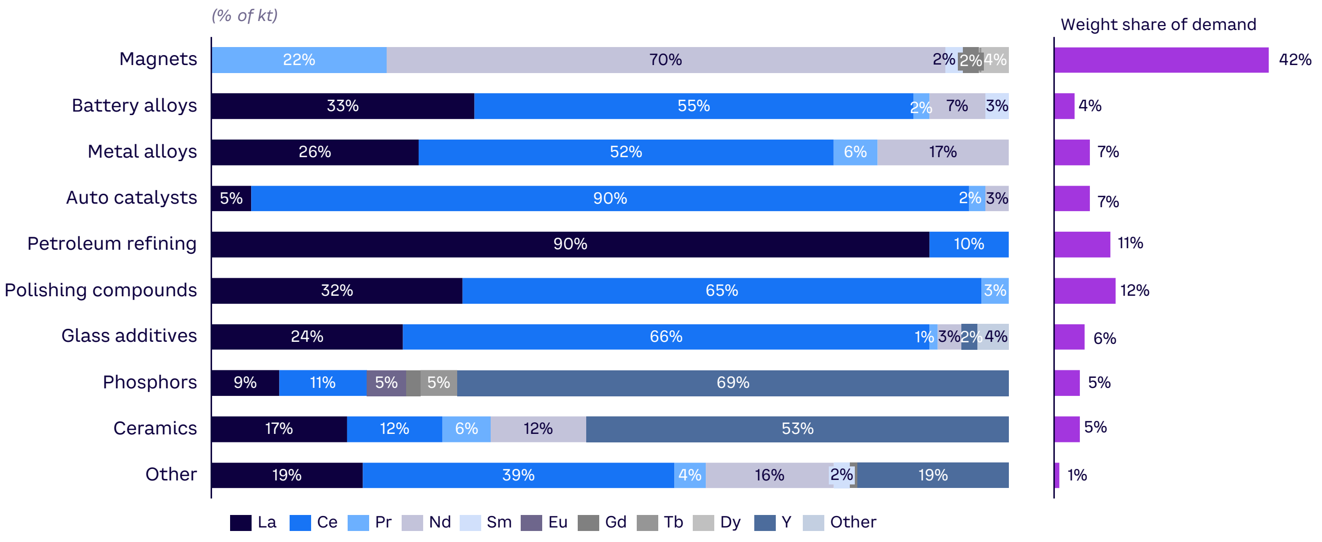
- **Gadolinium (Gd)** is highly valued for its use in magnetic resonance imaging (MRI) contrast agents and neutron-capture shields.
- **Elements like erbium, ytterbium, holmium, thulium,** and **lutetium** also play roles in emerging radiopharmaceuticals.

Advanced alloys

- **Scandium (Sc),** often considered an REE by association, significantly hardens aluminum alloys used in demanding aerospace applications and for solid-oxide fuel cells.

Global rare earth oxide (REO) mine output is sizable, at about 394 kilotons (kt) in 2024. However, demand for specific end uses is much lower — closer to 230 kt. This discrepancy is a result of the substantial "sacrificial" overproduction of cerium and lanthanum. Furthermore, this demand is far from evenly spread, with permanent magnets and catalyst applications dominating. Permanent magnets, especially NdFeB, lead the pack at ~42% of total consumption, propelled by EVs, wind turbines, and a host of electronic devices. Catalysts for automotive applications and petroleum refining come next, with a combined share of about 18%, driven by lanthanum- and cerium-rich formulations for oil cracking stability and automotive exhaust treatment. High-growth markets — high-performance permanent magnets, in particular — set the agenda for both supply strategies and pricing across the REE value chain.

Figure 3. REE weight composition in major applications and volumetric demand, 2023



Source: Arthur D. Little, Chen et al.

2. GLOBAL REE RESOURCES & PROJECT PIPELINE

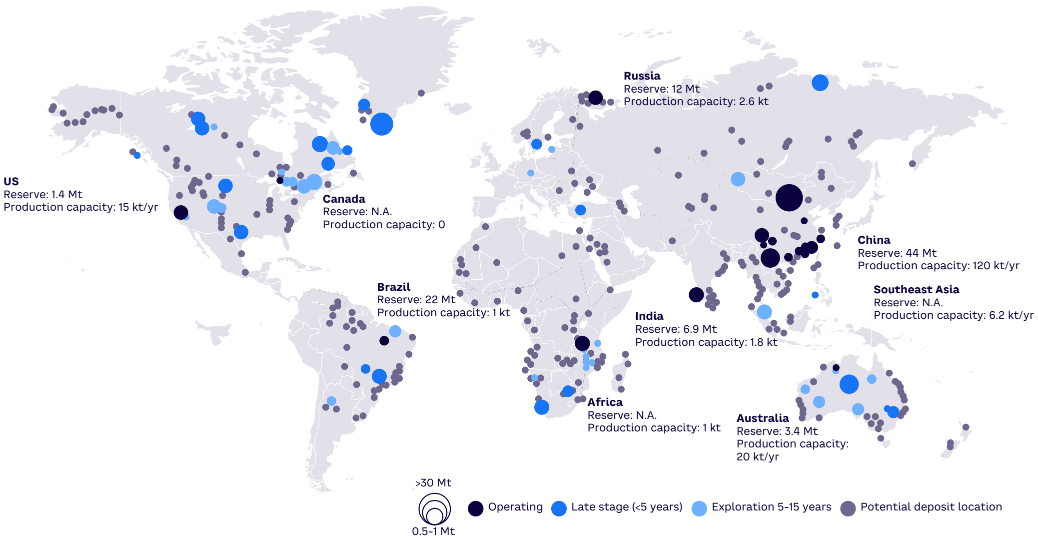
The high-level overview of what REEs are — and why they matter — sets the stage for the upcoming analysis of their global distribution and the nature of projects focused on their development. While geological occurrences of REE resources are spread worldwide, active mining operations remain highly concentrated in only a few countries: China, the US, Australia, and Myanmar, followed at a distance by Russia, India, and Brazil. The three major REE deposits — Bayan Obo in China, Mountain Pass in the US, and Mount Weld in Australia — account for ~55% of current global REE output (and 40% of reserves), with Bayan Obo leading by far, overseeing ~40% of global production and ~30% of global reserves. This concentration stems from technical hurdles, economic barriers, and geopolitical considerations that differ by deposit type and jurisdiction, ultimately determining where and how REEs advance from rock to market.

REE RESOURCES BY GEOGRAPHY

Global REE mine resources are significant (~303 million tons [Mt] REO for 2023) but highly concentrated. Economically extractable reserves are estimated at a level of 91 Mt, and China accounts for the lion's share of them (44 Mt). More critically, it controls ~95+% of global REE separation and refining capacity and virtually 100% of commercial HREE separation. This gives the country immense leverage over global supply and pricing.

Outside China, only a few countries hold or approach double-digit figures: Brazil's vast alkaline-carbonatite provinces hold about 22 Mt; Australia, India, Vietnam, and Russia collectively account for another 20 Mt. While REE deposits exist globally, with significant reserves in China, Brazil, Vietnam, Russia, India, Australia, and the US, resuming or starting production is challenging (see Figure 4).

Figure 4. Global distribution of REE reserves and advanced project status, 2023



Source: Arthur D. Little; Chen et al.; Liu, Shuang-Liang, et al. "Global Rare Earth Elements Projects: New Developments and Supply Chains." *Ore Geology Reviews*, Vol. 157, June 2023

The geopolitical imperative to diversify supply chains away from China is a primary driver for investment in new REE projects in politically stable jurisdictions.

TYPES OF REE DEPOSITS

In simple terms, an REE deposit is a location that holds enough rare earth minerals to be mined profitably. There are five primary types of REE deposits (see Figure 5):

