The New Landscape for Rare Earth Permanent Magnets

- U.S.-Sourced Feedstock
- Secure Supply Chains
- Long-Term Price Visibility
- Less Reliance on “Heavy” Rare Earths
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Main Points

1. Demand is growing for higher efficiency motors as a result of rising energy efficiency standards and consumer demand for smaller, lighter, and more energy efficient products. Rare earth (RE) permanent magnets help reduce motor size, weight, and energy consumption to better meet these regulatory and market demands.

2. In the past two years, rare earth price volatility, lack of supply security, and concerns over “heavy” rare earth availability have discouraged manufacturers from using RE permanent magnets and encouraged them to find alternatives, which can increase energy usage and degrade performance.

3. However, production of magnetic rare earths outside of China is now growing rapidly, which is driving greater long-term supply of RE permanent magnets. New, vertically integrated supply chains outside of China can now offer flexible entry points, security of supply, pricing visibility, and long-term contracts.

4. Additionally, engineering advances and new economic realities are bringing manufacturers back to rare earth magnets. NdFeB magnets that contain little-to-no Dysprosium (Dy) can meet or exceed the performance of traditional sintered magnets with high Dy content (8-10%) for applications that operate in higher temperature environments.
Update: Molycorp’s Production Ramp & Global Supply Chains
✓ Operational ramp proceeding as planned to Phase 1 run rate (19,050 mt/year) by mid-2013; annual production rate now at ~6,000 mt/year.
✓ Current bottlenecks to production ramp are mechanical, not technological, with issues such as filtration and equipment/infrastructure. All are being managed.
✓ Chloralkali facility on track for completion and commissioning in 2H 2013.
✓ Target production cost range ($6-$7/kg) on track assuming achievement of Phase 1 run rate and successful commissioning of chloralkali facility.
✓ Operating cash position remains good, with an additional $100-$150M credit revolving facility nearing completion.
Diverse, Vertically Integrated Supply Chains

**Mining & Production of Concentrate**

**Value-Added Supply Chain OUTSIDE China**

- **LREE REO Separation**
  - Mountain Pass (Calif.)
  - Silmet (Estonia)

- **Metal / Alloy Production**
  - Tolleson (Arizona)
  - Silmet (Estonia)
  - Tolling Companies

**Value-Added Supply Chain INSIDE China**

- **HREE REO Separation**
  - HREE Facility
  - Expected 2013/14
  - Location outside China TBA

- **Magnetic Materials**
  - Korat (Thailand)
  - Intermetallic Japan

**Products sold directly from Mountain Pass**

- **LREE REO Separation**
  - Zibo, China

- **HREE REO Separation**
  - Jiangyin, China

- **Magnetic Materials**
  - Tianjin, China

CUSTOMERS WORLDWIDE

Diverse, Vertically Integrated Supply Chains
The Powerful Benefits of Rare Earth Permanent Magnets
The Power of Rare Earth Magnets in Motors

By replacing Ferrite magnets in motors with:

Rare Earth Permanent Magnets

You can REDUCE:

- Power Consumption By 10%
- Dependence on Liquid Fossil Fuels
- CO₂ and other Emissions
- Consumption of natural resources
- Lifecycle Costs
- Weight and Size

RE motor vs. Ferrite based motor
The Power of Rare Earth Magnets in Motors

Rare Earth magnets help make technologies more effective and more efficient.

- Computing & Network Technologies
- High-Efficiency Motors for Energy-Efficient Homes
- Aerospace
- Automobiles
- Clean Energy
The use of Rare Earth Permanent Motors can help achieve energy efficiency savings of up to 20%.

45%* Percentage of global power consumption by Electric Motor Driven Systems.

45%** Source: 2011 International Energy Agency analysis

55% All Other Consumption

* Global Energy Savings Potential of RE Magnet Motors

** Source: Mitsubishi Corporation.
How The Landscape For RE Magnets Has Changed in the Past Year
Prior to 2010

Manufactures Increasingly Designing Products with Rare Earth Magnets

- Low and Relatively Stable Rare Earth Prices
- Reliability of Rare Earth Supplies was Less of a Concern than Today
- Rare Earth Magnets Cost-to-Performance Ratio Was Steadily Improving

2010 – 2012

A Period of Increased Risk for Magnet Users

- Manufacturers Dissuaded from Rare Earth Magnet Use
- Limited Supply Options
- Supply Constraints & Shortages
- Rare Earth Prices Highly Volatile
2013: Rare Earth Supply Situation is Greatly Improving

New Supplies Coming Online Outside China

Global Rare Earth Supply Landscape is Greatly Improving

Security of Supply

Visibility Into Pricing

Long-Term Supply Agreements

Less Dependence on Heavy REs (Dy)

