U.S. Department of Energy
Energy Efficiency and Renewable Energy

vehicle technologies program

Advanced Power Electronics and Electric Machines

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2009 DOE Hydrogen and Vehicle Technologies Programs Annual Merit Review

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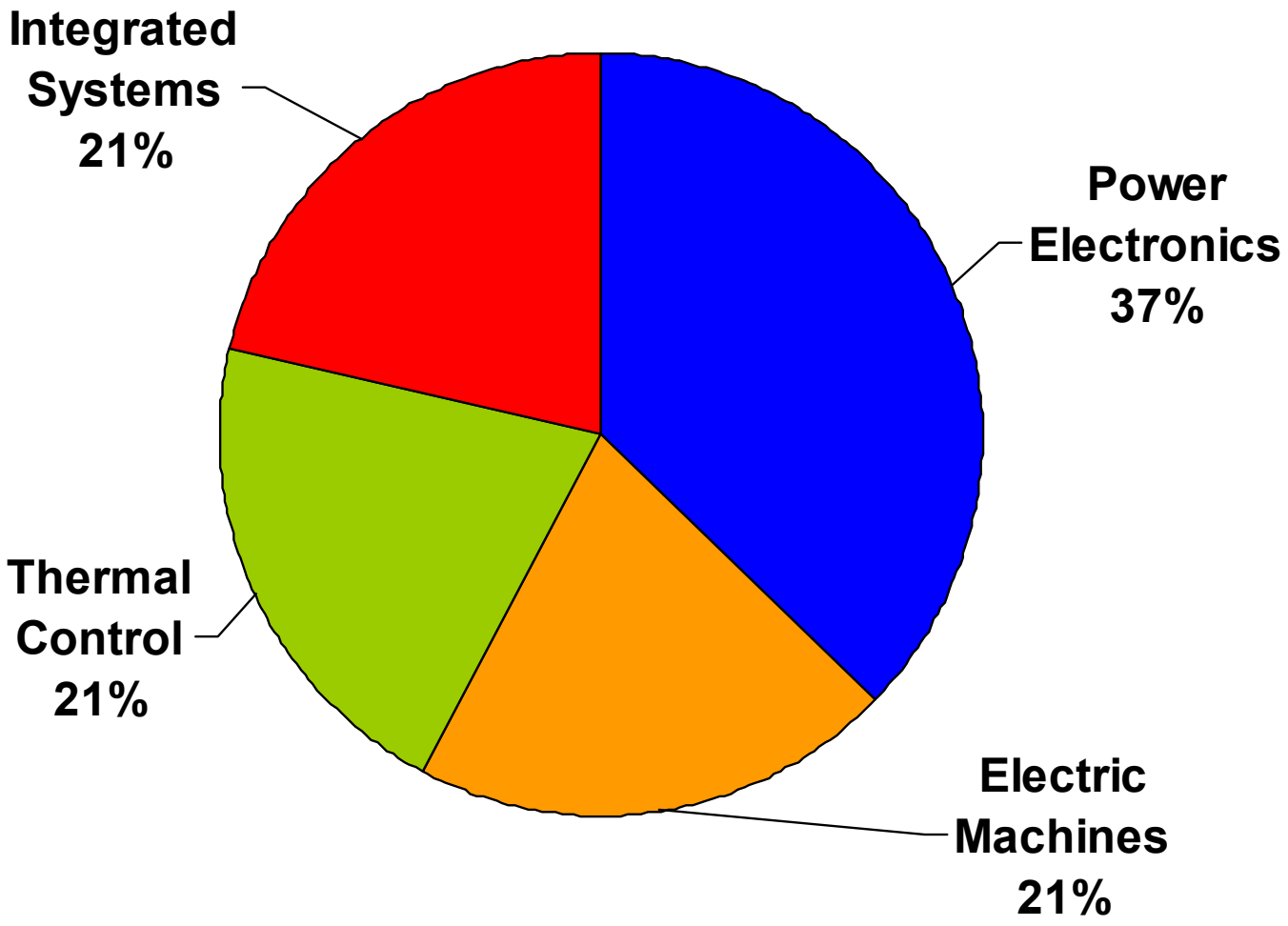
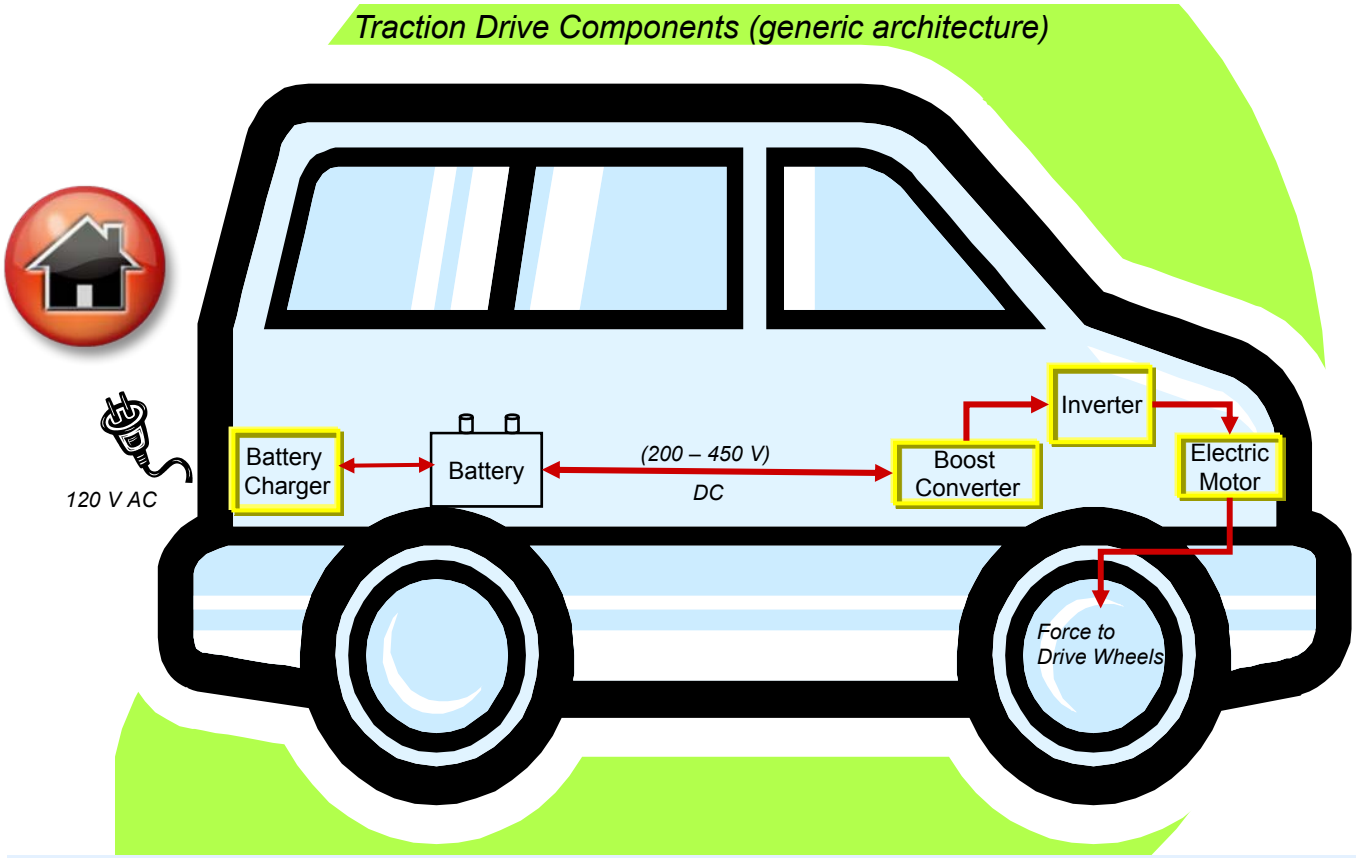
FY09 R&D Budget



