Les Terres Rares

Matériaux stratégiques, enjeux économiques

Diner débat UNAFIC 26 Novembre 2013

RES

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➢ 1st characteristic: RE are everywhere

Médical

Communications

Industries de défense

Energie

Batteries

Piles à Combustible

Eclairage

Alliages

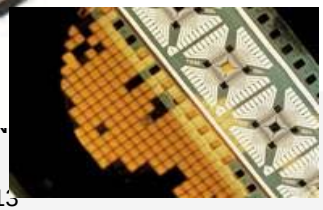
Automobile

A specialty market dispersed and complex

DVD TV

Ordinateurs

GSM Ipod MP3



Céramiques

Joaillerie

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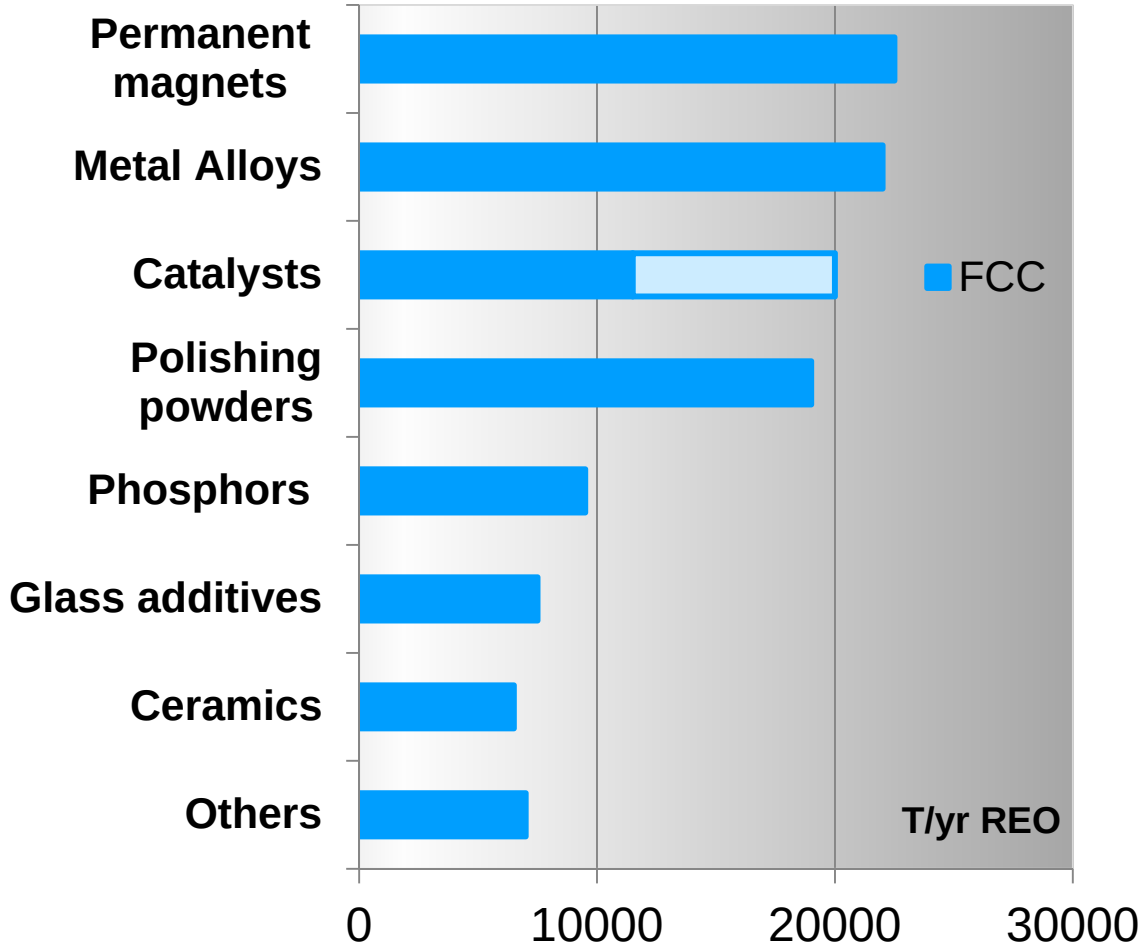
➢ 2nd characteristic:
The global market remains relatively small.
World wide consumption of RE was about 115kT/year in 2012



