CIRCULAR REPUBLIC

Closing the Loop on Rare Earth Magnets

An Industrial Imperative for European Resilience

powered by Porsche Consulting

BY UNTERNEHMERTUM

Management Summary

- **China dominates rare earth magnets - Europe faces strategic vulnerability**: Europe's industrial base is critically dependent on China for magnets made from rare-earth elements (REE), especially Neodymium, which are essential for electric motors, wind turbines, electronics and defense systems. China controls around 70% of global mining, over 90% of processing, and nearly all magnet production. This dominance is leveraged through export restrictions, creating supply shocks and price volatility. For European industry, relying on imports is therefore a strategic vulnerability.
- **The risks are economic, geopolitical, and environmental:** Supply disruption could halt production across Europe, threaten millions of jobs, and weaken sovereignty. Uncontrolled foreign mining is also linked to toxic waste, biodiversity loss, and human rights violations - exposing European companies to ESG and compliance risks.
- **Recycling offers the fastest path towards supply resilience:** The opportunity is clear - while alternatives like diversification, domestic mining, and substitution all face significant short-term constraints, recycling, if supported by advances along the value chain, offers a faster route to improving REE magnet supply security and resilience.
- **Strategic levers for business can cut dependency and emissions:** Recycling and urban mining can reduce dependency and can cut CO_2 emissions by up to 60–95% vs. virgin material. Design for circularity will enable easier recovery of magnets, while technological innovation and material substitution can reduce heavy rare earth demand. Partnerships with allied countries such as Canada, the U.S., Australia alongside strategic value chain collaborations in Asia, Africa and South America can further diversify supply.
- **Investment in recycling is a business hedge, not a cost burden:** While recycled materials are more expensive today, they act as a risk hedge against future disruptions, tariffs, and carbon costs. Companies that commit to offtake agreements and pooled procurement can make recycling commercially viable and secure long-term supply.
- **Industry and policymakers need to act in concert:** The EU's Critical Raw Materials Act sets ambitious targets, but these will not be met without active industry leadership. Industry must dedicate part of their procurement to recycled magnets, support European recycling and refining, and embed resilience and ESG into sourcing decisions. Policymakers must provide incentives, streamline permitting, enforce eco-design, and integrate magnet supply into Europe's wider industrial strategy.
- **Urgent action can secure Europe's future competitiveness:** If Europe acts, by 2050 recycling and diversification could cover close to 50% of demand, securing sovereignty, competitiveness, and sustainability. If it does not, Europe will remain exposed to external shocks and geopolitical leverage. The need for action is urgent to invest now in a circular, resilient supply chain for rare earth elements.

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Foreword

Europe's ambition for technological sovereignty and its committed transition to a sustainable economy rest on a foundation that is dangerously exposed to geopolitical risk. Our industry - spanning such diverse sectors as electric mobility, wind energy, advanced electronics, data centers, and defense systems—firmly relies on the secure, stable availability of permanent magnets made with Rare Earth Elements (REEs), which are critical enablers of Europe's wealth and security.

Escalating geopolitical tensions over the past years have repeatedly exposed the fragility of global supply chains. As this report details, the European industrial base is overwhelmingly dependent on a single major actor, which controls approximately 70% of global REE mining and over 90% of essential processing capacity. What this means shows the example of Neodymium, with more than 90% of finished permanent magnets currently being imported from China. This extreme concentration of control is repeatedly leveraged through export restrictions and other measures, leading to severe supply shocks and posing significant economic and sovereignty risks for Germany and Europe. In fact, it endangers our sovereignty in the very technologies driving Europe's green and digital transition. We must therefore reject the passive acceptance of this strategic dependency, which constitutes a clear gamble with our industrial future.

The time for deliberation is over; we require decisive, strategic action. While long-term strategies like diversifying primary sources and establishing domestic mining operations are essential for future needs, they are inherently slow, capital-intensive and come with large environmental and social costs.

Fortunately, we hold a powerful, comparatively cheap, and immediate tool in our hands: the Circular Economy. By systematically prioritizing recycling and efficient material re-use, we can immediately tap into the vast, underutilized stock of REEs already embedded in products across our economy. Closing the loop offers the fastest, most pragmatic route to improving supply resilience. Focussed efforts on scaling our recycling activities would allows us to rapidly establish a robust European secondary supply chain that complements and strengthens, rather than waits for, new primary sources. This parallel action is vital for mitigating risks today.

This report, *Closing the Loop on Rare Earth Magnets: An Industrial Imperative for European Resilience*, is an evidence-based blueprint that spotlights the areas for necessary action.
It outlines the interplay between industrial investments, policy interventions and collaborative structures required to secure European material independence.

We must now turn this imperative into tangible results.

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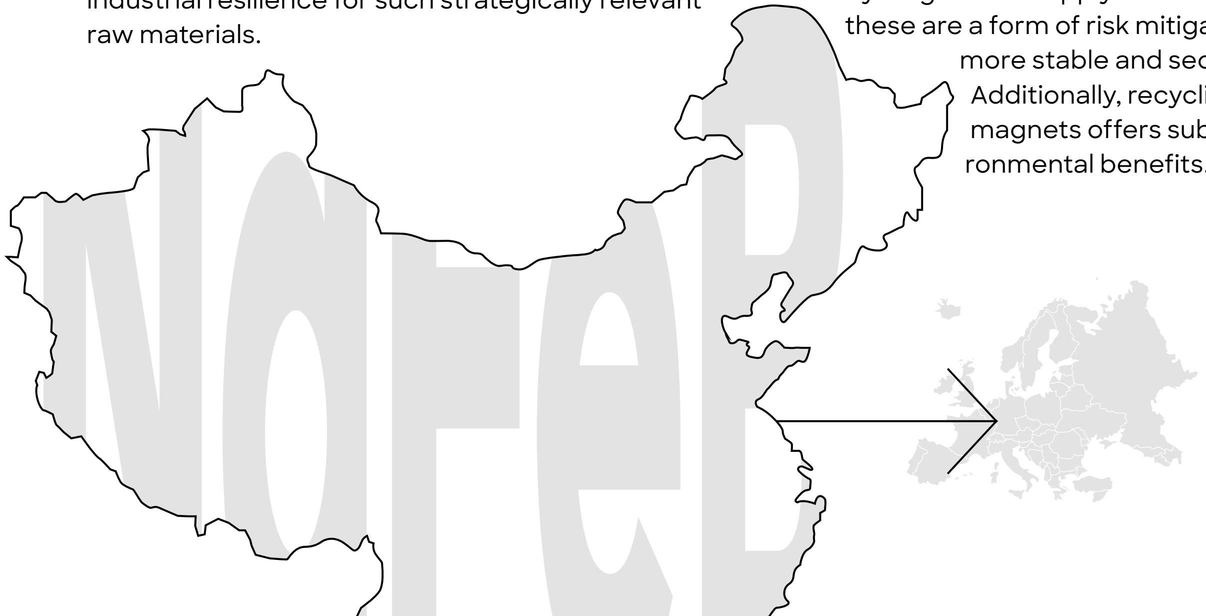
Introduction

Driving an EV, running a factory or powering a drone depends on the same hidden enabler: rare earth magnets. Among them, neodymium-iron-boron (NdFeB) magnets are particularly critical, yet the supply rests on a fragile foundation, an overwhelming dependence on a single country. China has established control over almost the entire NdFeB value chain, from rare earth mining and separation to magnet production. This dominance is the outcome of a deliberate industrial strategy and has been reinforced through export restrictions. Recent export controls show how this leverage can be used to disrupt supply, raise costs, and erode European sovereignty. Relying on cheap imports is therefore not a strategy but a risk to long-term security - calling for alternative approaches to ensure industrial resilience for such strategically relevant raw materials.



Securing Europe's Rare Earth Resilience starts with NdFeB recycling

To date, most businesses continue to prioritize the lowest-cost primary materials from China, inadvertently strengthening the very monopoly that poses a threat. Keeping critical materials in local circulation by recycling them offers a direct way to reduce this risk. Moving beyond pure financial hedging strategies, traditional tools like futures and options can smooth price risks but only circular solutions such as recycling secure physical access to critical materials when supply chains are disrupted. While implementing a recycling-based supply chain has its costs, these are a form of risk mitigation to ensure more stable and secure supply. Additionally, recycling NdFeB magnets offers substantial environmental benefits.

Industry Can Shape Solutions, even with Limited Policy Intervention

Currently, locally sourced and recycled NdFeB magnets cannot compete on price with cheap Chinese imports. However, the survival of Europe's industrial base depends on the immediate establishment of a domestic recycling value chain. Political initiatives, such as the EU Critical Raw Materials Act (CRMA) represent a step in the right direction, but so far have fallen short of providing an effective solution, leaving the responsibility for immediate action to the private sector. Companies must take the lead, starting with sourcing part of their NdFeB needs from recycled materials. Collective demand, even in small shares, can secure investment, scale recycling, and reduce individual risk. Alongside secondary sourcing, firms should also use other strategic levers - such as long-term agreements and co-investment in supply chains - to strengthen resilience and amplify their voice in shaping supportive policy. Europe's access to magnets made from rare earth elements (REE) will be determined by the choices industry makes today.

