PASSENGER
FOR SUSTAINABLE AND EFFICIENT RE-FREE MAGNETS

Pilot Action for Securing a Sustainable European Next Generation of Efficient RE-free magnets

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Strategic Intelligence Bulletins aim to enrich strategic and managerial decisions and to engage stakeholders based on partners networks.

CIRCULAR ECONOMY IN PERMANENT MAGNETS

The world is currently facing the long-term challenge of aligning the economy with future realities and focusing efforts on appropriate reforms and investments. One of the most crucial areas of focus for the EU government is the development of a "green" economy. In March 2020, the European Commission adopted a circular economy action plan (CEAP) (Figure 1), which is one of the key building blocks of the European Green Deal, Europe's new agenda for sustainable growth. The transformation of a linear economy into a circular economy is associated with numerous social, economic, and environmental benefits. It is, therefore, a possible response to modern challenges in the EU. As numerous studies have shown, circular economic activity can, for example, decouple economic growth from the increased demand for primary raw materials, reduce existing environmental impacts and create new jobs. However, the analysis of the European Commission of critical supply chains and key technologies reveals a high level of EU dependence on foreign raw materials needed to move towards green and digital technologies. Meanwhile, REEs are important raw materials for strategic EU industries. The European Union intends to diversify the primary rare earth materials supplies and establish a viable recycling chain, including domestic end-of-life magnets. Permanent magnets (PM) are critical components in wind turbines and, especially, in electric vehicles. Modern cars are equipped with electromagnetic devices, – such as sensors and electric motors, which rely on rare earth magnets..

Figure 1. CEAP logo, Source: European Commission

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CIRCULAR ECONOMY IN THE AUTOMOTIVE INDUSTRY

The circular economy concept is gaining traction in the automotive industry, which is associated with two major waste streams. The first is the colossal greenhouse gas emissions from cars with internal combustion engines. The second mainstream is associated with the waste generated by under utilising the life cycle of a car. The development of the circular economy presents several opportunities for the automotive industry, including the potential for substantial reductions in vehicle emissions during their use. Renault, for example, was the first automaker to commit to implementing the concept of a circular economy by establishing Renault Environment in 2008. This subsidiary controls the flow of automotive waste and parts. As a result, its vehicles are 85% recyclable and contain 95% end-of-life parts. The company currently recovers secondary raw materials from end-of-life vehicles (ELVs) for reuse in the production of new vehicles, and spare parts, which are also used to repair vehicles in their post-sales network. In the past five years, 350000 ELVs were recycled and Renault's network of 300 ELV centres was compliant with Renault Group.

According to Eurostat, since 2015 EU Member States have been required to achieve reuse and recycling rates of ≥ 85% and reuse and recovery rates of ≥ 95% on an average weight per vehicle basis. In 2019, the reuse and recycling rate for end-of-life vehicles in the EU was 89.6%, an increase of 2.3% from 2018 (87.3%) and 1.7% from 2017 (87.9%) (Figure 2).

	2018 % rate	2019 % rate	% difference	2018 tonnage	2019 tonnage
Austria	86.2	87.3	1.1	52724	46757
Belgium	93.5	92.9	-0.9	165978	156823
Bulgaria	94.8	95.8	1	97697	84660
Croatia	97.4	96.3	-1.1	29824	43998
Cyprus	89.8	88.7	-1.1	6525	8804
Czechia	95.5	93.3	-2.2	163673	173470
Denmark	89.9	94.6	4.7	122892	135681
Estonia	87.1	87.6	0.5	19168	16533
Finland	82.8	84.7	1.9	107035	95824
France	86.9	87.1	0.2	1493604	1569575
Germany	87.1	86.9	-0.2	518870	435732
Greece	98.7	69.7	-29	45357	33908
Hungary	95.1	94.4	-0.7	15137	20637
Iceland	- -	- -	- -	- -	- -
Ireland	86.4	87.4	1	148785	138501
Italy	82.6	84.2	1.6	992864	1088653
Latvia	96	88.9	-7.1	10622	9779
Liechtenstein	74.5	74.7	0.2	187	159
Lithuania	92.4	93.5	1.1	25473	28131
Luxembourg	94.1	96.7	2.6	3210	3355
Malta	81	- -	- -	6014	- -
Netherlands	87.1	87.2	0.1	194415	162828
Norway	87.7	85.2	-2.5	164944	162575
Poland	93.4	118.8	25.4	515000	660376
Portugal	86.1	88.2	2.1	89743	99049
Romania	85.2	- -	- -	56536	- -
Slovakia	95.1	95.5	0.4	36158	50156
Slovenia	97.6	89.5	-8.1	11651	13124
Spain	85.9	86	0.1	737686	817003

