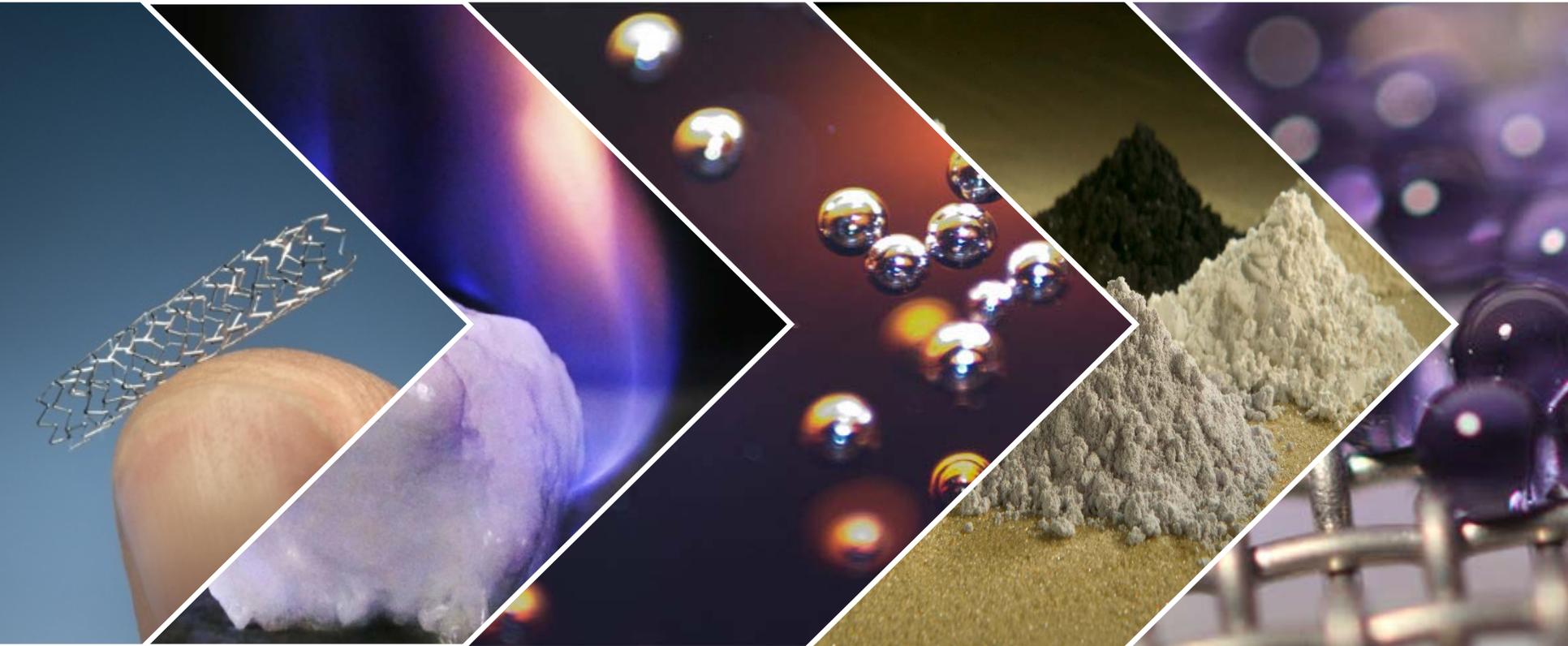


*Driving Innovation ♦ Delivering Results*



## S&T REE Tech Team Meeting

Peter Balash, Morgan Summers  
Energy Systems Analysis Team  
June 27, 2016

- **Argus International Rare Earths Summit**
- **Rare Earth Markets**
  - Production, Demand, Applications, and the Future
- **China's Success**
- **The “Toxic” Side of Renewable Energy**

# Argus International Rare Earth Summit



- **Over 70 Delegates from 14 Countries**
  - Included Mine Owners, Existing Processors, Novel Processors, Metal Producers, Magnet Manufactures, Consumer Product Makers, Consultants, along with DOD and DOE Representatives
- **Topics Covered Included:**
  - Rare Earth Consumption in the Everyday World
  - The Changing Production of FCC Catalysts
  - Assessing The RE Industry Post – Molycorp
  - Analyzing the Changing Global RE Supply and Demand Outlook
  - Supply Chain Workshops with round table discussions
  - China's Ongoing Battle Against Illegal Mining
  - Recycling NdFeB Magnets
  - The design and Application of PM Motors
  - The Market Dynamics of the Permanent Magnet Industry
  - Status of DOD's Management of RE Supply Chain Risks
  - Strategic Materials Policy in the Defense Department and RE in the National Defense Stockpile
  - Examining the Technology Gaps in the RE Supply Chain

