Recovery of Rare Earth Elements from magnetic waste in the WEEE recycling industry and tailings from the iron ore industry

**Reporting**

<table>
<thead>
<tr>
<th>Project Information</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>REECOVER</td>
<td>Funded under FP7-ENVIRONMENT</td>
</tr>
<tr>
<td>Grant agreement ID: 603564</td>
<td>Overall budget € 7 902 037,92</td>
</tr>
<tr>
<td>Status</td>
<td>EU contribution € 5 995 741</td>
</tr>
<tr>
<td>Closed project</td>
<td>Coordinated by NORGES TEKNISK-NATURVITENSKAPELIGE UNIVERSITET NTNU Norway</td>
</tr>
<tr>
<td>Start date</td>
<td>End date</td>
</tr>
<tr>
<td>1 December 2013</td>
<td>30 November 2016</td>
</tr>
</tbody>
</table>

**Final Report Summary - REECOVER (Recovery of Rare Earth Elements from magnetic waste in the WEEE recycling industry and tailings from the iron ore industry)**

**Executive Summary:**
The REEcover project aimed to contribute to European security of supply of Rare Earth Elements (REEs), bringing forward SME competence and business opportunities in the REE recovery area, as well as strengthening ties between SMEs and innovative research- and education institutions. As such, the project has developed, demonstrated and assessed the viability of recovering REEs, primarily Dysprosium (Dy) and Neodymium (Nd), that are especially critical to the European economy - from two types of industrial wastes:
1. Apatite tailings from the iron ore industry
1. Apatite tailings from the iron ore industry
2. Magnetic waste material from the WEEE recycling industry

These two waste streams were chosen because of:
- their complementarity in characteristics, giving specific demands on the recovery technologies to be developed;
- closed-loop-recycling ambitions and resource efficiency targets: REEs from raw materials largely end up in WEEE-waste or in mining waste, and instead of being deposited in tailing dams or by smelters as slags/dust, they can become valuable REE-based products for further use.

The REEcover project operated from the drive of the industrial partners, mainly SMEs that have high innovation potential (Indumetal (ES), LCM (UK), Elemetal (NL), Chemconserve (NL), Metsol (SE), SIMTEC (F)) as well as the two partners with waste-streams that they would like to commercialise instead of deposit (LKAB (SE), Indumetal (ES)). Due to the overall low concentrations in the raw material, REE recovery and recycling from industrial waste is a massive challenge. In order to increase the potential for successfully reaching a cost-effective route to recover REEs from the two mentioned waste streams, processes to retrieve REE-containing materials from them will be developed throughout the project value chains.

During the project period, the consortium has developed two separate routes to valorise both apatite tailings and magnetic/ferrous fractions of WEEE waste. In order to achieve cost efficiency, apatite tailings will need to be upgraded to concentrate, optimizing REE mineral recovery. Similarly, ferrous WEEE waste fractions need to be physically beneficiated to extract REE contents without destroying metal value. This upgrading work was carried out in WP1. Low grade REE concentrates from WP1 were subsequently pyrometallurgical treated to extract phosphorous-values (apatite tailings) or Rare Earth Oxides (REO) in a more concentrated slag phase (WP3). In WP2, pure or mixed REOs were extracted from the upgraded concentrates. In WP4 and WP5, REO was transformed to REE, using improved existing- and new innovative electrolysis routes. In WP6, analytical techniques for composition determination were evaluated and raw material variability assessed. In WP7, the developed value-chains were assessed for their technical, economic and environmental viability, using a unique process modelling approach, combined with economic and environmental assessment criteria. Throughout the project, WP8 has maintained a dissemination and IPR record, while targeting and involving the scientific, policy and broader community in dissemination activities such as scientific and policy workshops and storyboard publications. The project has published 19 journal and conference contributions in peer reviewed fora.

