The Rare Earth Elements in the European context

« ASTER – REE Systemic analysis – Flows and stocks »
A project co-funded by ANR,
the French National Research Agency
Project closing Conference

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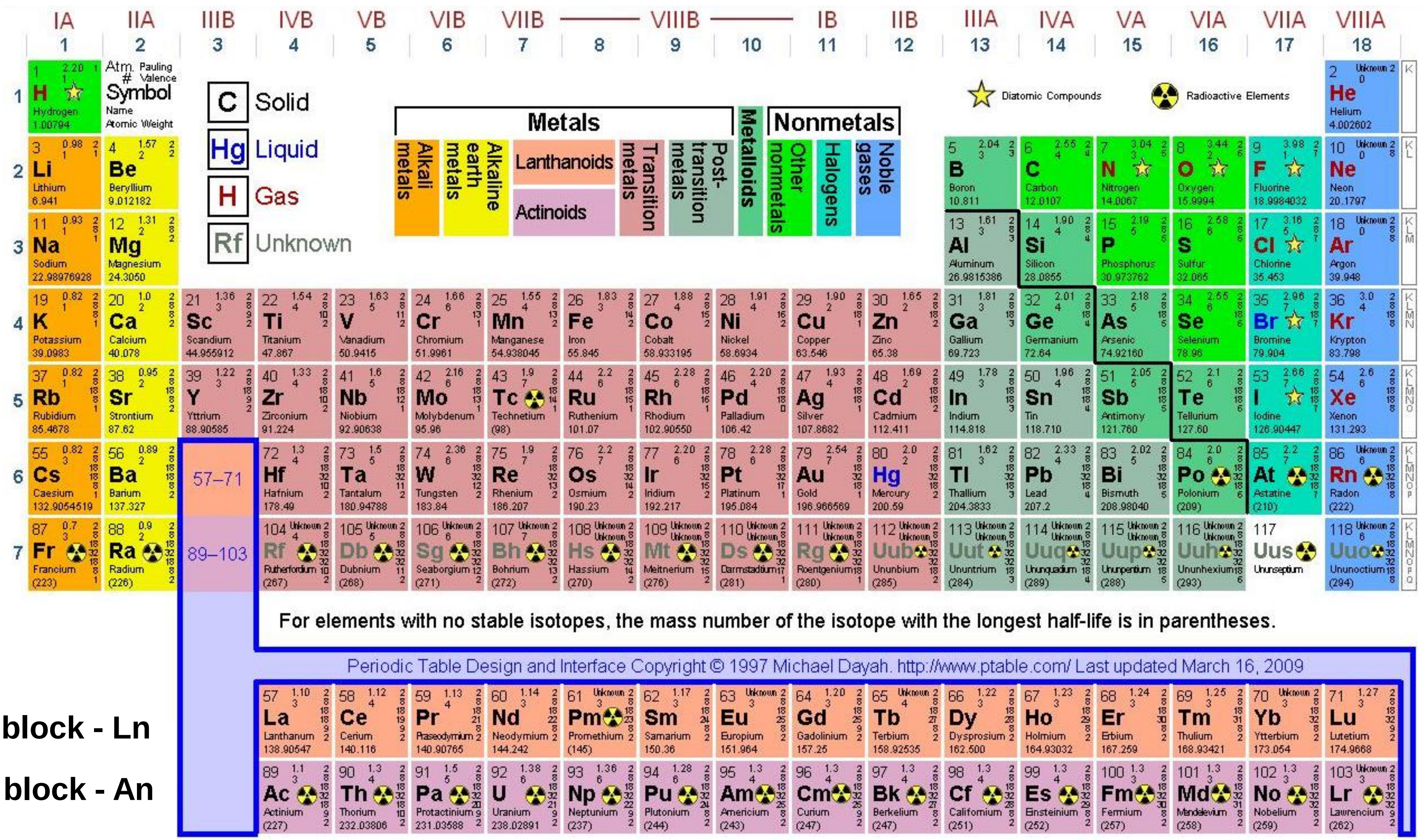
Presentation outline

1. Reminder on Rare Earth Elements
2. The Rare Earth industry in 2015
3. A European perspective
4. Europe's response to the REE challenges
5. Conclusions: the end of the Chinese monopoly?

1 – REMINDER ON RARE EARTH ELEMENTS

A group of 17, 16, or 15 elements?



4f block - Ln

5f block - An

f-block elements

↳ Here we consider: 14 lanthanides + Y (15 elements!)

