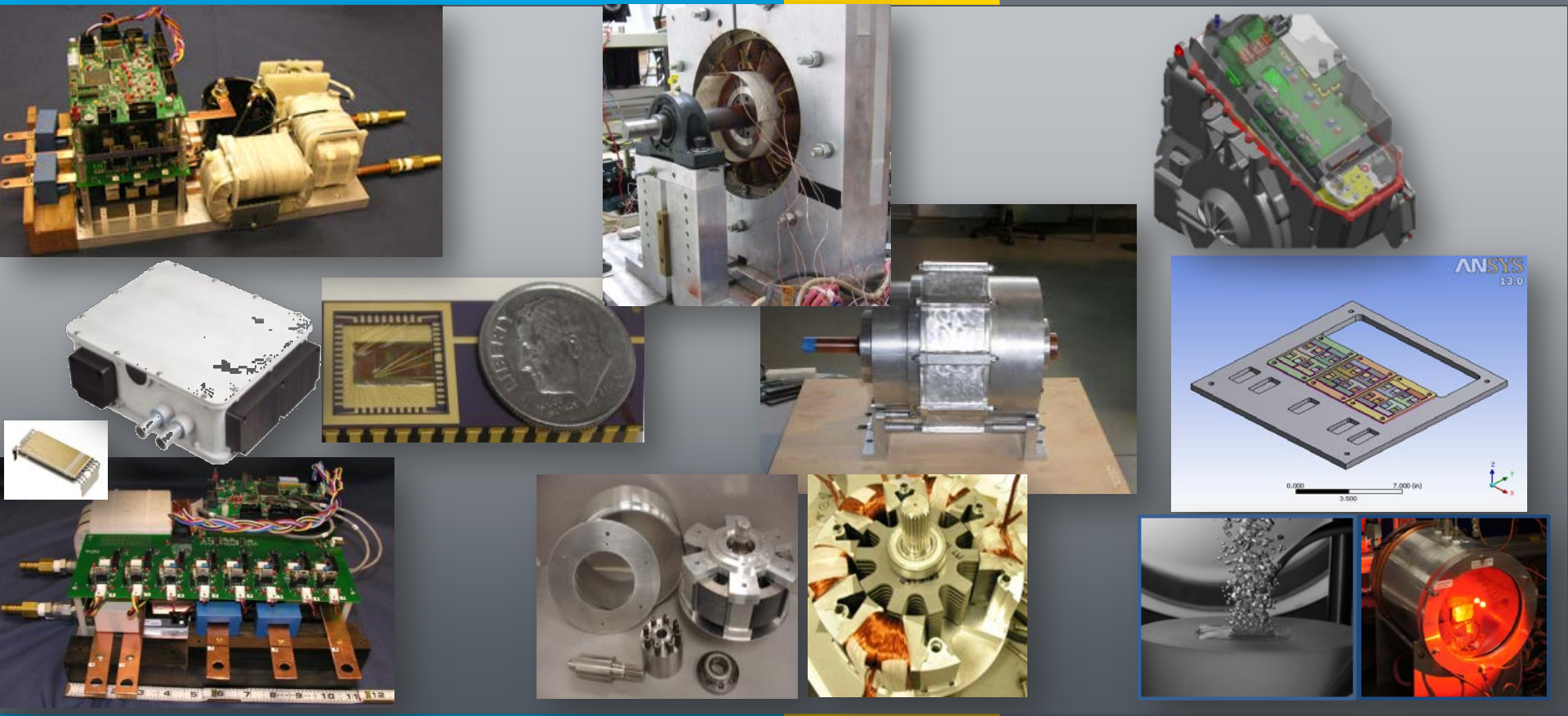
EV Everywhere Grand Challenge

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Electric Motors and Critical Materials Breakout

July 24, 2012

Laura Marlino
Oak Ridge National Laboratory
Iver Anderson
Ames Laboratory
Facilitators

Electric Drive Status and Targets

2022 EV Everywhere Targets

		Current Status*	PHEV 40**	AEV 100**	AEV 300+
System Cost	$/kW	20 ($1100)	5 ($600)	14 ($1680)	4 ($600)
Motor Specific Power	kW/kg	1.3	1.9	1.5	2
PE Specific Power	kW/kg	10.5	16	12	16.7
System Peak Efficiency	%	90	97	91	98

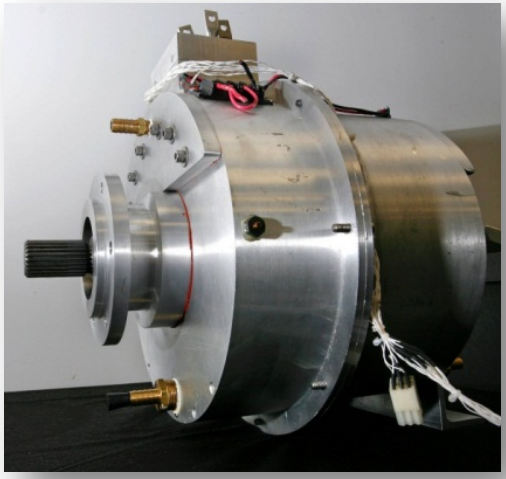
*** 55kW system** **** 120kW system** **+ 150 kW system**

