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Sustainable REE supply from magnet recycling

The EIT DysCovery project is scaling up a recycling process for end-of-life (EoL) permanent magnets (PMs) through dismantling, comminution, partial dissolution using a hydrogen-free leaching process, metal separation by extraction chromatography and metal/alloy production from 2022 until 2024. The raw materials will be EoL PMs, but also swarf and sludges from recycling processes performed at magnet producer sites. The new plant will recycle 630 t/a of EoL material, enhancing EU recycling capacity by at least 23%, to produce magnet-specification metals (300 t/a), commercialised at competitive prices. The metals will be tested in NdFeB/SmCo magnets for e-mobility applications.

By Beate Orberger, Géosciences Conseils-Catura Geoprojects

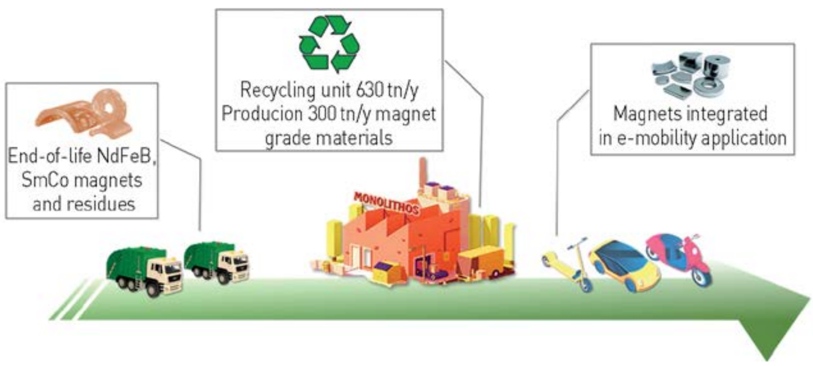
Monolithos (Greece), MEAB (Germany), KTH (Sweden) and TU Bergakademie Freiberg (Germany) will demonstrate at pre-industrial scale all the steps, including innovative hydrometallurgical solutions and molten salt electrolysis, to achieve magnet-quality (>95% purity) recycled metals at >90% recovery rates. These materials are then ready to be used for green magnet manufacturing and utilized in end-use applications. Besides, residual ferrous materials will be produced and sold to a nearby steel producer.

NdFeB and SmCo magnets made from recycled materials will be manufactured at Magneti (Slovenia), while CRF (Italy) will test the performance of the green magnets for potential application in the field of electric mobility. DysCovery is supported by an expert international industrial and academic advisory board.

DysCovery will provide solutions for the magnets, e-mobility and green energy production sector, proposing a zero-waste process. Its residual iron-rich material will be used in steel production at Sidenor S.A., which is close to the Monolithos recycling plant in Greece. The DysCovery project is aligned with EIT RawMaterials objectives as well as with goal 9 of the UN SGDs. DysCovery will build resilient infrastructure, promote sustainable industrialization and foster innovation through the development of a business case with high market potential in the RIS countries and Europe. Moreover, goals 11 and 17 of the UN SGDs are addressed in fostering "Sustainable cities and communities dealing with recycling leading to a sustainable environment", and "Partnerships to achieve the goal of building a fruitful collaboration between partners from five different countries of Europe". In our case, these are Greece, Slovenia, Germany, Sweden and France.

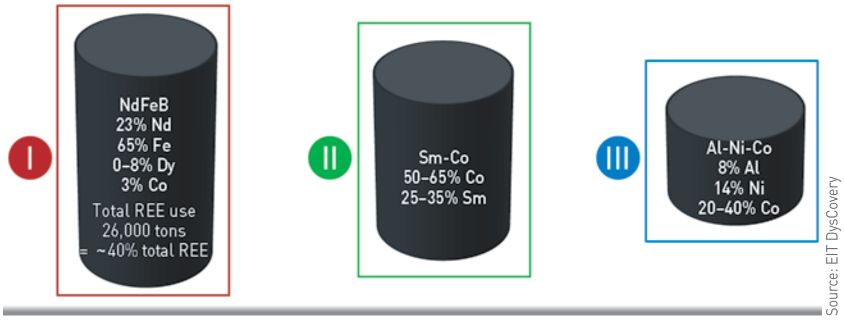
The European Raw Materials Alliance (ERMA) task force "Magnets and Motors" alerted us to the need for high-performance permanent magnets (PMs) and the necessary raw materials for the energy transition and related markets (ERMA action plan, 2021). Permanent magnets are used in consumer electronics, electric hybrid vehicles (EVs and PHEVs), in motors for satellites, and the generators of wind turbines. Another new application for NdFeB magnet material is additive manufacturing.

