EUROPEAN RAW MATERIALS ALLIANCE | ERMA

eit RawMaterials
Connecting matters

Co-funded by the European Union

Rare Earth Magnets and Motors: A European Call for Action

A report by the Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance

EUROPEAN RAW MATERIALS ALLIANCE ERMA

eit RawMaterials Connecting matters

Co-funded by the European Union

Please cite the report as follows:

Roland Gauß, Carlo Burkhardt, Frédéric Carencotte, Massimo Gasparon, Oliver Gutfleisch, Ian Higgins, Milana Karajić, Andreas Klossek, Maija Mäkinen, Bernd Schäfer, Reinhold Schindler, Badrinath Veluri

Rare Earth Magnets and Motors: A European Call for Action. A report by the Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance. Berlin 2021

Design: Ferdinand Bulmer and Javor Dimitrov

Foreword

Bernd Schäfer
CEO, Managing Director
EIT RawMaterials

Europe is the global leader of the Green Transition. The EU aims to become climate neutral by 2050. A successful transition fundamentally depends on Europe's ability to develop and deploy clean energy and mobility solutions in an economically and environmentally sustainable way. The raw materials needs to facilitate this energy transition are massive. In addition, industrial and home appliances will need to run under the highest energy efficiency standards. Electric motors that translate electric energy into motion are essential components of all these applications. The most energy-efficient electric motors and generators contain rare earth permanent magnets. Whilst EU companies are world leaders in the manufacturing of electric motors, they are fully import dependent along the entire value chain of rare earth magnet materials.

This European Call for Action on Rare Earth Magnets and Motors is the result of a stakeholder consultation process. It was conducted under the auspices of the European Raw Materials Alliance (ERMA), which was launched in 2020 by the European Commission under the leadership of Commissioner Thierry Breton and Vice President Maroš Šefčovič. One of the objectives was to identify and address regulatory bottlenecks and related opportunities that would support the growth of alternative European and global rare earth supply chains - to make EU industrial ecosystems more resilient. Thus, rare earth magnets and motors became the first priority theme for ERMA, which – overall – aims to make Europe economically more resilient by diversifying its supply chains, creating jobs, attracting investments to the raw materials value chain, fostering innovation, training young talents and contributing to the best enabling framework for raw materials and the Circular Economy worldwide. The Alliance addresses the challenge of securing access to sustainable raw materials, advanced materials, and industrial processing know-how, which are the nucleus for strategic technologies and key enablers to achieve the Green Deal. Raw materials are essential to the successful execution of the European economic and green agenda. By 2030, ERMA's activities will increase the production of raw and advanced materials and address Circular Economy by boosting the recovery and recycling of Critical Raw Materials.

We are grateful and excited that EIT RawMaterials has been given the opportunity to manage ERMA on behalf of the European Commission. Innovation, education, matchmaking, business development, and intelligence very much represent the DNA of our Innovation Community. We are committed to supporting Europe's transition towards a circular, green, and digital economy whilst strengthening its global competitiveness and securing employment.

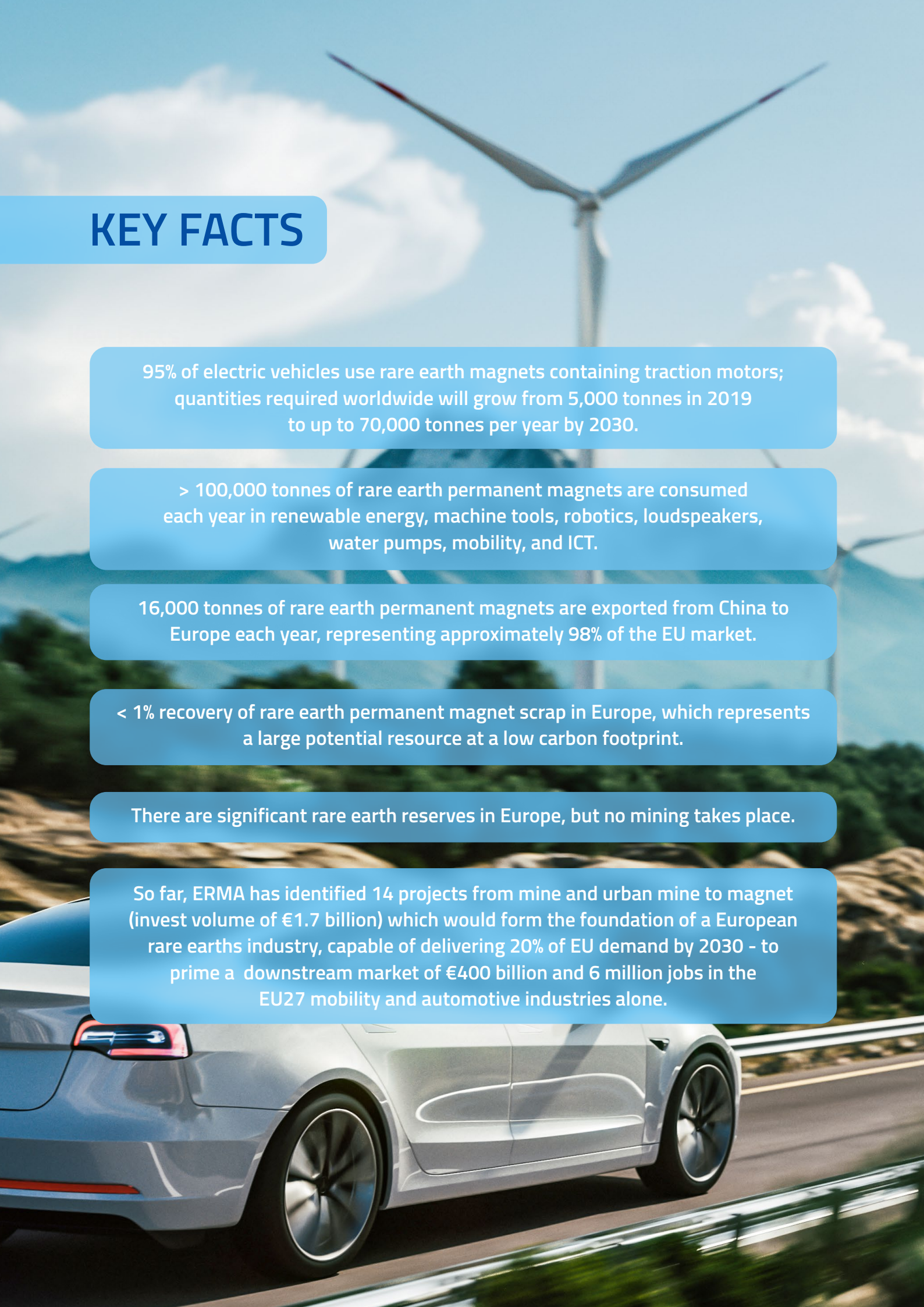
The Commission's in-depth review of critical supply chains and key technologies has highlighted the EU's high level of foreign dependency on inputs required for our green and digital transition and our continent's resilience. The EU depends on others – mainly China – for the import of permanent magnets, as well as the rare earth elements they are made of. The European Raw Materials Alliance plays a key role in addressing these dependencies by identifying an EU project pipeline covering diversification of supplies, domestic sourcing and recycling. I invite companies large and small, Member States and regions, researchers and civil society organisations to help us achieve these objectives.

Thierry Breton
Commissioner for Internal Market

Our strategic foresight shows clearly that the demand for critical raw materials is only going to rise, especially given the ongoing transition towards a green and digital economy. The pandemic has also highlighted the criticality of raw materials for our recovery. To secure a sustainable supply of raw materials we need to join forces across Europe, as we have done for the EU Battery Alliance. The European Raw Materials Alliance will mobilise industrial and innovation actors, Member States, regions, the EIB, investors and civil society – to help build our capacities and investment cases along the entire value chain, from extraction to processing and recycling. This will in turn strengthen our resilience and boost our open strategic autonomy.

Maroš Šefčovič
Vice-President for Interinstitutional Relations and Foresight, European Commission

Contents



KEY FACTS

95% of electric vehicles use rare earth magnets containing traction motors; quantities required worldwide will grow from 5,000 tonnes in 2019 to up to 70,000 tonnes per year by 2030.

> 100,000 tonnes of rare earth permanent magnets are consumed each year in renewable energy, machine tools, robotics, loudspeakers, water pumps, mobility, and ICT.

16,000 tonnes of rare earth permanent magnets are exported from China to Europe each year, representing approximately 98% of the EU market.

< 1% recovery of rare earth permanent magnet scrap in Europe, which represents a large potential resource at a low carbon footprint.

There are significant rare earth reserves in Europe, but no mining takes place.

So far, ERMA has identified 14 projects from mine and urban mine to magnet (invest volume of €1.7 billion) which would form the foundation of a European rare earths industry, capable of delivering 20% of EU demand by 2030 - to prime a downstream market of €400 billion and 6 million jobs in the EU27 mobility and automotive industries alone.

Executive Summary

The challenge: Rare earth elements are essential materials for Europe's economy and green political agenda. They are used in various high-tech applications and are of particular strategic importance in magnets for electronics and communication devices and also in renewable energy, robotics, electric vehicles (EVs), as well as aerospace and defence applications. Strikingly, 95% of EVs use rare earth permanent magnet traction motors, because they provide the highest energy efficiency, which translates into driving range. While rare earths used for magnets (neodymium, praseodymium, dysprosium, and terbium) constitute only 25% of the total rare earths production volume, they represent 80% to 90% of the total rare earths market value[1]. More than 90% of rare earth magnets are produced in China today: this high production concentration in combination with rising global political tensions and a growing Chinese domestic market demand - particularly driven by a growth in electric mobility - results in a high supply risk for these materials from a European perspective. In addition, there is a lack of supply chain transparency, standards and certification schemes regarding environmental and social impacts and governance. Indeed, the European Commission considers rare earths to be among the most resource-critical of all raw materials and has been promoting research and innovation across the entire value chain for years[2]. Yet, the European rare earth industry has been massively eroding over the last two decades. In China, the rare earth value chain is considered to be a highly strategic asset to secure a growing market share in major downstream industrial ecosystems. Lately, this has been demonstrated by the new Chinese "Export Control Law", effective since 1 December 2020. The largest rare earths mining and processing companies are state-owned and are sustained by various direct and indirect state subsidies. The combination of a lack of diversified rare earths supply chains and the exponential growth in the demand for high performance permanent magnets, particularly in automotive and renewables, creates the perfect conditions for supply chain disruptions. EU manufacturers are at a disadvantage in accessing the materials over their Asian competitors and particularly suffer from price fluctuations driven by speculation. The political impact of not regaining control over the rare earth value chain are tremendous. Whilst the rare earth permanent magnet market itself is relatively small – about €6.5 billion – its downstream leverage is enormous: the EU27 mobility and automotive business alone is expected to grow to around €400 billion, with 6 million jobs by 2030[3]. If Europe loses a significant share of electric traction motor manufacturing to China, a massive downstream market value and many jobs are at risk. In addition, there is the strategic importance of rare earths for defence applications. Thus, the real costs of having access to sustainably produced magnets in larger volumes need to be considered, i.e., financially, environmentally, socially, and in terms of supply risks – also considering the cost of potentially not having access to these materials at a given point in time.

