



REE4EU: integrated high temperature electrolysis (HTE) and Ion Liquid Extraction (ILE) for a strong and independent European Rare Earth Elements Supply Chain

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Deliverable 9.6. Replication Plan

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List of abbreviations and definitions

Abbreviation	Definition
EC	European Commission
EoL	End-of-Life
HREE	Heavy Rear Earth Element
HTE	High Temperature Electrolysis
ILE	Ionic Liquid Extraction
LREE	Light Rear Earth Element
PM	Permanent magnet
PMS	Permanent Magnet Swarf
REA	Rare earth alloy
REE	Rare earth elements
SoA	State-of-the-Art
SPM	Spent Permanent Magnets
TREO	Total rare earth oxides





Executive Summary

D9.6 – Replication plan is devoted to the development of a replication strategy based on the REE4EU pilot results, business plan and further value chains identified from the literature. To that end, different cases of potential feedstocks related to end-of-life products, mine tailings, mine deposits and industrial wastes have been studied in order to define their potential to be processed with the REE4EU technology. The results show that REE4EU technology can be applied in most of the cases adapting the operational conditions of the processes with the aim of obtaining a product alloy with industrial interest.





1 Introduction

The scope of the deliverable

This deliverable summarises the work done in task 9.5 “Replication plan” within the Work Package 9 “Market analyses, exploitation and dissemination” of REE4EU project.

In task 9.5, the objective was to develop a strategy based on the REE4EU pilot results, business plan and further value chains identified from literature for the replication of the REE4EU technology. In this context, the replication has been focused on how the REE4EU developed process can be adapted to treat the potential feedstocks identified from the different sources.

The strategy developed for the REE4EU replication technology, drafted in Figure 1, has been:

- 1) To briefly compare the REE4EU process with the SoA technology for REE extraction.
- 2) To identify potential feedstocks for the REE4EU technology based on the business plan developed by PNO in the previous task 9.4 and other REE sources identified in the literature and previous H2020 projects dealing with REE.
- 3) To describe the feedstocks in detail with the relevant data for the MDO replication.
- 3) To introduce the relevant data into each of the modules that compose the MDO system adapting these modules when required.
- 4) To study the obtained results provided by the MDO.
- 5) To analyze the feasibility of the application of the REE4EU technology for the specific case under study.

In order to overcome all these steps for the replication strategy, this deliverable is structured in four main sections. First, potential sectors for replication such as end-of-life products, mine tailings, mine deposits and industrial wastes are identified and described in section 2. After that, the integration of the REE4EU processes and technology will be analysed for the mentioned sectors studying specific cases. A treatment flowsheet will be defined in section 3 for each of the cases with the aim of identifying where the REE4EU technology could be integrated. In section 4, MDO will be applied to the most relevant cases adapting the operational conditions. The results obtained will be analysed in order to provide indications of the workability of the proposed process flowsheet. Finally, the main conclusions obtained will be described in section 5.

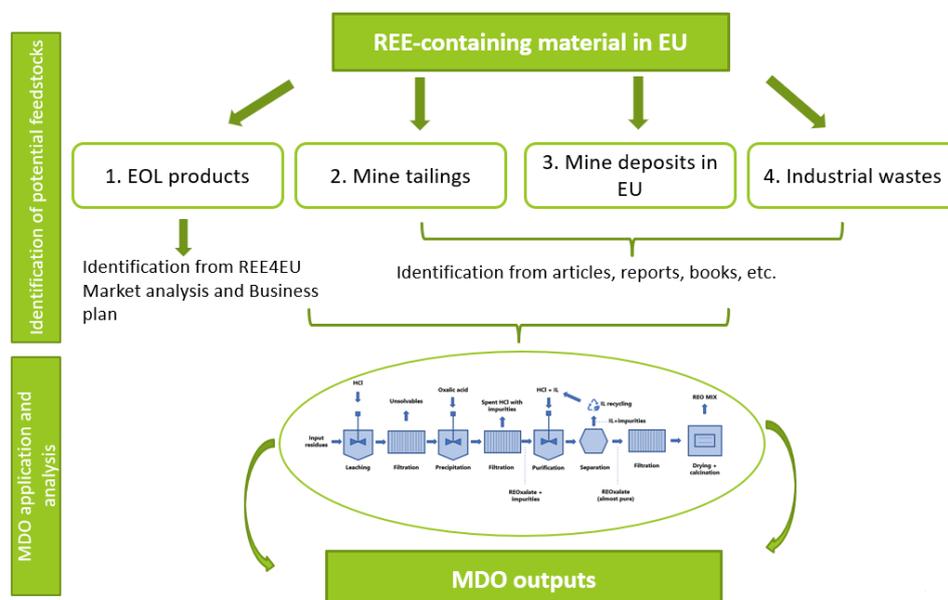


Figure 1. REE4EU replication strategy



2 Identification and description of potential sectors for replication

The first part of the work done for the REE4EU replication has been the identification and description of suitable sources of REE, which can represent an important feedstock for the REE4EU technology. Thus, four sectors have been the object of the search done: End-of-Life products (which were reviewed in the market analysis and business plan of REE4EU), mine tailings in EU, REE potential deposits in EU and industrial wastes containing REE. The most suitable feedstocks identified from reports and literature according to its REE content and availability of the resource in the EU are described below.