Extremely Aggressive Targets

Especially Challenging for the Electric Motor

Electric Motor Challenges & Issues

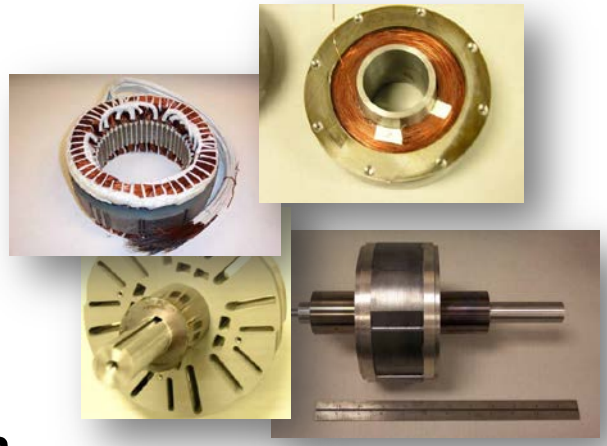
- **Cost is the biggest challenge**
  - ***Impossible (?) to meet targets with RE machine***
- **Efficiency improvements**
- **Volume and mass reductions**
  - ***Alternatives to higher speed operation?***



16,000 rpm Brushless Field Excitation (BFE) IPM Motor

Overall Target Achievement will require significant engineering leaps—'out of the box' thinking

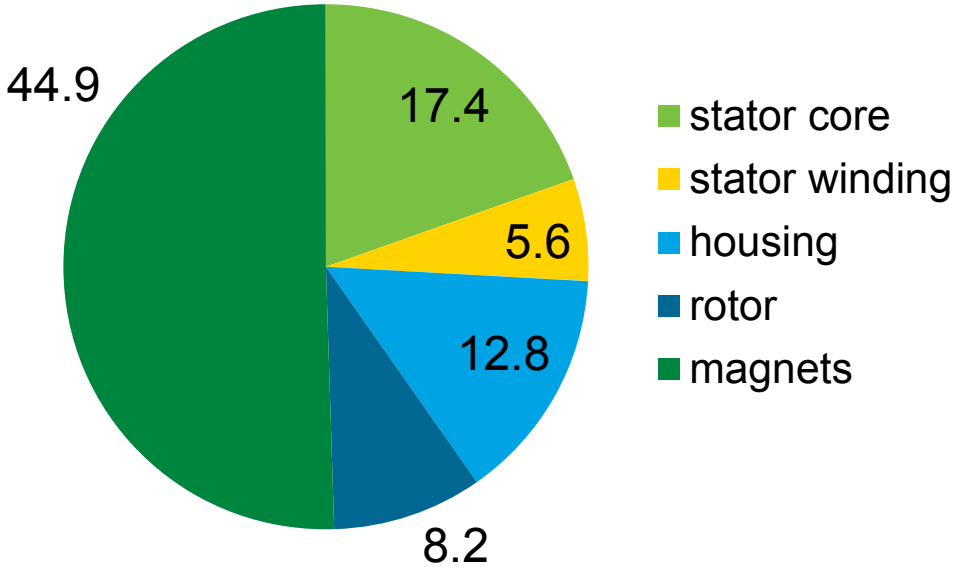
- **New designs**
- **Advanced materials**
- **Thermal Management**
- **Packaging**



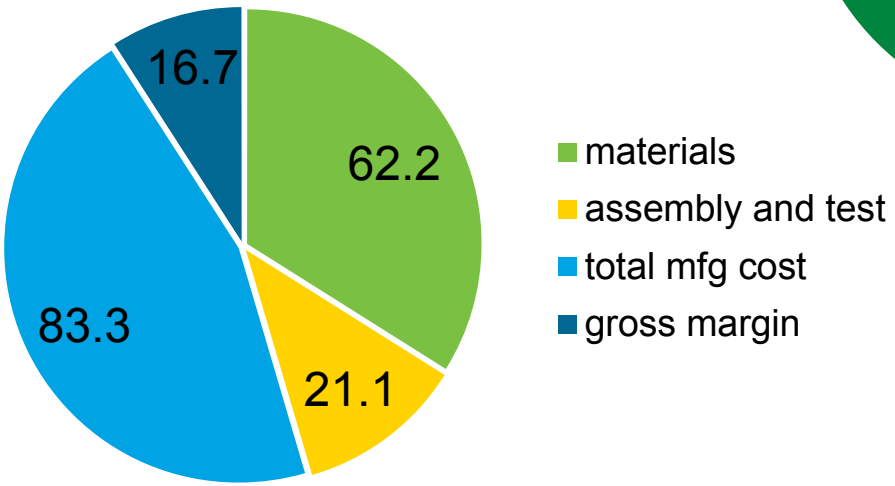
All the while maintaining cognizance of system impacts

