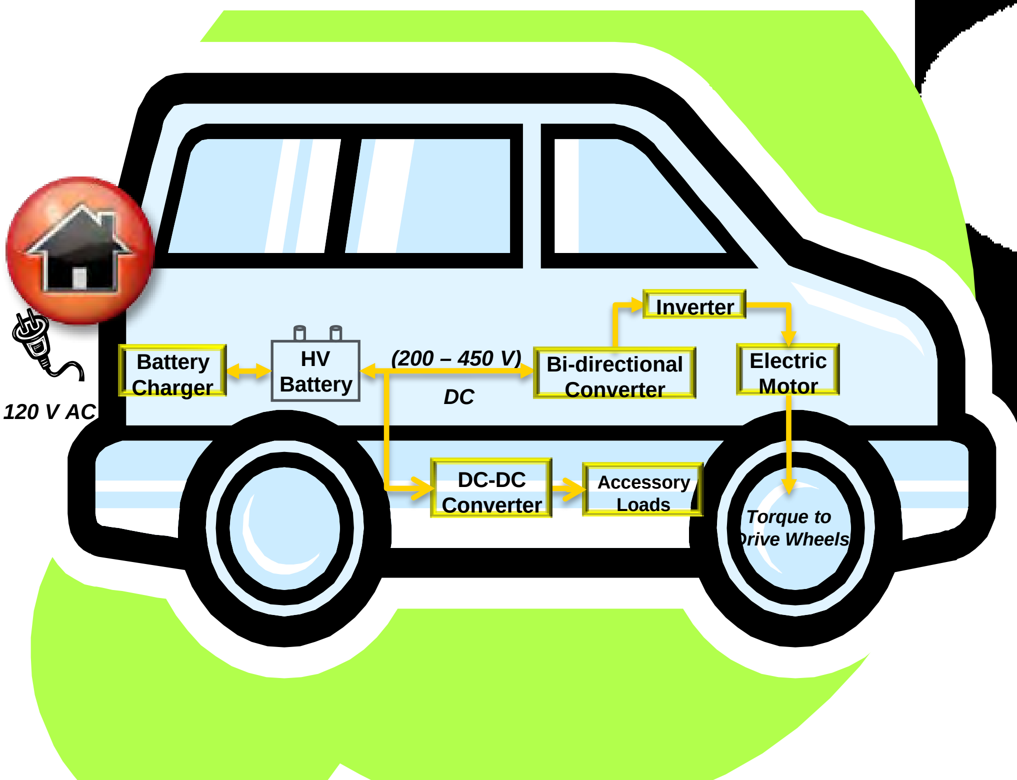
Advanced Power Electronics and Electric Motors R&D

Susan Rogers

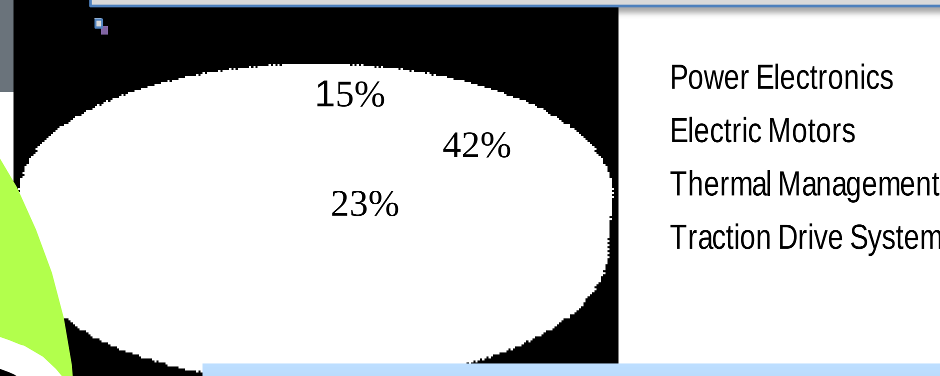
Advanced Power Electronics and Electrical Motors (APEEM)

CHARTER: Develop APEEM technologies to enable large market penetration of electric drive vehicles.



