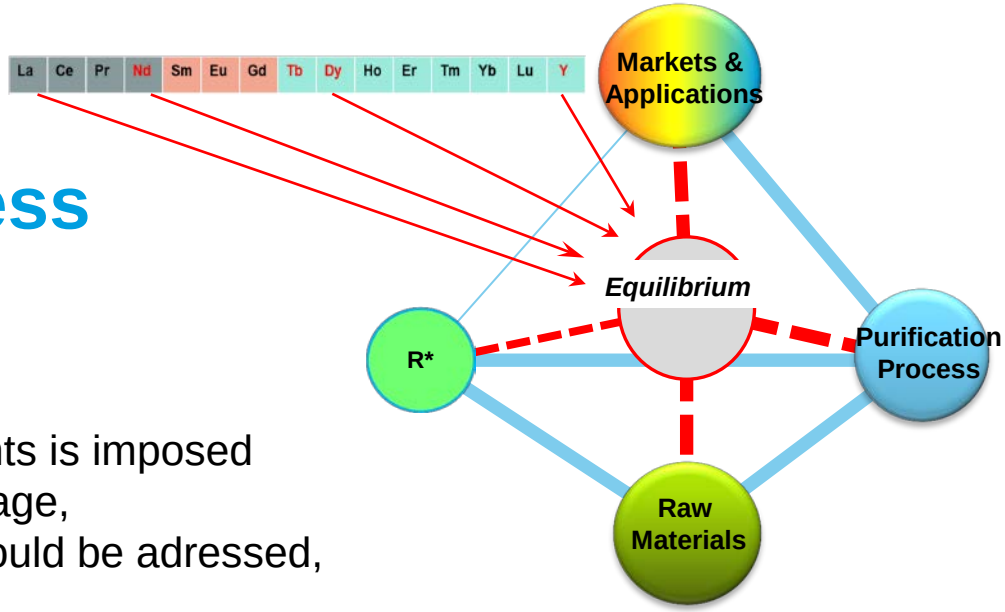
Key messages for the panel « separations »

- **Equilibrium** *is the key factor for that business at the level of the* ***RE refinery*** *(separations)*
- **Raw material**
  - Needs for HRE resources (but opportunity for only 2-3 projects)
- **Separations**
  - Process for new HRE resources projects
    - Needs to manage radioactivity preferably on the mine site (a killer)
  - Capacity for purified individual RE
    - Non-Chinese existing capacities fit the needs for both LRE & HRE
    - No need for new plants with a mid-term perspective.
  - Cost of different routes can be equivalent but learning curve is critical especialy for HRE

Rare Earths
A fascinating business



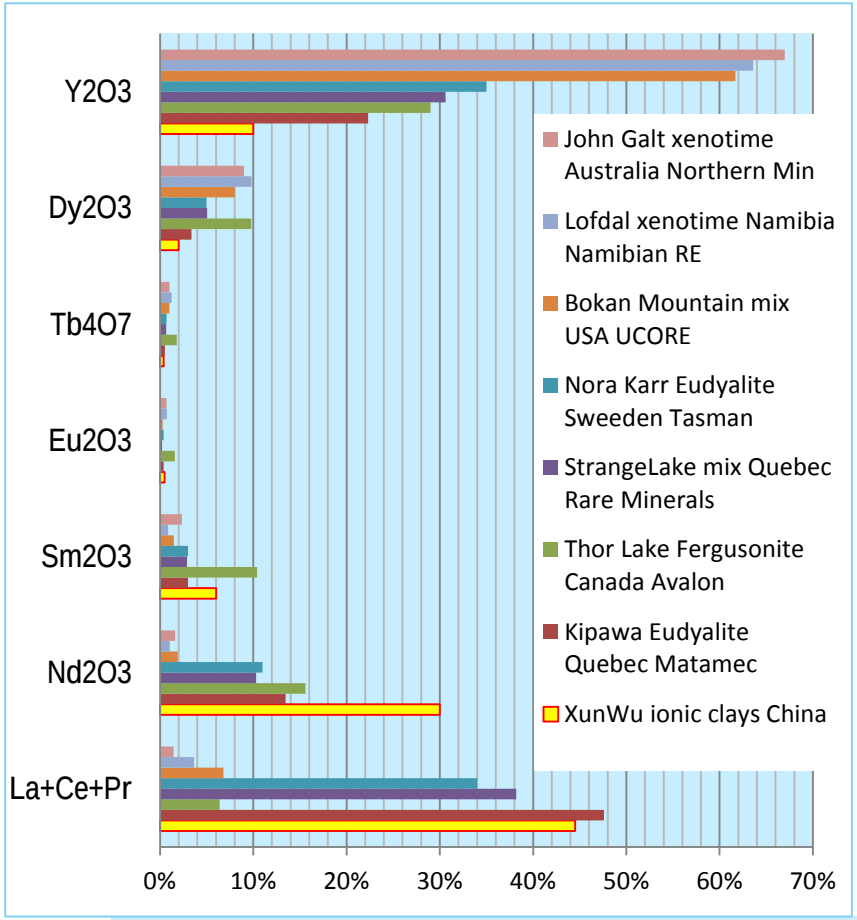
- **Raw materials**
  - Dispersed and not so available,
  - Distribution of the 15 RE elements is imposed without any link with the final usage,
  - Radioactivity always present should be adressed,
  - Strong political context.

