

Understanding the Rare Earth Element Supply Chain

Identifying Domestic Gaps and Opportunities

W. Morgan Summers, DOE/NETL Energy Systems Analysis Team

<div><div></div>Heavy Rare Earth Elements</div> <div><div></div>Critical Rare Earth Elements</div>																		5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon						
2 3 Li Lithium	4 Be Beryllium																			13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon				
3 11 Na Sodium	12 Mg Magnesium	21 Sc Scandium 44.955908 **	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton												
4 19 K Potassium	20 Ca Calcium	39 Y Yttrium 88.90584	40 Zr Zirconium	41 Nb Niobium	57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90766	60 Nd Neodymium 144.242	61 Pm Promethium 145	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25 *	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93033	68 Er Erbium 167.259	69 Tm Thulium 168.93422	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	
5 37 Rb Rubidium	38 Sr Strontium	57 Y Yttrium	58 Zr Zirconium	59 Nb Niobium	60 La Lanthanum	61 Ce Cerium	62 Pr Praseodymium	63 Nd Neodymium	64 Pm Promethium	65 Sm Samarium	66 Eu Europium	67 Gd Gadolinium	68 Tb Terbium	69 Dy Dysprosium	70 Ho Holmium	71 Er Erbium	72 Tm Thulium	73 Yb Ytterbium	74 Lu Lutetium	81 Ag Silver	82 Cd Cadmium	83 In Indium	84 Sn Tin	85 Sb Antimony	86 Te Tellurium	87 I Iodine	88 Xe Xenon		
6 55 Cs Cesium	56 Ba Barium	57 Y Yttrium	72 Zr Zirconium	73 Nb Niobium	74 La Lanthanum	75 Ce Cerium	76 Pr Praseodymium	77 Nd Neodymium	78 Pm Promethium	79 Sm Samarium	80 Eu Europium	81 Gd Gadolinium	82 Tb Terbium	83 Dy Dysprosium	84 Ho Holmium	85 Er Erbium	86 Tm Thulium	87 Yb Ytterbium	88 Lu Lutetium	89 Hf Hafnium	90 Ta Tantalum	91 W Tungsten	92 Re Rhenium	93 Os Osmium	94 Ir Iridium	95 Pt Platinum	96 Au Gold	97 Hg Mercury	
7 87 Fr Francium	88 Ra Radium	89 Y Yttrium	104 Rf Rutherfordium	105 Db Dubnium	106 La Lanthanum	107 Ce Cerium	108 Pr Praseodymium	109 Nd Neodymium	110 Pm Promethium	111 Sm Samarium	112 Eu Europium	113 Gd Gadolinium	114 Tb Terbium	115 Dy Dysprosium	116 Ho Holmium	117 Er Erbium	118 Tm Thulium	119 Yb Ytterbium	120 Lu Lutetium	121 Hf Hafnium	122 Ta Tantalum	123 W Tungsten	124 Re Rhenium	125 Os Osmium	126 Ir Iridium	127 Pt Platinum	128 Au Gold	129 Hg Mercury	130 Tl Thallium