Critical and Strategic Raw Materials in Europe

The European Commission distinguishes between *critical raw materials (CRMs)* and *strategic raw materials*. CRMs are those with high economic importance for European industry combined with a high risk of supply disruption. Within this group, strategic raw materials form a narrower subset essential for priority technologies such as electric mobility, renewable energy, digital infrastructure, and defense. *Rare earth elements (REEs)* – a group of 17 elements including the lanthanides plus scandium and yttrium – are classified as both critical and strategic. They are further divided into *light REEs* (e.g. neodymium, praseodymium, lanthanum, cerium) and *heavy REEs* (e.g. dysprosium, terbium, europium, yttrium), with the latter generally scarcer and more geopolitically sensitive. In the European context, REEs are indispensable for permanent magnets, batteries, catalysts, and electronics, making them central to the EU's strategy for raw material security and industrial resilience. [1-4]
Four REEs are central to magnet production: neodymium (Nd) and praseodymium (Pr) as main constituents, with dysprosium (Dy) and terbium (Tb) as performance-enhancing additives. Although magnet REEs account for only about 30% of total rare earth volumes, they represent more than 80% of value [5].

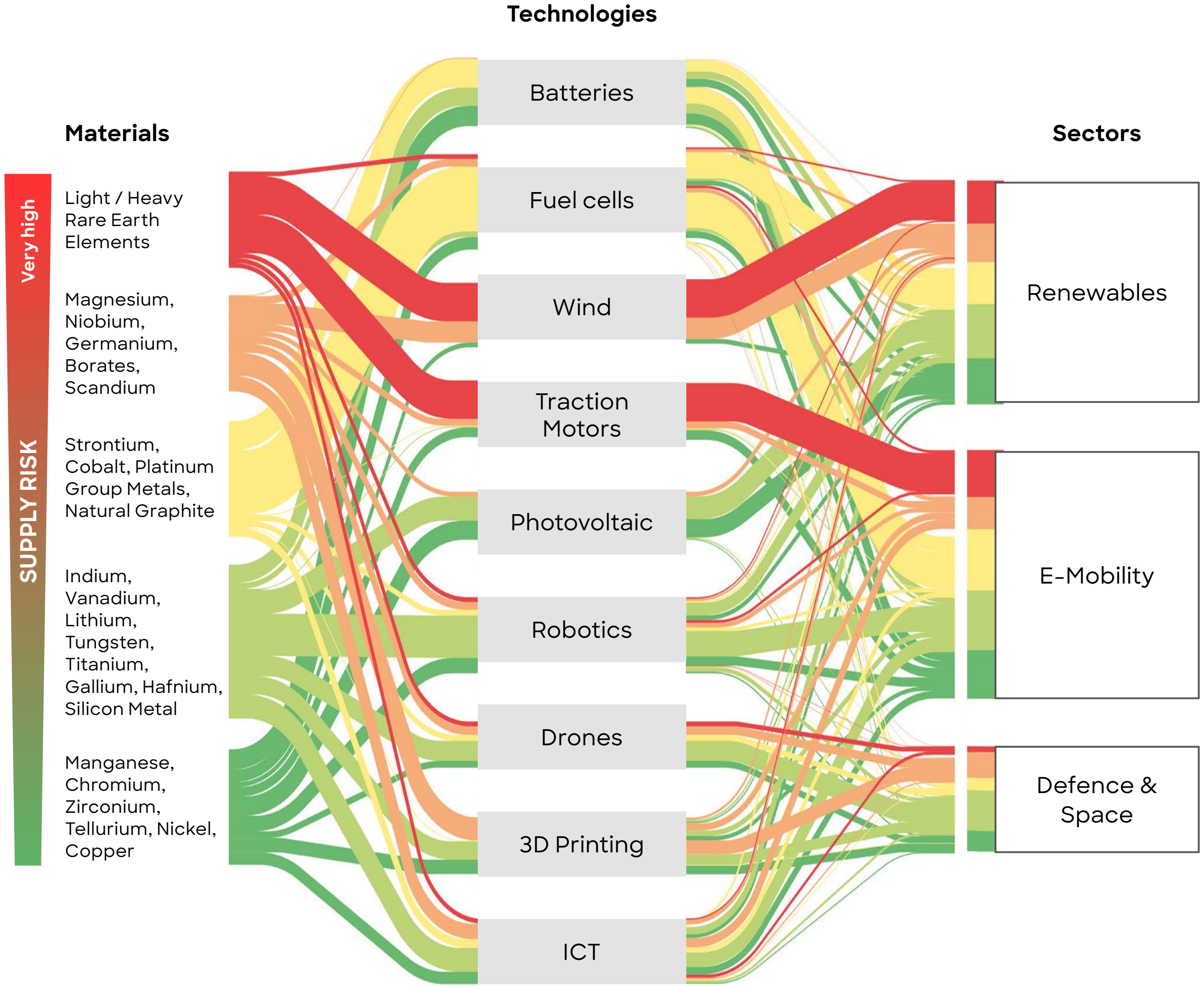
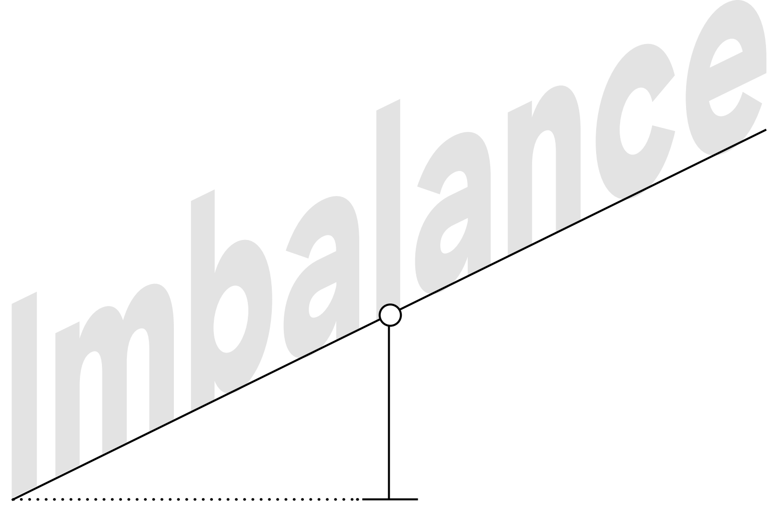


Figure 1: Representation of flows of raw materials and their current supply risks to selected technologies and sectors (Source: Own illustration based on European Commission – Joint Research Centre (JRC))

REE Magnet Recycling: Urgent Need & Unmet Challenge



Rare Earth Magnets Drive Industry – But Supply Cannot Keep Pace

From automotive to aerospace, Europe's most advanced industries rely on permanent magnets. Among them, neodymium-iron-boron (NdFeB) magnets stand out as critical enablers of high-performance motors, sensors, and generators. They are indispensable for the electrification of transport, the expansion of renewable energy, and the digitization of infrastructure [6].

Global demand for REE and specifically NdFeB magnets is growing rapidly, driven by their essential role in green technologies like electric vehicles and wind turbines, and is forecasted to double by 2030. However, supply is not projected to keep pace [7]. This growing imbalance presents a significant risk to industries worldwide, particularly in Europe [8].

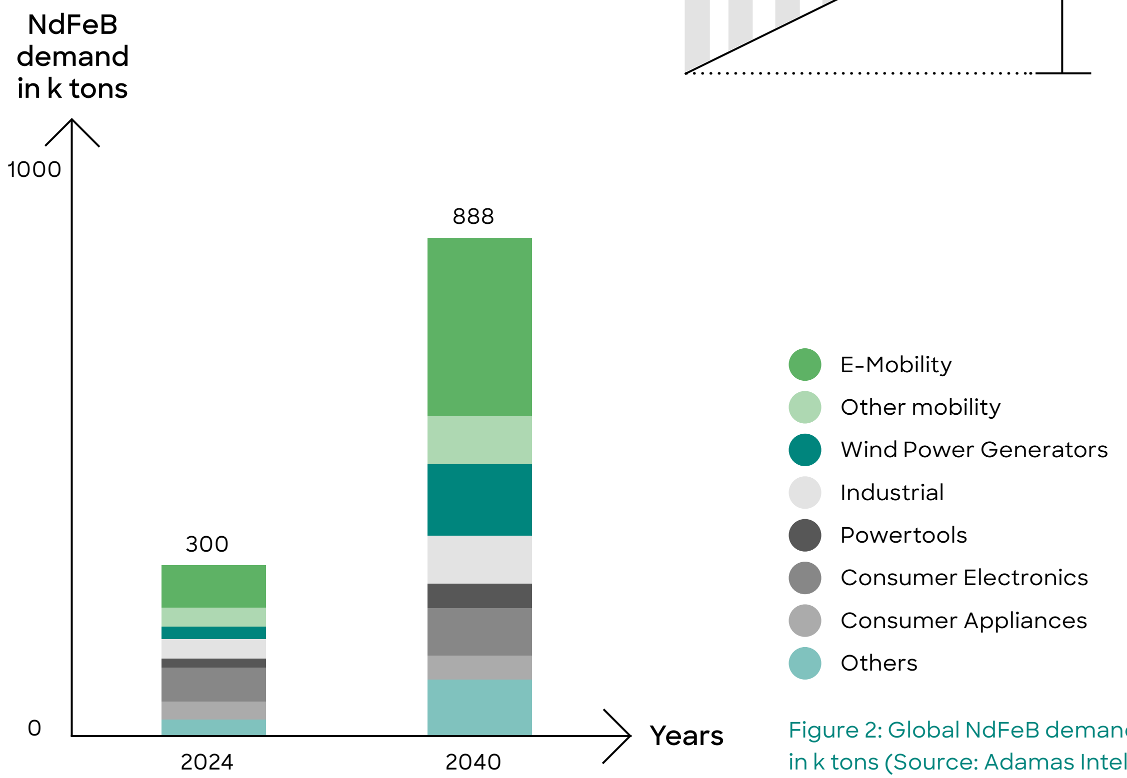


Figure 2: Global NdFeB demand 2024-2040, in k tons (Source: Adamas Intelligence)

Europe Relies on Imports while China Holds the Market Monopoly

The market for NdFeB magnets is largely monopolized by China, which accounts for about 85-90% of the global supply [9]. Europe is highly dependent on imports of magnet materials. Rare earth permanent magnets exports from China represent approximately 98% of the EU market, with Germany as one of the biggest importers [10].This dominance is not merely geological – it is a result of strategic government involvement, which has historically kept material prices low, making it difficult for competitors to emerge.