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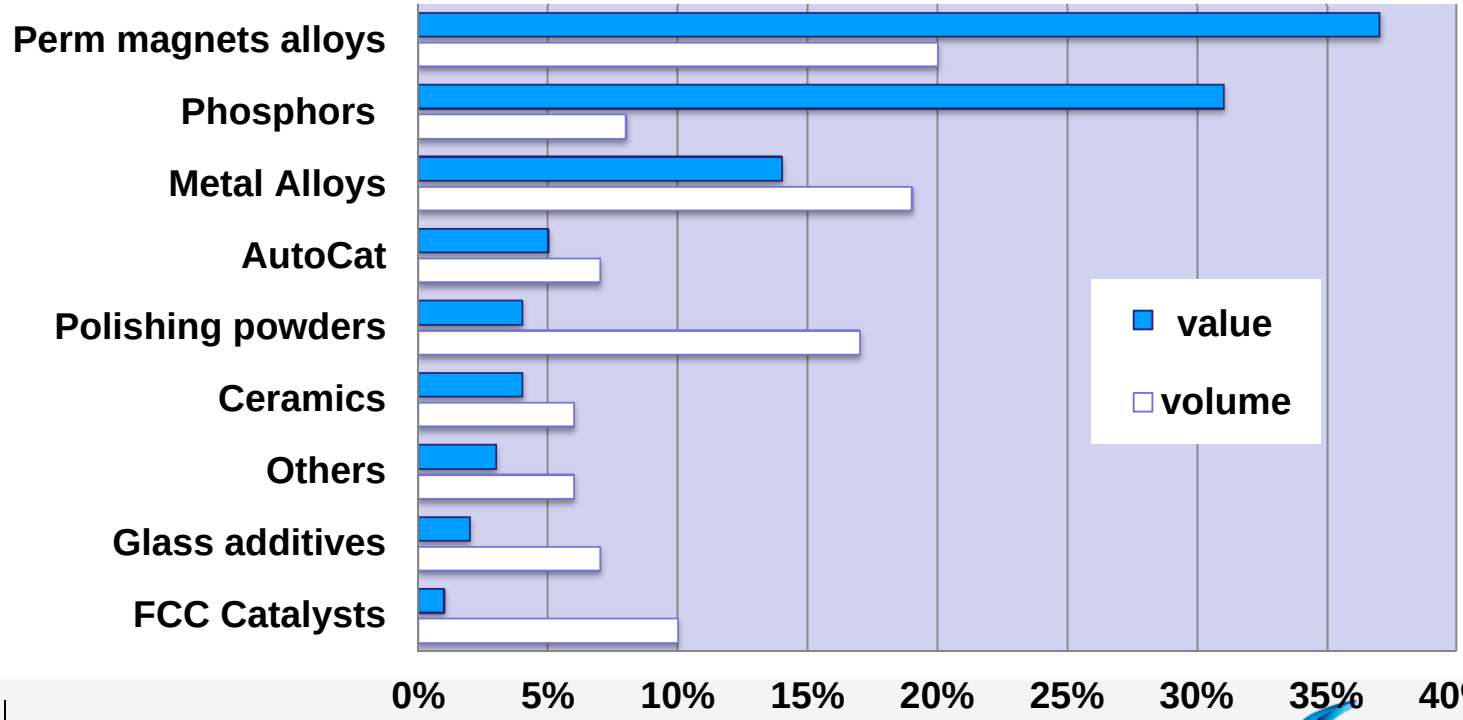
➢ 3rd characteristic:
-The RE prices are very different from one RE to another

China FOB prices – September 2013

USD/kg	La	Ce	Pr	Nd	Eu	Tb	Dy	Y
oxide	6.7	6.7	113	80	1025	950	541	24
metal	12.5	13.5	116	99		1150	727	63

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



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➢ 4th characteristic:

Due to their very specific properties, RE cannot be easily replaced and each RE has its own application field

		Light RE	Heavy RE
Rare Earths Properties	Applications Markets	La, Ce, Pr, Nd	Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Y
Magnetics	Magnets >Cars >Electronics >Wind turbine	Nd, Pr	Dy, Tb
Electric H2 storage	NiMH Batteries >Electronics, cars	La, Ce, Pr, Nd	
Catalysis	Cars depollution	Ce, La, Nd	
Catalysis	Petrochemical industry	La, Ce, Pr, Nd	
Luminescence phosphors	Lighting TV –Display	La, Ce	Eu, Tb, Y
Polishing Powders	Glass – Flat screens – eChips	Ce, La, Pr	
Dielectric	Electronic (Capacitors)	Nd	Gd, Dy, Y
NMR shift	MRI		Gd
Neutron absorption	Nuclear energy		Gd

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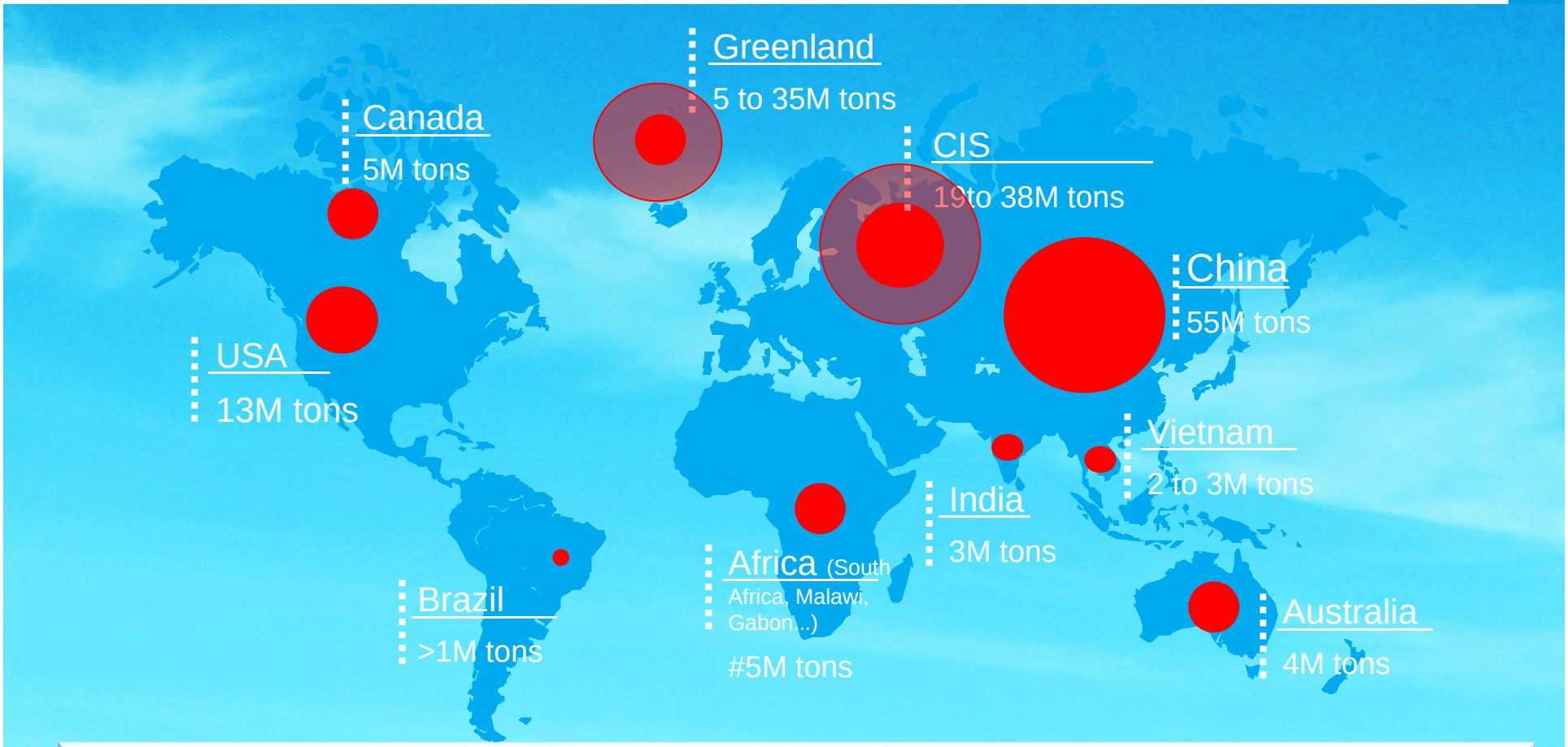
RE reserves are quite large and well distributed around the world



