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EREAN
EU FP7 Marie-Curie Initial Training Network

Policy | brief

# EU FP7 MC-ITN EREAN addresses the challenges laid out by the final ERECON report

Policy Brief No. 2 – February 2016

## Highlights


A REPORT BY THE EUROPEAN RARE EARTHS COMPETENCY NETWORK (ERECON)
STRENGTHENING THE EUROPEAN RARE EARTHS SUPPLY-CHAIN
Challenges and policy options

- EREAN is the European Rare Earth Magnet Recycling Network which trains 15 young researchers in the direct (alloy) and indirect (chemical) recycling of NdFeB permanent magnets, addressing the whole materials loop.
- In 2013 the European Rare Earths Competency Network (ERECON) was set up by the European Commission at the request of the European Parliament. The aim was to come up with recommendations in order to strengthen the supply chain for rare earths in Europe.
- The final ERECON report prioritised the rare earth magnet market for recycling. This market is not only the largest of all the rare earth sectors by volume and cost, but the rare earths used in permanent magnets (neodymium and dysprosium) are at greatest risk of supply shortages. Furthermore, the market is predicted to grow over the next 10 years.
- End-of-life e-bikes will become an increasingly important source for recycling. This market is predicted to account for around 10% of the NdFeB magnet market, and it is growing 20% per annum. Recycling of e-bikes, in which also solutions are found for the recovery of the battery, should become an R&D priority in Europe.
- As regards the direct (alloy) recycling of NdFeB magnets, there are three options with varying TRL levels: 1) recasting, 2) resintering and 3) melt spinning or HDDR processing. The ERECON report identified that the re-sintering and casting routes need to be demonstrated at a commercial scale, whereas the HDDR and melt spinning routes require further R&D to fully develop these processes. As regards the indirect recycling route of NdFeB magnets, the rare earths are recovered from end-of-life magnets as rare-earth concentrates or as purified oxides of the individual rare-earth elements. The indirect recycling route is to be preferred if the magnet waste streams show large variations in composition or contain many impurities.
- Ionic liquids are identified as a promising new technology for recycling of rare earths. So far, most ionic liquid extraction studies have been carried out on a small lab scale. The ERECON report recommends to support this emerging technology through funding of an industry-led pilot plant, dedicated to separation of the very critical heavy rare earths.

## Introducing EREAN

EREAN (European Rare Earth Magnet Recycling Network) is the FP7 Marie-Curie Initial Training Network Project that started on September 1, 2013. This European Rare Earth (Magnet) Recycling Network trains 15 young researchers in the science and technology of rare earths, with emphasis on the recycling of these elements from neodymium-iron-boron (NdFeB) permanent magnets. An intensive intersectoral and interdisciplinary collaboration has been established in the EREAN consortium, which covers the full materials loop, from urban mine to magnet. By training the researchers in basic and applied rare-earth sciences, with emphasis on extraction and separation methods and rare-earth metallurgy, sustainable materials management, recycling methods, life cycle assessment (LCA), and the principles of urban mining, they will become the much needed "rare earthers" for employment in the growing European rare-earth industry. The EREAN Consortium draws it talents from 9 Beneficiaries, including 7 Research Institutes (KU Leuven (coordinator), University of Helsinki, Chalmers, Technische Universiteit Delft, University of Birmingham, Öko-Institut EV, Fraunhofer IWKS) and 2 Companies (Umicore and Solvay). Concurrently, EREAN is strengthened with 6 more (industrial) Partner Organisations, being InsPyro, MEAB, Less Common Metals, Treibacher Industrie AG, Stena Metall and Magneti Ljubljana. All together 9 EU Member States are represented.