In this context, the European Commission launched the ERMA Cluster on Rare Earth Magnets and Motors[4], which is managed by EIT RawMaterials GmbH. The overall objectives are to secure access to sustainably produced magnet rare earths at competitive costs from primary and recycled sources; to make Europe a global leader in rare earth metal, alloys and magnet production; and to sustain and expand Europe's global leadership in electric motor and generator design. A two-fold approach was followed, that is, to identify promising investment cases as well as to recognise regulatory issues that hinder the growth of the sector in Europe.

[1] Roskill 2018

[2, 4] European Commission 2020a

[3] Eurostat data and team analysis: National accounts employment data by industry [nama_10_a64_e], 20.8.2020; National accounts aggregates by industry [nama_10_a64], 20.8.2020. The forecast was modelled grouping employment and value add data per industry to eight EU ecosystems defined as strategically relevant to European raw materials application. CAGR between 2017 and 2030 was modelled on industry level, resulting in an overall CAGR for the EU ecosystem Mobility / Automotive of 0.8 % p.a.

Our response: To increase Europe's strategic autonomy in rare earths, the EU will need to address the entire value chain. This involves creating a circular economy around rare earths by advancing recycling and substitution, as well as exploration, mining, processing, separation, metal making, alloying, magnet making, and motor design. Today there is no primary production within the EU and less then 1% of rare earth elements are recycled in Europe. This needs to change if the EU wants to successfully compete economically and lead the Green Transition. Within the first six months of its existence, the European Raw Materials Alliance (ERMA) has identified investment cases from rare earth mine and urban mine to magnet, with projects spread all across Europe and a total investment volume of €1.7 billion. If these projects were realised, 20% of Europe's rare earth magnet needs by 2030 could be sourced from the EU, that is, 15 times more than today[5]. More investment cases are expected to be submitted, potentially increasing the overall rare earths materials production and recycling capacity in Europe.

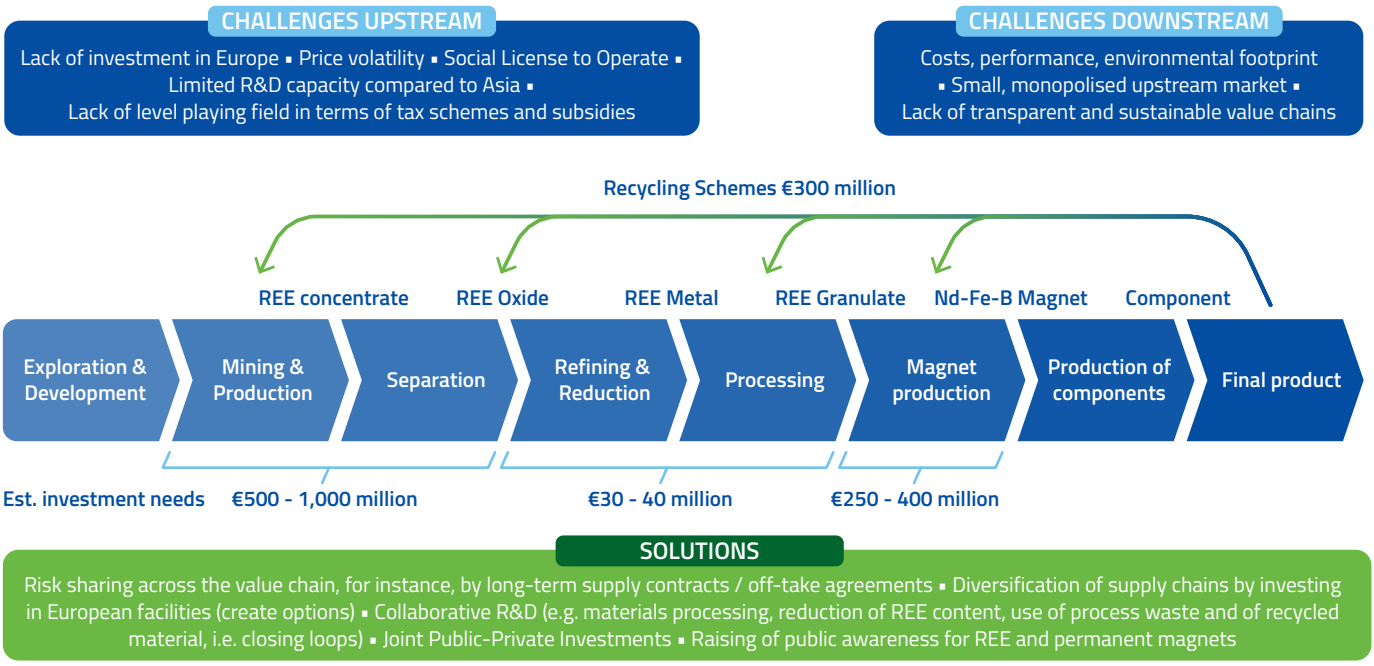


Fig. 1: ERMA Cluster Rare Earth Magnets and Motors: Challenges and solutions and price tags per value chain step indicating the order of magnitude of investment needs for an EU value chain capable of matching 20% of domestic materials demands by 2030 (see Fig. 8). The size of investments relates to the nature and cost structure of each value chain step and potential production outputs. Note that end-of-life electric vehicles will boost the magnet recycling market, particularly beyond 2030. (see Fig. 7).

The European Raw Materials Alliance ran a stakeholder consultation process to understand regulatory bottlenecks. More than 180 stakeholders from industry, academia, government organisations and NGOs participated and defined action items that centre around four key recommendations:

i) European policymakers will need to create a level playing field: The cost of EU production within the segment of rare earth magnets and motors is intrinsically higher than the Chinese production cost, which is massively lowered by a set of direct and indirect state subsidies and lower social, labour, and environmental

[5] Two cases have already received a French Recovery Fund grant: a rare earth magnet recycling plant developed by the French company Carester (€15 million) and the magnet recycling and manufacturing company MagREEsources (€0.75 million).

standards. Furthermore, trade facilitations, such as unilateral tax exemptions, discriminate against European and other global competitors.

ii) European OEMs will need to consider potential commitments to buy a significant percentage share of rare earth materials from European producers. Indeed, downstream industry would gain a significant advantage in diversifying its supply chains, gaining access to local suppliers, maintaining local access to materials knowedge for future motor designs and test facilities as well as in supporting the development of capacities for a circular economy of electric motors.

iii) The EU will need to make sure that end-of-life products (and waste materials) containing rare earths stay in Europe by introducing and implementing regulations and standards that facilitate the re-processing and recycling of products.

iv) There is a unique opportunity to trigger large private investments in the emerging European rare earths value chain by match funding. For this reason, the EU and its Member States should pull all financial levers including state aid, such as a dedicated Important Project of Common European Interest (IPCEI).

Along these four recommendations, Europe needs a decisive masterplan with dedicated strategic actions. A disruptive change is required now. This document lays out 12 Actions, which have been developed to different levels of detail. The document is designed to be the first outcome of a stakeholder interaction. Progress will have to be assessed and actions adapted accordingly.

Rare earth permanent magnets in wind energy

The European wind industry recognises the long-term strategic and commercial benefits of diversifying supplies of rare earths and permanent magnets used in wind turbines. A European rare earth and permanent magnet supply chain would bring jobs and growth and contribute to a "just" energy transition. And it would increase the bargaining power of end-users such as the wind industry vis-à-vis third country suppliers.

As an industry we are working hard to improve the social and environmental sustainability of the materials we use. Our approach to the rare earths and permanent magnets supply chain is no different. We are working to improve our material efficiency rates and actively exploring substitution options for rare earths. Sustainability standards and recycling will play an increasing role. We welcome the EU's work on the diversification of supply chains. Clearly it needs to recognise the costs involved and the potential consequences for energy prices. The costs of wind energy have fallen significantly over the last decade. And as renewables expand further it is in society's interests that they should continue to fall.

Giles Dickson, CEO, WindEurope

Wind turbines - particularly offshore - use several tonnes of rare earth permanent magnets due to energy efficiency and the robustness of technology.

Market Developments and Policy Context

Rare earth magnets and motors are essential components in battery and fuel cell electric vehicles as well as in wind turbines. But they also, for example, make machines, robots, and water pumps move, provide cool air in refrigerators and air-conditioning (compressors), and allow phones and laptops to have effective speakers and microphones. Invented and industrialised in Europe as early as the 19th century, the power of electric machines has been rediscovered today, and EU manufacturers are still world market leaders. The devices are driven by advanced materials that contain costly metals, including resource-critical rare earth metals. Securing the supply chain of these materials is crucial to sustaining Europe's global market leadership in electric motors and generators and to developing a Circular Economy of products driven by these devices.