Outline

Global Supply

Domestic Demand

Demand Projections and Value

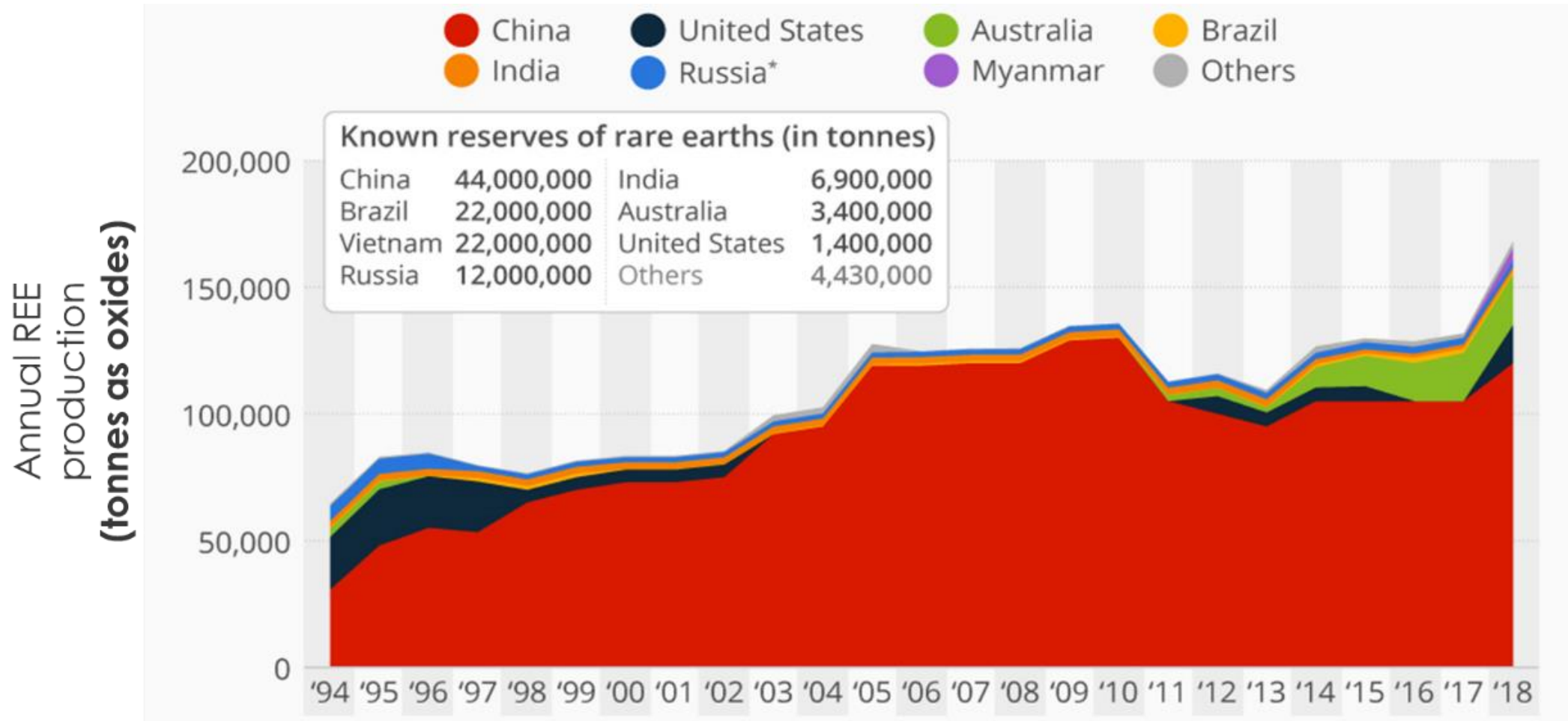
Understanding the Supply Chain

Challenges for a Domestic Supply Chain

Opportunities for Coal-Based Sources

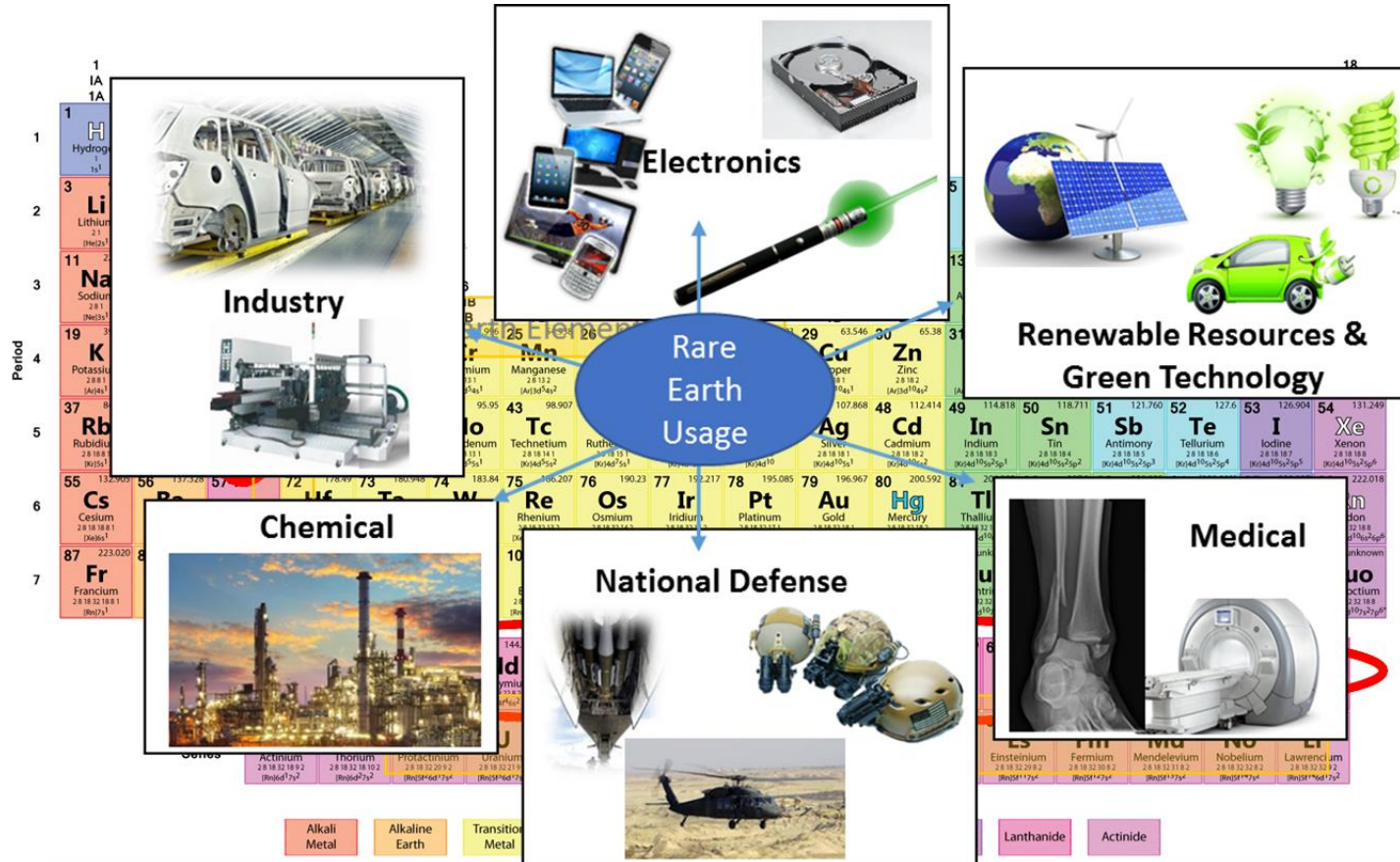
Filling Domestic Supply Chain Gaps

Global Supply and Demand for REE

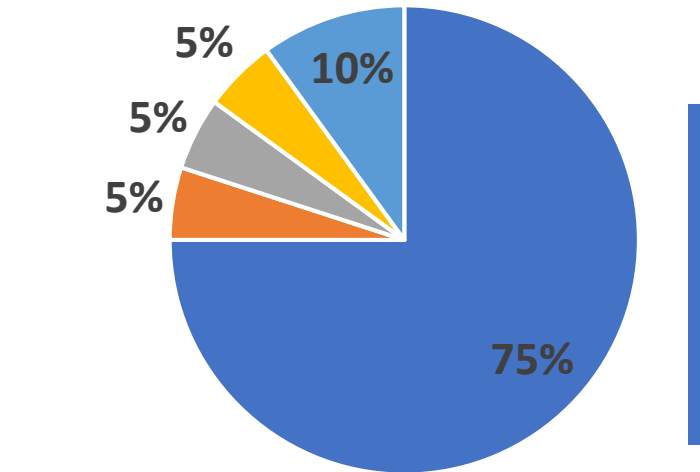


Source: USGS

Domestic Rare Earth Use



2019 Estimated Domestic End Use for Imported REEs



Total U.S
Demand for
Raw REE
Approx.
13,000
mt/year

- Catalysts
- Metal Alloys
- Ceramics & Glass
- Polishing
- Other

1. genius.com 2. Mos-Tech.co.uk 3. greenliving4live.com 4. cleantechica.com 5. shareimage.com 6. USGS Rare Earth Fact Sheet (2014) 7. lowereasternshorenews.com 8. esa.opn.org 9. army-technology.com 10. oilinvestingnews.com 11. alibaba.com 12. cardvice.com.au 13. demopolistimes.com 14. defenseimagery.mil

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Imports of Raw REE by Element

REOs Major End-Use Category

Lanthanum Oxide (La_2O_3):

By 2020, The global demand for this oxide is primarily fueled by catalyst related applications (64.5%) and will decrease (62.2%) as the demand for PVC stabilizers in the other end-use categories (3.7% to 11.2%) grows faster than the demand for catalysts

Cerium Oxide (Ce_2O):

In 2016 38.6% of the demand was driven by catalyst related applications, 27.4 % Glass Polishing Powders and 6.9% by other end uses like PV stabilizers. By 2025, the demand will shift to 38.2%, 26.9% and 12.6% respectively

Neodymium Oxide (Nd_2O_3):

In 2016 80.9% of the demand of Nd_2O_3 was driven from NdFeB permanent magnets. By 2025 this percentage will grow to 85%

Yttrium Oxide (Y_2O_3)

