Recycling NdFeB Magnets: Why is it so counterintuitive?

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Critical Materials Institute
AN ENERGY INNOVATION HUB

Spontaneous Materials

Outline

- Permanent magnets
  - What are they?
  - What do they do?
- The Rare Earths
- How are sintered NdFeB magnets processed?
- Where are the recycling opportunities?
  - Continuous
  - Non-continuous
- Stockpiling
- Final thoughts

What Are Permanent Magnets?

- Permanent magnets supply magnetic flux *without any external supply of energy*
- Resist demagnetization, H_{ci}
- $Nd_{2-x}Dy_xFe_{14}B$, SmCo, Ferrite, Alnico

What Do Permanent Magnets Do?

- What can we do with magnetic flux?
  - Torque: motor
  - Current: generator
  - Voltage: Hall effect sensor
  - Force
    - Linear Motion: speaker or actuator, linear motor
    - Levitation: MagLev
    - Magnetic braking

Magnet Applications

- Hard drive
  - Voice Coil Motor (VCM)
  - Spindle motor
  - 5x10^8 per year
  - 10 to 20 g of magnet

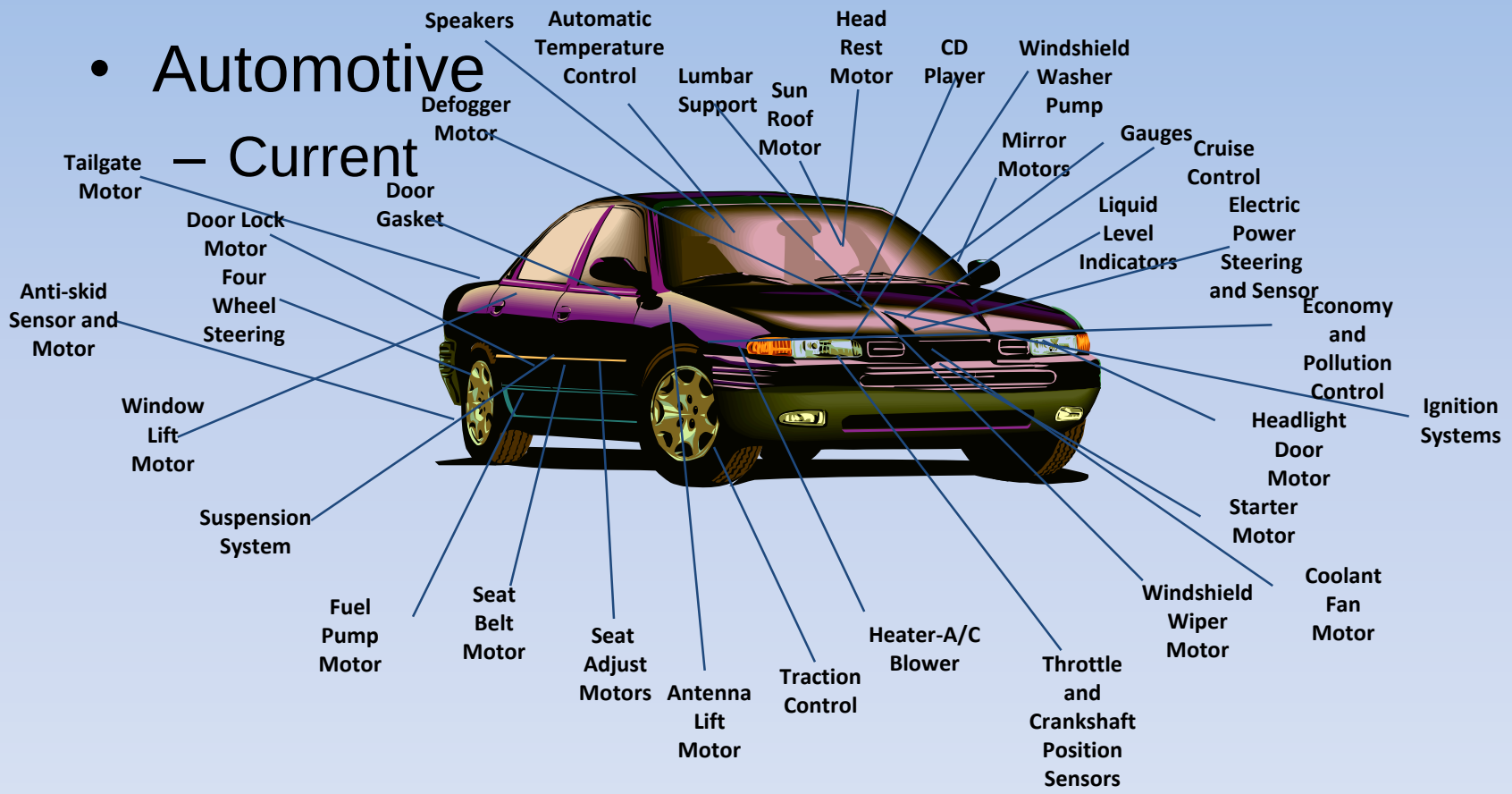
$$\left[\frac{5\times10^{8}\,drives}{year}\right]\left[\frac{10g}{drive}\right]\left[\frac{Nd}{3NdFeB}\right]\left[\frac{tonnes}{10^{6}\,g}\right]=1600tonnes/year$$