APEEM R&D Budget (FY 2011: $21.08M)

FY 2010: $22.295M
FY 2012 (Request): $48M



Requirements: 55 kW peak for 18 sec; 30 kW continuous; 15-year life

Technical Targets
Traction Drive System

Year	($/kW)	(kW/kg)	(kW/l)	Efficiency
2010	19	1.06	2.6	>90%
2015	12	1.2	3.5	>93%
2020	8	1.4	4	>94%

Program Flow Advances APEEM Technologies to the Marketplace

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Technical Target Input	Technology Development	Module Development
EE Tech Team	*National Laboratories*	*Industry*

Interactions with Others (e.g., IAPG, Office of Science, Solar, Wind)

Technical Target Input

- DOE
- Chrysler
- Ford
- General Motors

FreedomCAR & Fuel Partnership

Technology Development

- Ames Laboratory
- Argonne National Laboratory
- Oak Ridge National Laboratory
- Sandia National Laboratory
- National Renewable Energy Laboratory
- National Aeronautics and Space Administration
- National Institute of Standards and Technology
- Advanced Research Projects Agency (ARPA-E) Activities
- Small Business Innovative Research Grants (SBIR)
    - Phases I, II, & III

Module Development

- General Motors
- Delphi Automotive Systems
- GE Global Research

- American Recovery and Reinvestment Act (ARRA) Awards

Advancing Power Electronics and Electric Motors → More Fuel Efficient Vehicles on the Road

Power Electronics R&D

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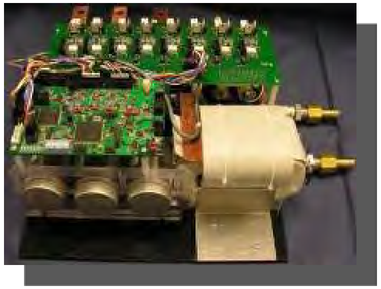
Research Focus Areas *(Reduce size, cost, and improve reliability)*	
New Topologies for Inverters and Converters	❑ Reduce capacitance need by 50-90% yielding inverter volume reduction of 20-35% ❑ Reduce part count by integrating functionality
Temperature – Tolerant Devices	❑ Wide Bandgap Semiconductors produce higher reliability, higher efficiency, and enable high-temperature operation ❑ Benchmarking state-of-the-art devices
Packaging	❑ Module packaging can reduce inverter size by 50% and cost by 40% ❑ Enable silicon devices to be used with high-temp coolant for cost savings of 25%, and enable use of air cooling ❑ Reduce stray inductance, improve reliability and enable module packaging options
Capacitors	❑ Reduce capacitor size by 25% and increase temperature limit ❑ Reduce inverter size by 10%
Vehicle Charging	❑ Focus on cost reduction

	Technical Targets		
Year	($/kW)	(kW/kg)	(kW/l)
2010	7.9	10.8	8.7
2015	5	12	12
2020	3.3	14.1	13.4



Current Source Inverter

Silicon-on-Insulator Chip (chip size 10x5 mm^2)

