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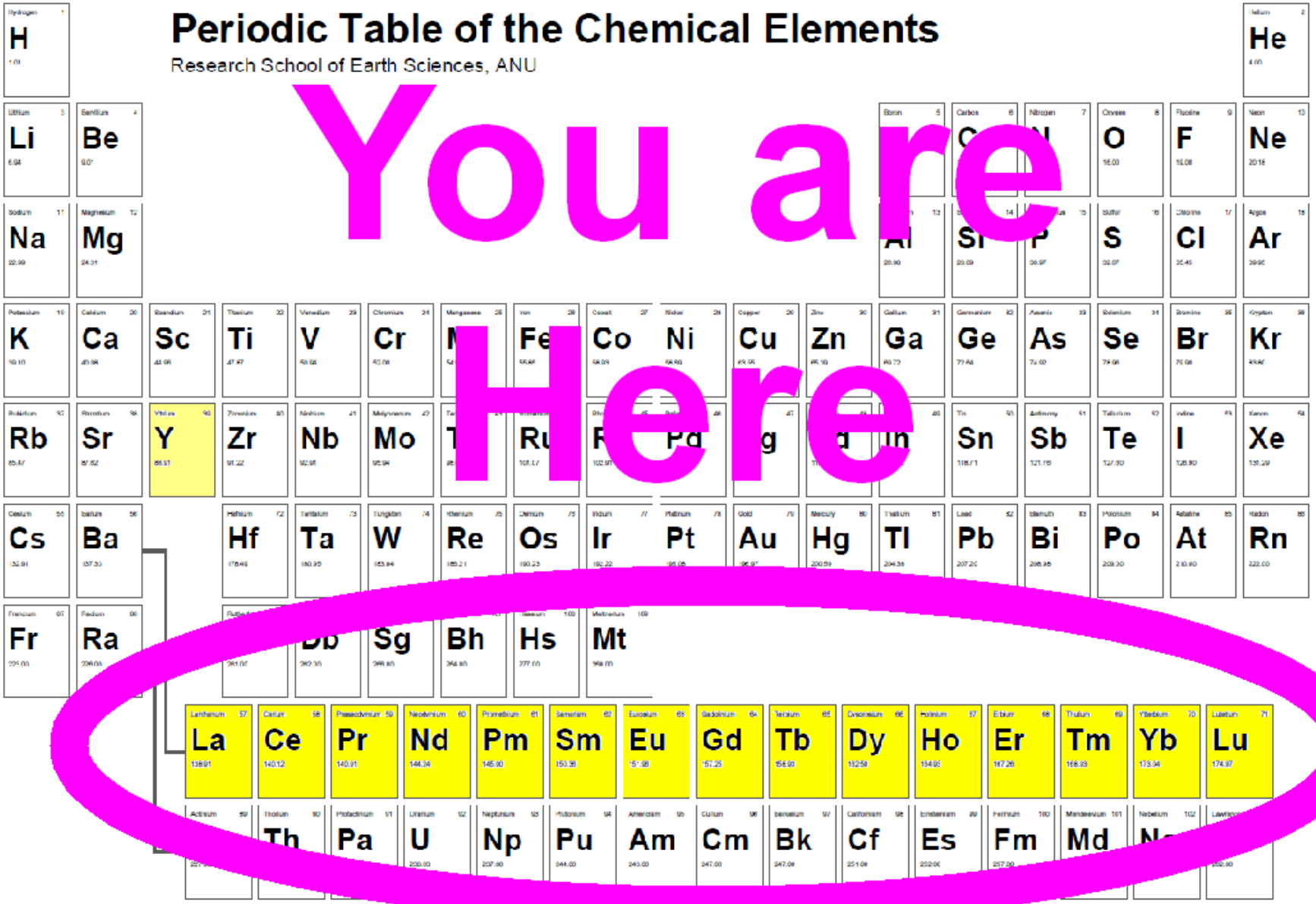
SOLVAY latest developments in Rare Earth Recovery from Urban Mines

Special Chem

Content

1. The RE market characteristics and the field of recycling
2. RE processing: Advantages and drawbacks of recycling
3. Recycling of RE at La Rochelle plant
   - From La Rochelle historical loss of yield
   - From NiMH batteries – A collaboration between Umicore and Solvay
   - From EOL lamps