Project Context and Objectives:
The transition toward resource efficient, low-carbon circular economies is a necessity. This transition will require initiatives towards innovation in resource- and energy efficiency, as well as in recycling, creating economic opportunities and improved security of supply for critical raw materials. REEs are in this respect especially important, as many of the REEs are crucial to development of “green technologies” and as such to the European economy and the objectives of the EU’s Strategic Energy Technology Plan and related climate goals. Amongst the critical raw materials, REEs are reported to have very low recycling rates of less than 1%. Strategic EU-documents acknowledge that through recovery of rare earths from mining and production waste materials, it will be possible to secure an independent source for the EU and shield the community from Chinese export quotas and price fluctuations. These REEs are, also in Europe, a constituent of e.g. mined iron ore minerals (apatite) although not currently extracted, thus ending up in...
constituent of e.g. mined iron ore minerals (apatite) although not currently extracted, thus ending up in
tailing wastes. Moreover, considerable amounts of these REEs used in imported electronic equipment,
originating from primary resources mainly from China, end up in urban solid waste streams at European
WEEE-recycling plants. In order avoid such un-necessary

REEcover main aims were hence:
A) Improve the European security of supply of critical Rare Earth Elements (REEs) raw materials
B) Strengthen European SME positions in the REE production and recovery value chain
C) Innovate and research two different routes for hydro-/pyro-metallurgical recovery of REEs, as Rare
Earth Oxides (REO) or Rare Earth Oxy-Carbides (REOC) in electrolytic reduction.
D) Demonstrate and assess the economic viability and potential for the two routes on two different types of
currently deposited industrial waste: apatite in iron ore tailings and magnetic fractions of WEEE processing
magnetic scrap.

These four main aims were targeted through 3 more specific, quantifiable project objectives:

Objective 1:
Demonstrate the techno-economic feasibility to achieve > 50% accumulated recovery of the REE content
in in-going magnetic scrap- and tailing- waste streams, by simultaneous development of:

a. Physical separation methods which will concentrate REE minerals and materials in two different waste
   streams:
   • Waste stream tailings: Understanding the occurrence of the REE containing minerals in this type of
     apatite tailings and adapting flotation and other techniques to fit these specific minerals.
   • Waste stream magnetic waste: Combine separation methods, which will separate strong magnetic
     materials from the ferro-magnetic material waste stream in the WEEE-waste streams to avoid it from
     ending up in slags and dust in the recycling smelters.

b. Hydrometallurgical upgrading techniques which can extract more than 80% of the REOs from both
   upgraded REE-bearing concentrates from tailings and physically upgraded REE magnet-bearing waste
   stream from the shredder into individual REO and / or REO mixtures suitable for oxy-fluoride based
   electrolysis.

c. Pyro-metallurgical upgrading techniques which can provide a cost effective an environmentally friendly
   alternative to hydro-metallurgical methods which can extract more than 80% of the REOs from both
   upgraded REE-bearing concentrates from tailings and physically upgraded REE magnet-bearing waste
   stream shredded and liberated/demagnetized materials into mixed REO or REOC mixtures concentrates
   suitable for oxy-fluoride based or oxy-carbide based electrolysis.

d. An adapted industrial oxy-fluoride electrolytic process for the production of the RE metals and alloys
   from targeted waste materials in terms of energy efficiency and reducing environmental impact.
   • Industrial scale demonstration at 10-50 kg input scale, targeting 80% recovery rate.

e. An electrolytic reduction method using RE oxy-carbide anodes produced from pyro-metallurgically
   upgraded wastes to produce REE metal or alloys.
   • Large laboratory scale proof of concept with 80% REOC recovery rate.

Objective 2:
Establish leading European competence and procedures on characterisation and analysis of REE
containing materials – from ores to alloys – with focus on:
Containing materials – from ores to alloys, with focus on:

a. Establishing standard and comparable methods for determining (REE) content and form in different types of waste materials in a range of matrices and concentrations.

b. Collect and provide input on REE-content and recovery yields to all process steps (WP’s) in the project to serve economic and life-cycle optimisation of the integrated value chain.

Objective 3:
Investigate new economic opportunities for the developed technologies based on improved resource efficiency, through focus on:

a. Evaluation and comparison of technical, economic and environmental feasibility of the sub-processes and the value chain(s) and benchmark towards existing technologies and value chains.

b. Based on the ecologic-economic-technologic (EET) evaluation, select at least one value-chain for demonstration in pilot, in order to demonstrate the economic value of the tuned integral chain.

c. Evaluation of existing business models, as part of market uptake development for the REEcover technologies, over the different process steps.

d. Dissemination of results to support further uptake in other scientific domains, technology domains and to support business development.