2.1. End-of-Life products: conclusions from market analysis and business plan

In the REE4EU Market Analysis (D9.3) and business plan (D9.5), the authors revised a wide range of End-of-Life (EoL) products containing REE for assessing the market potential respecting REE extraction and production from them. The authors claimed that two EoL products were the most suitable ones for REE extraction due to its already established collection schemes, the maturity of regulations towards their recycling, and potential to co-recycle multiple REE (in case of electric vehicles). These important EoL feedstocks are:

a. EoL Electric Vehicles (EVs)

The EVs use one or more electric motors or traction motors for propulsion. The main REEs used in EVs are Nd and Dy for the permanent magnets (PMs). The Nd content is from 0.25 to 1.1 kg in the PMs used in the motor. The Dy content is estimated as a percentage of Nd (from 5 to 10%)

Rare Earths in xEVs

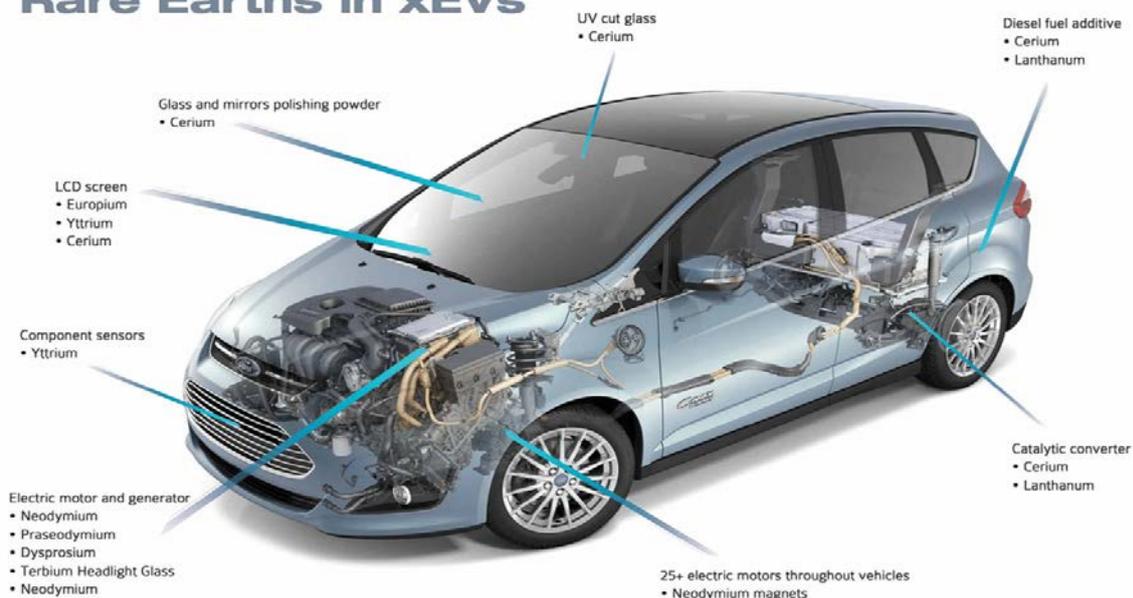


Figure 2. Rare earth location in EVs

Source: UBS Electric Car Teardown May 2017

b. EoL Residential air conditioners

Rare earths magnets used in air conditioners are found inside components used in compressor rotors attached to the surrounding component with a rather powerful magnetic force. Mitsubishi Electric has developed technologies for automatic dismantling which can dismantle, sort and remove the REE magnets used in compressors at a pace of one air conditioning unit every 30 seconds. Thus, these magnets can be reused or could be processed for REE recovery (Electric, s.f.) through REE4EU technology.

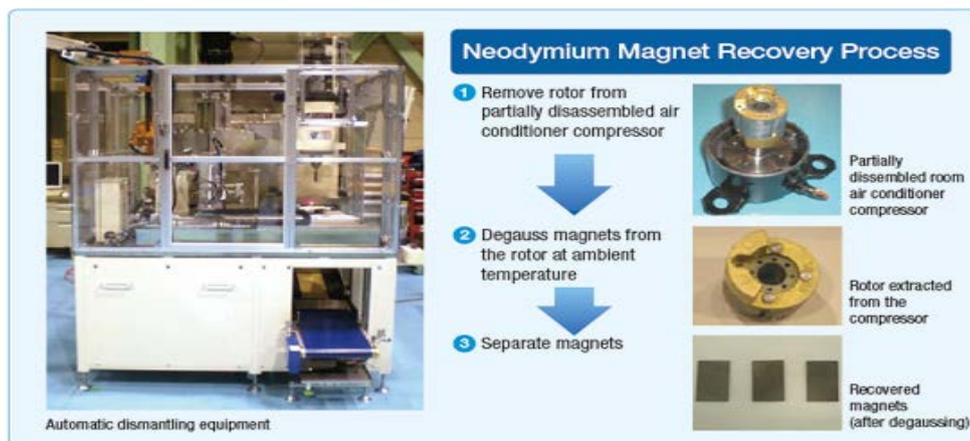


Figure 3. Nd magnet recovery process developed by Mitsubishi

The main REE used is Nd in the alloy NdFeB. The Dy is also commonly added. The Domestic air conditioners have an average NdFeB content of 100-500 grams. The industrial air conditioners have around 250-330 grams of the alloy NdFeB.

Dy content in NdFeB magnets is about 3-7% weight.

On the other hand, it is also mentioned in the business plan that not much research is done for REE recovery from industrial waste residues as old landfills, whose volumes are enormous as are its total amount on REE contained in.

2.2. Mine tailings containing REE in EU

Mine tailings are the ore waste of mines, and usually, have the appearance of mud-like material. The storage and handling of mine tailings around the world is a global environmental problem, due to the toxic elements that make part of them. The scale of tailings production is very wide, and they can contain valuable metals and critical raw materials, like rare earth elements, normally in low-grade, which can be extracted by cost-effective and selective technologies as it is REE4EU process. Thus, a search in the literature has revealed the existence of different REE-containing mine tailings across the EU, which could represent a potential feedstock for the REE4EU technology. These resources are listed and described in the tables below.

a. New Kankberg tailings in Sweden

These tailings come from the production of Au and Te. Around 700 Mt are stored, and around 1300 Mt are expected by 2045. Mine mineralogy includes quartz, muscovite, kaolinite, and K-feldspar. The highest concentration of REEs among other EU tailings. Most of the REEs present in monazite: 170 pp Ce, 90 ppm La, 70 ppm Nd (Tunsu, Menard, Eriksen, Ekberg, & Petranikova, 2019).