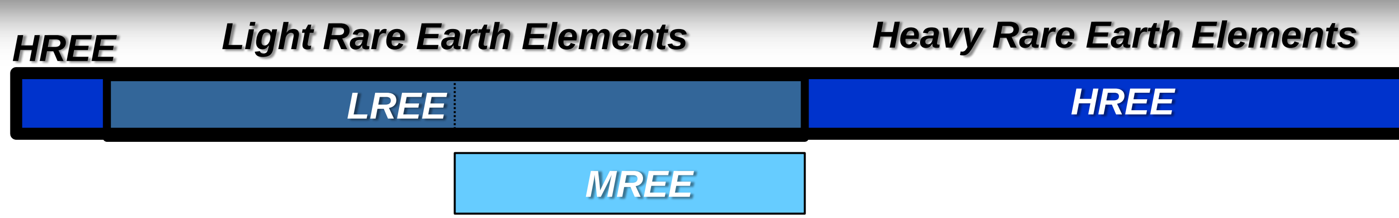
A group of 15 elements splitted into light and heavy REE!

Half-filled $4f^7$ (Gd)

Fully filled $4f^{14}$ (Lu)

Rare Earth Elements - selected characteristics, chemical data and their grouping into LREE, MREE and HREE

Atomic number	21	39	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
Element		**Y**[3]	**La**	**Ce**	**Pr**	**Nd**		**Sm**	**Eu**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
Orbitals[1]		$4d^15s^2$	$5d^16s^2$	$4f^26s^2$	$4f^36s^2$	$4f^46s^2$		$4f^66s^2$	$4f^76s^2$	$4f^75d^16s^2$	$4f^96s^2$	$4f^{10}6s^2$	$4f^{11}6s^2$	$4f^{12}6s^2$	$4f^{13}6s^2$	$4f^{14}6s^2$	$4f^{14}5d^16s^2$
Oxidation states[1]		+3	+3	+3 +4	+3 +4	+2 +3 +4		+2 +3	+2 +3	+3	+3 +4	+3 +4	+3	+3	+2 +3	+2 +3	+3
Color[1]			no color	no color	yellow green	violett		yellow	nearly no color	no color	nearly no color	yellow green	yellow	pink	green	no color	no color
Atomic radius [pm][1]		180	187	182	182	181		180	204	179	178	177	176	175	174	193	174
Ionic radius [pm][1]			103	101	99	98		96	95	94	92	91	90	89	88	87	86
Atomic mass [u][3] rounded		88,9	138,9	140,1	140,9	144,2		150,4	152,0	157,3	158,9	162,5	164,9	167,3	168,9	173,0	175,0
Mass in geosphere [%][3]		0,003	0,002	0,004	$5 * 10^{-4}$	0,002		$6 * 10^{-4}$	10^{-5}	$6 * 10^{-4}$	$9 * 10^{-5}$	$4.2 * 10^{-4}$	10^{-4}	$2 * 10^{-4}$	$2 * 10^{-5}$	$3 * 10^{-4}$	$7 * 10^{-5}$
Boiling point [K][2]		3611	3730	3699	3785	3341		2064	1870	3539	3396	2835	2968	3136	2220	1466	3668
Melting Point [K][2]		1795	1194	1072	1204	1294		1350	1095	1586	1629	1685	1747	1802	1818	1097	1936
Density [kg/m³ at 293K][2]		4469	6145	8240 [298K]	6773	7007		7520	5243	7900 [298K]	8229	8550	8795 [298K]	9066 [298K]	9321	6965	9840 [298K]
Classification of metals	Light metals		Heavy metals (Density > 5000 kg/m³)														



This is the view of geochemists

A group of 15 elements splitted into light and heavy REE!

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Orbitals[1]		$4d^1 5s^2$	$5d^1 6s^2$	$4f^2 6s^2$	$4f^3 6s^2$	$4f^4 6s^2$		$4f^6 6s^2$	$4f^7 6s^2$	$4f^7 5d^1 6s^2$	$4f^9 6s^2$	$4f^{10} 6s^2$	$4f^{11} 6s^2$	$4f^{12} 6s^2$	$4f^{13} 6s^2$	$4f^{14} 6s^2$	$4f^{14} 5d^1 6s^2$
Oxidation states[1]		+3	+3	+3 +4	+3 +4	+2 +3 +4		+2 +3	+2 +3	+3	+3 +4	+3 +4	+3	+3	+2 +3	+2 +3	+3
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Classification of metals	Light metals		Heavy metals (Density > 5000 kg/m³)														