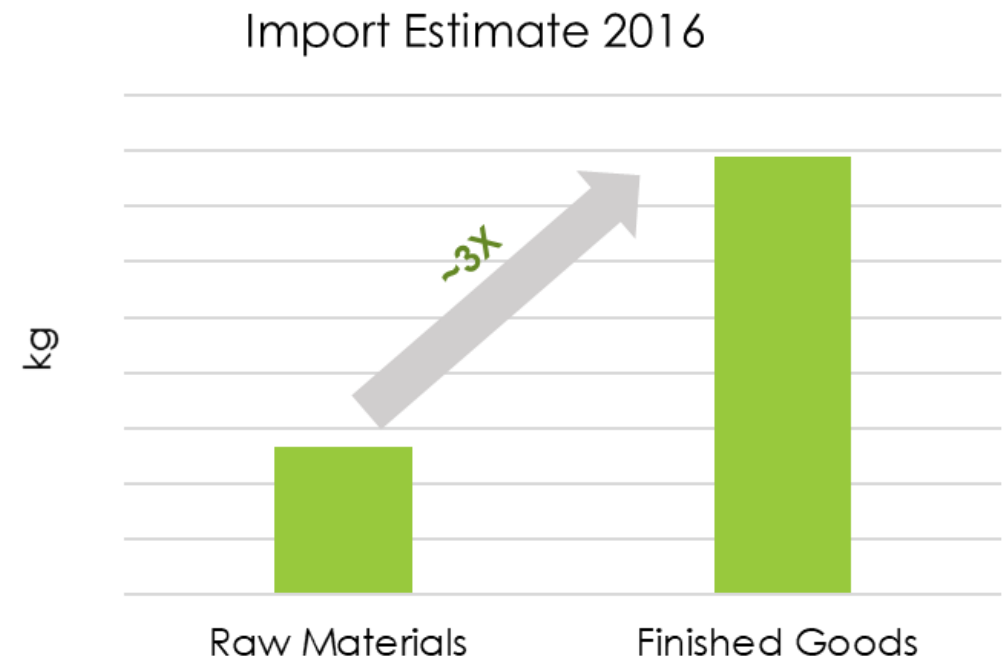
Yttrium demand is primarily fueled by phosphors used on linear fluorescent lamps (LFLs), compact fluorescent lamps (CFLs) and light emitting diodes (LEDs).

Domestic Demand by End Use

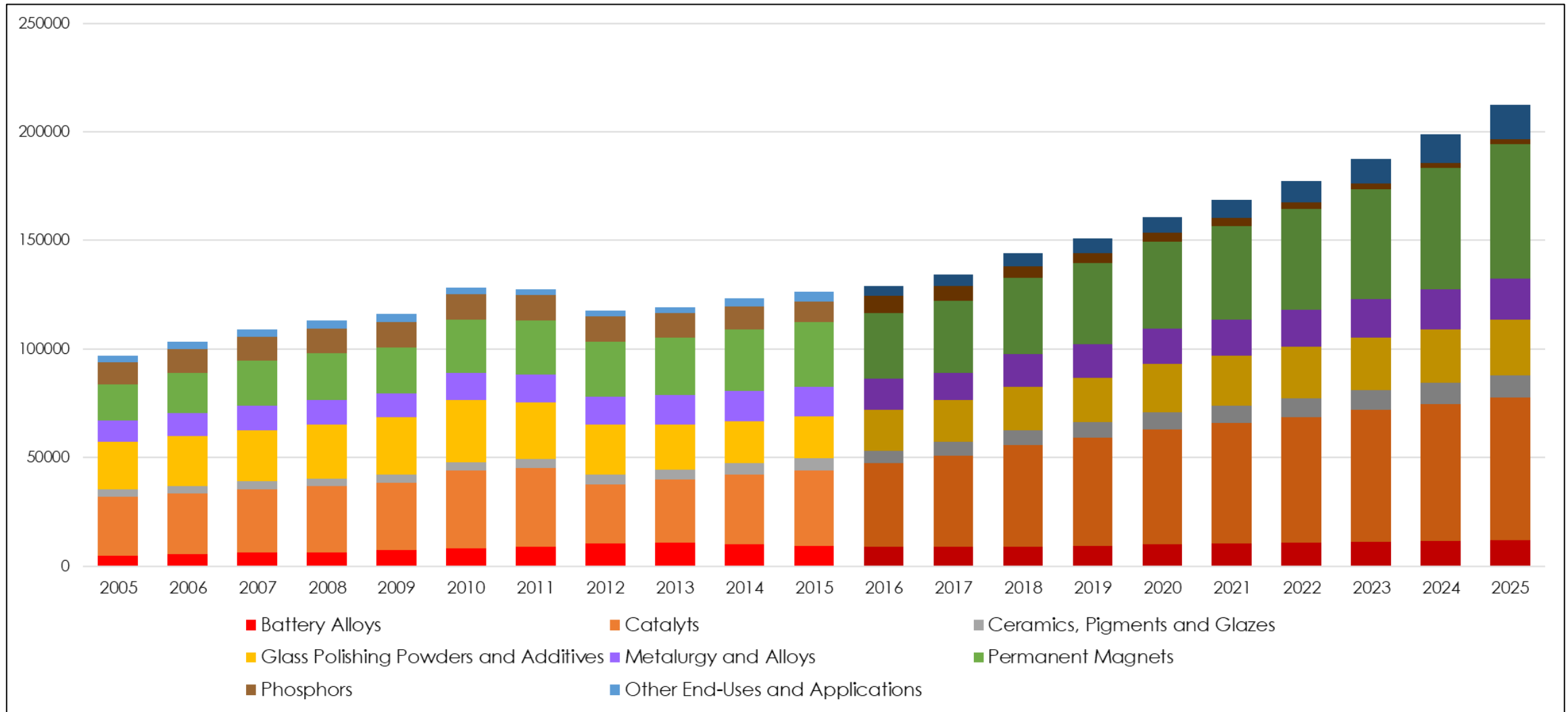
REE Embedded in Imported Goods

Imported Product	Parts with REES
1. Light Emitting Diodes (Modules/ Lamps)	Modules/Lamps
2. Ceramic Capacitors	Capacitors
3. Headphones	Permanent Magnets
4. Linear Fluorescent Lamps	Modules/Lamps
5. Mobile Phones	Vibration Motor, Speakers, Screen (Permanent Magnets/Phosphors)
6. Laptops	HDD, Speakers, LED display (Permanent Magnets/ Phosphors)
7. Speakers	Permanent Magnets
8. PVC Stabilizers	PVC stabilizer
9. Desktop Monitors (Non Cathode Ray)	LED Backlight (Large Screen)
10. AC and Refrigerator Compressors	Magnetic Pumps
11. Finished Refrigerators	Magnetic Pumps
Total Units Imported in 2016	12.6 billion
Percentage of Total Embedded Demand	20%