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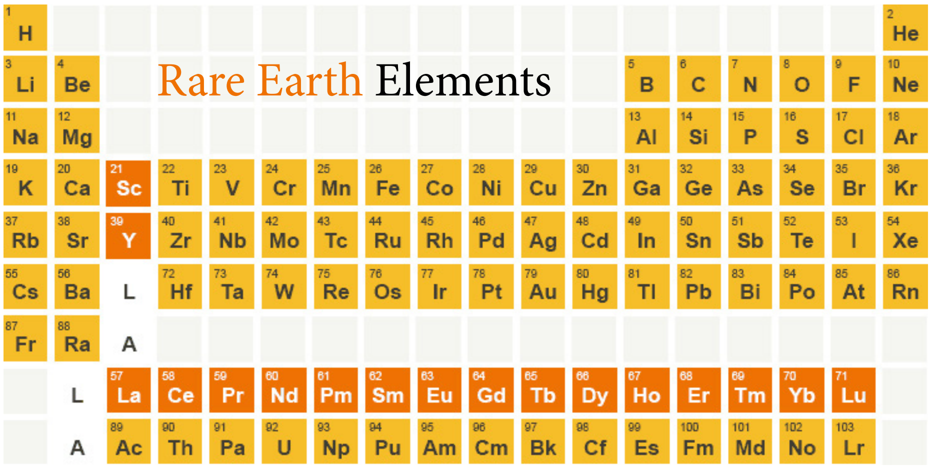
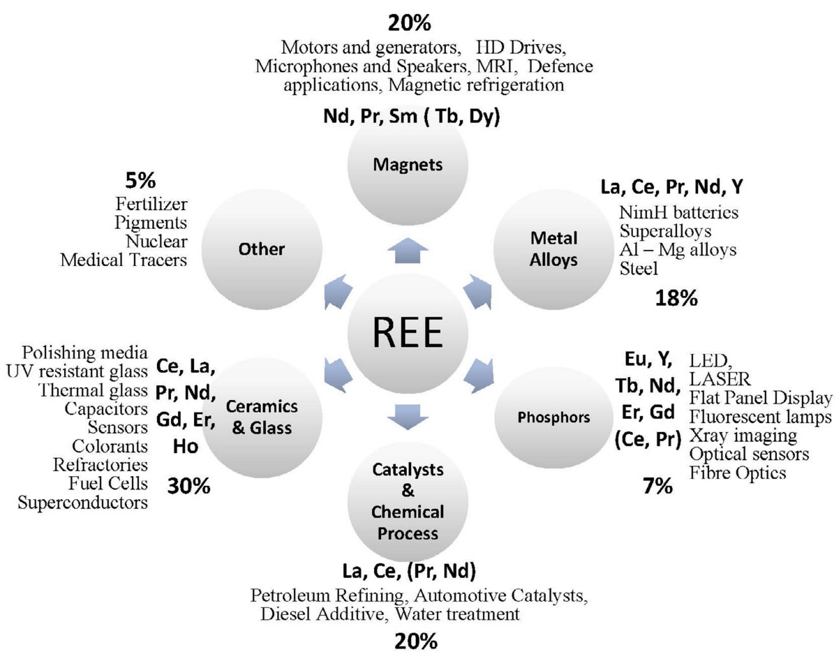



## EREAN and the final ERECON report


**Download report through:**
http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/erecon/index_en.htm

### Introduction to ERECON

In 2013 a Rare Earth Network was established called ERECON (European Rare Earths Competency Network). The initiative was set up by the European Commission's Directorate-General for Enterprise and Industry at the request of the European Parliament. The network was comprised of 80 experts in rare earths from industry, academia and the policy world. Under the guidance of a high level steering committee, three working groups were established on 1) mining, 2) recycling and substitution and 3) policy. The aim of the ERECON network was to come up with recommendations for the Commission in order to strengthen the supply chain for rare earths in Europe. Many of the EREAN team had a direct role in the ERECON project including Matthias Buchert (Oeko Institut), Koen Binnemans (KU Leuven), Oliver Gutfleisch (TU Darmstadt), Roland Gauss (Fraunhofer Institute) Alain Rollat, Olivier Larcher (Solvay) and Allan Walton from the University of Birmingham who chaired the working group on recycling. All of the people noted above contributed to the chapter on recycling in the final report, which included a series of recommendations to promote recycling of rare earth materials in the EU. Here below a summary of ERECON's recycling recommendations is provided and linked with the on-going work in the EREAN project.



## ERECON recommendations as regards recycling

The working group on recycling initially created a priority list ofwww rare earth application areas where recycling could have a significant impact. In order of priority this included:

1. Permanent magnets – Nd, Pr, Dy, Tb, Sm
2. Phosphors – Eu, Tb, Y, Ce, Gd,La
3. Batteries – La, Ce, Nd, Pr.
4. Polishing compounds – Ce
5. Catalysts – La, Ce, Pr, Nd, Y

This list took into account the criticality of the rare earths, future demand, value of the waste stream, size of the sector and potential for substitution. For all rare earth sectors the following recommendations were put forward in the report:

1. Mapping of the urban mine is urgently required to assess the potential for recycling of all REEs.
2. Eco-design should be promoted in order to enable easier recycling of the rare earth elements.
3. Take back & buy back schemes should be evaluated to stimulate collection of rare earth materials.
4. Regulations surrounding recycling targets for REE containing products are often based on weight percentages for the whole product, which does not promote recycling of the small quantities of rare earths. Therefore regulations should be finetuned to emphasize the importance of the minor metals including for example REEs.