Figure 4. Kankberg Mine in Sweden (from mining-technology.com)

b. Covas tailings in Portugal

These tailings come from past underground tungsten mining (scheelite and minor wolframite). The tailings contain 1-3 m thick lenticular skarn levels hosted by schists. Skarn levels contain zones of massif sulphide with wolframite, scheelite and ferberite. The REE content is: 32 ppm Ce, 16 ppm La, 15 ppm Nd and 1900 ppm W (Tunsu, Menard, Eriksen, Ekberg, & Petranikova, 2019).



Figure 5. A scientist taking a sample from Covas tailings (from ENVIREE EU project)

c. Luossavaara-Kirunavaara Aktiebolag (LKAB) tailings in Sweden

The annual tailings production is 8Mt, and the mine has the potential of producing 15Kt of REEs per year. 50-100 Mt are already present in the tailings pond. These tailings are one of the largest potential REE resources in EU. The REE in the tailings are in monazite and apatite minerals. REE contents in monazite are LREEs (approx. 2100 ppm). In apatite trace amounts of REE are found. 903 ppm La, 2047 ppm Ce, 239 ppm Pr, 906 ppm Nd, 148 ppm Sm, 19.1 ppm Eu, 138 ppm Gd, 16.2 ppm Tb, 664 ppm Y, 101 ppm Dy, 17,3 ppm Ho, and 54,1 ppm Er (Peelman, Kooijman, Sietsma, & Yang, 2018).



Figure 6. LKAB mine tailings in Sweden

2.3. REE potential deposits in the EU

Despite the existence of rare earth deposits in the EU, the EU is currently 100% dependent on imports from China. There are REE deposits in the EU, normally with lower metal grade compared with common sources, so their extraction is uneconomical. To compensate for the relatively low grades, a cost-effective extraction process is needed, as for example, it is REE4EU. Two deposits have been identified in the literature as the most promising ones.

a. Hydrothermal metalliferous sediments in Troodos ophiolite (Cyprus)

These sediments are normally composed of amorphous Fe and Mn oxides with minor goethite, quartz and zeolites, and contain 350-500 mg/kg of REY (200 times lower than many of the major REY sources ores, 0.06% TREO) with low concentrations of radioactive elements (Josso, et al., 2018). Some studies have confirmed the potential of deep-sea sediments as REY sources (Yasukawa, Nakamura, Fujinaga, & Machida, 2015)



Figure 7. Massif sulphide deposit in Troodos ophiolite (Young, 2014)

b. Fen carbonatite complex in south Norway: enriched REE/Th deposit

This complex is considered among the largest REE deposits in the world, as it is reported to have 486 Mt of soviet rock type grading about 0.9% TREO. REE concentration in the samples is (approximate values) 89.82 mg/kg Sc, 1566.78 mg/kg La, 3355.32 mg/kg Ce, 525,56 mg/kg Pr, 2292.56 mg/kg Nd, 329.1 mg/kg Sm, 69.24 mg/kg Eu, and 192.50 mg/kg Gd (Davris, et al., 2018). Caustic soda cracking, sulfuric acid baking or a combination of roasting and HCl leaching are the main industrial methods for the treatment, so the REE4EU technology can represent an economic and viable alternative for REE removal from this deposit.



Figure 8. Fen carbonatite complex in Norway (from Fennoscandian Exploration and Mining web)

2.4. Industrial wastes containing REE in EU

The industrial wastes contain in general much lower concentrations of rare earth than the EoL consumer goods, but the volumes of industrial wastes are so wide that the total amounts of rare earth are very large and may secure and independent source of rare earth and a shield resources-poor countries from export quotas and price-fluctuations (Binnemans, Jones, Blanpain, & Gerven, 2015). The most important industrial wastes identified in the EU are described below.

a. Bauxite residue or “red mud”

The bauxite is a mixture of impure hydrated aluminium oxides. All rare earths end up in the red mud after the processing of bauxite by Bayer process, so the enrichment factor of the rare earths in bauxite residue is about two, being for example the average concentration in the bauxite residue from the Parnassos-Ghiona mountains in Greece of 1040 ppm. Sc concentration is about 130 ppm in Greek bauxite residues. The rest of REE concentrations in Greek bauxite residues are 149 ppm La, 418 ppm Ce, 25.8 ppm Pr, 115 ppm Nd, 28.9 ppm Sm, 5 ppm Eu, 23.3 ppm Gd, 12.8 ppm Dy, 4.3 ppm Ho, 17.2 ppm Er, 15.6 ppm Yb, 2.4 ppm Lu, 93.9 ppm Y (Binnemans, Jones, Blanpain, & Gerven, 2015). Aluminium of Greece contains over 4,5 Mt of bauxite residue, and it is estimated to be in operation for another 20 years. The TREO content is 0.14% and is claimed to amount nearly the 10% of the annual European demand. These residues are subject of REE leaching in several H2020 past and on-going projects: EuRARE, REDMUD MSCA, ENEXAL, SCALE, REMOVAL and ENSUREAL, but the REE4EU technology would be unique for the REE extraction from these residues (Balomenos, 2018) .



Figure 9. Bauxite residues at Aluminium of Greece mine

b. Phosphogypsum

Phosphogypsum is the main by-product of the production of phosphoric acid by sulphuric acid digestion of a concentrated slurry of pulverised phosphate ores (Binnemans, Jones, Blanpain, & Gerven, 2015). Around 70-85% of the REE originally present in the phosphate rock are present in the phosphogypsum waste, whose average REE concentration is 0.4 wt.%. Phosphogypsum contributes to global environmental and economic problems (Podbiera-Matysik, Gorazda, & Wzorek, 2015).