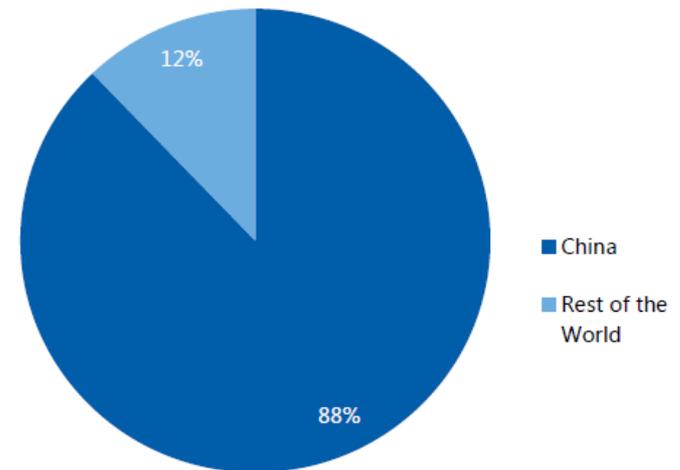
# Rare Earth Production



- China obviously the dominant rare earth producer – almost 90pc of output in 2015
- Rest of world production = 12pc (Molycorp & Lynas)

## Estimated 2015 Rare Earth Production

Total REO production estimated at 170,000t



— Argus

- **Production Outside of China**

- Molycorp (US) – Filed for bankruptcy in June 2015. Mountain Pass mine was placed on care and maintenance in late 2015. Produced 4,100 tons in 2015. Facility was designed to produce 20,000 ton/year.
- Lynas (Australia) – now the only operating rare earth miner outside of China. Produced 10,000 tons in 2015. Lynas's Advanced Materials Plant (LAMP) in Malaysia is the world's largest rare earth refinery and handles refining duties for Lynas's mines in Australia.
- Solvay (France) – Concentrates and separates rare earths from recycled light bulbs. Will concentrate and separate other rare earth containing feeds for a tolling fee of €23/kg (~\$46/lb).

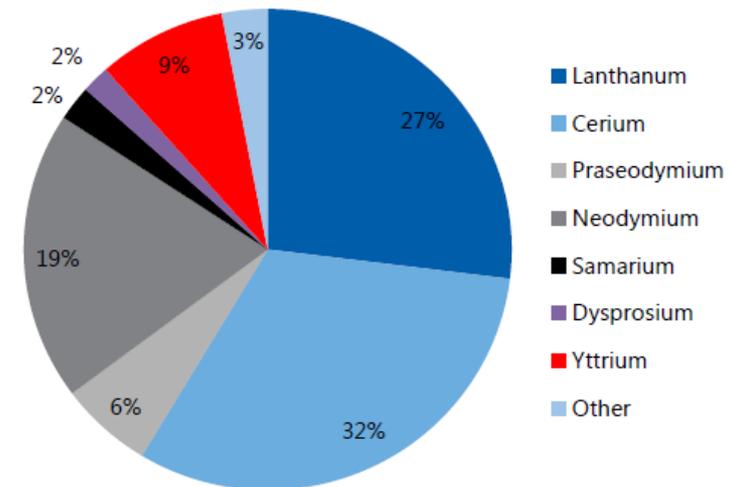
# Rare Earth Production



- LREEs dominate rare earths production – 85pc+
  - Ce = 32pc
  - La = 27pc
  - Nd = 19pc
  - Pr = 6pc
  - Sm = 2pc
- HREEs much less prominent in volume terms – less than 15pc:
  - Y = 9pc
  - Dy = 2pc

**Estimated rare earth oxide production by product, 2015**

Total REO production estimated at 170,000t



— Argus

# Rare Earth Requirements by Industry



The eight industry sectors require different types of rare earth and options to substitute can be limited.

