Recycling of permanent magnets of WEEE

Challenges and Innovation in Recycling Processes, June, 2-3 2015

Nour-Eddine Menad & A. Seron
BRGM / Waste and Raw Material Unit
### CONTEXT

The developed countries deal with a persistent concern about the supply of rare metals. These rare metals are essential to the development of innovative high-tech industries, and particularly those associated with green energy.

The recent political crisis caused by China towards Japan with REE supply in balance (95% of the world's needs) did that amplify those concerns.

In this context, the European Union published in July 2014 report 'Critical raw materials for the EU' which classified twenty raw materials (REE) as strategic metals.

At the French level, the roadmap to improve the productivity of the resources is marked by the installation in April 2010 strategic metals Plan and the creation of the COMES (Committee for strategic metals) in January 2011.
Generally the REE are used in small proportions but their application for mass-market products makes that the world demand quickly increases.

Source: D. Kingsworth IMCOA 2011
### Forecasts supply/demand for rare earths in 2016

<table>
<thead>
<tr>
<th></th>
<th>World Demand</th>
<th>World Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>150-170 000 t</td>
<td>180-210 000 t</td>
</tr>
<tr>
<td>Cerium</td>
<td>60 - 70 000 t</td>
<td>75 - 85 000 t</td>
</tr>
<tr>
<td>Neodymium</td>
<td>25 - 30 000 t</td>
<td>30 - 35 000 t</td>
</tr>
<tr>
<td>Europium</td>
<td>625 - 725 t</td>
<td>450 - 500 t</td>
</tr>
<tr>
<td>Dysprosium</td>
<td>1 500 - 1 800 t</td>
<td>1300 - 1 600 t</td>
</tr>
<tr>
<td>Terbium</td>
<td>450 - 500 t</td>
<td>300 - 300 t</td>
</tr>
<tr>
<td>Yttrium</td>
<td>12 - 14 000 t</td>
<td>9 - 11 000 t</td>
</tr>
</tbody>
</table>

Ref: Dudley Kingsnorth, IMCOA – 02/2012
Applications of REE

Catalysts 21%
Glass industry 10%
Polishing 16%
Ceramics 5%
Phosphors 7%
Magnets 22%
Alloys 19%

Places of production of magnet

- China: 81%
- Japan & NE Asia: 13%
- USA: 2%
- RW include EU: 4%

Sources: IMCOA - Lynas Corp.
Permanent magnets

Reductions of size and weight made possible thanks to the permanent magnets Nd-Fe-B

![Magnets comparison diagram]

Source: Arnold magnetics
Rare earth permanent magnets

Rare earths:
17 elements

- Nd (Neodymium, 144.24)
- Fe (Iron, 55.847)
- B (Boron, 10.811)

Comparative table of maximum energy product for different permanent magnets:

- Nd-Fe-B
- Sm-Co
- AlNiCo
- Ferrite
Manufacturing process for Rare Earth Magnets

Neodymium value chain

- Nd-Fe-B magnet
- Nd-Fe-B alloy
- Pure Nd metal
- Rare Earth separation
- Rare earth concentration
- Mining rare earth ore (mixed)

Production process of Nd-Fe-B permanent magnet:

1. Melting
2. Milling
3. Pressing
4. Sintering
5. Annealing
6. Machining
7. Plating

Nd-Fe-B lingot produced by arc-melting
European Commission classify Rare Earth as strategic and critical materials\(^{(4)}\)
Permanent magnet containing REE in WEEE

For European (2012):

- Total magnet deposit estimated at 2 500 t/yr
- Neodymium deposit estimated at 550 t/yr
- Tripling of volumes by 2016?
China Dominates Growing Magnet Materials Market

WW Total Market Size $7B
2010, $15B by 2020

NdFeB magnets 75%

Rare Earth Oxide Ore production 95%

Rare Earth pure Metals nearly 100%

Japan, US, European producers close plants, move production

Approx ½ WW Alnico & SmCo production

Hard ferrites 65+ %
EXTRADE PROJECT (Recycling process units)

> Thermal treatment (demagnetization)
> Electrical (high-voltage electric pulses) and Mechanical treatment to recover magnets from the computer system unit
> Route 1 – elaboration of new magnets with recycled magnets powder (short loop)
  • Separation of Ni coating from NdFeB magnets
    — Mechanical treatment
    — Chemical treatment: solvo-thermal decrepitation
  • Press-molding in magnetic field / sintering / magnetization

> Route 2 – extraction of REE using innovative hydrometallurgical techniques
  • Weak & cheap acid selective dissolution
  • Selective recovery of REE using biomaterials