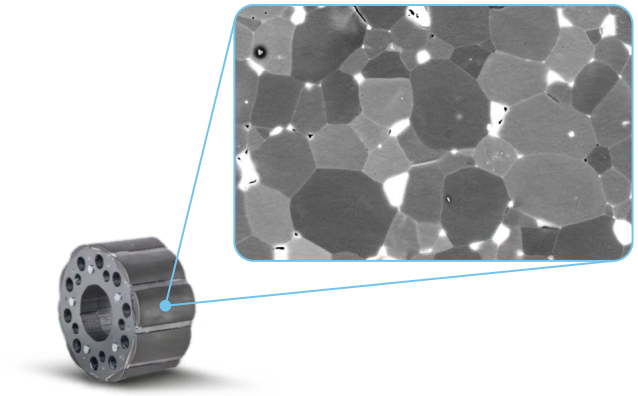


Fig. 2 Rotor with mounted rare earth permanent magnets. The magnetic field of the magnets interacts with the magnetic field created by the electric current in the copper coils of the stator (not visible) which makes the rotor spin. A carefully engineered microstructure is a key enabling factor for powerful magnets: sintered magnet with grains (grey) and intergranular phases (white).
TU Darmstadt / Fraunhofer IWKS

The European Commission considers rare earths to be amongst the most resource-critical raw materials: they are of highest economic importance and at the same time feature a high supply risk. They play a vital role in the industrial economy of Europe, that is, in traditional sectors as well as in emerging ones, including aerospace and defence. In 2019, about 130,000 t of rare earth permanent magnets (Nd-Fe-B) were produced worldwide[6] which corresponds to a market volume of about €6.5 bn. 93% of these magnets were produced in China, reflecting a very high production concentration (which is, in fact, found across all rare earth value chain steps, from mining to recycling). Today, there is a 1,000 t production capacity left in Europe competing with 16,000 t of Chinese magnets imported each year[7]. In addition, rare earth magnets are increasingly imported as part of motors and generator assemblies and products. Despite a growing market, the EU magnet production capacity is not fully

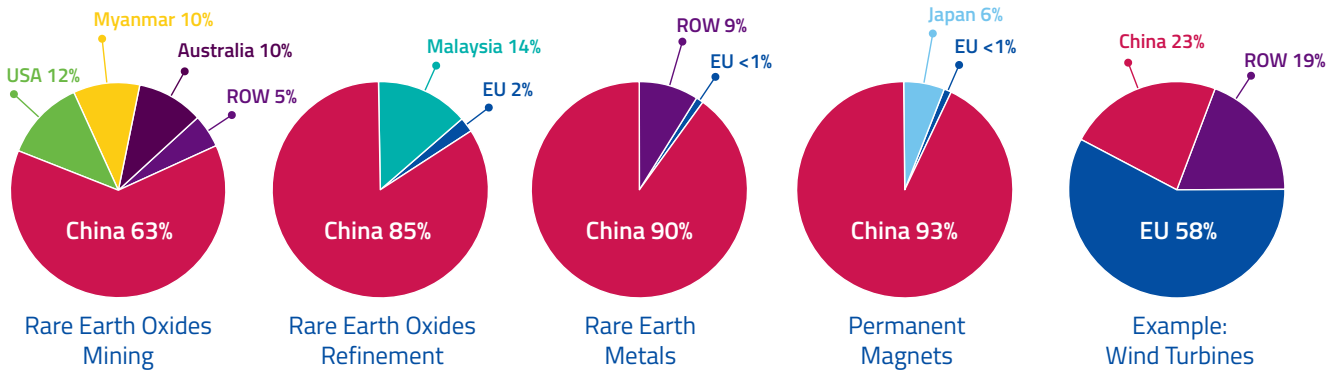


Fig. 3: From rare earths mining to wind turbine manufacturing: market shares. Sources: Roskill 2018; Adamas Intelligence 2019; Peteves 2017; Carrara et al. 2020.

[6] Estimates based on Roskill 2018, Adamas Intelligence 2020, and consolidated reports by REIA 2021. Other sources indicate higher global production figures, i.e., up to 200,000t of Nd-Fe-B per year in 2019. The big challenge is to differentiate between production capacities and actual production output. Obviously, there is a lack of transparency in the global rare earths value chain.

[7] Chinese Customs data 2021; REIA 2021.

utilised today and is rather serving specialised niche applications. This is due to the fact that European producers can hardly compete in terms of prices with Chinese magnet makers, because there is a lack of a level-playing-field (see further details below). In fact, after decades without investment into the rare earths industry in the Western hemisphere, China has a gained a monopoly in rare earths, which is very hard to compete with in a free market. There is a lack of, i) supply chain diversification, market driven competition, and resilience against supply shocks; ii) supply chain transparency and a clear definition of sustainability standards; iii) industrial capacity to implement an EU Circular Economy of rare earth materials; and iv) strategic investments aiming to benefit from a growing materials market to create economic growth and new jobs in Europe, i.e. jobs directly related to the rare earth magnet and motor value chain as well as indirect jobs secured downstream.

The economic importance of the rare earths value chain becomes obvious by looking at the emerging electric vehicle market: over the last decade, the evolution of technology has resulted in 95% of EVs using permanent magnet motors by 2019, particularly because they provide the highest energy efficiency which translates into drive range[8]. In 2019, about 5,000 t of rare earth permanent magnets were used in EVs worldwide. By 2030, the number may rise to between 40,000 and 70,000 t on a global level, depending on the anticipated growth scenario. A global EV market worth of about € 625-1,000 billion would depend on securing access to sustainably produced rare earth magnets – a comparatively small but specialised market of about € 2-3 billion (value corresponding to magnet volume share needed in the respective EV sector)[9]. As indicated above, this pattern is reflected in other industrial ecosystems: energy efficient electric motors are also needed in fuel cell electric vehicles and domestic appliances, like energy efficient refrigerators, washing machines, and dishwashers; rare earth containing wind turbines are gaining market share, particularly in offshore wind farms due to their robustness and efficiency; all microphones and speakers of mobile devices contain rare earth magnets due to the need for miniaturisation.

Chinese rare earth magnet prices are government controlled and follow a strategic, cross-value chain, long-term rationale that aims to take leadership in key downstream industrial sectors: in China, the rare earth value chain is considered to be a highly strategic asset to secure a growing market share in major downstream industrial ecosystems (see above). The largest rare earths mining and processing companies are state owned and are sustained by various direct and indirect state subsidies. The most obvious of these is a strategic set of import charges and VAT refund mechanisms that are WTO compliant, but down the line make rare earth business elsewhere in the world almost impossible: rare earth ores can be imported duty free into China whereas the import of processed rare earth materials, including magnets, comes with a tax. The country wants to protect higher value creation steps from competition.

Fig. 4: Export rare earth magnet VAT refund by Chinese government in 2019, i.e., related to products exported to the EU (yellow) and to the rest of the world (blue). Chinese Customs data (16% VAT from Jan-Mar/2019 and 13% VAT from Apr-Dec/2019 result in average of 13.75%).

[8] Roskill 2018; Adamas Intelligence 2020

[9] Assumptions: Global electric vehicle market will have grown to 25-40 million cars per year by 2030, including battery electric and plug-in hybrid electric passenger, light-duty vehicles; average price per car is €25,000; Nd-Fe-B use per car is 1-2 kg; average Nd-Fe-B price is €50/kg. After SPS and SDS scenarios by IEA 2021; see also Adamas Intelligence 2020.

Even more importantly, there is no VAT refund on the export of processed rare earth ores, that is, rare earth oxides, metals, and alloys, whilst there is a VAT refund on exported rare earth magnets. As a consequence, whilst Chinese magnet manufacturers can bypass the VAT on rare earth raw materials to their end customers (only the end customer is liable to pay VAT), non-Chinese ones must pay it and thus have a cost disadvantage of 13% on the full price. This is a significant competitive disadvantage, since raw materials costs determine up to 90% of the cost of the magnet strip cast alloy and 40-45% of the final sintered magnet (depending on the fluctuating raw materials costs). In addition to this massive disadvantage, other significant market distorting factors include lower environmental and social sustainability standards as well as easy access to cheap finance, land, specific manufacturing equipment, electricity, and a growing academic community talent and research centres. Hence, non-Chinese companies along the entire rare earth value chain have difficulties entering the market, unless they want to deliver raw materials to China. Outside of China, magnetic materials are mainly produced for niche market applications.

The goals of the EU include sustainable development and a competitive market economy. Thus, there is a need to create a level playing field for European rare earth materials manufacturers to be able to compete in a global market. Therefore, the guiding question should not be whether EU manufacturers can compete with Chinese ones in terms of a spot market price for a rare earth product. In fact, today, there is a price difference of about 20-30% for a magnet produced in Europe compared to an equivalent one produced in China, depending on the application. The key question is rather what the real costs are to have access to a sustainably produced magnet, that is, financially, environmentally, socially, and in terms of supply risks – also considering the cost of potentially not having access to these materials at a given point in time.

Rare earths research, development, and engineering have always delivered major innovation breakthroughs: the materials were first discovered and developed for applications and industrial production in Europe. They were essential for the industrial deployment of streetlights (gas lamps), colour television, catalysts, specialty alloys, glasses, aerospace applications, electronics, medical imaging technologies (such as magnetic resonance imaging), and energy efficient electric motors and generators (see above). Discovered in 1983 by Japanese and American industrial researchers, Nd-Fe-B – the mass market rare earth permanent magnet material – began to be produced in Europe as early as 1985[10]. Since then, the European Commission and EU Member States have funded research on rare earths and

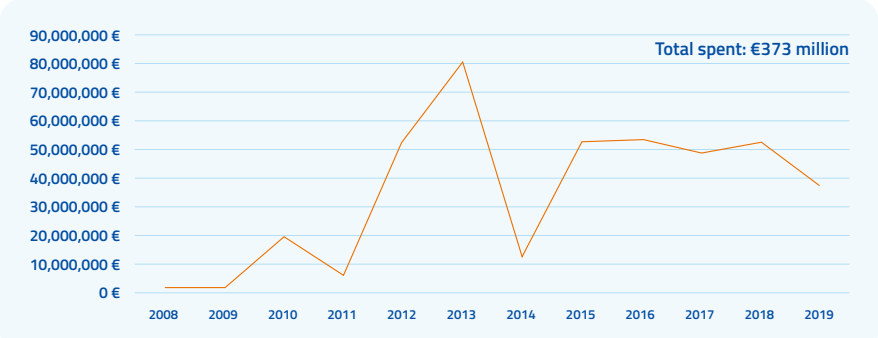


Fig. 5: EU R&D funding in "rare earth": projects that started 2008-2019. Major research fields considered: metallurgy, magnets, optical fibres, electronics, LED, OLED, sensors, speciality glasses, e-motor and generator designs. (Source: CORDIS database)

[10] Vacuumschmelze, Germany, has been producing Nd-Fe-B since 1985, Sm-Co magnets since 1973. Together with its Finnish subsidiary Neorem, it is the only major sintered magnet producer that has survived in Europe. The industrial capacity to produce sintered magnet manufacturing also exists at Magneti Ljubljana, Slovenia, and Magnetfabrik Schramberg, Germany.

particularly magnetic materials. A milestone was the EU funded project called Concerted European Action on Magnets (CEAM) which started in 1985. Europe was at the forefront of rare earth magnet research and industrial production, and many students educated in this period have become industrial or academic leaders in the field today. Over the last ten years, the European Commission has invested € 373 million in the field of rare earth research and innovation via its respective Framework Programmes (Figure 5). Now it is time to exploit the achieved results and to make Europe a leader in a sustainable rare earth industry again. In addition to the existing use of rare earth materials, tomorrow, they might be essential for new cooling technologies (magnetocaloric cooling), optoelectronics, hydrogen technologies, and medical technology applications – equipment developed by world leading European researchers in the labs, today.

