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EXPERTS IN
- RARE EARTH MAGNETS
- MAGNET DESIGN
- MAGNET SYSTEMS

Rare Earth Magnet Recycling

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Rare Earth Elements Workshop

EPA – Colorado May 10, 2012

Outline

- Overview of Rare Earth Magnets and supply chain
- REPM Current Recycling Practices
- REPM Recycling Opportunities

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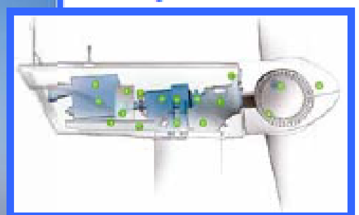
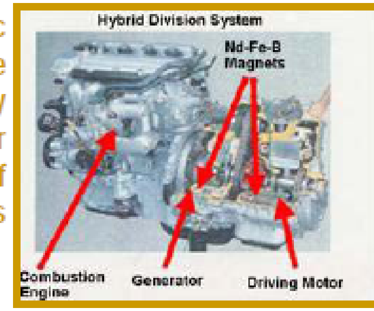
Rare Earths Magnets- Modern Technology’s Backbone

- The strength of permanent magnets (PMs) is the single factor affecting the power density and energy efficiency of countless devices.

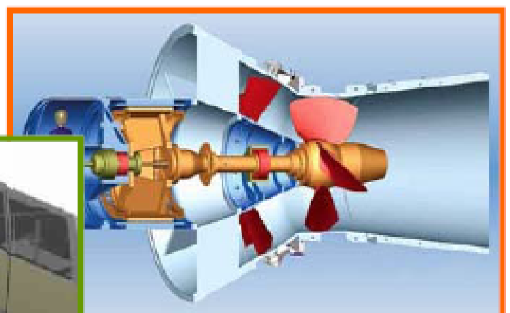



Wind turbines with PM generators are very efficient at low wind speeds.

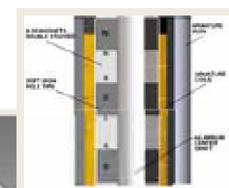
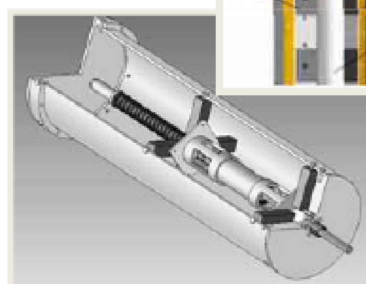
Hybrid electric vehicles are particularly demanding for power density of their PM motors



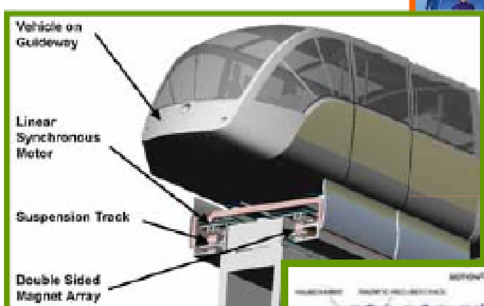
Missiles, tanks, warplanes & submarines

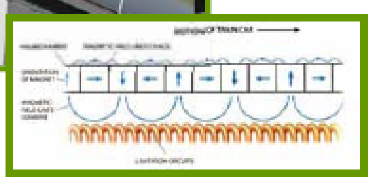


PM hydroelectric turbine generators eliminate need for gearboxes

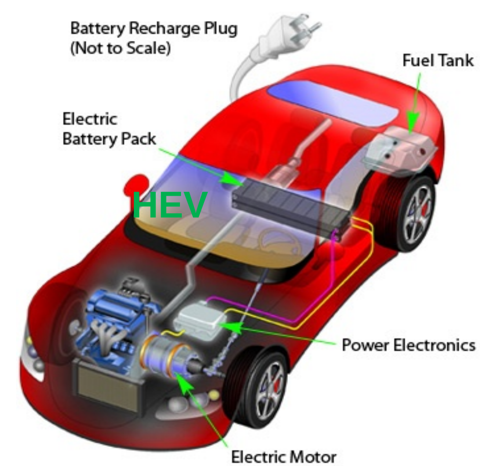



In this generator buoy, the floater moves coils relative to the PM to induce voltages

