Alternative High-Performance Motors with Non-Rare Earth Materials

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DOE Peer Review Presentation

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imagination at work

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Prototype Manufacturing

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Overview

Timeline

- Start: October 1, 2011 (official kickoff with DoE February 7, 2012)
- End: January 31, 2016
- 30% complete (Kickoff meeting Feb. 7, 2012)

Budget

- $ ~12M total budget
- $ ~6M DOE share
- $ ~6M GE cost share

•Funding received from the DoE to date: $ 2,757,776

Barriers

Very challenging set of specs

- High efficiency over a wide speed and load ranges
- High power density and high coolant inlet temperature
- Low cost targets based on 100,000 units/year
- High speed poses mechanical challenges
- No rare-earth permanent magnets

Partners

- GE Global Research (lead)
- GE Power Conversion/GE Licensing
- University of Wisconsin-Madison
- North Carolina State University
- University of Akron
- ORNL
- NREL
- McCleer Power
- Ames National Lab
- Arnold Magnetics

The Problem

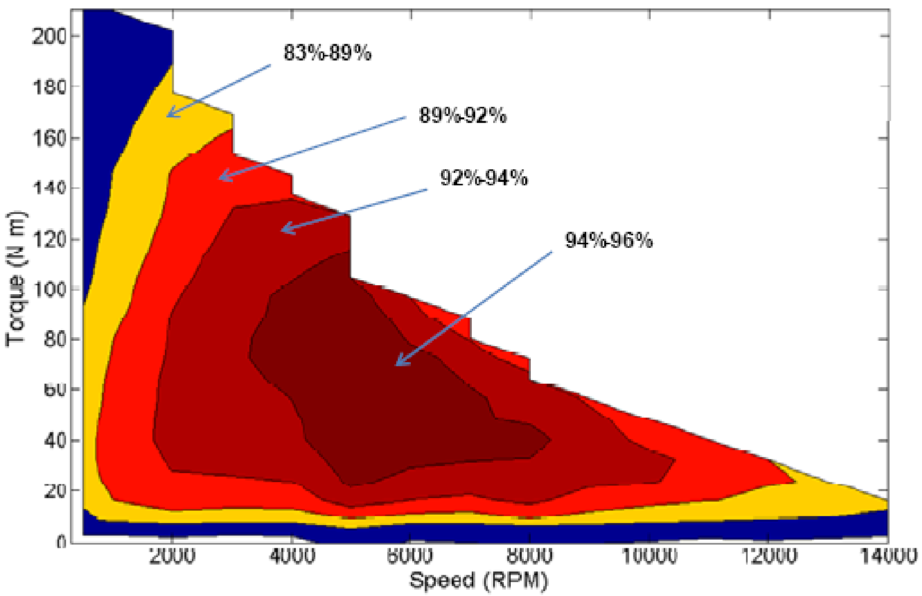
- The specifications for hybrid vehicle motors are challenging in terms of power density, efficiency and cost. This requires a comprehensive approach to advance the state of the art, including novel concepts to push past barriers.
- High speed is key to high power density
- High speed leads to higher electrical frequency
- Higher stator core and rotor losses
- On top of all these challenges, eliminating rare-earth permanent magnets makes the problem an order of magnitude more challenging

Project Objective (FY13/FY14)

Items	Specification
Max. Speed	14,000rpm
Peak Power	55kW @ 20% speed for 18sec
Maximum Current	400Arms
Cont. Power	30kW @ 20~100% speed @ Vdc=325
Efficiency	Refer to target efficiency map
Operating Voltage	200~450V (325V nominal)
Back EMF	<600Vpk line-to-line @ 100% speed
Torque Pulsation	<5% of Peak Torque @ any speed
Characteristic Current	< Maximum Current
Weight	≤35kg
Volume	≤9.7L
Cost @100k	≤$275
Ambient (outside housing) Operating Temperature	-40~140°C
Coolant inlet	105°C, <10LPM, 2psi drop, <20psi inlet
Minimum isolation impedance-phase terminal to GND	1Mohm