## ERECON has prioritised the recycling of REE permanent magnets

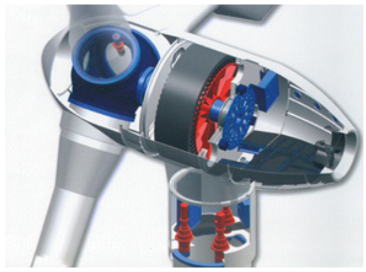
The permanent magnet market is not only the largest of all the rare earth sectors by volume and cost, but the rare earths used in permanent magnets (neodymium and dysprosium) are at greatest risk of supply shortages compared to nearly all other rare earths. Furthermore, the market is predicted to grow over the next 10 years. However, of all the rare earth sectors, the magnet market presents significant challenges for recycling which are not always posed by the other sectors. One of the initial challenges for magnets is that the market is very diverse and mapping is urgently required to assess the potential. Within the working group a priority list was suggested per application, where initial recycling efforts should be concentrated. This list was based upon the availability of scrap, ease of identification of products, collection rates, the amount of material per application, scarcity of rare earths in the application. The list of applications was as follows:

1. Hard disk drives, DVD and CD players
2. Automotive applications
3. Motors in industrial applications
4. Loudspeakers
5. Air conditioning compressors
6. Magnetic separators
7. Mixed electronics
8. Electric bicycles
9. Wind turbines

The EREAN project is already targeting automotive applications, while the electronics markets are covered by several other EU funded projects, including for example REMANENCE.

However, moving forward, end-of-life electric bikes will become an increasingly important source for recycling. The e-bike market is predicted to account for around 10% of the NdFeB magnet market, and it is growing substantially year on year (20% per annum). Recycling of e-bikes, in which also solutions are found for the recovery of the battery, should become an R&D priority in Europe.

During the ERECON discussions it also became evident that the challenges for recycling of each of the products on the priority list differed significantly, and this may lead to unique recycling technologies being developed for each application. For example, new techniques are required in order to identify magnets in mixed waste streams, to separate magnets from often very complicated architectures, to purify the rare-earth alloys/elements and then to re-process the extracted materials back into new magnetic materials. Once the NdFeB material is extracted from the waste stream then the material can either be processed directly as an alloy, or indirectly by separating the rare-earth elements.



>>It was evident during the discussions in ERECON that the rare earth magnet market should be prioritised for recycling. <<

>> Recycling of e-bikes, in which also solutions are found for the recovery of the battery, should become an R&D priority in Europe. <<

## Importance of sound preprocessing

The separation of the rare earth magnet material from the waste stream should not be underestimated. If this cannot be achieved economically then the downstream processes will become redundant. To remove the magnets from the waste stream then several problems need to be overcome. The magnets are often coated, glued and mechanically held in the assemblies and they are fully magnetised. In order to remove the magnets from the waste streams then demagnetisation will be crucial. Two main methods have been proposed. Firstly the magnets can be heated above their curie temperature (>320ºC) to demagnetise them or secondly the University of Birmingham have proposed a route called HPMS (Hydrogen processing of magnet scrap - see reference below). This route reduces the magnets to a demagnetised hydrogenated alloy powder, which can be used for downstream processing. Further funding should be put in place to research new technologies to tackle the separation problem for each major application in the field as the issues for separation can be quite different depending on the design of the component. The HPMS route is being explored for automotive scrap in the EREAN project. As described in the earlier section for all rare earths, the design of magnet containing technologies should also be tailored to make separation and recycling easier.

## Direct versus indirect recycling of REE magnets

In the EREAN project both direct and indirect recycling routes are being developed. In the former the magnets are treated as a raw material for the production of fresh magnet alloys and, subsequently, new magnets. In the latter magnet scrap material is transformed to its elemental components. The REEs are recovered from the magnets and separated from each other for use in subsequent permanent magnet production or, possibly, in other applications such as magnetocaloric materials or lamp phosphors. Research breakthroughs in EREAN were already discussed in the EREAN Policy Brief 1, which can be obtained from http://erean.eu/wordpress/erean-policy-brief-nr-1-just-published/ A full list of EREAN papers on direct/indirect recycling of NdFeB magnets can be found on http://erean.eu/science.php

**EREAN Policy Brief 1**

## Direct recycling of REE magnets: the way forward

There are several options which can be implemented in order to recycle the rare earth alloys directly into new alloy forms. 1) the material can be re-cast into a master alloy, 2) the magnets can be broken down to a powder and re-sintered into new permanent magnets 3) the extracted materials can be processed into a new form which is suitable for resin bonded magnets (using either melt spinning or HDDR processing, i.e. hydrogenation, disproportionation, desorption & recombination). The ERECON report identified that further work is required in all of these routes but at different scales. The re-sintering and casting routes need to be demonstrated at a commercial scale in order to demonstrate that consistent products can be developed across large batch sizes. On the other hand, the HDDR and melt spinning routes require further R&D to fully develop these processes. For more info on these processes, see A.Walton, Y. Han, N. A. Rowson, J. D. Speight, V. S. J. Mann, R. S. Sheridan, A. Bradshaw, I. R. Harris, A. J. Williams, The Use of Hydrogen to Separate and Recycle Neodymium-Iron-Boron-type Magnets from Electronic Waste, *Journal of Cleaner Production* **104,** 2015, 236-241.