RE Permanent Magnet Motor

Material Cost %

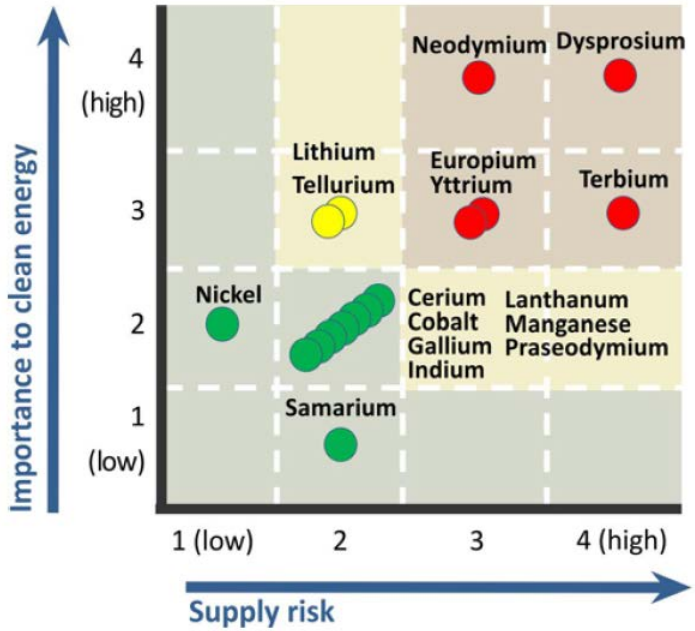


OEM cost %

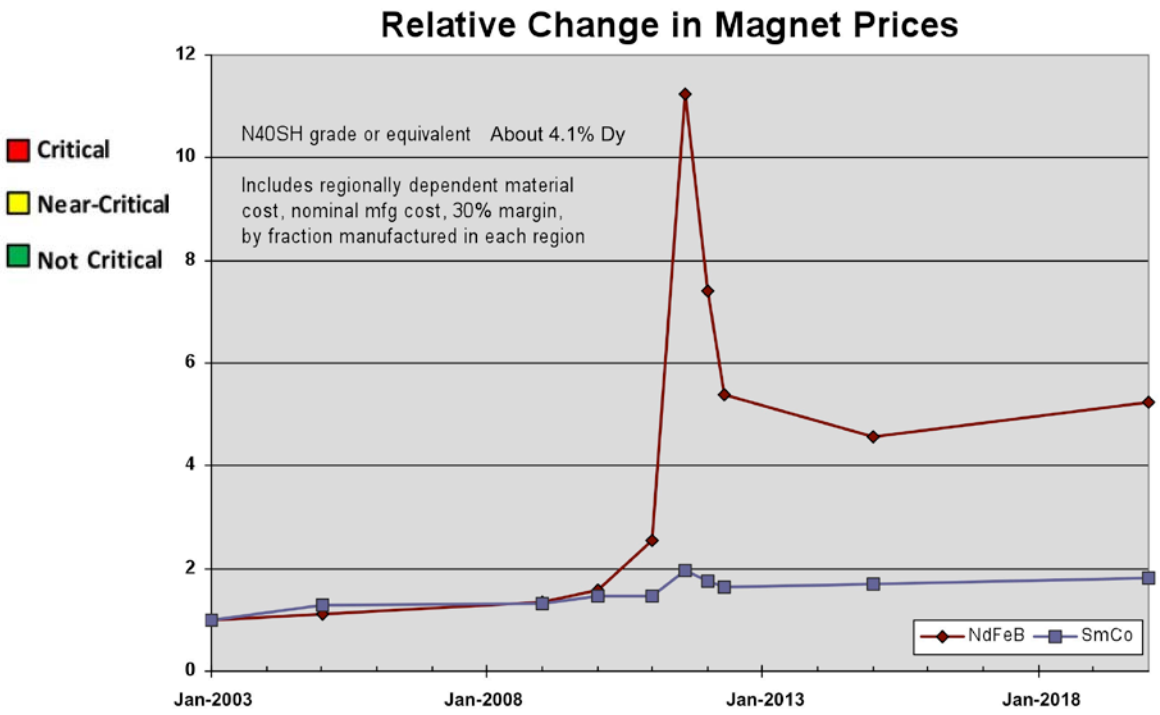


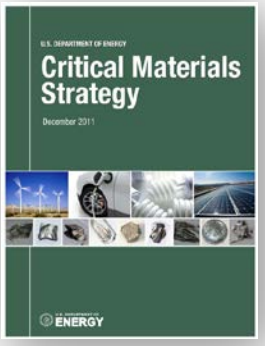
Rare Earths in Permanent Magnets for Drive Motors are "Critical Materials"