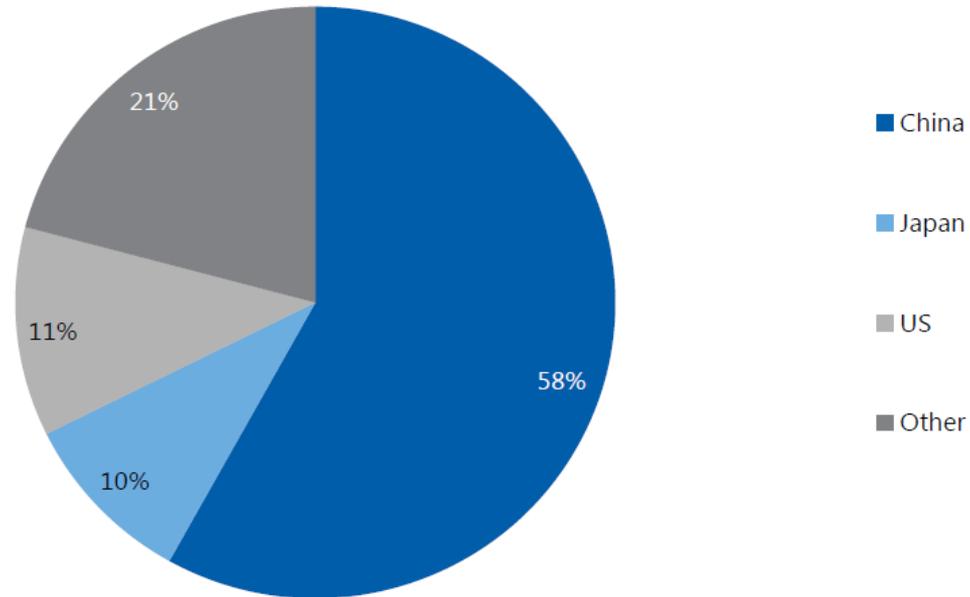
Industry	RE used	LRE/HRE	Substitution potential
Glass	Cerium, Lanthanum, Praseodymium, Neodymium, Yttrium	LRE	High
Neodymium magnets	Neodymium, Praseodymium, Dysprosium, Gadolinium, Terbium	HRE/LRE	Low-Medium
Refinery catalysts	Lanthanum, Cerium	LRE	Low
Battery alloys	Lanthanum, Cerium, Neodymium, Praseodymium, Samarium	LRE	-
Metallurgy (excl. batteries)	Cerium, Lanthanum, Neodymium, Praseodymium	LRE	Medium
Phosphors	Yttrium, Cerium, Lanthanum, Gadolinium, Europium, Terbium	LRE/HRE	Low