China Shapes Global Risks Through Supply Chain Dominance

China strategically controls rare earth magnet prices across the entire value chain, using state-owned companies, subsidies, and tax policies to undercut global competitors and enforce vertical integration, from extraction to final magnet manufacturing. Furthermore, China holds ~70% of REE mining and >90% of processing capacity worldwide and has also invested strategically in non-Chinese mines, reinforcing global dominance [11]. The EU remains critically dependent on Chinese exports while domestic demand for rare earths will rise sharply in the coming years.

Export Controls Become a Strategic Geopolitical Tool

China has repeatedly demonstrated its willingness to weaponize its market power through export restrictions, turning supply security into a geopolitical instrument. Historically, China imposed export quotas on rare earths, causing prices to surge by and disrupting industries in the U.S. and Europe [12]. More recently, following export restrictions on gallium and germanium (July 2023), antimony (August 2024), and tungsten, tellurium, bismuth, indium, and molybdenum (February 2025), in April 2025 China further restricted seven rare earth elements and related magnets, including samarium, dysprosium, and terbium [13–15]. Exports of rare earth magnets have plunged by 74% year-on-year in May 2025 [16]. These measures have led to significant price increases and supply disruptions for EU industries. For example, Chinese REE export restrictions recently forced parts suppliers in the automotive sector to halt production lines [17] and in April 2025 caused production delays for EV and wind turbine manufacturers [18]. Beyond this, China now also aims to inhibit stockpiling of REEs by other countries [19].

> German industry is highly dependent on China for critical minerals, rare earths, and magnets, in some cases by more than 90%. This applies not only to raw materials, but also to refined processing stages. Naivety in procurement vis-à-vis China must end in order to avoid becoming even more vulnerable to blackmail. This includes higher investment in substitute research, diversification of supply sources, and government support in establishing partnerships with resource-rich countries.
>
> **Dr. Timo Blenk,** *Agora Strategy*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EU Policy Alone Cannot End Supply Dependency

In response to this mounting vulnerability, the EU adopted the Critical Raw Materials Act (CRMA) in May 2024. Its purpose is clear: to secure a more resilient, diversified, and sustainable supply of materials indispensable for the green and digital transition.

The Act sets quantitative benchmarks to be achieved by 2030 [1]:

at least 10%
of EU demand to be met through domestic mining

at least 40%
of processing carried out within the EU

at least 25%
of demand covered by recycling

no more than 65%
of supply for any material sourced from a single third country

The CRMA will not by itself secure Europe's supply of REEs. Even full compliance would leave the EU substantially dependent on external sources, as high costs, low acceptance of mining, vague recycling obligations, and weak incentives for resource efficiency remain unresolved – meaning CRMA is necessary, but not sufficient.
Politics and regulations are moving in the right direction, but not ambitious and decisive enough to measure up the size of the challenge faced – especially when compared to other regions like the US. The US response combines talks for a deal to ease export controls while pursuing a long-term strategy to reduce dependency by investing in a domestic supply chain and creating partner-ships with allies to diversify sources. [20]

This is where the business opportunity lies for companies in circular solutions to increase resilience and strategic space for maneuver. Waiting for Brussels is not a strategy – unless companies take action, an effective solution remains out of reach.

Primary REE Supply Brings Heavy Environmental and Social Costs

In addition to market and geopolitical challenges, the extraction of REEs comes with severe environmental and human impacts across the supply chain. These bring responsibilities and risks for European companies relying on imported materials. Related costs are often externalized in producer countries – but for European companies, they rebound as ESG risks, reputational damage, and hidden liabilities. In the long run, 'cheap' imports may come at the expense of the license to operate.

Land use and biodiversity:
Open-pit mining drives deforestation and habitat loss, as seen in Myanmar where thousands of hectares of forest were cleared between 2018–2023 (satellite imagery). Such landscape disruption often causes landslides and leaves ecosystems irreversibly damaged. [21–23]

Toxic and radioactive waste:
REE ores often contain thorium and uranium. For every ton of REE produced, up to one ton of radioactive residue is generated. China's Bayan-Obo mine holds ~200 million tons of radioactive tailings, leaking into soil and groundwater. [26–27]
Water use and pollution: REE mining consumes 200–1,500 m^3 of water per ton of oxides; Bayan-Obo alone uses ~13 million m^3 annually. Wastewater often contains acids, heavy metals, and radioactive thorium, contaminating local water supplies. [28]

Energy and CO_2:
REE extraction and processing are highly energy intensive. Studies report carbon footprints ranging from 165–672 kg CO_2 per ton of REE metal, and 17.8–24.3 kg CO_2 eq per kg of mixed rare earth oxides from ionic clays, largely from electricity and chemical use (e.g., ammonium sulfate). [24–25]

Human rights impacts:
Mining operations frequently involve unsafe working conditions, gender-based violence, and–in other CRMs like cobalt–documented child and forced labor. Communities near mines face displacement, health issues (e.g., lung diseases, arthritis, dental damage), and bioaccumulation of REEs in human tissue. [29–30]

Alternative Supply Options face Short-Term Barriers

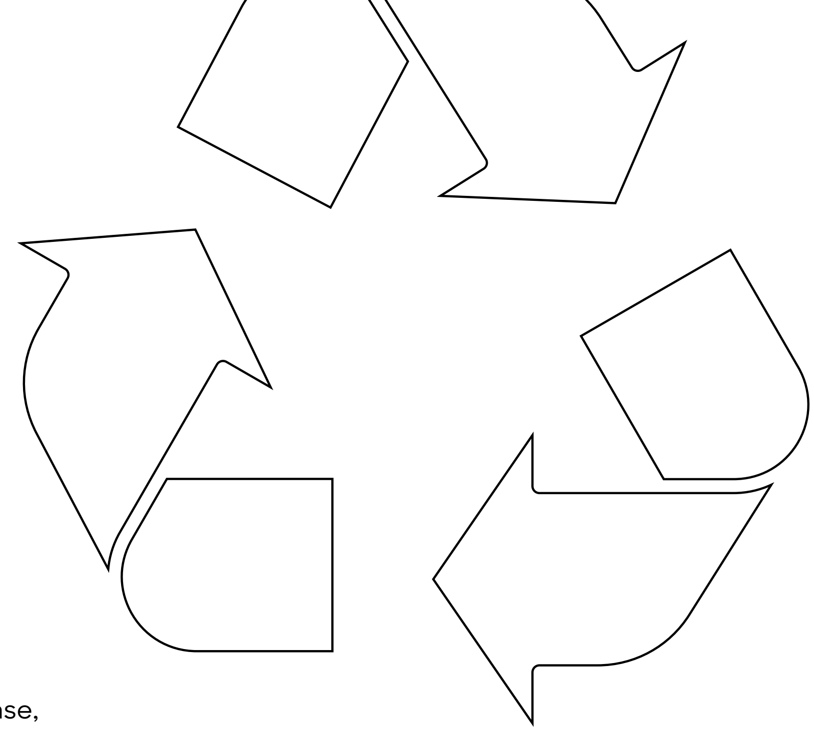
Developing alternative supply chains or establishing production outside of China is currently not considered viable mainly due to higher costs, driven by factors such as wages, energy prices or ESG standards. Further, according to market experts, the comparatively lower REE concentrations in European deposits, such as those in Sweden, mean that significantly more material must be extracted than at China's Bayan Obo mine – in some estimates more than ten times as much – rendering European production inherently less efficient and cost-competitive. Domestic mining and processing, while essential for long-term security, also implies high upfront costs and long permitting and investment timelines. Even under optimistic estimates, operations are not expected to take off for about another decade [31]. Strategic import partnerships with countries on other continents will be relevant but are too slow to develop for a short-term solution.

Recycling Can Strengthen Independence – If Commercial Barriers Are Overcome

Similarly, REE magnet recycling, while technologically feasible, faces commercial hurdles – but represents a way to address the current challenge more immediately [5]. The outlook for recycling depends heavily on future price developments for rare-earth elements. The strong price decline in recent years has made recycling a less attractive option, but as global supply constraints and geopolitical risks increase, the economic case for domestic recycling may strengthen over time.

Today, the primary obstacle for REE magnet recycling is commercial viability, not technology. European magnet makers face significantly higher costs than Chinese competitors [10], with no market premium for local, sustainable, or recycled materials.

This challenge cannot be addressed by supply-side measures alone. Without a market for European materials, no domestic project can survive. Product and component manufacturers must recognize their responsibility: it is imperative that firms invest in their own supply chain resilience by, at least partially, shifting to European secondary REE sources. Failure to do so will only exacerbate current and future dependencies.