HREE

LREE | *HREE*

This is the view of metallurgists

2 – THE RARE EARTH INDUSTRY IN 2015

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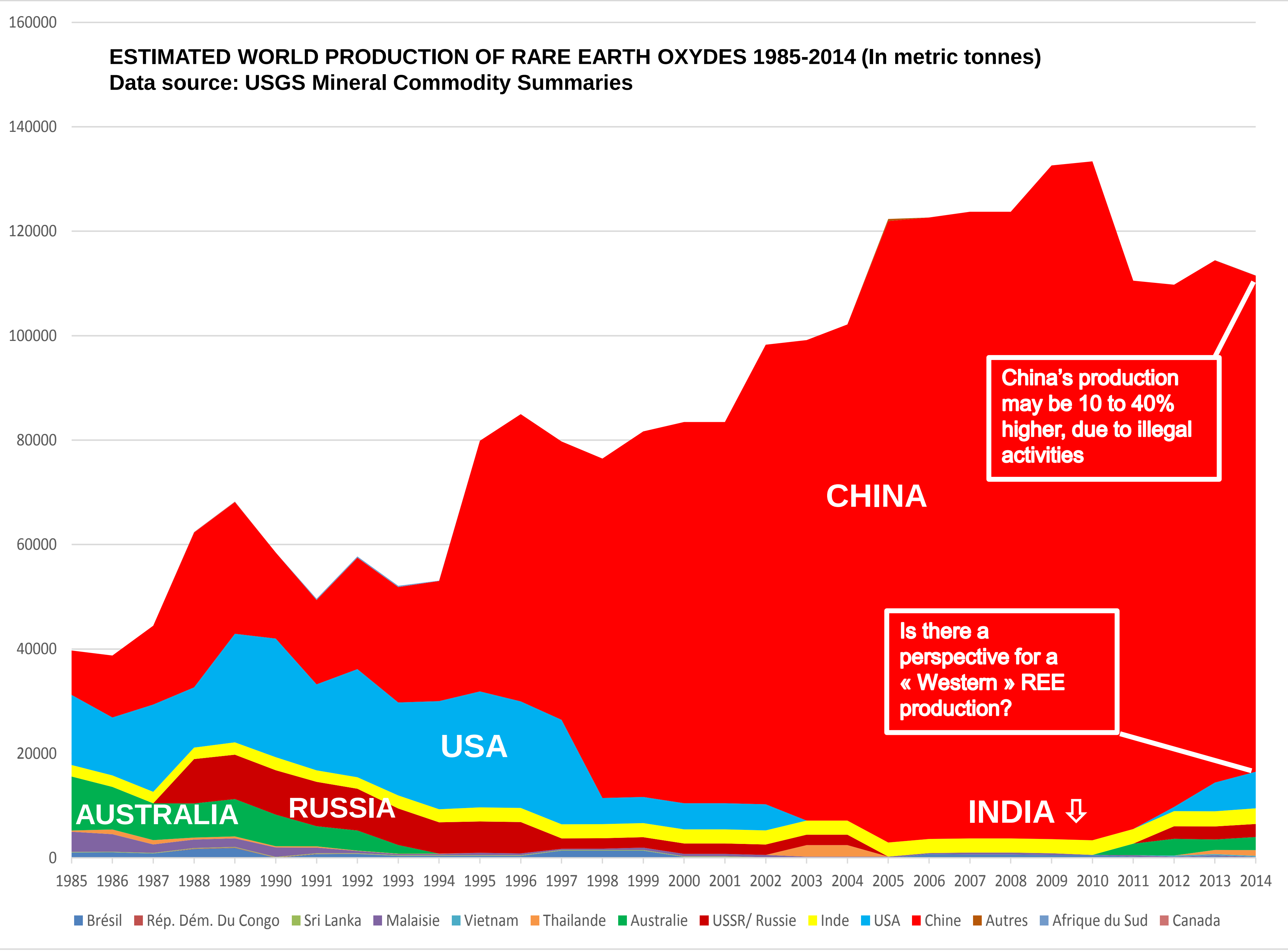


ESTIMATED WORLD PRODUCTION OF RARE EARTH OXYDES 1985-2014 (In metric tonnes)
Data source: USGS Mineral Commodity Summaries
160000
140000
120000
100000
80000
60000
40000
20000
0
China's production may be 10 to 40% higher, due to illegal activities
CHINA
Is there a perspective for a « Western » REE production?
USA
RUSSIA
AUSTRALIA
INDIA ⇩
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014
Brésil
Rép. Dém. Du Congo
Sri Lanka
Malaisie
Vietnam
Thailande
Australie
USSR/ Russie
Inde
USA
Chine
Autres
Afrique du Sud
Canada