Reserves are at least 110 Millions tons REO when the world wide consumption is expected to be 150 kT-180 kT REO in 2018

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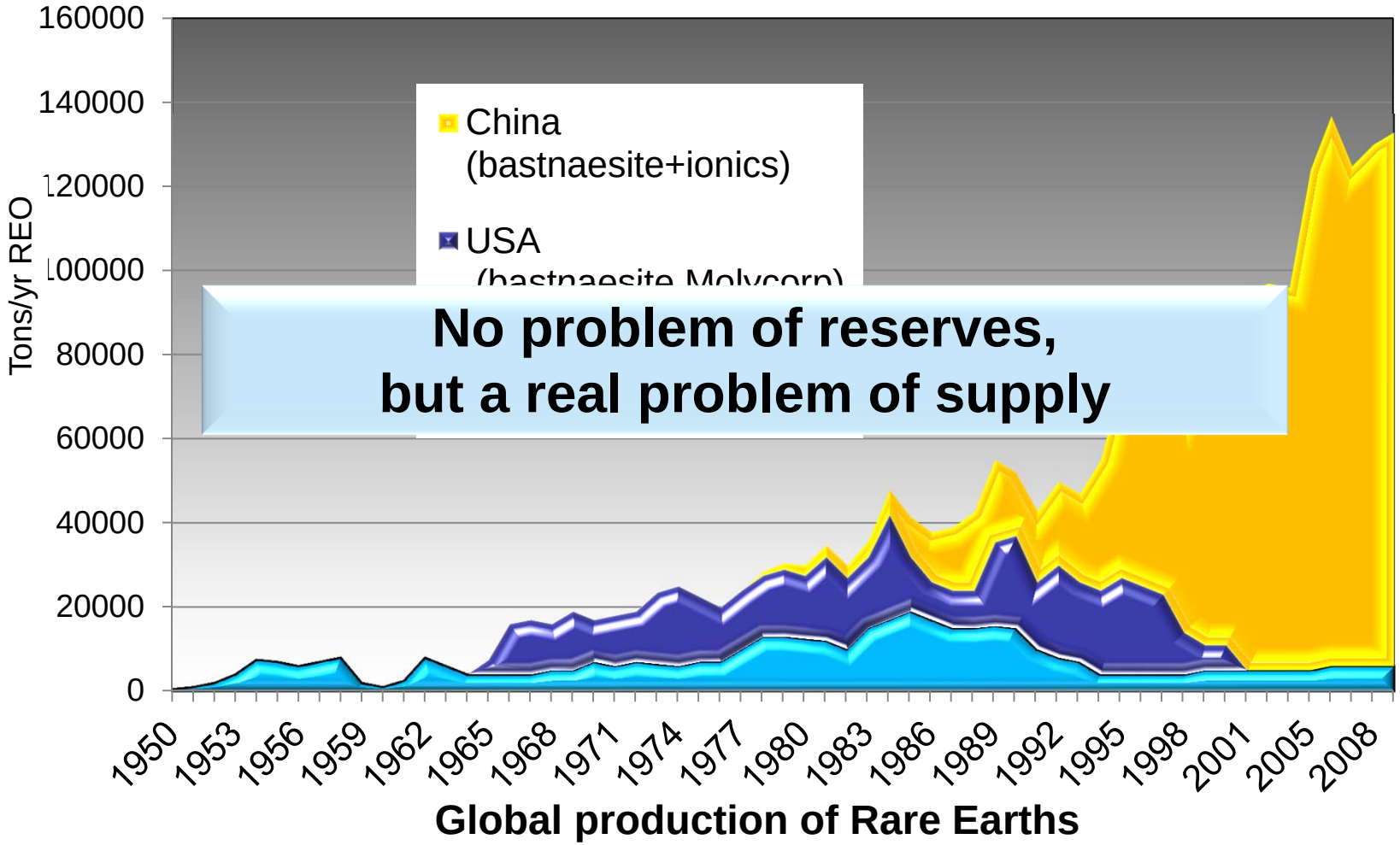
… but WW production of raw materials has been progressively concentrated in China.