> The security of our future depends on acting decisively on circularity today. Alternatives are either too slow or too complex and we cannot afford to wait. At present, we are doing too little, and relying on either market forces or government intervention in isolation is not a viable strategy – progress demands both.
>
> **Dr. Benedikt Franke,** *Munich Security Conference*

The current state of REE (NdFeB) Magnet Recycling in Europe

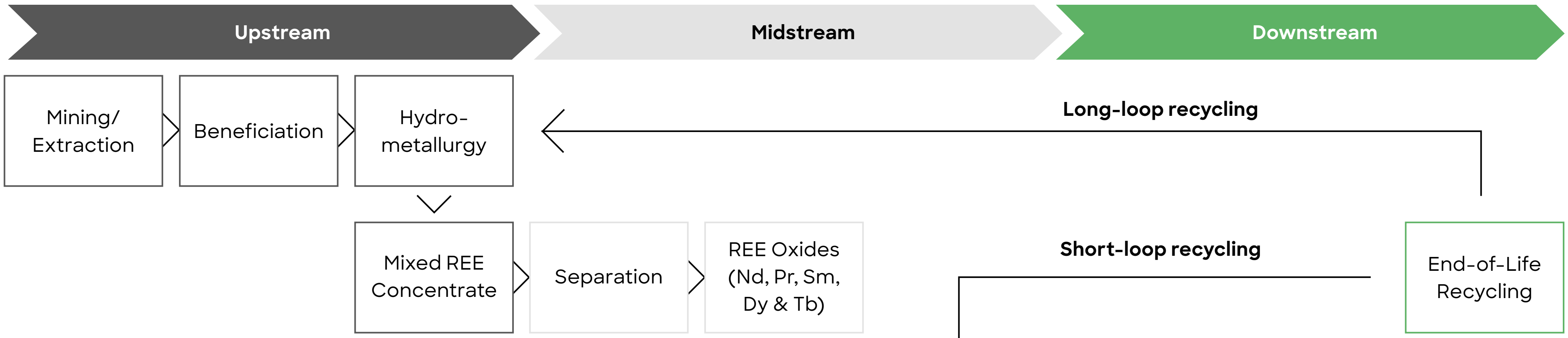
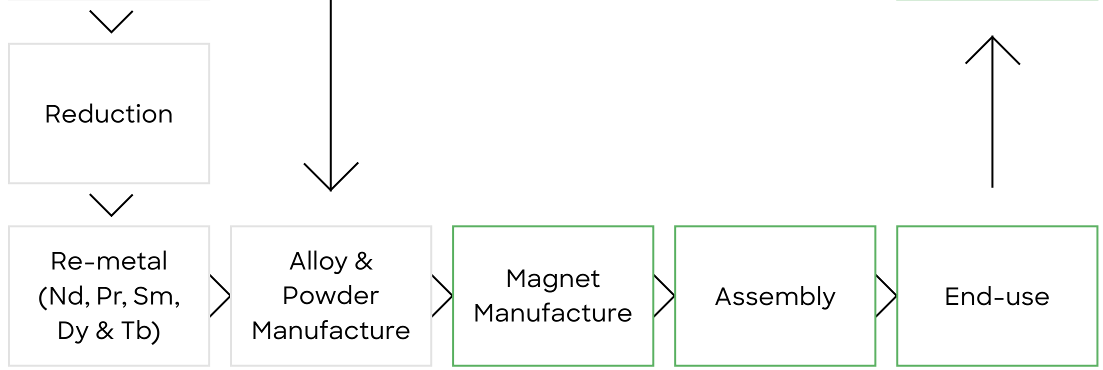



Figure 3: Rare Earth Permanent Magnet Supply Chain and Recycling Model (Soure: Own illustration based in depiction by Argus Media (https://global-reia.org/rare-earth/))

Europe’s NdFeB Recycling Industry Is Emerging but Small

Europe is beginning to build its own NdFeB supply chain, though still small compared to China, with some players along the primary REE magnet supply chain already established and new players coming up. The market was valued at approximately USD 1.85 billion in 2024, with strong growth projected to USD 3.25 billion by 2030 (CAGR ~9.8%) [32]. Yet, as result of current commercial uncertainties, some European producers are considering pausing activities while awaiting supportive policy measures.

Long- and Short-Loop Recycling Define Technological Pathways

Rare-earth magnet recycling generally follows the same fundamental steps as primary magnet production but adapted to the type of input material and desired output quality. Two main concepts are distinguished:

- **In long-loop recycling (elemental)**, end-of-life (EoL) magnets are demagnetized and chemically processed back into rare-earth oxides. These oxides are indistinguishable from primary raw materials and can be alloyed into new NdFeB magnets of any grade or performance specification.
- **In short-loop recycling (functional),** magnets are treated mechanically or metallurgically (e.g. hydrogen decrepitation, powder metallurgy) to directly reuse the alloy in magnet form. This avoids full re-processing, resulting in faster turnaround and lower chemical use, though final magnet quality depends on consistent feedstock, scrap purity and alloy composition.

Industrial Implications and Trade-offs Must Be Addressed

Performance: Long-loop enables *highest-grade, virgin-equivalent magnets*; short-loop can match performance if inputs are clean but may deliver lower consistency for mixed or contaminated scrap.

Cost: Short-loop is generally *more cost-effective* by bypassing chemical processing; long-loop involves *higher processing and energy costs.*

Sustainability: Short-loop has a *smaller environmental footprint* (lower energy, fewer chemicals), while long-loop offers *greater flexibility to recover mixed waste streams* that short-loop cannot handle.

For Europe, the business case is to combine both: short-loop recycling for efficient use of production scrap and well-sorted end-of-life magnets, and long-loop recycling to secure flexible, virgin-quality feedstock from more complex waste streams.

Magnet Type	Description	Main Applications	Recycling Route
Sintered magnets	Pressed and sintered powders; high density, high magnetic strength	EV motors, wind turbines, industrial drives (90% share of NdFeB magnets globally)	*Short-loop* (hydrogen decrepitation plus re-sintering) if clean; *long-loop* for mixed/degraded scrap
Hot-deformed magnets	Hot pressed/deformed powders; fully dense, excellent mechanical and thermal properties	Aerospace, e-mobility traction motors, miniaturized high-performance devices	*Short-loop* into aligned powders possible; long-loop needed for top-grade specs or mixed inputs
Bonded magnets	NdFeB powder and polymer/resin binders; complex shapes, lower strength	Consumer electronics, sensors, small motors, precision devices	*Long-loop* preferred, as binders / additives prevent direct reuse

Recycling and Circular Supply Offer Potential but Lack Scale

Recycling represents a promising alternative to sourcing primary magnet material from China – but one that remains narrowly viable and available. Studies show the potential, e.g. mechanical pre-treatment of end-of-life motors can increase the magnet content in the recovered stream from ~10% to over 50%, lowering costs for subsequent recycling [33]. And in ambitious 2050 scenarios, cumulative recycling could supply a large share of EU REE demand, contingent on high collection and full industrial scale-up. However, European recycling activities today are far from reaching a critical scale, with recovery rates remaining below 1%, as Europe lacks both consistent volumes of end-of-life magnets and robust industrial recycling infrastructure [34].

Several structural gaps and constraints still further hinder European self-sufficiency:

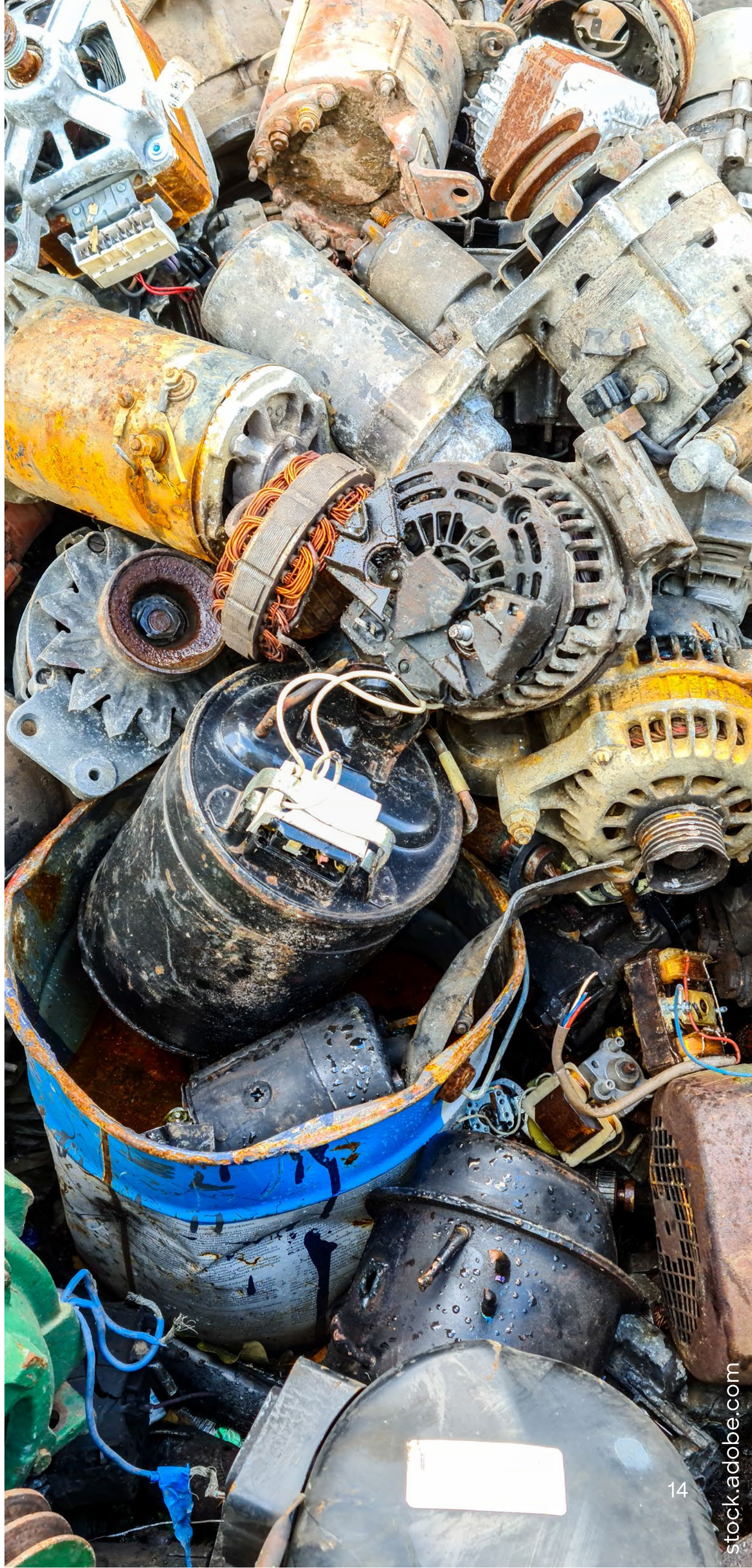
- **Limited processing capacity:** The current scale within Europe is negligible - early-stage projects exist, e.g., in France, Germany, UK and Nordic countries [35].
- **Value chain bottlenecks:** Critical steps of the recycling process are concentrated in only a few European players, e.g. alloy making, leaving recycling efforts dependent on scarce and fragile capacities.
- **Lack of scalable recovery solutions:** Current approaches (robotic disassembly, metallurgical and hydrogen processes, residue extraction) remain at pilot stage and are not yet integrated into established recycling ecosystems [5].