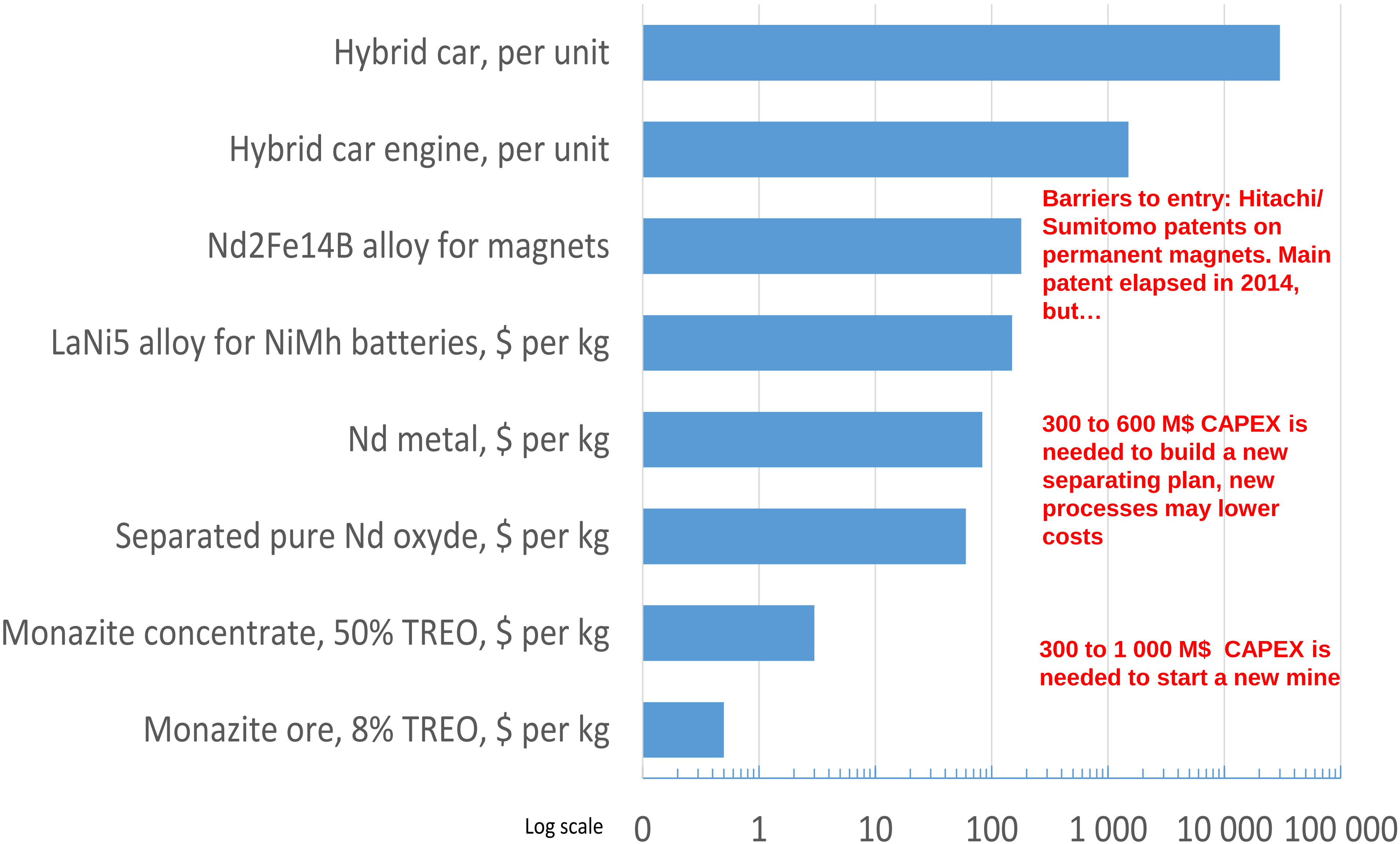

Lynas Corporation Limited (ASX:LYC)
0.0440 +0.0010 2.33%
Apr 2 - Close
ASX data delayed by 20 mins - Disclaimer
Currency in AUD
Range -
52 week 0.04 - 0.22
Open -
Vol / Avg. 0.00/15.77M
Mkt cap 148.32M
P/E -
Div/yield -
EPS -0.18
Shares 3.37B
Beta -
Inst. own -
Total Debt to Total Capital: 66%
Debt/ total equity: 197%
Essentially a producer of light rare earth. 10 years Nd supply contract signed with Siemens on mid-April
2010
2011
2012
2013
2014
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25


Molycorp Inc (NYSE:MCP)
0.403 +0.016 (4.19%)
Apr 2 - Close
NYSE real-time data - Disclaimer
Currency in USD
Range 0.40 - 0.46
52 week 0.28 - 5.15
Open 0.40
Vol / Avg. 7.31M/5.25M
Mkt cap 112.02M
P/E -
Div/yield -
EPS -2.67
Shares 277.96M
Beta 4.85
Inst. own 30%
Total Debt to Total Capital: 60% (important role of Japanese lenders)
Debt/ total equity: 147%
Rich in Dy, Tb, Eu
2009
2011
2012
2013
2014
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0