Wide Bandgap Semiconductors

Electric Motors R&D

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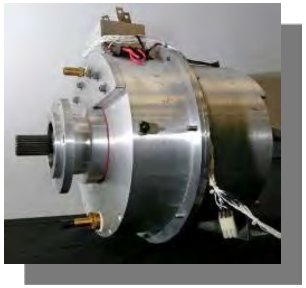
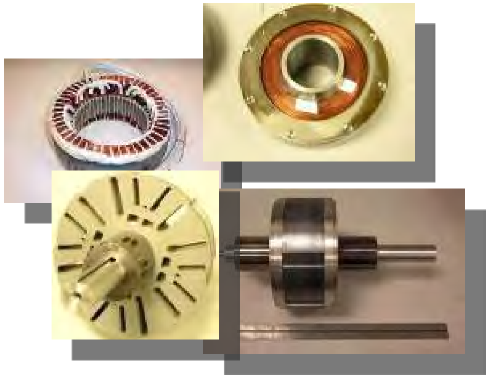
Research Focus Areas *(Reduce cost and maintain performance)*	
Permanent Magnet (PM) Motors	❑ Reduce cost by 75% - required to meet 2020 target ❑ Motor design optimization may reduce cost by 25% to 40%.
Magnet Materials	❑ Magnet material costs are 50% of 2015 target and 75% of 2020 target ❑ Reducing PM cost and increasing temperature capability could reduce motor cost by 5% to15%
Non-PM Motors	Non-PM motor technology yields the greatest opportunity for motor and system cost reduction: ❑ Could reduce motor cost by 30% ❑ Eliminating boost converter (required for IPM machines due to back emf) saves 20% in PE cost ❑ Optimized power factors of non-PM machines can result in up to 15% PE cost savings
New Materials	❑ New materials for laminations, cores, etc. could save 20% of motor cost

	Technical Targets		
Year	($/kW)	(kW/kg)	(kW/l)
2010	11.1	1.2	3.7
2015	7	1.3	5
2020	4.7	1.6	5.7



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



Addressing Rare Earth Issues

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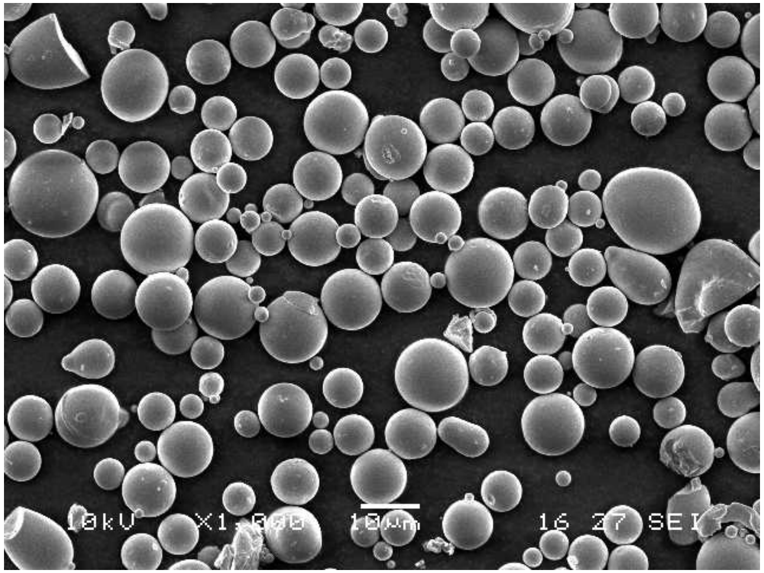
Ames National Laboratory (BREM – Beyond Rare Earth Magnets)

- Optimize the use of RE materials in PMs
  - Focus on magnet processing, composition, and high-temperature magnetic performance
- Develop high performance non-RE magnet materials for use in PM motors for vehicle applications
  - Builds on Office of Science fundamental research with a prospectus of monolithic and composite material systems



Magnet powders produced from gas atomization

Oak Ridge National Laboratory

- Alternative motor designs to reduce or eliminate the use of rare earth permanent magnets

National Renewable Energy Laboratory

- Motor cooling technologies to reduce size and cost of motor designs reducing or eliminating rare earth permanent magnets

Industry Led R&D Activity

- GE Global Research
  - Improving interior permanent magnet motor designs to more fully utilize permanent magnet flux
  - Focus on improving the hard and soft magnetic material characteristics

New BAA topic for research and development of non-rare earth magnet motor technologies

Thermal Management R&D

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Research Focus Areas (*Reduce cost, increase power density, improve reliability*)	
Thermal System Integration	❑ Define thermal requirements and identify thermal solutions to enable integration with module packaging and reduce inverter size by 50% and cost by 40%. ❑ Link thermal technologies to electric traction drive subsystems; provides system-wide thermal solutions at reduced cost.
Heat Transfer Technologies	❑ Develop and demonstrate low cost, high efficiency heat transfer technologies to increase power density and lower cost by up to 30% over 2010 targets. ❑ Characterize thermal performance of candidate technologies. ❑ Develop fundamental thermal models to understand mechanisms of heat transfer enhancements.
Thermal Stress and Reliability	❑ Develop advanced predictive thermal stress and reliability models for bonded interfaces and electrical interconnects to ensure reliability of new designs aimed at lower cost, higher power density and specific power.