Without demand commitments from industry, no recycling project can scale. Companies must therefore treat recycled inputs as an insurance premium against future shocks, not just a cost item.

Industry needs to show clear demand and commitment.

NdFeB Recycling Practice Cases

Europe's rare-earth magnet recycling ecosystem is still fragmented, but a number of projects and players are emerging across the value chain. Together, these collaborations and innovations showcase Europe's growing momentum toward building a resilient, circular NdFeB supply chain and fostering new industrial players across the rare-earth value chain.



European Projects and Players in NdFeB Recycling (illustrative overview – not exhaustive)

Category	Organisation / Project	Specialisation / Focus	Partners / Involved Players	Status
Collection & Pre-processing (Enablers)	Rocklink GmbH (Germany)	System for collection, dismantling, separation of NdFeB, SmCo, AlNiCo magnets; >20,000 tons per annum (tpa) capacity; also trades rare earths & battery metals.	Works with WEEE collectors, recycling networks; linked to REE4EU.	Operational
	Inserma (Germany)	Automated dismantling of HDDs, motors, speakers to supply clean magnet feedstock.	Partner in SUSMAGPRO and other EU projects.	Operational (small scale)
Short-loop Recycling	Heraeus Remloy (Germany)	Europe's largest short-loop recycler; hydrogen decrepitation → alloy powders.	Partnering with Wilo (pumps) + OEMs in automotive & energy.	Operational / Scaling
	HyProMag (UK & Germany)	Commercialising HPMS (Hydrogen Processing of Magnet Scrap); ~100 tpa UK pilot, German expansion.	Linked with Univ. of Birmingham, Mkango Resources, EU SUSMAGPRO.	Pilot → Scaling
Long-loop Recycling	Carester (France)	Long-loop separation/refining start-up; building ~2,000 tpa RE oxide capacity.	MoU with Solvay; linked to French/EU strategic programs.	Planned (2026)
	Solvay (France)	Re-establishing REE oxide separation at La Rochelle; aims for ~30% EU demand by 2030.	MoU with Carester; engaged with EU CRM Act.	Scaling / Expansion
	Ionic Technologies (UK)	Hydrometallurgical long-loop recycling; recovery of high-purity REOs, esp. Dy/Tb.	Backed by Ionic Rare Earths (Australia); engaging with EU OEMs.	Pilot / Early Commercial
Recycled Magnet Production	MagREEsource (France)	Developing recycled NdFeB magnet production; target ~1,000 tpa by 2030; blends short- & long-loop feeds.	Spin-off from CNRS; French industrial partners.	Pilot Planned
	Magnolia Project (France)	Pilot EV-grade magnets with up to 25% recycled NdFeB content.	Led by Orano, with automotive sector partners.	Pilot
System-level Resilience & Modelling	REEsilience (EU Horizon Europe)	Builds digital twin of REE supply chain; models disruptions & circularity.	Consortium: Fraunhofer IWKS, SINTEF, BRGM + others.	Ongoing *(2022–2026)*
Technology Pilots / Demonstrators	HARMONY (EU Horizon Europe)	Recycling rare earths from NdFeB magnets, developing closed-loop processes	Led by CEIT-BRTA (Spain), 20+ EU partners, member of CRMs4EU cluster	Pilot active *(2024–2027)*
	SUSMAGPRO (EU Horizon 2020)	Short-loop recycling of NdFeB magnets via hydrogen-based processes across multiple applications Recycling	Coordinated by Pforzheim University., 19 partners in 9 EU countries	Completed *(2019–2023)*
	REE4EU (Horizon 2020 SPIRE)	Pilot-scale closed-loop REE recycling (ILE + HTE)	Coordinated by SINTEF (Norway), EU consortium	Completed *(2025–2019)*

Example: Wilo & Heraeus Remloy Collaboration for Short-Loop Recycling

German pump manufacturer Wilo collaborates with Heraeus Remloy to recycle NdFeB magnets from end-of-life pumps and production scrap. Using short-loop processes such as hydrogen decrepitation and re-sintering, Heraeus converts magnet waste into nanocrystalline powders that can be reused in new high- performance magnets. This partnership allows Wilo to secure a low-carbon, locally sourced feedstock, reduce material dependency, and advance its circularity goals [36].

Heraeus Remloy's Bitterfeld-Wolfen plant, opened in 2024, is Europe's largest NdFeB recycling facility with a capacity of 600 tons per annum (scalable to 1,200). The process cuts CO_2 emissions by around 80% versus primary production and could eventually supply up to 30% of Europe's magnet demand [37]. Still, the facility faces challenges in securing sufficient scrap volumes and competing with low-cost Chinese magnets.

In summary, Europe's NdFeB magnet ecosystem is gradually developing through industrial leadership, recycling pilots, and strategic projects under the CRM framework. Yet the region remains highly vulnerable due to low domestic production, recycling rates under 1%, and sustained reliance on China.

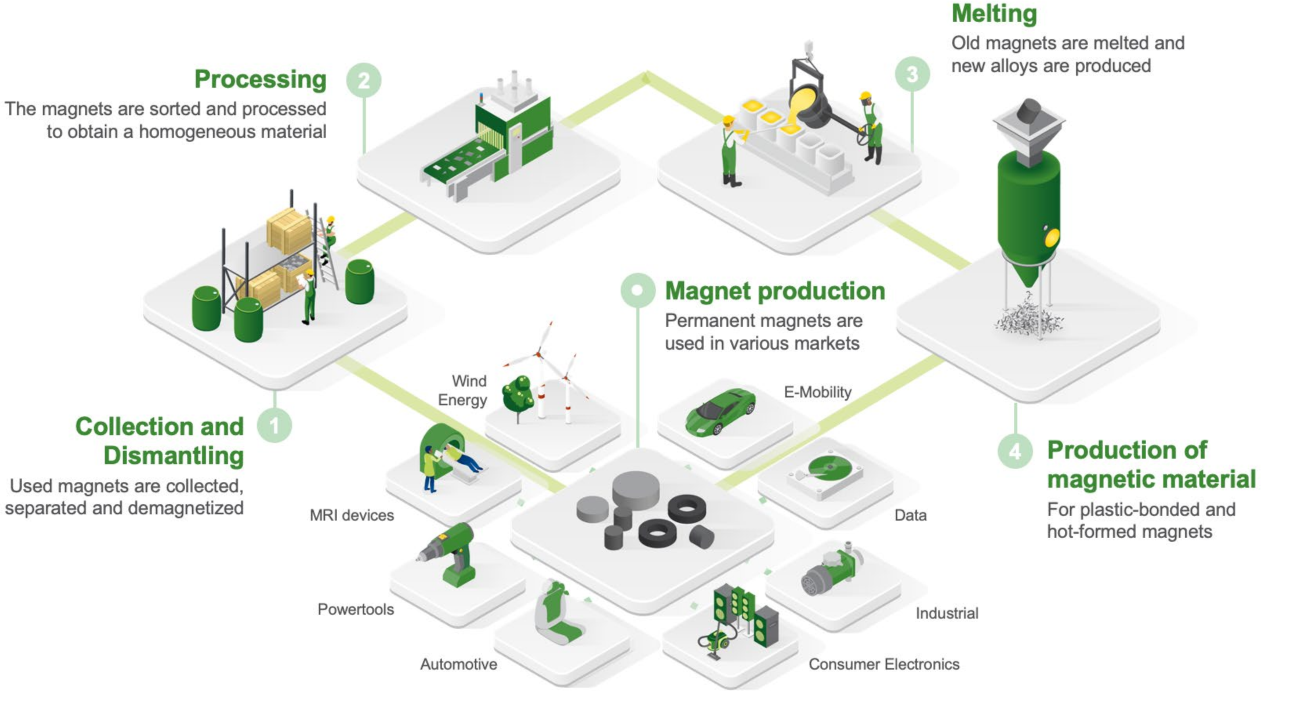


Figure 4: Overview of Short-Loop Recycling Process by Heraeus (Source: Heraeus Remloy)

Supply Diversification & Long-Term Commitments

+

Collective Industry Action & Political Backing

+

Substitution & Technological Innovation

+

Circularity & Recycling

long-term resilience & sovereignty

Strategic levers to secure resilience for NdFeB magnets

Addressing Europe's dependency on NdFeB magnets calls for a portfolio of coordinated levers – spanning market strategies, political frameworks, environmental measures, and technological innovation. Each lever provides partial relief – together they build long-term resilience and sovereignty.