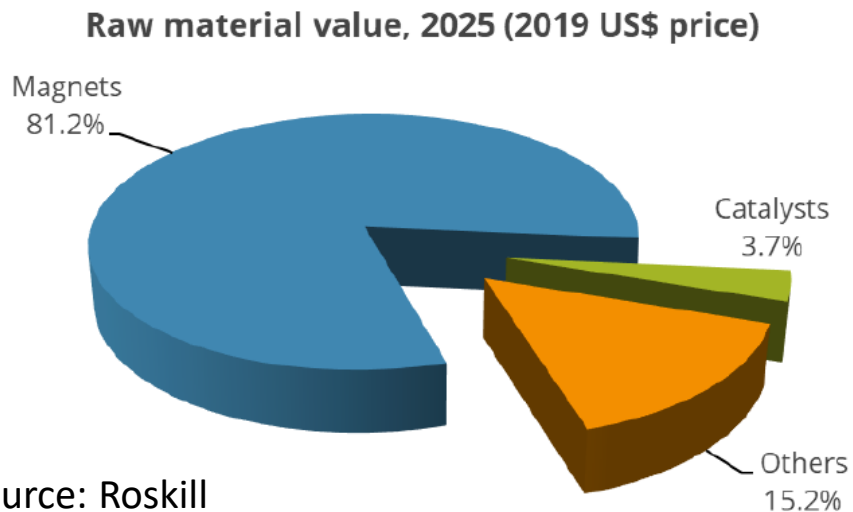
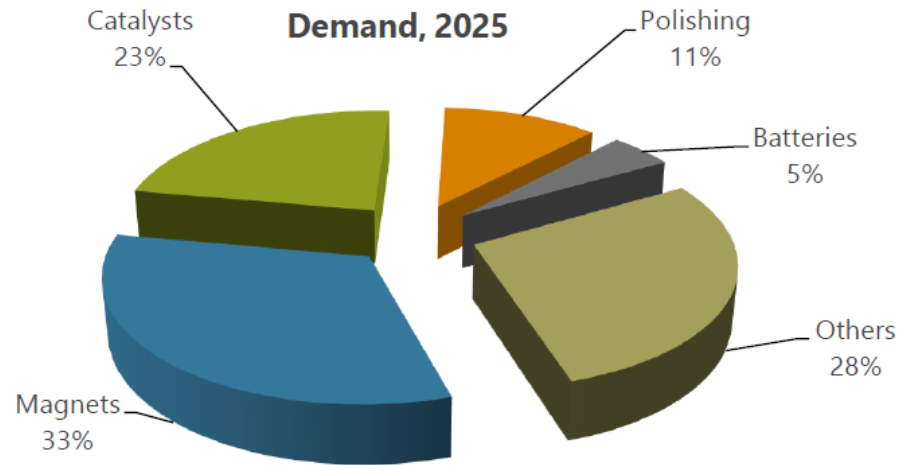
Of imported goods containing REE, the top 11 categories of imports (by number of units) contained more than 8,000 metric tons of REE, representing approximately 20%