- Finalize tradeoff study to identify promising motor topologies and advanced materials
- Down-select and build/test promising concepts for 55kWpk non-rare earth motor to meet DOE specifications

Figure 1. Motor Efficiency Targets



Relevance

Developing a low-cost, high-performance advanced traction motor is a key enabler to meeting the 2020 technical targets for the electric traction system. Elimination of rare-earth permanent magnets is very strategic in terms of eliminating the uncertainty regarding sustainability of rare-earth magnets

Table 1. Technical Targets for Electric Traction System

	2010[a]	2015[b]	2020[b]
Cost, $/kW	<19	<12	<8
Specific power, kW/kg	>1.06	>1.2	>1.4
Power density, kW/L	>2.6	>3.5	>4.0
Efficiency (10%-100% speed at 20% rated torque)	>90%	>93%	>94%

[a] Based on a coolant with a maximum temperature of 90°C.

[b] Based on air or a coolant with a maximum temperature of 105°C.

[c] A cost target for an on-board charger will be developed and is expected to be available in 2010.

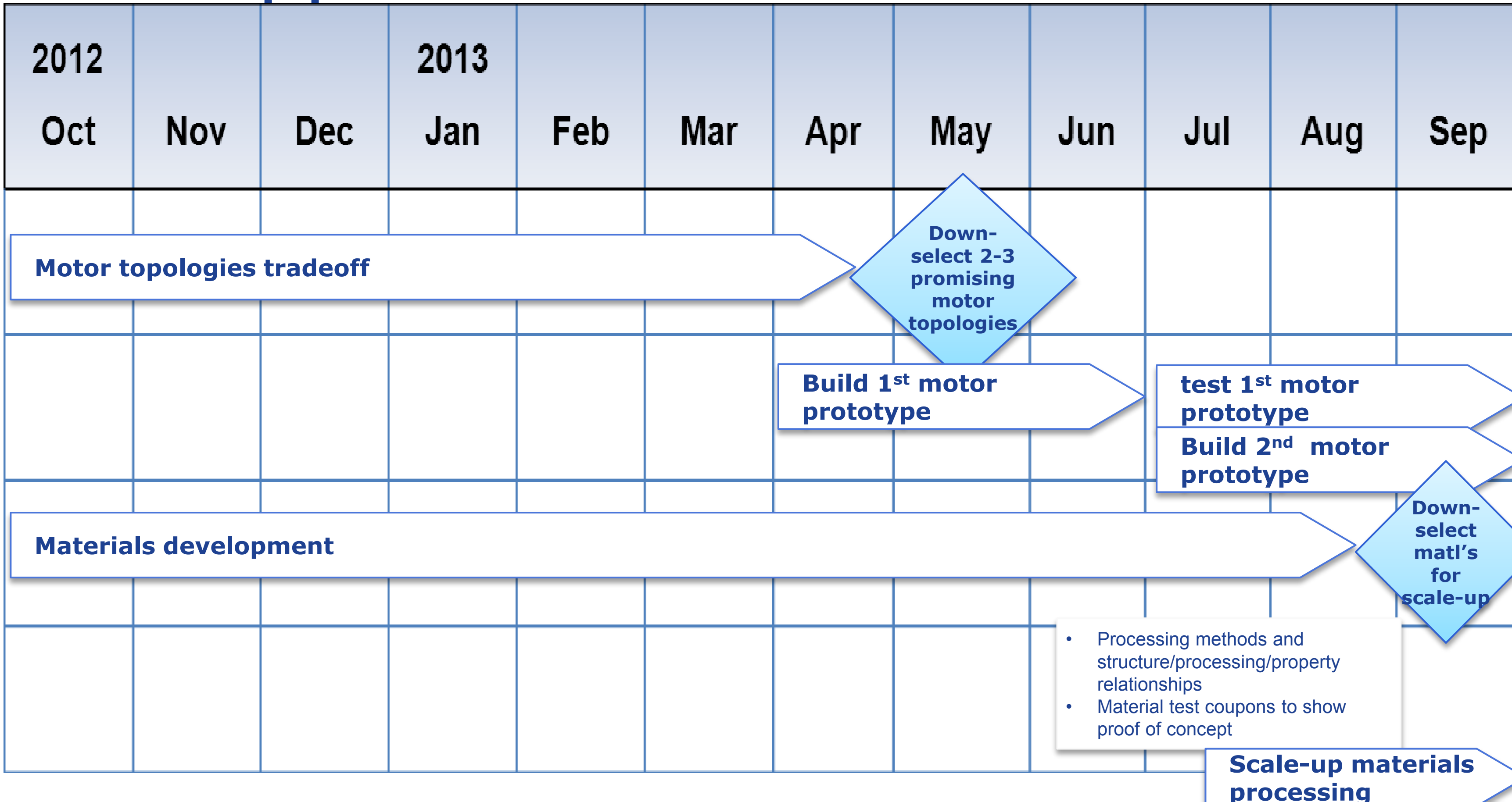
Project Uniqueness and Impacts

- The project proposes a very comprehensive approach in terms of identifying the technologies that will meet the required performance
- The project will explore various motor topologies; some include no magnets at all and some include non-rare earth magnets
- Some of the motor topologies use only conventional materials while others will be enabled by advanced materials that will be developed under the project
- Advanced materials including magnetic as well as electrical insulating materials will be developed to enable the motors to meet the required set of specifications
- Advanced motor controls and thermal management techniques will also be developed.
- By evaluating the wide range of motor topologies and advanced materials, down-selected topologies/materials are expected to meet the required set of specifications

Approach

- Perform tradeoff study of various motor topologies (≈10 topologies: some use conventional materials while others will be enabled by new materials)
