CLOSING THE LOOP ON RECYCLING OF RARE EARTH ELEMENTS

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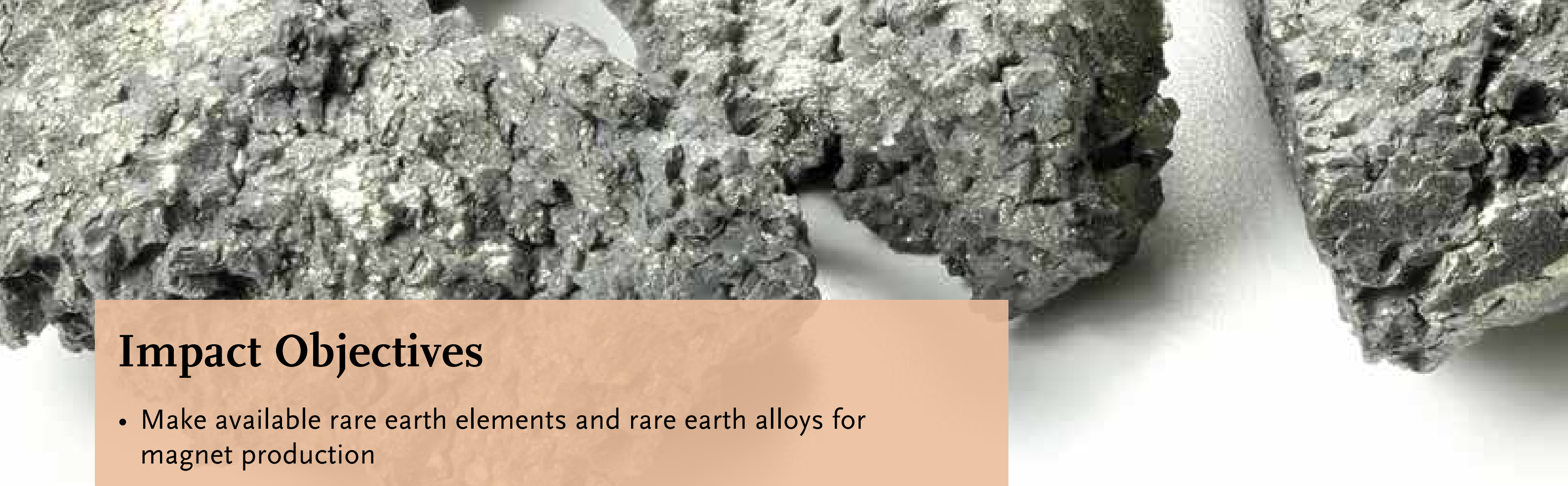

Impact Objectives

- Make available rare earth elements and rare earth alloys for magnet production
- Develop an efficient and cost-effective method of extraction and a direct production route for rare earth alloys

An independent rare earth elements supply chain

***Ana Maria Martinez** of Norway's **SINTEF Materials and Chemistry** is **Project Coordinator** of the **REE4EU** project. She shares how this work will improve the availability of rare earth elements in Europe*

What are the goals of the Rare Earth Recycling for Europe (REE4EU) project?

REE4EU aims to realise a breakthrough in securing the availability of rare earth elements (REE) in Europe. This means providing, for the first time, a cost-effective and efficient REE extraction and direct rare earth alloys (REA) production route from abundantly available in-process and end-of-life REE waste streams. We hope to show that it is possible to maintain the whole value chain during permanent magnet production and electrodes for nickel metal hydride batteries using secondary raw materials, thus avoiding the dependency of importing expensive REE from China. The project might also open up market opportunities to stakeholders seeking sustainable REE recycling technologies.

Who are the partners involved in REE4EU?

The consortium covers the core value chain and surrounding stakeholders with interest in realising and implementing REE recovery from permanent magnets and secondary battery waste, from those involved in REE metal production and the manufacturing of permanent magnets to end users of automotive, electric and hybrid vehicles, as well as recycling companies. The REE4EU consortium consists of 14 partners from seven European countries. SINTEF is the coordinator and the scientific leader of the project, and is also leading the high temperature electrolysis (HTE) work, both at laboratory and pilot scale.