Ceramics	Yttrium, Lanthanum, Cerium, Neodymium, Praseodymium	LRE	High
Catalytic converters	Cerium, Lanthanum, Neodymium, Praseodymium	LRE	Low
Other	Cerium, Lanthanum, Yttrium, Neodymium, Praseodymium, Samarium, Gadolinium, Other REOs	LRE/HRE	N/A

# Rare Earth Demand



Rare earth consumption by country, 2014

Total world consumption = 149,000t



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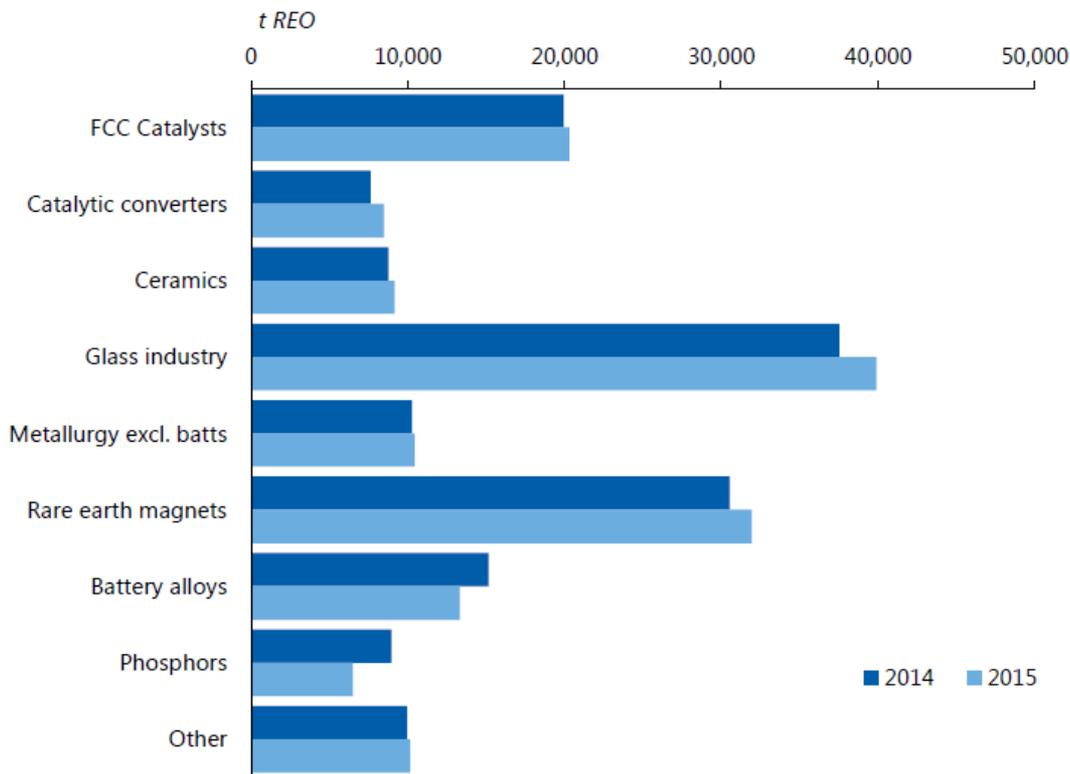
~\$5 billion Industry