Project Results:
In the REEcover project, the development of environmentally and economically viable recovery technologies for Rare Earth Elements (REE), -with particular focus on Neodymium (Nd) and Dysprosium (Dy)- from apatite tailings and ferrous WEEE fractions, has been the main overall objective. The project has carried out work along different process value chains, including physical separation, pyro- and hydrometallurgical upgrading and electrochemical reduction techniques.

In WP1, the two waste streams have been provided and processes have been developed to increase the REE-concentration in these low-grade materials. LKAB has provided the mining tailings, and together with LTU developed processes to retrieve REE-containing materials from it ferrous fraction of WEEE scrap, as that is a fraction of scrap that has high REE content.

Indumetal (IM) has supplied four different inputs streams coming from the treatment of E-waste, selected as representatives: Input 0, Input 1, Input 2, and Input 3. Indumetal has been supported by NTNU, LTU, and TUD to develop physical separation processes in order to increase the REE concentration and to demagnetise WEEE scrap, as that is a fraction of scrap that has high REE content.

Based on trials with physical separation methods, a simple process for upgrading of different WEEE has been found and typical material balances have been established. It consists of four steps:

1. Thermal demagnetisation at 500 C for 1 hour to make the magnetic REE containing “dust” come loose from iron/steel in the WEEE.

2. Pre-screening on 10 to 1.75 mm screens to separate the “dust” from larger WEEE fragments. Depending on the feed stream this may be sufficient to upgrade for example Nd to 1 % or more.

3. If higher upgrading is needed, the dust may be submerged in liquid nitrogen to introduce thermal stress, and then ground in a cutting mill to liberate ceramic REE fragments from ductile metal.

4. Finally, sieving on 75 or 150 µm sieves will get a fines fraction enriched in REE.
Typical material balances for different inputs have been established. The upgrading process was refined in terms of sieving sizing to obtain best possible REE yield. 6 parallel batches from IM of the earlier described “Input 2” material was upgraded by LTU and NTNU, to -for the first time in Europe- establish the degree of variation between such feeds – important information for developing a recycling business case. The result shows that the content of REE in such material is highly variable, up to an order of magnitude difference. The upgrading process was later demonstrated in large scale, yielding a total of approximately 110 kg of upgraded material, which was further pyro-metallurgically upgraded in WP3.

For the apatite concentrate material, the REE mineralogy has been studied and revealed that there are four major REE-sources present in the iron ore tailings: lattice-bound REE in apatite, monazite, allanite, and titanite. In the current processing only apatite and monazite may be won. Allanite and titanite report to flotation tailings. However, it was also discovered that titanite is preferentially enriched in certain process streams, and this may lead to new processing paths for winning of titanite. This is a major finding, since in titanite approx. 30% of the REE are HREE. The existence of REE-containing titanite in iron ore tailings was previously unknown. Apatite tailings and concentrate were shipped by LKAB to NTNU and TUD for hydrometallurgical processing in smaller scale.

In WP2 the REEcover project aimed to hydrometallurgically extract the REEs from these streams (tailings and dilute complex magnet shredder residues after physical upgrading) into individual REO's or their mixtures. For leaching of apatite concentrate upgraded from the tailings, many different leaching agents were investigated.

For processing apatite concentrate, a leaching process with HNO3 was investigated to achieve the extraction of REE and phosphorous. This process produces H3PO4 from the apatite while simultaneously dissolving the REE. The resulting leach liquor is then cooled to remove the unwanted Ca as Ca(NO3)2. Analysis of the leach liquor reveals extraction rates of between 75% and 100% for the heavy REE (Y, Eu, Dy etc.) and below 40% from the light REE (Ce, La). Full phosphorous extraction was also achieved. For processing upgraded WEEE, two parallel routes were explored: pure hydrometallurgical process – direct leaching, and a combined pyro-hydrometallurgical process – leaching of the REE-bearing slag from WP3 pyrometallurgical treatment.

Methods for selectively direct leaching of the Nd from the shredded WEEE (upgraded in WP1) were thoroughly developed. The explored methods include total dissolution and weak acid leaching, while the use of water and oxygen to induce wet-corrosion was investigated in the later phase of the project. The wet corrosion process, where the shredded WEEE was first oxidised in water for 24h (at elevated temperature) and then leached with diluted H2SO4, has proven to be superior to both the total dissolution process and the weak acid process developed in the early stage of the project.