>> As regards the direct (alloy) recycling of NdFeB magnets, there are three options with varying TRL levels: 1) recasting, 2) resintering and 3) melt spinning & HDDR processing. The ERECON report identified that the re-sintering and casting routes need to be demonstrated at a commercial scale, whereas the HDDR and melt spinning routes require further R&D to fully develop these processes. <<

## Indirect recycling of REE magnets: Research challenges addressed by ERECON/EREAN

In the indirect recycling route, the rare earths are recovered from end-of-life magnets as rare-earth concentrates or as purified oxides of the individual rare-earth elements. The indirect recycling route is to be preferred if the magnet waste streams show large variations in composition or contain many impurities. This route also has to be followed if new magnets with well specified compositions have to be produced.

In the older processes for indirect recycling of rare-earth magnets, the magnets are dissolved in strong acids and the rare earths are precipitated to yield a rare-earth concentrate that can be further processed. In modern indirect recycling processes, the rare earths are selectively leached from NdFeB magnets after roasting, leaving iron behind as an insoluble iron oxide that can be valorised as a red pigment [See for example, EREAN results: M.A.R. Önal, C.R. Borra, M. Guo, B. Blanpain, T. Van Gerven, Recycling of NdFeB Magnets Using Sulfation, Selective Roasting, and Water Leaching, *Journal of Sustainable Metallurgy*, **1** (3), 2015, 199-215 - DOI 10.1007/s40831-015-0021-9. The leachate with the dissolved rare earths is further purified by solvent extraction. At the end of the process, pure rare-earth oxides are obtained. A main issue with the indirect recycling route is that it consumes a lot of chemicals and large volumes of waste water are generated, so that there is plenty of room for improvements and process intensification.

One possible improvement of conventional solvent extraction is replacement of the organic phase by an ionic liquid. Ionic liquids (ILs) are solvents that consist entirely of ions. Since they are non-volatile and non-flammable, they can be safer alternatives for volatile molecular organic solvents in extraction processes. Ionic liquids can be used to design more selective extraction processes because the chemistry of extraction is different in ionic liquids than in molecular organic solvents. However, there are still several issues related to the use ionic-liquid-based solvent extraction processes: (1) most ionic liquid phases are very viscous; (2) ionic liquids have the tendency to extract via an ion exchange mechanism, resulting to losses of ionic liquid components to the aqueous phase; (3) some fluorinated anions such as the hexafluorophosphate can hydrolyse in water; (4) the recyclability of ionic liquids needs to be addressed; (5) some ionic liquids are (cyto)toxic; (6) many ionic liquids are still much more expensive than conventional organic solvents.

Notwithstanding these difficulties that need to be addressed in further research, ionic liquids offer a great potential in the field of separation and purification of rare earths. This is illustrated by the split-anion process (which was developed by the research group EREAN coordinator Prof. Koen Binnemans within the framework of the FP7 project EURARE). For more information on this process see: K.

>> So far, most ionic liquid extraction studies have been carried out on a small lab scale. There exist only very few extraction studies with ionic liquids on a larger scale, so that the proof-of-principle for their use in industrial solvent extraction processes is still lacking. The ERECON report recommends to support this promising technology through funding of an industry-led pilot plant, dedicated to separation of the very critical heavy rare earths. <<

Larsson and K. Binnemans, *Hydrometallurgy*, **156**, 2015, 206–214 - [doi:10.1016/j.hydromet.2015.04.020](https://doi.org/10.1016/j.hydromet.2015.04.020). Solvent extraction processes based on ionic liquids could give a competitive advantage over the older Chinese separation processes.

So far, most ionic liquid extraction studies have been carried out on a small lab scale. There exist only very few extraction studies with ionic liquids on a larger scale, so that the proof-of-principle for their use in industrial solvent extraction processes is still lacking. New solvent extraction equipment dedicated to handling of viscous ionic liquid phases has to be designed. The ERECON report recommends to support this promising technology through funding of an industry-led pilot plant, dedicated to separation of the very critical heavy rare earths.

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