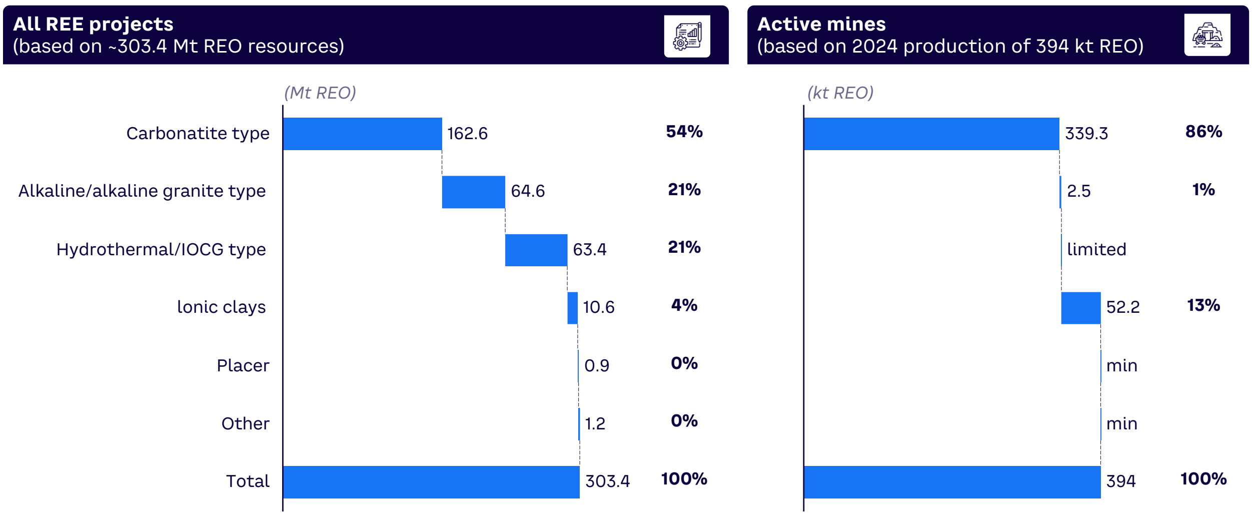
1. **Carbonatite deposits.** Carbonatite deposits, composed of more than 50% carbonate minerals, are the main source of REE production, mainly hosting bastnäsite and monazite. Key locations include the top three global REE mining operations: the Bayan Obo Mining District (China), the Mountain Pass Rare Earth Mine (US), and Mount Weld (Australia).
2. **Alkaline igneous rock and alkaline granite deposits.** These deposits, associated with peralkaline granites and syenites, can be enriched in HREEs. Examples, from ADL analysis, include the Lovozero Mining and Processing Plant (Russia) and the Strange Lake Rare Earth Mining Reserve (Canada). They contribute about 1% to total global production but represent 21.5% of resources, making them potentially significant for future HREE supply.

Resource estimates by country

Current global resources and reserves statistics are evolving rapidly, with many new deposits being discovered and developed in different countries, notably IAC deposits in Australia, Brazil, Malaysia, and other geographies. For example, Malaysia concluded that its total REO resources in 2024 were already estimated at 18.87 Mt, based on a report issued that year by the Malaysian Ministry of Natural Resources and Environmental Sustainability. These shifts will dramatically change the global picture of rare earth resources and reserves within the next couple of years.

3. **IAC deposits.** Formed by weathering REE-rich rocks, these deposits are mainly found in southern China and Myanmar and are essential for HREEs like dysprosium and terbium. Per ADL analysis, they currently account for 13% of global production and approximately 21% of resources. IAC deposits deserve particular attention due to their unique geological formation, enrichment in HREEs, and simpler extraction methods (see section on IACs below).

Figure 5. REE projects and active mines by REE deposits by volume, 2023



Source: Arthur D. Little, Chen et al., Liu et al.

4. **Iron oxide copper gold (IOCG) and hydrothermal deposits.** These deposits often contain REEs as byproducts, with the Olympic Dam in Australia as a notable example. However, they are not primary sources for REE production.
5. **Placer deposits (monazite sands).** Accumulations of heavy mineral sands in beach or alluvial environments have historically sourced REEs; they contribute minimally to current production.

While carbonatites dominate the current LREE supply, IACs are pivotal for future HREE supply and diversification efforts.

TYPES OF REE MINERALS

REE deposits are defined by their mineral hosts, which reflect the geochemical and tectonic conditions of their formation and dictate both processing routes and the light to heavy REE mix recovered. There are several types of REE minerals:

- **Bastnäsite** (a fluorocarbonate) is the dominant mineral host globally, primarily found in carbonatite deposits like Mountain Pass and Bayan Obo, and accounts for 70%-75% of REE reserves. Bastnäsite is predominantly rich in LREEs.
- **Monazite** (a phosphate mineral) is the next most significant, often extracted as a byproduct of heavy mineral sands mining, with notable deposits in Australia, India, and Brazil; it also contains mainly LREEs but can have significant thorium content, posing processing challenges. Monazite accounts for roughly 10% of reserves.
- **Xenotime** (an yttrium phosphate) is a primary source of yttrium and HREEs, often found with tin and tungsten ores, with significant deposits in Malaysia and China, contributing around 5% to reserves.
- **IACs,** predominantly found in southern China and Southeast Asia, are particularly important for HREEs.
- **Other minerals like loparite** (a titanate, mainly in Russia's Kola Peninsula, LREE-rich) and eudialyte (a complex silicate, in Russia and Greenland, LREE and yttrium) contribute less than 5% collectively.

The economics of the minerals depend on the market value of the element mix recovered. The value of the "basket" of REEs recoverable from a specific mineral type depends on its chemical composition, particularly the proportion of high-demand magnet elements (neodymium, praseodymium, dysprosium, and terbium). For instance, ion-adsorption clays, whose chemistry is enriched in premium HREEs, can command a significantly higher basket value and consequently make projects with a higher proportion of neodymium, praseodymium, dysprosium, and terbium in their basket more economically attractive.

IACs: THE HOLY GRAIL OF THE MODERN RARE EARTHS SECTOR

IACs are crucial to the global REE supply chain due to their unique geological formation, enrichment in HREEs, and simpler extraction methods. Unlike hard-rock deposits, where REEs are locked in crystal structures, IACs occur when REE ions from granitic or volcanic rocks are adsorbed onto fine-grained clay in humid environments. Despite being low-grade (0.05-0.5 weight % REO), their relative ease of extraction using mild chemical solutions at ambient temperatures makes IACs highly valuable in the REE sector.

Price variation is evident even within IACs, largely due to differences in REE composition. Australian and Malaysian IACs command the highest basket values, ranging from US $34 to $38/kilogram (kg). This is driven by a higher concentration of HREEs (particularly dysprosium), terbium, a still-high concentration of neodymium and praseodymium, and a reduced presence of low-value elements like lanthanum and cerium. These higher-value IACs have positioned themselves as compelling targets for strategic investment, offering attractive basket price levels.

The advantages & limitations of IAC development

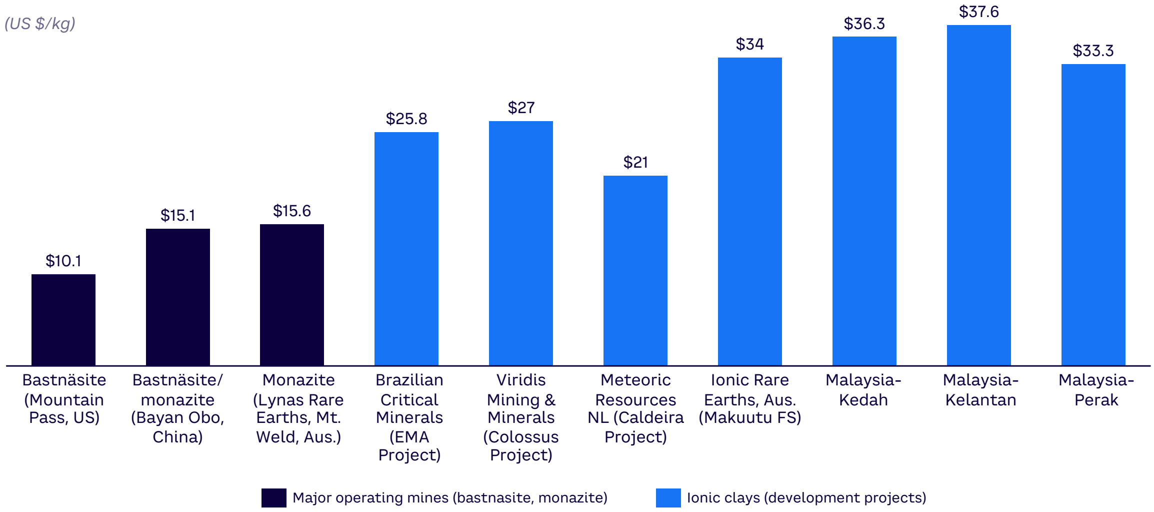
Advantages

- **Superior HREE profile.** High concentrations of HREEs and high NdPr grades, coupled with relatively lower proportions of cerium and lanthanum, significantly enhance the REE basket value, making it up to twice as valuable compared to conventional deposits (see Figures 6 and 7).
- **Streamlined extraction process.** The leaching agent is directly applied to the deposit, creating a pregnant solution from which REEs can be readily precipitated and extracted. This process largely eliminates the need for drilling, blasting, crushing, milling, and other conventional beneficiation processes.
- **Rapid project development.** The estimated progress of current IAC projects from exploration to production is four to seven years, compared to the 12 to 15 years required for conventional REE deposits.
- **Reduced radioactive burden.** The thorium content is minimal, unlike major REE-bearing minerals such as monazite and xenotime, where the safe removal and storage of thorium presents a significant challenge.
- **Lower environmental footprint.** In situ leaching, using ammonia or magnesium-based compounds, offers a comparatively safe approach that eliminates the need for extensive land disturbance, soil removal, and subsequent rehabilitation efforts. While the risk of groundwater contamination remains, proper operational practices can substantially mitigate this concern.