In cooperation with WP3 a new input material was introduced in WP2: the slag produced by pyrometallurgically treating the shredded WEEE. This slag contains all of the REEs, but almost free of Fe. Two slags were received, one from Input2-Met2 processed by Tecnalia and one from Input2-Met1 processed by NTNU. Both slags were leached using concentrated HNO3 (65wt.%) in order to break the complex mineralogy of the slags. For the NTNU slag this yield very high Nd extraction rates (>95%), however the slag from Tecnalia did not respond as well to the same treatment only yielding Nd extraction rates between 50-60%. The NTNU slag also responds well to leaching with diluted HNO3 (8.3wt.%) yielding similarly high extraction rates (>95%). The lower acid concentration improves the acid economy of the process and
High extraction rates (>95%). The lower acid concentration improves the acid economy of the process and also facilitates the subsequent solvent extraction steps. After leaching the liquors were neutralised with NH4OH to make it suitable for solvent extraction. Successful solvent extraction trails on the slag leach liquors have been performed by Elemetal. The trails were run using D2EPHA and kerosene at an operating pH of 1. This successfully extracted the Nd (as well as Pr and Dy) from the liquor with minimal impurities. The REEs were extracted from the resulting solution using oxalic acid precipitation and the obtained precipitates were calcined to oxides. A flowsheet of the leaching and solvent extraction process is developed by TUD and Elemetal jointly. In the final demonstration:

- a >99% pure mixture of REOs was produced from pyro-metallurgical pre-treated WEEE e-scrap on a scale of 10 kg input material/day and with a recovery of >90%.
- A flowsheet for a hydrometallurgical extraction process for the non-pretreated inhomogeneous WEEE e-scrap is developed.
- Currently similar hydrometallurgical extraction processes are not known to be operational in Europe.

In WP3 extensive work on development of thermodynamic measurements in REO-containing oxide systems, in order to enable both pyro- and hydrometallurgical processing of REE containing waste, was carried out by SINTEF and NTNU. This work has resulted in two journal publications and several conference contributions, as detailed in the dissemination section. A new route to treat the apatite concentrate carbothermally to produce P4 and CaC2 was demonstrated in large laboratory scale at NTNU. The CaC2 contains the REO which may be extracted hydrometallurgically. The process may be a strong business case for obtaining both P and RE, both elements on EUs critical raw materials list. Extraction of P from the apatite concentrate and distribution of REE between slag and metal was also investigated at Tecnalia yielding interesting scientific results. The work on apatite has produced two submitted journal publications. The work on smelting of upgraded WEEE material progressed in laboratory scale, yielding valuable experience for the demonstration activities. Material physically demo-upgraded in WP1 (110 kg), was hence used during the demonstration activities in WP3, carried out by Tecnalia and Metsol, gained significant insights into pyro-processing. The REE extraction yield was found to be strongly related to melting conditions and slag formation. Thus, induction furnace was selected as the most appropriate method for melting as oppose to plasma furnace. The results stressed the importance of having extensive and reliable analysis of the feed in order to control the energy consumption and flux additions, thus maintaining a sufficient slag formation during operations. It was concluded that the design of a future industrial pyro-treatment facility is likely to be similar to today's foundry operations. A total of approximately 20 kg of slag containing the REO was produced by Metsol and Tecnalia and shipped to Elemetal for hydrometallurgical upgrading (in WP2).

In WP4, SINTEF has focused on the investigations of improvement of today's industrial electrolytic processes, for Dy-Fe alloys by investigating the best conditions for securing stable cell operation using synthetic feeds. The studies included the experimental determination of the Dy2O3 solubility in the fluoride-based electrolytes as well as electrolysis experiments using on-line analysis (FTIR) of the cell off-gas in order to optimise the electrolytic parameters of the process. The tailored results obtained at laboratory scale by SINTEF using pure Dy2O3 provided the fundamental basis for DyFe production using the secondary feeds where more impurities are expected. Moreover, it is expected that the optimized conditions for the electrolytic production of Tb-Fe will be similar to those for Dy-Fe alloys. The investigations will be shortly sent to publication to a peer-reviewed journal, being very useful for the scientific community outside China, as reliable information about the Dy-Fe electrolytic process is scarce, if not inexistent in English language.
In WP4, TU Delft focused on in-depth understanding the electrolytic process for preparation of REE metals or alloys by oxide-fluoride electrolysis. The outcome of the research at TU Delft provided the basis of electrolyte composition and process parameters for the demonstration of Rare Earth production at LCM.