- **Purification processes**
  - Complex technology which requires specific know-how and expertize,
  - Is rather capitalistic.

- **Applications and End Markets**
  - They are numerous,appearing,growing and disappearing at various speeds,
  - No link between them, with a strong usage in new technologies,
  - Prices are volatils.

➢ ***Equilibrium*** between RE distribution you got in the ore and the end market demand is the key for the economy of the system.

Several projects are in the pipe for HRE



- **For HRE chinese ionic clays provide the present requirements**
- **Future is for projects based on**
  - *Eudyalite* type mineral mix composition between Mz et Xeno i.e. Kipawa (Quebec),Nora Karr (Sweden)
  - *Non china « ionic »* i.e. Antsiranana (Madagascar) or Mkango (Malawi)
  - *Xénotime* type ore i.e. John Galt(Australia),Lofdal (Namibia)
  - *Other mix type minerals i.e. Strange Lake (Quebec) ,Bokan Mountain (USA), Thor Lake (Canada)*

- Maturity for such projects is still low and **no industrial perspective before 2016**
- There will be an **opportunity for a limited number of projects** (2 or 3 ?) because the RE market is limited.
- Projects should mix **ore composition** and **processability,** key points for success

SOLVAY asking more from chemistry®

All Rare Earths raw materials contain natural radioactivity

RE containing minerals occuring in nature contain more or less Thorium and Uranium

	bastnaesite	monazite	pyrochlore	xenotime	apatite	eudyalite
REO contents in deposit	0,5%-10%	3%-15%	1%	0,6%-6% (max12%)	0,6%-0,8%	0,90%
Thorium / REO	0,50%	0,5%-15%	7%	3%	2%	0,15%-0,3%
Uranium / REO	-	0,05%-0,5%	2%	0,1%-0,2%	0,3%-0,8%	0,20%

- Whatever is its level, that natural **radioactivity is a key challenge for the projects**.

- **Projects should consider a processing route which leaves radioactivity at the mine site (- or near by-)**
  That is essentially a societal -and economical- statement more than a technical one.

- **Radioactivity is a relatively complex technical challenge** due to the fact that separation processes make cuts in radioactives families of Thorium and Uranium.
  Radioactive isotopes Th^{232} Ra^{228} Ac^{228} Th^{228} Ra^{224} Rn^{220}…Ra^{226} ..have a complex chemistry and are split according various behaviours during separations
  Th / U / RE / Ac / Ra …

- **The skills required to handle these questions are not common ones**
  and not easily available to technical teams usually involved in projects.