Figure 2. Total recycling and reuse rate of end-of-life vehicles, 2008–2019 (% and tonnage of the weight of vehicles). Source: Eurostat.

Nevertheless, there is still room for improvement. In electric vehicle manufacturing, dismantling robots are used to dismantle the vehicle. The EU project ETN-Demeter (European Training Network for the Design and Processing of Rare Earth Motors and Permanent Magnet Generators in Hybrid and All-Electric Vehicles), addresses the issue of sustainable design. For example, they are designing electric motors from which the magnets can be easily removed for processing rare earth metals. The EU ExpSkills-

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REM project, on the other hand, is developing a training course for professionals in the field of REE magnets and motors. The course covers all critical aspects in the REE value chain, providing education and training to enhance the skills and preparedness for jobs in the e-mobility automotive sector in the EU. ExpSkills-REE project activities are fully in line with the Strategic Agenda 2021-2027 of the European Institute of Innovation and Technology - Raw Materials (EIT RM).

PERMANENT MAGNET APPLICATIONS OVERVIEW

Rare earth magnets are strong permanent magnets made from rare earth alloys. The main types of rare earth magnets that are presently on the market are samarium cobalt and neodymium magnets. Hard magnetic materials based on rare earth metals have higher magnetic parameters compared to cast and ferrite materials. This ensures reducing the weight and dimensions of finished products while maintaining their quality characteristics.

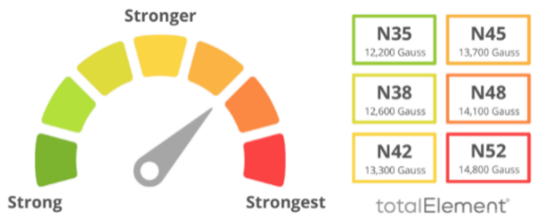

Figure 3. The magnet ws N rating. Source: Toral Element

Samarium cobalt magnets belong to the rare earth family of magnets with a maximum energy product range from 15 MGOe to 32 MGOe, and from neodymium up to 52 MGOe (Figure 3). Samarium-cobalt magnets consist of praseodymium, cerium, gadolinium, iron, copper and zirconium. They can maintain their magnetic properties at high temperatures while being highly resistant to oxidation. Due to their lower magnetic field strength and high manufacturing cost, they are less commonly used than other rare earth magnets. They are currently used in high-quality electric motors (Figure 4), turbomachinery, and in many applications where performance must be matched to temperature change.

Neodymium magnets, on the other hand, are the most affordable and strong type of rare earth magnets. They are tetragonal crystal structures made from alloys of neodymium, boron, and iron. The technology used to produce REE magnets consists of sintering powders in the presence of a liquid phase or casting. The liquid phase is created by extracting REE in excess. The prospects for the use of this kind of alloys are great[1]. The main disadvantages of alloys are poor mechanical properties (high brittleness), the use of scarce materials and high cost. The key areas of application of Nd-Fe-B rare-earth magnets include

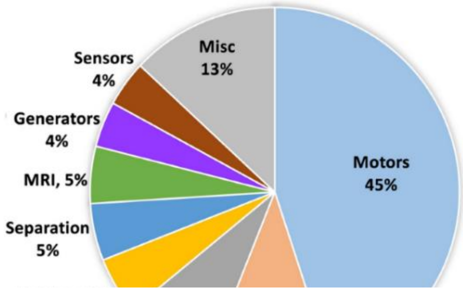

Figure 4. Applications of permanent magnets by market ($) share in 2019. Source: Jun Cui, John Ormerod at al, 2022.