Limitations

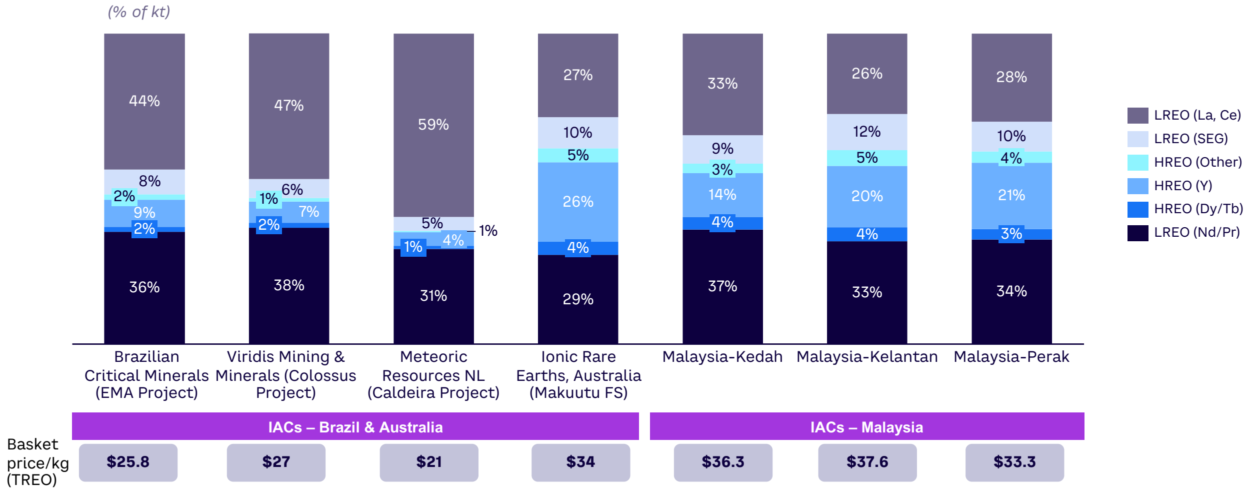
- **Lower-grade deposits** generally contain much lower total REE concentrations (typically 0.05%-0.1%), though this is offset by the fact that REE ions are adsorbed to clay surfaces rather than embedded within mineral structures, making extraction more straightforward.
- **Reduced recovery efficiency.** IACs typically yield lower REE recovery rates (approximately 60%-70%) compared to traditional operations using bastnaesite, monazite, or xenotime (around 80%). This occurs because conventional methods involving fine grinding and leaching in tanks create greater mineral surface area for reagent contact. While technical studies indicate potential for improving IAC recovery rates to 80%-90% through extraction and milling, implementing such processes would negate many of the cost and environmental advantages that make IACs attractive in the first place.
- **Higher impurity levels.** The pregnant solution from IAC processing contains a much higher ratio of impurities compared to beneficiated traditional hard-rock concentrates (five to 10 times higher, according to some technical assessments). This significantly increases costs for reagents needed in the purification process.

Figure 6. Overall basket value for different types of ore, given stated chemical composition, May 2025



Source: Arthur D. Little, company reports

Figure 7. REO basket composition for IAC projects, May 2025



Source: Arthur D. Little, company reports

Despite these limitations, successfully developing IAC deposits hinges on innovation and effective standard setting. This involves pioneering new extraction and purification technologies to improve recovery efficiencies and manage impurity levels cost-effectively. Alongside these technical advancements, resource characterization is crucial for optimizing mine plans, while rigorous environmental management and strong stakeholder engagement are essential for ensuring sustainable and socially responsible operations by setting standards and operational norms for the emerging sector.

Cost structure of ionic clay projects

Ionic clay projects demonstrate a highly attractive cost structure, with average cash costs ranging from $6-$7/kg of TREO (total rare earth oxides) and $16.5-$20.5/kg of MREO (magnetic rare earth oxides). This favorable cost profile indicates strong capital efficiency and often results in rapid payback periods, sometimes in less than three years.

CAPEX for major ionic clay projects currently under development in Brazil varies significantly, reflecting differences in resource size and project scope. For example, Brazilian Critical Minerals is advancing a project with a CAPEX of approximately $55 million, while Viridis Mining & Metals (VMM) and Meteoric Resources (MEI) are developing larger-scale projects with CAPEX estimates in the range of $370-$400 million.

CAPEX FOR MAJOR IONIC CLAY PROJECTS CURRENTLY UNDER DEVELOPMENT IN BRAZIL VARIES SIGNIFICANTLY

When comparing all-in sustaining costs, these Brazilian projects remain highly competitive, with costs between $6.7-$8.9/kg of TREO. This cost advantage, combined with the relatively low capital and operating expenditures inherent to ionic clay deposits and the high estimated basket value of the contained REEs in the range of $30/kg of TREO and estimated ~70% payability, positions these projects for robust financial performance. Many of the current ionic clay initiatives are projecting significant pre-tax internal rates of return in the range of 40%-60%.

Overall, the combination of low costs, manageable CAPEX requirements, and strong projected returns underscores the compelling investment case for ionic clay rare earth projects.

The evolving global landscape for IACs

The global landscape for IAC production is undergoing a significant transformation. Historically dominated by southern China (particularly the Jiangxi, Guangdong, and Fujian provinces), production has expanded to Myanmar's Kachin State, which emerged as a major supplier of HREE-rich material to China. More recently, Brazil has joined the producer ranks with the commissioning of the Serra Verde project. Current exploration and development activities indicate a rapidly expanding footprint for IAC production:

- **Brazil is emerging as an important IAC hub,** with MEI (Caldeira Project), VMM (Colossus Project), and Brazilian Critical Minerals (Ema Project) advancing large, high-grade IAC deposits that could significantly impact global HREE supply.
- **Africa presents substantial opportunity,** with Australian-listed Ionic Rare Earths advancing the Makuutu Rare Earths Project in Uganda, which demonstrates favorable metallurgy and accessibility.
- **Chile is positioning itself** in the IAC space with Aclara Resources developing the Penco Module Project, leveraging the country's established mining framework.
- **Exploration in North America and Asia continues,** with Malaysia showing particular promise due to its favorable geological profile and potential for high REE basket values.

CURRENT EXPLORATION AND DEVELOPMENT ACTIVITIES INDICATE A RAPIDLY EXPANDING FOOTPRINT FOR IAC PRODUCTION

Geographic diversification is essential to mitigating supply concentration risks, building a more resilient global REE supply chain, and reducing vulnerability to geopolitical disruptions — making it a strategic priority for both governments and the private sector. IAC deposits are likely to be developed sooner in regions with more permissive environmental regulations, granting these countries valuable first-mover advantages — particularly in technology piloting and the refinement of beneficiation practices. Striking the right balance in environmental standards will be a critical success factor for any country aiming to lead in this space.

3. BENEFICIATION & SEPARATION PROCESSES

The journey from raw REE-bearing ore to mixed REOs and individual, high-purity REEs represents an extraordinarily complex and technically demanding undertaking. Physical beneficiation initially produces a mineral concentrate (~60% REO content) through crushing, grinding, magnetic separation, and flotation techniques tailored to specific ore mineralogy.

Chemical/thermal treatment follows with distinct approaches by mineral type. Bastnäsite undergoes flotation and acid leaching; monazite requires aggressive "cracking" via high-temperature roasting or acid digestion, which is complicated by thorium and uranium removal; and ionic clays permit simpler direct leaching with salt solutions. These processes yield mixed REO intermediates with approximately 90% REO content.

The subsequent separation of individual REEs presents a significant technological challenge due to their remarkably similar ionic radii and electrochemical properties.

China possesses the vast majority of global separation capacity. Solvent extraction dominates industrially, requiring hundreds to thousands of mixer-settler stages and generating significant chemical waste. Ion exchange chromatography, while capable of exceptional purity, remains less suited for industrial-scale separation, though continuous processes show increasing promise.

Owing to these complex beneficiation and separation processes, the value addition along the chain is significant, with neodymium increasing from $41.7/kg in concentrate to $88.5/kg as metal (see Figure 8). On the other hand, the industry confronts the persistent "balance problem" wherein mining for high-value elements inevitably co-produces excess cerium and lanthanum, creating structural oversupply that frequently drives prices below production costs and undermines overall project economics.