Heat Exchanger R_{th} (C/W)

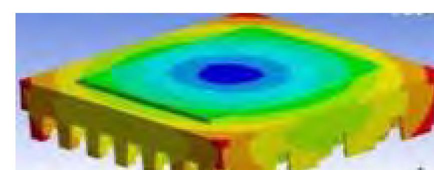
Air

Finned

Jet

Heat Exchanger and Package Thermal Performance [example: IGBT Heat Flux (W/cm^2)]

40°C Coolant In 70°C Coolant In 105°C Coolant In



Traction Drive System R&D

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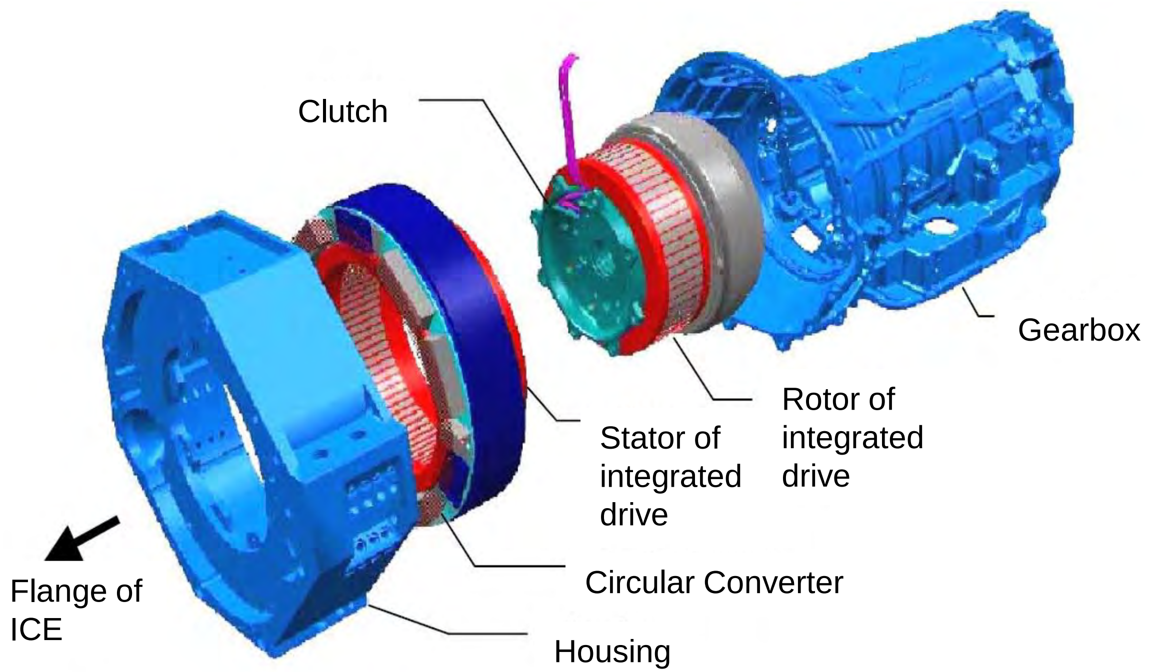
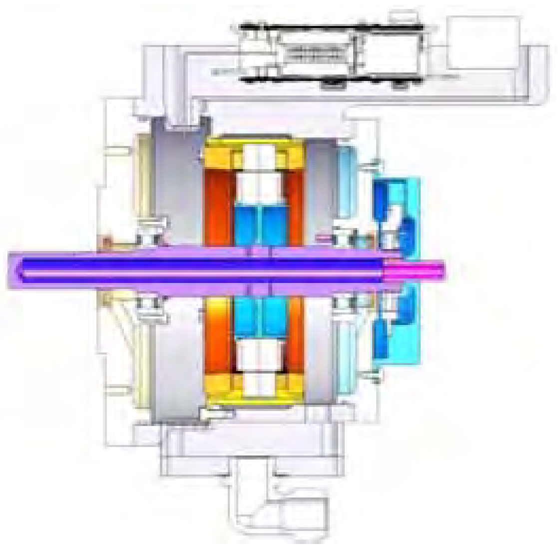
Research Focus Areas	
Focus Area	**Benefits**
Innovative Systems Design	Modular and integrated solutions to meet size, weight, and cost 2015 and 2020 targets for drive system.
Benchmarking	Vital to program planning and project performance activities.