# Rare Earth Demand



- Glass industry main consumer of rare earths (Ce)  $\approx$  40,000t REO in 2015
- Magnets  $\approx$  32,000t REO & growing
- Catalysts  $\approx$  29,000t REO (growth in catalytic converters)
- Demand in batteries down to  $\approx$  13,000t in 2015 (preference for Li-ion over NiMH in electric vehicles)

Global rare earth oxide demand by industry sector

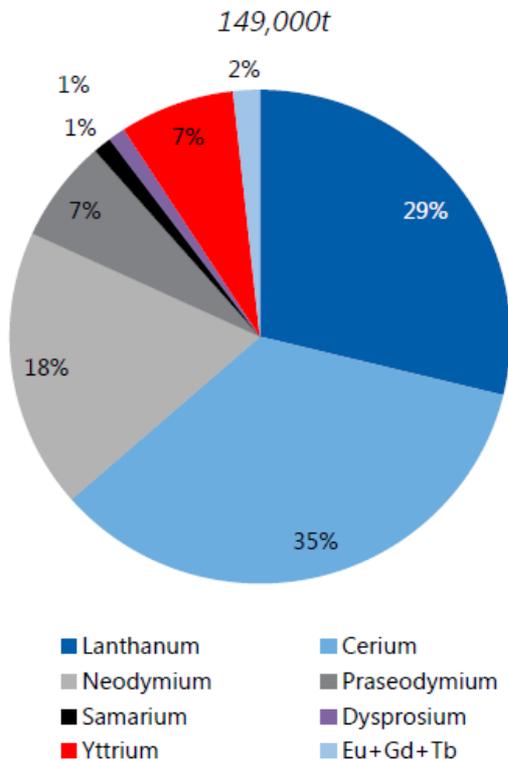


- Argus

# Applications

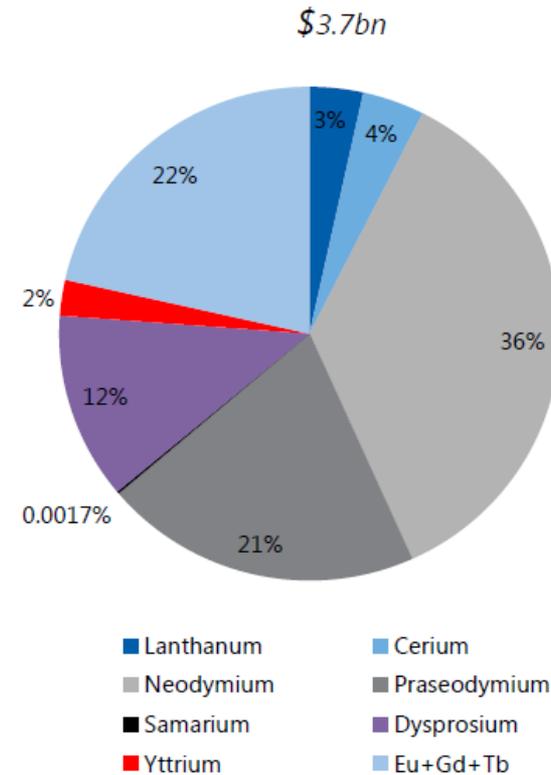


Rare Earth Product Consumption by Volume, 2015



— Argus