Diversify Supply and Secure Long-Term Commitments

The most direct lever to reduce Europe's supply dependency on China is to diversify across the entire REE value chain and reinforce this through long-term commitments.

Moving Beyond Financial Hedging Strategies

Mitigating material-related risks is not new, companies have long relied on financial instruments such as swaps, futures, and options to hedge against commodity price volatility. These mechanisms, while effective in smoothing out unpredictable cost fluctuations, come at a premium that industry has historically accepted as part of risk management. However, such measures only address financial exposure; they do not guarantee physical access to materials. In scenarios where monopolistic suppliers impose export bans, as seen with China's REE dominance, prices would first skyrocket and then supplies become unavailable altogether, bringing production to a stop. In this context, recycling emerges as a highly relevant hedge against non-price risks in procurement and supply chain management. Just as financial derivatives are recognized tools in corporate risk portfolios, circular economy strategies, such as material recovery and closed-loop supply, must be treated as vital instruments of resilience.

Drive Diversification Across the Full Value Chain – Beyond Traditional Procurement

True independence requires engagement across all stages – mining, separation, refining, alloying, and magnet production. European companies must move beyond transactional purchasing and actively support emerging projects in allied regions, while also enabling European-based refining and magnet-making initiatives. Strategic tools include equity participation, joint ventures, and early-stage offtake agreements that provide certainty to new suppliers. Further, procurement must align with that strategy, moving beyond cost and integrating resilience, ESG, and geopolitical risk. Diversification entails premiums, best seen as insurance against shocks and risks. These can be accounted for, e.g., through risk-adjusted total-cost-of ownership or real options valuation, as investments in risk mitigation.

	Mining	Processing	Metal Refining	Magnet Manufacturing	Recycling
China	**~69%**	**~92%**	**~90%**	**~90%**	**<1% of magnets are currently being recycled**
USA	~11%	<1%	<1%	<1%	
Australia	~3%	0	0	0	
Africa	~4%	0	0	0	
Rest of Asia	~12%	<5%	<10%	<6%	
Rest of World	<1%	<3%	<2%	<3%	

Companies outside China*

Mining	Processing	Metal Refining	Magnet Manufacturing	Recycling
Lynas Rare Earths	Lynas Rare Earths	MP Materials	TDK	MP Materials
MP Materials	MP Materials	neo	VAC	MagREEsource
Arafura	neo	LCM less common metals	NOVEON	SOLVAY
VITAL METALS	SOLVAY	Hitachi Metals, Ltd.	Hitachi Metals, Ltd.	ionic technologies
RAINBOW	PENSANA Plc	Shin-Etsu	Shin-Etsu	urbanmining
ILUKA	SRC Saskatchewan Research Council		Schramberg	Re
PENSANA Plc	CARESTER		GKN	Heraeus
MKANGO	ILUKA			Cyclic Materials
RARE EARTHS NORWAY				HYPROMAG
eF				

Figure 5: Market shares within NdFeB value chain (Not exhaustive)
(Sources: Own illustration based on USGS, IEA, U.S. Department of Energy, USITC)

* Non exhaustive

Stabilize Supply and Pricing Through Long-Term Agreements

Long-term agreements (LTAs) are the most effective means to stabilize supply and pricing in volatile markets while de-risking new entrants. By committing to guaranteed volumes, buyers give suppliers the confidence to invest at scale in mining, processing, and magnet-making capacity. For buyers, LTAs ensure predictable costs, reliable volumes, and smoother handling of unavoidable premiums. Diversification and LTAs reinforce each other: buyers gain stability, suppliers gain certainty to scale.

Example: Toyota Tsusho & General Motors – Strategic Offtake Agreements Driving Global Diversification

Toyota Tsusho has signed an agreement with Pensana to secure up to 20,000 tons per year of rare earth carbonate from a mine in Angola, which will be refined through its Indian subsidiary TREI. This deal establishes a non-Chinese supply route for Japanese magnet manufacturers while giving Pensana the financial certainty to scale operations [38]. Similarly, General Motors has secured multiple LTAs with U.S. suppliers including MP Materials [39], Vacuumschmelze, and Noveon Magnetics [40], covering the full value chain from mining to alloying and finished magnet production. By committing to guaranteed volumes years in advance, GM enables its partners to expand at scale and supports the globalization of companies like VAC [41], a German-based magnet manufacturer. This approach has resulted in a rapidly expanding, non-Chinese supply base for NdFeB magnets used in GM's Ultium EV motors.

Pursue Collective Action and Political Backing

Given the scarcity of alternative supply sources, coordinated action at the European level has become essential. Without a unified approach, Europe risks reinforcing its dependency, and jeopardizing thousands of jobs.

Unite Industry Voices to Define Roadmap and Framework Conditions

NdFeB magnets are critical components in millions of industrial and consumer applications. More than half of all industrial products rely on electric motors – from pumps and compressors to medical devices. Meaning, that dependencies threaten the entire industrial base.

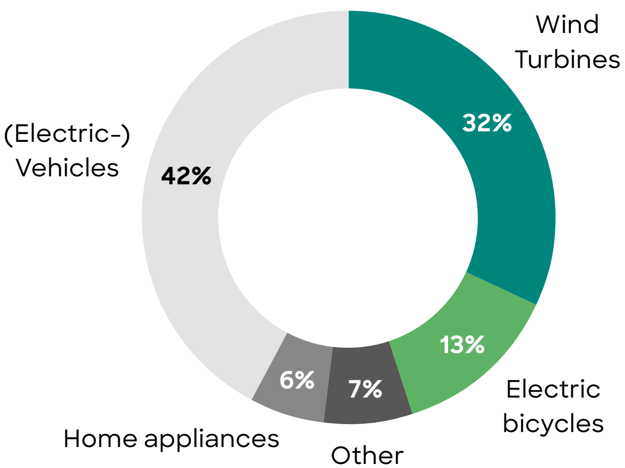


Figure 6: Demand of NdFeB magnets in EU by industry (2030) (Source: Centre for European Policy Studies (CEPS))

A joint industry voice is therefore a strategic imperative. When industry voices align on priorities – like investment incentives for refining and magnet-making, stronger recycling policies, and state-backed financial guarantees – they gain more political weight and are far more likely to turn into concrete action. Only by aligning across industries will Europe be able to safeguard millions of jobs, secure its energy transition, and protect its resilience.

> “
>
> One strong voice from industry is needed go give policymakers the clarity and confidence to act decisively.
>
> **Dr. Claas Oehlmann ,** *Federation of German Industries (BDI)*

Back Industry Action with Decisive Political Support and Policy Instruments

Sustained political backing is required to overcome structural barriers and ensure competitiveness against entrenched global players. Critical measures include:

- **Investment incentives** (grants, tax credits, co-financing) to de-risk recycling and magnet-making projects.
- **Permitting acceleration** to meet the 2030 CRMA targets.
- **Partnership facilitation** through trade diplomacy and investment treaties with emerging producers in allied regions.

Beyond this, calls from industry underline the need for policy interventions specifically to neutralize the cost disadvantage of European REE supply and create the market conditions to compete, including mandatory quota for European REE material use, financial (tax) incentives and support for recycling infrastructure. Furthermore, industry urges policymakers to address Europe’s magnet sector gaps by investing in skills, training, and R&D, while creating an EU framework for magnet labelling, collection, and export controls to keep end-of-life magnets within Europe.

Consider Stockpiling as an Enabler for REE Resilience

Strategic stockpiling is a key political tool to enhance CRM and REE resilience. By creating and maintaining reserves, governments can buffer industries against supply shocks, price spikes, or geopolitical disruptions. Japan's JOGMEC (Japan Oil, Gas and Metals National Corporation) provides a strong example: it manages national stockpiles of rare metals to ensure supply security for Japanese industry and intervenes in times of shortage. Similar approaches are being considered in Europe and the US as part of broader resilience strategies. For individual firms, stockpiling can also serve as a buffer against supply disruptions and price volatility.

Example: U.S. Department of Defense – Guaranteeing Supply via Price Floors and Equity Stakes

The U.S. has made rare earth security a matter of national industrial policy. Through the Defense Production Act, the Department of Defense has funded new refining capacity and de-risked investments with long-term offtake commitments. In 2025, the Department of Defense signed a multi-billion-dollar agreement with MP Materials that guarantees a price floor of $110/kg for NdPr oxides [42] – almost double China's market price – while also taking an equity stake in the company [43]. This political backstop provides MP with the certainty to expand mining, refining, and magnet-making capacity at scale in the U.S. For industry, the deal exemplifies how coordinated government support can act like an LTA: stabilizing prices, ensuring demand, and accelerating the emergence of a resilient supply chain.

Example: European Raw Materials Alliance (ERMA) – Driving Collective Action

An example of European aligned industry advocacy is ERMA – launched by the European Commission, as a key driver of resilience in the CRM and REE value chain. ERMA's platform leverages opportunities to access EU-level funding instruments, supports the industry to increase recycling practices, and promotes innovation and industrial production [44]. The ERMA outlines 14 strategic projects across the REE value chain, representing €1.7 bn in investments. If implemented, these could meet up to 20% of EU rare earth demand by 2030, while anchoring a €400 billion downstream market and protecting 6 million jobs.

Accelerate the Shift to Magnet-Free and Low-REE Technologies

Innovate to Reduce Use of REEs in Key Applications

Technological innovation offers a vital means to reduce structural reliance on REEs. Two distinct pathways are emerging. The first is the development of magnet-free motors [45], which eliminate permanent magnets altogether and thus bypass REE dependency entirely. The second is the use of non-REE magnets, where motors continue to employ magnets but made from alternative materials, avoiding REEs [46]. Pursuing both routes in parallel helps balance performance, cost, and resilience.