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Taken from Figure 1 of the Energy Innovation Hub—Critical Materials Funding Opportunity Announcement



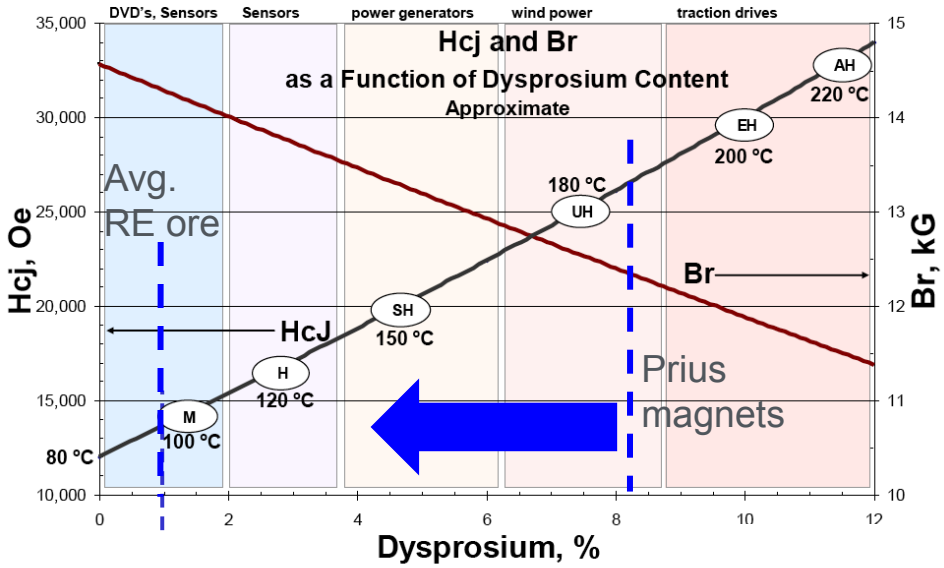


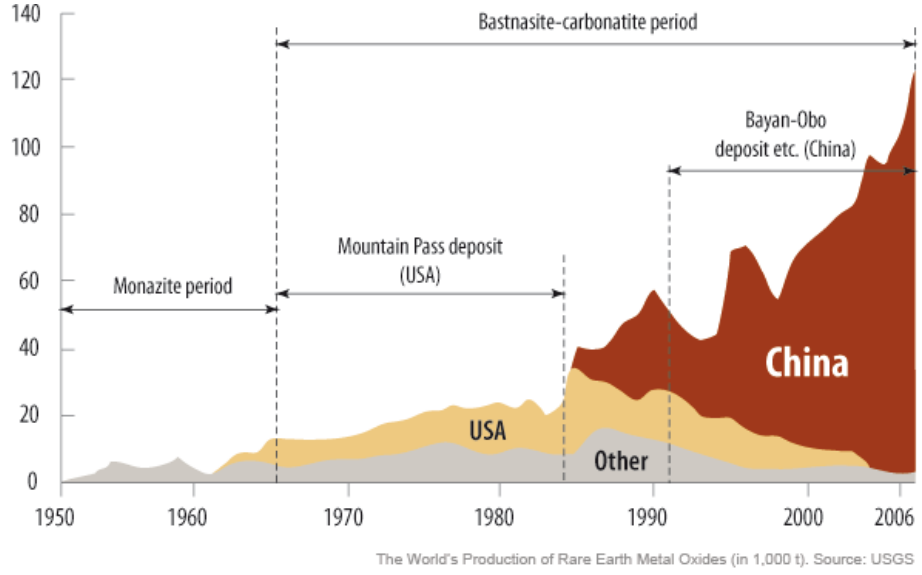
Nd and Dy in high strength magnets are essential for compact, high torque drive motors that tolerate high vehicle operating temperatures.
Critical supply risk and rising price trend motivate research into finding alternative permanent magnets.