SEPARATIONS - Non Chinese capacities fit the needs for both LRE & HRE with a mid-term perspective

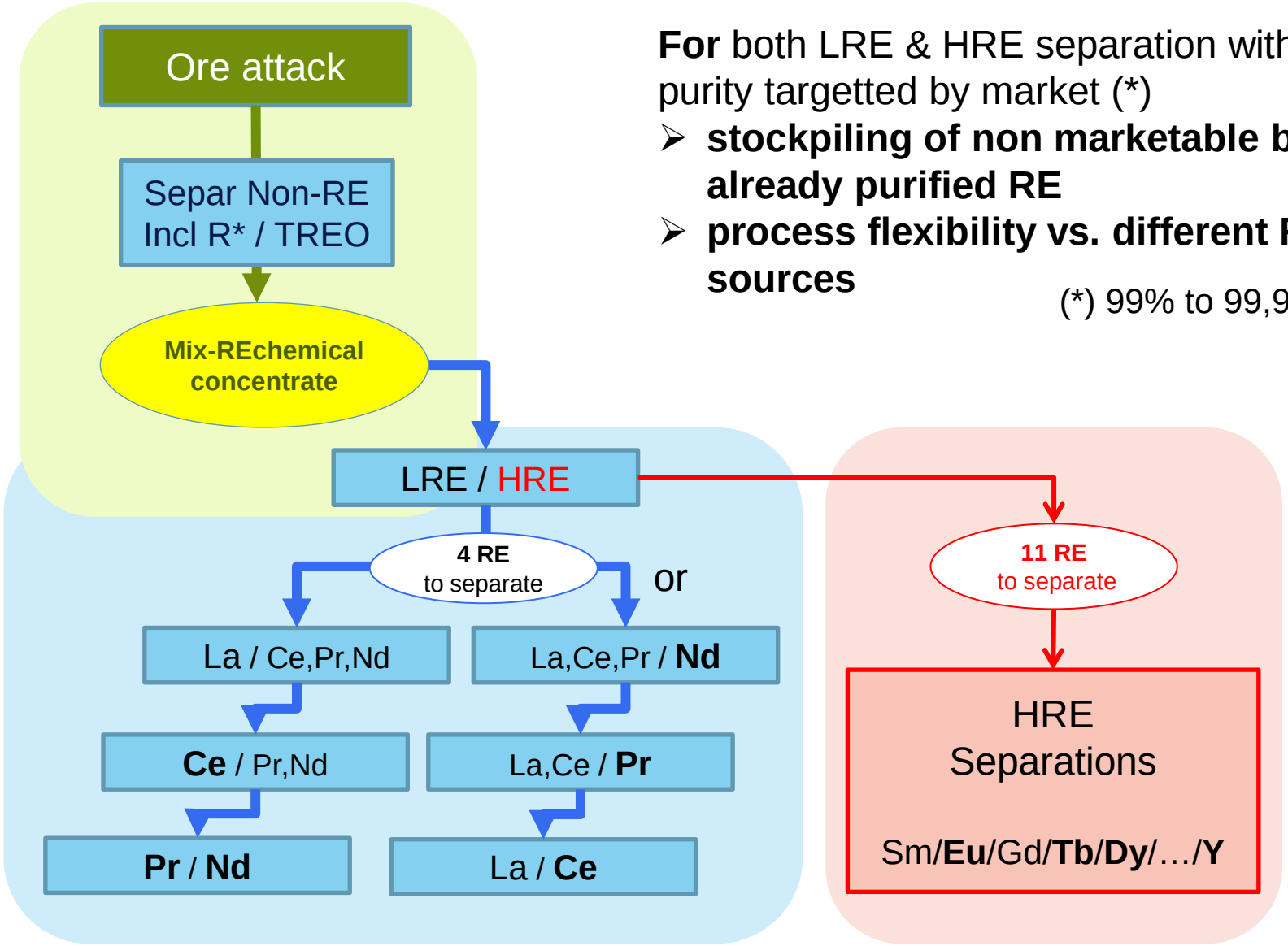
- *Chloride* and *nitrate* route are competitives
- *Sulfate* route is not suitable for purification , limited to upstream concentration plant and first separation step

	CAPEX	*OPEX*	*SEPARATION PURIFICATION*
CHLORIDE ROUTE	✚	▬	well adapted
	plastic & limited nb stages	*acid & base chem reagent*	
NITRATE ROUTE	▬	✚	well adapted
	stainless steel & nb stages	*water & steam*	

- ***LRE separations are rather easy , with a significant size effect on CAPEX and purity required is low***
- ***HRE separations are a difficult technology and no size effect is expectable***

- **Outside China for HRE Solvay still operates a large séparation plant (CAPEX several years ago) and can be a toller.**
- **Solvay is the only company able to separate all RE , in China and outside China using chloride route and nitrate route.**

SEPARATIONS: « equilibrium » is critical for *the refinery*



For both LRE & HRE separation with the purity targetted by market (*)

- **stockpiling of non marketable but already purified RE**
- **process flexibility vs. different RE sources**

(*) 99% to 99,999%

SOLVAY
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High CAPEX, Long Lead Time, Learning curves
can all of these be lowered ?