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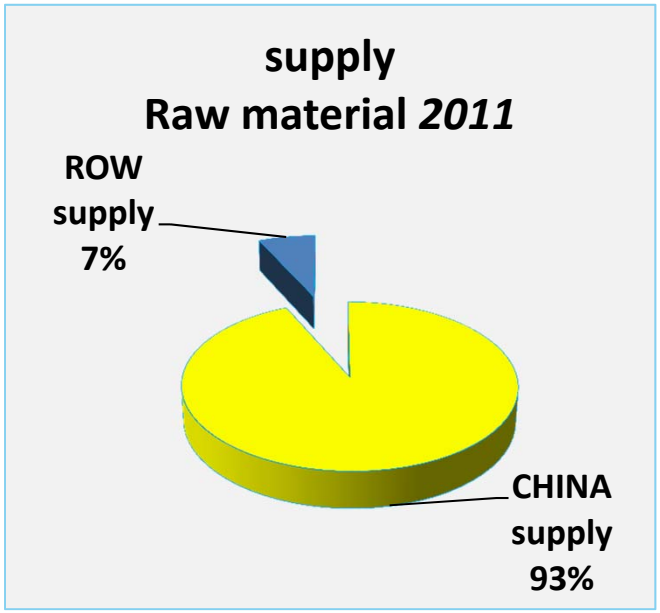
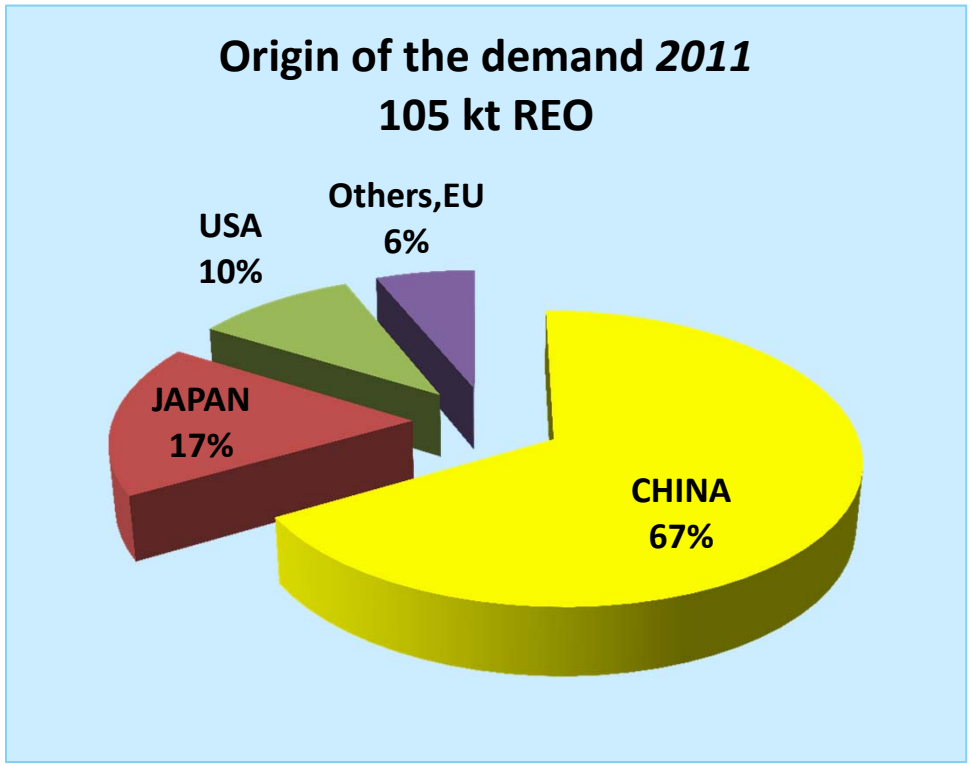
And progressively China has integrated a large part of downstream applications

