“Minor Metals and Rare Earths 2007”
Rare Earths:
An Industry at the Crossroads

by

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Disclaimer

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Summary of Presentation

- The Rare Earths Industry today
- China
- Demand and supply
- Forecast future demand and prices
- Opportunities for new producers

Rare Earths: A Short History

1794:	Rare earths discovered by Johan Gaddin at Ytterby in Sweden	
1903:	First commercial production of rare earth flints at Treibach in Austria	
1953:	Demand ~1,000t REO	Value ~US$25M
2003:	Demand 85,000t REO	Value US$500M
2006:	Demand 108,000t REO	Value US$1,000M
2012:	Demand 185,000t REO	Value US$2,000M

The Rare Earths Market Today

- Total demand: 117,000t REO pa (2007)
- Average price: US$10-12/kg REO
- Total value: US$1,250 million pa
- Constraints on Chinese supply are creating opportunities for new non-Chinese projects

China: Still Dominant

- Reserves: >25M tonnes REO
- Excess secondary processing capacity
- Access to cheap processing chemicals
- Leading edge RE technology
- Rapidly growing manufacturing sector
- Largest rare earth consumer (~60%)

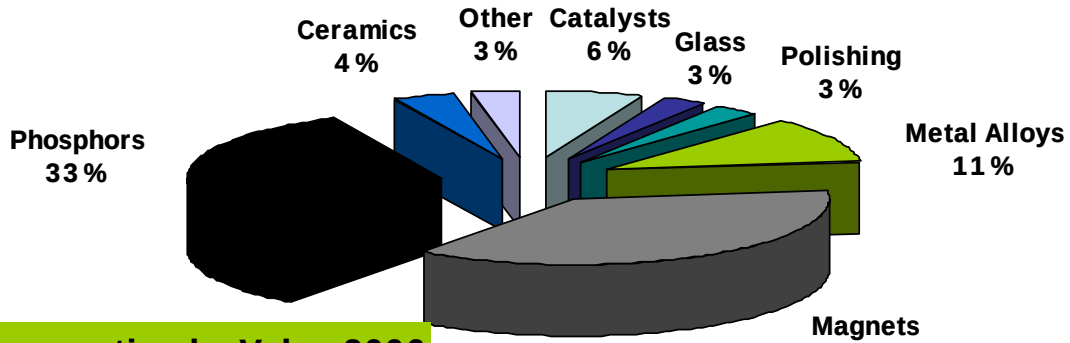
China: Industry Constraints

- Production quotas – ore reserves limited
- Export quotas plus 10% tax
- VAT rebate on exports withdrawn
- Issue of rare earth mining licences suspended
- Environmental legislation enforced
- Shortage of Nd, Pr and Tb.
- Significant increase in energy prices

Global RE Consumption 2006

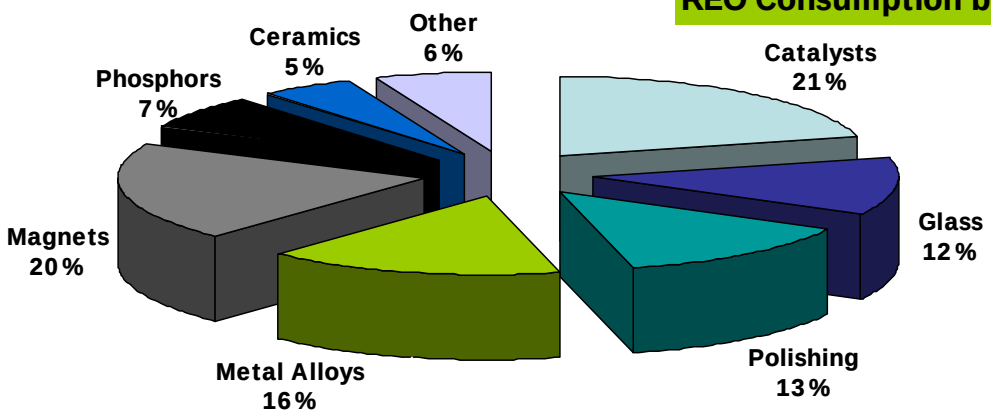
Global Rare Earths Consumption in 2006 (t REO ±10%)						
Application	**China**	**Japan and SE Asia**	**USA**	**Europe**	**Others**	**Total**
Catalysts	6,500	3,500	6,000	5,000	500	21,500
Glass	7,250	3,500	1,000	1,000	250	13,000
Polishing	7,000	4,500	1,000	1,000	500	14,000
Metal Alloys	10,250	4,000	1,500	1,000	250	17,000
Magnets	14,000	5,000	750	500	250	20,500
Phosphors	4,500	2,750	500	500	250	8,000
Ceramics	2,000	2,000	1,000	500	negligible	5,500
Other	6,500	1,000	250	250	negligible	8,000
Total	58,000	26,250	12,000	9,750	2,000	108,000