The main findings of through electrochemical studies can be summarized as follows:

- The solubility of REOs in fluoride melts is relative low, below 3 mol. % (10 wt. %). It increases with temperature and RF3 content. A semi-empirical model was developed and good agreement was obtained between predicting values and experimental data.
- Based on CLSM Nd2O3 dissolution experimental results, the dissolution of Nd2O3 is found to be diffusion controlled. Increasing temperature and NdF3 concentration can enhance the dissolution rate and capacity.
- Various voltammmogramatic studies for cathodic reaction mechanisms of Nd2O3 in fluoride electrolyte (LiF-24CaF2) reveals that the reduction of Nd(III) in the fluoride electrolyte consists of two steps, from Nd(III) to Nd(II) and then from Nd(II) to Nd. It is also a diffusion controlled process.
- An alloy mainly containing Nd (and other REEs) was obtain by constant potential electrolysis from synthetic feed in molten fluorides. The current efficiency is determined to be 50 % and energy consumption is 3.4 kWh/kg alloy (assuming that the product is pure Nd metal), at much lower cathodic current density.

This proves that a lower current density at a much greater cathode surface area (together with shorter electrode distance) could be an effective way to reduce the cell voltage and total power consumption.

LCM has in turn designed, built and tested a pilot electrolysis cell which can be used to test oxide and fluoride combinations sourced from mine tailings and magnetic scrap. The 1KA pilot cell has flexibility of consumable anode, consumable cathode and different fluoride mixtures to produce various RE-metal output 10-50kg. The key features are external heating to independently control the molten fluoride bath temperature and achieve high current efficiency. The cell has vacuum tapping capability to remove metal produced without manual operation which is typical of Chinese operation. The extraction hood facility enables off-gas and potential harmful gases to be removed and cleaned through a bag house before emitting to the environment. The 1KA cell has advanced instrumentation to allow process monitoring of current densities at the anodes, vessel temperatures, data capture, storage and process control. The 1KA cell is an advanced state of the art electrolysis cell that has improvement on the Chinese model of producing critical rare earth metals such as Neodymium(Nd), Dysprosium (Dy) etc. in terms of health and safety, process control and energy savings. LCM has tested the capability of the cell to operate at current densities of 0.1A/cm²- 0.25 A/cm² at the anode and 1.5 A/cm²-2.85 A/cm²..

In WP4, LCM has also carried out demonstration work to verify the findings of experimental work by other partners in REEcover consortium. Neodymium metal was produced by using synthetic Rare Earth mixed oxide with impurities similar to those observed in mine tailings and magnetic scrap. The electrolyte of ethetic composition NdF3:LiF was heated to 900°C to obtain a molten bath with the external heating feature of the pilot cell. The molten bath temperature was independently controlled by the external heating capability of the cell which ensured controlled oxide feed additions based on set current. Thus, stable cell operations was achieved without anode effects which results in off-gas emissions containing CH4 and other PFC gases typical of Chinese Rare Earth electrolytic cells. The cell was operated at constant current of 1000A and with an average voltage of 7.8V.

One of today's most important RE-uses, i.e. Nd-based permanent magnets, uses RE in the form of metal and/or alloy. Electrolysis, as described above, is the common state of art method to produce Nd metal or
and/or alloy. Electrolysis, as described above, is the common state-of-art method to produce Nd metal or Nd-Fe master alloy for the magnetic alloy.

A good operation of an electrolytic cell depends on obtaining a good balance between REO feeding rate and the oxide consumption. In today's process, this is a major challenge due to the relatively low REO solubility (described above) and dissolution rate.

For an optimal electrolysis operation, it is necessary that the amount of dissolved oxides match the supply of faradic current. If the oxide concentration becomes too low, the fluoride electrolyte itself will start to decompose and perfluorinated carbon (PFC) green-house gases - ranked with very high global warming potentials for ozone-depleting substances - are produced at the anode instead of CO/CO2. On the other hand, if the oxide-feeding rate becomes too high, some of the REO will not dissolve and it will settle at the cell bottom as sludge instead. This can affect the metal product and current efficiency in a bad way.