DYSCOVERY RECYCLING SCHEME



Source: EIT DysCovery

PERMANENT MAGNET TYPES AND COMPOSITIONS



Permanent magnets have the advantage of providing a constant magnetic field and magnetic behaviour at all times. NdFeB magnets are primarily made of neodymium (Nd), iron (Fe) and boron (B). They belong to the rare earth magnet family and have the highest magnetic properties of all PMs, stronger than PMs composed of samarium and cobalt (SmCo), or magnets made of aluminium, nickel and cobalt (AlNiCo), and ferrite. They have a high magnetic strength and are relatively inexpensive. Therefore they are an ideal choice for a wide range of applications. NdFeB magnets are the most powerful type used in lightweight mobile applications, while SmCo and AlNiCo are used to a lesser extent. Expensive SmCo magnets are mainly used in high-temperature (>100°C–350°C) environments (space, aviation, military). They have lower mechanical properties (brittle, cracking, chipping) than NdFeB, but have higher corrosion resistance (Roskill, 2020).

Consumer electronics contain about 1–5 g of NdFeB, EVs about 1.4 kg and wind turbines 1-2 tonnes of PMs.

However, PM performance and lifetime can be impacted by heat (above the Curie temperature), mechanical impacts, welding and liquid ingressions. The lifetimes of PMs can differ quite significantly. On average, PMs found in consumer electronics last 2–3 years, while PMs installed in wind turbines last 20–30 years.

Taking the growing EV market as a key indicator, the annual demand for PMs is expected to increase from about 5 kt/a in 2019 by roughly a factor 10 (about 50 kt/a) by 2030. This corresponds to a conservative scenario market estimation of about 700 billion euros. A high-demand scenario predicts demand of 50 kt to 225 kt per year by 2030, dominated by the EV sector (180 kt) and wind turbines (50 kt).

Almost 100% of the REE refined products (from primary and recycled materials) and magnets come from China. Europe imports 16,000 t of magnets every year. These materials are sold to EU customers at Chinese government dumping prices and tax legislations, which is an advantage for buying the entire value chain in China. Moreover, the Chinese supply chain does not necessarily meet EU environmental and societal standards. In 2020, wind turbines consumed 4 t of NdFeB magnets and 95% of EVs use motors containing NdFeB magnets.

Europe's 98% dependency on China for magnets and its rare earth metals needs to be reduced. The ERMA proposes increasing PM recycling capacity in the EU from about 500 t/a at present to 7000 t/a by 2030. According to projections of current recycling projects, the recycling capacity is likely to reach approximately 1500–2000 t/a in the EU by 2025.

Europe produces only about 1 kt/a of magnetic materials at six production sites (Vacuumschmelze (FI), Arnold Magnetic (CH), Magnetfabrik Bonn (DE), MS-Schamberg (DE), Kolektor (SI), and Magneti (SI – partner of our project). China's operating recycling capacity accounts for 34 kt/a REO. Apart from China, Urban Mining (USA) has a capacity for sintered NdFeB of 1kt/a and Innord (GéoMégA, Canada) operates a unit of 160 kt/a REO. China is the major magnet producer globally (165 kt/a).

At present, PMs are recycled at a capacity of about 500 t/a in the EU. Projects close to the market will increase this capacity to about 1500–2000 t/a.

DysCovery will reinforce this initiative by (1) targeting a capacity of 630 tn/y of EoL material and (2) by taking it one step further to the manufacturing of magnet-grade metals/alloys Nd, Pr, Dy, Sm, and Co ready for use in the field of magnet production.

DysCovery focuses on the best-performing NdFeB and SmCo magnets.

NdFeB (neodymium, iron, boron; $Nd_2Fe_{14}B$) magnets are composed of about 30% of rare earth elements (REEs). The major REEs contained in PMs are neodymium (Nd) and praseodymium (Pr). Minor quantities of dysprosium (2.2%, Dy), terbium (Tb), and gadolinium (Gd) are used in specific applications. SmCo magnets have different compositions. $SmCo_5$ contains 30% Sm, whereas 50% can be replaced by Pr and 70% Co. Sm_2Co_{17} contains 26-35% Sm and 50-60% Co.

Europe's dependency of China for magnets has to be reduced

Sintered NdFeB magnets account for 80-90% of global NdFeB production, while only 10–20% are bonded NdFeB magnets. Interestingly, China is less dominant in high-end sintered PMs for EVs. Fifty per cent of the world's high-performance magnets are produced in Japan and Germany, with Japan holding 20% of the patents for sintered PMs.