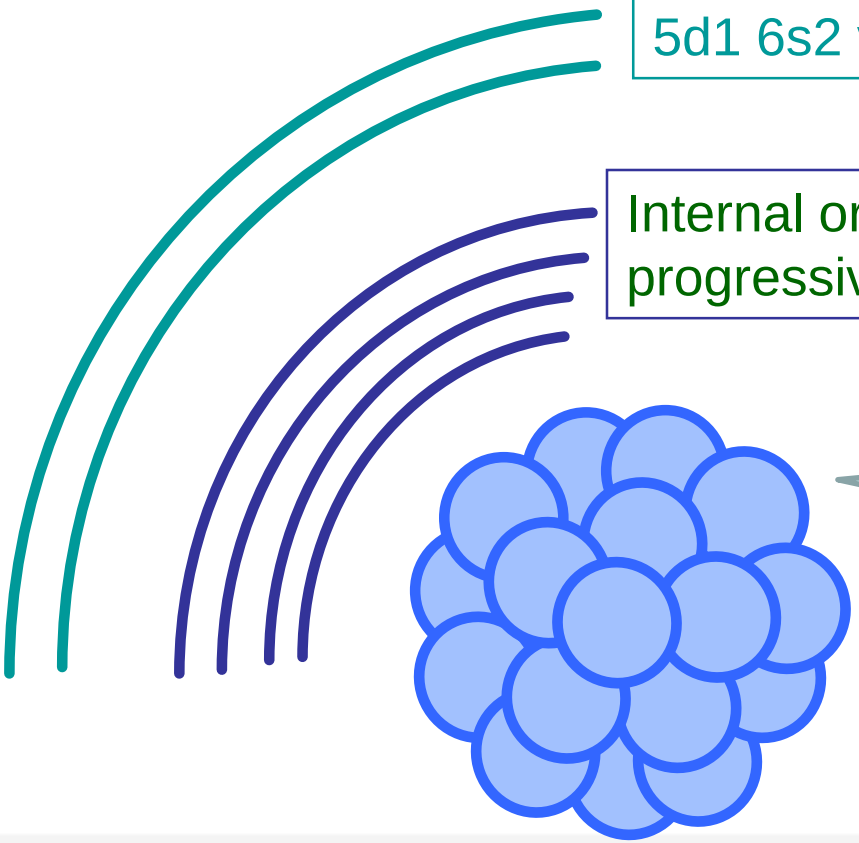
CHEMICAL AND PHYSICAL PROPERTIES OF RARE EARTHS