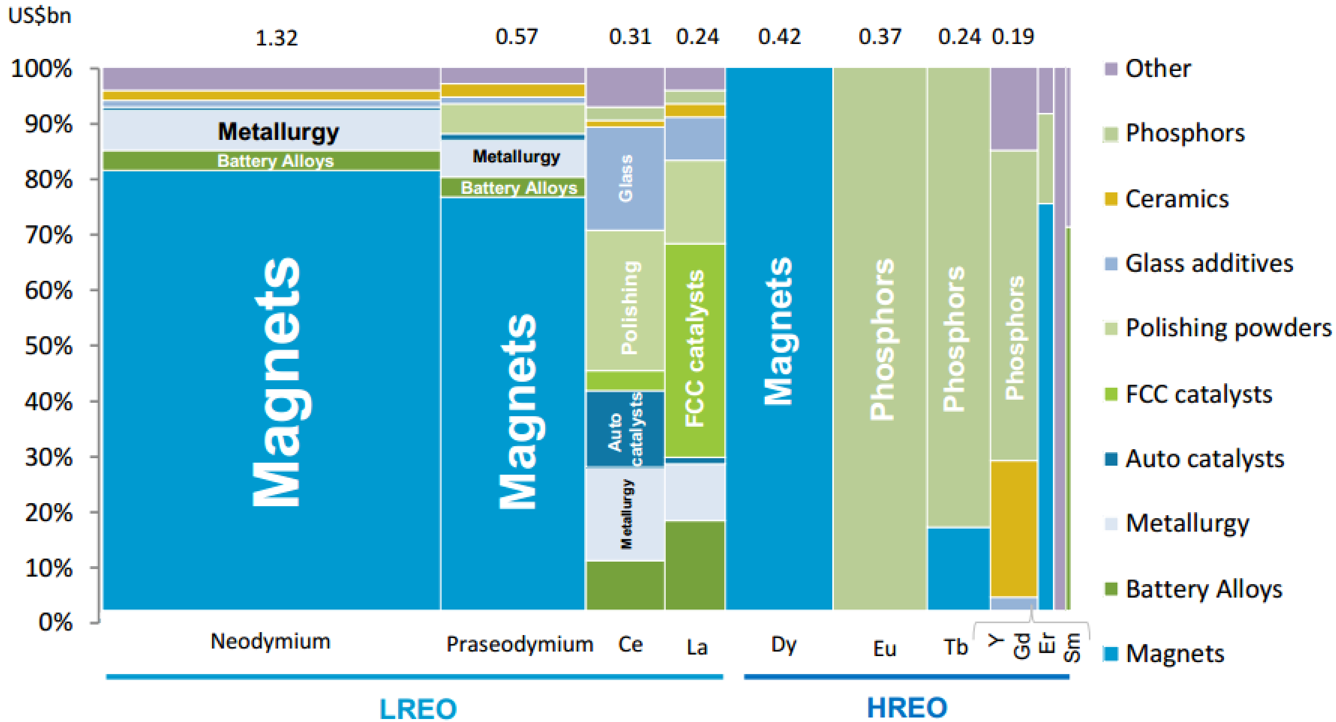
Rare Earth based value adding

(Examples, average 2014 prices)

Data sources: IMCOA - Duddley Kingsnorth, Conférence ERECON 10/2014



The 2013 global REE production was worth about 4 bn US $, split across very diversified markets, dominated by the REE permanent magnets (50% of the total market value) and the phosphors markets (18%) . Only 8 out of the 15 REE have a significant market value: Nd, Pr, Dy, Eu, Ce, La, Tb. Nd + Pr a re worth almost 50% of the total REE market. The per kg. value is highest for Tb, Eu and Dy.



Source: Peak Resources, from MCOA Rare Earth Quarterly Bulletin n° 6 data (02/2014)