$$\left[\frac{19,000tonnesREO}{year}\right]\left[\frac{Nd_2O_3}{8REO}\right]\left[\frac{0.85Nd}{Nd_2O_3}\right]=2000tonnes/year$$

Source: Western Digital

Magnet Applications

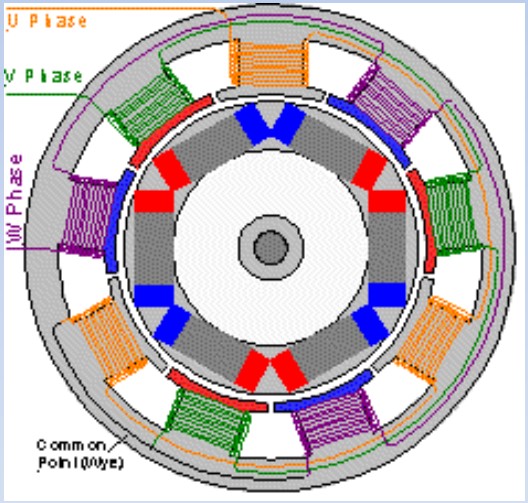
- Automotive
  - Current



Source: Magnequench

Magnet Applications

- Automotive
  - Hybrids
  - Electric Vehicles



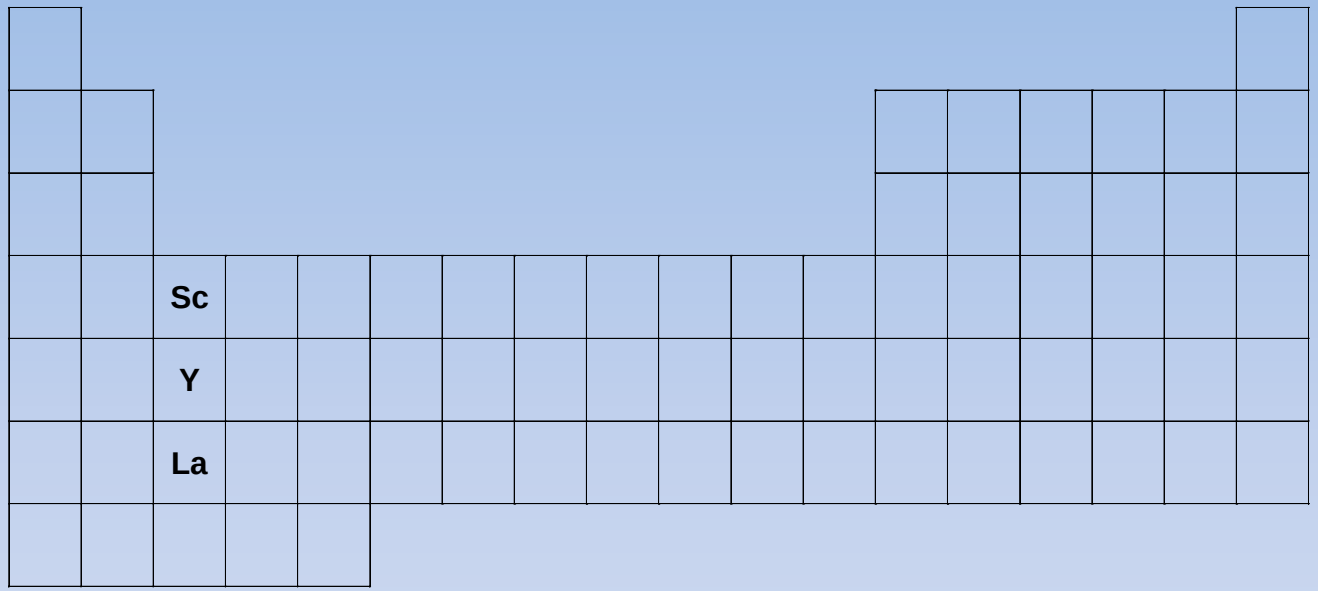
Source: Toyota

Magnet Applications

- Wind Turbine
  - The gearbox problem
  - Direct drive solution
    - ~500kg/MW
  - The future?