Acknowledge Limitations of REE-Reduced Solutions – and Apply Selectively

However, both approaches involve important trade-offs. Magnet-free motors tend to be bulkier and heavier, which can reduce efficiency. They require more complex power electronics, and their noise and vibration levels are often higher than in smooth-running permanent magnet motors. Non-REE magnets, on the other hand, currently offer lower energy density than NdFeB magnets, which can limit torque and efficiency [46]. Their production technologies remain at pilot scale, resulting in higher costs, unproven reliability at scale, and limited market acceptance until long-term durability is demonstrated. These drawbacks suggest that rare-earth-reduced solutions will be applied selectively – where performance compromises are manageable and outweighed by the benefits of reduced supply risk.

Make REE Substitution a Strategic R&D Priority

To accelerate adoption, manufacturers should integrate material substitution directly into their long-term R&D and procurement strategies.
A concrete step is to establish joint development programs with suppliers and research institutions that benchmark performance trade-offs across different use cases, set modular design standards so motors can be adapted to either NdFeB or alternative magnet systems with minimal redesign, and pool demand commitments to de-risk scaling of alternative magnet production.

Example: Advanced Electric Machines (AEM) – Rare-Earth-Free Motor Innovation

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Example: Horizon – Europe as a Catalyst for Low-REE Innovation

The EU's €95.5 billion Horizon Europe program actively supports innovation to reduce reliance on rare earth elements in electrification and renewable energy. Dedicated projects focus on next-generation e-drive systems that either avoid permanent magnets entirely or use recycled and low-REE materials. Horizon Europe fosters cross-sector collaboration, bringing together OEMs, Tier-1 suppliers, recyclers, and research institutes to accelerate development. Funded initiatives have already advanced technologies for REE recycling, substitution, and sustainable magnet production, with several pilot-scale demonstrations underway. Outcomes are expected to scale into industrial deployment before 2030, strengthening Europe's strategic autonomy in critical raw materials.

Manufacturers should integrate material substitution directly into their long-term R&D and procurement strategies.

Strengthen NdFeB Magnet Recycling within Europe

Enable circularity to secure secondary supply

Europe's recycling capacity remains largely in pilot phases, preventing material from reaching the market at competitive prices. Many start-ups face financial and scaling constraints, slowing the ramp-up of technologies that could supply between 24% and 48% of European NdFeB demand by 2050 [35].

European mining and recycling allow for higher environmental and human rights standards.

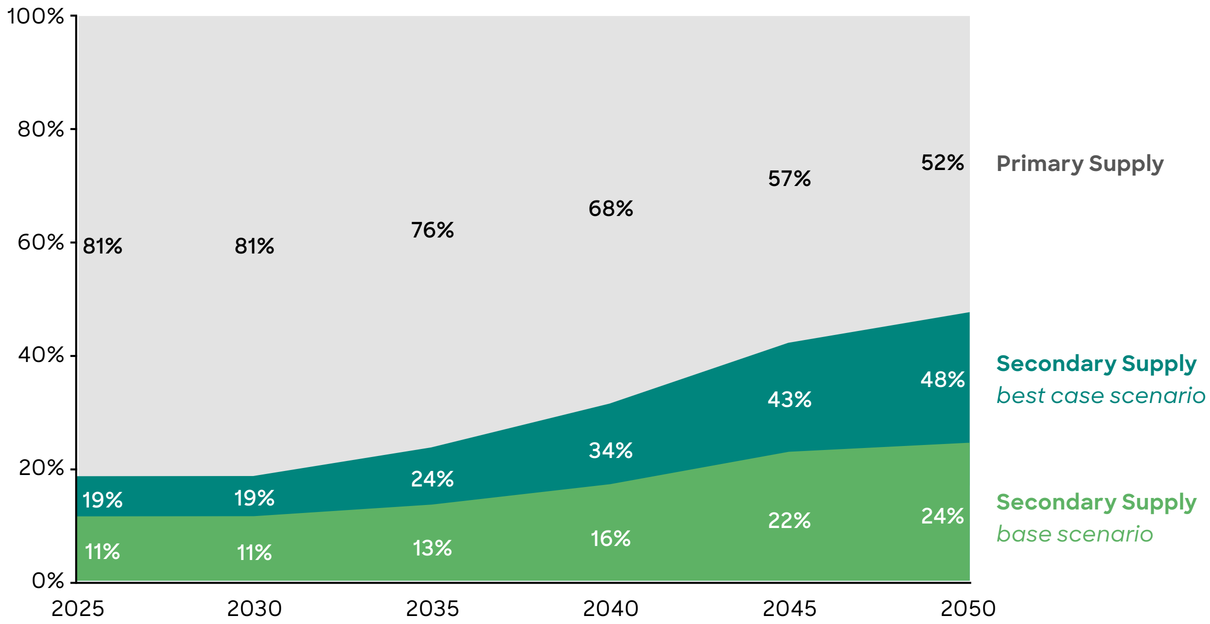


Figure 7: Secondary supply development of NdFeB magnets in EU (Source: Centre for European Policy Studies (CEPS) (CEPS))

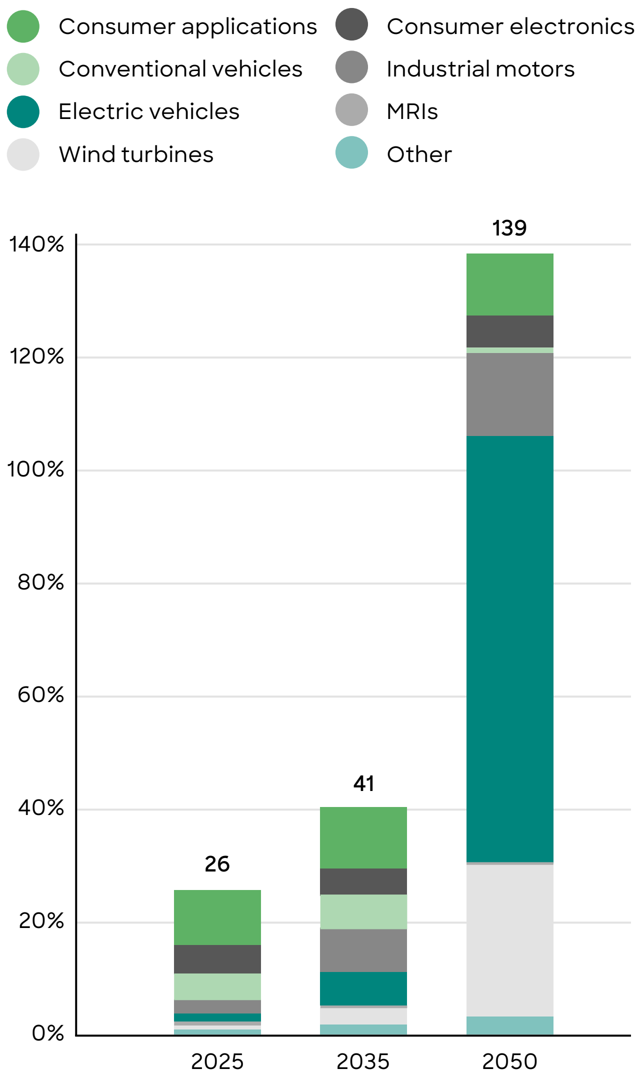
Limit the footprint of REE supply through secondary materials

Compared to primary supply, European mining and recycling allow for higher environmental and human rights standards. Recycling NdFeB magnets can cut emissions by up to 95% [47], reduces waste and avoids the radioactive by-products common in REE mining [48]. At the same time, European supply chains help avoid the labor and human rights risks associated with mining activities in other regions.

Leverage urban mining for access to end-of-life products

A critical enabler is Europe's "urban mine" of end-of-life products. Vehicles alone are expected to represent a major share of recyclable magnets by 2050 [5]. Regulatory frameworks will reinforce this shift: from 2025, updated e-waste directives will mandate recovery of critical raw materials, and by 2032 the expected End-of-Life Vehicle Regulation will require OEMs to take back vehicles – systematically unlocking access to secondary magnet feedstock. For industry, this makes direct access to EoL products, partnerships with dismantlers and recyclers an immediate priority.