Rare earths are not rare, and they are not necessarily produced with a high environmental footprint: geologically speaking, they are comparatively abundant. Europe has its own deposits. What makes them resource-critical is the highly concentrated production along the entire value chain in one part of the world, which is China. According to the new Chinese "Export Control Law", effective since 1 December 2020, the country is closely monitoring its domestic needs and is strategically securing access to rare earth sources worldwide, including deposits in California, Madagascar, and Greenland. Europe imports rare earth materials not accounting for the real costs, and exports problems in terms of environmental footprints (such as CO2 emissions, radioactivity, or mining impact), and costs linked to appropriate social standards. In fact, the EU has the potential to be the world leader in the sustainable production of rare earth materials. A concerted European action in rare earth materials innovation would allow the bloc to benefit from a growing market, make it more resistant to supply shocks, and would secure a great number of direct and indirect jobs, particularly in the transforming automotive, energy, and machine industries. The last year highlighted the high vulnerability of, particularly, single source supply chains, considering travel restrictions and production breakdown related to the coronavirus pandemic.

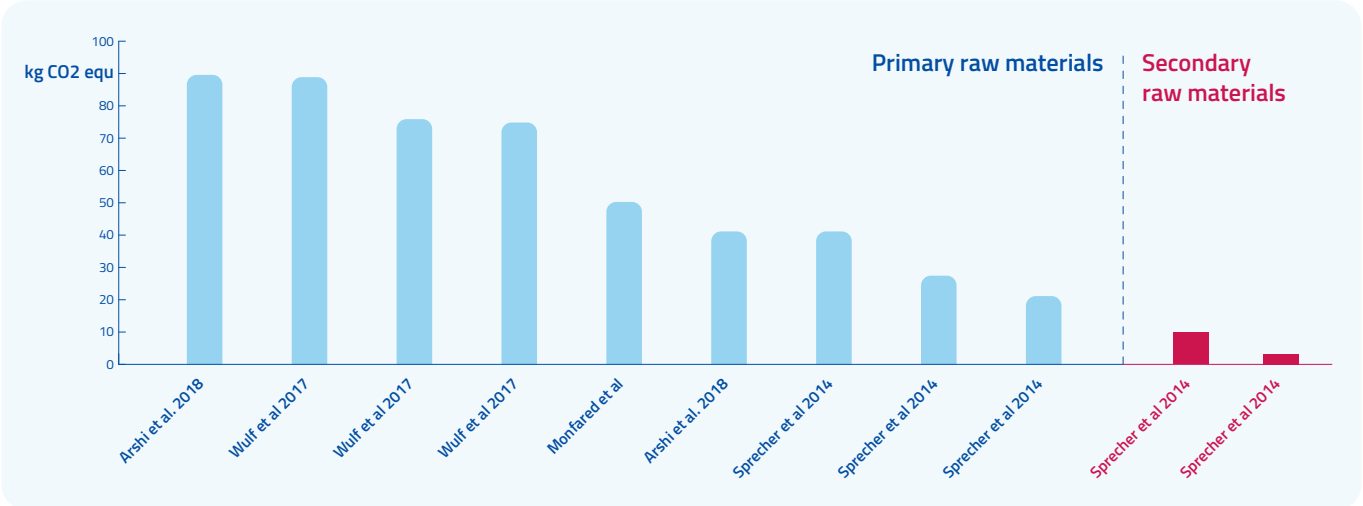


Fig. 6: Global Warming Potential of 1 kg Nd-Fe-B (kg CO2 equ.) according to various LCA reports. The scores vary greatly depending on the raw materials, the processing routes, and the LCA methodology used. There is a lack of a standardised LCA approach to rare earths. For direct quantitative comparison of processing routes, only consider each data of the same publication to ensure comparability. The authors of each report are shown beneath the individual data columns.

Rare earth magnets can be produced in a responsible or a less responsible way. Figure 6 shows the CO2 equivalents emitted in the production of 1 kg of Nd-Fe-B, according to various ore processing sources and recycling. The data show a large variation and will have to be substantiated by future industry-based research. There is a huge potential to increase the use of renewable energy in the mining and processing sectors, which would significantly reduce the environmental impact of primary raw materials production. In any case, even considering a magnet with a comparably high CO2 footprint, the environmental impact of the magnet is minor compared to that of the corresponding lithium-ion battery, which contributes the equivalent of several thousand kilograms of CO2 emissions during the production process[11]. An energy efficient rare earth synchronous motor would significantly help to reduce battery size, thus environmental impact, to achieve the same drive range and performance.

Both primary metal mining and production as well as recycling needs to be developed to meet the materials demands of an exponentially growing rare earth magnet market: for the foreseeable future, recycling alone can only meet a minor fraction of the growing materials demands (Figure 7).

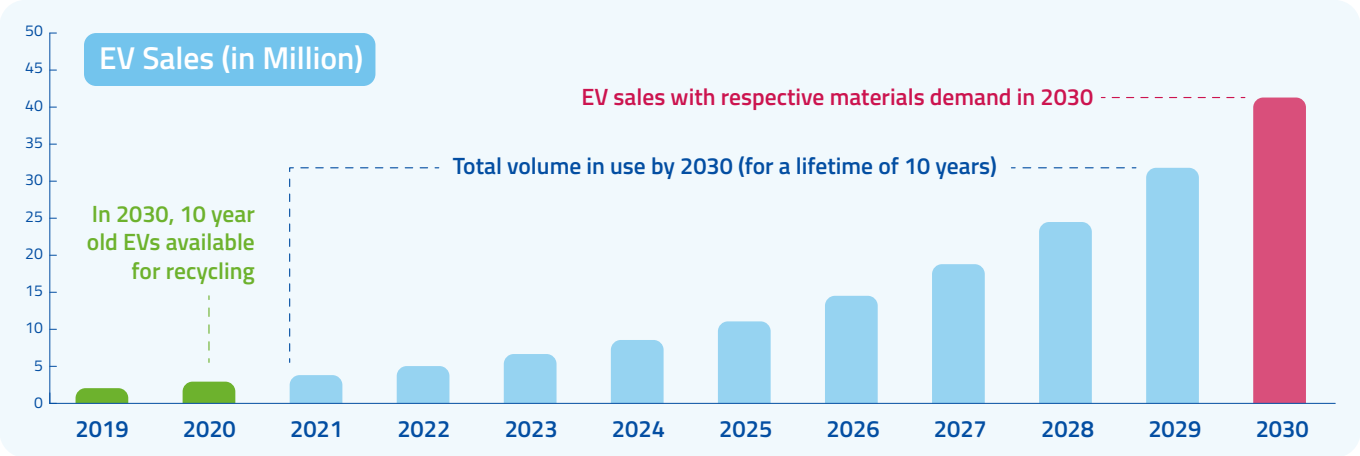


Fig. 7: The Electric Vehicle market is growing exponentially, which is why the recycling of any kind of EV material can only contribute a minor share to meeting growing materials demands. Assumptions: EV lifetime of 10 years; global car sales with a CAGR of 30% according to the Sustainable Development Scenario (SDS) of the International Energy Agency (IEA 2021). Own calculations after King 2021

[11] Agora Verkehrswende 2019

95% of EVs use rare earth permanent magnet motors due to their high energy efficiency which translates into longer driving range.

Strategic Action Areas

Through EIT RawMaterials, the European Commission launched the ERMA Cluster on Rare Earth Magnets and Motors with the objectives of securing access to sustainably produced magnet rare earths at competitive costs from primary and recycled sources; of making Europe a global leader in rare earth metal production, alloys and magnets; and of sustaining and expanding Europe's global leadership in electric motor and generator design. During the stakeholder consultation process, four main recommendations were identified:

- European policy makers will need to create a level playing field: the cost of EU production within the segment of rare earth magnets and motors is intrinsically higher than the Chinese production cost, which is massively lowered by a set of direct and indirect state subsidies and lower social, labour, and environmental standards. Furthermore, trade facilitations, such as unilateral tax exemptions, discriminate against European and other global competitors.

- European OEMs will need to consider potential commitments to buy a significant percentage share of rare earth materials from European producers[12]. Downstream industry would gain a significant advantage in diversifying its supply chains, gaining access to local suppliers, maintaining local access to materials knowledge for future motor designs and test facilities as well as supporting the development of capacities for Circular Economy of electric motors.

- The EU will need to make sure that end-of-life products (and waste materials) containing rare earths stay in Europe by introducing and implementing regulations and standards that facilitate the reprocessing and recycling of products.

- There is a unique opportunity to trigger large private investments in the emerging European rare earths value chain by match funding. For this reason, the EU and its Member States should pull all financial levers including state aid, such as a dedicated Important Project of Common European Interest (IPCEI).

In the following section, the Rare Earth Magnets and Motors stakeholder group identified a set of 12 specific actions (Actions 1-12), which are related to these recommendations and clustered in 6 strategic action areas (Strategic Action Areas I - VI). As indicated below, most of the action items have a clear reference to the Critical Raw Materials Action Plan of the European Commission published in 2020[13].

[12] During the discussions in the Cluster meetings, some participants raised that a "significant percentage share" would represent a value of at least 15% of EU demand, in order to reach an economy of scale. In 2019, this would have represented a production of 2,000-3,000 t of Nd-Fe-B, which is likely to be the critical mass for a new high efficiency magnet plant to be competitive. Other Cluster members raised the point that this number would have to be substantiated further and linked to a specific timeline of developing such capacities.

[13] European Commission 2020a

I. Establish a secure supply of rare earth raw materials

The EU should strategically invest in the rare earths value chain and become world leader in the Circular Economy of rare earths. To enable this, improved intelligence in the rare earths magnets and motors value chain is required as a sound basis for decision making, that is, for political and industrial leaders, investors as well as for consumers. Many primary rare earth sources around the world have been identified and investigated over the past 10-15 years, but the results of such studies have been published in various locations and it is time consuming to try to compile key information about them on a comparable basis. Europe hosts several occurrences, some of which are currently being investigated. In particular, the quantity (resource and reserve tonnages) and quality (resource and reserve grades of individual REEs) of mineralisation, and the key technical and economic assumptions (e.g., processing recoveries, price and cost assumptions) are of critical importance when assessing primary rare earth sources. Under the current circumstances, public and private investors should consider the possibility of supply interruptions and price volatility. EU stakeholders should respond by building up stock, and state incentives should be considered to kick-off a Circular Economy of rare earths, to overcome the "chicken and egg situation" in which no large investment in magnet recycling will materialise unless there is a market for recycled magnets, whereas, at the same time, there is no market for recycled magnets unless there is major investment in the supply of the respective materials. At the same time, there is a need to reassess policy cohesion to promote primary rare earth production within the EU as a strategic goal, because recycling can only partly bridge the gap indicated by the forecasted demand increase (see Figure 7). Low impact rare earth extraction from existing mining by-products and tailings needs to be promoted as well as the establishment of cost-effective production facilities using raw materials from multiple sources.