Others over the long-term

Lynas
Today’s State-of-the-Art: NdFeB Permanent Magnets With Little-to-No Dysprosium
Low-to-Zero Dysprosium NdFeB Magnets

**MQ1**

- Zero-Dy Bonded Magnets
- Cost-effective replacement for iron-based (ferrite) magnets
- Allows for smaller/lighter motors
- Helps vehicles meet higher fuel efficiency and performance standards
- Made from abundant Mountain Pass, California rare earth ore

**MQ3**

- Hot-Pressed, Fully Dense Magnets With Low-Dy Content
- 2-4% “Dy advantage” over sintered NdFeB magnets
- Excellent magnetic properties at temps of up to 180°C with little Dy
- Made from abundant Mountain Pass, California rare earth ore

**MQ2**

- Hot-Pressed, Fully Dense Magnets With Zero-Dy Content
- Provides a 4-7% “Dy advantage” over sintered NdFeB magnets
- Excellent magnetic properties at temps of up to 200°C with zero Dy
- Made from abundant Mountain Pass, California rare earth ore

![Graphs and diagrams showing efficiency and irreversible flux loss over temperature for MQ1 and MQ3 magnets.]

- **Efficiency (%) vs. Torque (mNm):**
  - Motor with Ferrite Magnet
  - Motor with MQ1 Magnet
  - Allows for higher efficiency

- **Irreversible Flux Loss after 1 hr (%) vs. Temperature (°C):**
  - MQ3 grade with low Dy (2%)
  - Excellent thermal stability
MQ magnets (MQ1, MQ2, and MQ3) fill the gap between fully dense anisotropic sintered neo magnets and sintered ferrite magnets.

MQ magnets, with only very limited exceptions, contain no heavy rare earths such as Dy or Tb.
The MQ2 and MQ3 Dysprosium (Dy) Advantage

- Smaller grain size improves $H_cJ$, so less Dy needed
- MQ3 grain size is 20X smaller than traditional sintered NdFeB magnet
- MQ2 grain size is 100x smaller than traditional sintered NdFeB magnet

√ MQ3 vs. traditional sintered (2-4% less Dy at a given temperature)
√ MQ2 vs. traditional sintered (4-7% less Dy at a given temperature)

1 Micrometers ($\mu$m) = 1000 Nanometers (nm)
High-Performance, Low-Dy Sintered NdFeB Magnets

- **High-Performance, Low-Dy Sintered Magnets**: Intermetallics Japan is now producing next-generation, high-performance sintered NdFeB magnets with 50% or less dysprosium content than traditional sintered magnets. IMJ recently has developed high-performance Dy-free sintered NdFeB magnets.

- **Abundant Feedstock**: Magnetic rare earths are sourced from Molycorp’s world-class rare earth facility in Mountain Pass, California.

- **Target markets**: Automotive and home appliance sectors.

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**IMJ’s Next-Generation, Low-Dy Sintered NdFeB Magnets**

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Magnetic Performance</strong></td>
<td>• GBD (Grain Boundary Diffusion) and fine powder technology yields higher magnetic properties and magnet performance.</td>
</tr>
</tbody>
</table>
| **Cost Advantages**             | • Higher production yield (80～90%)  
  • Less heavy rare earth (Dy & Tb) content for lower cost and price stability.  
  • Zero-Dy sintered magnets                                                                                                                  |
| **Superior Quality**            | • Quality assurance is overseen by one of the world’s leading producers of high-end rare earth permanent magnets: Daido Steel.                                                                              |
| **Stable Feedstock Sourcing**   | • Magnetic rare earth feedstock comes from the world-class, high-tonnage rare earth deposit of Molycorp’s Mountain Pass, California facility.                                                              |
| **Strong Global Alliance**      | • Research and development capabilities of Intermetallics Co. Ltd. combined with strategic alliances with Daido Steel, Mitsubishi Corporation and Molycorp.                                                 |
Approaches to Dy-diffusion by the top Japanese Sintered Magnet Makers

A number of different grain boundary diffusion techniques have been reported by the various Japanese sintered magnet manufacturers.

- **Blending** \( \text{Dy}_2\text{O}_3 \) powder with the NdFeB powder and combining the sintering and Dy-diffusing stages.
- Also discussed treating Dy-coated sintered magnets.
- Savings in Dy: 20-50% less Dy

**Traditional method**

High baking temperature causes Dy to diffuse into the interior of crystalline particles.

**Dy Diffusion**

Cross section showing Dy distribution in a neodymium magnet made using the HAL process:

Dy gathers non-centrally at the periphery of crystalline particles.