Upstream



Applications



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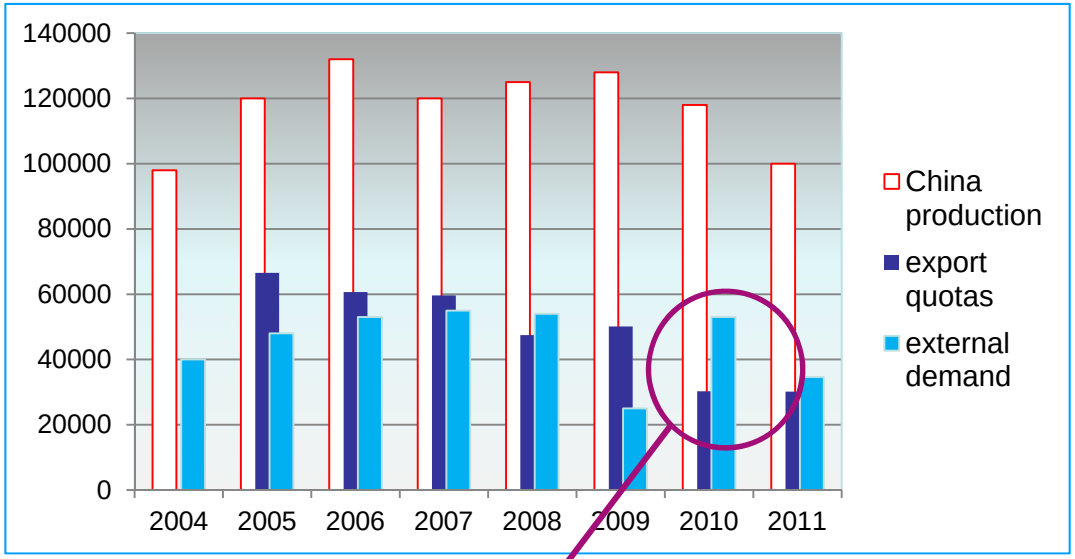
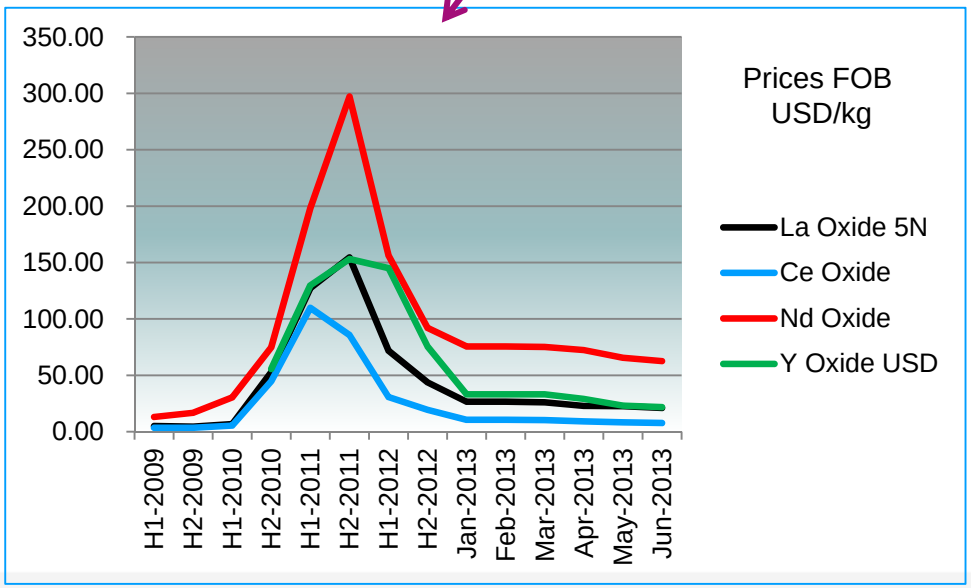
Since 2005 China has decided to limit its exports by a quotas policy …

With 2 objectives:

- **Controlling its resources,**
- **Promoting its downstream production**





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

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This situation has initiated a large number of mining projects outside of China

Some RE mining projects among more than 50 outside of China …

- **But most of these projects were based on unrealistic economic data…and will not survive.**

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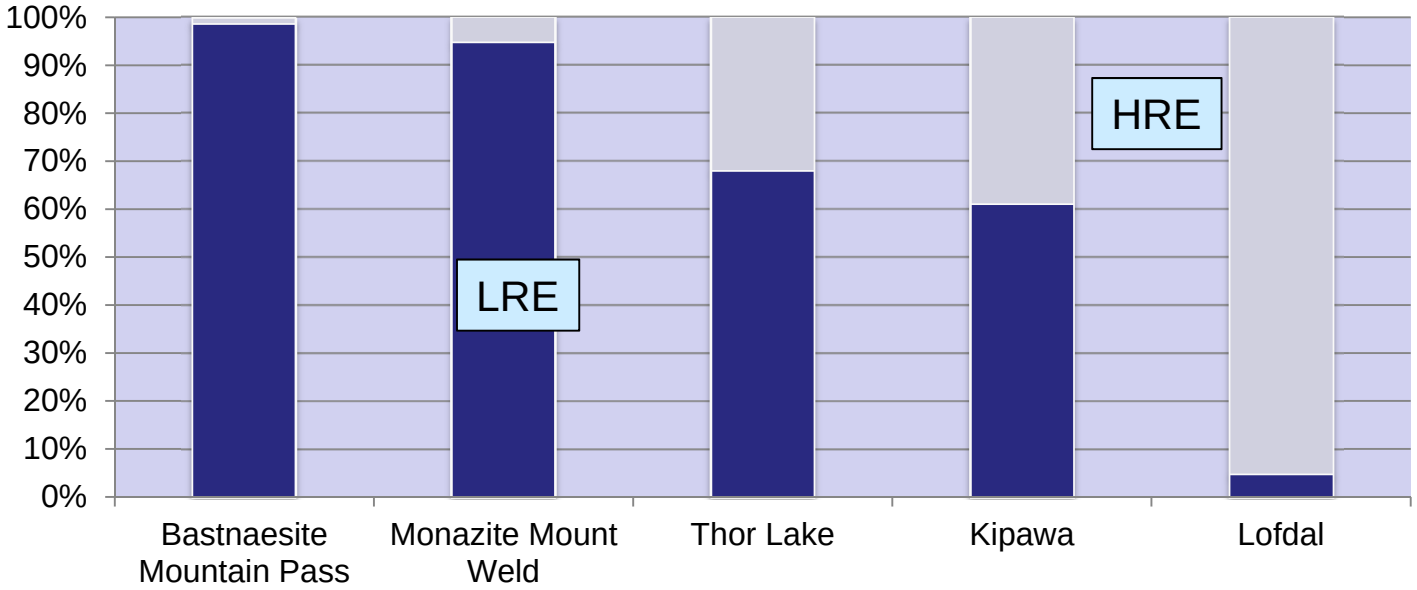
All the RE mining projects are not comparable