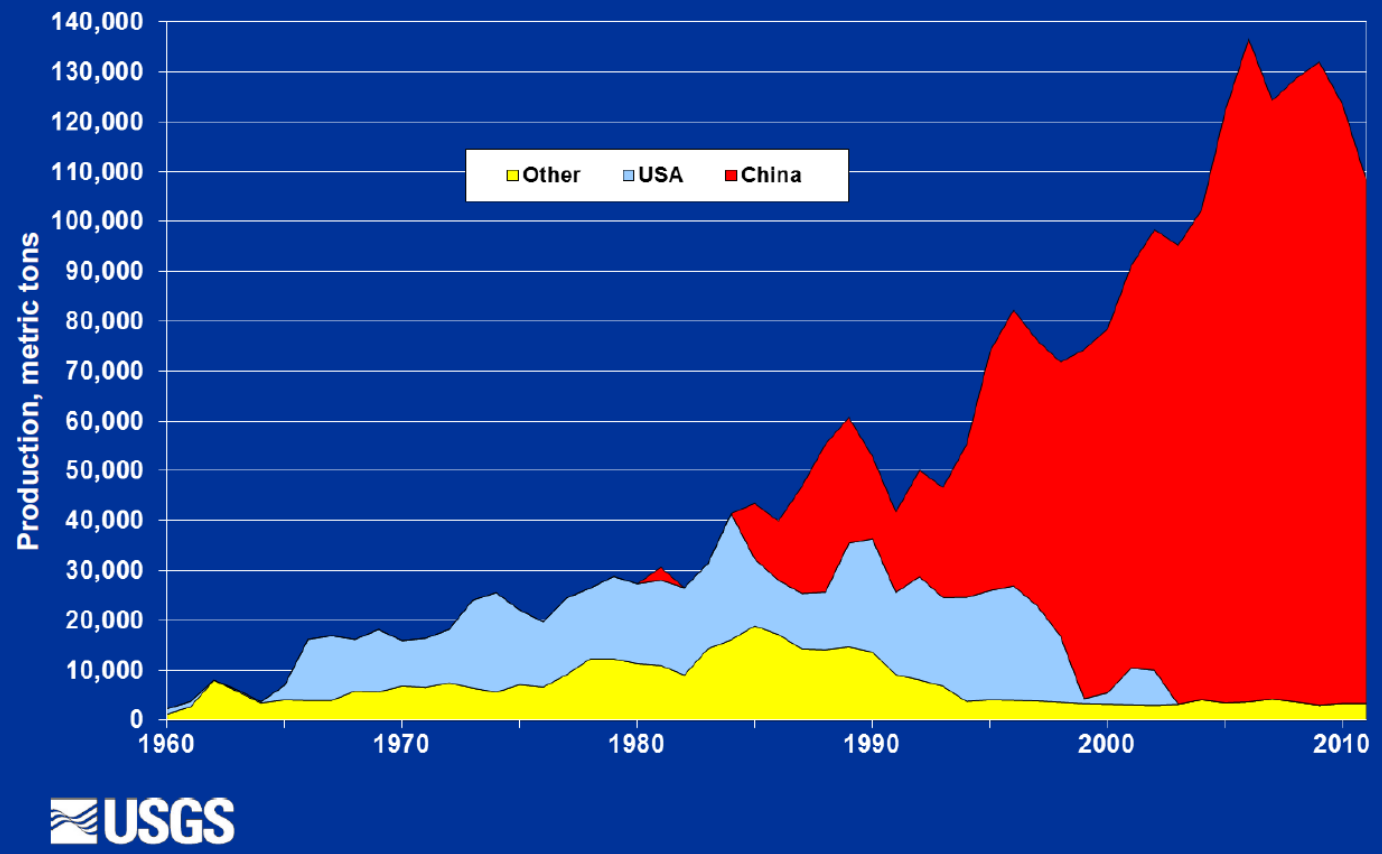
Source: Vestas AS

Rare Earths



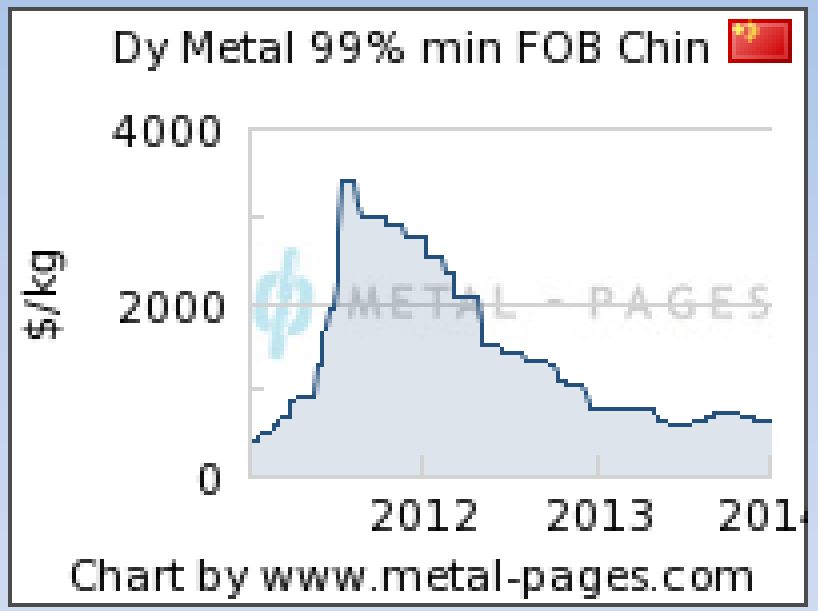
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

Global Rare Earth Oxide Mine Production



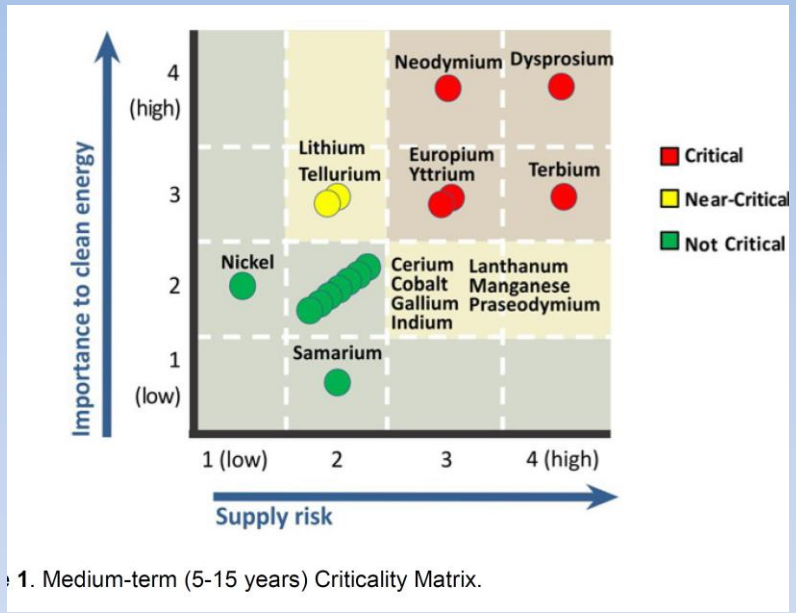
USGS

Recent RE Metal Prices



Critical Materials Hub

- DOE Program
  - $120 million, 5 years
  - National Labs
  - Academe
  - Industry
- Reduce criticality
  - Five of the most critical elements are rare earths