The possibilities of its waste-free processing are large, but the requirement of suitable technologies allowing for the individual characteristics of given wastes is stated. Thus, REE4EU technology could represent a suitable technology for REE removal from phosphogypsum, as common method is based on sulfuric acid leaching (Binnemans, Jones, Blanpain, & Gerven, 2015).

In EU two deposits are identified as the most promising ones (Zevenhoven, Morales-Flórez, Santos, & Esquivias, 2017) s:

- Silinjärvi deposit in Finland: 55 Mt of phosphogypsum (1.5 Mt added each year) are stored in the Silinjärvi deposit (Finland). The most abundant REE present in this deposit are Nd, Er and Eu.
- Huelva deposit in Spain: around 120 Mt after depositing during 1968-2010. 28000 tonnes of REE are present in this deposit.



Figure 10. Phosphogypsum deposits in Huelva (on the left) and in Silinjärvi (on the right) (Zevenhoven, Morales-Flórez, Santos, & Esquivias, 2017)



In the following picture, the different feedstocks described above for the REE4EU replication plan have been placed in the EU. For the sake of clarity, the different type of feedstocks has been differenced by colours (see legend) which coincide with the colours used for the description of each of the above.

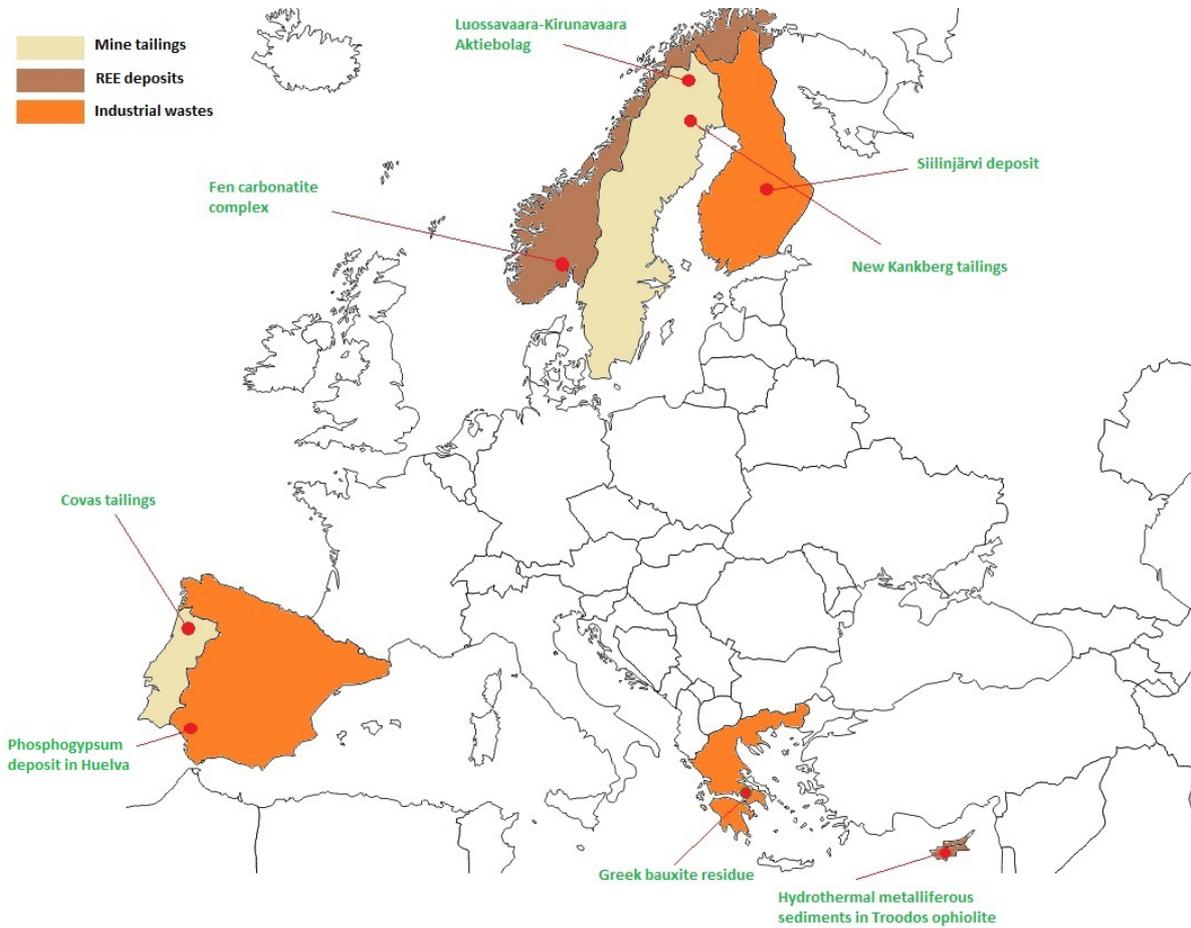


Figure 11. Map showing the main locations in EU of the feedstocks identified in section 2





3 Integration of REE4EU processes for REE extraction from identified sources

3.1. REE production from mine tailings

Mine tailings have the inconvenient of being composed of a huge variety of metals apart from REE. Past processing methods for REE ores were not very efficient and targeted metals were not REEs. Several authors have attempted to develop metallurgical processes for REE extraction from mine tailings. Solvent extraction allows for the recovery of individual REEs with high purities (Tunsu, Menard, Eriksen, Ekberg, & Petranikova, 2019). Thus, the ILE process of REE4EU is proposed as an alternative to the conventional solvent extraction (using Cyanex 272, Cyanex 925, Cyanex 923, Cyanex 572, DEHPA, etc) as a more sustainable one, being possible to tune the ionic liquid for making it more selective for the targeted metals. In the following Figure 12 and Figure 13, the possible integration of REE4EU is shown for the different mine tailings selected before: New Kankberg and Covas tailings.