2006 REO Consumption



REO Consumption by Value 2006

REO Consumption by Volume 2006



Applications of Individual Rare Earths

Lanthanum	•alloys are used in lanthanum-nickel-hydride batteries •oxide is a component of fcc catalysts for petroleum refining •the oxide is used in making special optical glasses for lens •oxide improves the alkali resistance of glass •metal used an additive to produce nodular cast iron •alloys/mischmetal used in hydrogen absorption alloys and creep resistant magnesium alloys •metal is a constituent of mischmetal
Cerium	•oxide is used in autocatalysts •oxide is used in mechano-chemical polishing of computer chips •oxide is used in 'uv cut' glass for automobiles •oxide is used as a glass polishing agent •oxide is used in CRT and LCD glass panels as a decolouriser •oxide is used in the catalyst in "self-cleaning" ovens •oxide used in carbon-arc lighting with other rare earth elements •ulphide is used as a red pigment in plastics •metal is a constituent of mischmetal

Applications of Individual Rare Earths

Praseodymium	•metal improves corrosion resistance of neodymium-iron-boron magnets •salts used to colour glasses and enamels: produces an intense yellow colour •component of didymium used for colouring glass to make welder's goggles
Neodymium	• metal used in neodymium-iron-boron magnets, in lap-top computers, personal audio-visual equipment (i-pods) and voice coils •component of didymium used for colouring glass (e.g. welder's goggles) •salts are used as a colourant for enamels •oxide used in lasers (to produce coherent light) •oxide is used in autocatalysts to enhance the performance of cerium oxide •metal is a constituent of mischmetal
Samarium	• metal used in permanent magnet ($SmCo_5$) •oxide used in carbon-arc lighting for motion picture industry •used to dope CaF2 crystals for use in optical masers or lasers •oxide is a catalyst for the dehydration and dehydrogeneration of ethanol •metal is a constituent of mischmetal

Applications of Individual Rare Earths

Europium	•oxide used as a phosphor activator •europium-activated yttrium vanadate is used in red phosphors •europium isotopes are good neutron absorbers and are used in nuclear control applications
Gadolinium	•used for making gadolinium yttrium garnets which have microwave applications •gadolinium compounds are used for making phosphors superconductive properties •used as intravenous contrasts to enhance images in patients undergoing MRI (magnetic resonance imaging)
Terbium	•oxide is an activator for green phosphors •used in rare earth magnets to enhance magnetic properties •used with ZrO_2 as a crystal stabilizer of fuel cells which operate at elevated temperatures
Dysprosium	•used in rare earth magnets to improve high temperature properties •in combination with vanadium used for making laser materials

Applications of Individual Rare Earths

Yttrium	•oxide used in yttrium stabilised zirconia •yttrium-europium phosphors give the red colour in colour television tubes •oxide is used to produce yttrium-iron-garnets, which are very effective microwave filters •used in laser systems •used as a catalyst for ethylene polymerisation •used in ceramics as the oxide has a high melting point and imparts shock resistance and low expansion characteristics to zirconia •metal increases the strengths of alloys of metals such as aluminium and magnesium

