EV & Transportation Applications of Permanent Magnet Materials

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Permanent Magnet Materials

OUTLINE

1. What are key Permanent Magnet motor materials?
2. How are they used? Why important?
3. How are the materials manufactured? What is the PM supply chain?
4. What is the outlook for economy, ecology, & security?
Permanent Magnet Materials

RECENT HISTORY

• Electric Vehicles increasingly use Permanent Magnets made from Rare Earth material NdFeB
• USA no longer produces Rare Earths (since 2002)
• PM materials demand in transportation and many high-tech products is booming
• Criticality is increasing in product supply chains
• Few or no substitutes
• 2011 Price Shock caused a short market alarm
• Prices moderate since 2012, now increasing again
Electric Vehicles: 1895

Electric innovator

Thomas Edison

Most US cars were all-electric 1895..1918

NYC taxi fleet: 1000+ EVs

Self-Start, Electric Lights
New gasoline car: Ford Model T 1908

Crank to start
No Battery
Magneto-spark
Timing adjust
Fuel Headlamps
Fuel Tank
>HARD TO USE

1918: ELECTRIFICATION!
Electric motors in modern cars & EVs

Automotive trends are:
- Improved energy efficiency
- More features & functions
- More electrification
- More batteries
- More motors
Why electric motors?

1. Wide speed range (+10kRPM..0..-10kRPM), variable
2. Directional reversibility with high bandwidth
3. High Torque. Good torque at all speeds & zero RPM
4. Small Size. Flexible: shape can be tailored to fit
5. Light weight. Down-sized to fit the job
7. Wide environmental operating range: Temp, pressure, humidity, etc.
8. Durable. Low maintenance, little or no lubrication
9. Reliable. Long MTBF, simpler mechanicals
10. Quiet acoustics, low EM radiation emissions
11. Natural affinity with electronic controls “intelligent” functions: safety
12. Energy scavenging through regeneration

Motors work better!
Electric motor applications in modern cars: Interior

- Seat Adjust
- Track Height
- Seat Track
- Seat Recline
- Seat Tilt
- Door Assembly
- Lift Motor
- Window Glass Lift
- Door Glass Lift
Electric motors in modern cars

Under-Hood

Windshield Wiper
Coolant Pump
Heater Valve
Vacuum Pump
A/C Compressor
Transmission Actuators
Electric motor applications: Doors

Power Doors

Safe Software

DANGER
WATCH YOUR HANDS

DANGER
PINCH POINT WATCH YOUR HANDS

Safe Software
Automatic Folding Side Mirrors

Motorized operation, sensor logic control
Electric motor applications in modern cars: Entertainment

Audio Speakers

This application is **cost-sensitive**!

After 2011 Rare Earth price shock

- magnet substitutes were developed
- RE use was sharply reduced in speakers
- Advertised as “Green RareEarth Free”
New motor Applications

1. Normally-flush door handle
2. Motorized pop-out
3. Hand opened

Safe Software

Automatic Door Handle Presentation
Traction Motor Applications: EV

In-wheel motor

Larger motor = more torque = more RE materials
Hybrids & PEVs (Plug-in Electric Vehicles)

Electric propulsion

Petrol

$1.0x

Electric

>$0.4x!

Hybrid Propulsion reduces transport cost
New motor Applications:
BEV = Battery All-Electric Vehicles

All-Electric

>$0.4x$!
Recent EV sales history (Oct 2017)

Steady sales growth

USA EV Sales, Monthly
2010-2017 Stratigraph of 48 EV Models - D. Christian
Strong Correlation in USA: Fuel prices -and- EV sales

Customers remember price shocks
Strong Correlation in USA: Fuel prices -with- EV sales

PEV reduces the risk of petrol price-shock
Lessons from EV history:

1. Customers are very sensitive to fuel cost
2. Customers remember price shock volatility
3. New PEV cars reduce total cost TCOO
   - Many US customers don’t believe PEV is real
   - As PEV benefit gains confidence, sales increase
BEV sales prospects

Expectation: brisk EV sales growth
Primarily use PM motors
2017: OEM & Governments outlawing non-electric drivetrains!