**ShinEtsu**

- Coating 1-5mm thin magnets with \( \text{Dy}_2\text{O}_3 \) and \( \text{DyF}_3 \) slurries and heating these coated magnets for 1-10 hours at 800-900°C
- Savings in Dy: 60% from original
- Can be found in new Nissan Leaf 2012 model

**Hitachi**

- Dy-vapor diffusion technique, where thin sintered magnets are thermally treated in Dy-vapor environment
- Hitachi is currently running a sample evaluation program with key customers and expects full commercialization of the series with new Dy-reduction technologies in 2014.

**ULVAC**

- Savings in Dy: 20%
- Can be found in new Nissan Leaf 2012 model
How Manufacturers Today Are Using Low-to-Zero Dy Rare Earth Magnets
The Benefits of Using Rare Earth Permanent Magnet Motors

- **Permanent Magnet Motors**
  - Energy Efficiency
  - Dynamic Performance
  - Operational Efficiencies
  - Continuous Torque
  - Bearing Life

- **Induction Motors**
  - Lifecycle Costs
  - Size & Weight
  - Noise & Vibration
  - Operating Temperature
  - Current

- **Motors with MQ1 Magnets**
  - Performance
  - Torque Density
  - Fuel Efficiency
  - Energy Efficiency (esp. for appliances)
  - Greater Functionality

- **Motors with Zero-Dy MQ2 Magnets**
  - Lower Dy content leverages larger global supply of light REs
  - 18% lower overall material cost in a similar size and weight envelope

- **Sintered Neo Magnets w/Dy**
  - Thermal Stability, Torque Density, Fuel & Power Efficiency
  - Noise, Vibration, Cogging Torque

MQ2 magnets can offer 18% lower total material cost in a similar size and weight envelope.

### Comparative Table

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Length</th>
<th>Magnet Weight</th>
<th>Total Weight</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sintered Neo (4.5% Dy)</td>
<td>1</td>
<td>1</td>
<td>1.13</td>
<td>0.97</td>
</tr>
<tr>
<td>MQ2 (0% Dy)</td>
<td>1</td>
<td>1</td>
<td>1.07</td>
<td>0.82</td>
</tr>
</tbody>
</table>
**Design Innovation Allows Low-to-Zero Dy Magnets**

**High Efficiency Refrigerator Fan Motor**

**Action:** Replaced motors using ferrite magnets in refrigerator fan motor with MQ1 magnets

**RESULTS:**
- Reduce the size of the motor: height by 70% and diameter by 27%
- Motor efficiency improved by 10%, resulting in 1~2% improvement in whole refrigerator system
- Better design by eliminating protruded parts due to the height of motors and fans

**Residential HVAC Circulation Pump**

**Action:** Replaced induction motor in circulation pumps with motors using MQ1 magnets

**RESULTS:**
- Helps pumps meet new energy efficiency standards
- Reduces energy consumption
- EU ordinance prohibits the sale of technically outmoded, inefficient pump models from 2013 onwards
- Replacement is cost-effective

**Compressors for AC Systems**

**Action:** Replaced motor using sintered Neo magnets (7-8% Dy) with MQ3 (2-3% Dy) magnets

**RESULTS:**
- Performance maintained while reducing component costs with less Dy
Companies Utilizing NdFeB Magnets in Motors & Components

- Bicycle Dynamo
- Engine Cooling Fan Motor
- AC Compressor Motor
- Fuel Pump Motor
- Window Lift Adjustment Motor
- Headlight Adjustment Motor
- Seat Motor
- Power Steering Sensor Motor
- AC Compressor Motor
- Engine Cooling Fan Motor
- Bicycle Dynamo
Companies Utilizing NdFeB Magnets in Motors & Components

- Ceiling Fan
- Refrigeration
- AC Motor
- Vacuum Cleaner
Companies Utilizing NdFeB Magnets in Motors & Components

- Hard Disk Drives
- Optical Disk Drives
- Servers
- Office Automation
Conclusions

1. Global production outside of China of magnetic rare earths is rising, and newly integrated supply chains offer flexible entry points, security of supply, pricing visibility, and long-term contracts – inside or outside of China.

2. Heavy rare earths are becoming less and less of an impediment to the security of supply of high-performance NdFeB magnets.

3. Using rare earth permanent magnets in motors, instead of ferrite magnets, delivers many powerful economic and environmental benefits to manufacturers and consumers.

4. Given that motors consume an estimated 45% of all energy generated globally, increasing motor efficiencies through rare earth permanent magnets promises many powerful environmental and energy savings benefits to the world.
Questions?

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