Making it happen

Action 1: The EU should identify on a global level primary sources (mining) and secondary sources (recycling) of rare earth raw materials suitable for a supply into an EU value chain. [Timeline: Q1 2022]. Financial, environmental, and social sustainability, resilience of supply, as well as technical and economic feasibility of extraction should be considered, in order to enable an EU-based value chain to become fully competitive with the established industry. Member states should be encouraged to produce information of interest to attract exploration investments (from both primary sources and secondary sources, i.e., mine waste). A project database should be created that enables comparative studies in harmonised formats (UNFC and CRIRSCO standards). The EU should characterise the European rare earths and permanent magnet market and demand in tonnes per year (from raw materials to manufacturing and recycling).

Action 2: The EU should promote the diversification of raw materials supply for European industries through strategic trade partnerships with resource-rich countries. [Timeline 2021-2030]

Action 3: The EU should explore regulatory measures to incentivise exploration, mining, and a full rare earth Circular Economy, across the entire value chain [Timeline: Q1 2023]:

- **to develop a market for end-of-life magnets and to generate a contracted flow of magnets for recycling companies**. Existing waste directives and related legislation should be reassessed to develop measures that enforce the establishment of systems for the collection, extraction, and processing of magnets in Europe. Legislation that promotes the retention of End of Life (EOL) products containing rare earth permanent magnets in Europe should be considered (including processed EOL magnet scrap). The Commission should assess the feasibility of obliging OEMs that want to sell products in the EU to only buy magnets with a minimum amount of recycled rare earth metals content.

- **to promote exploration and mining using best available strategies and technologies that come with the lowest environmental impacts.** The EU should carry out an investigation that identifies inconsistencies and obstacles in the EU regulatory framework in order to reduce the institutional risks for investments that depend on the use of land and water. Member States should be encouraged to determine the fitness of their raw materials policies (incl. the framework of adequate community consultations), mining codes and incentives for exploration to address the strategic needs of materials for rare earth magnets and motors.

Reference to Critical Raw Materials Action 2, 9 & 10.

Creating a rare earth recycling facility

Our target is to recover all kinds of end-of-life magnets which contain rare earth elements and to produce separated rare earth oxides. We will produce raw materials from magnets of the same quality as the virgin material. It means we can recycle as much as we want without compromising on the quality.

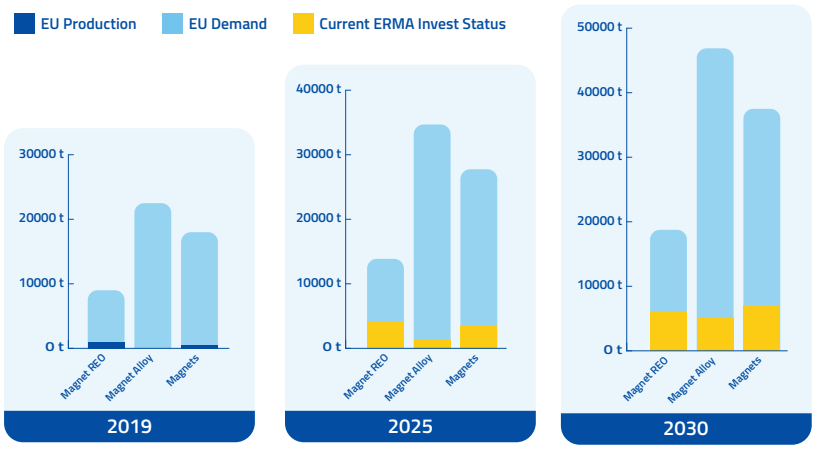
Frédéric Carencotte, CEO, Carester

II. Facilitate access to finance for rare earth projects across the value chain

The European Raw Materials Alliance (ERMA), established only 6 months after the new EU Industrial Strategy, has created a Raw Materials Investment Platform[14], which triggers the identification and realisation of new raw materials investment cases in Europe and in third countries with a European interest. ERMA has identified priority investment areas that include materials efficient motor designs, the recovery of rare earths from end-of-life magnets and processing waste, magnet manufacturing, rare earth refining, extraction of primary rare earth ores and recovery from mining waste. There is a need for early-stage financing to identify and develop possible mining operations. Both prefeasibility and definite feasibility studies require funding to establish proven resources for future mining.

So far, 14 specific investment proposals have been submitted from various different parts in Europe: France (magnet making and recycling), Germany (magnet making), Estonia (rare earths metallurgy and magnets), Belgium (recycling), Norway (mining), Sweden (mining), Finland (mining), Poland (separation), and Slovenia (magnet making). The overall investment needed for these projects is € 1.7 billion. The potential capacity increase along the rare earth value chain from now to 2030 would be substantial. For example, we could ramp up magnet production in Europe from 500 tonnes to 7,000 tonnes annually by 2030. About 20% of Europe's rare earth magnet needs could be sourced from the EU, significantly strengthening its strategic autonomy. Over the same period of time a minimum of 5,000 direct jobs would be created, and a multitude of indirect jobs in Europe's downstream industry would be saved; furthermore the competitiveness and autonomy of various European Industrial Ecosystems would be significantly strengthened.

The initial capital investments required to get an efficient, sustainable, and best available technology production up and running in Europe is substantially higher than what it is, or was, in China as most Chinese productions are already built. It is very clear that Chinese state-owned operations do not have to factor depreciation into their pricing. Thus, to realise the full investment potential of the Raw Materials Investment Platform, bridge financing capacities in the form of a Raw Materials Bridge Fund and the pooling of raw materials demands in the single market through a Raw Materials Investment Vehicle that invests into certified sustainable value chains are needed. An Important Project of Common European Interest (IPCEI) on Rare Earth Magnets and Motors should be initiated to facilitate larger scale investments. At least 4 EU Member States have indicated that they would have a strong interest in promoting such an IPCEI. The financing tools need to be established quickly to allow the anticipated materials production facilities to deliver on time, in order to avoid supply bottlenecks that would slow down the Green Transition.



EU demand versus ERMA target capacities in 2025 and 2030 as reflected by the investment cases submitted so far.

[14] See erma.eu

To put these figures into context, one of the scenarios described below could be envisaged:

- The EU strategy on offshore renewable energy proposes to increase Europe's offshore wind capacity from its current level of 12 GW to at least 73 GW by 2030, which corresponds to the installation of 7 GW per year[15]. Wind turbines contain up to 650 kg of permanent magnets per MW. Hence, 7,000 tonnes of magnet production per year would easily cover the magnet demand for the emerging offshore wind sector. Overall, EU wind energy is expected to grow from 180 GW today to 451 GW by 2030[16]. Wind turbines using larger amounts of permanent magnets are primarily installed in offshore windparks.

- Assuming the use of 1.5 kg of Nd-Fe-B per electric vehicle (EV) and an an EU market of about 7 million EVs by 2030, the EU could source 70 % of its rare earth magnet needs for EVs from domestic production[17].

Fig. 9: ERMA investment cases in the rare earth value chain identified so far are located in various European locations

[15] European Commission 2020b

[16] WindEurope 2021a

[17] IEA 2021; Marscheider-Weidemann et al. 2021

Making it happen

Action 4: In close collaboration with the Member States, the European Commission should create 3 tools to facilitate access to finance [Timeline: Q4 2022]:

- **A Raw Materials Bridge Fund**: a new financial instrument to secure bankability and de-risk projects in the volume of 150-200m EUR p.a. (issued as loans, equity, mixed forms together with EIB / EIF). Similar to the EIC Fund recently set up in Luxembourg; financing of projects up to 15m EUR.
- **A Raw Materials Investment Vehicle**: a new European, state-supported investment and procurement organisation acting as lead buyer and pooler of raw materials demand across European countries. Similar to the Japan Oil, Gas and Metals National Corporation (JOGMEC): direct investment or guarantor of private sector investments.
- **An IPCEI for Rare Earth Magnets & Motors.**

Reference to Critical Raw Materials Action 3 & 6.

Rare earth permanent magnets are used in speakers and microphones, particularly in mobile devices.

III. Sustainability: define standards and certification schemes for the making of sustainable rare earth magnets and motors

Taken for granted today for food products and textiles, Europeans want to know what they consume. When purchasing a mobile phone, you also consume natural resources. Sustainability does not come for free. Rare earth extraction and processing come with a footprint. Europeans should be in the position to determine the scale of that footprint by choosing between products based on transparent supply chains. There is also a need for getting a clear understanding of the cost structures in the rare earth value chain to be able to justify an EU price premium (if necessary) and to better identify innovation needs. In addition, sustainability criteria for the rare earth value chain need to be defined, including schemes to certify sustainability accordingly. Instruments to increase transparency in the rare earth value chain worldwide should be developed and installed. Tracking rare earth materials would permit the systematic development of intelligence on the environmental and social footprints of specific rare earth value chains. By law, downstream industries that use rare earth magnets and want to sell their products in Europe will have to comply with and factor into their cost and pricing schemes these sustainability standards.

Making it happen

Action 5: The EU should establish an EU sustainability standard and certification scheme. [Timeline: Q3 2022]
The European Commission and industrial representatives need to align on a framework in establishing sustainability in the rare earth value chain. This involves leaders from the downstream industry, particularly the automotive and machine industries, and would include the analysis of existing schemes by a dedicated and EU-financed taskforce. EU delegates should participate in and become active members of the ISO/TC298 Rare Earth group, the leading standardisation initiative in rare earths worldwide today. The Commission should have an interest in using this platform to push the sustainability agenda for rare earths at the global level. Traceability and independent auditing of standards will be hugely important.