The goal in WP 5 was to demonstrate the feasibility of a method for RE-metals and RE- alloys production based on electrolysis from a molten salt using a consumable anode which is able to supply the electroactive species into the electrolyte. In this way, the following gains with respect to SoA method are expected:

- More robust process, as the electroactive oxide species are supplied by the faradaic current of the process.
- More environmental process, as no molten fluorides are used, and no PFC gases and other harmful compounds (HF) are emitted.

After a significant effort, NTNU and SINTEF managed to synthesize such consumable anodes - a challenge due to the high reactivity of the anode with the ambient humidity. The electrolysis process developed by SINTEF gave promising results and was demonstrated in large laboratory scale. A numerical model was designed for predicting the current distribution at the surface of a 2-electrode cell for the production of REM and alloys using a consumable anode by SIMTEC. The model simulates the current distribution with both secondary and tertiary current description. In the secondary approach, the over-potentials are a result of the voltage decomposition and the activation over-potentials while in the tertiary approach, the concentration over-potentials are also taken into consideration.

The process is subject of a patent application (EP16196270.9 filed 28 October 2016).

In WP6, different characterization procedures for REE (and other elements) were investigated for both tailings from the iron ore industry and magnetic waste material from WEEE recycling industry. In order to get an overview of needs for characterization and to assess potential weaknesses, inputs of specific needs from the partners in the consortium were collected. From the evaluation of the information compiled a summary of preliminary lacks for the characterization of both waste streams. The major lacks identified for waste flow characterization were prioritized. Accordingly, a first Round Robin test to establish the appropriate methods for the analysis of REE and major elements in apatite tailings was carried out.

Special effort was performed, with successful outcomes, in the main lacks identified in the Round Robin, ie difficulty to find a suitable method for sample digestion when facing the analysis of elements with different properties (some rare earth elements are hard to be dissolved) and in different forms (combined as oxides, for example); b) regarding WEEE stream, sampling was identified as an important matter of discussion and of worry within the partnership. Waste from electronic devices tends to be very heterogeneous and relatively large in size; as a consequence, homogenization of the whole sample is not feasible in many cases. Preparation of test portions from the laboratory is a very sensitive step in the analysis of this type of samples. These results are very useful in the assessment of future experimental results analysis.

Inter laboratory studies among partners were carried out together with dedicated laboratory research from
Inter-laboratory studies among partners were carried out together with dedicated laboratory research from Tecnalia concerning laboratory sampling, metallic heterogeneous samples analysis methods and WEE variability input, allowed obtaining validated reliable methods and characterization procedures for the two above mentioned material types.

During the project, several recovery routes have been researched producing as a result a high number of samples and characterization results. A database specially designed for the purpose of REEcover was built at the very beginning of the project and was continuously fed during its whole lifetime, requiring a strict control of the samples exchanged between partners from different activities in order to not to lose any information. It includes nearly 240 samples, with characterization information for many of them. As a result of the effort devoted to maintain the information updated, the tool offered to any partner of the project at any time the possibility to quickly search information about a specific sample. This has been of special importance at the final part of the project when evaluation of the whole process for both technical and economic purpose was being carried out.

In WP7, techno-economic and environmental assessments of the value-chains and individual sub-processes in the REEcover project were carried out. The results are unique in terms of its innovative analysis of quantitative and economic aspects of the two value-chains; WEEE to REE alloys and Apatite concentrate to P4 and CaC2 containing REE. These analyses represent the essence of project impact and will be used for future project development and dissemination at up-coming conference and policy sessions.

WP8 has kept an IPR and a dissemination database, as well as established the project website (www.reecover.eu). In WP8, a well-attended scientific workshop (26-27 September 2016) as well as a policy workshop (8 November 2016) were arranged in Brussels. Both events were open to both the scientific community and to the public. These workshops have both show-cased the achievements in REEcover and other EU-financed CRM-related projects, as well as brought forward input to future policy development in the area of Raw Materials in Europe. In WP8, a popular science “story-board” publication was also produced. Both the storyboard and the presentations at the two workshops are available at the project website. The project has published (and has got acceptance for publication) > 20 scientific contributions to journals and conferences.