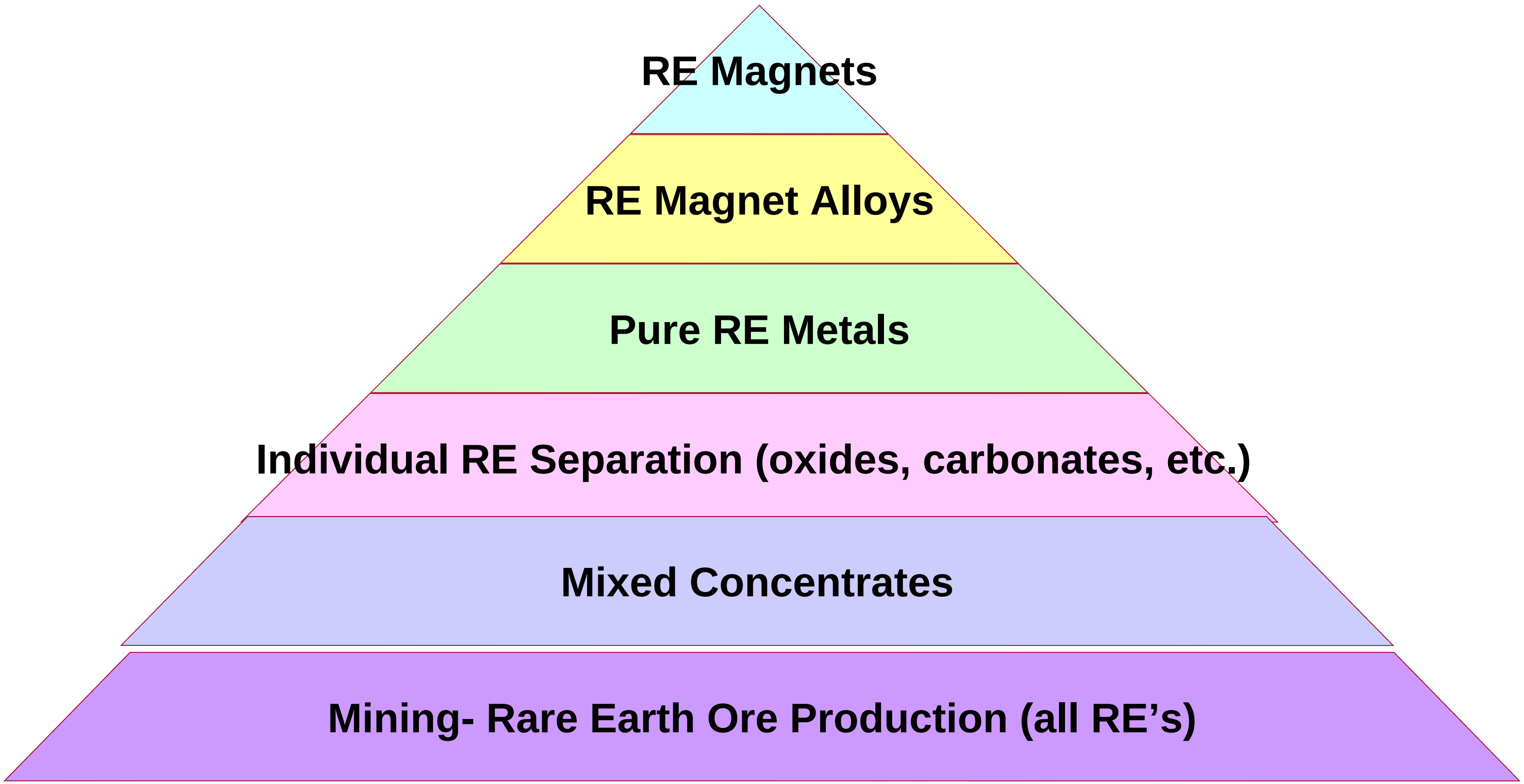




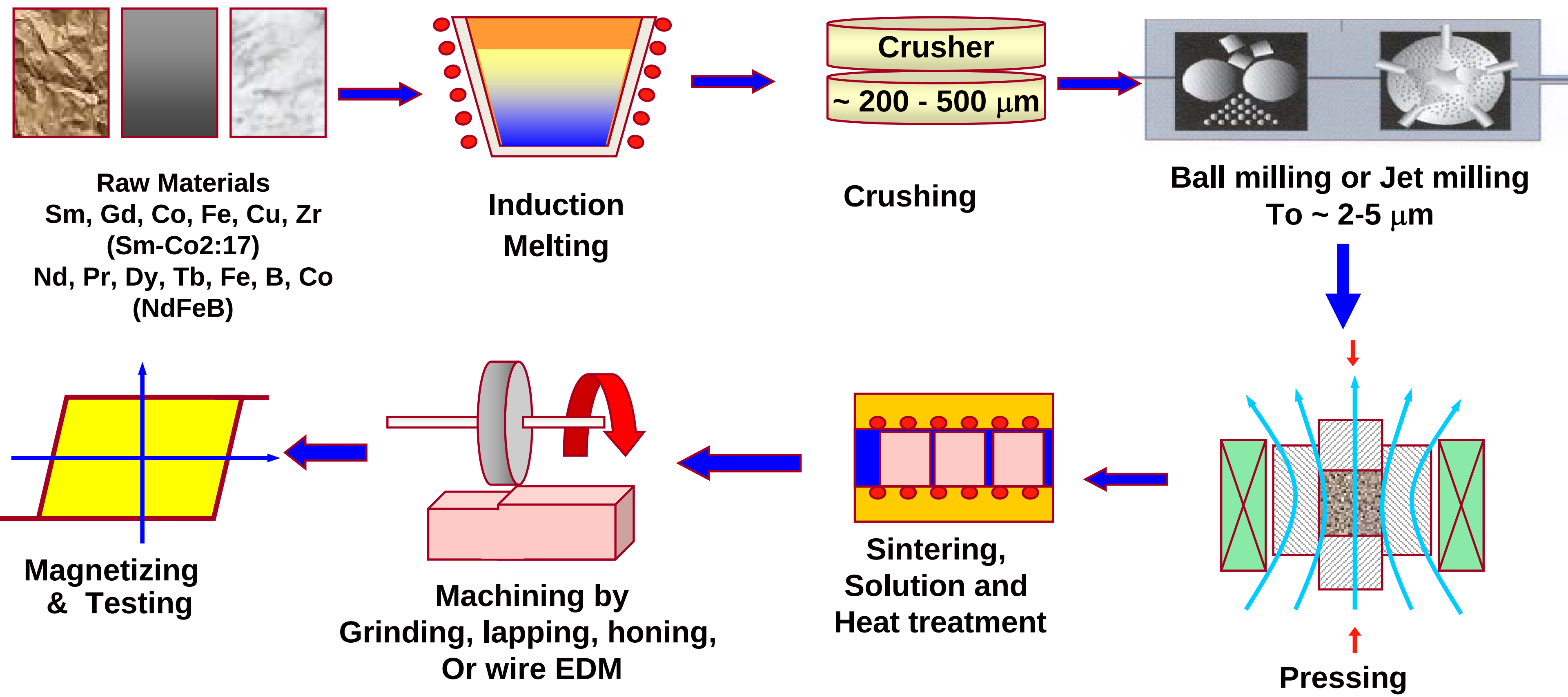
Efficient and fail-safe *Inductrack* maglev train



The Rare Earth Value Chain



Manufacturing Process for Sintered Rare Earth Magnets



DoE- Critical Materials Strategy

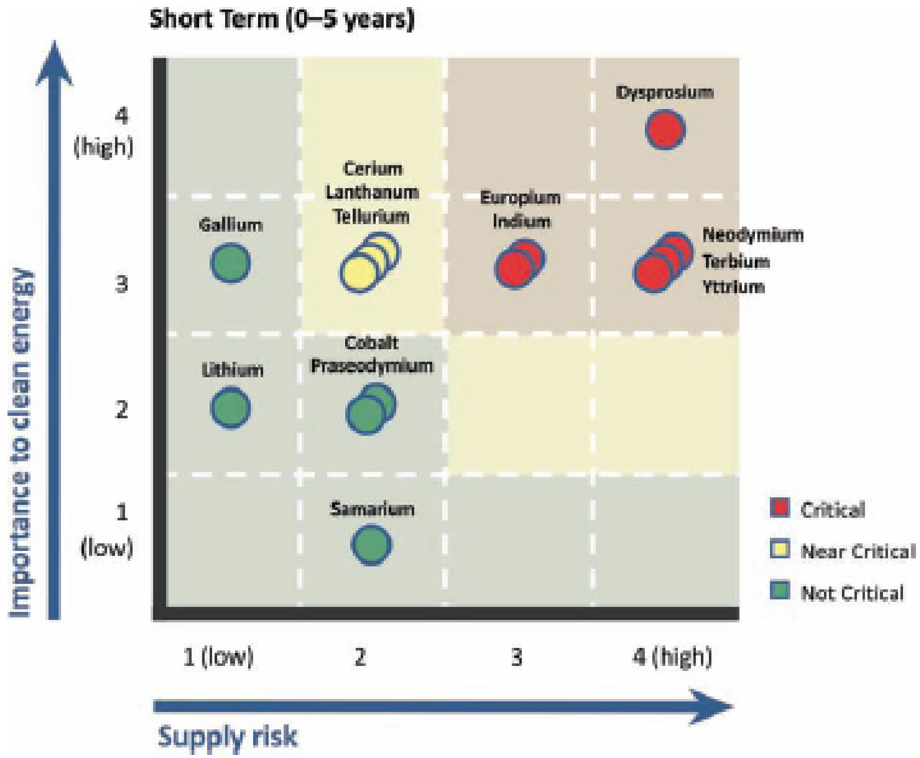


Figure ES-1. Short-term criticality matrix

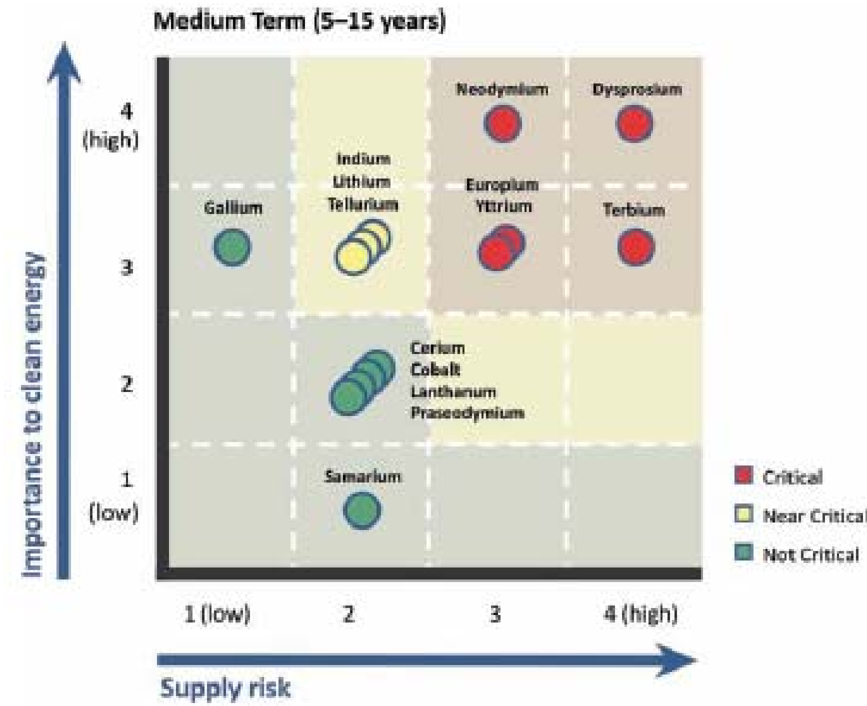
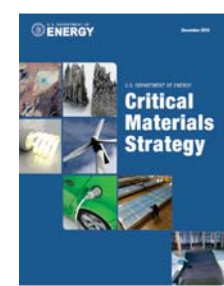


Figure ES-2. Medium-term criticality matrix



Source: DOE Critical Materials Strategy, December 2010

Global Metal Production 2008 - Record Year

Large users volume have mature recycling infrastructure

RE Recycling market not yet developed

-Rare metals have high price

-Recycling economics

High recovery cost

Questionable economic model

2011 Nd = $400-450/kg

2012 Nd = $200/kg

Item	2008 Mine Prod. (Metric Tons)	Item	2008 Mine Prod. (Metric Tons)
Raw Steel	**1,360,000,000**	Uranium (2007)	41,279
Pig Iron	**958,000,000**	Lithium	27,400
Aluminum	**39,700,000**	Silver	20,900
Copper	**15,700,000**	Cadmium	20,800
Manganese	**14,000,000**	Bismuth	5,800
Zinc	**11,300,000**	Boron	4,100
Lead	**3,800,000**	Gold	2,330
Nickel	**1,610,000**	Selenium	1,590
Magnesium	**808,000**	Zirconium	1,360
Strontium Materials	**512,000**	Tantalum	815
Molybdenum	**212,000**	Yttrium (2001)	600
Antimony	165,000	Indium	568
Rare Earths (mixed, oxides)	**124,000**	Palladium	206
Cobalt	71,800	Platinum	200
Vanadium	60,000	Rhenium	45
Niobium (Columbium)	60,000	Rhodium	30
Tungsten	54,000	Hafnium	25