Magnet material collection: No unique models for magnet collection exist so far in the EU. However, the collection steps are indispensable and will be part of the DysCovery business model in order to ensure a continuous supply of raw materials. At present, EoL magnet material is still mainly shipped to China for recycling (85% of the world's recycling capacity). In order to stabilize a PM recycling and production chain in Europe, the EU Commission needs to promote and support PM collection in and for Europe. Collection models propose to implement a magnet collection service based on a deposit of 2–10% added to the sales prices, which can be reduced on return. Such logistics need to be established at EU scale. Other options are that each recycling plant insures the EoL and scrap magnet material on its own, depending on its recycling expertise. This can be a specialization in magnet sizes (e.g. large wind turbine magnets, or smaller ones for consumer electronics), or NdFeB versus SmCo magnets, etc.

Magnet material preparation: Materials containing rare earth metals must be handled with care due to the reactivity of the rare earth elements. The material has a pyrophorous character, which can lead to a burning of the powdered material when crushed. During comminution processes the material must be treated with caution (e.g. by milling in an inert atmosphere) and packed for storage and further use.

The DysCovery project upscales the following technologies:

1. **Leaching of Nd, Pr, Dy, Sm, Co, and Fe from powdered magnet material at min 90% efficiency**
   The novel Cu-based process will be used to achieve >90% leaching efficiency. No H2 gases will be produced, thus avoiding explosions. In addition, uncontrollable exothermic reactions will be prevented, increasing the process safety for larger-scale applications.

2. **Create high purity (>95%) commercial specification metal streams**
   After leaching, chromatographic separation will create two different streams that will constitute the intermediates for the commercial products: (1) i.e., for NdFeB magnets: 22% Nd, 6% Pr, 8% Dy, 3% Co, and (2) for SmCo magnets: 35% Sm, 60% Co. Mixed streams can also be commercialised from its intermediates with high added value, such as high-purity Nd metal (>95%) and NdPr/NdDy alloys. This will be demonstrated during molten salt electrowinning. The remaining iron-rich material will be sold to a steel producer. KTH (Sweden), TU Bergakademie Freiberg (Germany), NIC (Slovenia) and Monolithos (Greece) will upscale these processing steps.

3. **Pilot unit to be constructed and operational within 2.5 years**
   The pre-industrial unit will be constructed at the Monolithos recycling site. The unit will be optimised and tested for seamless operation and will be ready within 2.5 years. Industrial demonstration and full production capacity will be achieved in 2025. During the project time, the pilot unit will be used for demonstration and training purposes. Material flows will be optimised. The metal streams will be directed for the development of magnets. The pilot unit will be designed and constructed by MEAB and operated by Monolithos.

4. **Material flow analyses and life cycle assessment**
   Enalos (Greece) will perform the life cycle inventory (LCI) of the processes, define and structure scenarios, benchmark the LCA of conventional technologies and perform the LCA and LCC of the upscaled technologies up to industrial scale. The material flow analysis (MFA) of DysCovery is indispensable for positioning the DysCovery results and commercialised solutions in the European and global material supply chain. The social impact in the life cycle will be modelled on the basis of DysCovery results. This model takes into account Europe's dependency on Nd, Dy, Sm, Pr, and Co products for magnet production after the implementation of the recycling plant. The environmental performance and possible optimization of the DysCovery technologies will be assessed through a flowsheet simulation with the upscaled technologies, and integrate LCA indices for direct environmental monitoring when operating the pilot plant facilities.

5. **Creation of pre-evaluated magnet prototypes (one NdFeB and one SmCo)**
   The manufacturing of recycled magnets will use 50% of DysCovery's recycled metals at Magneti (Slovenia). The preindustrial demonstration of the holistic closed loop of the DysCovery concept, the creation and evaluation of magnets made from about 50% recycled metals will be performed by the end of 2024. These magnets will be tested and evaluated by CRF (Stellantis, Italy) in EVs for entering the EV manufacturing process. During the commercial implementation, the "DysCovery" magnets will be manufactured according to the specifications defined by our stakeholders.

6. **DysCovery's go-to-market strategy**
   DysCovery will reach the markets as of 2025, including the magnet collection step. DysCovery foresees the expansion in the upcoming market of magnets for e-mobility and green energy production to diversify and secure its business portfolio. Monolithos will present the first magnet recycling pole in southeast Europe.

Foto: falco; pixabay .com