1. RE composition



2. Mineralogy

Project	Rare earth mineral	Formula	Type of REE	Existing process
Mountain Pass	Bastnaesite	$CeFCO_3$	LRE	Yes
Mount Weld	Monazite	$(Ce,Y)PO_4$	LRE	Yes
Lofdal	Xenotime	YPO4	HRE	Yes
Thor Lake	Fergusonite	(Y,Er,U,Th)(Nb,Ta,Ti)O4	HRE	No
Kipawa	Eudialyte	Na4(Ca,Ce)2(Fe,Mn,Y)ZrSi8O22(OH,Cl)2	HRE	No

The 2 mines having already started their production outside of China are both LRE deposits

From 2014

- **31,000 TREO - raising rapidly to 62,000 TREO - should be available outside of China.**
- **These 2 projects will satisfy the demand outside of China in Light RE, but will not solve the problem of Heavy RE availibility.**

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All the non China HRE projects will take more time to start up

- **All of the new HRE deposits are more difficult to work than HRE deposits worked in China and have at least one of the following drawbacks**
  - *Polymetallic* deposits requiring to valorize several elements (RE / Nb, Ta / Zr / U)
  - Minerals which have never been industrially treated and requiring *development of new processes* (ex: Eudialyte, Fergusonite…)
  - Low grade ores - *less than 5% REO* – with difficult physical concentration.

There will not be any significant Heavy RE production outside of China before 2017

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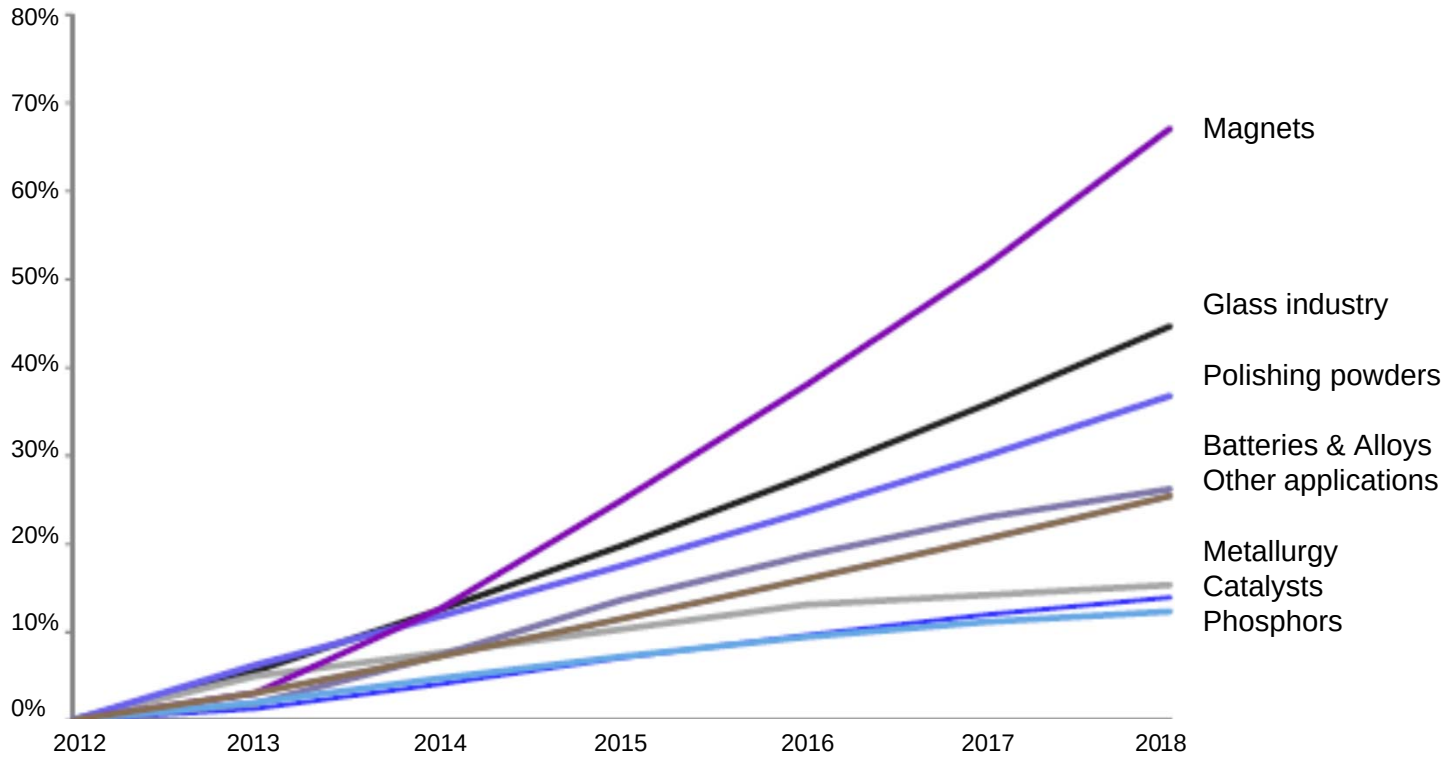
Market evolution: a global growth dominated by magnets needs(2018 forescat)