Action 6: Following the example of the latest battery regulations, the EU should launch a study on the key determining factors for the production of sustainable rare earth magnets. [Timeline: Q1 2023]
Based on that study, the EU should:

- identify the possibility of developing a standardised EU life cycle assessment scheme for rare earth magnets, focusing on a "Product Environmental Footprint" pilot project in close cooperation with industry.
- put forward rare earth magnet motor sustainability 'design and use' requirements for all motors to comply with when placed on the EU market (comprises a suitability assessment of different regulatory instruments such as the Ecodesign Directive and the Energy Labelling Regulation).
- monitor the coherence of different regulatory instruments (e.g., REACH, Waste Framework Directive) to ensure smooth functioning of the internal market for rare earth magnets and motors, end-of-life-magnets and materials obtained from recycled motors.

Action 7: In line with the Sustainable Corporate Governance Directive, the EU should promote ethical sourcing and transparency in the value chain by enforcing the respective regulation. [Timeline: Q3 2025] OEMs should track their supply chain and provide certified information on environmental and social standards in the production of rare earth magnets and motors. Until 2025, this approach should be facilitated via incentives, for instance, by establishing self-certifying blockchain systems for rare earths tracing, labelling, and sustainability assessment.

Reference to Critical Raw Materials Action 3,10.

IV. Competitiveness: create a level playing field with global competitors

The European Commission should support European rare earth materials producers to be able to compete with Chinese competitors on a level playing field. There is a need to provide incentives for magnet producers for each magnet produced and sold in the EU. Otherwise, no private company would start to invest and run a profitable business in the mass market production of magnets in Europe. The European Commission should support the creation of a market for "made in the EU" rare earth magnets among EU magnet customers. The Commission should stress the importance of balancing sustainability with corporate profitability and incentivise magnet users to procure a certain percentage share of magnets locally. Offtake by major European downstream industries is vital for the long-term survival of an EU rare earth materials industry.

Making it happen

Action 8: In close collaboration with the Member States, the European Commission should explore measures to balance a fair level of reciprocity regarding state subsidies and the externalisation of social and environmental costs in rare earth metal mining and production, magnet making, and recycling. [Timeline Q1 2023]

- Find a solution to help EU rare earth magnet manufacturers to procure raw materials (oxides, metals, alloys) under same cost conditions as Chinese competitors; today, this is equal to 13% of the market price of rare earth raw materials. Incentivise industrial magnet consumers (automotive, energy etc.) to procure rare earth magnets made in EU, that is, via taxation incentives with respect to capital gains tax or corporate tax.
- Create a tax shield for the investments in these sectors that will allow companies not to pay revenue tax before recovering their investment.
- Explore how to best apply the Carbon Border Adjustment Mechanism to the rare earth supply chain, given the lack of transparency and standards in the global rare earth business; consider also social and governance standards.

- Establish low-cost electricity zones, based on renewable energy to support energy-intensive industrial processes such as electrolytic production of rare earth metals and master alloys. Consider a substantial reduction in taxes on electricity.
- Define a mandatory minimum proportion of locally sourced rare earth material for the EU defence industry.

Reference to Critical Raw Materials Action 2 & 5.

V. Raise awareness of the importance of rare earths, that respective materials can be produced sustainably, and that they are needed to design clean tech

Rare earths are a key to engineering the most energy efficient and compact devices in various sectors and they can be produced and acquired in a sustainable way. Sustainability, however, does not come for free. It has an intrinsic value. There is a need to communicate and make society aware of the challenges and opportunities that come with rare earths. Education on the subject should be targeted at various levels of society, that is, in the wider society as well as towards political and industrial decision makers. In companies, product designers and procurement people need to be made aware of the business potentials of rare earths. In higher education, rare earth metal mining and production as well as materials design needs and recycling need to be promoted in respective curricula.

Making it happen

Action 9: The European Commission should elaborate a communication strategy addressing all stakeholders and society in general. This strategy would include [Timeline Q1 2024]

- The pooling of all existing activities undertaken by European research and education projects, associations and industry partners, governments and NGOs under the umbrella of ERMA - to set up a mapping of existing activities
- The creation of ERMA material and events (print, online, showcases, roadshows etc.) to stress the importance and criticality of rare earths, show the benefits and positive impact of research, innovation activities and greener (localised) production in building in a viable, sustainable circular economy for rare earths
- The continuous support of a rare earth expert group that would consult political and industrial decision makers and would help to raise awareness. The ERMA Cluster Rare Earth Magnets and Motors would represent a good starting point for this group.
- Creation of an author/publisher network for press releases on the European/national/regional level of EU member states to support ERMA activities

- Joining of all existing activities undertaken by European research and education projects, associations and industry partners

Reference to Critical Raw Materials Action 8

VI. Promote Europe's innovation capacity in the rare earths value chain

Rare earth elements have specific physical properties (particularly, magnetic and optical) that have a great exploitation potential for future technology that will enable us to confront major societal challenges, first and foremost climate change. The EU Framework Programmes for research and innovation should continue to incentivise efforts to better understand rare earths extraction, processing, recycling, and materials design. The shrinking EU academic community in rare earths should be supported via respective R&D&I calls for proposals and dedicated researcher mobility programmes. The establishment of preindustrial pilot lines to upscale rare earth technology and advanced materials production should help to transfer ideas to market more rapidly. Beyond developing its short- and medium-term innovation capacity, Europe should continuously invest in research and development of new rare earth processing technologies, magnetic materials, and applications. Materials science and engineering focusing on the identification of new magnetic materials and motor designs should consider the availability limitations given by nature, not those defined by man: light rare earths, for example, are highly abundant in the earth's crusts and occur all around the globe. Excluding them from materials and product designers' repertoires would artificially limit innovation capacity. Innovation in materials and processing must be combined with innovation in optimising rotor geometries of traction motors to increase motor efficiency.

Making it happen

Action 10: The EU should establish a European Rare Earth Research Factory [Timeline Q4 2024]: a versatile technology platform that enables the manufacturing and testing of new processes and materials on the industrial pilot scale. This platform should be connected to the (few) existing labs, pilot lines, and testbeds in a digital manner in order to facilitate a pan-European collaborative approach as well as confidential, case-by-case research.

Action 11: The EU should establish a researcher mobility programme to better enable scientists and engineers across Europe to share experience in rare earths. [Timeline: Q2 2023]

Action 12: The European Commission should consider the following R&D topics for the Horizon Europe framework programme [Timeline 2021-2027]:

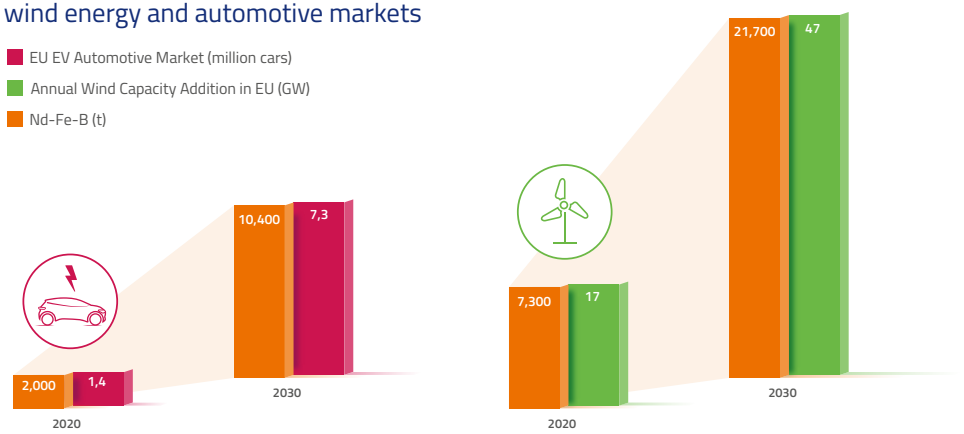
- Novel, cost-efficient rare earths extraction and processing routes (sampling, characterisation, beneficiation, separation, metal making, alloying); consider unconventional rare earth sources, like low-grade ores, non-ferrous metals beneficiation tailings and iron ore tailings, metallurgical waste apatite. Assessment of the status and potential suitability of disruptive technologies for rare earth separation; consider scaling effects, CAPEX and OPEX costs, and the efficiency of processes.

- Identification of novel magnetic phases and designing out of them a stable bulk magnet.
- New magnetic materials and applications for energy savings, including magnetocaloric applications.
- Additive manufacturing of permanent magnets: development of suitable powders and selective laser melting/sintering processes for additive manufacturing of permanent magnets.
- Advances in magnet microstructure design.
- Significant reduction or complete elimination of heavy rare earth elements (50 - 100 %) compared to current (Nd,Dy)-Fe-B.
- Development of prototype magnets and testing of them in demonstrator motors with regard to their performance in a relevant application.
- New resource and energy efficient electric motor designs.
- Significant reduction of environmental footprint and improvement of energy sustainability in rare earth value chains.
- Recycling of EOL products containing rare earth magnets with a particular focus on cost efficient dismantling lines.
- Product designs that facilitate the reuse and recycling of rare earth magnets.

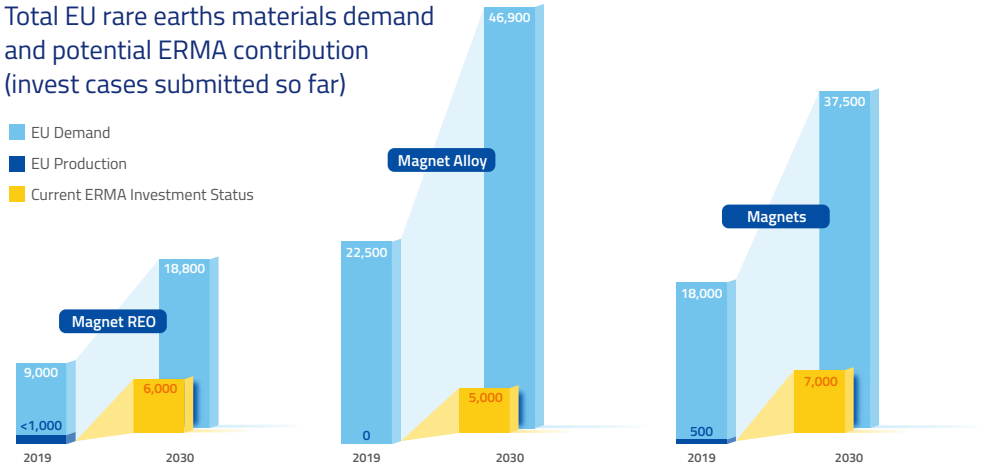
Reference to Critical Raw Materials Action 3, 6, 8 & 10.