Rare Earth Product Consumption by Value, 2015

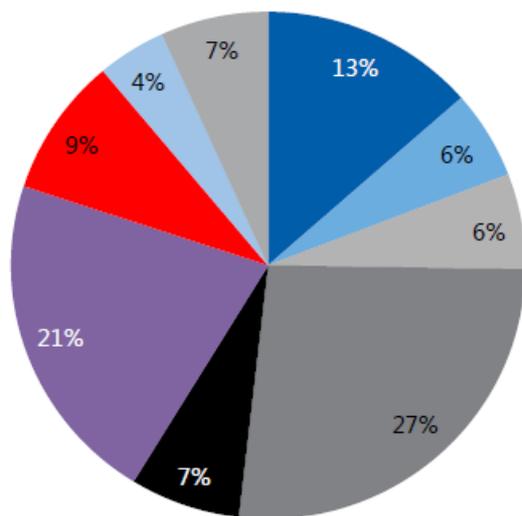


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# Applications



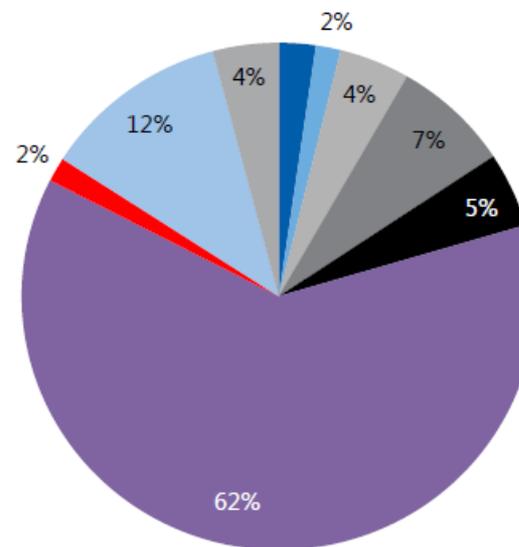
**Breakdown of Industrial Consumption by Volume  
2015**



- FCC Catalysts
- Ceramics
- Metallurgy excl. batts
- Battery alloys
- Other
- Catalytic converters
- Glass industry
- Rare earth magnets
- Phosphors

— Argus

**Breakdown of Industrial Consumption by Value 2015**



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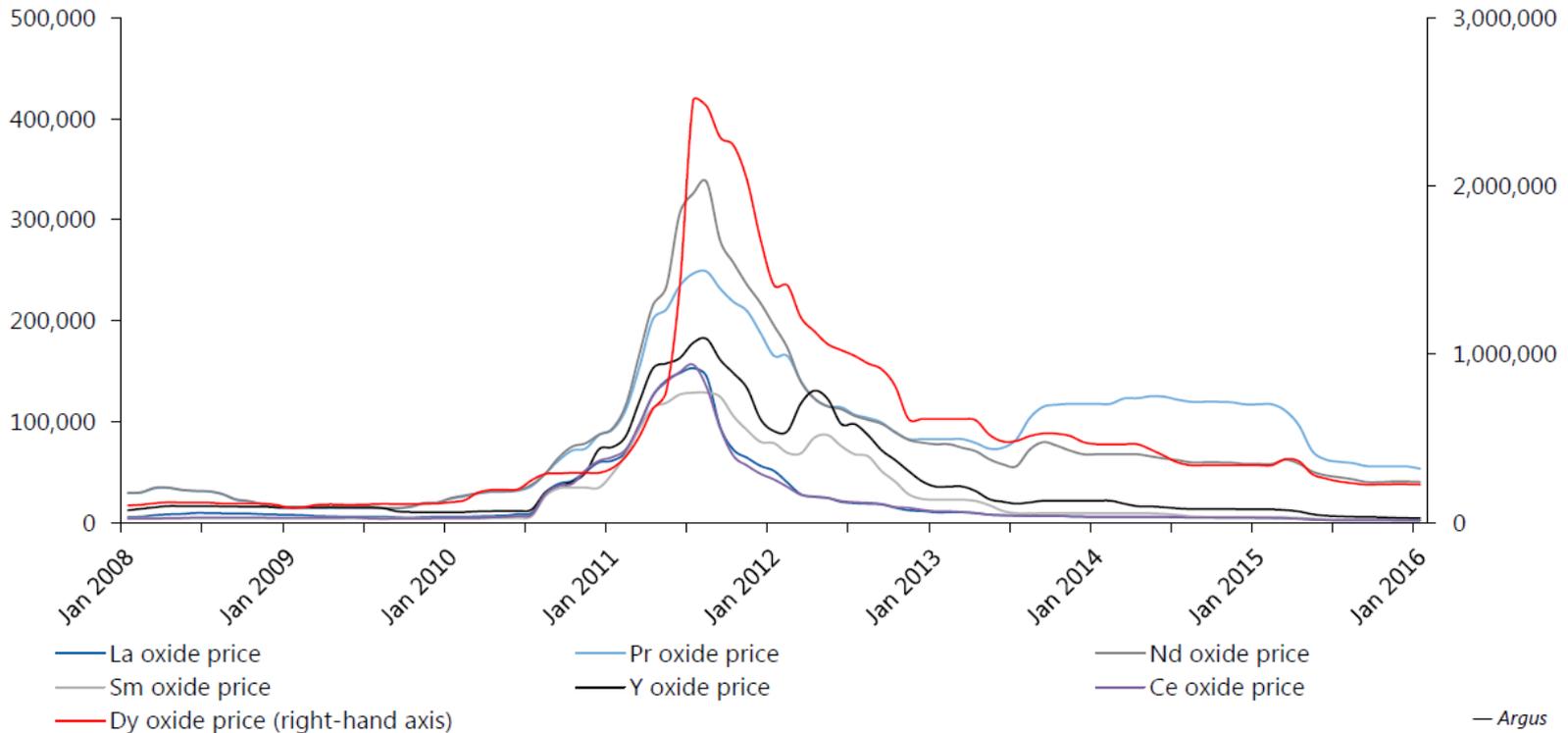
— Argus