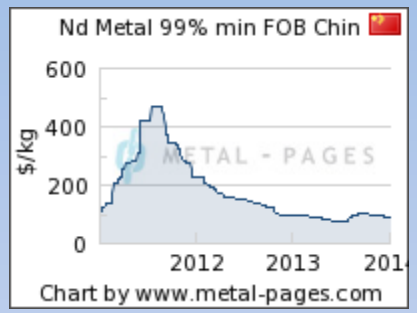


1. Medium-term (5-15 years) Criticality Matrix.

Source: DOE Announcement May 2012

Recycling Magnets

- Historically unimportant
  - Value
  - Difficulty



- Interest rises and *falls* with prices
- Center of Resource Recovery and Recycling (CR^3)
  - Eu, Tb and Y oxides from lighting phosphors
  - Nd and Dy from magnets, mainly hard drives

Sintered NdFeB
Mine to Magnets
In 19 “easy” steps

Every processing step after separation has a yield >98%, except one.
Which one is it?

Three Main Scrap Sources

- Internal
  - Reclaim without external help
- Grinding Sludge
  - Circa 20% losses in slicing and grinding small magnets
  - Oxidized, contaminated
- End of Life (EOL) magnets

Internal Recycling

- Sources
  - Broken magnets
  - Skulls, dross
- Process
  - Remelt
  - Recycle in magnet making process
- Economics
  - Yield OK
  - Lower magnetic properties, limited
- Currently in use

Grinding Sludge

- Losses due to slicing and grinding magnets
  - About 20% loss in a magnet plant is sludge
  - About 25% of sludge is rare earth
- Highly oxidized and contaminated
- Digest in acid, reprecipitate rare earth
  - Mixed Nd, Pr, Dy, Tb oxalate
  - Convert to metal
  - RE separation likely not necessary
- About a wash economically on average
- Currently done on a limited scale

Grinding Sludge

Sintered NdFeB magnets = 5×10^7 kg ← BCT Report 2010

20% sludge = 1×10^7 kg sludge.

25% of sludge is REO = 2.5×10^6 kg REO

	SLUDGE		MTN PASS	
comp.	rel%	wt (kg)	rel%	wt (kg).
REO	100	2.5×10^6	100	1.9×10^7 ← Phase I
Nd_2O_3	80	2×10^6	12	2.3×10^6
Pr_6O_{11}	10	2.5×10^5	4.3	8.2×10^5
Dy_2O_3	8	2×10^5	0.034	6.5×10^4
Tb_4O_7	2	5×10^4	0.016	3×10^3
			↑ Castor data.	

Grinding Sludge

- Potential to be a significant resource
- Dy may be the cost driver and not Nd
- Emergency resource

End of Life Magnets

- Lots of disc drive magnets
  - Small, coated and difficult to liberate
  - We need adhesives that allow for easy removal
  - Low or no Dy
- Motor magnets
  - Larger magnets, circa 100 g
  - Many applications, all different
  - Higher Dy content, up to 10%

End of Life Magnets

- Remelt Magnets
  - Low Yields (60%)
  - Uninteresting economics
- Reuse Magnets
  - Measure & sell to be cut up
    - Helmholtz coil
    - Pulsed magnetometry
  - Better economics
    - Near 100% yield
    - Higher value: Selling a magnet, not scrap metal
  - Market needs to be developed
  - Currently not being done

Stockpiling

- A DoD thrust, how to keep raw materials for magnets available in an emergency
- Scrap as one partial solution
  - Grinding sludge is the real opportunity
- Stockpile grinding sludge, only process when
  - We have an emergency
  - RE prices are high
  - Stockpile as an oxalate or oxide to reduce volume

Final Thoughts

- Recycling magnets is a good partial solution to the critical materials crisis.
- Dy may be the cost driver
  - Dy has higher value and is more critical
  - Older products have higher Dy levels
- Obey Stephen Covey's Habit #2
  - Begin with the end in mind.
  - Reusing magnets as part of the process, not an afterthought
  - EOL friendly adhesives and assembly
- Recycling as a stockpiling activity
  - Collect grinding sludge but don't fully reprocess until justified