- A global growth of 5% / year between 2012 and 2018
- All the RE application sectors are growing,
- But magnets are the main driver (7% / year)



Source Deutsche Bank

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The difficult issue of REE equilibrium

- There is no deposit (neither combination of deposits) with a RE distribution adapted to the individual REE market needs.
- We can adjust the raw materials production to the magnets needs
  - Nd-Pr (for LRE) and Dy (for HRE) are the drivers of the mining resources

RE	Needs 2018 (JPM 2013)	China Production	Non China Production	Lack / Excess
NdPr	41480	28880	12599	-1
Dy	1694	991	718	+14
La	39008	32709	15742	+9 443
Ce	36370	35277	25362	+24 269
Eu	241	385	238	+382
Gd				+2 388
Tb				+110
Y	4462	4543	4303	+4 384
Total	124 181	108700	62000	+46 519

Pr, Nd and Dy are at equilibrium
BUT all the other RE are in large excess

(*) Scenario based on existing Chinese mines (Bayan Obo and Ionic ore deposits) and the main advanced non China projects (Mountain pass, Mount Weld, Orissa, Thor Lake, Norra Karr and Dubbo)

The difficult issue of REE equilibrium perspectives for the RE business

The individual REE « equilibrium » constraint is a key characteristic of the RE business

- ***Individual REE have their own lifecycle on the market but they are linked in the raw materials with a limited flexibility.***
  Processing costs are significantly impacted by REE without market and the Magnet market cannot bear all the surplus costs

- ***The only way to give some flexibility to the "equilibrium" issue with a control of processing costs is RECYCLING***

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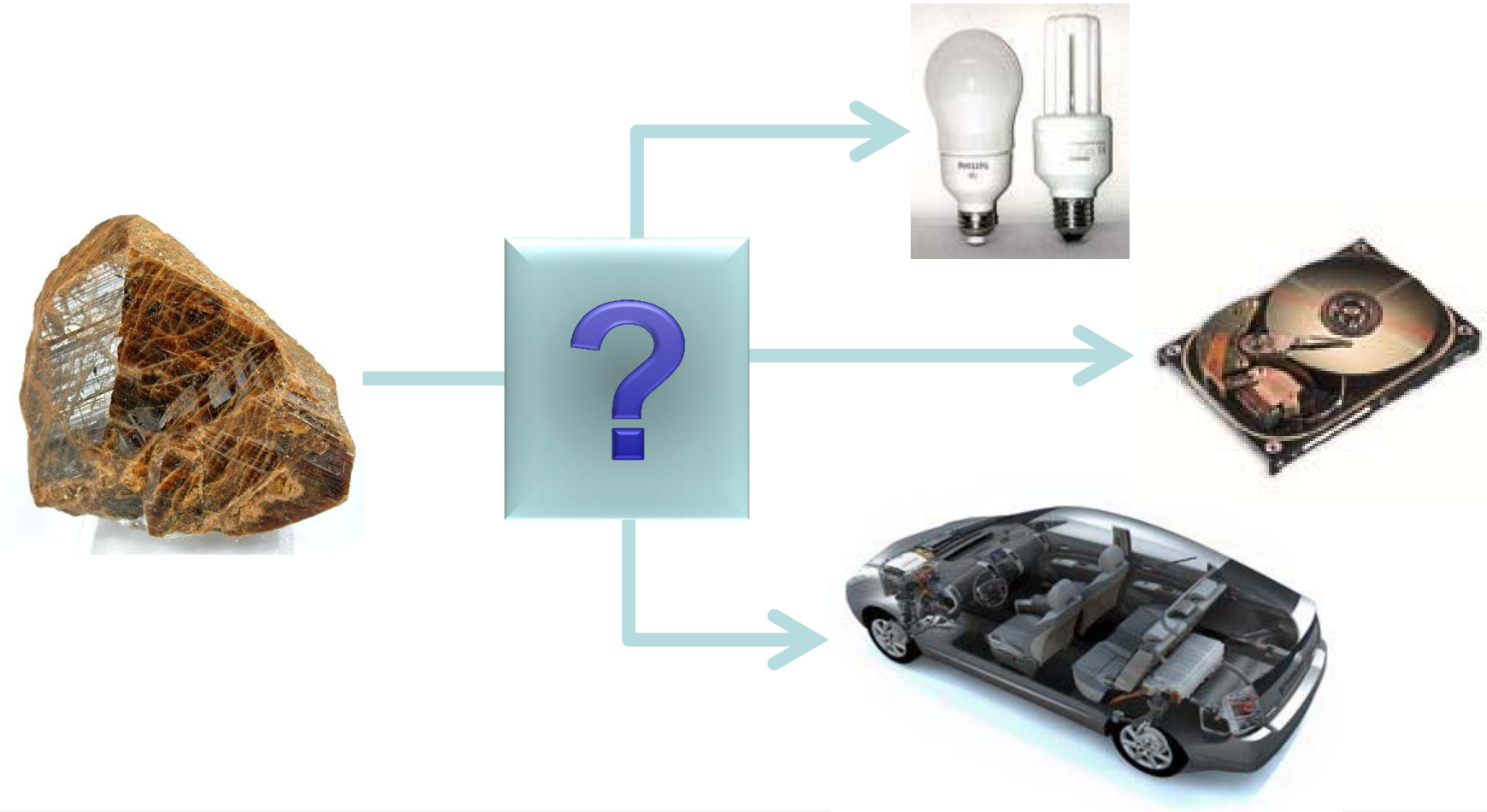
The value chain
A long way to the final application