Critical Materials Status

Permanent Magnet Materials Challenges and Issues

- To meet goals for reduced cost and broad availability of suitable permanent magnets (PM) for advanced electric drive motors, new magnet alloys and processing concepts are needed to replace $(Nd,Dy)_2(Fe,Co)_{14}B$ magnets.
- The fully developed PM material must:
  - ✓ achieve superiority for elevated temperature (150-200˚C) operation to minimize motor cooling needs.
  - ✓ remain competitive at room temperature with current high magnetic energy density (MGOe) materials to conserve weight, space, and valuable materials.
  - ✓ minimize or eliminate use of scarce RE, e.g., Dy, due to an impending world wide RE shortage or be developed as RE-free magnet alloys

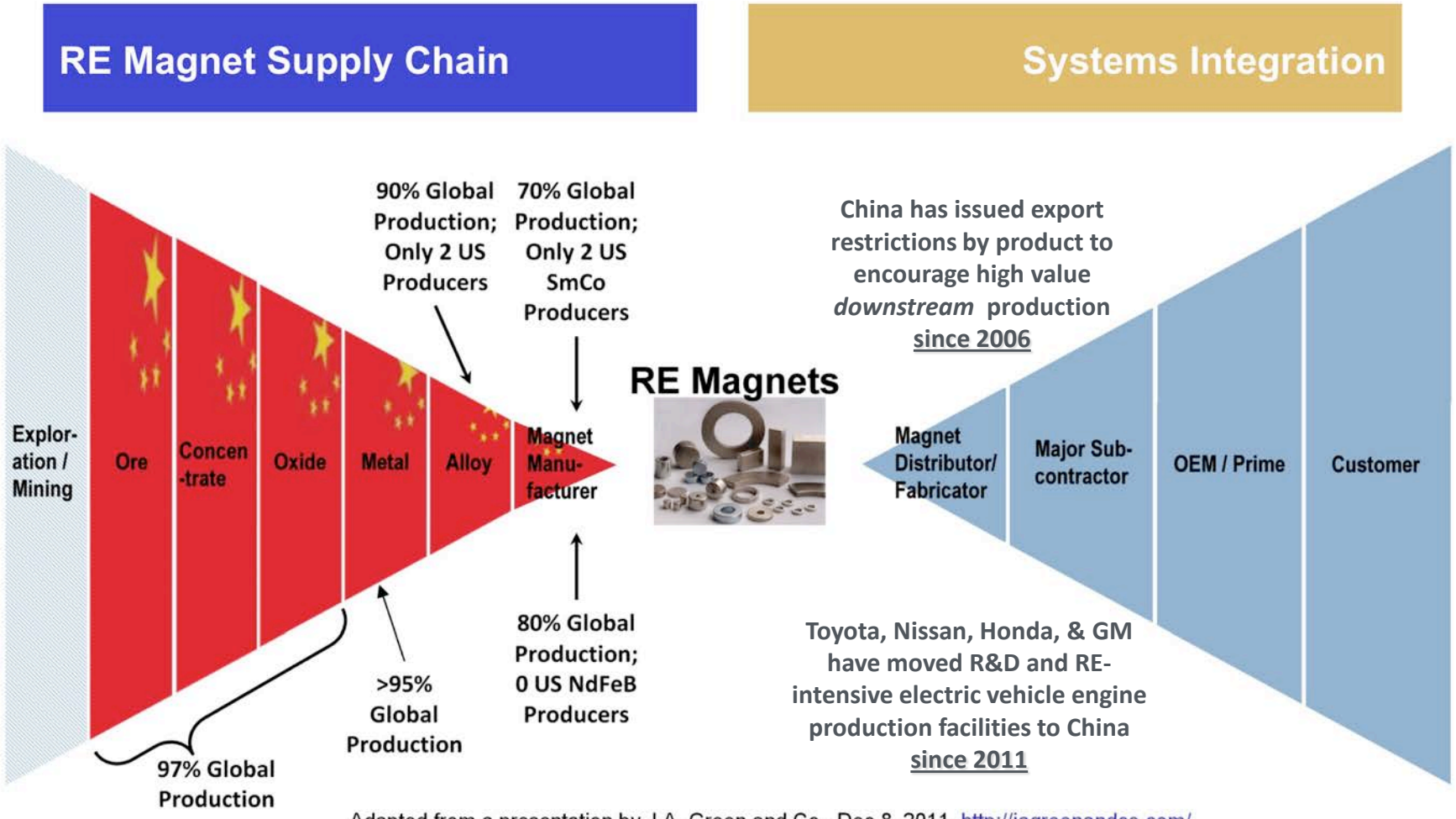




Stategic Impact on Manufacturing

ARNOLD MAGNETIC TECHNOLOGIES

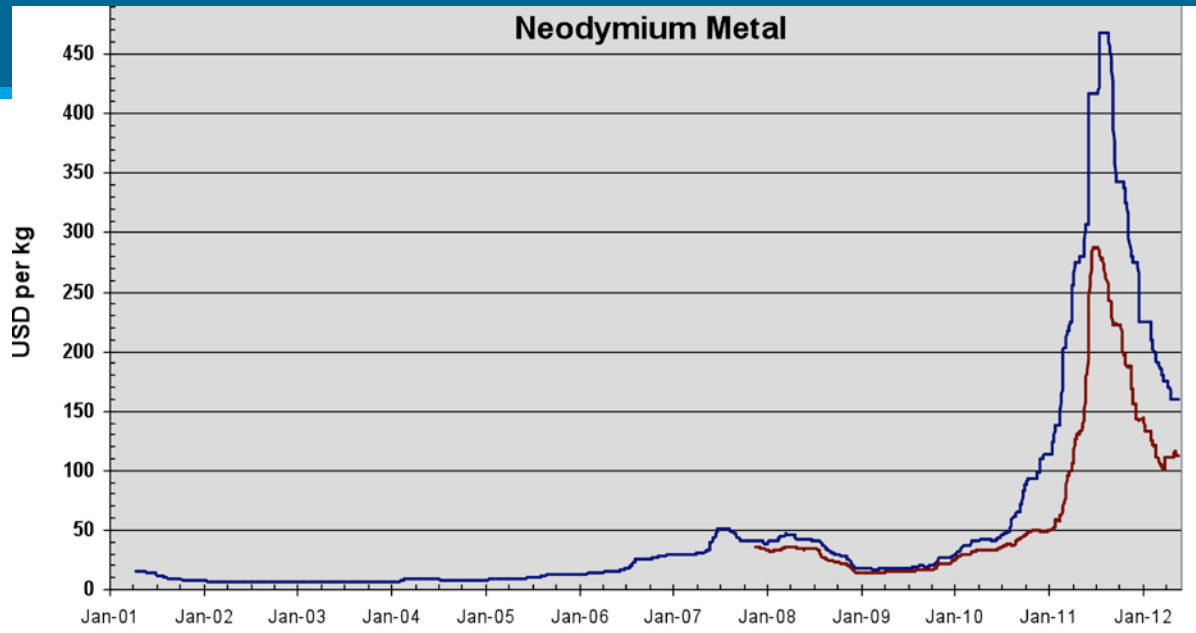
China cut export quotas for the first half of 2011 by 35%, following a 72% reduction in the second half of 2010

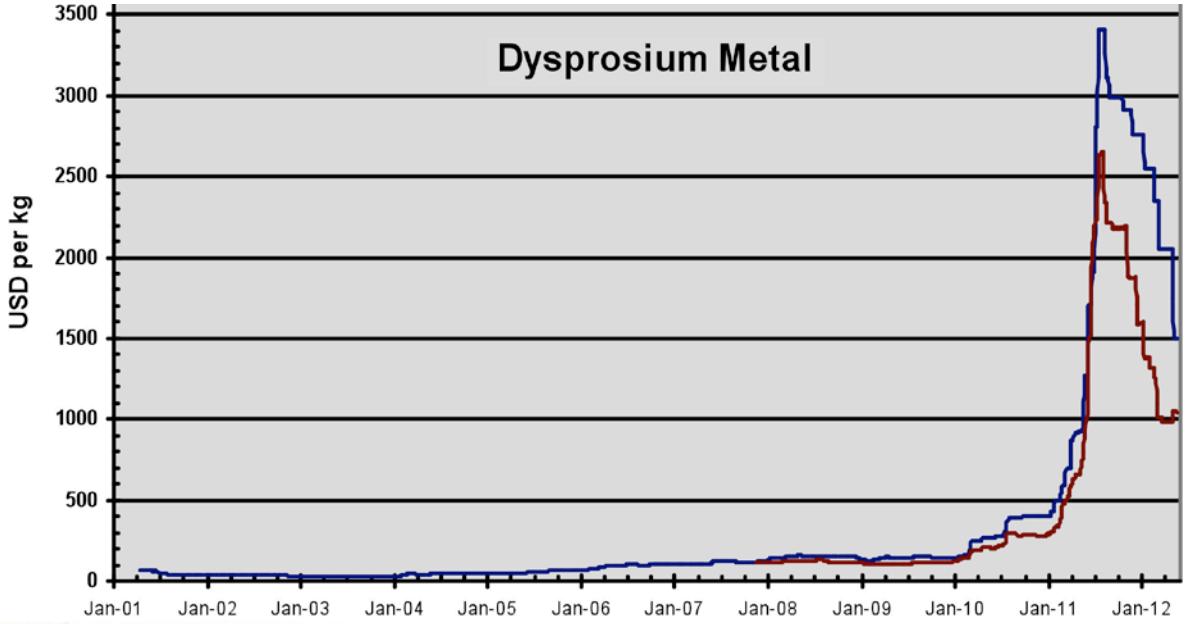


Adapted from a presentation by J.A. Green and Co., Dec 8, 2011, http://jagreenandco.com/

Steve Constantinides (Arnold Magnetics)—BREM Workshop, May 2012

RE Metal Pricing: May 18, 2012





ARNOLD MAGNETIC TECHNOLOGIES

Magnet Material Costs: 19-April-2012

[in US Dollars per kg of magnet, 1 kg block magnet, FOB China]