Figure 8. Value chain: beneficiation and separation process

MINING	PHYSICAL BENEFICIATION	CHEMICAL TREATMENT	SEPARATION	REDUCTION REFINING PURIFYING
• Open pit • In situ leaching	• Gravity • Magnetic • Froth flotation	• Acidic • Alkali • Ion exchange	• Solvent exchange • Ion exchange	• Electrowinning • Zone melting • Solid state electro transport
Ores with 0.1%-10% REOs	**Rare earth concentrates ~60% REOs**	**Mixed oxides/ carbonates/ chlorides/fluorides ~90% REOs**	**Individual 99+% rare earth compounds**	**Individual pure 99.99+% rare earth metals**

Source: Arthur D. Little; Eheliyagoda, Disna. "Tracing the Multiregional Evolution of the Global Dysprosium Demand-Supply Chain." *Resources, Conservation & Recycling*, Vol. 199, December 2023

While the Chinese leadership and expertise in this field cannot be overstated, a number of players outside China have actively contributed to the diversification of beneficiation and separation processes. These companies are leading efforts in developing ex-China separation capacity:

- **Lynas Rare Earths** is expanding its Advanced Materials Plant (LAMP) in Malaysia. By the end of 2025, Lynas aims to produce heavy rare earths like dysprosium and terbium for the first time, complementing its LREE output. New circuits will enable the separation of up to 1,500 tons of SEGH (a mixed heavy rare earth compound containing mixed samarium, europium, gadolinium, holmium, dysprosium, and terbium).
- Australia is heavily supporting the local sector capabilities. In November 2024, **Lynas Rare Earths** opened the Kalgoorlie Rare Earths Processing Facility, Australia's first, with a capacity of 68 kt per annum of mixed rare earth carbonate. Lynas also plans a US-based separation facility, backed by $258 million from the US government and an AUD 20 million Australian grant.
- **MP Materials** in the US has invested nearly US $1 billion to restore its domestic supply chain. It began producing separated NdPr oxide at Mountain Pass in Q3 2023 and expects full separation capabilities by late 2026, aiming for a fully integrated US mine-to-magnet pathway.
- **Neo Performance Materials** operates the Silmet facility in Estonia, which serves as the primary European separation plant (the former Soviet Union) with a capacity of around 2,000 tons of separated rare earth oxides. The company mainly supplies European customers.
- Other players, such as US-based **Energy Fuels,** are also developing separation capabilities, though currently at a more limited scale and output.

Collectively, these companies illustrate that a viable, global rare earth corridor that covers mining, separation, metallization, and magnet making is no longer aspirational, but rapidly becoming a commercial reality (see Figure 9).

Figure 9. Non-Chinese companies in the REE production value chain

Source: Arthur D. Little

4. GLOBAL PRODUCTION OF RARE EARTHS: CONCENTRATION, DISPARITY, MARKET VALUE & SUPPLY/DEMAND BALANCE

Global mine production of REO edged up from roughly 376 kt in 2023 to an estimated 394 kt in 2024, a gain of about 4%. The production output, however, is far more tightly clustered than the resource base. China, which controls just under half of identified reserves, still accounted for ~70% of mined tonnage, underscoring its unrivaled position at the front end of the value chain. The US followed at a distant 11%, while other reserve-rich nations such as Brazil, India, and Australia remained marginal suppliers, constrained by processing capacity and, in several cases, by permitting delays (see Figure 10).

The mismatch between where the rocks lie and where concentrates emerge highlights an important point in the rare earth narrative: geology sets the stage, but know-how and capital intensity decide the pace. Without sustained investment in beneficiation plants and separation processes, the costly steps that transform mixed concentrates into individual oxides, new mines will do little to diversify supply. The ability to master these processes represents the primary challenge in shifting the market's current concentration.

Figure 10. Major REO-producing countries, 2023 and 2024

(in est. kt)

Country	Y2023	% production, 2023	Y2024	% production, 2024	Reserves	% of reserves
China	255		270		**44,000**	**48.4%**
US	42	67.8%	45	68.5%	1,900	2.1%
Burma	43	11.1%	31	11.4%	NA	NA
Australia	16	11.4%	13	7.9%	**5,700**	**6.3%**
Nigeria	7	4.3%	13	3.3%	NA	NA
Thailand	4	1.9%	13	3.3%	5	0%
India	3	1.0%	3	3.3%	**6,900**	**7.6%**
Russia	3	0.8%	3	0.7%	**3,800**	**4.2%**
Madagascar	2	0.7%	2	0.6%	NA	NA
Other	1	0.6%	1	0.5%	NA	NA
Vietnam	0.3	0.4%	0.3	0.3%	3,500	3.9%
Malaysia	0.31	0.1%	0.13	0.1%	NA	NA
Brazil	0.14	0.1%	0.02	0.0%	**21,000**	**23.1%**
Canada	-	0.0%	-	0.0%	830	0.9%
Greenland	-	0.0%	-	0.0%	1,500	1.7%
South Africa	-	0.0%	-	0.0%	860	0.9%
Tanzania	-	0.0%	-	0.0%	890	1.0%
TOTAL	**376**	0.0%	**394**	0.0%	**90,885**	**100%**
		100%		**100%**		

Source: Arthur D. Little

MARKET VALUE CONCENTRATION & SUPPLY/DEMAND BALANCE

While cerium (estimated at 167 kt in 2024) and lanthanum (estimated at 95 kt in 2024) dominate production volumes, comprising roughly two-thirds of the total REO tonnage (see Figure 11), they contribute minimally to overall market value (cerium oxide, for instance, is only ~3.4%). The economic heart of the REE market beats for "magnet-critical" neodymium, praseodymium, dysprosium, and terbium, which are essential for high-performance permanent magnets in EVs, wind turbines, and defense, and account for approximately 90% of the total REE oxide market value. Neodymium oxide alone captures the largest share (~53.7%), followed by praseodymium (16.4%), with high-value, scarcer dysprosium and terbium (~9% each) punching well above their weight in production volume.

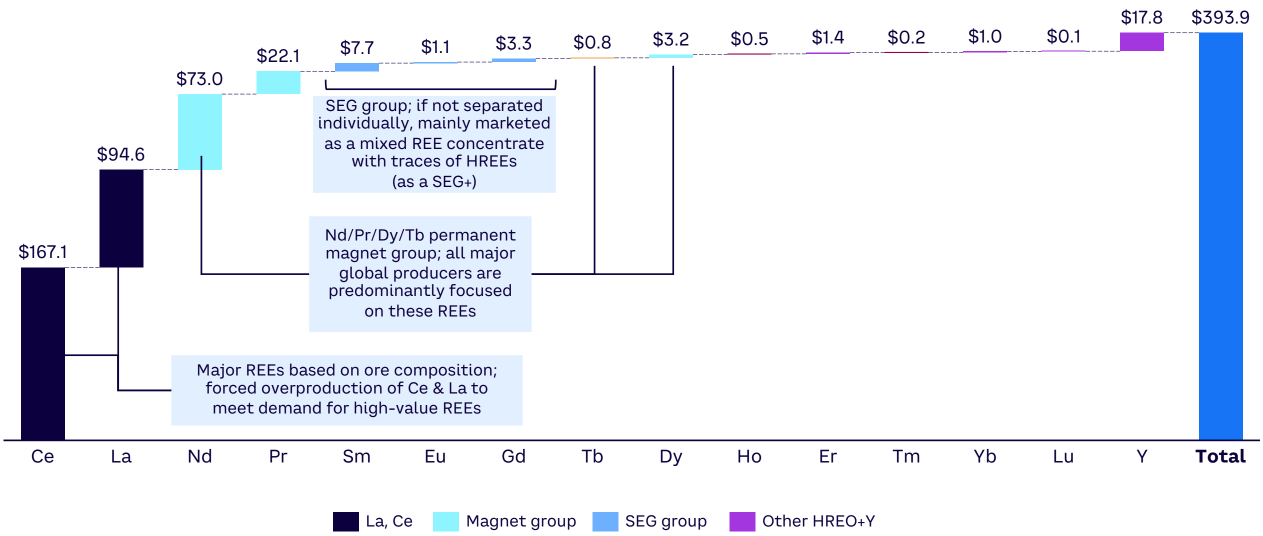
This stark value disparity creates a structural oversupply of cerium and lanthanum, often co-produced with the more valuable REEs. This can depress the prices of cerium and lanthanum, sometimes below their attributable production cost, impacting overall project economics. Investors must scrutinize projects for a high basket percentage of neodymium, praseodymium, dysprosium, and terbium, and assess strategies for managing or finding novel applications for lower-value co-products. The total estimated global value of produced REE oxides in 2024 is around $7.2 billion.

Sacrificial overproduction of cerium & lanthanum & the balance problem

REEs coexist in mined minerals. They are bound, extracted, and processed together until the mixed REO stage. Hence, some of the minerals, notably the most abundant ones (cerium and lanthanum) are in a state of constant overproduction, as market demand for them is far below the forced inherent mine supply. A significant amount of these two REEs (up to two-thirds of supply) are not used, and despite continuous effort to find them, there is no evidence of new potential high-volume applications. The prices for cerium and lanthanum are on a constant downward track, bringing down the total basket value of specific deposits and negatively impacting the economics. REE producers are working on ways to deliberately reduce their recovery to save on operating costs.