What is the breakthrough you are looking for in the field of recovery technologies for metals and other minerals?

For the first time, the extraction of REE and the alloy production will be demonstrated at pilot scale. Previous EU-financed projects either did not demonstrate the extraction technologies at pilot scale or, if they did, they did not go one step further, which is the production of valuable alloys and then final products. In REE4EU we will demonstrate a complete closed-loop recycling process for permanent magnets and battery waste, from the REE-containing waste material to the REE-containing product. At the same time, the project will demonstrate the economic viability of the REE4EU solution by developing several business cases as well as performing a market analysis.

The technologies are already demonstrated at project start (technology readiness level 4). Therefore, the project aims to demonstrate the concept at a larger scale. It will provide missing market data to enable sound business planning for recycling companies. We will also demonstrate that REE4EU will be able to accommodate different input stream categories.

What are the technologies you are hoping to develop?

There are three technologies we will be looking to develop to achieve the goals of the REE4EU project: HTE for providing the REE alloys; an extraction step involving ionic liquids (ILE) for recovering the REE elements in the form of oxides from the different waste streams; and advanced hydrometallurgical (HM) routes will also be developed as an extraction step. The HM routes will be enhanced compared to similar state-of-the-art methods and will be used for benchmarking the route using ionic liquids.

You have two planned industrial pilot projects. Can you share a little about them?

One of the pilots, which will be installed in Norway, will demonstrate the ILE-HTE technologies for all the waste streams. Another pilot will be installed in the UK and will demonstrate the feasibility of the HTE process using HM-upgraded feed. The results of both pilots will be benchmarked.

Closing the loop on recycling of rare earth elements

*The four-year **REE4EU** consortium is aiming to develop, validate and demonstrate a complete closed-loop waste recycling process for permanent magnets and batteries, ultimately improving resource management and environmental outcomes for Europe*

Rare earth elements (REE) are a group of 17 chemical elements that occur together in the periodic table. The group consists of scandium, yttrium and the 15 lanthanide elements. The REE are all metals, and the group is often referred to as the rare earth metals (REM). These metals have many similar properties, and that often causes them to be found together in geologic deposits. REM, alloys and oxides that contain them are part of devices that people use every day such as computer memory, DVDs, rechargeable batteries, cell phones, catalytic converters, magnets, fluorescent lighting and much more. During the past 20 years there has been an explosion in demand for items that require REE.

Ana Maria Martinez, a senior research scientist based at Norway's research institute SINTEF, is Project Coordinator for an innovative project called REE4EU (Rare Earth Recycling for Europe), which is looking at solutions for improving the waste from REE. She observes that a recent study, based on detailed trade data, estimates the global trade in REE-containing products: 'In 2010 this was estimated at around €1.5 trillion, or 13 per cent of the global trade. However, only 1 per cent of REE waste is being recovered as no adequate process is currently available.' It is hoped that REE4EU work will open up a fully new route bringing recovery of in-process wastes from valuable metal manufacturing within reach.

A TEAM EFFORT

Kicked off in 2015, this four-year project funded by the EU's Horizon 2020 Research and Innovation programme is supported by 14 partners from seven European countries. The partners in this consortium offer valuable experience to help deliver the required results. There are highly respected research institutes involved, as well as complementary research organisations and industrial companies with technical recycling knowledge. The combined brain power of this consortium is an essential component of the studies.

The consortium has now completed Phase 1 of the project, which saw them undertake lab-scale and off-line integration, tailoring the ionic liquid extraction (ILE) and high temperature electrolysis (HTE) steps of the project. 'The engineering teams IDENER and A3i-Inovertis, together with SINTEF, the University of Toulouse and Tecnalia, as well as the industrial partners responsible for the pilots, Elkem and Less Common Metals, established the corresponding conceptual engineering design for the process,' notes Martinez. They are now working on Phase 2, where they will be integrating the process engineering blueprint. Phase 3, which will be completed in the third and fourth years of activity, will involve pre-industrial scale piloting and evaluation.

