Recovery of rare earth elements from mine tailings

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Background

- LREEs and HREEs have the highest supply risk of all raw materials needed by the EU.

- REEs are regarded as critical materials not only by the EU.

- Availability, demand, price fluctuations, geo-political factors, large variety of applications, specificity etc.

- Essential in sustainable energy applications (efficient lighting, electric transportation, wind power) and many other fields.

European Commission, 2017. Study on the review of the list of Critical Raw Materials
Processing of secondary sources

• The EU imports about 8000 tons of REE/year (excluding REEs in products). This is about 14% of the REEs produced by China, by far the largest REEs exporter.

• No REEs production in currently located in the EU. There are, however, some plans for development, e.g. Norra Kärr (SE).

• Recent focus: the possibility to recover critical raw materials from secondary sources:
  • Fluorescent lamps, permanent magnets (e.g. from HDDs) and NiMH batteries are attractive urban mining sources for REEs.
  • Tailings and other by-products from previous mining activities in the EU can hold significant amounts of critical raw materials, not just REEs but also W, P etc.
• ERA-MIN 2\textsuperscript{nd} Joint Call Project. Launched in January 2015 and planned for 3 years.

• 11 partners from 8 countries. Coordinated by Chalmers University of Technology, Sweden.
## Research topics

- **Extraction**: Integrated processes and system approach, and innovative waste management.
- **Mineral processing**: Processing of low grade and complex materials in efficient ways.
- **Metallurgy**: Treatment of by-products and wastes with recovery of the contained metal value.

### Enviree Work Structure

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<th>WP6: Project Management <em>(Chalmers)</em></th>
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<td>WP5: Training, education, dissemination and market uptake <em>(IST-ID)</em></td>
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<td>WP2: Leaching of selected materials <em>(CEA)</em></td>
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<td>WP4: Evaluation of environmental impact and economic feasibility <em>(AGH)</em></td>
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### Target materials

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<th>Material provider</th>
<th>Type of material provided</th>
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<tr>
<td>Bolden, Sweden</td>
<td>Tailings containing REE</td>
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<td>Council for Geoscience, South Africa</td>
<td>Different secondary materials and mine residues from South Africa mines and processing plants where REE has been identified as potential by-product</td>
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<tr>
<td>EDM, Portugal</td>
<td>Waste rock and tailing potentially containing REE</td>
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<td>Rio Tinto, Australia</td>
<td>By-product from the mineral sand operations with potentially high content of REE and Th</td>
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<td>ZNP SAV s. r. o., Slovakia</td>
<td>Red mud from abandoned alumina production (from bauxite)</td>
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| DIAMO-GEAM a.s., Czech Republic    | a) samples from uranium production  
                                  b) samples from tailing ponds  
                                  c) mine water from Zlate hory area  
                                  d) samples from waste rock pile |
| Hellenic copper mines LTD, Cyprus | Tailings from copper mining and processing                                                |
| AGH, Poland                       | Tailings from copper ore processing – post flotation waste                                 |
|                                  | Tailings from zinc and lead ore processing – post flotation waste                         |
|                                  | Tailings from sculpture ore processing – post flotation waste                            |
| TERAMED Ltd., Czech Republic      | Mining waste from different locations in the Czech Republic                              |

- Tailings from lead, zinc, copper, sulfur, phosphate ores mining and treatment
- Red mud.
- Waste rock from other mining activities, possibly enriched with REEs.
Two examples

• Tailings from sulphide flotation stage of the Boliden concentrator, New Kankberg (Sweden)
  • Phosphates present as monazite and apatite, with minor amounts of xenotime and berlinite

• Tailings from underground tungsten mining (1954-1984), Covas (Portugal)
  • W: mainly scheelite and minor wolframite

Sulfides flotation tailings
- 170 ppm Ce
- 90 ppm La
- 70 ppm Nd
- 0.17% P₂O₅

Covas tailings
- 32 ppm Ce
- 16 ppm La
- 15 ppm Nd
- 1900 ppm W
Beneficiation

New Kankberg tailings

**Phosphates flotation**
- depressant: Water glass 700 g/t
- Collector Resineline 802 + Aero 845 : 80 + 50 + 30 g/t
- 1 rougher step
- 2 scavenging steps
- 1 to 2 washing steps

**Pre-concentrate**
- 1.8 % P₂O₅ (recovery: 70%)
- 1600 ppm Ce (recovery: 50%)
- 800 ppm La (recovery: 50%)
- 650 ppm Nd (recovery: 50%)

**Magnetic concentration of Monazite**
- 2 steps (4 000 & 15 000 G)

**Concentrate**
- 2.5 % P₂O₅ (recovery: 17.5%)
- 5000 ppm Ce (recovery: 37.5%)
- 2800 ppm La (recovery: 37.5%)
- 2300 ppm Nd (recovery: 37.5%)

Covas tailings

**COVAS tailings**
- 32 ppm Ce
- 16 ppm La
- 15ppm Nd
- 1900 ppm W

**Gravity separation**
- MGS

**Pre-concentrate**
- 175 ppm Ce (recovery: 75%)
- 87 ppm La (recovery: 75%)
- 78 ppm Nd (recovery: 75%)
- 3 000 ppm W (recovery: 50%)

**Concentrate**
- 250 ppm Ce (recovery: 55%)
- 140 ppm La (recovery: 55%)
- 120 ppm Nd (recovery: 55%)
- 24 000 ppm W (recovery: 35%)
Hydrometallurgical treatment

- Leaching of metals
- Separation and recovery of metal ions in solution using solvent extraction
Leaching

• Low solubility of REEs phosphates:
  • acidic leaching
  • heating/conversion of phosphates required for efficient leaching

• Leaching selectivity between REEs/W for Covas tailings

• Potential for P recovery from New Kankberg feed
Solvent extraction of REEs

Finding extraction systems that perform satisfactory in various acidic media (high phosphate, Fe, Cu concentrations)

- Diglycolamides (TODGA and analogues of TODGA)
- Ionic liquids
- New malonamides

Figure 4.1-1: Molecular structures of: a - N,N,N',N'-tetrakis(2-ethylhexyl)malonamide (TIOMA); b - 2,2'-(1,2-phenylenebis(methylene))bis(N,N,N',N'-tetrabutylmalonamide) (B-BMA)
Solvent extraction of REEs

• Commercial extractants

Aliquat 336

Cyanex 923

Cyanex 572

DEHPA

Finding an efficient system that works in sulfuric acid media and allows for easy separation of LREEs/HREEs in the presence of large amounts of phosphate, Fe, Cu
Conclusions

- REEs still have the highest supply risk among raw materials needed by the EU.
- Tailings and by-products from previous mining activities can be a source of critical raw materials, REEs included.
  - Tailings from sulphide flotation, New Kankberg (Sweden) – REEs, P
  - Tailings from W mining, Covas (Portugal) – REEs, W
- Hydrometallurgy (leaching and solvent extraction) can be employed to recover critical raw materials.
Thank you for your attention!