Figure 11. Global production of REO, 2024

Taking prices as of 18 April 2025 (US $) and % of US $ value

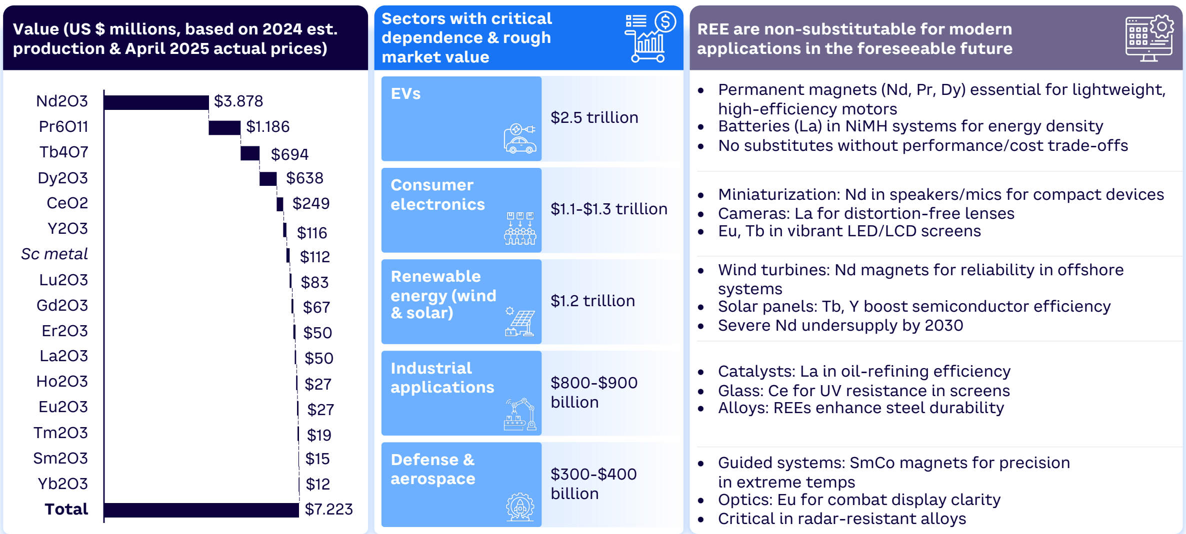


Note: Modeled calculations of the market value and volumes have been made on the basis of total mined REO production in terms of REO contained in the mined concentrates. However, it is worthwhile to note that concentrate-to-mixed REO recoveries stay in the range of 90+% depending on technology used, element-specific recoveries, and feed origin (from traditionally mined and refined bastnaesite, monazite, or xenotime concentrates to pregnant IAC solutions).
Source: Arthur D. Little

This relatively modest market size, compared to its immense strategic importance, means that targeted investments and government support can significantly influence supply chain resilience and create substantial leverage for well-positioned companies (see Figure 12).

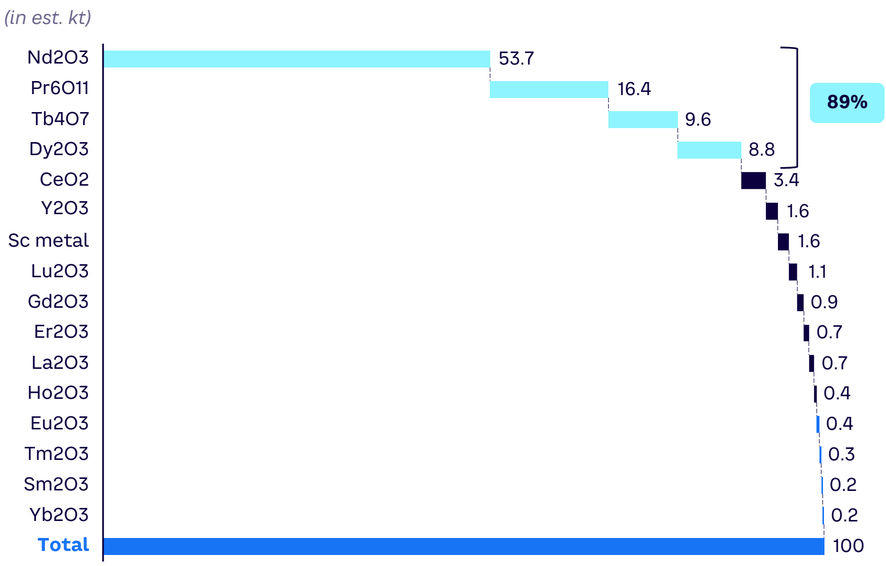
Within the market-balance situation, cerium and lanthanum continue to be significantly overproduced (see Figure 13). As for neodymium and praseodymium, Chinese rare earth production quotas have more than doubled: from 120 kt in 2018 to 270 kt in 2024, leading global mine production of NdPr oxide to increase by ~120%. At the same time, global demand for NdFeB magnets increased by ~75%-80% overall, resulting in a NdPr oxide inventory buildup and current oversupply in 2024 at a level of about 4%-5% in volumetric terms. By 2026, the market is expected to underproduce by 5%, resulting in the drawdown of historically accumulated inventories and a growing deficit through 2030–2035. Despite the start-up of several new projects, production will increasingly struggle to keep up with demand growth (see Figure 14).

Figure 12. Market value of mined REE oxides, 2024 production/April 2025 actual prices



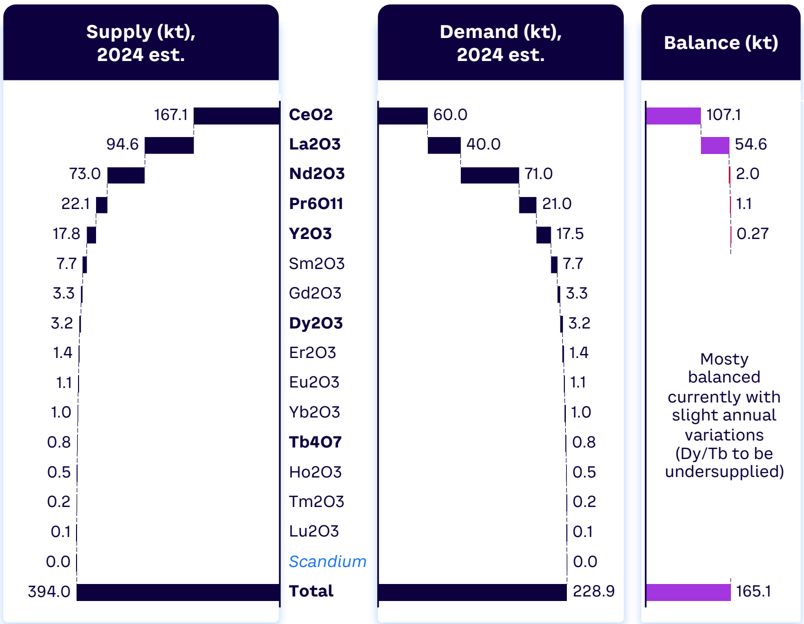
Source: Arthur D. Little, SMM price, Adamas Intelligence, MP Minerals, market reports

Figure 13. Market value of REE oxides, 2024 production/April 2025 actual prices



Note: Without scandium
Source: Arthur D. Little, SMM price

Figure 14. Estimated supply and demand of REOs, 2024



Note: Scandium (35 tons at current SMM price as of April 2025)
Source: Arthur D. Little, SMM price, Adamas Intelligence, MP Minerals, market reports

Dysprosium and terbium are currently in line with market demand, with around 4 kt combined supply, equaling current 2024 market demand. Significant undersupply with a projected deficit of up to 50% is expected in 2030 and beyond, due to strong demand and long lead times for new IAC and Xenotime projects. There is also a potential slight oversupply of yttrium due to significant new supply from HREE-bearing deposits, namely IACs and xenotime-based, picking up in the market.

GLOBAL REE PRODUCTION IS HIGHLY CONCENTRATED

The global REE output is significantly influenced by a few large-scale mining operations:

- **Bayan Obo, China.** This massive iron-niobium-REE deposit in Inner Mongolia is the world's largest REE producer, accounting for a substantial portion of China's output and, consequently, global supply (estimated at around 40% of global production). It is primarily a bastnäsite and monazite deposit.
- **Maoniuping (Sichuan), Weishan (Shandong), and the South China IAC belt (Jiangxi to Guangxi), China.** Together, these deposits anchor the country's non-Bayan Obo supply chain: Maoniuping's multi-million-ton bastnäsite-monazite carbonatite is the largest southern hard-rock REE mine. Weishan, an eastern carbonatite now in steady commercial production, adds another light-REE feed outside Inner Mongolia, and roughly 70 weathered-granite clay deposits across seven provinces (e.g., Longnan and Xunwu) dominate global heavy REE output, providing about 70% of the world's dysprosium, terbium, and yttrium via low-cost ambient temperature leaching.
- **Mountain Pass, US.** Located in California and operated by MP Materials, Mountain Pass is the largest REE mine outside of China. It primarily produces a bastnäsite concentrate rich in LREEs.
- **Mount Weld, Australia.** Operated by Lynas Rare Earths, this mine is a significant source of high-grade monazite, yielding a concentrate rich in LREEs, including a notable proportion of NdPr.
- **Myanmar Mines.** Various operations in Kachin State and other regions of Myanmar focus primarily on IACs and have become a critical source of HREEs, much of which is exported to China for processing.

This concentration, both geographically and in terms of the number of major producing assets, creates significant supply chain risks and bottlenecks. It underscores the premium on new REE projects in diverse, stable jurisdictions, especially those capable of producing HREEs. Opportunities abound for companies that can de-risk the supply chain by bringing new production and, crucially, processing capacity online.