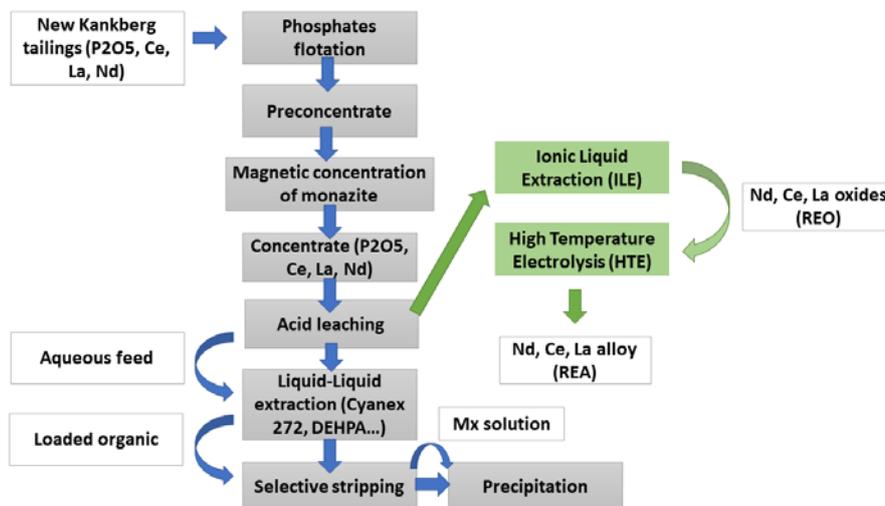


Figure 12. Possible integration of REE4EU processes for REA production from New Kankberg mine tailings. Redrawn from (Tunsu, Menard, Eriksen, Ekberg, & Petranikova, 2019)

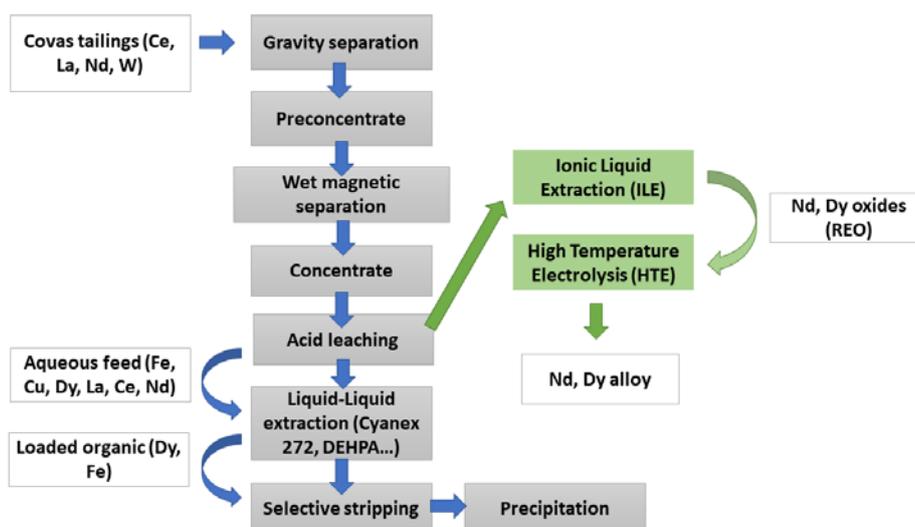


Figure 13. Possible integration of REE4EU processes for REA production from Covas mine tailings. Redrawn from (Tunsu, Menard, Eriksen, Ekberg, & Petranikova, 2019)





In the case of mine tailings from Kiruna mine in Sweden, the authors proposed the process shown in Figure 14. This process uses kerosene and P350 as solvent extractants, and after precipitation and calcination the electrolysis produces the REE metal. Thus, the REE4EU could be integrated as shown in Figure 14 (in green).

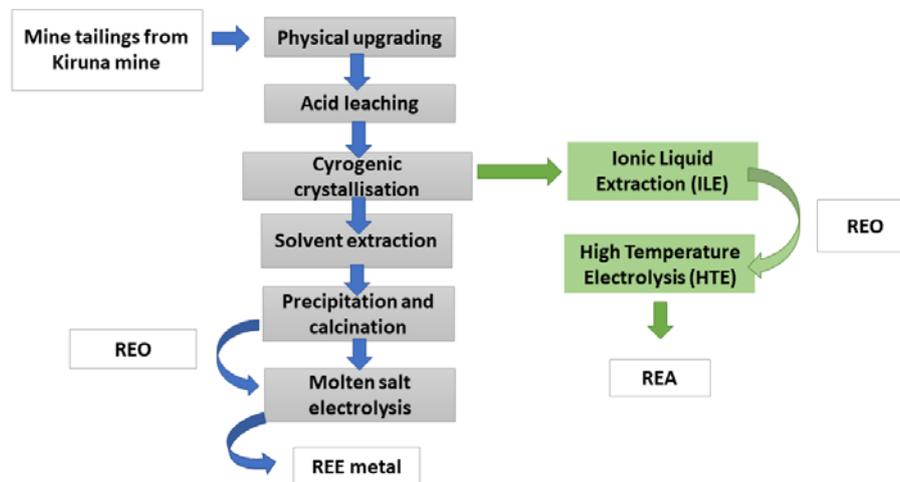


Figure 14. Possible integration of REE4EU processes for REA production from Kiruna mine tailings. Redrawn from (Peelman, Kooijman, Sietsma, & Yang, 2018)

3.2. REE production from EU mine deposits

The Troodos ophiolite resource is dominated by amorphous Fe and Mn oxides with 350-500 mg/kg of rare earth elements and yttrium. Such low grades must be compensated with a cost-effective extraction process (Josso, et al., 2018). A possible flowsheet (Figure 15, in grey) was presented as an option by (Josso, et al., 2018) to obtain a mix of REO from the resource. To avoid so many steps (time, costs, wastes) it could be possible to tailor the ILE process of REE4EU.