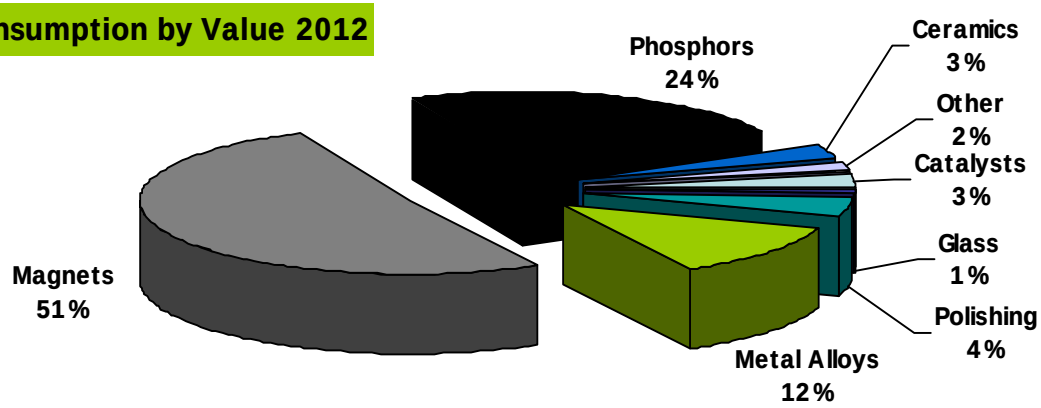
Forecast Demand in 2012

Global demand for rare earths in 2006 & 2012 (t REO) ± 10%

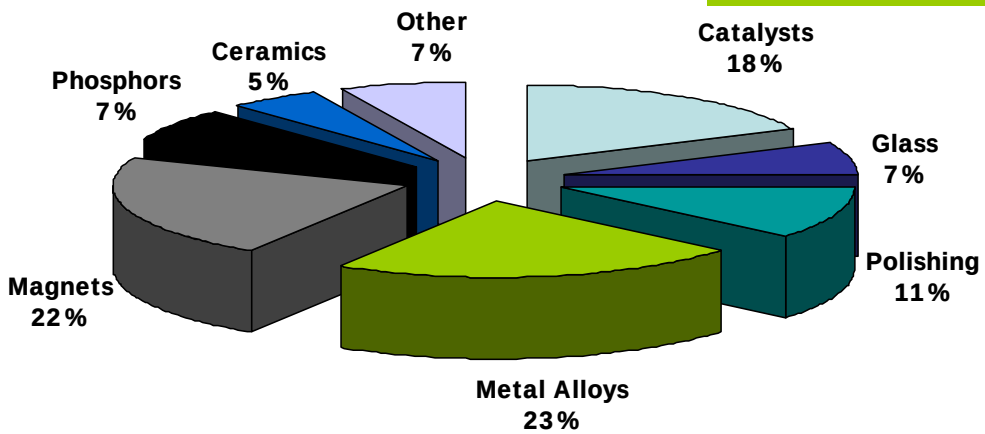
Application	Consumption tpa REO		Growth Rate
	2006	2012f	% pa
Catalysts	21,500	30-34,000	6-8%
Glass	**13,000**	**14,000**	**Negligible**
Polishing	14,000	20-22,000	6-8%
Metal Alloys	**17,000**	**42-46,000**	**15-20%**
Magnets	**20,500**	**40-44,000**	**10-16%**
Phosphors & Pigments	8,000	13-14,000	7-10%
Ceramics	5,500	8-10,000	7-9%
Other	8,000	12-14,000	7-9%
Total/Range	**108,000**	**180-190,000**	**9-11%pa**