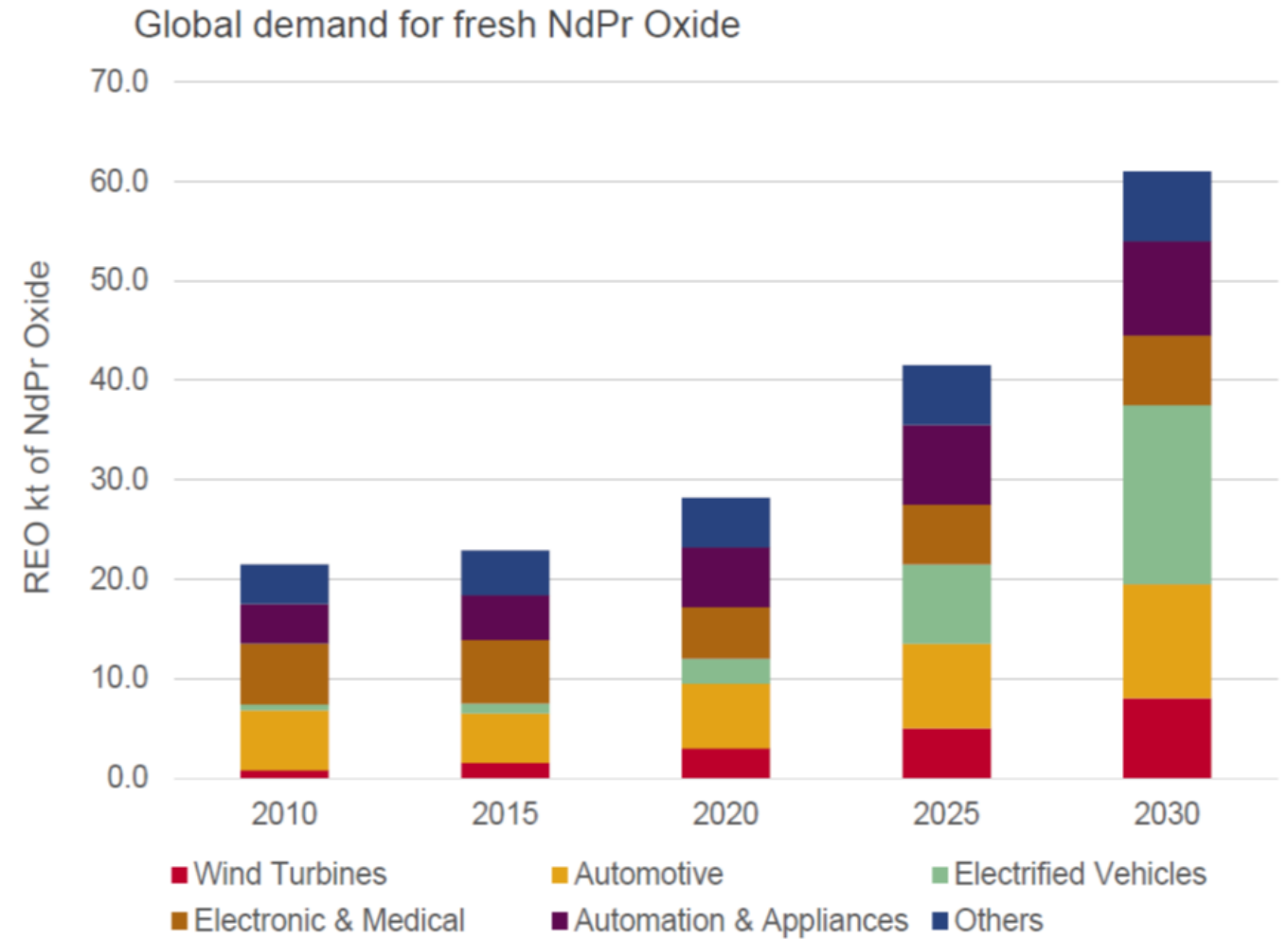
Projected Demand Growth by End Use



Demand Growth and Value



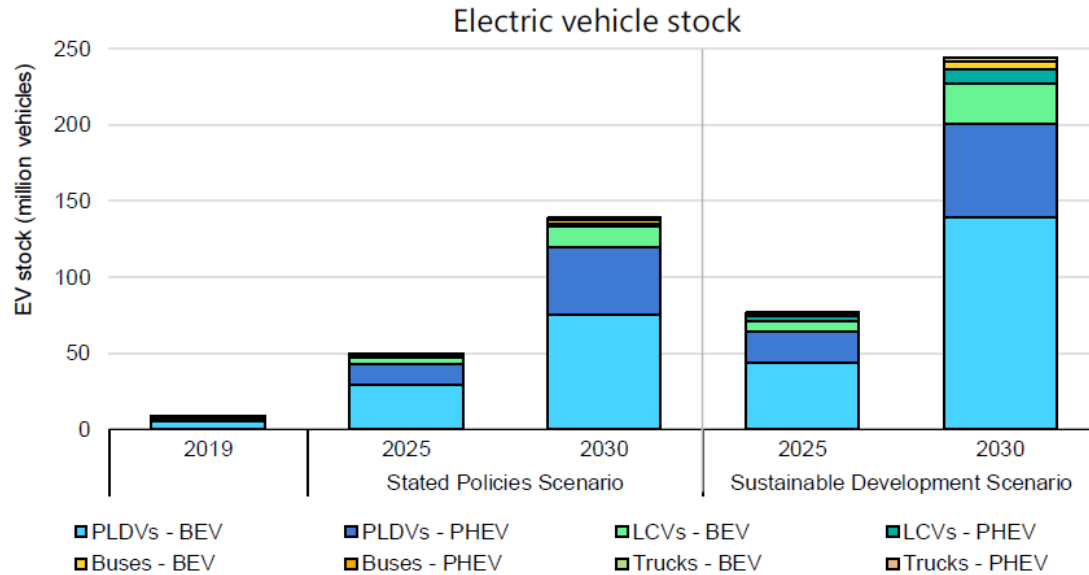
Source: Roskill



Source: Lynas Corporation

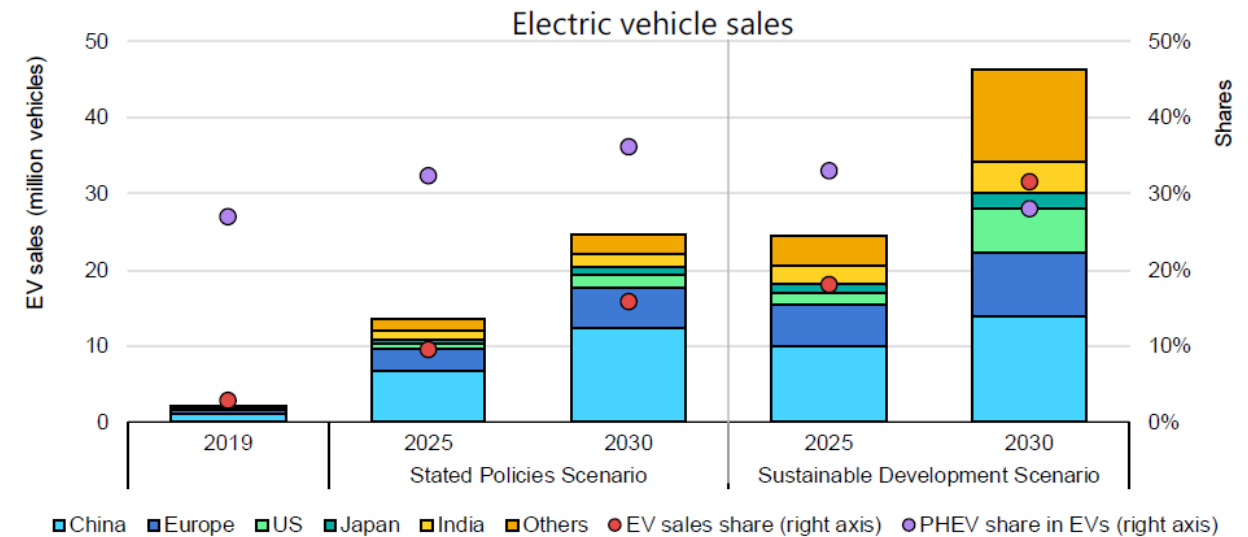
Projected Global EV

Stock and Sales by Scenario 2019, 2025, and 2030



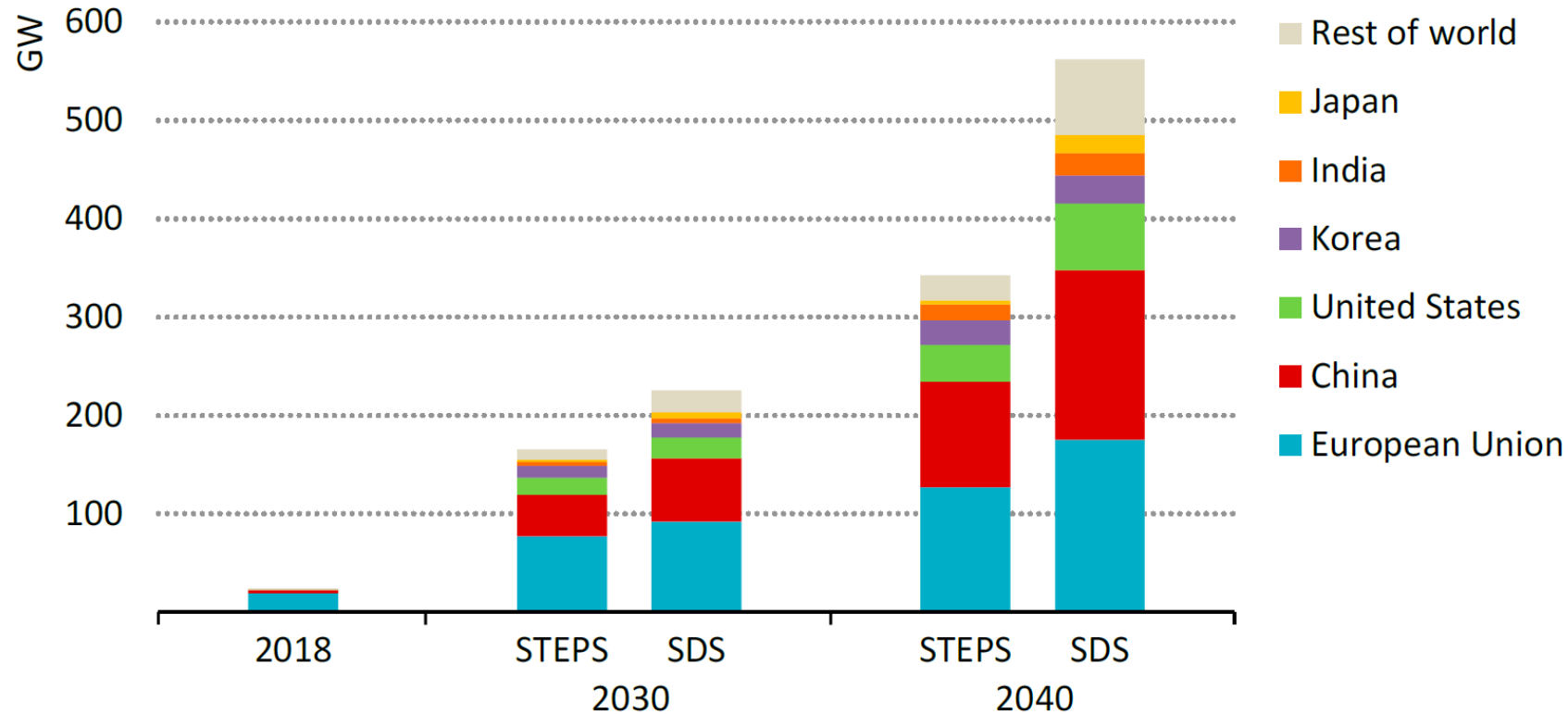
In 2018, 93% of all passenger EVs sold used permanent magnet traction motors.