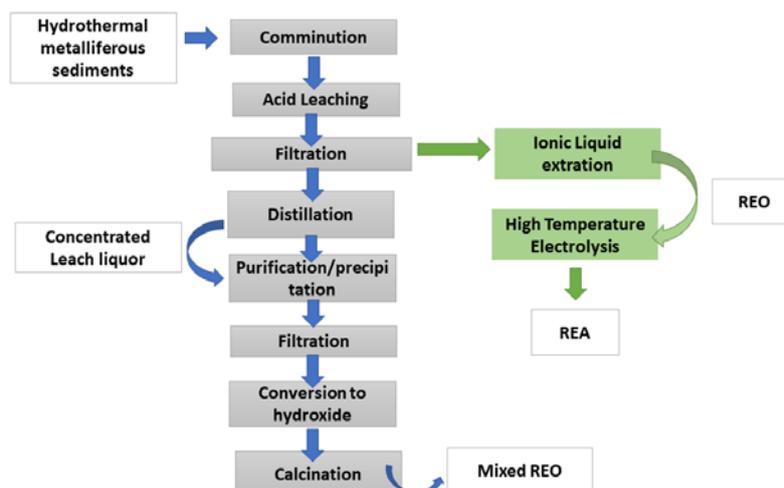


Figure 15. Possible integration of REE4EU processes for REA production from hydrothermal metalliferous sediments. Redrawn from (Josso, et al., 2018)

Fen carbonatite deposit in Norway is dominated by fluoro-carbonates of bastnäsite group minerals. It contains LREE and HREE.



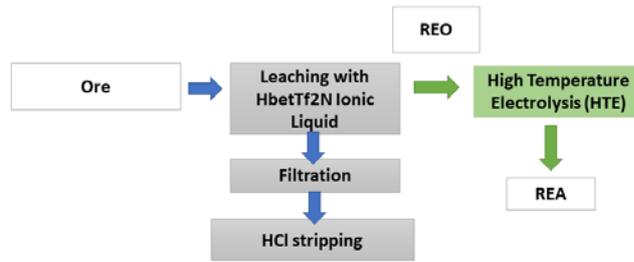


Figure 16. Possible integration of REE4EU processes for REA production from FEN carbonatite complex. Redrawn from (Davris, et al., 2018)

3.3. REE production from industrial wastes

Around 70-80% of REEs originally present in the phosphate rock end up in the phosphogypsum. Although its low-grade, the huge volume of this landfilled residue near fertiliser industries may contain enough REEs to be mined if selective recovery methods are developed (Cánovas, Chapron, Arrachart, & Pellet-Rostaing, 2019). Thus, the ionic liquids are perfect candidates as they can be tailored to make them specific for certain metals. Cánovas *et al.* (2019) studied the metal leaching of the phosphogypsum from Huelva following the scheme shown in Figure 17. Possible integration of REE4EU for REE recovery from phosphogypsum is also drafted.

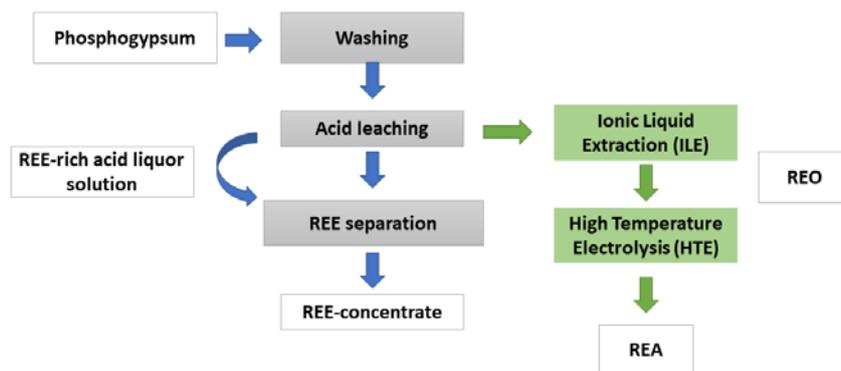


Figure 17. Possible integration of REE4EU processes for REA production from phosphogypsum. Redrawn from (Cánovas, Chapron, Arrachart, & Pellet-Rostaing, 2019)

On the other hand, as commented above, the bauxite residues or “red mud” also contain REE which could be economically extracted due to the high quantity of existing residues.

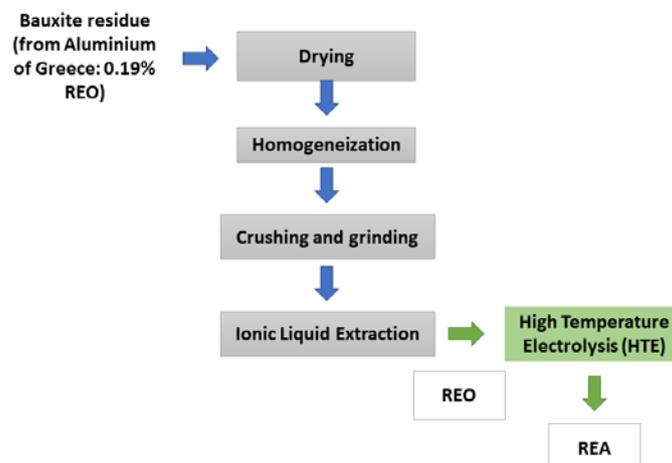


Figure 18. Possible integration of REE4EU processes for REA production from bauxite residue. Redrawn from (Bonomi, et al., 2018)





4 REE4EU replication to potential feedstocks

Once that the potential REE feedstocks are identified and studied, representative cases of each potential feedstock have been selected in order to predict the general behaviour of these REE sources within the REE4EU process:

- Mine tailings: Covas (Portugal) and New Kankberg (Sweden) mines.
- Mine deposits: Rödberg (Norway).
- Industrial wastes: phosphogypsum from phosphate production in Huelva (Spain).