Courtesy: Jack Lifton

China Dominates Growing Magnet Materials Market

WW Total Market Size $7B 2010, $15B by 2020

Japan, US, European producers close plants, move production

NdFeB magnets 75%

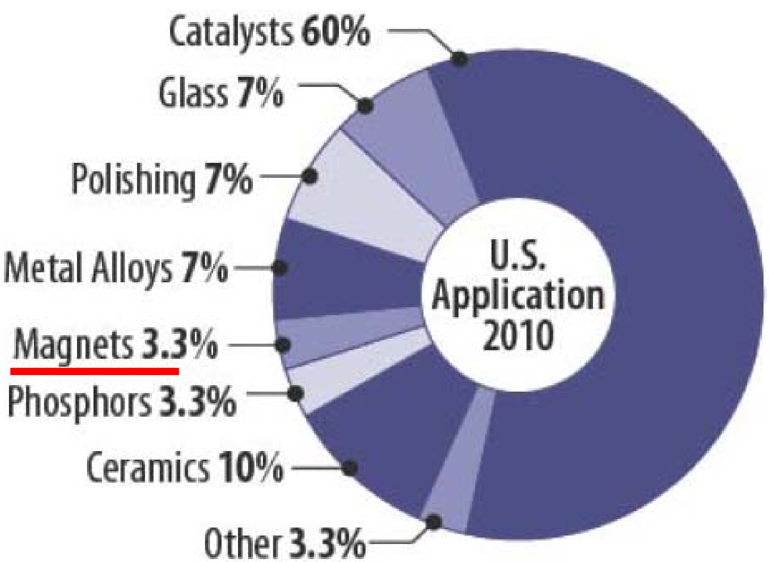
Approx ½ WW Alnico & SmCo production

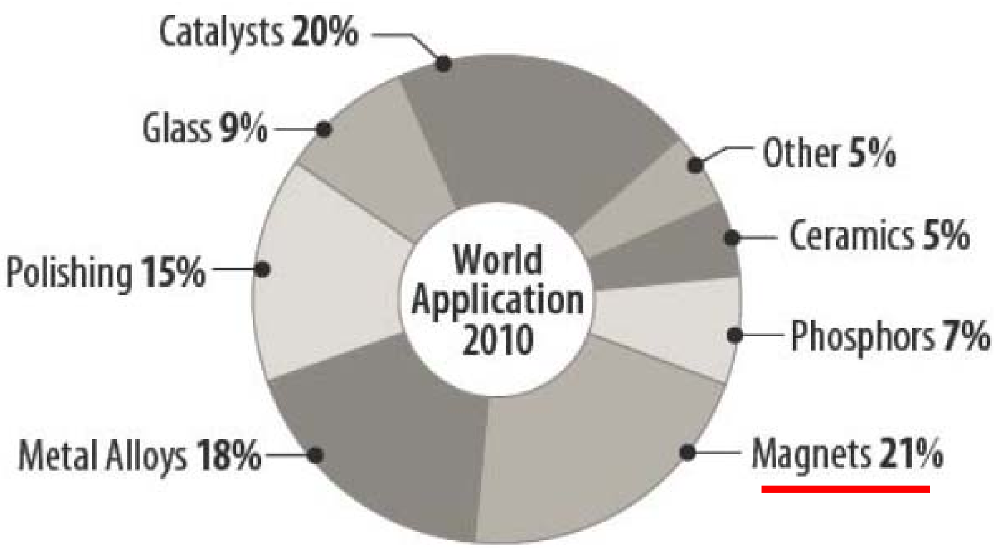
Rare Earth Oxide Ore production 95%

Hard ferrites 65+ %

Rare Earth pure Metals nearly 100%

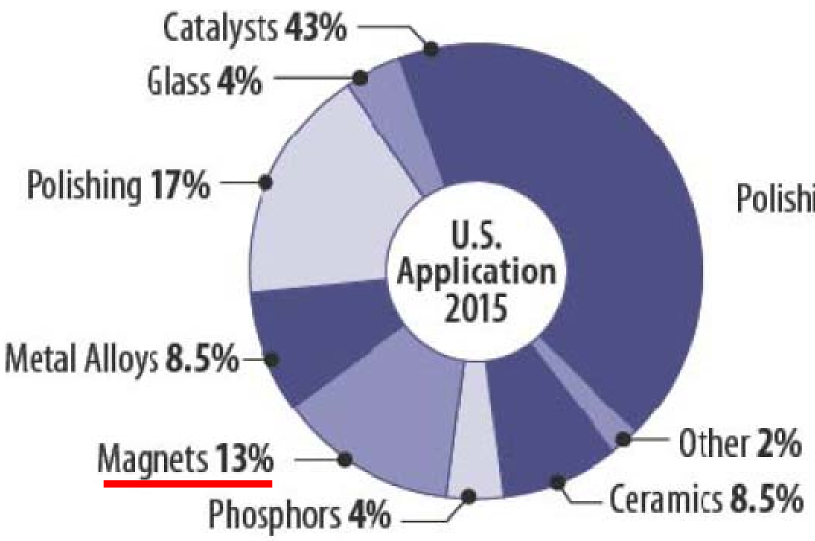
The RE Demand by Application- US and World-2010

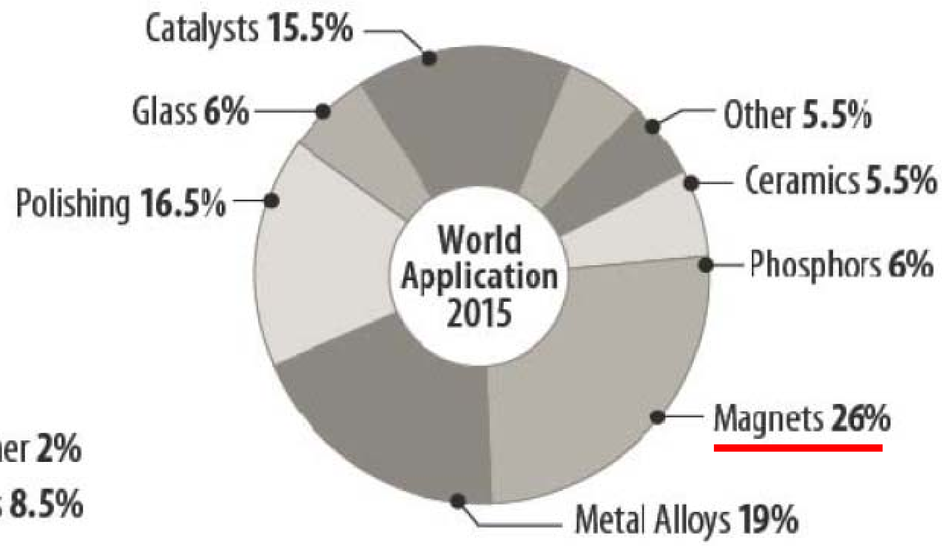




Source: Congressional Research Service 7-5700, R41347, 2011

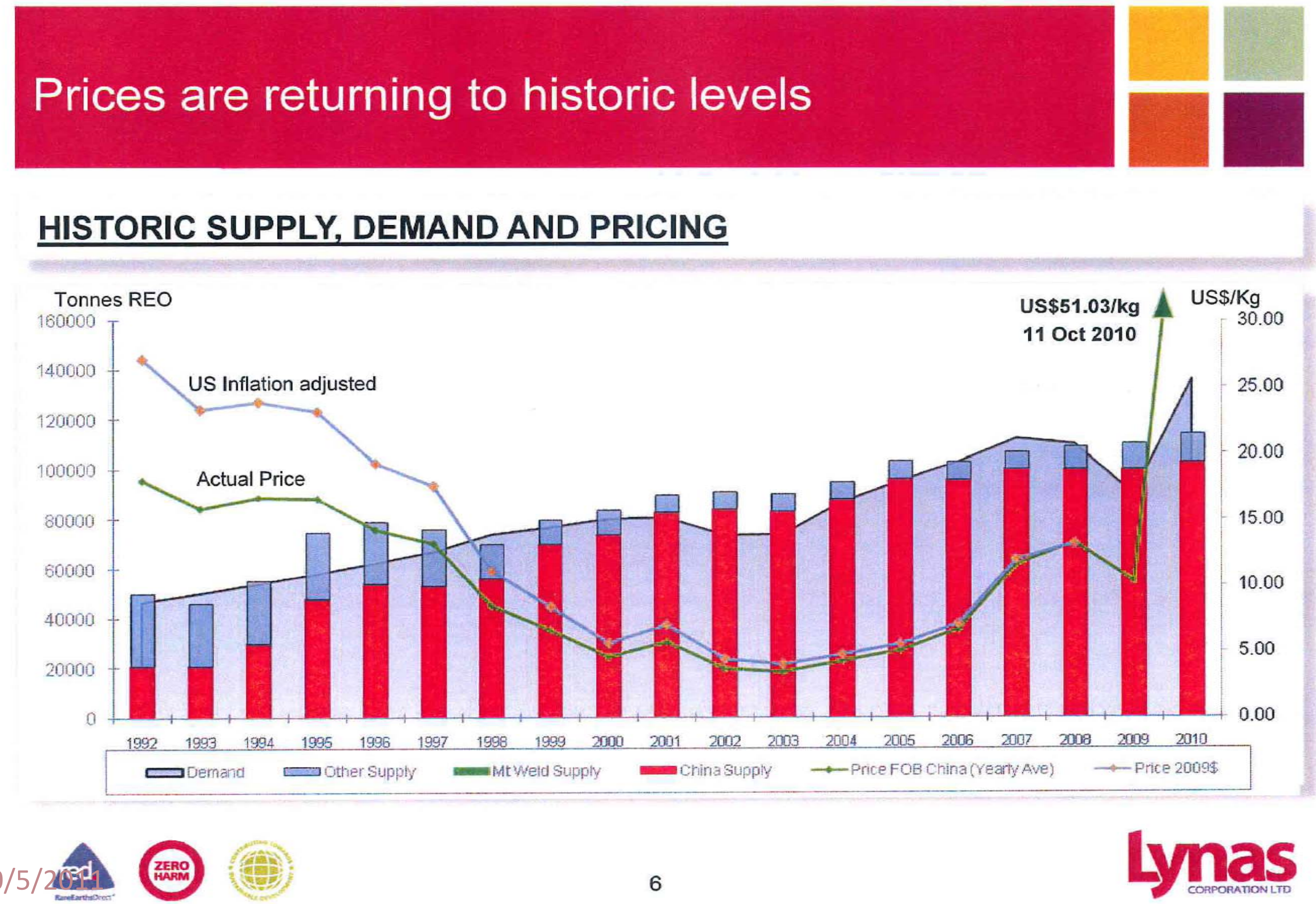
The RE Demand by Application- US and World-2015