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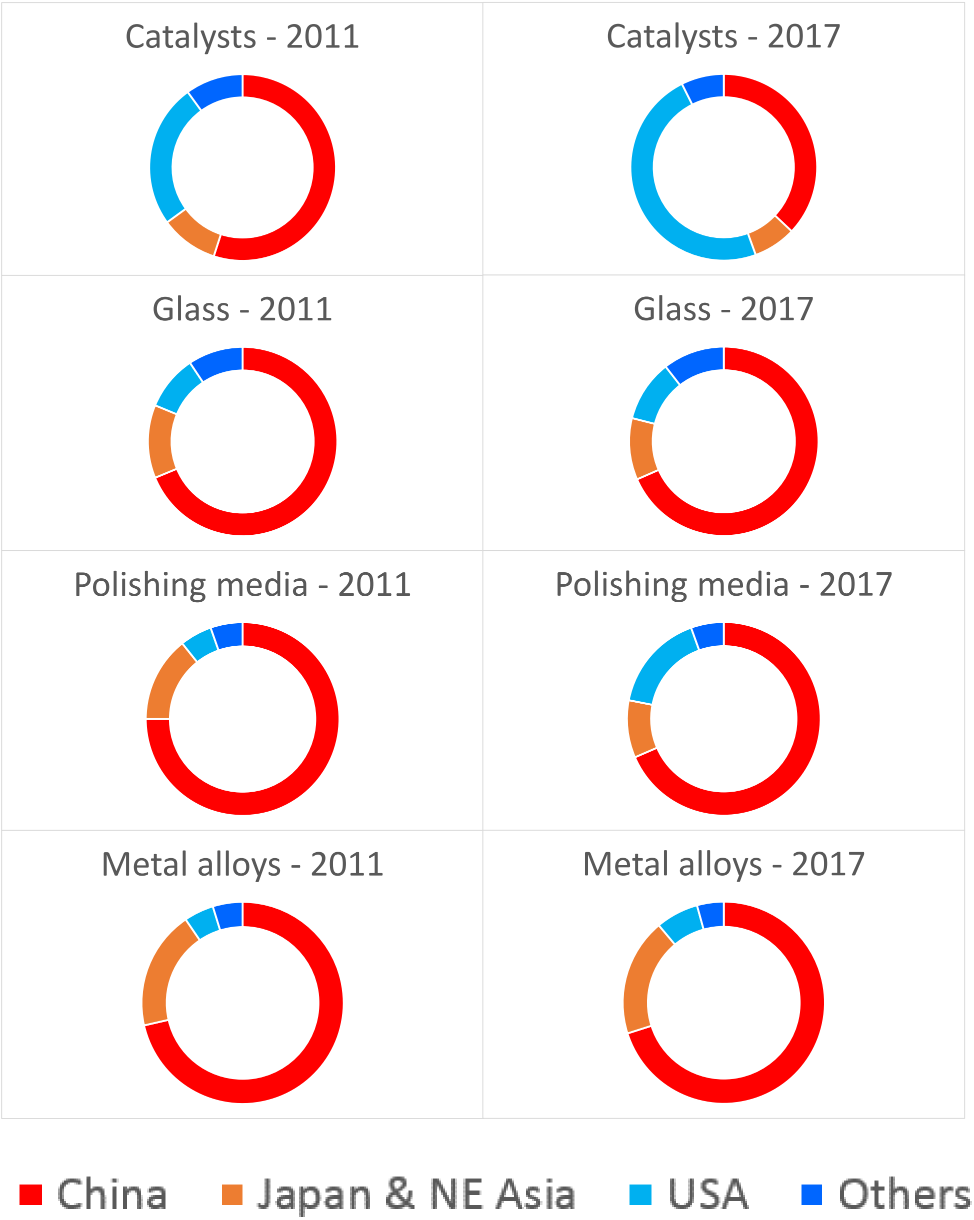
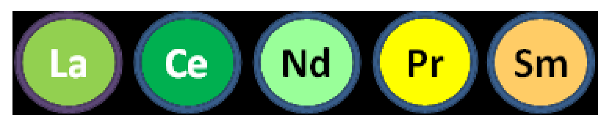