In the following subsections, each case will be run using the MDO tool developed for the REE4EU project. The model in which the MDO is based is divided into operations or modules (Figure 19); therefore, each block can be simulated individually, and its operating conditions can be optimized simultaneously.

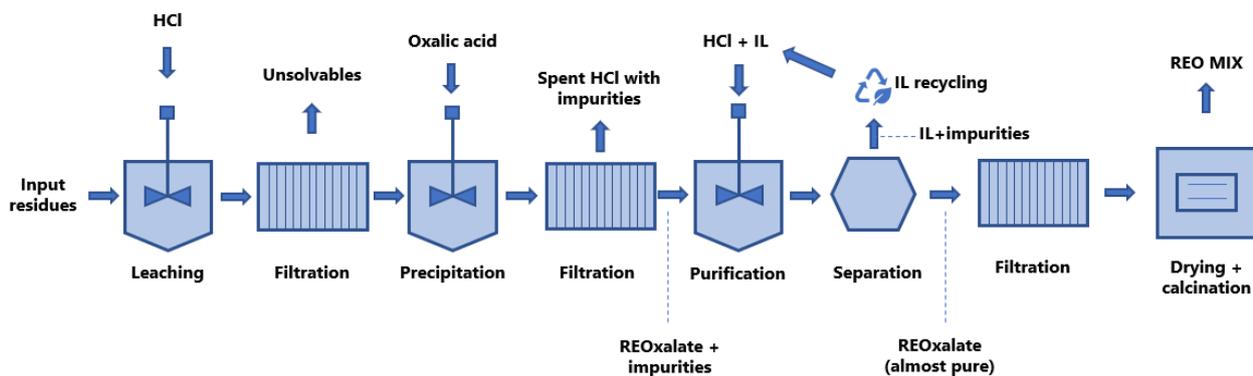


Figure 19. Modules conforming the REE4EU MDO

4.1 Mine tailings case replication

Mine tailings are the ore wastes generated during normal operation in mines and, therefore, they contain several toxic elements, which makes it an environmental problem. REE4EU technology, though, enables the mining industry to exploit its residues and benefit from it, as mine tailings carry multiple REE and other critical raw materials, reducing environmental impact as well.

Two representative cases have been chosen between a myriad of options, Covas mine in Portugal (Tunsu, Menard, Eriksen, Ekberg, & Petranikova, 2019) and New Kankberg in Sweden (Tunsu, Menard, Eriksen, Ekberg, & Petranikova, 2019). Both mine tailings contain REE such as Ce, Nd, La and Dy, and a high concentration of non-REE elements like Fe, Cu or P. Table 1 shows compositions of both tailings.

Table 1. Mine tailings initial concentrations

Element	Concentration (% w/w)	
	Covas	New Kankberg
Nd	0,11	3,73
Dy	0,03	0,84
Ce	0,19	6,80
La	0,11	4,01
Fe	49,79	0
Cu	49,77	0
P	0	84,62

For the case of the tailings of these two mines, the main results obtained from the MDO are collected in the following Table 2 and Table 3.



Table 2. Main results from Covas tailings mine

Leaching	Precipitation	Purification and Separation	Drying and Calcination	HTE
REE in leachate: Nd 79%, Dy 96%, Ce 76%, La 76%	REE precipitation: ~ 100%	-	Target mass loss: 50%	Total REA obtained from the feedstock: 0.64%
Fe in leachate: 37% Cu in leachate: ~ 100%	Fe precipitation: ~ 0% Cu precipitation: ~ 0%	Fe recovery: 57% Cu recovery: 0%		

Table 3. Main results from New Kankberg tailings mine

Leaching	Precipitation	Purification and Separation	Drying and Calcination	HTE
REE in leachate: Nd 79%, Dy 96%, Pr 77%	REE precipitation: ~ 100%	-	Target mass loss: 50%	Total REA obtained from the feedstock: 1.85%
P in leachate: ~ 100%	P precipitation: 0%	P recovery: 0%		

In this replication case, the results obtained in the leaching step show a good conversion of the process for the REE. However, in both cases, impurities such as Cu in the case of Covas tailings and P for New Kankberg tailings go through the treatment process where they can't be precipitated or separated in the following steps. As a result, these impurities remain until the HTE step where they interfere in the obtention of the REA product. Besides, the amount of total REA in the output is much less than the one obtained in the end-of-life product case and the composition, based on Nd, Dy, Ce and La as REE, doesn't allow to get an REA with direct industrial applications and market interest.

In order to overcome these issues and to get a potential REA as an output of the process, some modifications of the conditions of the subprocesses involved in the REE4EU process could be applied. For instance, in the leaching step, selective dissolution of rare-earth elements, Nd in this case, could be obtained using other leachate agents. A recent study (Entezari-Zarandi & Larachi, 2019) shows that dissolution in choline-chloride based deep eutectic solvents (DES) of multicomponent mixtures of REE, allows the separation of Nd from La and Ce. With this approach, and within the mine tailings use case, Nd and Dy could be selectively leached from the feedstock and recovered as a suitable REA at the end of the process. For Cu and P impurities, the solution is in the purification and separation agents. Research on selective purification agents (Cyanex 272, Cyanex 925, Cyanex 923, Cyanex 572, DEHPA, etc.) should be developed in order to find the proper reactants to be present in this stage. This way, a purification and separation step could be designed in several stages so the present impurities could be removed from the main stream before the calcination of the solid products. This processes could be integrated into the system flowsheets defined in Figure 12 and Figure 13 so, in the end, the desired obtained product could be ready to be introduced into the market.