Source: Congressional Research Service 7-5700, R41347, 2011

Rare Earth Prices



Where will prices fall over the long term? Big impact on economics of recovering REE's

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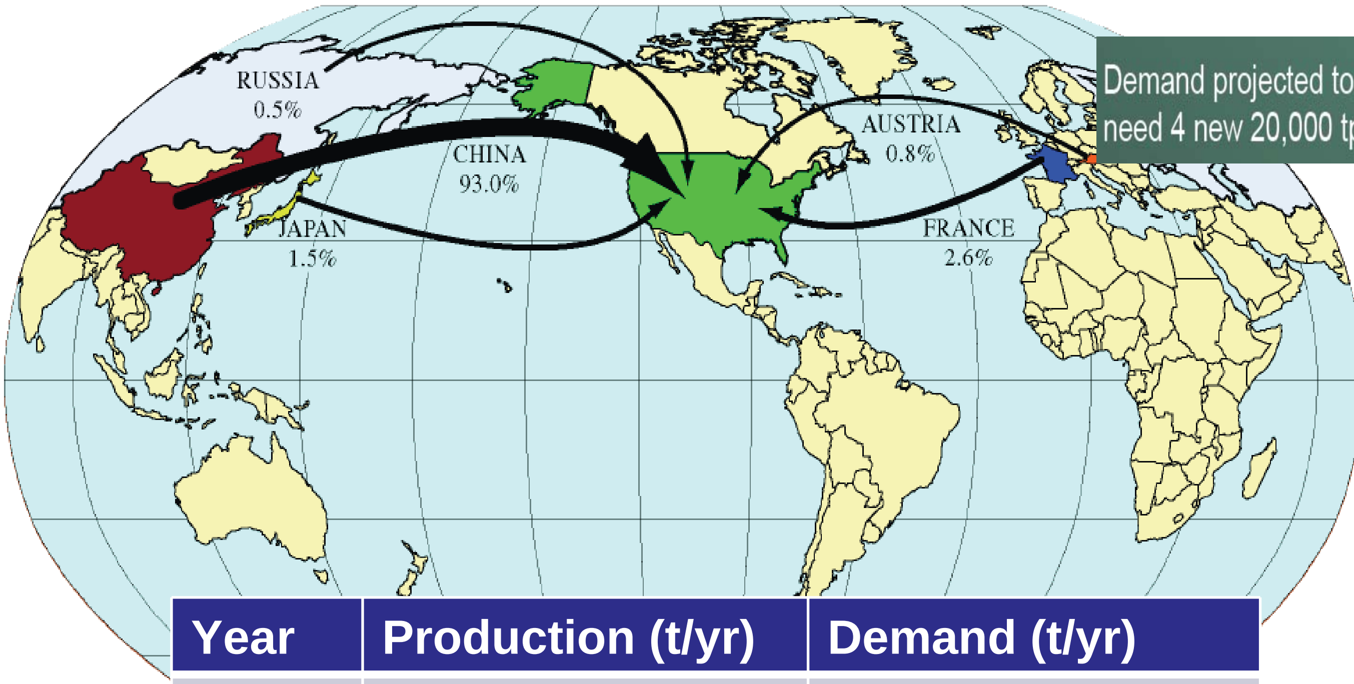
The RE supply Chain

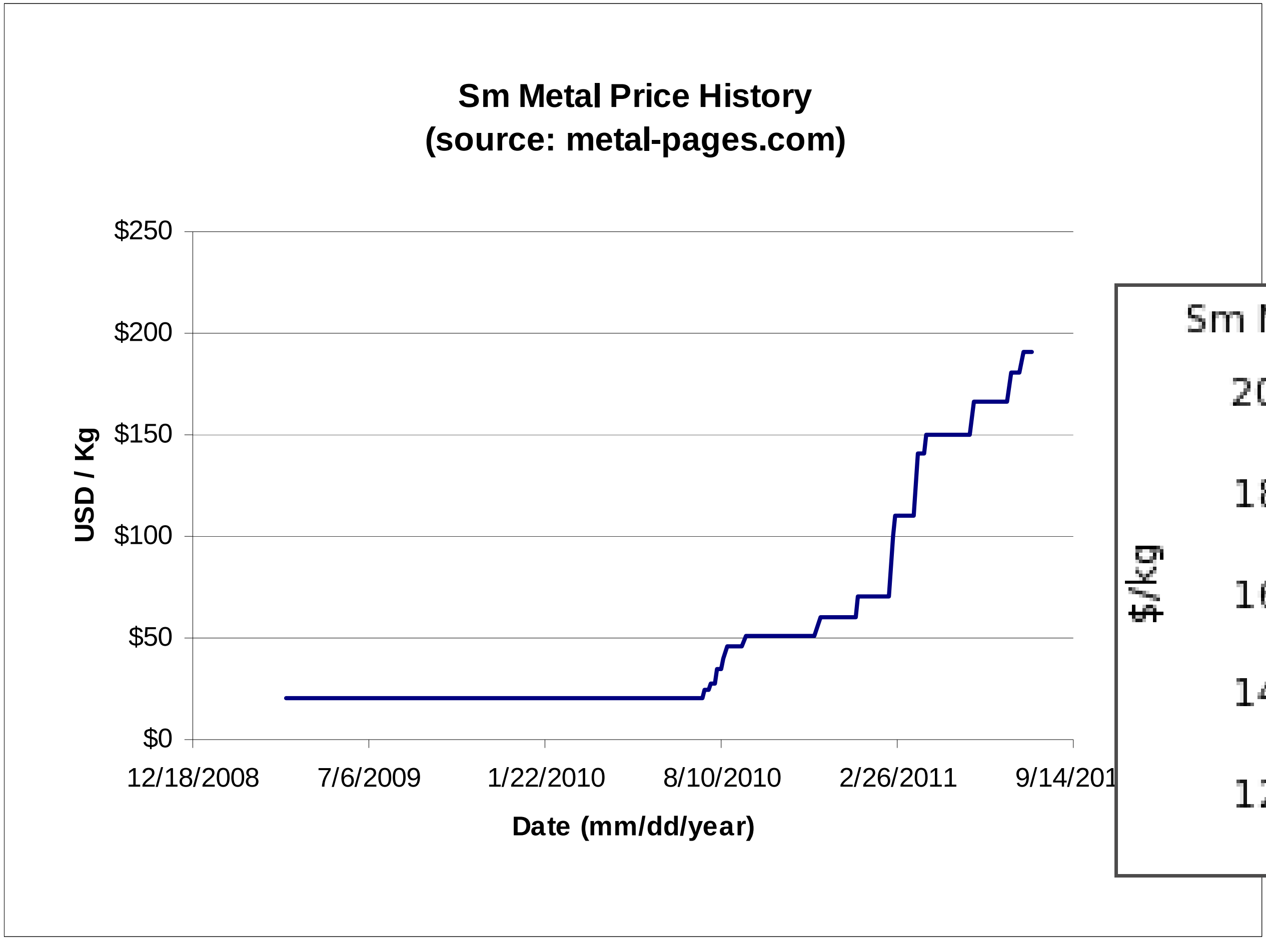


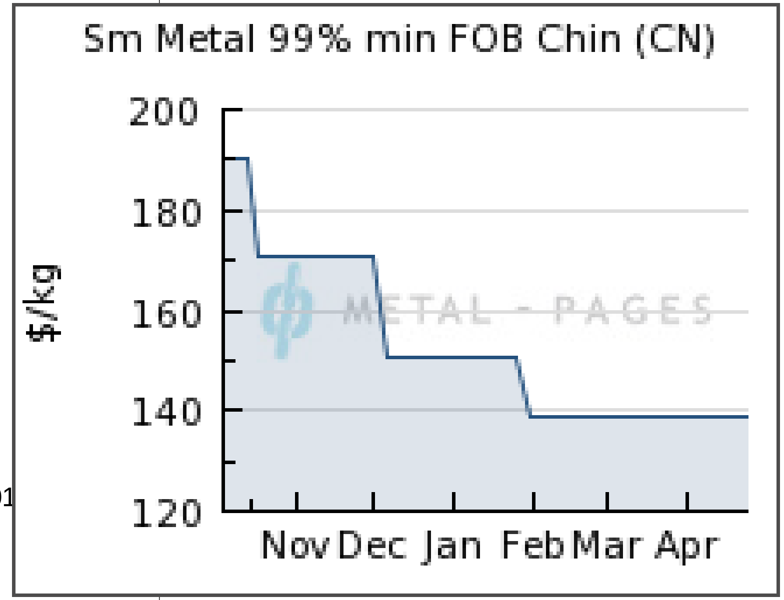
Demand projected to increase by 8 to 10% per year – by 2015 need 4 new 20,000 tpa TREO operations

Year	Production (t/yr)	Demand (t/yr)
2010	125,000	134,000
2014		182,000
2015		200,000