Integrated Motor and Inverter Concept

APEEM 2010-11 R&D Accomplishments

Power Electronics

- 55kW Current Source Inverter developed, built, and tested by ORNL; achieved a 90% reduction in capacitor size resulting in cost reduction of 25% & volume reduction of 33%.
- High temperature traction drive inverter developed by Delphi ; incorporated double sided cooling & advanced packaging concepts.

Electric Motors

- Beyond Rare Earth Magnets (BREM) research; identified two pathways to develop magnets without rare earth elements using collaborative web-based tools, biannual workshops, and project-specific databases.

Thermal Management

- Developed a passive pump-less cooling system; reduced power module thermal resistance by over 50%.

Traction Drive System

- Industrial effort with GM developed a traction drive system that achieved $19/kW, >90% efficiency, 1.06 kW/Kg, and 2.6 kW/L

Federal Collaborations

- **Inter-APEEM Program with NREL and ORNL**
  - Close coordination in key focus areas
- **Vehicle Technologies Program**
  - Propulsion Materials Program (Poster Session)
    - ORNL - Low-Cost Direct Bonded Aluminum Substrates
    - ORNL - Flexible Substrates and Circuitry for Automotive Power Electronics
    - ORNL - Non-Rare Earth Magnetic Materials
    - ORNL - Materials Compatibility of Power Electronics
    - ORNL - Materials by Design – Solder Joint of High Performance Power Electronics
  - Vehicle and Systems Simulation and Testing Program
    - INEL – Performance evaluation and degradation assessment of "end of life" traction drive systems
    - ORNL – Wireless power integration into vehicle
  - Hybrid Electric Systems Team
    - NREL - Combining fluid loops in electric drive vehicles
- **Department of Energy**
  - Office of Science - Results from activities used in magnet material work
  - Office of Electricity - Grid Interaction Tech Team
- **Other Federal Agencies**
  - IAPG - Coordination in capacitors and wide bandgap devices
  - NIST - Reliability efforts
  - NASA - Wide bandgap development

FY 2011 Reports and Publications

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

- **FY 2010 Advanced Power Electronics and Electric Motors Annual Progress Report**
  http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/2010_apeem_report.pdf
- **Electrical and Electronics Technical Team Roadmap**
  http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/eett_roadmap_12-7-10.pdf
- **Vehicle Technologies Multi-year Program Plan 2011-2015**; Section 2.2.1
  http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/vt_mypp_2011-2015.pdf
- **ORNL/TM-2011/73, *Final Report on Assessment of Motor Technologies for Traction Drives of Hybrid and Electric Vehicles***, by R. R. Fessler published March 10, 2011.
- **ORNL/TM-2010/253, *Evaluation of the 2010 Toyota Prius Hybrid Synergy Drive System***, by T. A. Burress, S. L. Campbell, C. L. Coomer, C. W. Ayers, A. a. Wereszczak, J. P. Cunningham, L. D. Marlino, L. E. Seiber, and H.-T. Lin published March 7, 2011.

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