2012 REO Consumption

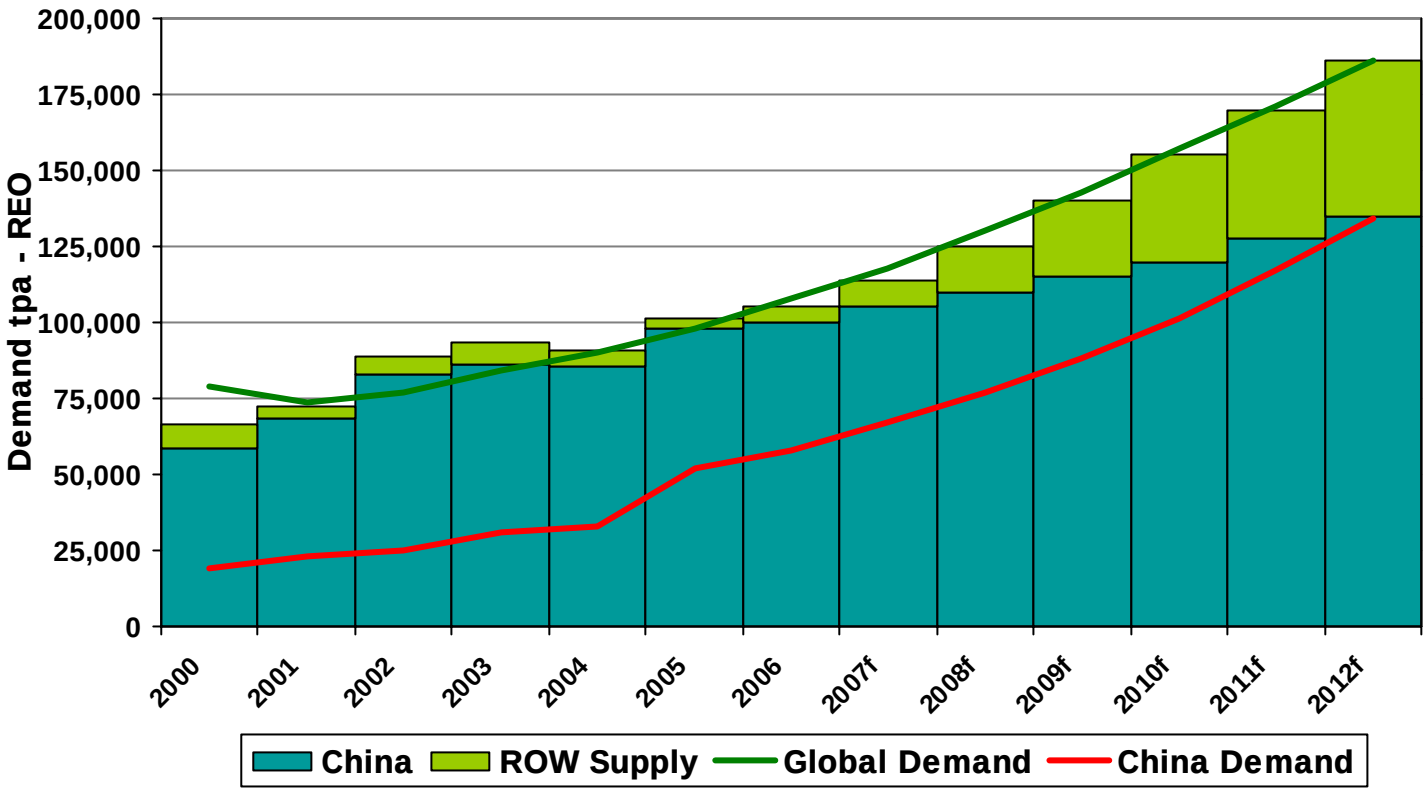
REO Consumption by Value 2012



REO Consumption by Volume 2012



RARE EARTHS SUPPLY & DEMAND



Source: IMCOA & CREIC

Potential Impact of Hybrid Vehicles

- Toyota committed to produce 1M hybrid vehicles in 2010, considering 2M
- Assume total of 3M hybrid in 2012
- Typically an NiMH battery for a hybrid vehicle contains 10-12kg rare earths
- If NiMH batteries achieve a 60-70% market share additional demand could be 20,000t REO p.a.