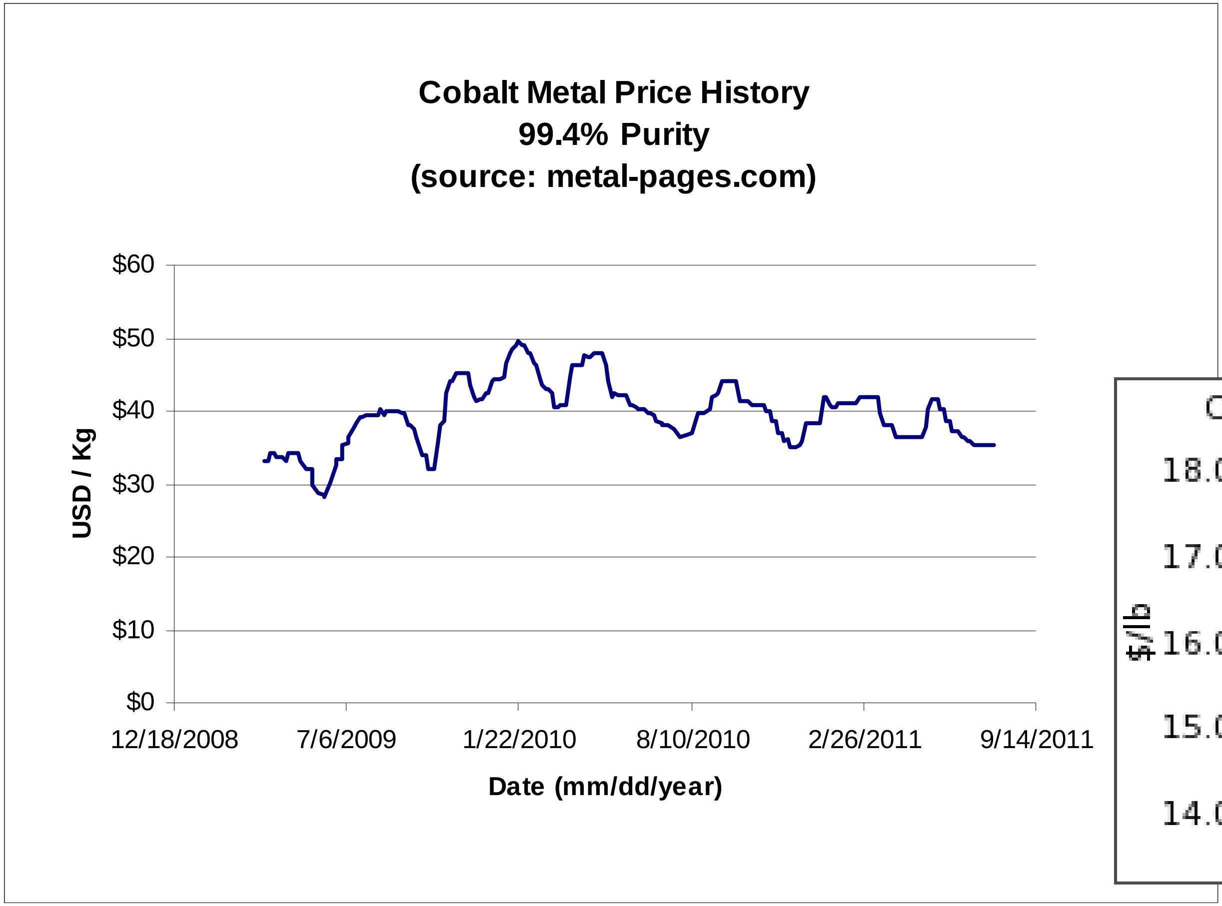
Projected 5 year REE tons/year.
(IMCOA projections)

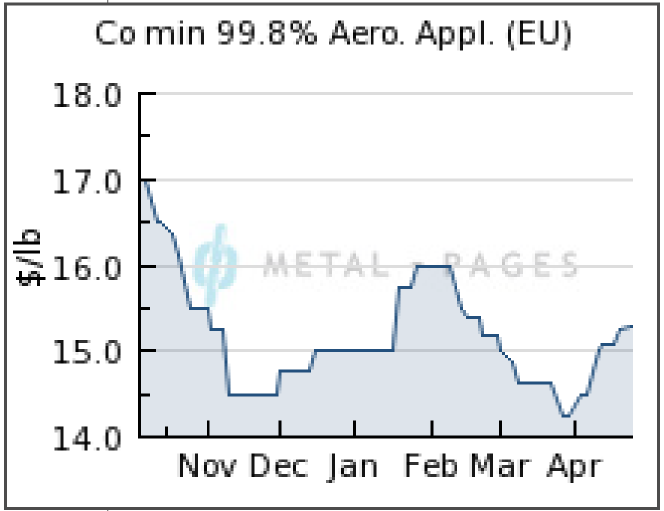
Cost of Sm


Sm Metal Price History
(source: metal-pages.com)
USD / Kg
$250
$200
$150
$100
$50
$0
12/18/2008
7/6/2009
1/22/2010
8/10/2010
2/26/2011
9/14/201
Date (mm/dd/year)

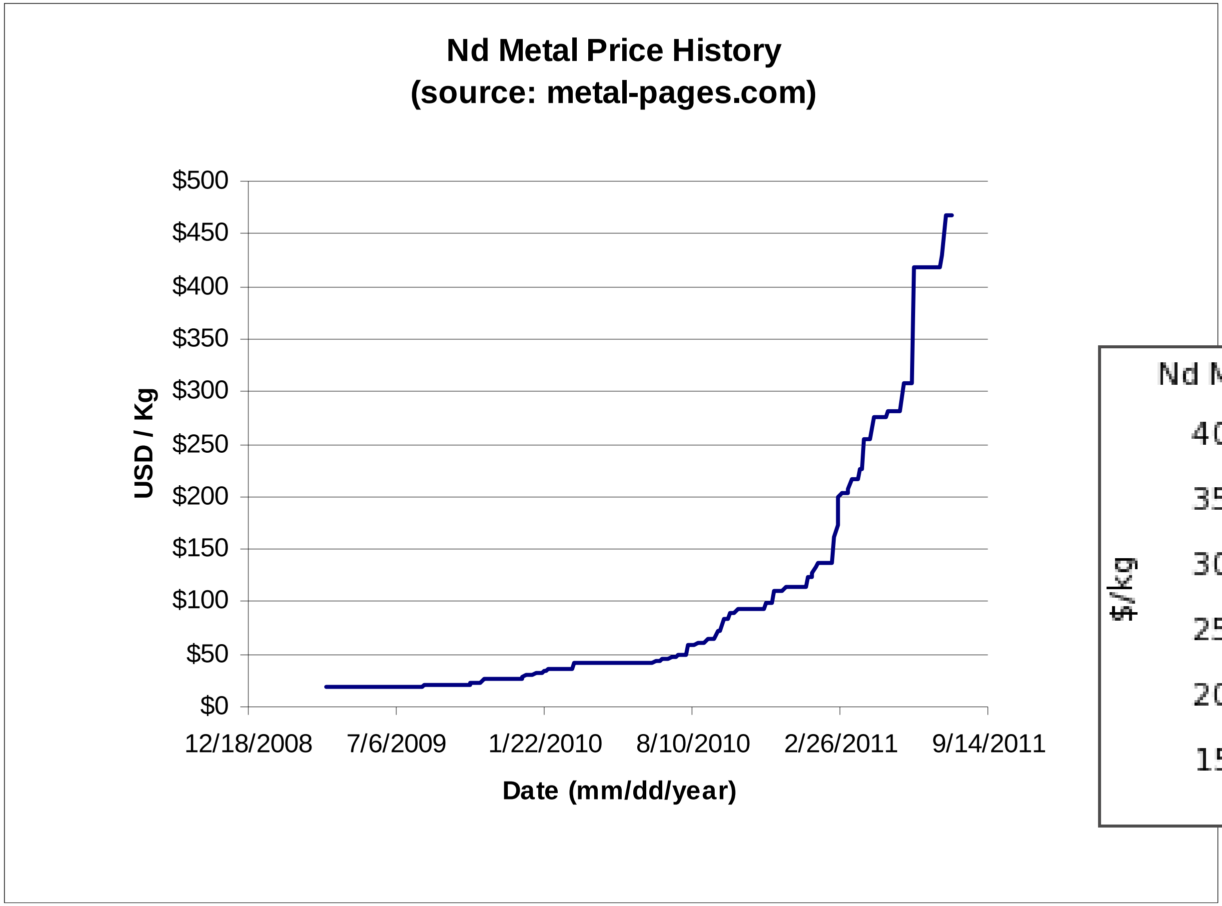

Sm Metal 99% min FOB Chin (CN)
$/kg
200
180
160
140
120
METAL - PAGES
Nov Dec Jan Feb Mar Apr