Potential Impact:
Breakthrough innovation in novel technologies, products or services with high potential to achieve a more green economy
REEcover has focused on technology development for REE recovery adapted to industrial waste from WEEE-recycling and apatite tailings from the mining industry. From both groups, a significant quantity of REEs (Nd, Dy etc) – which is crucial to green technology development -can be recovered. For the apatite tailings, a carbothermic route to produce both valuable products such as P4 (another critical element) and calcium carbide (CaC2, a pre-cursor for acetylene production) where the rare earths are concentrated , has been demonstrated in laboratory scale. For ferrous WEEE waste, an integrated value-chain for concentrating and recovering the REEs, has been developed. The benchmark of the technologies developed in REEcover has been that they are more energy efficient, have higher yields and better environmental performance than existing technologies, thus contributing to European Green Economy targets. Both these value-chains are more energy- and environmentally beneficial that state-of-the-art technologies.

More sustainable consumption and production patterns. Improved resource efficiency and reduced environmental impacts. Reduced waste production and pressure on raw materials.
environmental impacts. Reduced waste production and pressure on raw materials. REE are currently primarily produced in China, incorporated into products and exported to for example Europe where these values are mainly lost in landfill or by dilution. This is clearly not a sustainable consumption pattern – especially not for elements like Dysprosium, which are very scarce. As such, pre-dilution recovery is desirable. As the consumption of these materials are steadily rising, setting up closed-loop recycling systems and by utilisation of existing but currently not exploited European waste ore resources, as exemplified by REEcover activities, the environmental burden may be lowered, and reduce the pressure for exploitation of new ore resources and mine sites. With the recovery of elements from waste fractions key to REEcover, new and more viable production patterns are placed in focus for exploitation by the commercial partner Chemconserve. This approach has led to knowledge transfer from RTD-partners to companies, as intended in the project.

Substantial contribution towards sustainable supply of raw materials of economic importance in Europe. REEs are in the group of critical elements identified by the EU in terms of highest economic impact and largest supply risk. REEcover has identified the potential in both WEEE resources and apatite tailing resources. With current REE prices low, these resources are not economically viable to extract alone but must be brought out to market together with other elements in the resource utilized. However, LKAB’s annual tailings production alone is such that a large proportion of Europe’s REE needs could be extracted, given economic feasibility.

Improved communication and transfer of knowledge to policy making, business and to general public. REEcover partners with their wide academic and business network has contributed to the transfer of knowledge to both students, peers and the public. Two workshops with scientists, industry and policy makers has delivered both research and policy recommendations for future strategic EU orientation regarding innovative REE-recovery technologies and resource efficiency. Through a project “story-board”, the project has made a popular, yet fact-based introduction to resource efficiency and REE.

SME Benefit and business potential
From a general perspective, with participation of 7 SMEs, the REEcover project has addressed the European Commission’s horizontal SME policy, promoting competitiveness and innovation. The REEcover participants will seek to commercialise the technologies developed for their application in similar waste circumstances worldwide.

Main dissemination activities
In line with the EC-guidelines for reporting, a plan for use and dissemination of foreground (including socio-economic impact and target groups for the results of the research) has been established at the end of the project. During the project, an extensive IPR database has been kept updated, to include realised scientific publications and dissemination activities.

After first only listing the actual published results and attended dissemination activities, the consortium
After first only listing the actual published results and attended dissemination activities, the consortium decided to also start listing their intentions, so that industrial partners could see from an early stage what part of the work would preferably be published.

At every General Assembly meeting, a short discussion was held on the planned dissemination and the use of results. Only after the 24M meeting, discussions on exploitation potential became more focused, as the value chain data was progressing. Moreover, IPR and exploitable foreground has been discussed during these consortium meetings, in close relation to the value chain potential.

19 scientific publications were made, though not all in peer reviewed journals, as conferences and workshops turned out to be an excellent platform for disseminating our project’s results. Many publications are still to be expected (submitted for publication after project end). Moreover, a “story board” that gives an overview of the need for REE recycling and how REEcover has contributed to solving this problem in popular science terms, has been created: https://issuu.com/ottopaans/docs/reecover_-_towards_a_circular_econo

The consortium also organised 2 workshops in Brussels, targeting scientific and policy / decision makers.

List of Websites:
http://www.reecover.eu/

Last update: 16 August 2017
Record number: 202427