[1] Alloys for Aeronautic Applications: State of the Art and Perspectives. Antonio Gloria et al.

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hybrid cars and electric cars. Intensive work on environmentally friendly transport is being carried out by European and global industry representatives. Thus, the American auto giant General Motors announced that it intends to stop selling petrol and diesel models by 2035. Audi plans to stop producing such cars by 2033. Many other automotive multinationals have voiced similar plans for electric mobility. Following Jun Cui, John Ormerod at al, 2022 - another growing area of demand is the production of generators and electric motors running on environmentally friendly fuel. In general, the major advantages of using permanent magnets can be formulated as follows:

- *Automotive industry.* Every modern car is equipped with electromagnetic devices, which include rare-earth magnets - sensors, electric motors, etc
- *Electronics.* The uniform magnetic field of materials ensures the proper functioningof high-precision electronic devices, including medical devices and mobile phones.
- *Computer technology.* The importance of the magnetic properties of products can be assessed on one component of the computer - a hard disk, the design and principle of which are entirely based on the use of magnets.
- Alarm systems. In signal systems of various types, elements with magnetic properties are also indispensable.
- *Filtration and separation systems.* The products are used in the production of filters and separators. Magnetic filters are used to purify technical fluids, fine mixtures and drinking water.

PERMANENT MAGNET VS RARE EARTH RECYCLING MARKET

According to Research and Markets, the global rare earth metals recycling market is estimated to be USD 480 million in 2022 and is projected to reach USD 882 million by 2031, at a CAGR of 7% from 2023 to 2031 The wide range of applications for magnetic materials highlights the need for cost-effective processing, which has identified two issues. One is how to reduce the number of metals in magnets that are scarce, expensive, or problematic because of their severe environmental and social costs. The other is to improve the recycling of magnets so that the valuable metals can be effectively reused. This type of waste can differ significantly in the context of rare elements and impurities; determining their chemical composition is a complex analytical task. For example, used samarium-cobalt magnets may contain various non-ferrous and rare metals, including samarium, cobalt, iron, and silicon. The range of element concentrations can vary widely. Because of this, methods for the analysis of magnetic materials containing rare metals should have high accuracy, versatility, and selectivity. On the other hand, the EU has also encouraged the industry to research more efficient ways to recycle magnets. Since it is still cheaper to mine metals than to refine them, in most cases, the key goal is to develop processes to recover valuable metals at a competitive cost compared to freshly mined metals. Also, there is a need to

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reduce the dependence on metals by substituting them with available raw materials within the EU, thus mitigating supply risks. Life Cycle assessment studies (LCAs) - led by Hongyue Jin - have shown that recycling processes have significantly less environmental impact than the production of permanent magnets from primary raw materials.

It should be noted that despite the lack of mass recycling of permanent magnets, individual researchers have already achieved a positive result. For example, in 2015, German scientists from the design team of the Fraunhofer-Institut für Silicatforschung (ISC), following the publication on chemie.de, built a demonstration pilot that can process up to 500 grams of permanent magnet melt (Figure 5). The process takes place in several stages. First, the material is liquefied. Heated to over 1,000°C, it is fed to a water-cooled copper wheel rotating at a speed of 10-35 metres per second. As soon as a drop of the molten metal touches the copper, it transfers its heat to the metal within a second and solidifies. The resulting flakes are then ground into powder, which is used as the raw material for making new permanent magnets. Until now, the magnetic properties of the by-product have been inferior to those of commercial magnets.