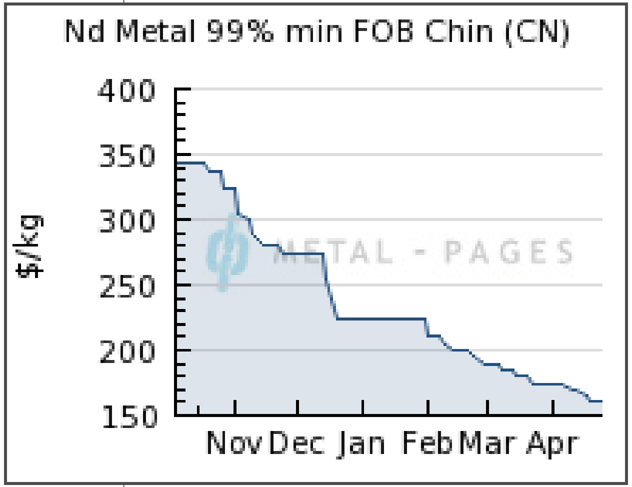
Cost of Co


Cobalt Metal Price History
99.4% Purity
(source: metal-pages.com)
$60
$50
$40
$30
$20
$10
$0
USD / Kg
12/18/2008
7/6/2009
1/22/2010
8/10/2010
2/26/2011
9/14/2011
Date (mm/dd/year)

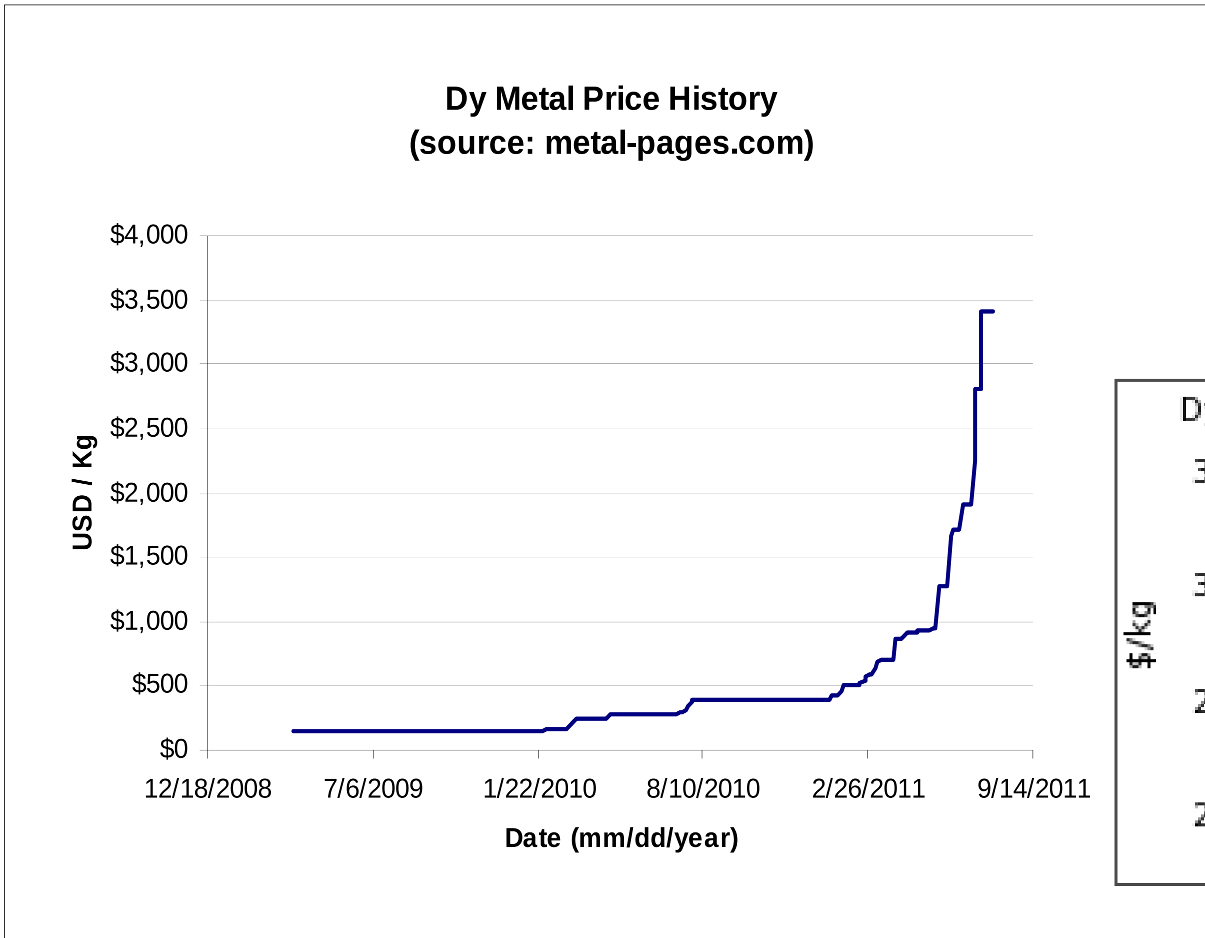

Co min 99.8% Aero. Appl. (EU)
18.0
17.0
16.0
15.0
14.0
$/lb
METAL - PAGES
Nov Dec Jan Feb Mar Apr

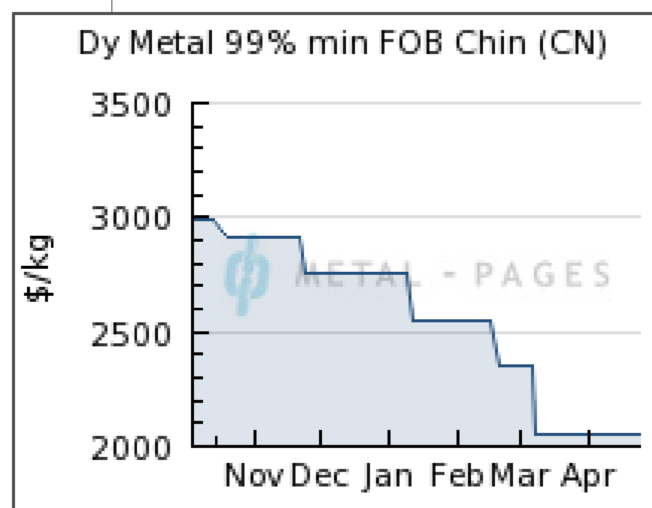
Cost of Nd


Nd Metal Price History
(source: metal-pages.com)
$500
$450
$400
$350
$300
$250
$200
$150
$100
$50
$0
USD / Kg
12/18/2008
7/6/2009
1/22/2010
8/10/2010
2/26/2011
9/14/2011
Date (mm/dd/year)


Nd Metal 99% min FOB Chin (CN)
400
350
300
250
200
150
$/kg
METAL - PAGES
Nov
Dec
Jan
Feb
Mar
Apr

Cost of Dy


Dy Metal Price History
(source: metal-pages.com)
USD / Kg
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
12/18/2008
7/6/2009
1/22/2010
8/10/2010
2/26/2011
9/14/2011
Date (mm/dd/year)


Dy Metal 99% min FOB Chin (CN)
$/kg
3500
3000
2500
2000
Nov Dec Jan Feb Mar Apr
METAL - PAGES

REPM Current Recycling Practices

Nd-Fe-B

- some scrap is remelted into virgin alloy
- reduces properties and limits amounts
- Many grades with many chemistries

Sm-Co

- most scrap is recycled for Cobalt only
- Predominantly chipped and broken magnets
- Organics from machining contaminants preclude swarf and machining scrap opportunities

REPM recycling issues

- Brittle magnets assembled on assemblies with epoxies – very difficult to physically remove.
- Powders are very reactive, oxidize readily
- Nickel coating for corrosion protection – has magnetic properties, detrimental to magnetic structure
- Unknown compositions of the scrap magnets
- Complete removal of plating from the scrap magnets is not easy

Possible solutions

- Labeling of magnets in consumer products?
- Hard drives, air conditioner, HEV, wind turbine, TWT magnets
- Industrial scrap magnets are easy to identify the composition than consumer product used magnets

REPM Recycling Opportunities

- In a typical neodymium-iron-boron (Nd-Fe-B) magnet manufacturing facility, about 20–30% of the magnets were wasted as scraps in order to machine them to desired shapes, which is estimated to be about 1500–2500 tons/year.
- In the case of Sm-Co magnets, about 15-30% of the raw materials were wasted as scraps in a typical Sm-Co manufacturing sites.
- Rare earth element recovery is on the verge of being the next big thing