Perspective is different for level 1 and level 2 of the global process

Level 1 going to the mix-RE concentrate

- High CAPEX, size effect is clearly important.
- Technology is rather a classical one and used in other mineral processing.
- The learning curve could be relatively short.
- But process for new raw material have no industrial experience (except xenotime)
- At that level , **radioactivity** has to be handle, which is not a common and easily available expertise.

Level 2 RE separation and purification

- High CAPEX, significant size effect for LRE but not for HRE where the volume are always limited.
- The requirement of the market will ask for a very limited number of HRE separation plants.
- RE separation is not a common technology. The knowledge of the extraction chemistry as well as the technology -these two skills being closely linked- is key and not usual.
  May be no other metal purification requires such a level of expertise and experience.
- Processes are not easy to design and to run .A long learning curve is required.
- Due to the limited number of actors in the field, processes are proprietary , internally developped and usually not available for licensing.
- Regarding the variety of raw materials for the future especialy for HRE, a significant flexibilty of the processes is required which adds to the complexity.

Learning curve at Solvay

- **Research on RE separation starts in the early 60's**

- **Production at La Rochelle plant**

- 1965- First separation battery for RE separation > pure Th, pure La, pure Y
- 1966- chloride route development for LRE and Y.
- 1968- first nitrate route batterie for LRE
- 1970- solvent extraction replaces solid resin technology to produce HRE. (capacity 5000T/y REO)
- 1981- chloride plus nitrate route reach 8000T/y capacity.
- 1987- end of chloride route. All separations in nitrate route (capacity 9000T/y REO).
  - During that period monazite,bastnaesite and xenotime raw materials
  - From 1995 - raw material chinese concentrates

- **Production In China**

- 1995- JV at Baotou Rhodia RE to separate LRE - chloride route
- 2000- JV at Liyang Rhodia RE New Material to separate HRE - chloride route

Today at La Rochelle

- 18 batteries (plus pilot batteries) with a total of 1300 mixer-settlers.
- Several different solvents used depending on separations

Can today's high costs be overcome by innovation ?

Where innovation can help ?
Where does the costs come from ?

Everywhere in the process but also **innovation in management**

1) A good understanding of RE business
2) How to avoid the mis-match inventory which is not link to the process but to the raw material strategy. Which is the most critical cost.

Is there process improvement to help ?

Yes but …

- SX is a mature science and technology which came in replacement of solid IEX technologies.
- Developping a new process requires money and a long time.
- high OPEX but at their minimum today.

A dream for any RE producer:
have a process able to extract –pickup- selectively one RE in a mixture

- *Could save some costs*
  - *But do not solve the **equilibrium** question*
  - *And Is **highly challenging** for a mature technology !*

Innovation in process ? Yes… but not critical for the business

The cycle for the « End-of-life » products is implementing rapidely in Europe

Solvay is active on the three major segments

Thanks to its existing facilities Solvay is active on 3 types of products under consideration today with a special focus on HRE

- ***Lamp phosphors > Tb,Gd,Y,Eu***
- ***NiMH Batteries , partnership with Umicore (Ni and La recovery)***
- ***Magnets > Nd, Dy***

The different steps of the cycle

- Collecting by specialized companies (i.e. WEE,..)
- Prétreatment for concentrating RE
- Chemical cracking
- Séparation in existing plant.

The level of implementation of the cycle is different for the various products types and the regional organization in Europe,US or Asia.

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

Solvay recycling process in operation

Several thousands Tons of powders are landfilled each year

Rare Earth recovery
HRE
Several hundreds tons/y

Recycling Companies

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

Rare Earth Concentration

Rare Earth Separation

Rare Earth Finishing

LAP & YOx

Consumers Professionals

Lamp users

Collectors

Lamp collection

Sorting

Lamp treatment

De-mercurising

Eco-organisms

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