# Historic Rare Earth Pricing



Rare earths prices peaked in 2011 and have generally trended down since then

Rare earth FOB oxide prices, 2008-16 (\$/t)



# Projects Proposed



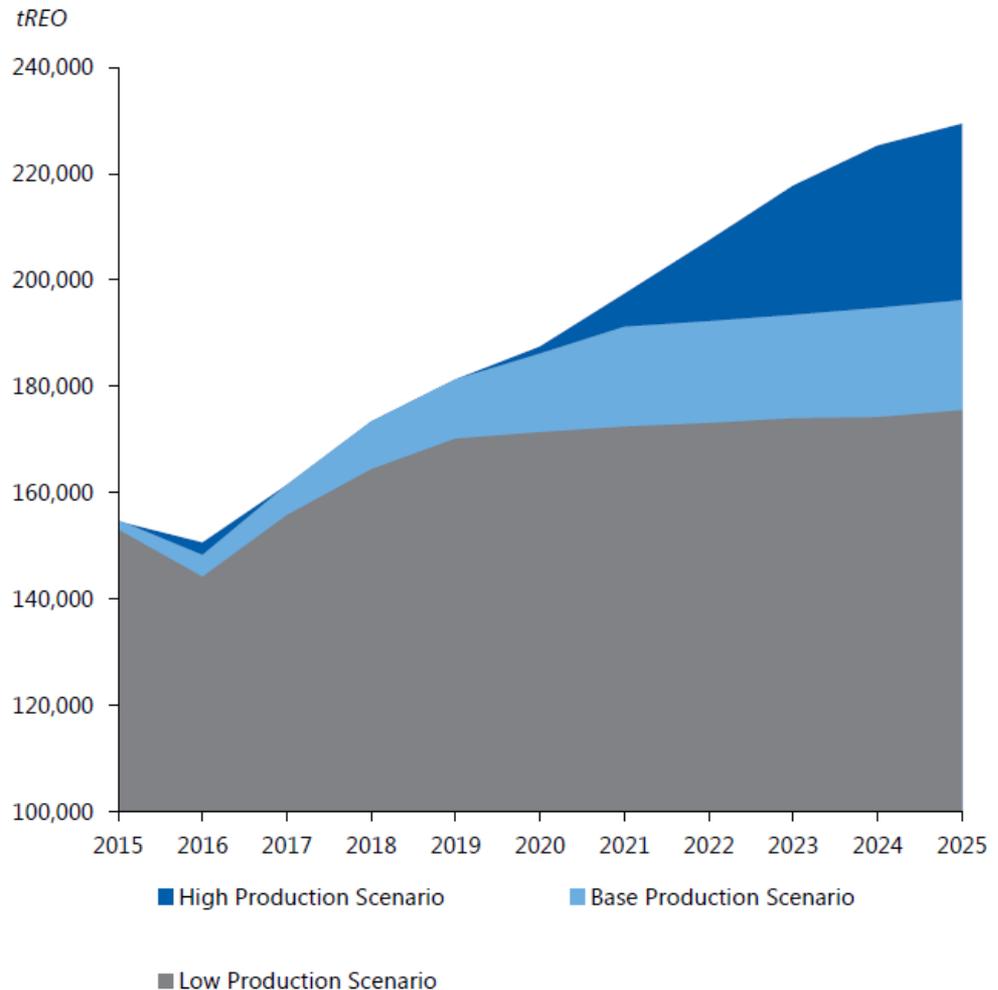
Rare Earth Project tracker

Company	Project	Country	Scheduled Start Date	Mineral Resource (mn t)	Intended Output (tREO/yr)
AMR Mineral Metal Inc.	Aksu Diamas	Turkey	2016	494.00	5,800
Rainbow Rare Earths Ltd.	Gakara	Burundi	2016	0.26	2,500
Matamec Exploration Inc.	Kipawa	Canada	2016	19.80	3,650
Hastings Rare Metals Ltd.	Yangibana	Australia	2016	6.79	3,560
Northern Minerals Ltd.	Browns Range	Australia	2017	8.47	3,100
Rare Element Resources Ltd.	Bear Lodge	USA	2016	14.70	4,950
Tantalus Rare Earths AG	Tantalus	Madagascar	2016	429.90	10,000
Tasman Metals Ltd.	Norra Kärr	Sweden	2016	31.11	6,800
Alkane Resources Ltd.	Dubbo Zirconia	Australia	2017	73.20	5,947
Greenland Minerals and Energy Ltd.	Kvanefjeld	Greenland	2017	956.00	23,000
Peak Resources Ltd.	Ngualla	Tanzania	2017	20.70	10,000
Ucore Rare Metals Inc.	Bokan Mountain	USA	2017	6.70	2,260
Avalon Rare Metals Inc.	Nechalacho	Canada	2018	14.60	4,600
Mkango Resources Ltd.	Songwe	Malawi	2018	36.47	2,800
Arafura Resources Ltd.	Nolans Bore	Australia	2019	47.00	20,000
Commerce Resources	Ashram	Canada	-	278.32	16,800
Galileo Resources PLC	Glenover (JV)	South Africa	-	2.60	-
Geomega Resources Inc.	Montviel	Canada	-	183.90	-
Hudson Resources Inc.	Sarfartoq	Greenland	-	14.00	200,000
Montero Mining & Exploration	Wigu Hill Twiga	Tanzania	-	3.30	20,000
Namibia Rare Earths Inc.	Lofdal	Namibia	-	3.28	1,500
Pele Mountain Resources Inc.	Eco Ridge	Canada	-	563	9,000
Steenskampskraal Thorium	Steenskampskraal	South Africa	-	0.60	-