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From the ore to the pure RE oxides

➢ *A common process for all applications*

Mining site

1

Mining & concentration

Ore concentrate

2

Ore cracking

RE mix concentrate

3

RE Separation

Pure RE solutions

4

RE finishing

Pure RE salts or oxides

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1 *From « ore » to « mineral concentrate »*

REO 0.2% - 15%

Beneficiation

REO 20% to 60%

- The aim of this step is to get the RE bearing mineral(s) as pure as possible
- At this step all the technologies are physical technologies and all the wastes are minerals without chemical wastes
  - Crushing
  - Milling
  - Classifying
  - Magnetic separation
  - Flotation

2 *From « mineral concentrate » to « chemical concentrate »*

The 2 main process routes

H_2SO_4 cracking

Radioactive wastes

$RE_2(SO_4)_3$

Anion exchange Chemical or SX

NaOH cracking

Radioactive wastes

$RE(OH)_3$

HCl or HNO_3 attack

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3 *From « RE concentrate » to « pure RE solutions ».*

➢ *Solvent extraction is the only industrial process*

Dissolution

Pure RE solution

Solvay La Rochelle plant is the only facility outside of China able to separate all RE including HRE. The plant has 18 SX « batteries » with more than 1100 mixer-settlers.

- There are 2 RE solvent extraction processes:
  - Chloride route used by all chinese manufacturers
  - Nitrate route
- ➢ *Solvay* uses both routes chloride in its Chinese plants and nitrate in its LR plant.

	Advantages	Drawbacks
Nitrate route	Lower OPEX	Higher CAPEX Nitrate waste waters to deal with
Chloride route	Lower CAPEX	Higher OPEX

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4 *From pure RE solutions to pure salts or oxides*

Precipitating agents
$NaOH$, NH_4OH, Na_2CO_3, NH_4HCO_3, H_3PO_4, NH_4F, $H_2C_2O_4$

Waste water

The ***purity*** is reached at the separation step

The ***physical properties***:
- Morphology
- Particule size
- Surface area

are got at the finishing step.

All these characteristics are key for final applications.

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From pure RE oxides to final application

➢ *A specific process for each application*

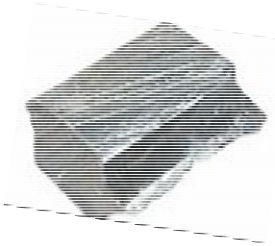
Example 1 : The magnets application

Pure RE salts or oxides

RE Producers

Molten salt electrolysis

Pure RE Metal



RE Users

Magnet making

Magnet component

Component integration

Hard Disk

From pure RE oxides to final application

➢ A specific process for each application

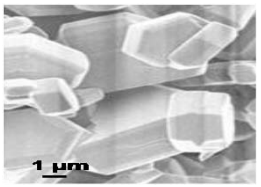
Example 2 : The phosphors application

Pure RE salts or oxides

RE Producers

Formulations synthesis

Specialty Designed RE product



RE Users

Phosphors making

RE Phosphors

Component integration

Low-energy lamps

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From pure RE oxides to final application

➢ *A specific process for each application*

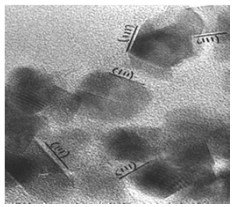
Example 3 : The autocatalysts application

Pure RE salts or oxides

RE Producers

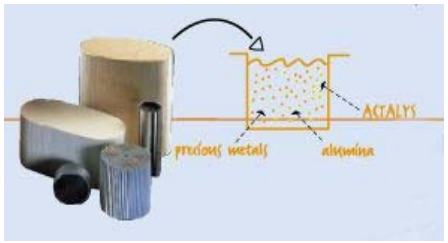
Formulations synthesis

Specialty Designed mix RE-Zr oxides



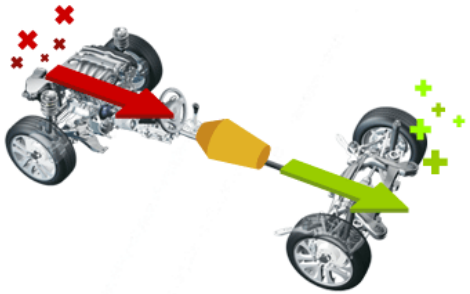
RE Users

Catalysts making



Component integration

Exhaust line manufacturers



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Fields of recycling

Like all minerals, the RE can be recycled. Two different fields should be considered:

- *Recycling of losses* generated during applications manufacturing. This part exists since a while.
- *Recycling of end of life (EOL) products*. This part is just starting.

The recycling of EOL products must take into account 2 criteria:

- Existence of a collecting circuit
- *In situ value* of the RE to be recycled.

➢ Based on these criteria, ***Solvay*** decided to start the recycling of RE from 3 types of EOL products:

- **Low energy consumption lamps**.
- **magnets**
- **NiMH batteries** in cooperation with *Umicore* who recycles the nickel.

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 phopshors

Recycling companies

Valorization
- **glass**
- **metals**
- **plastics**
- **mercury**

Used lamps Collectors

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RE recycling from End of life lamps

Le recyclage des ampoules reçoit le prix responsible Care du Cefic

Le 4 octobre, le CEFIC (conseil européen de l'industrie chimique) a décerné le premier prix de ses Responsible Care Awards 2013 au projet de recyclage des terres rares "Coleop'terre" de Solvay.

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Merci de votre attention