4.2 Mine deposits case replication

Mine deposits have the inconvenient of being composed of a huge variety of metals apart from REE. There are multiple REE deposits in the EU, but their exploitation could be economically unfeasible due to a lower REE grade compared to other available sources. In order to assess this, Rödberg mine in Norway has been chosen as a representative case to be simulated, and its results will be analysed. Table 4 shows the composition of this specific mine.



Table 4. Mine deposit initial concentration

Element	Concentration (% w/w)	Element	Concentration (% w/w)
Nd	0,73	Gd	0,06
Dy	0,01	Eu	0,02
Pr	0,15	Th	0,20
Ce	0,97	Ca	76,16
La	0,54	Fe	7,08
Sm	0,11	Mg	13,91
Y	0,06	Sc	0,02
Er	0,01		

Main results obtained from the MDO will be analysed based on Table 5.

Table 5. Main results from mine deposits case

Leaching	Precipitation	Purification and Separation	Drying and Calcination	HTE
REE in leachate: ~ 54%	REE precipitation ~ 90%	-	Target mass loss: 50%	Total REA obtained from the feedstock: 4.35 %
Other metals in leachate (Ca, Mg, Fe) ~ 40%	Other metals precipitation ~ 0%	Fe recovery: 57% Mg, Ca recovery: 0%		

In the specific case of mine deposits, and as it was said at the beginning of this section, the variety of metals present in the feedstock makes difficult the direct implementation of the REE4EU technology when processing this material. The initial concentration of REE is low, with the presence of impurities in bigger amounts such as Ca and Mg. As a result, the obtained REA from the process is composed of an alloy made of different REE that don't have a direct industrial application. In this sense, the proposed solution for the replication of the REE4EU technology in the case of mine deposits lands on the integration of the REE4EU ILE technology into the actual process, as mentioned in section 3.2. A potential solution is to extract the REE using the functionalized ionic liquid HbetTf2N (Davris, et al., 2018) and to design a selective process for the precipitation of the REE of interest. This way, the purification and separation stages will be more efficient and the output could be dried, calcinated and treated with the HTE technology as proposed in Figure 16.

4.3 Industrial wastes case replication

Some chemical processes use mineral rocks as feedstock, such as the fertilizer industry, which processes phosphate rock with an important number of REE. Nevertheless, around 70-80% of initial REE present in the rock ends up in phosphate residue, phosphogypsum, so that it is a valid candidate for evaluating REE4EU within industrial waste management. A representative example is phosphogypsum generated at Huelva (Spain), as it contains many REE.

It is usually to subdivide REE in two groups: Heavy REE (from Eu to Lu plus Y) and Light REE (from La to Sm), and both of them exist in a concentration around 100 ppm in the proposed replication case (Table 6); therefore, it is foreseen that it will occur as in mine deposits case replication, in section 4.2. In order to analyse the outputs from the MDO, the main results are collected in Table 7.





Table 6. Phosphogypsum initial concentrations

Element	Concentration (ppm)	Element	Concentration (ppm)
Nd	48,0	Gd	12,0
Dy	13,0	Eu	1,8
Pr	11,0	Ho	3,0
Ce	36,0	Tb	1,8
La	62,0	Tm	1,1
Sm	9,2	Yb	7,2
Y	129,0	Lu	1,0
Er	8,9	Fe	52

Table 7. Main results from industrial waste case

Leaching	Precipitation	Purification and Separation	Drying and Calcination	HTE
REE in leachate: ~ 40%	REE precipitation ~ 85%	-	Target mass loss: 50%	Total REA obtained from the feedstock: 0.014 %
Other metals in leachate (Ca, Mg, Fe) ~ 60%	Other metals precipitation ~ 0%	Fe recovery: 57% Other metals recovery: 0%		

In this study case, the REE4EU process is not a suitable solution for the separation and recovery of REA. Due to the low concentration of REE in the feedstock and the diversity of REE and other metals, the process is not economically and technically feasible. A potential solution for this industrial waste case would be in the concentration of the metals before the leaching process. This step could be included after the washing process, shown in Figure 17. This way the input material would be prepared to be used as feedstock for the ILE process that has to be conditioned for a selective leaching process, as proposed in section 4.2 with the mine tailings case, and a proper precipitation and purification steps. This way, the REE4EU process could be integrated into the process as a solution for the treatment of phosphogypsum as industrial waste.





5 Conclusions

- In this deliverable, a replication strategy for the REE4EU process and technology has been developed.
- The replication strategy is based on the pilot results, the business plan and other value chains that have been identified in the literature.
- As a first step, potential feedstocks have been identified and described covering four main sectors: end-of-life products, mine tailings, mine deposits in EU and industrial wastes.
- Several examples have been selected for all sectors in order to analyse their potential to be used as feedstock for the REE4EU process:

Sector	Case
Mine tailings containing REE in EU	New Kankberg tailings in Sweden
	Covas tailings in Portugal
	Luossavaara-Kirunavaara Aktiebolag (LKAB) tailings in Sweden
REE potential deposits in the EU	Hydrothermal metalliferous sediments in Troodos ophiolite (Cyprus)
	Fen carbonatite complex in south Norway: enriched REE/Th deposit
Industrial wastes containing REE in EU	Bauxite residue or "red mud"
	Phosphogypsum

- Relevant data from the most representative cases have been identified and selected to be introduced into the MDO.
- Main outputs from the MDO have been selected in order to analyse the results.
- Mine tailings and REE deposits in EU sectors can be replicated adapting the operational conditions and the reactants involved in the leaching, precipitation and purification steps in order to obtain a suitable product that can be introduced into the market. Further experimental research is needed in these sectors to provide the optimal solution based on the selectivity of the metals of interest.
- Due to the high variety of metals involved and their low concentration, the industrial case can't be replicated as it is. Integration of the current process with the ILE process, besides a previous concentration step, could be a potential solution to this specific case.





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