- Identify promising scalable materials and produce coupons showing the expected properties (1 hard magnetic, 2 soft magnetic, 1 dielectric)
- Down-select promising topologies/materials
- Design/build/test 2-3 proof-of-principle motors
- Down-select final motor topology
- Design/build/test 3 identical motors as the key project deliverable(s)
- Develop cost model for the final motor

FY13 Approach and Milestones



Go No/Go Decision Point: The key go no/go decision point will be after the 3 down-selected motor prototypes are built and tested to determine base don test results how do they compare to the baseline IPM with rare-earth magnets. Testing of the 2nd prototype and the building of the 3rd prototype will take place in 4th quarter of 2013

Challenges/Barriers: The set of specifications is very challenging and eliminating rare-earth permanent magnets is a big hit in terms of torque density and efficiency

Accomplishments to Date

Motor accomplishments:

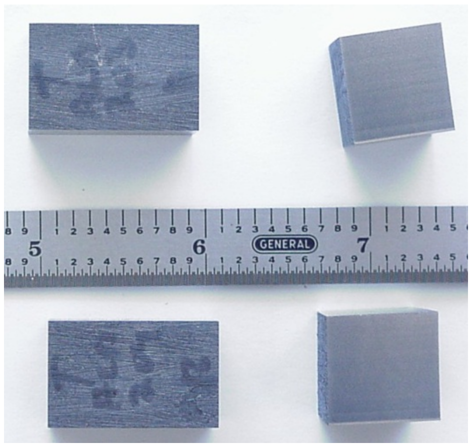
- Finalized the motor topologies that will be evaluated and done evaluating 9 of them
- Preliminary down-selection of 3 topologies that will be built and tested:
  - 1 has reduced rare-earth content
  - 1 has non-rare earth magnets
  - 1 has no magnets
- Identified the theoretical properties for the advanced materials to be developed and quantified their impact on some of the motor topologies
- All the contracts with our external partners are in place and technical collaboration already started

Materials accomplishments:

- Applied advanced manufacturing methods to non-rare earth permanent magnet materials and quantified processing factor dependence of key magnetic properties
- Completed first microstructural investigation GE-synthesized non-rare-earth Permanent magnets at Ames Laboratory
- Demonstrated higher tensile strength soft magnetic laminates with magnetic properties approaching those of Si-Steel
- Demonstrated stability of high temperature insulation materials at temperatures > 250 °C
- Performed initial studies on scalability of new materials for sub-scale prototype motor builds.