– Adamas Intelligence



Projected Offshore Wind Deployment

Installed Capacity by Region and Scenario

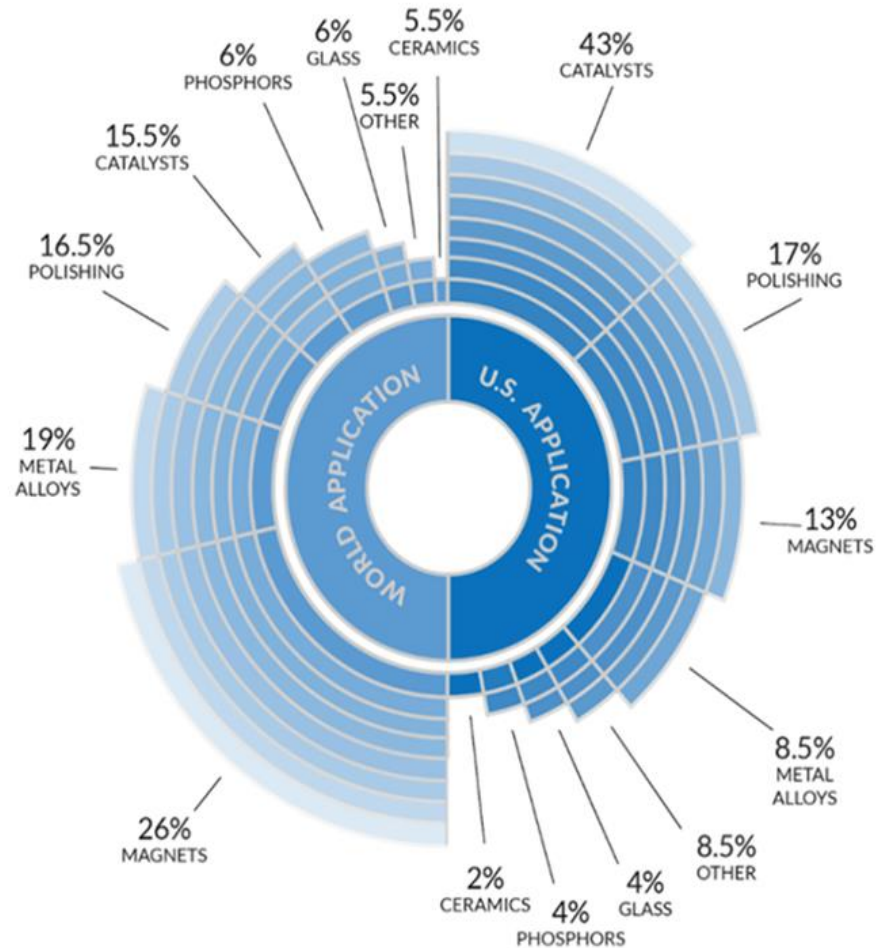


Major hindrances to the deployment of direct drive permanent magnet wind turbines is cost and availability of permanent magnets

European Union and China account for 70% of the global offshore wind market to 2040, but a number of countries enter the market and increase their capacity

Opportunities for Demand Growth

By Element and Application



MAGNETICS

Computer Hard Drives
Disk Drive Motors
Anti-Lock Brakes
Automotive Parts
Frictionless Bearings
Magnetic Refrigeration
Microwave Power Tubes
Power Generation
Microphones & Speakers
Communication Systems
MRI

Nd Tb Dy Pr



METAL ALLOYS

NiMH Batteries
Fuel Cells
Steel
Super Alloys
Aluminum/Magnesium

Nd Y La Ce Pr



DEFENSE

Satellite Communications
Guidance Systems
Aircraft Structures
Fly-by-Wire
Smart Missiles

Nd Eu Tb Dy Y Lu Sm Pr La



CATALYSTS

Petroleum Refining
Catalytic Converter
Fuel Additives
Chemical Processing
Air Pollution Controls

Nd La Ce Pr



CERAMICS

Capacitors
Sensors
Colorants
Scintillators
Refractories

Nd Y Eu Dy Lu Gd La Ce Pr



GLASS & POLISHING

Polishing Compounds
Pigments & Coatings
UV Resistant Glass
Photo-Optical Glass
X-Ray Imaging