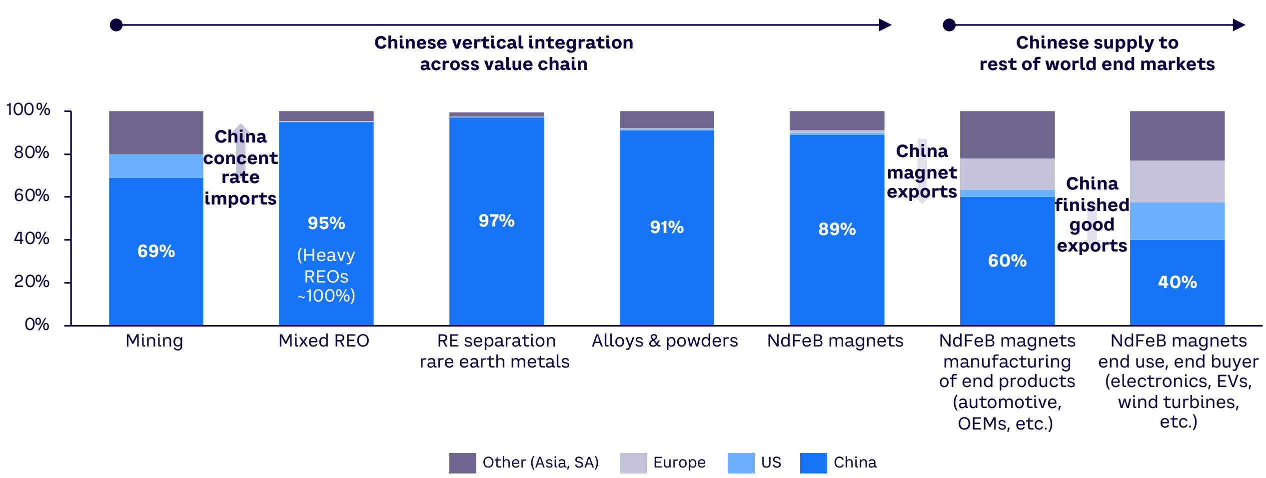
5. REE SUPPLY CHAIN, PRICING & EFFECTS OF CHINESE DOMINANCE

The transformation of REEs into valuable materials involves a complex global supply chain, intricate pricing mechanisms, and significant geopolitical influences, particularly the effects of Chinese market dominance (see Figure 15). China's strategically significant position in the global REE industry accounts for a large share of mining (69%), separation (80%-90%), and almost all commercial HREE oxide production. The country's extensive involvement has a considerable influence over the market, and its market position has evolved as Western nations outsourced operations due to lower costs and regulatory considerations. China has strategically invested in advanced processing capabilities, including handling radioactive byproducts, which remains a significant challenge for Western reestablishment efforts.

Despite its vast domestic production, China imports about 20% of its REE feedstock from countries like the US and Myanmar, capturing downstream value through processing before supplying finished products globally. China's significant role in the metals market gave the Asian Metal Index (see Figure 16), which reflects the country's domestic policies, a major role in shaping pricing. Recent adjustments in production quotas to meet domestic demand have led to changes in NdPr prices, which have implications for the global supply chain and market dynamics.

Figure 15. Global market share of rare earth supply chain, 2024

(in % of weight)



Source: Arthur D. Little, US Geological Survey (USGS), International Energy Agency (IEA), Global Wind Energy Council (GWEC), Argus, Adamas Intelligence, company reports, rare earth-focused conferences

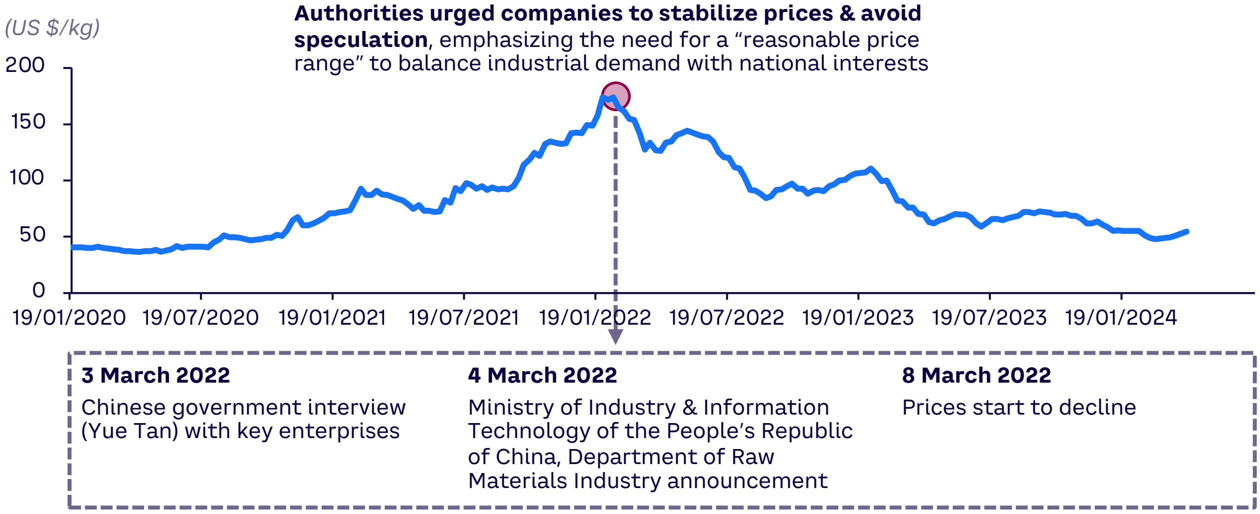
Fluctuations stemming from geopolitical factors contribute to market instability, including the possibility of altered export policies for critical elements from key producing nations. This structural instability particularly affects projects outside China that lack state support.

These complexities present a structural drag on the economics of the entire industry, particularly for projects that cannot always rely on state support to weather periods of low prices for these co-produced elements. The current ex-China supply chain is fragmented, with many junior miners and explorers lacking the capital and technical expertise for downstream processing and separation. To foster a more resilient and diversified global REE supply chain, significant state support, investment in new technologies, and streamlined permitting processes for new mining and processing facilities are deemed essential by many industry observers.

China-US rare earth trade dispute

In April 2025, China implemented export controls on seven critical REEs in response to tariffs imposed by the US. These measures affected elements crucial for defense, energy, and automotive technologies. Given that China controls 90% of global refined rare earths, this action impacted the global supply chain and posed a challenge to US military readiness. In response, US-based MP Materials ceased shipping concentrates to China after facing 125% retaliatory tariffs and focused instead on domestic processing and developing US magnet manufacturing capabilities. While current stockpiles may suffice temporarily, experts anticipate potential shortages later this year as Western nations struggle to develop alternative supply chains.

Figure 16. Daily Asian Metal Index NdPr price



Source: Arthur D. Little, company reports, rare earth–focused conferences

6. GLOBAL REE OXIDE SUPPLY/DEMAND OUTLOOK

REEs ARE INDISPENSABLE IN A VAST ARRAY OF APPLICATIONS

The REE market, while modest in overall dollar value compared to major commodities, holds immense strategic significance due to the critical and often irreplaceable role these elements play in modern technology and the green energy transition. As previously noted, the global market value for produced REOs in 2024 is estimated at approximately $7.2 billion. This figure belies the true economic impact of REEs, as they are enabling components in industries worth trillions of dollars (e.g., consumer electronics, automotive, renewable energy). REEs are indispensable in a vast array of applications:

- **EVs** — NdFeB magnets for high-efficiency motors
- **Wind turbines** — NdFeB magnets for direct-drive generators
- **Robotics** — high-torque, energy-efficient NdFeB permanent-magnet motors, often dysprosium/terbium-doped for thermal stability
- **Consumer electronics** — miniaturized magnets (neodymium, samarium) in speakers and hard drives; phosphors (europium, terbium, yttrium) in displays
- **Defense and aerospace** — high-strength alloys (scandium), precision guidance systems (SmCo magnets), lasers, and sensors
- **Lighting** — LED and fluorescent phosphors (europium, terbium, yttrium, cerium)

In many of the above applications, particularly for permanent magnets, there are no technologically or economically viable substitutes that can match the performance of REE-based materials without significant compromises in efficiency, size, or weight. Moreover, demand for NdFeB magnets is projected to grow robustly, driven by:

- **Electrification of transport** — rapid adoption of EVs and hybrid vehicles
- **Renewable energy expansion** — increased deployment of wind turbines
- **Industrial automation and robotics** — growing use of high-efficiency electric motors
- **Consumer electronics** — continued demand for compact, powerful devices

Nearly all NdPr oxide is used to produce NdPr alloy for NdFeB permanent magnets, with minor uses in batteries, catalysts, ceramics, and other applications. Between 2024–2035, global NdPr oxide demand is forecast to grow at an 8.4% CAGR, from 92 kt to 214 kt, driving growth in NdFeB magnets for EVs, robotics, and advanced air mobility.