RE separation
is very difficult

Common external orbitals
5d1 6s2 valence electrons → Chemical properties

Internal orbital
progressival fillings 4f ➔ 0-14 → Physical properties

RE have very specific optical and magnetic properties



Nucleus

RE are the salt and pepper of emerging technologies

Medical

Communications

Defense Industry

Energy
Batteries
Fuel Cells

Lighting

Catalysis
Refinery

Specialty alloys

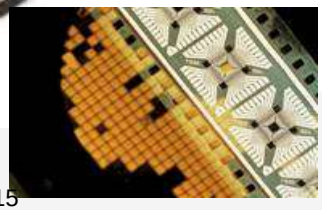
Car Industry

Nuclear Industry

DVD TV computers

Glass

GSM Ipod MP3



Ceramic

jewelery

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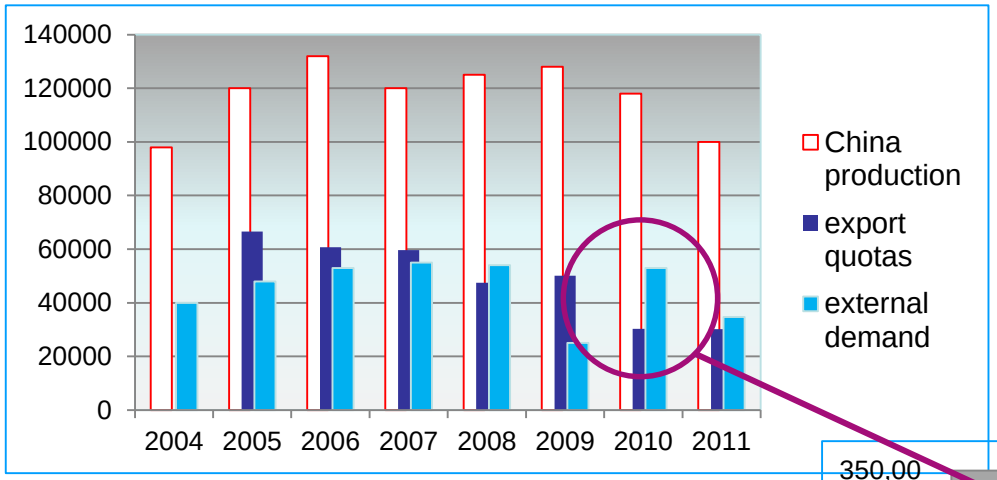
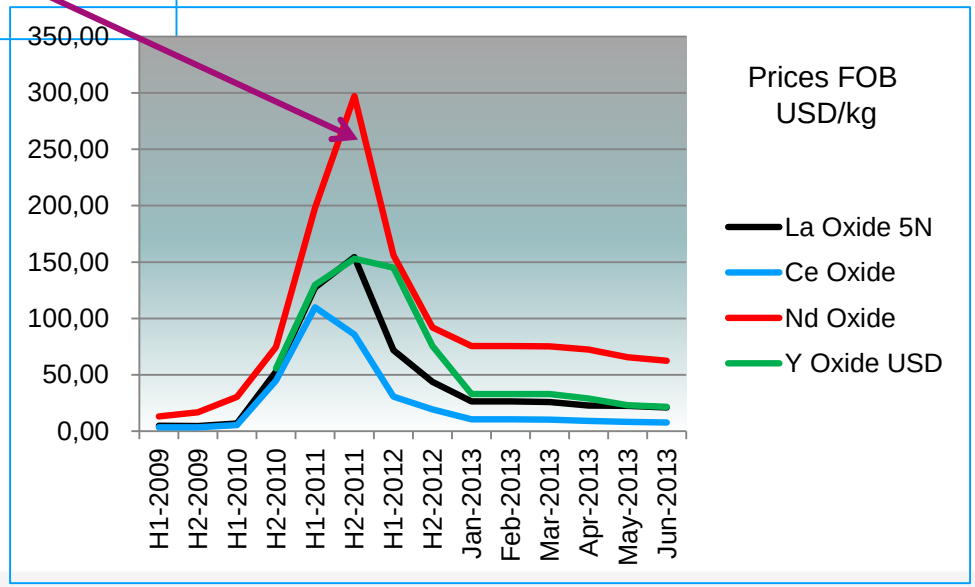
Most of the RE recycling projects have been launched during the RE crisis



Since 2005 China has decided to limit its exports by a quotas policy …

…in 2010 a -40% cut in the quotas generated a major crisis impacting drastically the prices on the market



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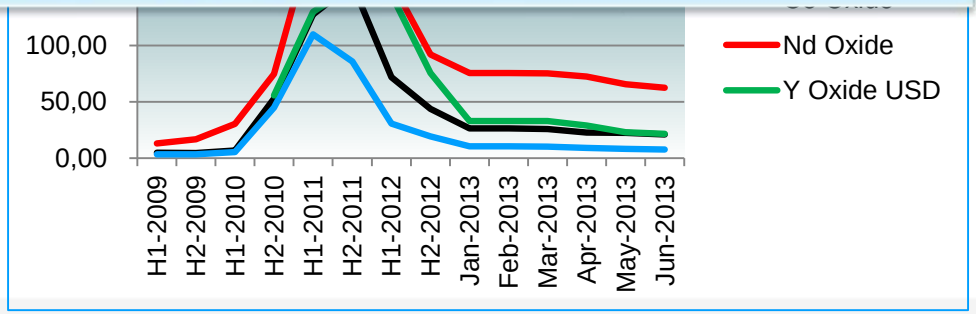
Most of the RE recycling projects have been launched during the RE crisis

This situation has led to a large number of recycling initiatives.

Now that RE are back to more normal prices most of these initiatives are unprofitable

a major crisis impacting drastically the prices on the market



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The RE recycling projects must take into account the key RE market characteristics

What are they?

1st characteristic: RE are everywhere

Communications

Medical

Defense Industry

Energy

Batteries

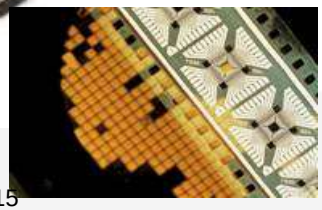
The RE recycling should be focused on existing concentrated deposits.