Nd Gd Er Ho La Ce Pr



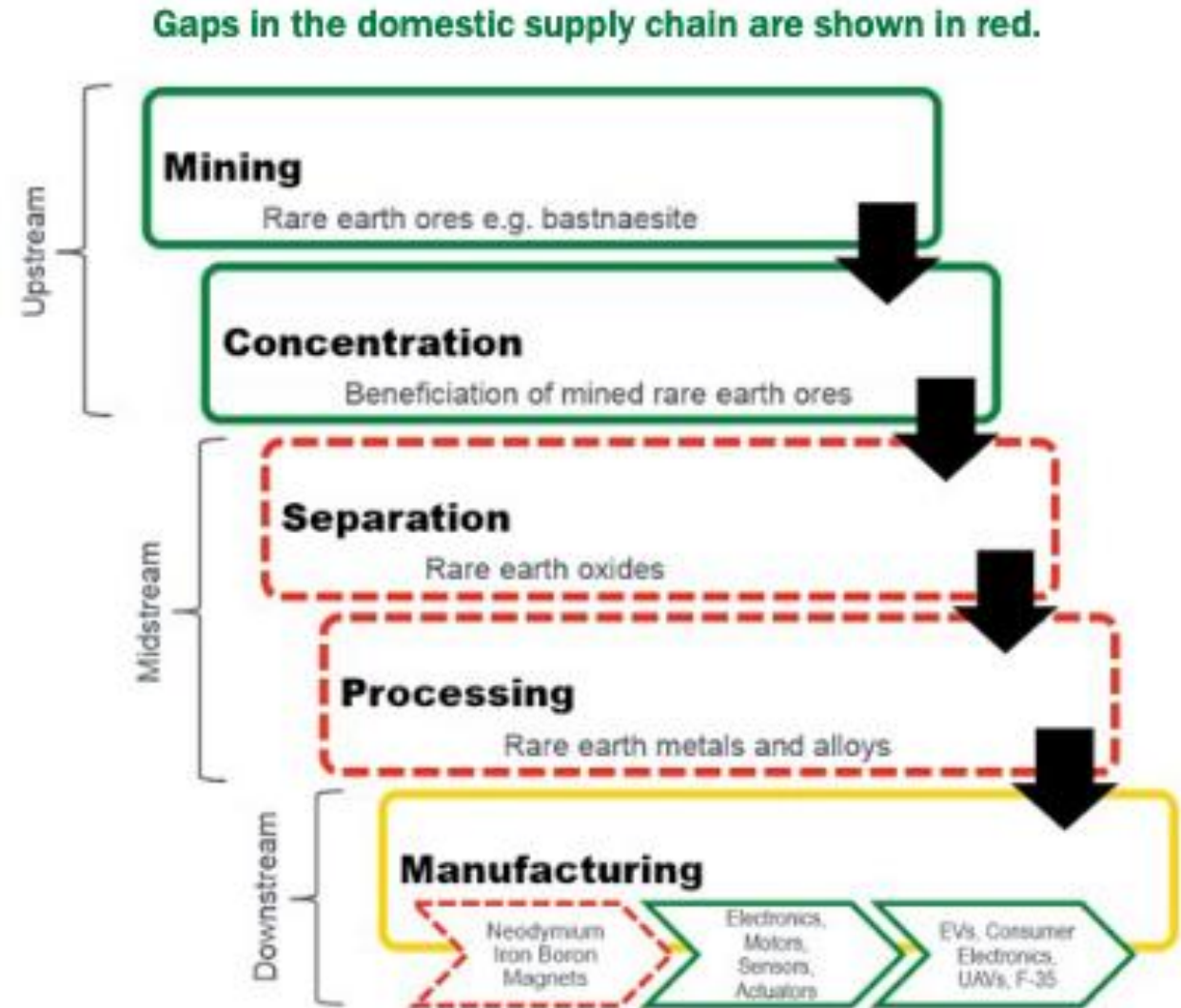
PHOSPHORS

Display phosphors-
CRT,LPD,LCD
Fluorescents
Medical Imaging
Lasers
Fiber Optics

Nd Eu Tb Y Er Gd Ce Pr

Understanding the REE Supply Chain

- Domestically, the supply chain is broken with few links connected to one another
 - Ore producers ship offshore for processing
 - Catalyst producers are importing raw materials
 - Finished goods are produced offshore and imported
- Internationally, supply chain is vertically integrated
 - Each link feeds directly into the next

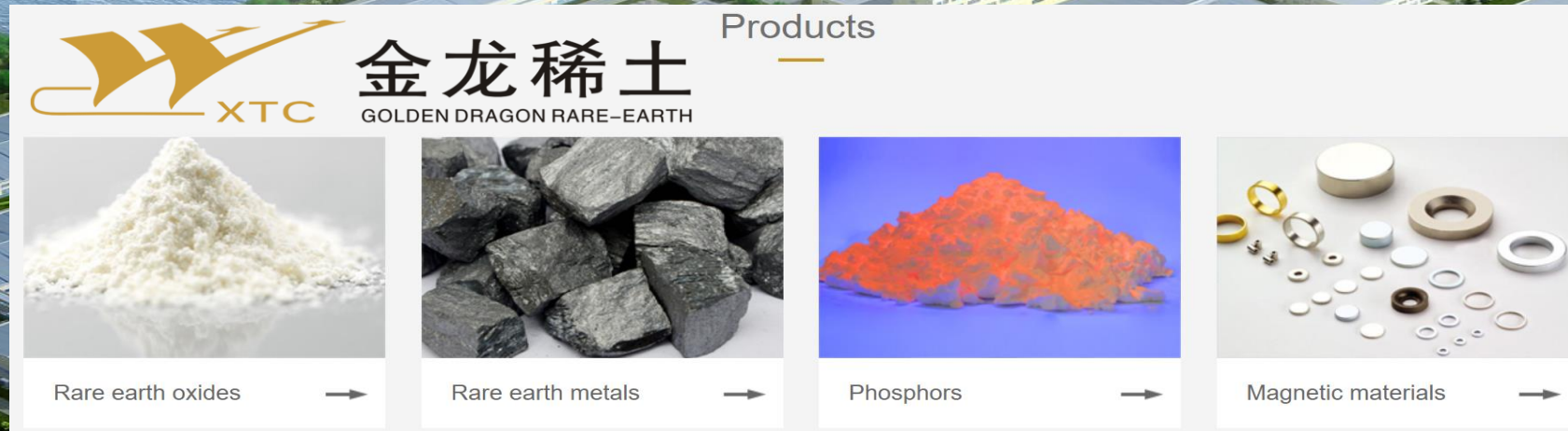


Challenges for a Domestic REE Supply Chain

Existing Vertically Integrated Supply Chain

China's head start: 30+ years of subsidies

Responsible Waste Disposal Options

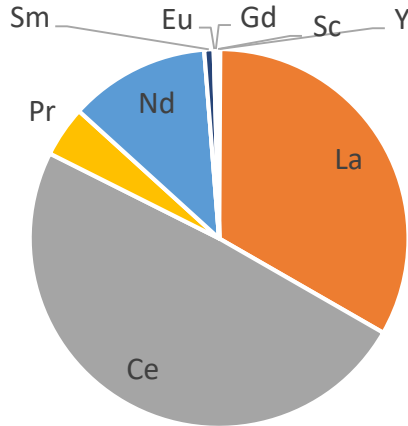


Supply Chain Takeaways

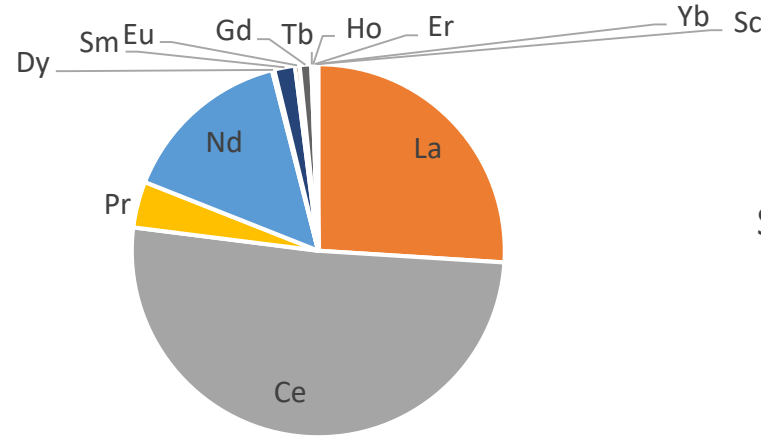
- Opportunities exist across the board in mining, extraction, separation, alloy production, and finished goods manufacturing
- Utilization of rare earths is going to continue to grow
- The US has significant reserves of rare earth containing materials: ore, tailings, recycled materials, and even coal
 - Hub & spoke transportation models could present opportunities for feedstocks that are distributed in smaller quantities across the country
- Endless Possibilities
 - End uses exist for each REE if supply exists and prices are stable
 - Domestic industry is on the sidelines due to concerns over supply, limiting innovation