Impact of Demand for NdFeB Magnets

- Demand for rare earth magnet alloys grew from 2,500tpa in 1990, to 12,000tpa in 2000 to 20,000 in 2006.
- 2003/06 growth in demand was 15-20%pa
- Demand for rare earth magnets for voice coils (i-pods), for drives of equipment in vehicles and for electronic equipment remains high.
- At current rates of growth, total demand for Nd2O3 could be 50,000tpa in 2012, but price and supply constraints mean it is more likely to be 40-50,000tpa.

Occurrence & Demand for Individual REs

	Occurrence (%) in China	Demand (%) 2006	Demand (%) 2012 (f)
Lanthanum	**22-24**	**24-26**	**26-28**
Cerium	**44-48**	**37**	**29-31**
Praseodymium	4-6	4	4-6
Neodymium	**15-17**	**20**	**23-27**
Samarium	1-2	1½	2
Europium	¼-½	½	½
Gadolinium	1-2	2	2
Terbium	**¼-½**	**½**	**½**
Dysprosium	1-2	1-2	1-2
Yttrium	10-12	8	8

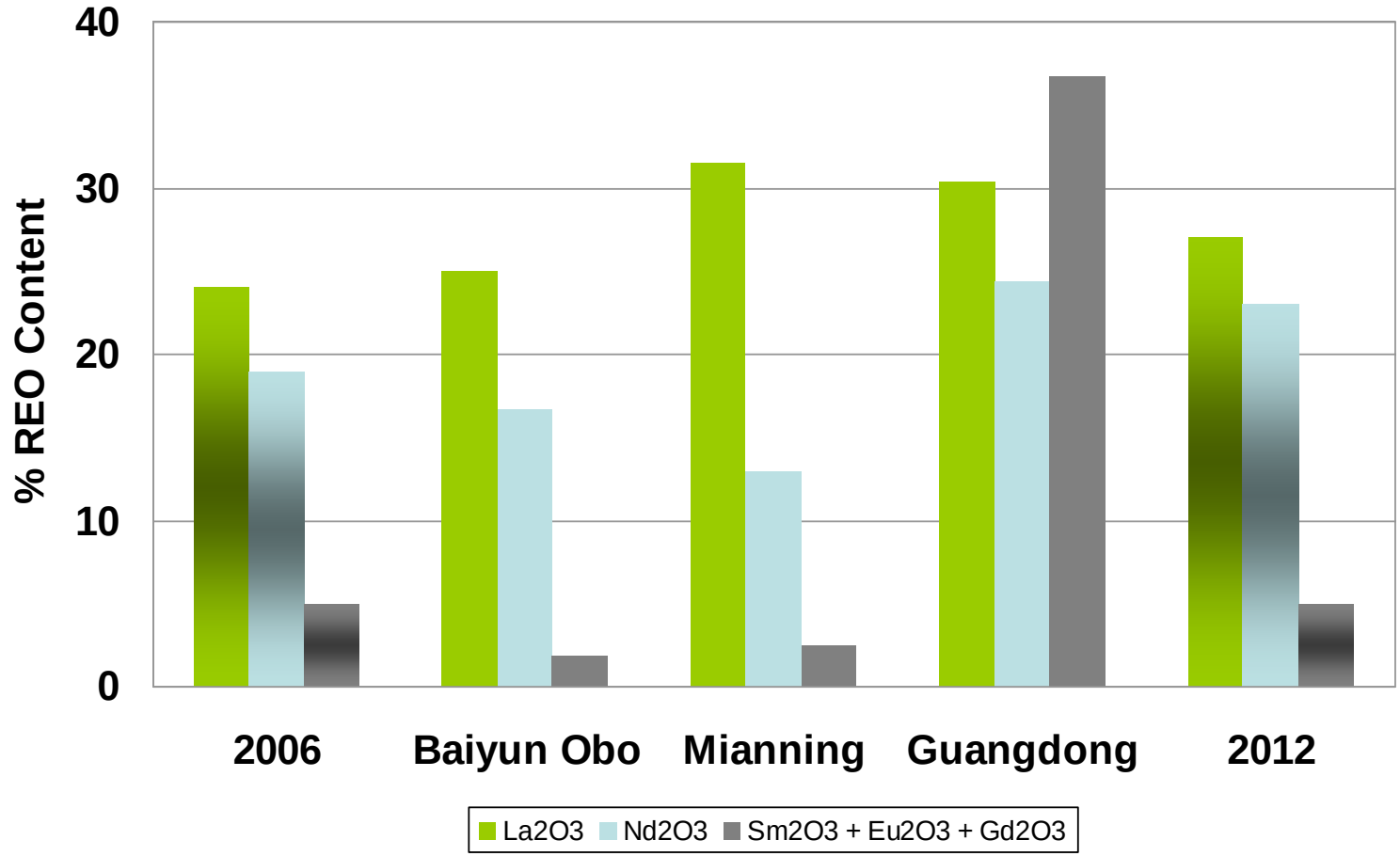
Major RE Source Minerals #1

Rare Earth Content of Major Source Minerals (% total REO)						
	Bastnaesite		Xenotime		Ion adsorption clays	
	Baiyun Obo, Mongolia, China	Mountain Pass, California USA	Lahat Perak, Malaysia	Guangdong,China	Xunwu, Jiangxi, China	Longnan, Jiangxi, China
La_2O_3	23.0	33.2	1.2	1.2	42.0	1.8
CeO_2	50.0	49.1	3.1	3.0	2.3	0.4
Pr_6O_{11}	6.2	4.3	0.5	0.6	8.8	0.7
Nd_2O_3	18.5	12.0	1.6	3.5	30.8	3.0
Sm_2O_3	0.8	0.8	1.1	2.2	3.8	2.8
Eu_2O_3	0.2	0.1	trace	0.2	0.5	0.1
Gd_2O_3	0.7	0.2	3.5	5.0	2.9	6.9
Tb_4O_7	0.1	trace	0.9	1.2	trace	1.3
Dy_2O_3	0.1	trace	8.3	9.1	trace	6.7
Y_2O_3	trace	0.1	61.0	59.3	8.0	65.0
Total	**99.6**	**99.8**	**81.2**	**85.3**	**99.1**	**88.7**