DVD TV computers

Nuclear Industry

Glass

GSM Ipod MP3



Ceramic

jewelery

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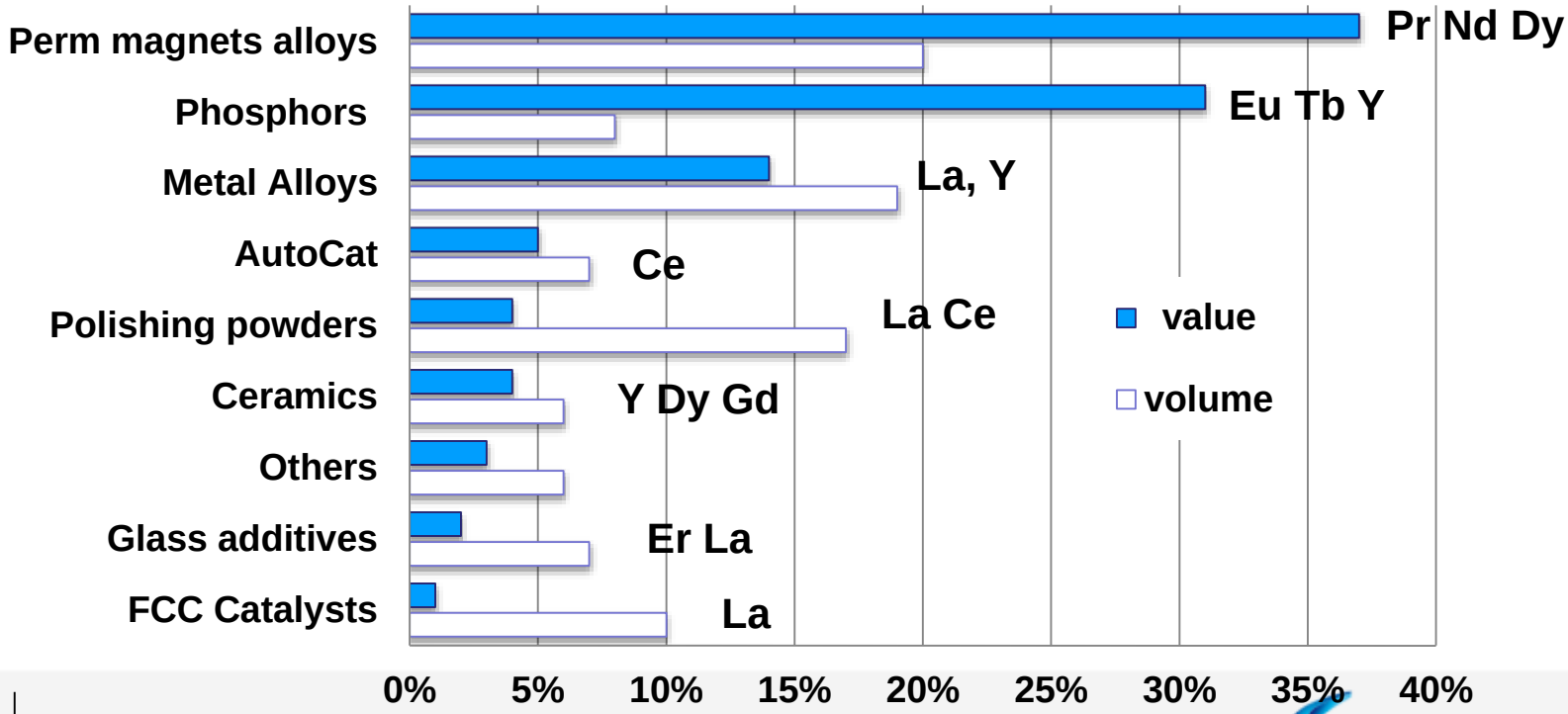
2nd characteristic:

The RE prices are very different from one RE to another

China FOB prices – December 2014

USD/kg	La	Ce	Pr	Nd	Eu	Tb	Dy	Y
oxide	4.1	3.7	98	56	545	555	295	11

-The size of the market is different in value and volume



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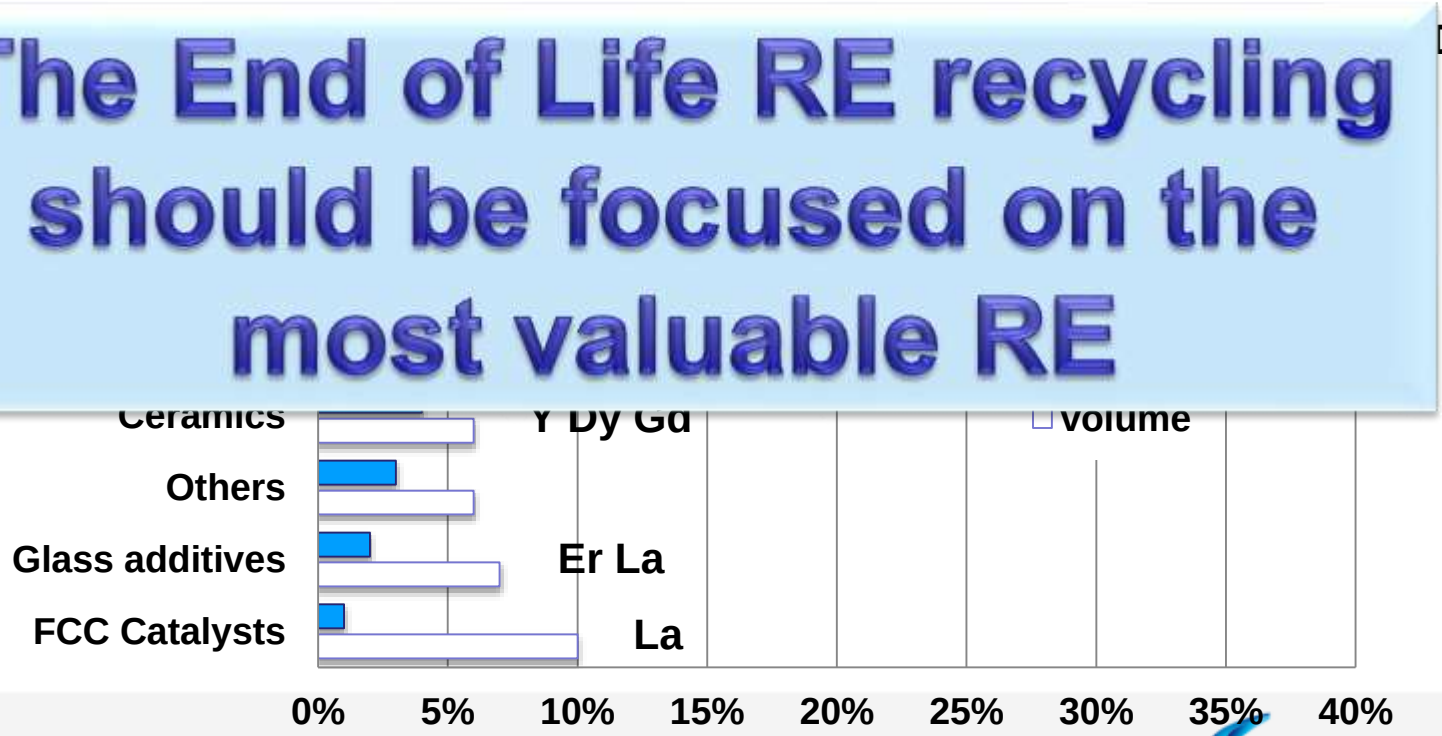
The End of Life RE recycling should be focused on the most valuable RE



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The key criteria for a RE recycling project

- The recycling of RE should be focused:
  - on existing concentrated deposits:
    - Existing tailings or losses from RE value chain
    - Existing recycling loops for End of Life products
  - on the most valuable RE

- Based on these criteria, ***Solvay*** decided in 2010 to recycle RE from:
  - Solvay La Rochelle plant historical loss of yield (All RE)
  - Production losses of Magnet manufacturers (Pr, Nd, Dy)
  - 2 types of EOL products:
    - Low energy consumption lamps (La, Ce,Tb, Eu, Gd & Y).
    - NiMH batteries (La, Ce, Pr, Nd) in cooperation with *Umicore* who recycles the nickel.

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A long value chain from the ore to the pure RE oxides, RE separation is the key step.

Mining site

Mining & concentration

Ore concentrate

Ore cracking

RE mix concentrate

All RE applications use pure individual Rare Earths

This RE mix concentrate has no market.

A long value chain from the ore to the pure RE oxides, RE separation is the key step.

Mining site

Mining & concentration

Ore concentrate

Ore cracking

RE mix concentrate

Solvay La Rochelle Separation facility

Pure RE solutions

RE finishing

Pure RE salts or oxides

- Solvent Extraction is the only industrial process used nowdays for RE separation
- Solvay La Rochelle plant is the only facility outside of China able to separate all RE including HRE.

A long value chain from the ore to the pure RE oxides, RE separation is the key step.