EU MARKET NEEDS AND ERMA ACTIONS

EU rare earth magnet demand in the emerging wind energy and automotive markets



Total EU rare earths materials demand and potential ERMA contribution (invest cases submitted so far)



2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
A1: Suitable rare earth sources for EU identified									
A2: Establish global raw materials trade partnerships									
A3: EU rare earth circular economy incentivised									
A4: Access to finance secured for invest cases (disruptive state aid + private funding)									
A5: EU standards and certification scheme established									
A6: Study defining sustainable rare earth magnets completed									
A7: Transparent supply chains established to promote ethical sourcing									
A8: Level playing field with global competitors created, in terms of market conditions									
A9: Dedicated programme to raise awareness on the challenges and opportunities related to REE established									
A10: EU Rare Earth Research Factory installed									
A11: A researcher mobility programme related to REE established									
A12: Consider rare earth related R&D topics in Horizon Europe									
	Investment decisions for rare earth projects needed								
	Installation time of a major rare earth processing, magnet manufacturing, and recycling plant is 2-5 years								
	Installation of primary extraction of rare earths from new or existing mining projects (by-product) is 8-15 years								

IMPACTS

1. OEMs have access to a diversified and sustainable rare earths magnets supply chain – with at least 20% EU share
2. Increase in competition, thus innovation along the value chain driven by an active European research and innovation community
3. EU jobs and growth are created from (urban) mine to magnet and motor
4. The EU becomes a global leader in the Circular Economy of rare earth products
5. Rare earths come with standards and transparent supply chains

Assumptions: The EU electric vehicle (EV) market would follow the "Stated Policy Scenario" of the International Energy Agency (IEA 2021), which fits closely to the EU Green deal "Fit for 55" targets (European Commission 2021). In addition, it was assumed that 95 % of EVs would use permanent magnet motors with an average of 1.5 kg of Nd-Fe-B per car (the shares of permanent magnet traction e-motors may decrease until 2030, however, the magnet mass in EVs using this motor technology will most likely increase; increase; c.f. Roskill 2018; Bobba et al. 2020; Marscheider-Weidemann et al. 2021; IEA 2021). The EU wind energy market would follow the High-Demand-Scenario (HDS) forecast of the Joint Research Center (Carrara et al. 2021), which comes close to the "Fit for 55" targets defined by the European Commission (European Commission 2021); the modelled scenario provides specific tonnages of Nd-Fe-B demand by the emerging EU wind energy sector, including onshore and offshore wind energy installations. Current ERMA invest status: The projected capacities refer to the investment cases submitted to ERMA so far (Aug 2021). There is a much larger number of specific rare earths related projects that would increase ERMA impact significantly.

References

Adamas Intelligence 2020, Rare earth magnet market outlook to 2030.

Agora Verkehrswende 2019, Klimabilanz von Elektroautos. Einflussfaktoren und Verbesserungspotenzial. <https://www.agora-verkehrswende.de/fileadmin/Projekte/2018/Klimabilanz_von_Elektroautos/Agora-Verkehrswende_22_Klimabilanz-von-Elektroautos_WEB.pdf>

Arshi, P., Vahidi, E. and Zhao, F., 2018, Behind the scenes of clean energy: The environmental footprint of rare earth products, ACS Sustainable Energy and Engineering 2018, 6, 3311-3320. <https://doi.org/10.1021/acssuschemeng.7b03484>

Bobba, S., Carrara, S., Huisman, J., Mathieux, F., Pavel, C., Critical raw materials for strategic technologies and sectors in the EU. A Foresight Study < https://op.europa.eu/en/publication-detail/-/publication/8e167f11-077c-11eb-a511-01aa75ed71a1/language-en >

Carrara, S., Alves Dias, P., Plazzotta, B., Pavel, C., 2020, Raw materials demand for wind and solar PV technologies in the transition towards a decarbonised energy system, JRC. <https://publications.jrc.ec.europa.eu/repository/handle/JRC119941>

Chinese Customs data 2021: < http://43.248.49.97/indexEn >

European Commission 2020a, Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability, COM(2020) 474 final, Brussels, 03.09.2020. <https://ec.europa.eu/docsroom/documents/42849>

European Commission 2020b, An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future. COM(2020) 741 final, Brussels, 19.11.2020. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2020%3A741%3AFIN&qid=1605792629666>

European Commission 2021. European Green Deal: Commission proposes transformation of EU economy and society to meet climate ambitions. <https://ec.europa.eu/commission/presscorner/detail/en/IP_21_3541>

Eurostat: < https://ec.europa.eu/eurostat/de/ >

IEA 2021, The role of critical minerals in clean energy transitions, World Energy Outlook Special Report. International Energy Agency.

King, A. 2021, presentation at the 26th International Workshop on Rare Earth and Future Permanent Magnets and Their Applications (REPM2021), 07-10 June 2021.

Marscheider-Weidemann, F., Langkau, S., Eberling, E., Erdmann, L., Haendel, M., Krail, M., Loibl, A., Neef, C., Neuwirth, M., Rostek, L., Shirinzadeh, S., Stijepic, D. and Espinoza, L.T., 2021, Rohstoffe für Zukunftstechnologien 2021. DERA Rohstoffinformationen 50. <https://www.deutsche-rohstoffagentur.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen/rohstoffinformationen-50.pdf?__blob=publicationFile&v=3>

Monfared, B., Furberg, R. and Palm, B., 2014, Magnetic vs. vapor-compression household refrigerators: A preliminary comparative life cycle assessment, International Journal of Refrigeration, 42, 69-76. <http://dx.doi.org/10.1016/j.ijrefrig.2014.02.013>

Peteves, S., 2017, Materials' supply chain bottlenecks in the course of the EU energy transition, JRC, WORLD RESOURCES FORUM 2017.

REIA 2021, Rare Earth Industry Association, Consolidated reports < https://www.global-reia.org >

Roskill 2018, Rare Earths: Global Industry, Markets and Outlook, 18th ed.

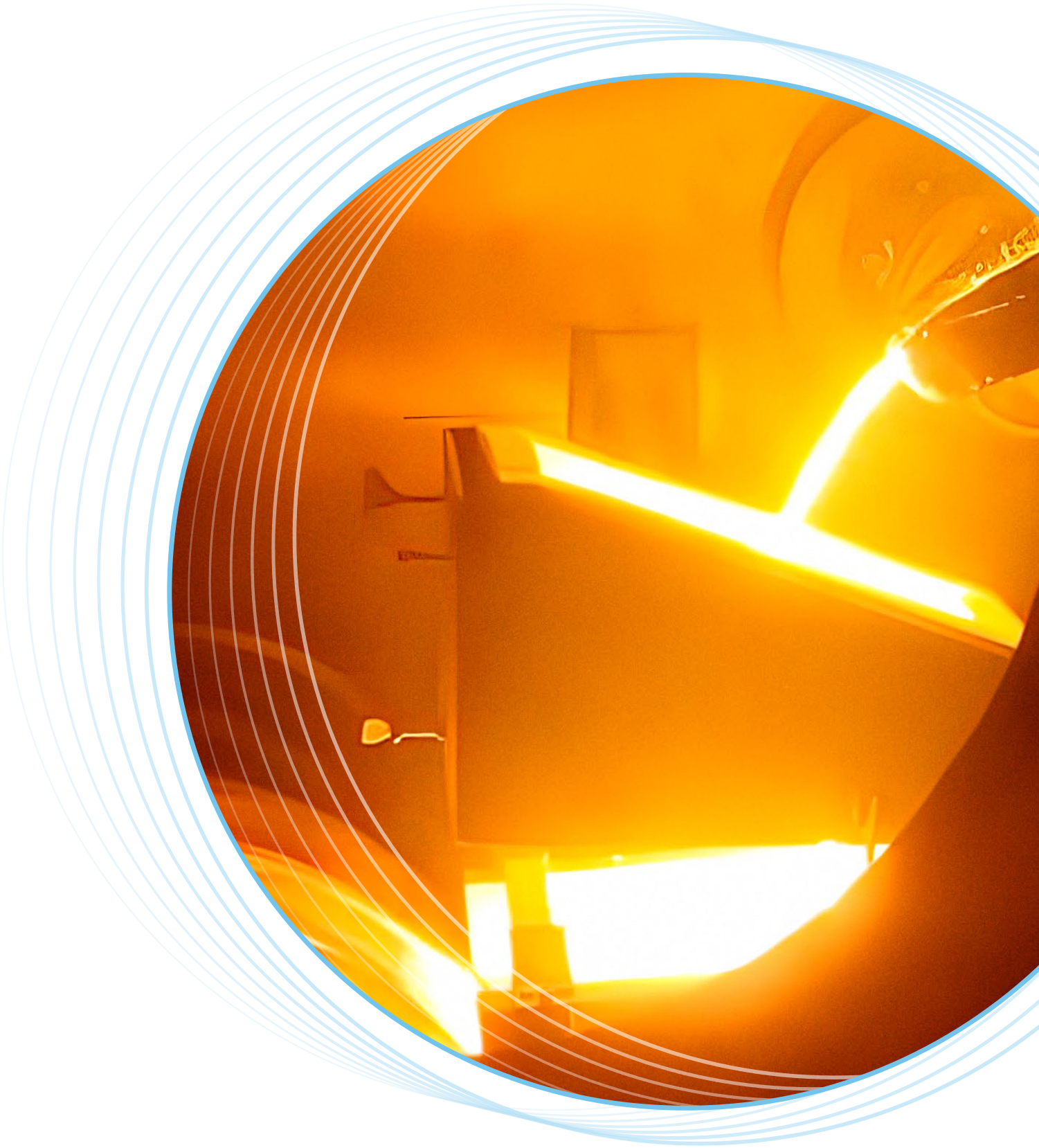
Sprecher, B., Xiao, Y., Walton, A., Speight, J., Harris, R., Klejin, R., Visser, G. and Kramer, J., 2014, Life Cycle Inventory of the production of rare earths and the subsequent production of NdFeB rare earth permanent magnets, Environmental Science and Technology 2014, 48, 3951-3958. <https://doi.org/10.1021/es404596q>

USGS. United States Geological Survey, Rare Earths Statistics and Information. <https://www.usgs.gov/centers/nmic/rare-earths-statistics-and-information>

WindEurope 2021a, It's official: The EU Commission wants 30 GW a year of new wind up to 2030. Press release 14 Jul 2021 <https://windeurope.org/newsroom/press-releases/its-official-the-eu-commission-wants-30-gw-of-new-wind-a-year-up-to-2030/>

