Recycling NdFeB Magnets: Why is it so counterintuitive?

S. R. Trout
April 15, 2014
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 \textit{without any external supply of energy}
- Resist demagnetization, $H_{ci}$
- Nd$_{2-x}$Dy$_x$Fe$_{14}$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
  - $5 \times 10^8$ per year
  - 10 to 20 g of magnet

\[
\left(\frac{5 \times 10^8 \text{ drives}}{\text{year}}\right) \left(\frac{10 \text{ g}}{\text{drive}}\right) \left(\frac{Nd}{3 \text{NdFeB}}\right) \left(\frac{\text{tonnes}}{10^6 \text{ g}}\right) = 1600 \text{ tonnes/year}
\]

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

Source: Western Digital
Magnet Applications

- Automotive
  - Current
    - Cruise Control
    - Mirror Motors
    - Tailgate Motor
    - Door Lock Motor
    - Four Wheel Steering
    - Anti-skid Sensor and Motor
    - Window Lift Motor
    - Suspension System
    - Fuel Pump Motor
    - Seat Belt Motor
    - Seat Adjust Motors
    - Antenna Lift Motor
    - Traction Control
    - Head Rest Motor
    - Sun Roof Motor
    - CD Player
    - Windshield Washer Pump
    - Mirror Motors
    - Gauges
    - Liquid Level Indicators
    - Cruise Control
    - Electric Power Steering and Sensor
    - Economy and Pollution Control
    - Headlight Door Motor
    - Starter Motor
    - Windshield Wiper Motor
    - Coolant Fan Motor
    - Ignition Systems
    - Heat and Crankshaft Position Sensors
    - Throttle and Crankshaft Position Sensors

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
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

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 x 10^7 kg < BCT Report 2010

20% sludge = 1 x 10^7 kg sludge.

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

<table>
<thead>
<tr>
<th>comp.</th>
<th>rel.%</th>
<th>wt (kg)</th>
<th>rel.%</th>
<th>wt (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>REO</td>
<td>100</td>
<td>2.5 x 10^6</td>
<td>100</td>
<td>1.9 x 10^7</td>
</tr>
<tr>
<td>Nd_2O_3</td>
<td>80</td>
<td>2 x 10^6</td>
<td>12</td>
<td>2.3 x 10^6</td>
</tr>
<tr>
<td>Pr_2O_3</td>
<td>10</td>
<td>2.5 x 10^5</td>
<td>4.3</td>
<td>8.2 x 10^5</td>
</tr>
<tr>
<td>Dy_2O_3</td>
<td>8</td>
<td>2 x 10^5</td>
<td>0.05</td>
<td>6.5 x 10^4</td>
</tr>
<tr>
<td>Tb_4O_7</td>
<td>2</td>
<td>5 x 10^4</td>
<td>0.016</td>
<td>3 x 10^3</td>
</tr>
</tbody>
</table>

**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