Mining site

Mining & concentration

No radioactivity

Waste management is easier than with natural raw materials

cracking

RE mix concentrate

Solvay La Rochelle Separation facility

Not all RE are present

RE separation step is simpler than with natural raw materials

Pure RE solutions

RE finishing

Pure RE salts or oxides

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RE mix concentrate

Solvay La Rochelle plant is the only facility outside of China able to separate all RE including HRE

In 2012 Solvay decided to restart main of its SX batteries for RE recycling

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Rare Earths recycling at La Rochelle plant

- Taking the adavantage of its existing separation facility at La Rochelle plant, Solvay decided in 2010 to launch a wide RE recycling project based on 3 pilars:

➢ RE recycling from La Rochelle historical loss of yield

➢ RE recycling from End Of life NiMH batteries – A collaboration between Umicore and Solvay

➢ RE recycling from End Of Life lamps

RE recycling from La Rochelle historical loss of yield

RE recycling from La Rochelle historical loss of yield

My God! A Rare Earth mine in La Rochelle!

Recycling started in October 2010

RE recycling from La Rochelle historical loss of yield

- Very complex stockpile with a large spectrum of individual compounds
- The process developped should be able to treat various types of minerals (oxides, phosphates, oxalates, silicates…)
- From 2010 until now this «deposit» represent an key part of La Rochelle raw materials

Recycling of RE from NiMH batteries
A collaboration between Umicore and Solvay

- Umicore started the recycling of Ni from NiMH with a specific process leading to a RE concentrate (M = La rich mishmetal)

- Solvay can recycle this RE concentrate at La Rochelle plant, producing RE specialties belonging to regularSolvay product portfolio

RE recycling from end of life lamps.. to close the loop

Several thousands Tons of powders are landfilled each year

Recycling companies

Valorization
- glass
- metals
- plastics
- mercury

Used lamps Collectors

LOOP
LIFE11 ENV/FR/744

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RE recycling from end of life lamps.. to close the loop

Several thousands Tons of powders are landfilled each year

Solvay recycling process

Rare Earth recovery
Several hundreds tons/y

Rare Earth Concentration

Rare Earth Separation

Rare Earth Finishing

New Green and red Phosphor precursors

Recycling companies

Valorization
- glass
- metals
- plastics
- mercury

Used lamps Collectors

LOOP
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RE recycling from end of life lamps

- The mineralogical composition of phosphor powders is very complex:
  - Halophosphates: $(Sr,Ca)_{10}(PO_4)_6(Cl,F)_2:Sb^{3+},Mn^{2+}$ **(halophosphates)**
  - RE oxide: $Y_2O_3:Eu^{3+}$
  - RE phosphates $(La,Ce,Tb)PO_4$
  - RE aluminates: BAM: $(Ba,Sr)MgAl_{10}O_{17}:Eu^{2+},Mn^2$
    CAT : $(Ce,Tb)MgAl_{11}0_{19}$
- The process is done in 2 sites:
  - Saint Fons (Lyon) for halophosphates removal
  - La Rochelle for RE minerals dissolution, RE separations and new phosphor precursor production

Solvay Strategy to guaranty the security of RE Supply outside of China

- 1st step : Recycling
  - Recycling of production La Rochelle wastes. La Rochelle plant started in 2010 to recycle wastes
  - Recycling of production wastes from magnet manufacturers
  - Recycling of End of Life Equipment.
    - From NiMH batteries – A collaboration between Umicore and Solvay
    - From EOL lamps
- 2nd step: Partnerships with key mining players outside of China
  - Solvay is offering tolling for heavy rare earths separation outside of China to key partners
- More globally, on Mining related industry : leverage Solvay Novecare product portfolio of solvents and organic additives to offer a wide range of products & services to global mining industry

Business model for Solvay mining business activity

A 3 pillars approach

- **Sales of existing products :**
  - Flotation collectors
  - Liquid-liquid extraction solvents:
    - Amines based, Phosphorous based
  - Emulsifiers
- **Develop a Service offer to mining company**
  - Accompany development of projects
  - Help mining companies to solve their operating problems (eg : operation of liquid/liquid extraction unit, radioactive impurities removal…)
- **New products development**
  - Ion Exchange resins for specific applications
  - Flotation
    - Amine based formulations for non sulfide ores : Iron, Potash and phosphates
  - New generation of emulsifiers

Conclusions

- The RE recycling can be a part of the RE sourcing outside of China, but due to the RE market dynamics this will remain a small portion of RE raw materials,

- The technologies developped by Solvay for RE recycling are similar to mining process adapted to the specific characteristics of urban mines

- The profitability of the RE recycling is mostly dependent on RE prices and in the current situation of low RE prices the economics are difficult

- SOLVAY can leverage its own know how and product portfolio to adress more general mining industry challenges

Thank you for your attention