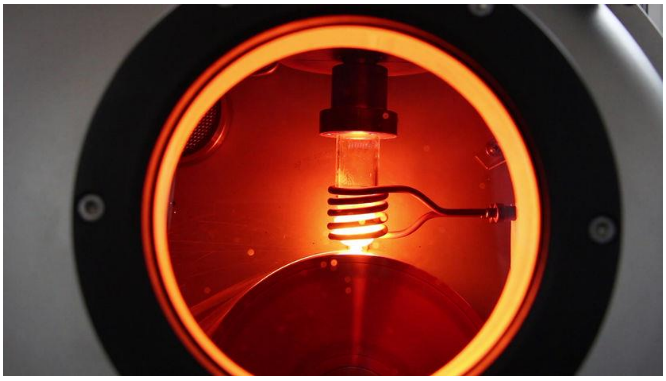

Figure 5. Melt-Spinning-Process pilot for permanent magnet recycling. Source: Fraunhofer-Projektgruppe IWKS

It is evident that close collaboration between the European recycling industry and research institutes is necessary to launch innovative solutions for answering the increasing demand of the rapidly growing permanent magnet market and creating circularity routes for permanent magnets through recycling. Political and sectoral interest in this approach is strong, as it promises both greater sustainability and reduced resource dependence. .

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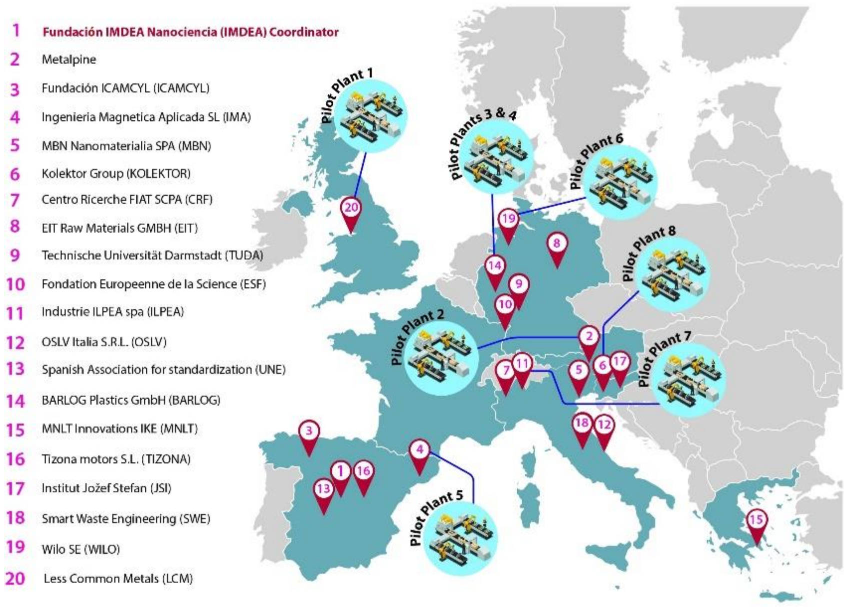

Figure 6. PASSENGER PROJECT mapping. Source: PASSENGER PROJECT

PASSENGER, with its pan-European presence (Figure 6), is actively working on optimizing the substitution process and new magnets could soon be used in electric motors. This ongoing work aims to demonstrate the success of scaled alternatives that rely on resources widely available in Europe and innovative technologies. The project focuses on improving strontium ferrite (Sr-ferrite) and developing a Manganese-Aluminum-Carbon (MnAlC) alloy as a substitute, ensuring the development of a sustainable permanent magnet value chain in the long term.

SUSMAGPRO
SUSTAINABLE RECOVERY, REPROCESSING AND REUSE OF RARE-EARTH MAGNETS IN THE CIRCULAR ECONOMY

Figure 7. *SUSMAGPRO PROJECT logo. Source: SUSMAGPRO PROJECT*

In parallel, PASSENGER collaborates with other EU-funded sister projects, including SUSMAGPRO (Figure 7) to foster synergy and cooperation. SUSMAGPRO seeks to create a rare earth magnet recycling supply chain in Europe and show how recycled rare earth elements can be used successfully in a variety of sectors.

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