VW, BMW, Ford

Tesla, Toyota, Mazda

Honda, GM, BYD, Dyson,

M-Benz, Volvo, Nissan

India, China

France, UK

Scotland, China

Netherlands, Norway, Germany
Alternatives to PM/rare earth Motors?

- Automotive RE applications are cost-sensitive.
- Delicate balance: Performance vs Cost
- PM/RE Performance is good.

> Fear of price shock motivates R&D for alternatives:
  - new **Lower**-RE motors (reduced RE use)
  - new **Zero**-RE motors (total elimination)
PM Technology Alternatives

• Modern Motor Designs:
  – Permanent Magnet *(baseline)*
  – AC Induction *(popular, cheapest)*
  – Switched Reluctance

• Requirements vary greatly between applications
• Motor designs have been iterated for 150 years
• PM performance is competitive or superior in all niches
• Most modern EVs use PM motors *(Nissan, Ford, GM)*
• Tesla’s Model 3 will use PM propulsion motor
• PM continues as the most popular technology
Electric Aircraft

Benefits: Efficient, Silent, Clean, Light, Safe, Economic

Siemens eFusion Trainer

D. J. Christian
Marine Electric Propulsion

Electric Thrusters
Rare Earths in Wind Energy

Wind Capacity 500 MW

- Neodymium
- Praseodymium
- Terbium
- Dysprosium
Cell Phone Rare Earths

**Vibrator Magnets**
- Neodymium
- Praseodymium
- Terbium
- Dysprosium

**Electronics**
- Neodymium
- Praseodymium
- Dysprosium
- Gadolinium

**Speakers**
- Neodymium
- Praseodymium
- Terbium
- Dysprosium

**Headphones**
- Neodymium
- Praseodymium
- Terbium
- Dysprosium

**Display Screen**
- Europium
- Praseodymium
- Yttrium
- Lanthanum
- Terbium
- Dysprosium
- Gadolinium

**Glass Polishing**
- Cerium
- Lanthanum
- Praseodymium
What are PM materials?

“Super-Magnets” Neodymium Iron Boron, NdFeB

Rare Earths or Lanthanide elements
Where are rare earths used?

A broad range of performance-critical applications
Power, weight, temperature, sensitivity, color,...
How are PM materials manufactured?

Mountain Pass mine, Calif
Plentiful ore: Bastnasite, Monazite
Where is PM material supply chain?

Source: USGS, CRS,

There is no challenge to Chinese monopoly.
Electromagnetic Rail-Gun Artillery

Navy

Army

USNS Zumwalt
USNS Millinocket

Bulk consumer of Rare Earth materials
Aircraft Carrier: Electromagnetic Catapult

USNS Gerald R Ford
commissioned July 2017 with EM catapults

Chinese Navy Carrier Liaoning
commissioned Nov 2016
Upgrades in development

Bulk consumer of Rare Earth materials
F35 Fighter: “Flying Periodic Table”

**F-35B jump jet**
- Main lift fan door
- Auxiliary lift fan door
- Pilot: Headset gives 360° view of battlefield
- AESA radar
- Optical targeting system
- Payload bay door
- Thrust vectoring nozzle
  
  Directs full thrust of engine down for vertical takeoff and landing

**F135 turbofan engine**

**Lift fan**: Powered by driveshaft from jet engine – balances lift generated at tail

**Bulk consumer of Rare Earth materials**

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**F-35 orders**

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Transportation Markets for Rare Earth materials

Trends are clear:
- Greater electrification for transportation
- More motors used in transportation
- More EV penetration: sales & operating fleet
- More motors electronically commutated
- More magnet rare earth material used

Projections (opinion):
- RE applications will continue to grow
- Some substitutes may be found, cost-driven
- If RE prices remain competitive, then RE markets will continue to grow
Critical Materials Institute

- Study and recommend supply chain strategies
- US Dept Of Energy initiative at Ames Laboratory

Criticality Matrices: Risk vs Strategic Importance

Further reading:

**Fiction**

“Rare Mettle”  
By Ann Bridges

**Non-Fiction**

“The Elements of Power”  
by David S Abraham
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Thank You for your attention!

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