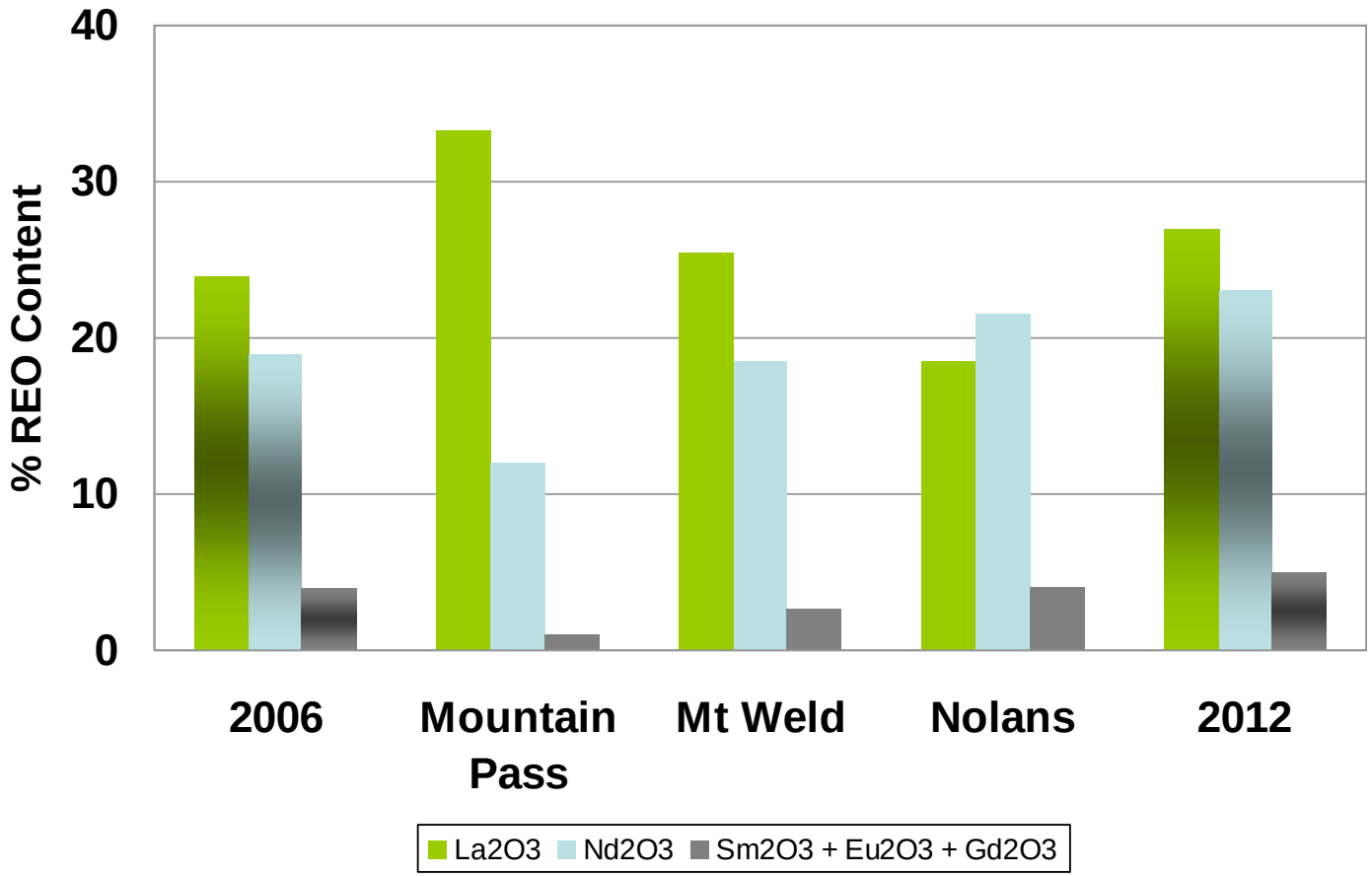
Major RE Source Minerals #2

Rare Earth Content of Major Source Minerals (% total REO)						
	Monazite				Apatite	
	Mt Weld, Australia	Green Cove Springs, Florida, USA	India	Nangang, Guandong, China	Nolans Australia	Russia
La_2O_3	25.1	17.5	23.0	23.0	18.5	25.1
CeO_2	48.5	43.7	46.0	42.7	47.8	45.0
Pr_6O_{11}	5.3	5.0	5.5	4.1	6.1	3.9
Nd_2O_3	16.7	17.5	20.0	17.0	21.4	14.0
Sm_2O_3	2.2	4.9	4.0	3.0	2.4	1.6
Eu_2O_3	0.6	0.2	-	0.1	0.5	0.5
Gd_2O_3	0.9	6.6	-	2.0	1.2	1.5
Tb_4O_7	0.1	0.2	-	0.7	0.1	0.1
Dy_2O_3	0.2	0.9	-	0.8	0.3	1.0
Y_2O_3	0.3	3.2	-	2.4	1.5	4.3
Total	**99.9**	**99.7**	**98.5**	**95.8**	**99.8**	**97.4**