REE postconsumer scrap by application, *kilotons*



REE postconsumer scrap by size of magnet, *%*

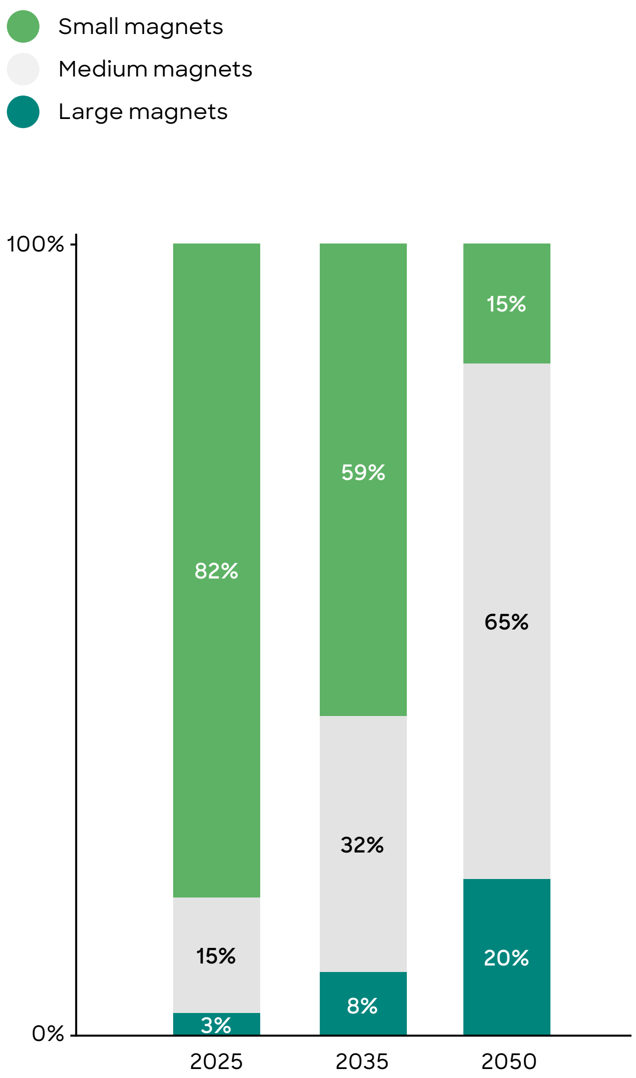


Figure 8: REE postconsumer scrap by application and size of magnets, metal contained (2025-2050) (Source: McKinsey & Company)

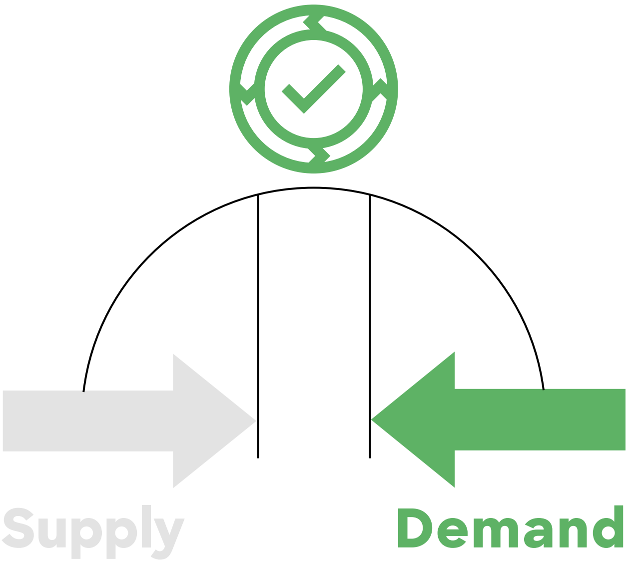
Design for recycling to make end-of-life materials accessible

However, recycling can only succeed if products are designed with circularity in mind. Today, many magnets are glued or encapsulated, making disassembly inefficient. By shifting to modular assemblies and reversible bonding methods, magnets can be removed intact and redeployed with minimal processing.

Collaborate to ramp-up and scale NdFeB Recycling

No single company can create a viable system on its own: collection of end-of-life products, dismantling, separation, refining, alloying, and magnet remanufacturing must be coordinated. A concerted effort linking manufacturers, recyclers, research institutions, and policymakers is essential to overcome technological barriers, share costs, and secure steady material flows. By pooling demand through offtake agreements, aligning standards, and co-investing in infrastructure, industry can create economies of scale for recycling to compete with primary supply. Collaboration not only reduces individual risk but also ensures that innovations are scaled rapidly.

No single company can create a viable system on its own.



Unlock the potential of circularity to bridge supply-demand gaps – beyond recycling

Recycling will play an important role in balancing supply and demand, but on its own it cannot deliver the volumes required for Europe's transition. Demand must also be curbed by extending product lifetimes, promoting reuse, and encouraging business models built on sharing rather than constant replacement. Strategies that keep products in use for longer – through repair, refurbishment, or reuse – preserve more value, bring efficiency gains, and avoid the material losses seen in recycling processes. These measures also strengthen local and regional supply loops. In the near term, recycling can help fill supply gaps, but only a broader commitment to circular economy principles will ensure long-term resource security. [49-50]

Example: Apple & MP Materials – Driving Closed-Loop Recycling with $500M LTA

Apple has entered into a $500 million long-term agreement with MP Materials to source magnets manufactured in Texas from 100% recycled feedstock processed in California (Mountain Pass) [51]. By locking in supply from a vertically integrated, U.S.-based producer, Apple is insulating its supply chain from geopolitical risk and driving innovation in closed-loop recycling. The contract provides MP Materials with guaranteed demand to scale a dedicated recycling line, while Apple gains predictable access to critical inputs for hundreds of millions of devices. Additionally, MP has received significant backing from the U.S. Defense Department, further facilitating ramp-up.

Example: Fraunhofer REASSERT – Industrializing Remanufacturing for EV Motors

The Fraunhofer REASSERT project (led by Fraunhofer Institute, Schaeffler, KIT, and others) pioneers remanufacturing of EV motors for a circular economy. Instead of shredding, the project emphasizes high value- retention – through reuse, repair, remanufacture, and material recycling. The approach includes a full process chain: from inbound inspection, over demagnetization until reassembly and end-of-line functionality -testing. An AI decision-making tool leveraging a digital twin guides the optimal- strategy – be it repair, remanufacturing, or recycling. [52]

> The circular economy is far more than a crisis response – it's about creating real economic opportunities. With a looming supply-demand gap for critical minerals, circularity is not optional; it is the foundation for the green transition and societal progress. To succeed, we need the whole value chain in the same space. Collaboration may appear challenging in today's world, but it remains indispensable.
>
> **Wen-Yu Weng,** *Ellen MacArthur Foundation*

Recycling alone cannot deliver the volumes required for Europe's transition.

Outlook

Securing a Circular and Sovereign Future for REE and other Critical Materials

Act Now on Neodymium – and Extend to other Critical Materials

The challenges around neodymium-based magnets are emblematic of Europe's wider dependency on critical raw materials that power the energy transition, digitalization, industry, and defense – and should be considered accordingly:

- **Confront rare earth dependencies:** Within the rare earth family, dysprosium and terbium are just as essential as neodymium for high-performance magnets, yet their supply is even more constrained. These heavy rare earths remain almost exclusively processed in China and tightened export controls may create structural bottlenecks for other countries' defense and high-tech sectors.
- **Address other critical and strategic raw materials:** Outside REEs, many elements carry similar risks. Lithium, cobalt, and nickel are indispensable for batteries but concentrated in politically fragile regions. Platinum group metals, critical for hydrogen and automotive catalysts, are tied to South Africa and Russia. Gallium and germanium, vital for semiconductors and optics, have been restricted by China. Tungsten and antimony remain indispensable for tooling and flame retardants, but European production capacity has dwindled.
- **Anticipate tomorrow's criticals:** Some materials not yet scarce may become bottlenecks. Copper, while abundant, faces surging demand from electrification and grids. Graphite and aluminum may also see constraints, where the challenge lies not in geology but in scaling sustainable production.

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Europe's rare earth magnet strategy needs to address a specific vulnerability linked to **heavy rare earth elements (HREEs)**, especially dysprosium and terbium. Chinese export controls now require lengthy case-by-case approvals, citing dual-use concerns. While HREEs are required to maintain magnetic performance above 140 °C, their use is often optional rather than essential for many civilian applications and could be avoided through engineering choices such as motor redesign or enhanced cooling. **Light rare earths (LREEs)** also have defense relevant applications, and similar restrictions could be applied at any time – with alternative supply and recycling outside China remaining limited, constrained by cost disadvantages. Europe must therefore plan for curtailed access to both HREEs and LREEs and aim to:

- **Build autonomy in LREEs:** diversify non-Chinese supply, scale recycling, use procurement and offtake contracts to anchor demand despite higher costs
- **Phase out HREEs:** establish an "HREE-free by default" rule with narrow exemptions, direct recycled HREEs to critical uses, while addressing supply for the medium term.

Unite Industry and Policy in a joint Strategy for CRM Resilience

Europe must **shift from fragmented responses to a systemic approach**. Recycling needs to expand beyond magnets to batteries, catalysts, and electronics, turning secondary supply into a reliable pillar. Product design should embed recyclability from the outset. Diversification of supply demands not only mining partnerships with Canada, Australia, Chile, or the U.S., but also co-investment in processing and refining. Innovation can reduce demand through substitution and efficiency gains, while foresight must track "future criticals" before they trigger crises.

This transformation will only succeed if **industry and policymakers act in concert**. Companies should commit a fixed share of procurement to recycled and responsibly sourced CRMs, sign long-term offtake contracts to de-risk investment, and pool demand to finance industrial-scale recovery. Governments, in turn, need to integrate CRM resilience into industrial and security strategies, provide incentives and streamlined permitting for recycling and substitution projects, and establish coordinated stockpiles for the most vulnerable materials.

Make Neodymium the Starting Point for Systemic Change

The case of neodymium is not unique – it is a **mirror of the systemic challenge of raw material sovereignty in the 21st century**. Similar patterns of dependency, concentrated supply, and environmental risk are present across a wider set of critical raw materials. Material criticality is dynamic, and today's abundant resources may become tomorrow's bottlenecks. Europe can continue to rely on fragile global supply chains and accept exposure to geopolitical shocks, or it can invest in building a resilient industrial base by combining circularity, diversified sourcing, and innovation.

Resilience will not be achieved by supply-side measures alone. For recycled and European-produced materials to become viable at scale, **offtake demand must be stimulated**. This requires targeted policy measures – such as quotas or procurement requirements – that compel key industrial users to integrate European and recycled critical raw materials into their supply chains. Without guaranteed demand, investments in circularity and new European production will remain underutilized, and Europe risks falling short of building a truly sovereign raw materials base.

Acting on neodymium today should be the **first step for Europe toward securing sovereignty and resilience across all critical raw materials** – and will determine our security and prosperity in the future.

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