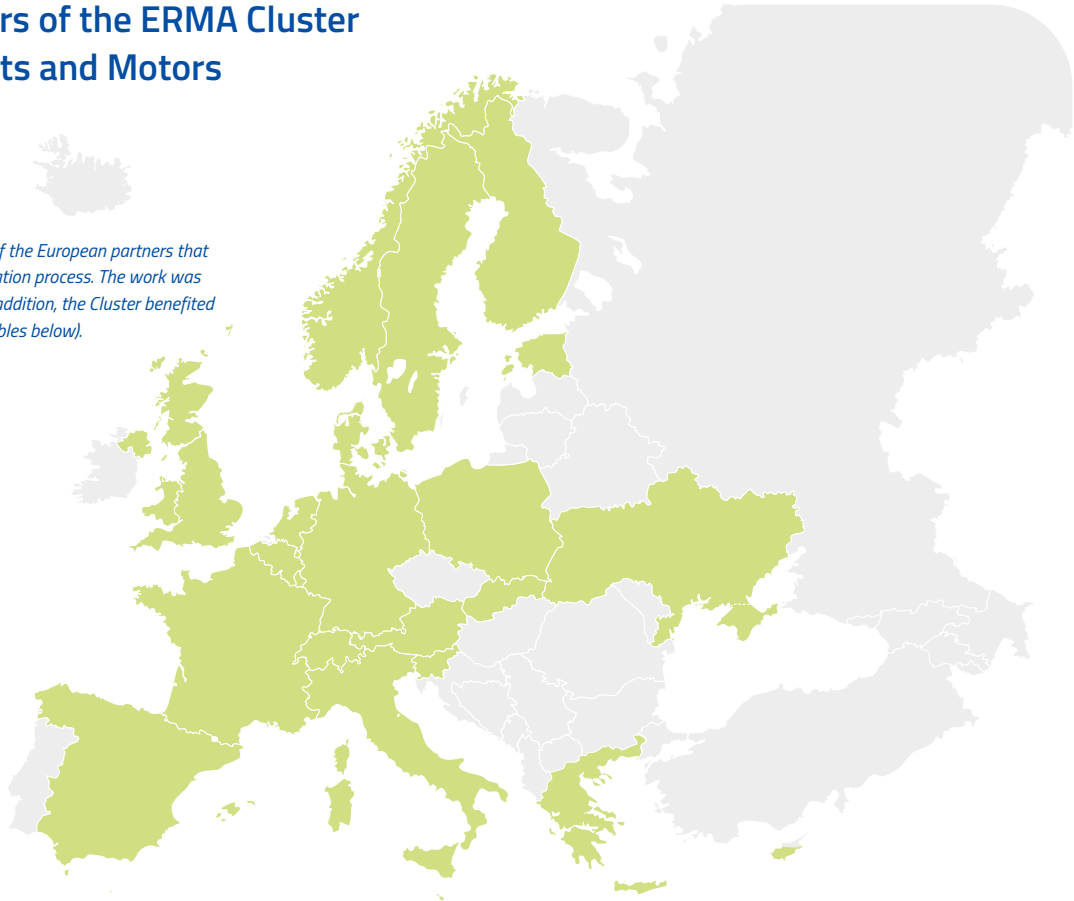
WindEurope 2021b, Setting the course towards climate neutrality. WindEurope position on the Fit for 55 package. <https://windeurope.org/wp-content/uploads/files/policy/position-papers/20210317-WindEurope-Fit-for-55-position-paper.pdf>

Wulf et al. 2017, Lessons learned from a Life Cycle Sustainability Assessment of rare earth permanent magnets, Journal of Industrial Ecology 21, 6, 1578-1590. <https://doi.org/10.1111/jiec.12575>



Stripcasting of Nd-Fe-B alloys. The alloys are cast onto a spinning copper wheel to achieve rapid cooling rates which enables the creation of fine grained microstructure. Source CEA Grenoble

Appendix. Members of the ERMA Cluster Rare Earth Magnets and Motors



Map indicating the countries of origin of the European partners that contributed to the stakeholder consultation process. The work was organisued in dedicated taskforces. In addition, the Cluster benefited from international participation (see tables below).

INDUSTRY, FINANCIAL ORGANISATIONS, AND BUSINESS CONSULTANCY

COUNTRY	ORGANISATION
Austria	MinPol GmbH - Agency for International Minerals Policy
Belgium	Comet Traitements SA
Belgium	CRM Group
Belgium	EUROALLIAGES
Belgium	Eurometaux - European Association of Metals
Belgium	intraw - International Raw Materials Observatory aisbl.
Belgium	PERC - PAN-EUROPEAN RESERVES & RESOURCES REPORTING COMMITTEE
Belgium	REIA - Rare Earth Industry Association
Belgium	Solvay S.A.
Belgium	WindEurope asbl
Denmark	Grundfos Holding A/S

INDUSTRY, FINANCIAL ORGANISATIONS, AND BUSINESS CONSULTANCY

COUNTRY	ORGANISATION
Estonia	Neo Performance Materials Inc.
Finland	Metso Outotec Oyj
Finland	Rovjok Oy
France	Arelec SAS
France	Carester
France	CATURA Geoprojects
France	EPMA - European Powder Metallurgy Association
France	Iumtek
France	MagREEsource - The Green Rare Earth Magnet Company
France	Nidec - Corporations
France	Nidec-PSA emotors SAS
France	Orano SA
France	Polymeris
France	Rare Earth Advisory
France	Renault SA
France	SUEZ Groupe SAS
France	Valeo
France	Stellantis N.V.
Germany	Aurubis AG
Germany	Brose Fahrzeugteile SE & Co. Kommanditgesellschaft
Germany	CRONIMET Holding GmbH
Germany	Deutsche Gesellschaft für Wertpapieranalyse GmbH (DGWA)
Germany	DMT GmbH & Co. KG
Germany	Dorfner Anzaplan GmbH
Germany	G.E.O.S. Ingenieurgesellschaft mbH
Germany	Institut für Energietechnik GmbH
Germany	Institut für Energietechnik GmbH
Germany	J&C Bachmann GmbH
Germany	RockLink GmbH
Germany	SBI Sons of Bavaria Investment AG
Germany	Siemens AG
Germany	Siemens Gamesa Renewable Energy
Germany	VAC - VACUUMSCHMELZE GmbH & Co. KG
Germany	VDA - Verband der Automobilindustrie e.V.
Germany	WITTENSTEIN SE

INDUSTRY, FINANCIAL ORGANISATIONS, AND BUSINESS CONSULTANCY

COUNTRY	ORGANISATION
Greece	Ecoresources IKE
Italy	Adaci Nazionale
Italy	B&C Speakers s.p.a
Italy	ERION
Italy	Fiat Chrysler Automobiles N.V.
Italy	La Mia Energia s.c.ar.l
Italy	MBN nanomaterialia S.p.A.
Italy	Stam srl
Italy	TREE srl
Luxembourg	Eco Connections Sárl
Netherlands	Circularise
Netherlands	TNO - Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek
Norway	AEC - Arctic Economic Council
Norway	Norne Securities AS
Norway	Rare Earths Norway AS
Norway	REE Minerals Holding AS
Norway	REETec AS
Poland	Mkango Polska
Slovakia	ekolive s.r.o.
Slovenia	Magneti Ljubljana
Spain	Atlantic Copper S.A.
Spain	CONFEDEM
Spain	INGENIERÍA MAGNÉTICA APLICADA, S.L.U.
Spain	INNCEINNMAT S.L.
Spain	Quantum Minería, S.L.
Sweden	GREENNA Mineral AB
Sweden	LKAB
Switzerland	Gaiffi International GmbH
Switzerland	MTO - Nornickel group
Switzerland	The Swatch Group Research and Development Ltd
United Kingdom	HyProMag Ltd
United Kingdom	Less Common Metals Ltd
United Kingdom	Pensana
United Kingdom	Resource 500 Group Ltd

GOVERNMENTAL ORGANISATIONS

COUNTRY	ORGANISATION
Denmark	GEUS - Geological Survey of Denmark and Greenland
France	BRGM - Bureau de recherches géologiques et miniéres
Netherlands	RVO - Rijksdienst voor Ondernemend Nederland (Netherlands Enterprise Agency)
Poland	Ministry of Climate and Environment, Poland
Sweden	SGU - Geological Survey of Sweden
Ukraine	State Service for Geology and Subsoil Use of Ukraine

UNIVERSITIES AND RESEARCH INSTITUTES

COUNTRY	ORGANISATION
Austria	Montanuniversität Leoben
Belgium	VITO - Vlaamse Instelling voor Technologisch Onderzoek
Finland	LUT University
France	CEA - Commissariat à l'énergie atomique et aux énergies alternatives
France	CNRS Institut Néel
France	Université de Lorraine
Germany	Aalen University
Germany	Fraunhofer Institut für Silicatforschung ISC
Germany	Fraunhofer-Einrichtung für Werkstoffkreisläufe und Ressourcenstrategie IWKS
Germany	HZDR - Helmholtz Zentrum Dresden Rossendorf
Germany	Pforzheim University
Germany	TU Bergakademie Freiberg
Germany	TU Darmstadt and Fraunhofer IWKS
Italy	ENEA - Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile
Italy	FBK - Fondazione Bruno Kessler
Italy	University of Milan Bicocca
Italy	University of Torino
Netherlands	TU Delft
Norway	SINTEF - Stiftelsen for industriell og teknisk forskning
Poland	IATI - Institute of Non Ferrous Metals
Poland	KGHM CUPRUM Sp. z.o.o. – Research and Development Centre
Slovenia	GEOSZ - Geological Survey of Slovenia
Slovenia	JSI - Jožef Stefan Institute

UNIVERSITIES AND RESEARCH INSTITUTES

COUNTRY	ORGANISATION
Spain	CEIT - Centro de Estudios e Investigaciones Técnicas
Spain	CETIM - Centro Tecnológico de Investigación Multisectorial
Spain	IMDEA Nanoscience Institute
Spain	Tecnalia

INTERNATIONAL PARTICIPATION

INDUSTRY, FINANCIAL ORGANISATIONS

COUNTRY	ORGANISATION
Australia	Arafura Resources Ltd.
Australia	Hastings Technology Metals Ltd.
Australia	Ionic Rare Earths Limited
Australia	Lynas Corporation
Canada	Torngat Metals Ltd.
Canada	Trinity Management Ltd.
Canada	WT&C Innovates Inc.
Greenland	Tanbreez
India	Ziptrax CleanTech Pvt Ltd
Japan	Shin-Etsu Chemical Co. Ltd
United States	AMV - Amerocap Mining Ventures LLC
United States	Controlled Thermal Resources US Inc.
United States	Materion Corporation
United States	Refacture Inc.
United States	USA Rare Earth LLC