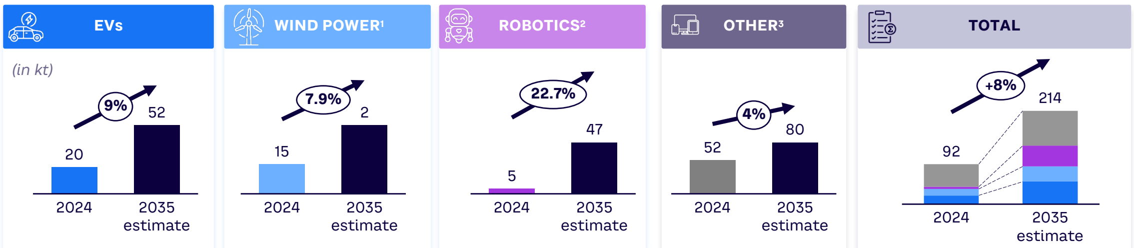
Robotics will be the top-growing segment (~23% CAGR). The most common use is for permanent magnet motors, which employ power robotic joints and actuators to provide high torque, energy efficiency, and rapid response, essential for fine motor control. EV traction motors and wind power applications will also experience 8%-9% growth annually. Industrial applications are projected to grow at ~4% CAGR, supported by demand for energy-efficient motors and equipment.

By 2035, EVs, wind energy, robotics, and energy-saving machines will account for more than 60% of the global demand for rare earth permanent magnets (see Figure 17). While output is expected to increase, supply constraints will likely persist in the short term, keeping prices stable and encouraging investment in alternative sources. These shortages are expected to intensify from the early 2030s onward as demand rises.

Such shortages are also expected to elevate the price levels for NdPr oxide in the near future (see Figure 18).

On the supply side, ongoing trade frictions — such as tariffs and export controls between the US and China — alongside internal conflict in Myanmar at the end of 2024, have had clear negative impacts. While rare earth inventory inflows into China have recently resumed, a prolonged conflict would likely accelerate China's push to diversify supply, as evidenced by emerging material flows from the Lao People's Democratic Republic.

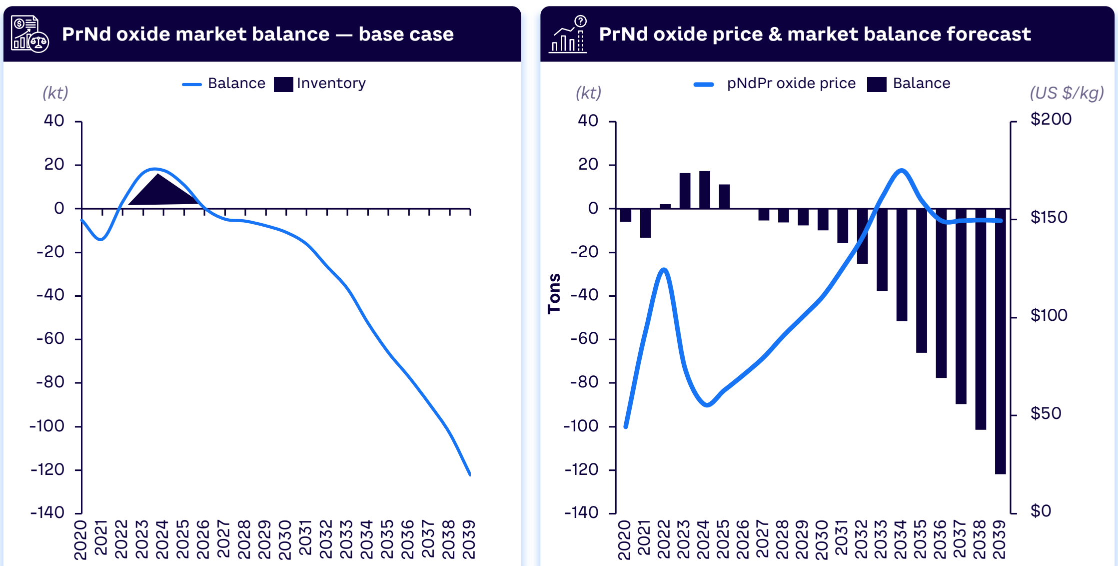
Figure 17. Global demand for NdPr, 2024–2035



	EVs 2024	EVs 2035	Wind power 2024	Wind power 2035	Robotics 2024	Robotics 2035	Other 2024	Other 2035	Total 2024	Total 2035
Dy/Tb	2 kt	4 kt	0.5 kt	1.5 kt	0.1 kt	2.0 kt	1.5 kt	2.0 kt	~4 kt	~9.5 kt

Notes: (1) PrNd oxide demand for direct drive and hybrid direct drive wind power generators for onshore and offshore applications; (2) PrNd oxide demand for robotics, advanced air mobility, and magnetocaloric chillers; (3) other automotive uses, consumer electronics, speakers, cordless power tools, industrial applications, speakers, home appliances, etc.
Source: Arthur D. Little, Adamas Intelligence, Argus, IEA, GWEC, company reports, rare earth–focused conferences

Figure 18. NdPr oxide market balance and price, 2020–2039



Source: Arthur D. Little, MP Materials reports, Adamas Intelligence

7. ALTERNATIVE REE SOURCING & USAGE OPTIMIZATION

Challenges in primary REE extraction and a concentrated supply chain have brought attention to two strategies: alternative sourcing of REEs and reducing their usage. Both require significant R&D investments.

ALTERNATIVE REE SOURCING

Magnet recycling

This involves two approaches: "short loop" recycling (reprocessing manufacturing scrap) and "long loop" recycling (recovering magnets from end-of-life products such as hard drives and EV motors). Benefits include reduced mining dependency and enhanced supply security. Challenges include efficient collection and dismantling, separating REEs from complex structures, and economic viability, especially as prices fluctuate. Initiatives like the European MAGNOLIA project aim to develop large-scale recycling facilities. For the moment, though, magnet recycling is not materially impactful. In 2023, recycled magnets met less than 1% of global REO demand.

Processing industrial waste streams

Phosphogypsum, a byproduct of phosphoric acid production, can contain REE concentrations that rival or exceed those in primary deposits, though handling associated radionuclides like uranium and thorium remains a key challenge. Companies like Rainbow Rare Earths in Phalaborwa, South Africa, are actively developing effective extraction technologies in this area. Bauxite residue (red mud) holds lower REE concentrations, making economic recovery more complex and dependent on integrated extraction of alumina, iron, and titanium. Other sources, including coal ash, mine tailings, acid mine drainage, metallurgical slags, and deep-sea minerals, are under active research, though most remain at early development stages.

STRATEGIES FOR REE USAGE REDUCTION & SUBSTITUTION

Alongside efforts to increase supply, research is focused on reducing critical REE content in permanent magnets without sacrificing performance from price volatility and supply concerns. While several technologies exist on this front, GBD deserves particular attention because, with one extra furnace step, it slashes the dysprosium/terbium content of NdFeB magnets while keeping high-temperature performance intact.

GBD coats finished magnets with dysprosium/terbium and reheats them just long enough for those atoms to migrate along grain boundaries. The tweak typically reduces heavy-REE use by 50%, and, in top EV grades, can eliminate dysprosium entirely while keeping coercivity intact. Depth is limited to ~3 to 4 millimeters and adds a furnace cycle, but the savings swamp the cost. Dual-alloy sintering, cerium/lanthanum substitution, and nanocrystalline hot deformation push the needle further, though most are still scaling. However, while GBD is a commercial reality, the complete elimination of dysprosium/terbium from the highest-performance magnets remains a significant R&D challenge.


* Lanthanide Series
* Actinide Series

8. INVESTMENT PATHWAYS IN REEs

The REE sector is undergoing a profound transformation. While the potential is immense, the sector's complexities, ranging from geological heterogeneity and high capital intensity to processing challenges and geopolitical sensitivities, pose formidable barriers. For investors, however, these challenges translate into differentiated opportunities across the REE value chain. This chapter explores how the preceding sectoral analysis translates into investment opportunities, segmented by investor type and geographic focus.

OPPORTUNITIES THROUGHOUT THE VALUE CHAIN

Reserve diversification

Investment in diversified reserves is among the most impactful pathways. Because conventional hard-rock mining often takes over a decade to reach production and demands high CAPEX, projects with faster timelines or superior economics stand out. IAC deposits, enriched in HREEs like dysprosium and terbium, offer promise. Likewise, high-grade carbonatite and alkaline systems are also emerging as attractive plays.

Preference will be given to projects in stable jurisdictions that can contribute to diversifying and strengthening global supply chains, providing alternative sources of materials. Yet, investors must be alert to the balance problem — the geological co-occurrence of high-demand and oversupplied elements like cerium and lanthanum. Investments should favor deposits with a higher natural concentration of magnet-critical elements (neodymium, praseodymium, dysprosium, and terbium).

In parallel, funding R&D for high-volume uses of cerium and lanthanum could unlock hidden value and shift project economics sector-wide.

Separating & refining mixed REEs

Separation remains the sector's critical chokepoint. Most REE concentrates must undergo complex refining, especially solvent extraction, to yield individual high-purity oxides. China dominates this capability, creating a structural vulnerability in global supply chains. Opportunities abound for ex-China capacity: new separation plants able to handle diverse feedstocks are urgently needed. Investors should also watch firms advancing cleaner, modular technologies, such as continuous ion exchange, which promise improved efficiencies and enhanced economic viability. These technologies could redefine the economics of REE processing and offer a pathway to more robust supply chains.