CAGR 2010 – 2020: 5%
Market value 2012: +/- 24 M USD

CAGR 2010 – 2020: 3%
Market value 2012: +/- 107 M USD

CAGR 2010 – 2020: 5%
Market value 2012: +/- 160 M USD

CAGR 2010 – 2020: 6.5%
Market value 2012: +/- 400 M USD



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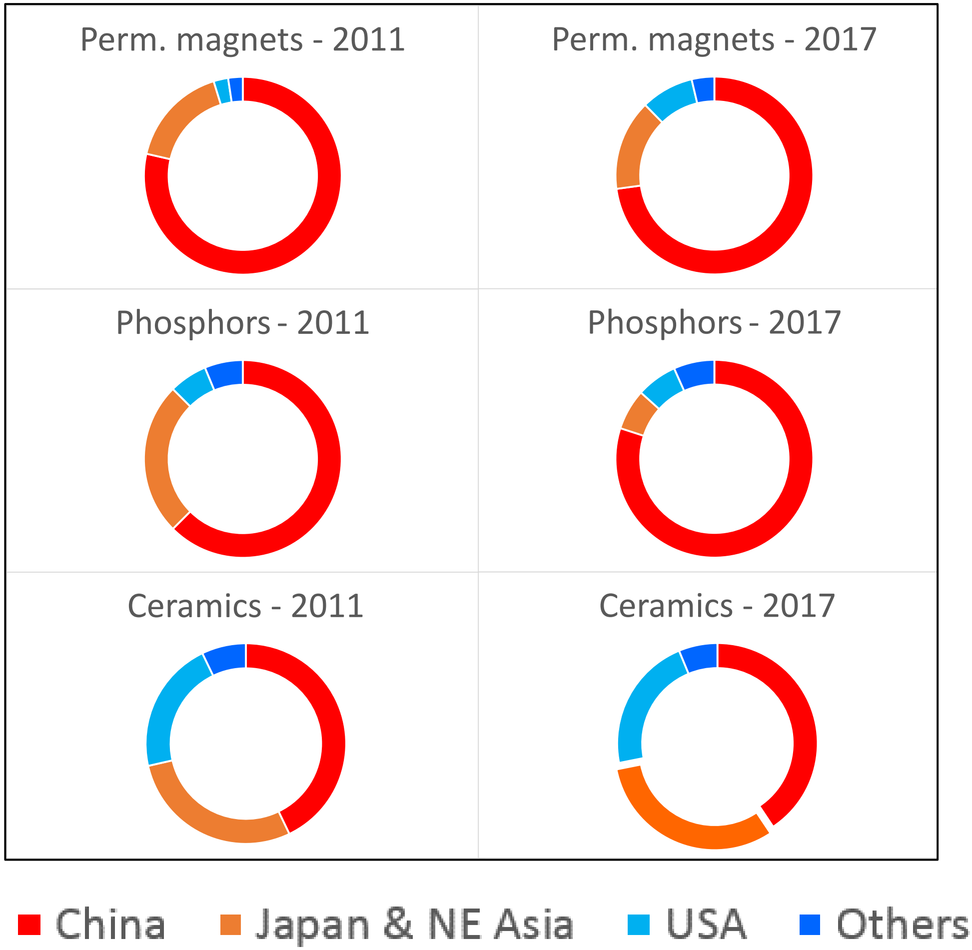
Direction de l'Evaluation et de la Stratégie



CAGR 2010 – 2020: 10%
Market value 2012: +/- 2 020 M USD

CAGR 2010 – 2020: 4% (possibly much less)
Market value 2012: +/- 214 M USD

CAGR 2010 – 2020: 5%
Market value 2012: +/- 100 M USD

Data sources: Dudley Kingsnorth, IMCOA;

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3 – A EUROPEAN PERSPECTIVE

Europe's situation

- **Rare Earth derived products (not Rare Earth!) are essential inputs to numerous downstream industries in sectors as diverse as aeronautics, automobile, defence, renewable energy, health, ICT, space**
- **There is No EU REE production so far, but there are advanced REE mining projects:**
  - Norra Kärr in Sweden, estimated CAPEX: 423 M$, no refinery and separation plant (presentation later on during this conference)
  - Kvanefjeld in Greenland, estimated CAPEX 1.53 bn M$, including a refinery in Greenland. Separation would take place at a Chinese plant.

Europe’s situation

- **Kvanefjeld, the world largest advanced REE project outside China, may end up as a China-controlled operation. China Non-Ferrous Metal Mining Group (CNMC) has signed an MOU with Greenland Minerals & Energy in April 2014 to cooperate on the preparation of the feasability study. CNMC is building a 7000 tpa separation plant in China that would be well suited to the processing of RE concentrate from Kvanefjeld (# 3 Dy + Eu + Nd + Pr + Tb stock outside China, # 28 by grade, out of 45 deposits)**
- **This appears as one of several moves by China to take control of key Nd-Pr-Dy-Eu-Tb rich deposits outside China. Other Chinese participations are developing:**
  - Nolans Bore, Australia (Shenghe Resources) - # 10, #12
  - Tantalus, Madagascar – ionic clay (Ganzhou Qiandong RE Group) - # 16, #42
  - Steenkampskraal, South Africa (Ganzhou Qiandong RE Group) - #25, #1
  - Browns Range, Australia (Jilin Jien Ni industry Co. Ltd.) - # 39, #40
  - Milo/ Mount Isa, Australia (Jiangxi Centre Mining Co. Ltd.) ?, ?