# Rare Earth World Production Outlook



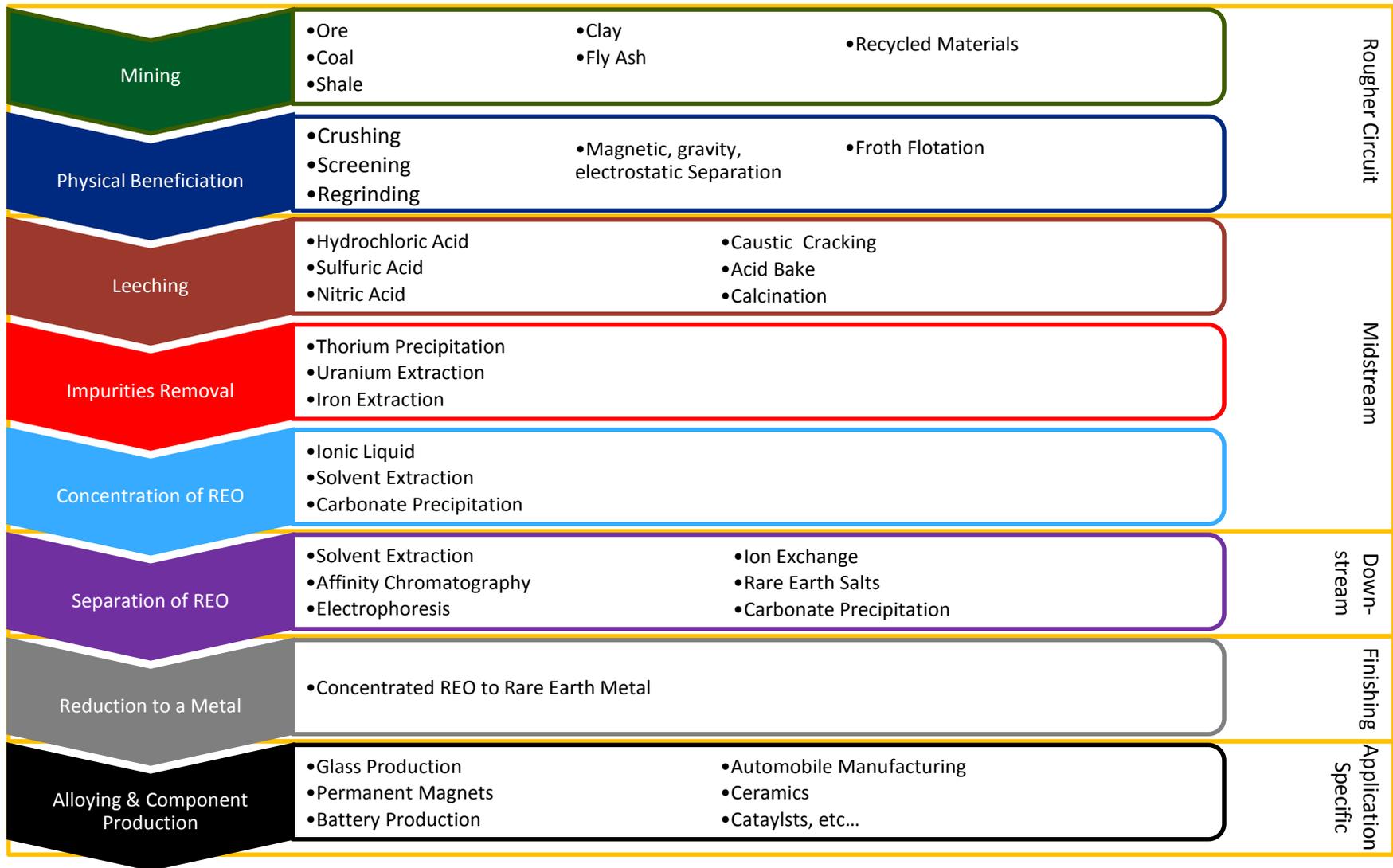
- Small drop in 2016 due to Molycorp closure and production cutbacks in China
- Output by 2025:
  - Low case  $\approx 175,000t$
  - Base case  $\approx 200,000t$
  - High case  $\approx 230,000t$



## China Produces over 90% of all the Rare Earths Globally, but Why?

- **Vertical Integration of the Supply Chain**
  - Mining, Concentrating, Separating, Reducing, Component Manufacturing
- **Global Market Value Set by Cheap Production and Processing**
  - Inexpensive Labor
  - Lack of Environmental Regulations
  - Illegal Mining

# Vertical Integration of the Supply Chain



# The “Toxic” Side of Renewable Energy



- **A 3 MW wind turbine can use up to 2,700 kg of NdFeB magnets.**
- **Rare Earths are also used in the batteries and motors for many electric cars**
- **Trading one emission type of others**

# REE Processing and the Chinese Environment



Black sludge is pumped into a toxic lake — byproducts of the ingredients that make up most of our technology. Picture: Liam Young/Unknown Fields

# REE Processing and the Chinese Environment



The toxic lake sits on the outskirts of town with dangerous radioactive levels. Picture: Liam Young/Unknown Fields. Source: *Supplied*

# REE Processing and the Chinese Environment



Farmland has been turned into a toxic lake just outside of the town. Picture: Liam Young/Unknown Fields. Source: *Supplied*

# REE Processing and the Chinese Environment



Surrounding factories pump their toxic waste into the man made lake. Picture: Liam Young/Unknown Fields.Source:*Supplied*

# Discussion



Clockwise from top center: praseodymium, cerium, lanthanum, neodymium, samarium, and gadolinium. (Photo by Peggy Greb).