Opportunity for Coal-Based Feedstocks

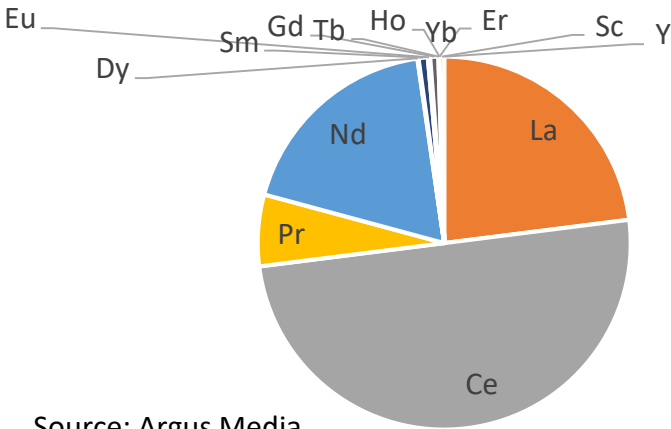
Mountain Pass (Bastnasite) ~8% REO



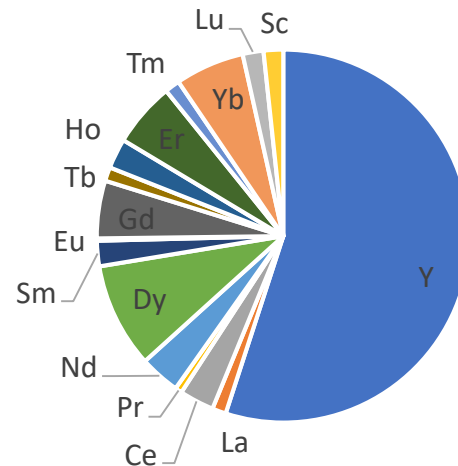
Mount Weld (Monazite) ~8% REO



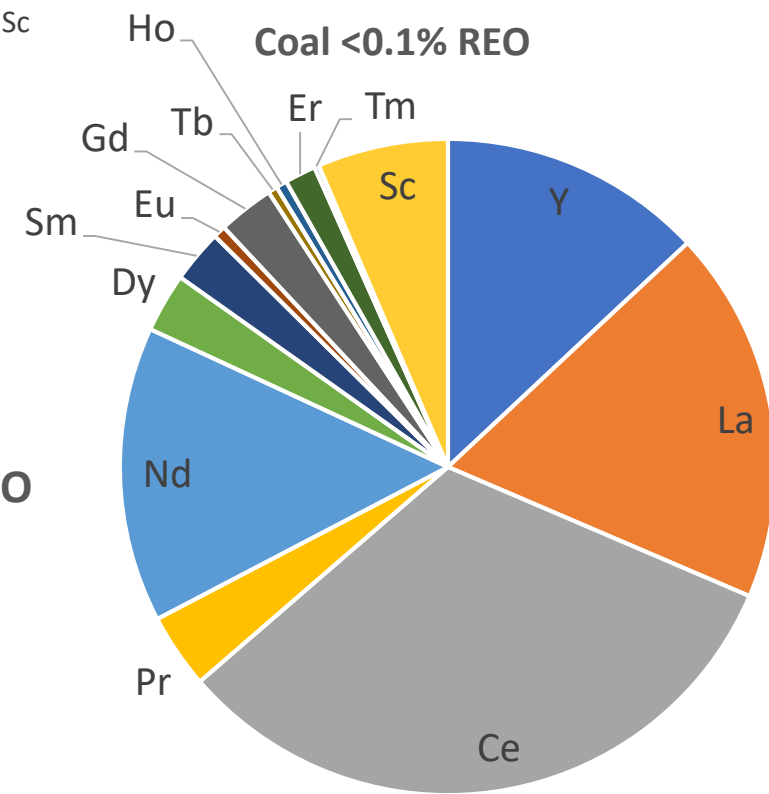
Bayan Obo (Bastnasite) ~6% REO



Southeast Guangdong (Xenotime) ~0.5% REO



Coal <0.1% REO

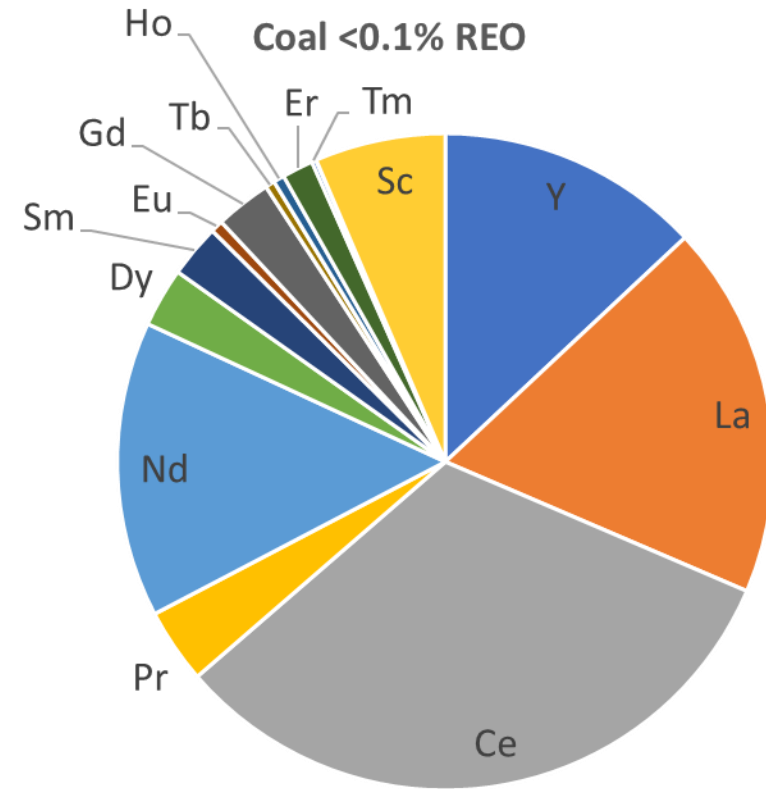


Source: Argus Media

Opportunity for Coal-Based Feedstocks

Filling the First Gap to a Domestic REE Supply Chain

- Coal-based feed sources include:
 - Coal (anthracite, bituminous, subbituminous, lignite)
 - Coal refuse
 - Fly ash
 - Acid mine drainage (AMD)
 - Mining underclay and shale
- These feed sources could be utilized with other domestic REE resources to produce the foundation for a domestic REE supply chain



Filling Domestic Supply Chain Gaps

Additional Opportunities

- Cooperatives (profit sharing)
 - Vertical integration of every step within the supply chain, no missing links
- Private investment at large scale
 - Royalty and streaming agreements
- Government Subsidies along the entire supply chain
 - Price guarantees, loan guarantees, etc.
- Research & development opportunities
 - New domestic REE feedstocks
 - New end uses for REE
 - New alloys, new metallurgical processes for metal and alloy production, etc.
 - The existence of a domestic supply chain would entice industry to expand R&D into innovative materials and uses for REE materials

Conclusions

With...

- Demand projections for rare earth elements set to grow over the next 10 to 20 years in high and low value applications
- Domestic dependence on the offshore REE supply chain for raw material, processing, and finished goods

**NOW IS THE TIME TO DEVELOP A DOMESTIC
SUPPLY CHAIN FOR RARE EARTHS**

RARE EARTH ELEMENTS COULD BE THE BUILDING BLOCKS FOR AN INNOVATION
REVOLUTION...

Acknowledgements



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Thanks for your attention

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