	N35EH	N40UH	N45SH
Nd	38.2	41.4	45.1
Dy	178.4	131.2	84.1
	-	-	-
	216.5	172.6	129.1

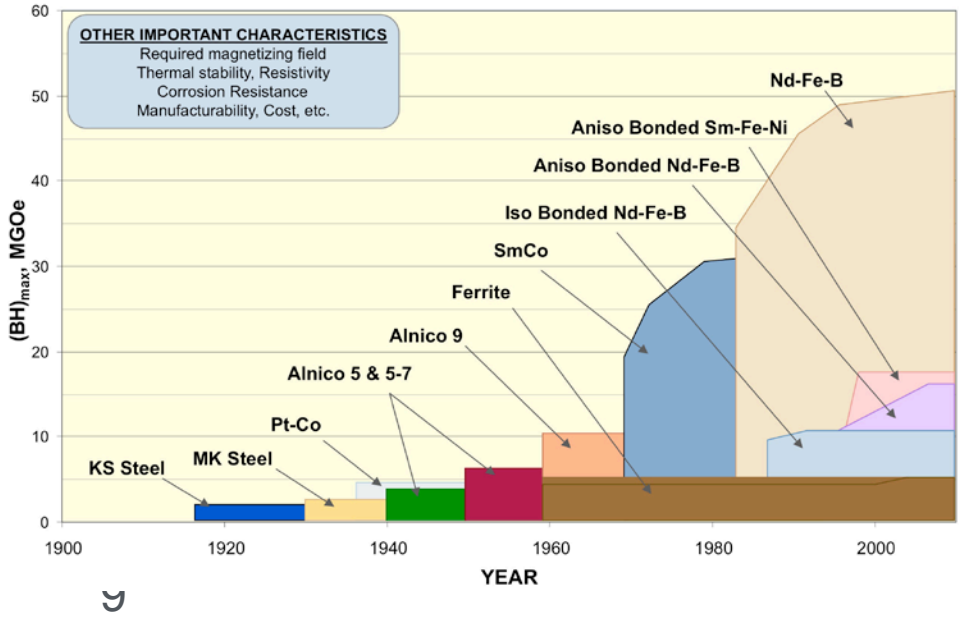
[Domestic China]

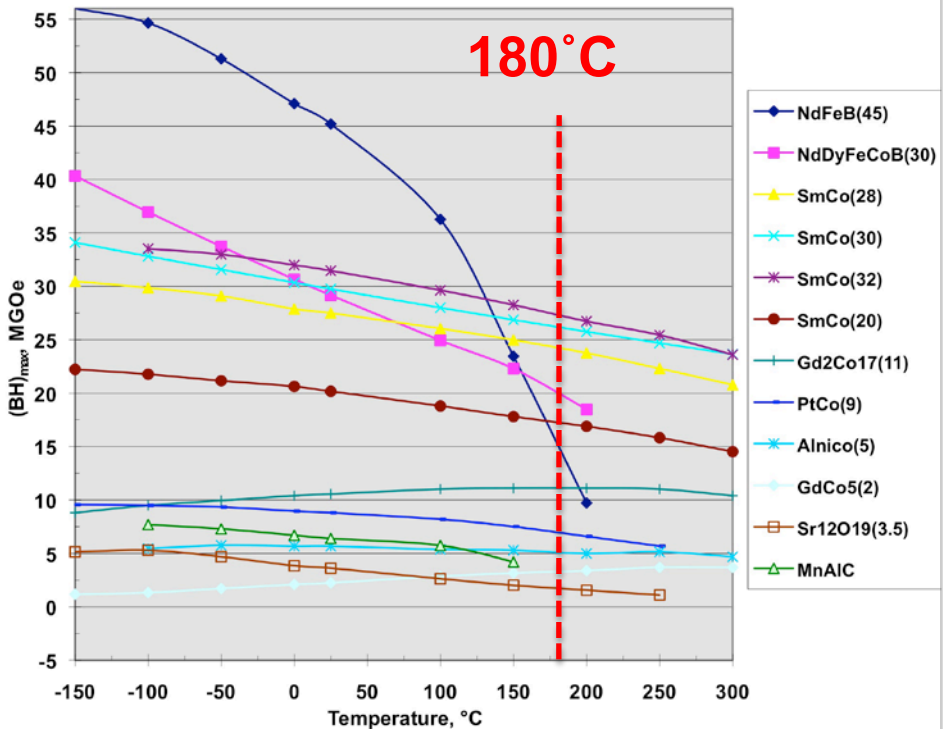
	N35EH	N40UH	N45SH
Nd	25.7	28.4	30.9
Dy	85.5	62.9	40.3
	-	-	-
	111.3	91.3	71.2