• 2 Patents in Progress
EXTRADE PROJECT

REEs containing components in WEEE

- Hard Disk Drives
- Loudspeakers
- Small electric motors

Metallic support
Magnet
durable
EXTRADE PROJECT (Sampling campagns)

Sampling of WEEE

*Manual sorting of HDD*

Loudspeaker shredding
EXTRADE PROJECT (Sampling campaigns)

Needs sampling
Manual dismantling

HDD

- Disque dur
- Magnet

Loudspeakers

- Metallic support
- Magnet

Small electrical motors

- Composite Magnet
- Magnets
- Magnetic field

## Quantification of magnet in electronic devices

<table>
<thead>
<tr>
<th>Sources</th>
<th>Weight % of magnet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer loudspeakers</td>
<td>4 – 6</td>
</tr>
<tr>
<td>HDD from central unit computer</td>
<td>2.5 - 2.8</td>
</tr>
<tr>
<td>HDD from Laptop</td>
<td>2 - 3</td>
</tr>
<tr>
<td>Small electric motors (A)</td>
<td>22 – 26</td>
</tr>
<tr>
<td>Small electric motors (B)</td>
<td>0.8 – 2</td>
</tr>
</tbody>
</table>
EXTRADE PROJECT (Characterization)

HDD characterization

- HDD from central unit computer
- HDD from Laptop

Graphs showing the mass % of permanent magnet vs. number of HDDs.
Composition of HDD

- Magnet: 3%
- Plastics: 1%
- Other metals: 1%
- Iron scrap: 8%
- PCB: 7%
- Aluminum: 80%
**EXTRADE PROJECT (Characterization)**

- Nd$_2$Fe$_{14}$B magnet
- Coating (Ni or Ni/Cu) thickness 28µm

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### Table: Elemental Analysis

<table>
<thead>
<tr>
<th>Elem</th>
<th>Weight %</th>
<th>Nd$<em>2$Fe$</em>{14}$B Theoretical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fek</td>
<td>69.6</td>
<td>72.0</td>
</tr>
<tr>
<td>NdL</td>
<td>28.1</td>
<td>27.0</td>
</tr>
<tr>
<td>DyL</td>
<td>2.3</td>
<td>1.0 (B)</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>
EXTRADE PROCESS (Recovery of magnets from HDD)

HDD → Demagnetisation → Liberation of magnets
Mechanical/Electro-fragmentation → Screening → HDD free of magnets to metallurgy

Permanent magnets

PATENT PENDING
EXTRADE PROCESS (Purification of magnet)

Isolated permanent magnet

Shredding

Milling

Mechanical Screening

Physical sorting

Product qualification Solvay-Rhodia

NdFeB magnet

Ni coating

PATENT PENDING
Route 1 – elaboration of new magnets with recycled magnets powder (short loop)
Route 2 – extraction of REE using innovative hydrometallurgical techniques

Dissolution kinetics of permanent magnets

Precipitation of Fe, Nd, Dy

Dissolution rate, %

Precipitation rate, %

Time, mn

pH

[Fe]  [Nd]  [Dy]
Route 2 – extraction of REE using innovative hydrometallurgical techniques

Selective sorption of REE using biomaterials

Remaining metals in solution, %

Bio materials

xA  xB xC xD xE xF

Nd  Dy Fe

Geosciences pour une Terre durable
Solvothermal treatment

Ni-Cu-Ni
Nd,Fe₂B
Nd-rich
Nd(OH)₃
Fe₃O₄

[Images of crystal structures and XRD patterns]
## Conclusions

The recycling of permanent magnets: an ecological solution to the difficulties of supply in rare earths

Recycling of REE from secondary materials complements the primary mining of REE ores

Waste stream of REE was identified
Amount of deposit was estimated

Recovery of REE from WEEE is challenging but possible

Extrade process is under development
THANK YOU FOR YOUR ATTENTION
Visit our website www.brgm.fr

You are welcome to visit our 2000 m² technology development facility

Geosciences pour une Terre durable
PETEC's neodymium magnet recovery system for air conditioning compressor motors

Magnet recycling by SANTOKU

- SANTOKU Corporation has opened in 2012
- a plant in Tsuruga (Japan) for recycling Nd and Dy from magnets
  - Motor magnets (air conditioners)
  - Magnet production scrap
- Demagnetization by heating (6 hours at 573 K)
- Milling under 75 micron by jaw crusher and pulverizer
- Oxidation by stirring for 12 hours in an alkaline solution
- Selective dissolution in HCl
- Magnet alloys prepared by molten salt electrolysis

Source SANTOKU

Panasonic Eco Technology Center Co., Ltd.

PETECK's neodymium magnet recovery system for motors of air conditioner compressors and drum-type washing machines (heating demagnetizing furnace)