A parallel track: Recycling & reducing REE usage

Another high-potential area is the circular economy. GBD for NdFeB magnets stands out; this technology can slash dysprosium and terbium use by as much as 70%-100% while integrating smoothly into existing magnet lines at modest CAPEX. Chapter 7 highlighted scalable innovations like biochemical extraction and microbial recycling, which are increasingly viable for permanent magnets and phosphogypsum waste. R&D-driven strategies to reduce REE usage, especially of critical HREEs, will be essential to bridging future supply-demand gaps. Investment in such solutions delivers both cost-efficiency and supply security.

MAIN ACTORS IN THE GLOBAL REE GAME

The REE sector is shaped by five key groups: private and sovereign investors, governments, magnet manufacturers, automotive OEMs, and the defense industry. We selected these groups based on strategic relevance, capital base, and operational leverage, as reflected in this report and verified via public sources.

Private & sovereign investors

Private equity, venture capital, and sovereign wealth funds (SWFs) have become increasingly active in REE plays, from upstream exploration to advanced separation. Several SWFs have begun targeting strategic deposits and processing assets. Their capital is de-risking early-stage projects, especially in geopolitically aligned jurisdictions, where countries share diplomatic ties and strategic interests. Moreover, impact-oriented funds are eyeing clean processing start-ups and recycling ventures. These investors provide capital, help institutionalize new players, and build market confidence.

Governments

National governments play an outsized role as investors, regulators, and strategic coordinators. For national security reasons, a number of governments are considering the implementation of a minimal REE reserve requirement to mitigate supply chain and geopolitical risks. US and Australian public agencies have co-funded separation plants (e.g., Lynas in Kalgoorlie, MP Materials in California), while Japan has invested in long-term offtakes via the Japan Bank for International Cooperation (JBIC) and the Japanese Organization for Metals and Energy Security (JOGMEC). In many cases, governments act as anchor buyers or financiers, mitigating project risk and catalyzing private investment. Policy tools, such as permit fast-tracks, strategic reserve requirements, loan guarantees, and co-investment vehicles, are instrumental in accelerating the REE ecosystem beyond China.

Magnet manufacturers

Magnet makers are securing upstream access to guarantee feedstock stability. This includes investment in IAC deposits and partnerships across the value chain. Leading manufacturers are also pushing hard on technology: GBD, magnet miniaturization, and reduced-REE formulations are reducing material intensity. Simultaneously, “magnet to magnet” recycling initiatives, enabled by modular processing and improved magnet design, are helping close the loop. Some are even piloting microbial and biochemical recycling to expand rare earth recovery from end-of-life magnets.

Automotives

Automakers, especially in the EV space, are entering upstream partnerships to stabilize magnet supply. Firms like Toyota, Tesla, and BMW are coinvesting in recycling and substitution R&D. Automotives are also advocating for design-for-recycling principles in motor systems to enable better REE recovery and lifecycle value retention.

Defense industry

Defense ministries, state defense corporations, and military contractors represent a growing force in the REE ecosystem. Given the strategic nature of REEs in systems like missile guidance, radar, and electronic warfare, defense actors are taking active roles in securing upstream resources and refining capabilities. This includes direct investment, procurement mandates, and other R&D initiatives. Governments often coordinate across ministries of defense and industry to secure dedicated REE supply chains for national security applications.

INVESTORS BY GEOGRAPHY: THE RISING REGIONAL PLAYERS

Despite China's dominance, there are active and emerging regions outside that country. These countries were selected based on resource potential, capital availability, and recent policy shifts. The list is illustrative, not exhaustive — other players may rise in importance over time as global REE dynamics evolve.

Southeast Asia

Malaysia leads Southeast Asia's REE opportunity. Its IAC resource base, coupled with Lynas's downstream capacity, forms a rare ex-China example of an integrated supply chain. Building a full end-to-end magnet ecosystem is a realistic next step. Meanwhile, Vietnam and Thailand, with large, underdeveloped resources, are emerging as strategic providers and are investing in beneficiation infrastructure to capture more value locally.

Japan

Japan continues to blend industrial strategy with innovation. Its government and manufacturers are deepening investments in overseas mining and separation ventures while leading global R&D in REE reduction and magnet recycling. Innovations include scalable high-efficiency magnets with lower dysprosium/terbium content and modular recycling units for EV and turbine magnets.

Australia

Australia remains a cornerstone in global REE supply diversification. Lynas and other emerging players are developing new deposits and processing hubs. The government's strong support for critical minerals and streamlined permitting enhances its appeal for both upstream and midstream investment.

OTHER PLAYERS MAY RISE IN IMPORTANCE OVER TIME AS GLOBAL REE DYNAMICS EVOLVE

Europe

Europe is focusing on recycling, eco-design, and strategic sourcing. EU-backed initiatives aim to develop separation capacity and integrated magnet-to-magnet loops. While resource endowment is modest, policy momentum and funding availability make Europe a growing hub for REE innovation.

US

The US is rebuilding its mine-to-magnet ecosystem, with MP Materials and others leading efforts. Federal backing has enabled new separation capacity, while R&D funding supports alternative refining, substitution, and magnet design. Tariff tensions with China add urgency to onshoring efforts.

Gulf Cooperation Council

The Kingdom of Saudi Arabia is positioning itself as a regional REE hub. The country has untapped granitic and alkaline deposits and large phosphogypsum reserves. With Maaden signing a memorandum of understanding with MP Materials, early steps are being taken to develop processing, separation, and potentially magnet manufacturing capabilities. In the meantime, sovereign funds in the United Arab Emirates and Qatar are starting to consider global investment opportunities across the REE value chain.

Japan's REE supply diversification strategy[1]

Japan's investment in Malaysian REE companies like Lynas mirrors its liquefied natural gas (LNG) diversification strategy. Japan has played a pivotal role in the development and ongoing operations of Lynas Rare Earths, primarily to secure a stable REO supply. The $250 million investment deal provided Lynas with crucial equity and loans in exchange for a long-term supply commitment to Japan.

Previously, Japan pioneered the global LNG industry, beginning with its first imports from Alaska in 1969. Driven by pollution concerns and energy demand, Japanese corporations and government entities played crucial roles in developing LNG projects worldwide.

Japanese state institutions, particularly JBIC, JOGMEC, and Nippon Export and Investment Insurance (NEXI), have been instrumental in unlocking private capital through financing, loan guarantees, and equity investments that mitigate political and commercial risks. This government backing has enabled some of history's largest project finance deals in the LNG sector.

Beyond their role as foundational buyers, Japanese utilities evolved into significant equity investors in LNG projects across Australia, Qatar, Oman, the US, and Southeast Asia by the 1990s. This direct investment secured equity offtakes while helping manage aboveground and partnership risks.

1 Cahill, Ben, Jane Nakano, and Kunro Irié. "How Japan Thinks About Energy Security." Center for Strategic & International Studies (CSIS), 22 May 2024.

CONCLUSION — NAVIGATING THE EVOLVING LANDSCAPE OF REEs

REEs are critical to the fabric of modern technological society. Their unique properties support a vast array of applications, from everyday consumer goods to cutting-edge green energy and defense systems. However, the REE sector is fraught with complexities. The conversion of ore into high-purity individual elements is a technically demanding and environmentally sensitive process. The global supply chain is characterized by an overwhelming concentration, with China exerting significant influence over production and pricing. This has led to price volatility and strategic vulnerabilities for nations reliant on imports.

Key challenges persist:

- China dominates across the value chain.
- The balance problem results in the chronic overproduction of certain REEs, depressing their prices and impacting overall project economics.
- Environmental concerns associated with traditional mining and processing methods necessitate continuous improvement and innovation.
- A looming structural deficit for key magnet REEs (neodymium, praseodymium, dysprosium, terbium) poses a significant risk to the growth ambitions of sectors like electric mobility and renewable energy.

Nevertheless, pathways to mitigate these challenges are emerging, and they all point toward the necessity of strategic investment, both from the public and private sectors.

Three areas stand out as focal points for forward-looking investment:

1. Development of new reserves outside traditional jurisdictions, particularly those offering high-value rare earth mixes
2. Expansion of separation and refining capacity with improved economic and technical performance
3. Industrialization of recycling and REE usage reduction, especially in high-impact applications like NdFeB magnets

Addressing the multifaceted challenges of the REE sector will require sustained investment, relentless innovation, and enhanced cooperation among governments, industry stakeholders, and research institutions. Such cooperation is manifesting in various forms, including efforts by individual countries to foster national companies capable of integrating significant portions of the REE value chain, as well as the formation of cross-national strategic alliances like the Mineral Security Partnership (MSP), aimed at collectively securing and diversifying critical mineral supplies among allied nations.

The indispensable role of REEs in enabling technological progress and a more sustainable future dictates that securing a resilient, diversified, and responsible supply chain is not merely an economic imperative — it is a strategic necessity for the 21st century.

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