Chinese Resources: REO Balance vs. Demand



New Projects: REO Balance vs. Demand



Potential Non-China RE Suppliers

Factor	Mountain Pass (USA)	Mt Weld (Australia/ Malaysia)	Nolans (Australia)	Thor Lake Canada	Hoidas Lake Canada
Status	Being re-commissioned	Start-up in late 2008. Project approvals in place. Construction commenced	Pre-feasibility study complete. Pilot plant starts late 2007. Project approval process commenced	Advanced exploration. Some prelim test work.	Advanced exploration. Some prelim test work.
Resource	50Mt @8-9% REO 4.3Mt REO contained	7.7Mt @ 12.0% REO 0.92Mt REO contained	18.6Mt @ 3.1% REO 0.58Mt REO contained	14Mt @ 1.2% REO 0.2Mt REO indicated	1.4Mt @ 2.6% REO 0.04Mt REO indicated
Potential Production	Potential 2-10,000t REO pa in 2008.; actual output not disclosed.	10,000t REO pa in mid 2009. Several sales contracts in place. Increase to 20,000t REO in 2010/11	Target 10-20,000t REO pa in 2010. Phosphate, calcium chloride and uranium co-products improve economics	Unknown Start-up later than 2010/11	Unknown Start-up later than 2010/11
Critical Issues	•Re-starting an 'old' plant. •Rare earths are non-core to Chevron	•Staffing in 'booming' mining sector. •Distance from Mt Weld to Malaysia	•Process (bench scale @ ANSTO proven) •Approvals (started) •Customer support	•Define resource •Develop process •Customer support •Approvals	•Define resource •Develop process •Approvals •Customer support • Above Arctic Circle

Price History of Selected Rare Earths

Products	Prices US$/kg REO				
	Q1 2002	Q1 2004	Q1 2006	Q3 2006	Q3 2007
$RECO_3$	1.05	1.20	1.55	2 - 3	3.5
La_2O_3 99%	2.40	1.60	1.85	1.45	3.8
CeO_2 99%	2.35	1.70	1.45	1.35	3.0
Nd_2O_3 99%	4.30	5.70	9.55	19.0	33.0
Eu_2O_3 99%	250	250	210	240	350
Tb_2O_3 99%	180	200	320	500	575
Source: metal pages® and CREIC					

The Neodymium Equation in 2012

- Total REO demand in 2012: 185,000t REO
- Nd_2O_3 demand @ 23% Nd_2O_3 : 42,000t
- Nd_2O_3 produced @ 17% Nd_2O_3 : 31,000t
- Extra production to meet Nd_2O_3 **:**65,000t
- Extra ‘cost’ to process @ US$ 6/kg: US$400M
- Extra cost per kg Nd_2O_3 sold: US$10/kg Nd_2O_3
- Current price (2007): US$33/kg Nd_2O_3
- Forecast price in 2012: US$40-50/kg Nd_2O_3
- Note: The extra ore processing would also ‘solve’ the La and Tb shortage

Price Outlook – 2007/2012

- RECO3 – Shortage of primary concentrates, particularly Nd-rich– US$3-4 rising to US$4-5/kg REO
- La2O3 – Sound demand for NiMH batteries – US$2-4 rising to US$3-5/kg REO
- Ce2O3 – Falling Demand – US$2-3 falling to US$1/kg REO
- Nd2O3 – Ongoing high growth in demand for rare earth magnets – US$33 rising to US$40-50/kg REO
- SEG Cons (8%Eu2O3) – Possible ongoing cut in production of heavy REs in Southern China, coupled with high demand for heavy REs, particularly for Eu for phosphors and for Tb for RE magnets – US$16 rising to US$20-30/kg REO
- Total value rare earths market in 2012 ~ US$2 billion

The Issues

- Can China maintain control of:
  - rare earth mining & production
  - environmental management practices
  - rare earth exports
- Will higher prices impact demand?
- How quickly can the new projects come on-stream – to meet a potential shortfall in excess of 40,000t REO?

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Sources of Reference

- Industrial Minerals Company of Australia Pty Ltd
- Data from Roskill's 13th Edition "The Economics of Rare Earths" (to be published in October 2007)
- Prices from *metal pages* ©