The team is combining two technologies – one for REE extraction and the other for producing marketable rare earth alloys (REA). The REE4EU consortium is uniting their collective brain power to validate the combined technology at pilot scale. 'The team is developing, for the first time at industrial scale, an efficient and cost-effective method of extraction and a direct production route for REA, which will be achieved through in-process and end-of-life permanent magnets as well as Ni metal hydride battery waste,' explains Martinez.

MARKET POTENTIAL

The work involves using available REE-containing wastes such as scrap waste created during permanent magnet manufacture and end-of-life wastes. At present, there are no projects devoted to the recovery of permanent magnet swarf. This material is sold to China, and could be an important secondary resource of REE in Europe, and the first input material to a future REE recycling plant in Europe. 'The project involves the full value chain to prove technical and economic viability of this technology for recycling magnetic waste,' says Martinez. 'The consortium's efforts will develop market data and business cases for a new European secondary REA production sector, creating new jobs, increasing Europe's independence from imports, and providing valuable raw materials for fast-growing

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European green technology industries. By accomplishing this, the project is fostering competitiveness, resource efficiency and environmental benefits.'

According to the US Geological Survey, in 2013 China produced about 90 per cent of the world's supply of REE ores. 'Today, the permanent magnet industry is suffering from the Chinese control of the supply chain,' says Martinez. 'Securing the supply of critical raw materials, in general, and REE in particular, is of great concern for Europe, Japan and the US for both economic and strategic reasons. Therefore, recovering REE from wastes leads to accessibility of REE raw materials that otherwise will need to be imported.' She explains that driven by the increasing market penetration for many maturing products that use REE, and fuelled by lower price, and a recovering world economy, the demand for REE is increasing: 'Magnet applications in particular could see double-digit growth rates in the coming years. Many of the technologies that will depend on high performance permanent magnets are only just beginning to reach mass markets.'

One of the biggest challenges to recovering REE is the economics of the overall recycling scheme. To be profitable, large amounts of residues containing REE must be treated. These wastes are available in large volume, but the amount of REE contained is very small. 'In some situations, although large amounts of waste streams are available, the content of REE is small and they usually end up in waste products (slags), as it is energy intensive and complicated to recover them,' says Martinez. On the other hand, with wastes containing large amounts of REE such as end-of-life permanent magnets the process of separating and collecting them safely is not only time-consuming, but requires the use of chemicals, leading to toxic wastes.

REAL-WORLD, INDUSTRIAL-SCALE TRIALS

The REE4EU consortium is aiming to develop an integrated solution that offers significant improvements in cost and environmental performance. 'The REE4EU concept features the integration of the novel HTE of REA with the new ILE but also with alternative pre-treatments, using multidisciplinary design optimisation (MDO),' says Martinez. 'MDO will enable optimised engineering of the integrated process managing the interactions between the different systems that involve a number of disciplines or subsystems such as thermodynamics, mechanics and fluid dynamics, developing the primary process and the downstream separation as one single integrated stage.'

They are now taking steps towards being able to demonstrate the REE4EU process in an industrially relevant environment. To achieve this the partners are undertaking a number of activities, including MDO and mathematical modelling of the subprocesses composing ILE, HM and HTE steps using dynamics programming to conduct optimisation. The results from this work will then feed into the life cycle assessment (LCA)- and conceptual engineering-related documents and the detailed planning for the construction of the pilot plant at a site in Norway.

With so much progress being made, Martinez is now starting to look at ways to share what they have achieved through stakeholder analysis, dissemination and exploitation of the project results. The aim now, she says, is to provide a 'thorough analysis and identification of the most significant and economically valuable end-of-life products to consider for the recovering of REE using the REE4EU pilot plants'.

REE4EU will facilitate the sustainability of green technologies in Europe

Project Insights

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PARTNERS

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