GOAL: Tuning magnetic scrap into possible alloy

REPM Recycling Opportunities

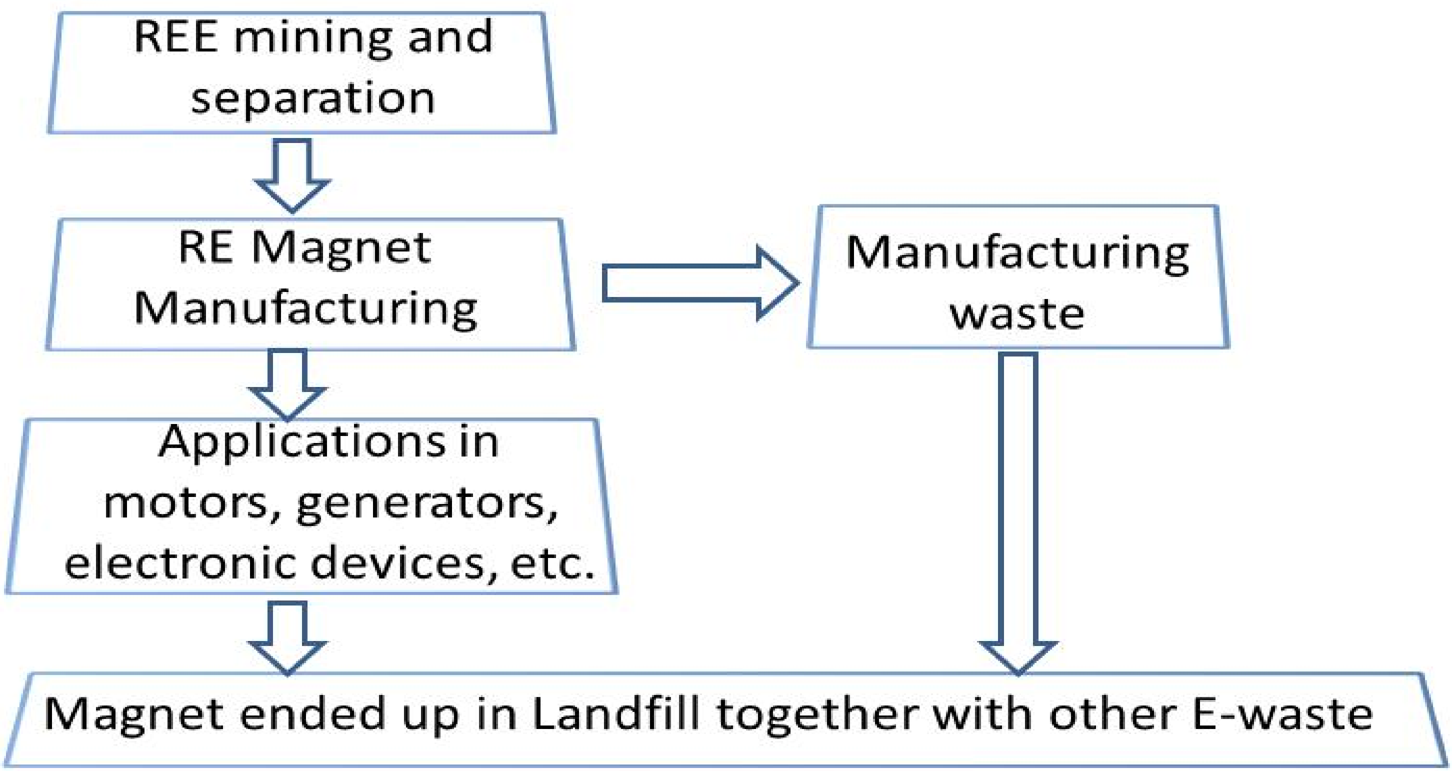
- From alloy to magnets roughly 50% of feed metals becomes finished magnets
- Limited number of REPM producers outside China – under 12
- Market could double by end of decade
- Non-Chinese production sintered REPM 2009 production
  - SmCo 2000 T/year => 580 T/yr Sm recovery potential
  - NdFeB 12000 T/year => 4080 T/yr Nd, Dy, Pr, Tb recovery potential

(*Source: W. Benecki, T. Clagett, S. Trout: Permanent Magnets 2010-2020 A Comprehensive Overview of the Global Permanent Magnet Industry c 2010)*

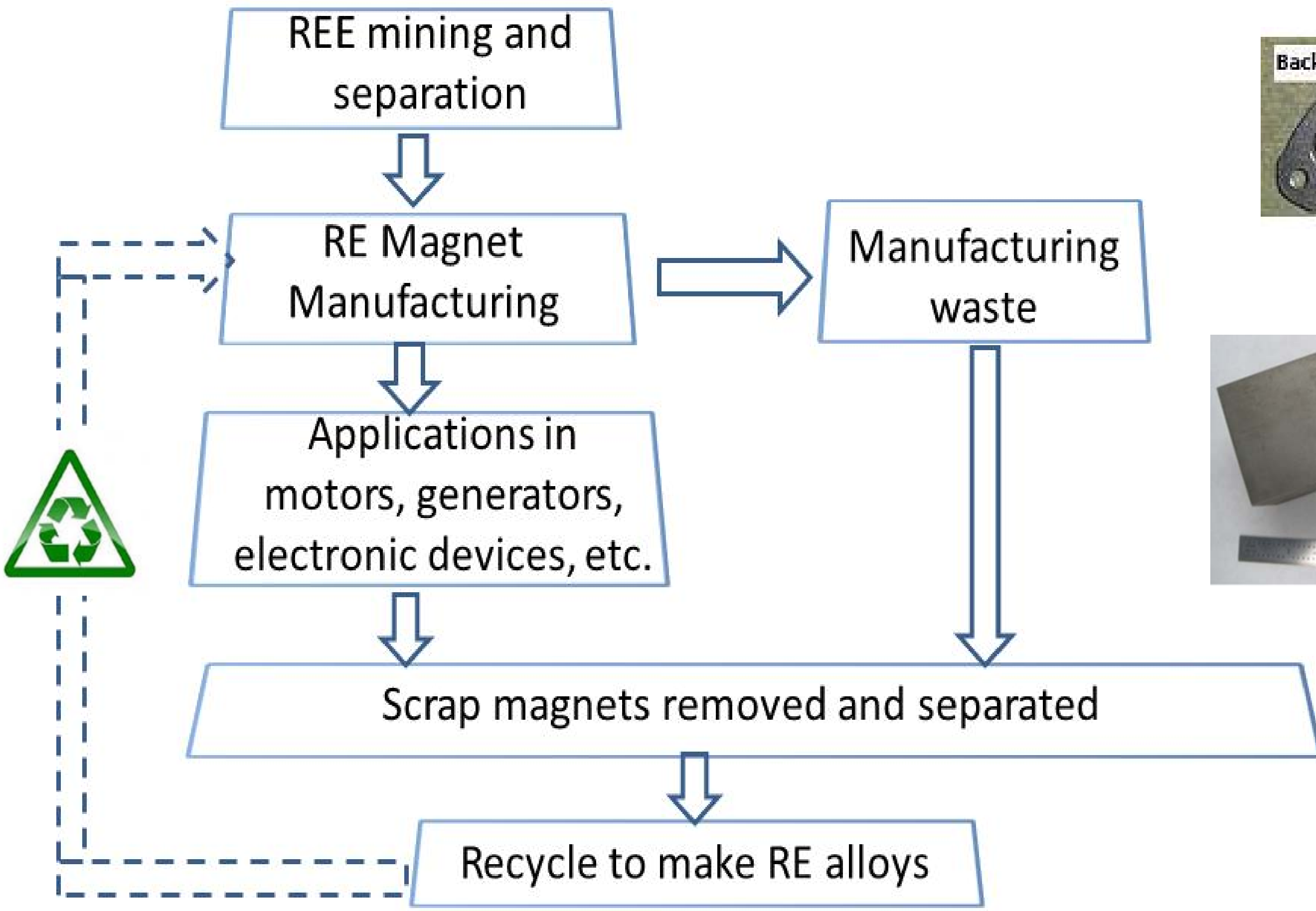
REPM Recycling Opportunities

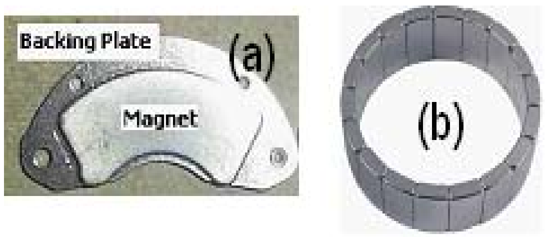
- To date, only very small quantities of rare earth elements (estimated to be around 1%) have been recycled from pre-consumer scrap, mainly permanent magnet scrap, despite the fact that typical magnet manufacturing processes could generate around 25% of scrap material.
- There is no information or evidence of any current activities in the post-consumer recycling of RE magnets on a large scale in the USA

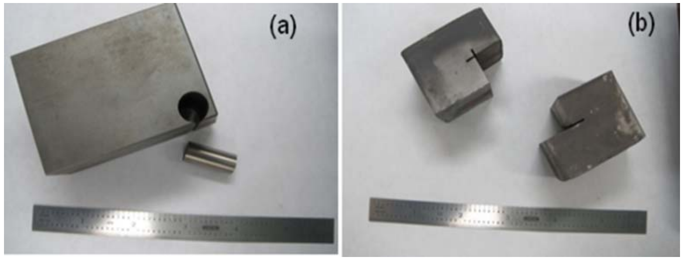
Current life cycle of rare earth element in permanent magnets



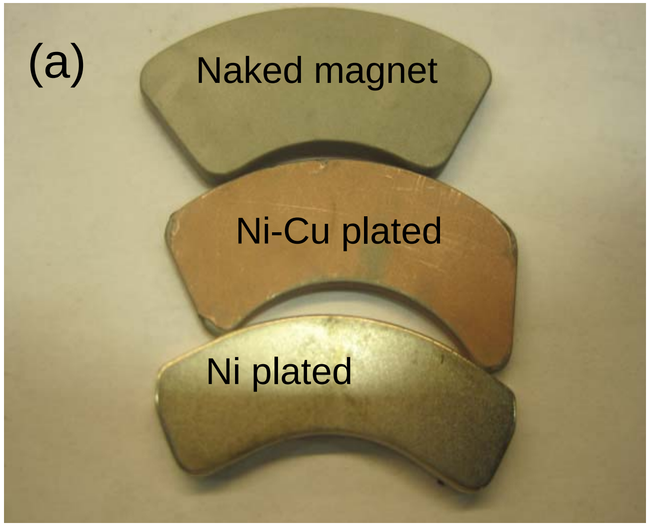
Life Cycle with EEC Recycling Approach







EEC recycling approach from E-wastes (Computer hard drive disk magnets)