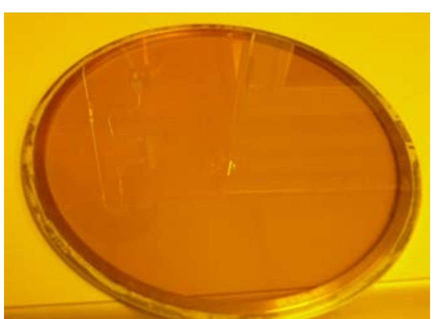
Materials accomplishments

Advanced processing of non-rare-earth permanent magnets



Higher tensile strength soft magnetic laminates

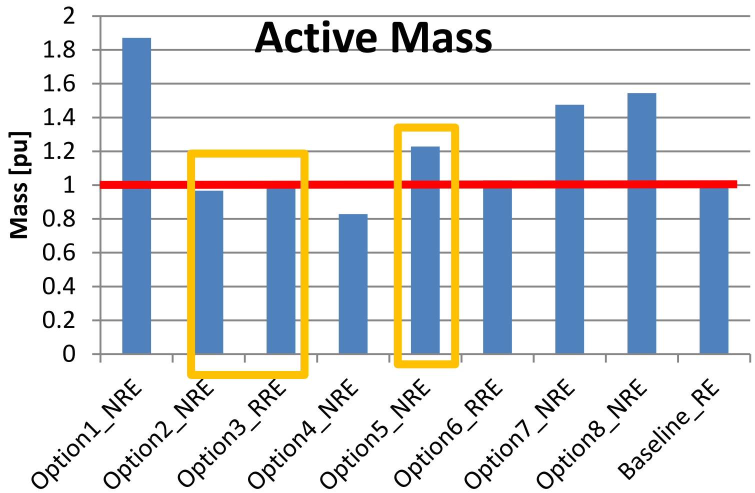
High temperature insulation

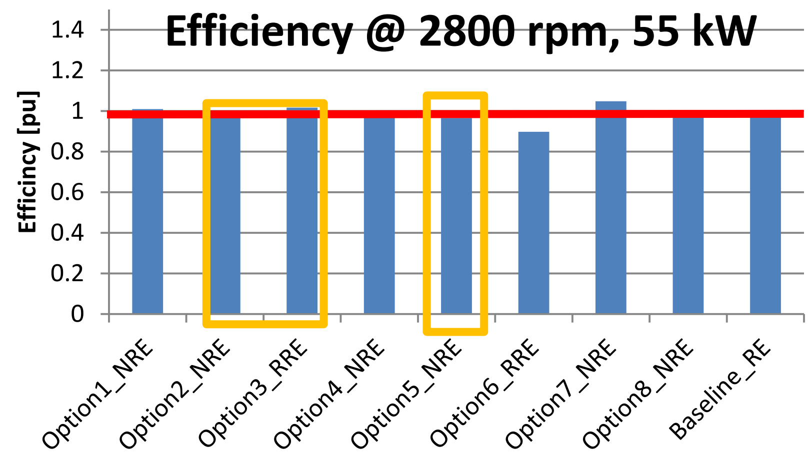


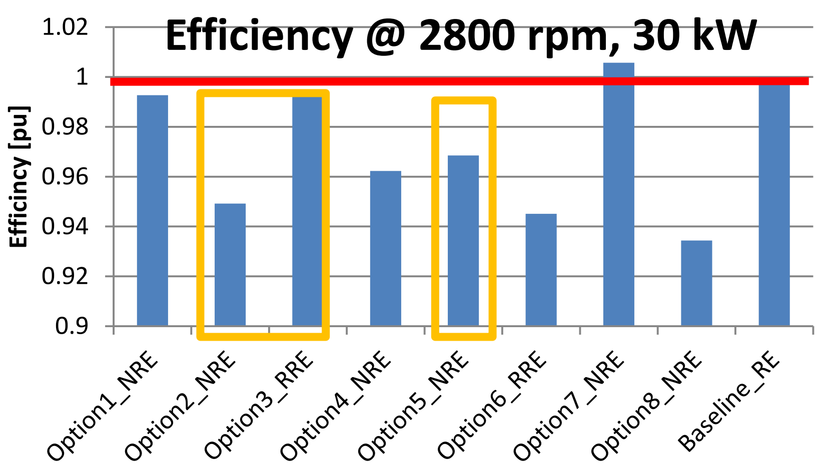
3” I.D. “Statorettes” manufactured to test performance of high temperature insulation

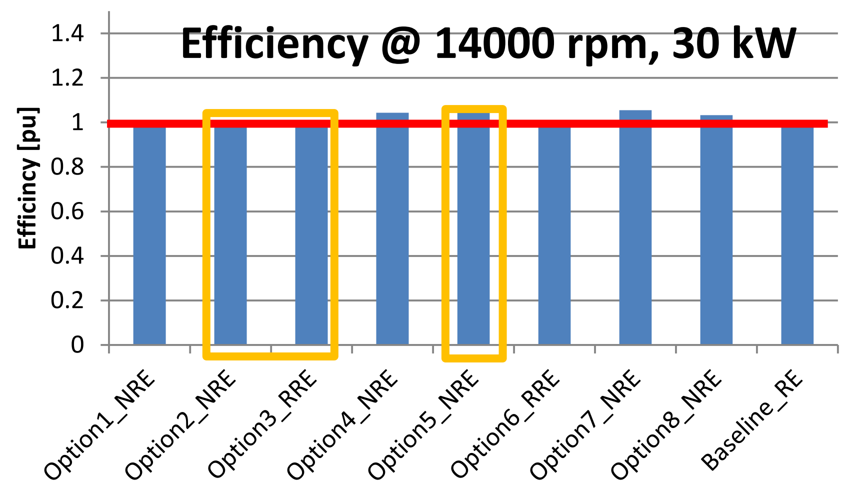
Motors Accomplishments

NRE: Non-Rare Earth
RRE: reduced Rare Earth
RE: Rare-Earth









Several motor topologies are promising in terms of power density and/or efficiency

Collaborations

Motor Development:

- North Carolina State University: Evaluation of motor topologies
- University of Akron: Evaluation of motor topologies
- University of Wisconsin: Evaluation of motor topologies
- NREL: Evaluation of thermal management schemes
- ORNL: Evaluation of motor topologies and materials

Materials Development:

- Ames Laboratory: High resolution microscopy of magnetic materials
- Arnold Magnetic Technologies: Specialized magnetic material processing and characterization

Proposed Work Beyond FY13

FY14

- Finish test proof-of-principle motors/materials
- Final selection of motor topology/materials based on test results of proof-of-principle motors
- Initiate design for final motor (s)

FY15

- Scaled manufacturing of selected materials
- Final motor build and test

Summary

- Significant progress made since last year
- 9 motor topologies fully evaluated
- 3 down-selected to build prototypes
- The first design is almost finalized and the build will be initiated shortly
- Impact of advanced materials on various motor topologies fully-quantified
- Test coupons of advanced motor materials have been manufactured and characterized
- Scalable manufacturing methods for advanced materials have been identified
- Improved performance has been quantified in soft magnetic laminates and high temperature insulation
- Contracts with all external partners in place and significant technical progress made with most of them