- While neodymium has become more costly, it is the very expensive dysprosium that dominates (Nd,Dy)-(Fe,Co)-B magnet material costs.
- Numbers do not include yield loss, mfg cost or profit margins

Apparent Options for Improved Non-Rare Earth Permanent Magnets

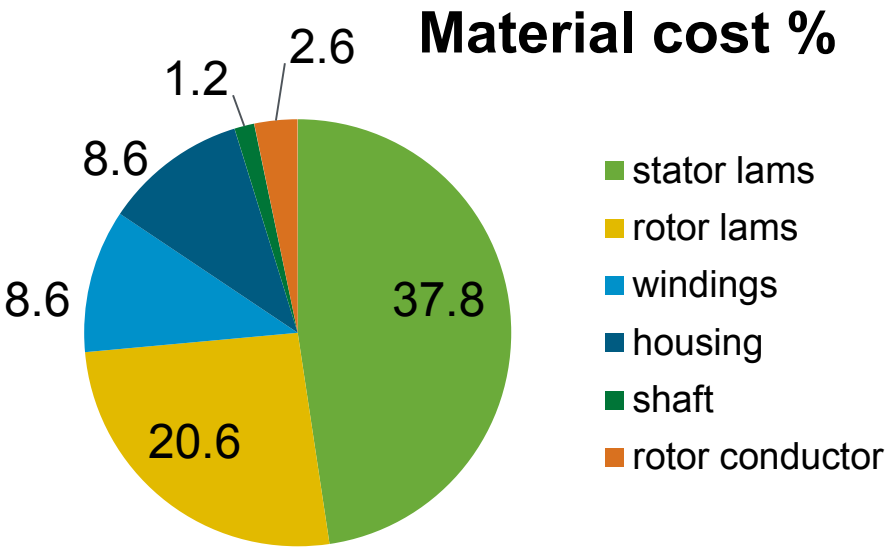
- Improve on best current non-RE system: e.g., Alnico (T_C=860˚C)
  - Enhanced knowledge of coercivity mechanisms
  - Enhanced control of composition and microstructure
- Discover new (low cost) Fe-Co based hard magnetic phases
  - High Curie temperature, high magnetization, and magnetic anisotropy.
  - Extrinsic properties after processing of bulk magnets.

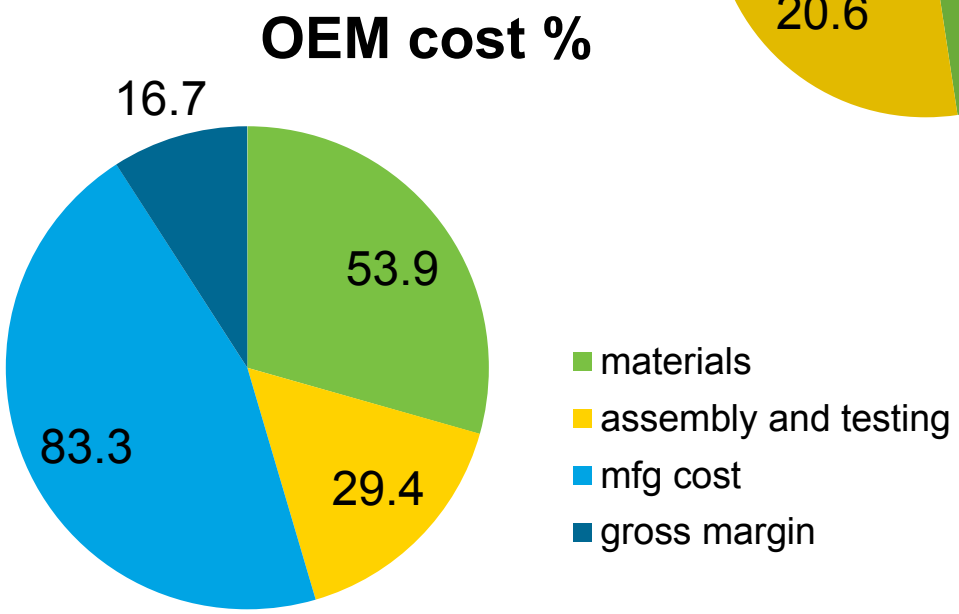




[M.J. Kramer, et al, JOM, accepted June 2012]

Induction Motor





Breakout plan and Questions

1. EV everywhere scope & technical targets
   - Current state of the art
   - Are performance and cost targets achievable?
   - Major pathways to achieving targets?
   - Major Barriers?
2. Indentify needs/game-changing ideas
   - Highest impact critical technology breakthroughs needed?
   - “out of the box”, risky approaches? ***VERY MUCH NEEDED!***
   - Each participant should propose a single research idea or concept!
3. Action plans and preparation of slides for plenary session and report
   - System level considerations