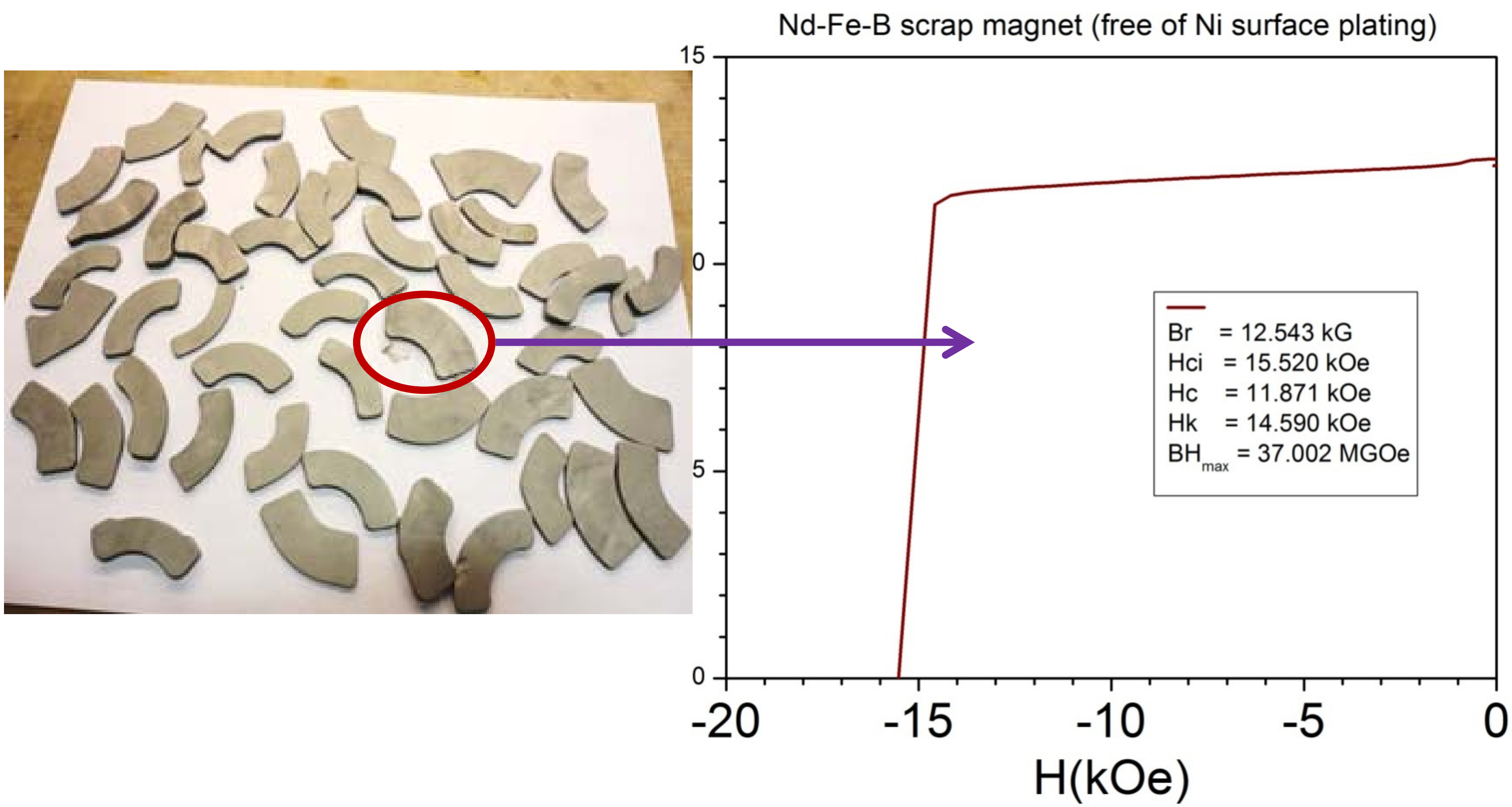


Hard drive Nd-Fe-B scrap magnets with bracket assembly

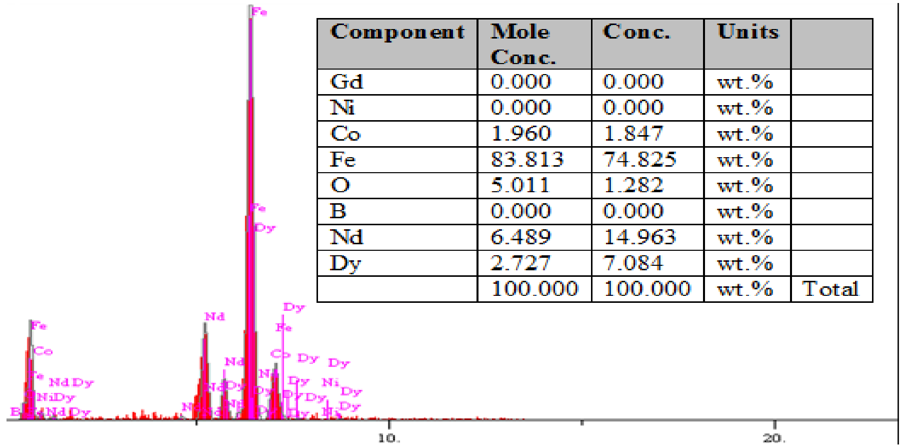
EEC's proprietory approach to make Ni/Cu coating free Nd-Fe-B magnets for reuse/recycle

Acknowledgement: EPA SBIR Phase I- EEC contract- EP-D12-030

EEC recycling approach

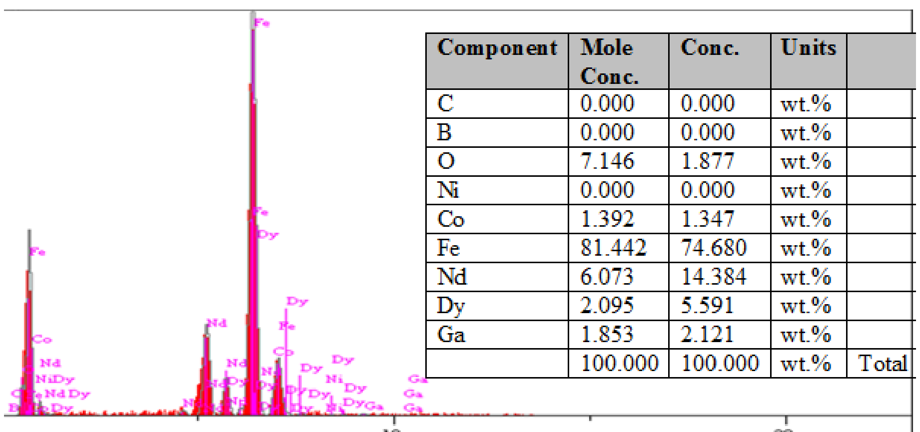


EEC recycling approach



Component	Mole Conc.	Conc.	Units	
Gd	0.000	0.000	wt.%	
Ni	0.000	0.000	wt.%	
Co	1.960	1.847	wt.%	
Fe	83.813	74.825	wt.%	
O	5.011	1.282	wt.%	
B	0.000	0.000	wt.%	
Nd	6.489	14.963	wt.%	
Dy	2.727	7.084	wt.%	
	100.000	100.000	wt.%	Total

SEM-EDX analysis



Component	Mole Conc.	Conc.	Units	
C	0.000	0.000	wt.%	
B	0.000	0.000	wt.%	
O	7.146	1.877	wt.%	
Ni	0.000	0.000	wt.%	
Co	1.392	1.347	wt.%	
Fe	81.442	74.680	wt.%	
Nd	6.073	14.384	wt.%	
Dy	2.095	5.591	wt.%	
Ga	1.853	2.121	wt.%	
	100.000	100.000	wt.%	Total

- ✓ Ni-free surface
- ✓ Oxygen is about 1-2%
- ✓ Less carbon content
- ✓ Dy content

EEC recycling approach

- ✓ Ni/Cu free surface (using EEC's Proprietory method)
- ✓ Oxygen is about 1-2 wt.%%
- ✓ Less carbon content
- ✓ Dy content from 5- 8 wt.%
- ✓ Large composition variation

Large quantity sample analysis is required to optimize the composition for recycling the E-waste magnets.

Possible solution: Labeling?

End of Life REPM Recycling

- High volume, larger magnets, limited number of compositions --- easier to recycle
- 100s of applications
- Many methods and tools to strip out components without RE content
- Small magnets ---- more costly to recover
- Return on Investment issues
- Long term pricing structure of REE?

Potential Environmental Benefits

- **To save natural resources, and prevent environmental pollution.**
  Example: Boron (B) that may be contained in acid dissolving sludge can pollute the underground water supply.

- **Preventing the resource depletion of rare earth materials by recycling the magnets from consumer products and hence to prevent the waste electronic landfills and its environmental effects.**

- **Reduced impacts on the environment including water resources and biodiversity, reduced energy requirements and hence cuts in greenhouse gas emissions.**

- **The valuable rare earths should be returned to the industrial metabolism “Rare Earth Recycling”**

Thanks you for your attention

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