Europe's situation

> **Europe has excellent know-how in REE separation and the production of several REE-derived materials for catalysis, lighting (phosphors), high-precision polishing, medical and nuclear applications, pigments (Solvay) and has two separation plants: one at La Rochelle, France (Solvay, about 10 000 tpa separated purified oxydes capacities) and the other in Silmet, Estonia (Molycorp, 3 000 tpa capacity, tailored to the processing of Russian loparite ore)**

> **Europe has several REE permanent magnet production facilities, operating under Hitachi licence:**
- Vacuumschmelze, Germany;
- Magnetfabrik Schramberg, Germany (older Hitachi Patents Only);
- Neorem Oy, Finland (a subsidiary of Vacuumschmelze)

> **Some companies operate under their own patents:**
- Magnetfabrik Bonn, Germany
- Magneti Ljubljana, Slovenia
- Less Commo Metals, UK (produces only NdFeB alloy)

> **All together thy represent only a tiny share of the global NdFeB production**

4 – EUROPE'S RESPONSE TO THE REE CHALLENGES

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Europe's responses

> **The EU raw materials initiative [COM(2008)699], launched in November 2008, is the broad policy framework designed to address the EU dependence on raw materials imports and the sustainability issues related to its raw materials use by:**

- Fostering access to raw materials on world markets at undistorted conditions;
- Foster sustainable supply of raw materials from European sources
- Reduce the EU's consumption of primary raw materials

> **In the REE domain this materialized in:**

- Setting-up the European Rare Earths Competency Network (ERECON), a joint European Parliament and European Commission (2013-2015)
- Support to REE-related research and innovation, via the 7th EU Research & Innovation Framework Programme (2007-2013) and, now, Horizon 2020 (2014-2020)

Europe's responses: ERECON

> **The Final ERECON report publication is pending.**

> **The conclusions of its draft version include:**

- Detailed mapping and **CONTINUOUS** monitoring of complex and changing REE supply chains – from mines to separation plants to end-users and end-of-life disposal > EU minerals intelligence capacity;
- Generous support to RE related research and technical education in exploration, mining, separation, recycling and substitution;
- Support and accelerate the scaling up and commercialization of key technologies through co-financing industry-led pilot plants for rare earth production and processing
- Provide financial support for the extensive R&D that is necessary to produce pre-feasibility and bankable feasibility studies
- Develop an EU circular REE economy through eco-design, collection of specific EOL products, development of an EU product-centric recycling policy, streamlining of the existing EU recycling policy and waste regulation
- Set-up a voluntary "EU critical raw materials fund" that de-risks project" and an "EU resource alliance" to take stakes in EU and foreign projects

Europe's responses: research and innovation

> **Several REE related EU co-funded research and innovation projects aim at addressing different issues all along the REE supply chains:**

- EURARE: EU REE resources knowledge, mibing, beneficiation, separation (to be presented later during this conference);
- REMSIL also looks at RE separation by means of ionic liquids;
- Numerous projects look are related to materials science, aiming either at a more efficient use of REE or at novel applications: RECRYSTENG, CIPRIS, NANOSWITC, NANOSPEC, REALISE, HI-WI, DRREAM, CEREPEP, TARTASEAL are examples of such projects;
- NANOPYME, MRHELIMAG are more specifically addressing magnetic materials;
- VENUS, ROMEO and REFREEPERMAG look at substitution of REE in permanent magnets.

5 – CONCLUSIONS: THE END OF THE CHINESE REEE MONOPOLY?

Conclusions

- **The mastery of the REE dependent industrial supply chain appears to be a key component of China's industrial policy, whose objectives are to be a world leader in the aeronautics, automotive, solar and wind energy, electronics industries**
- **Its 863 (launched in 1986, 22 years before the launch of the EU Raw Materials Initiative) and its siblings the 973 and 985 research programmes were very effective at bolstering the Chinese REE related innovation capacities.**
- **Europe's permanent magnet industry suffers from China's competition:**
  - A 18/02/2015 Vacuumschmelze press release states that due to growing competitive pressure from China, it will reduce staff at its Hanau facilities by nearly 25% (-340 jobs). Part of its magnets production will be transferred to China
  - All EU producers will be confronted with the nefarious consequences of China's persisting REE export restrictions and growing control of some of the best non-Chinese REE deposits. On 07/04/2015 Metal Pages listed the price Dy metal at an average of $ 525/ kg FOB China, while on the Chinese market the same metal was listed for $ 433, that is 17.5% less.

Europe's situation

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Conclusions

> **China faces a number of domestic issues that are likely to further stimulate its interest in REE mining projects beyond its borders:**
- Widely spread thorium contamination in the Bayan Obo and Baotou REE mining and REE processing/ separation facilites call for costly management of low-activity waste from light REE mining, processing and separation facilities;
- The high environmental impacts (forest clear-cutting, contamination of aquifers, land degradation and erosion of bare soil) of heavy REE production in South China and the existence of unregulated illegal mines are challenging the capacity of China to maintain vital heavy REE production at current levels.
- Reorganisation of the Chinese REE industry has started

> **De-siloing EU research and innovation accross disciplines and national borders is key to meet the challenges poised by REE as essential vitamins. FP7, EIT Raw Materials and, hopefully, the Juncker Plan are keys to address the de-industrialisation challenge threatening the EU and its Member States.**

THANK YOU FOR YOUR ATTENTION

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