FY09 Budget: $17,358,000

APEEM Components are Critical and Unique to Electrified-Driven Vehicles



Current power electronics and electric machine technologies must advance to achieve lower cost, smaller and lighter footprints, and higher efficiency to meet marketplace demands.

Traction Drive Components
(varies within vehicle architectures)

- ***Battery charger*** - plug-in vehicles require a battery charger.
- ***Boost converter*** – step up the battery voltage to a higher output voltage when the electronic circuit requires a higher operating voltage than the battery can supply.
- ***Inverter*** – convert direct current (DC) to alternating current (AC) to provide phased power for vehicle traction motors and generators.
- ***Electric motor*** - provide power for driving.

Power Management
(varies within vehicle architectures)

- ***Bi-directional DC-DC converter*** – step up or step down the high battery voltage to move power among vehicle buses to operate accessories, lighting, air conditioning, brake assist, power steering, etc.

APEEM Research Targets, Challenges, and Focus Areas

Reduce Dependence on Oil
Via Electrification of Vehicle Drives

Requirements: 55 kW peak for 18 sec; 30 kW continuous; 15-year life; coolant (105°C or air)

Technology Targets

Year	Traction Drive System				Power Electronics			Motors		
	($/kW)	(kW/kg)	(kW/l)	Efficiency	($/kW)	(kW/kg)	(kW/l)	($/kW)	(kW/kg)	(kW/l)
2010	19	1.06	2.6	>90%	7.9	10.8	8.7	11.1	1.2	3.7
2015	12	1.2	3.5	>93%	5	12	12	7	1.3	5
2020	8	1.4	4	>94%	3.3	14.1	13.4	4.7	1.6	5.7

Challenges

size cost weight

Research Focus Areas

Power Electronics
- inverters and converters
- innovative topologies
- packaging
- temperature-tolerant devices
- capacitors

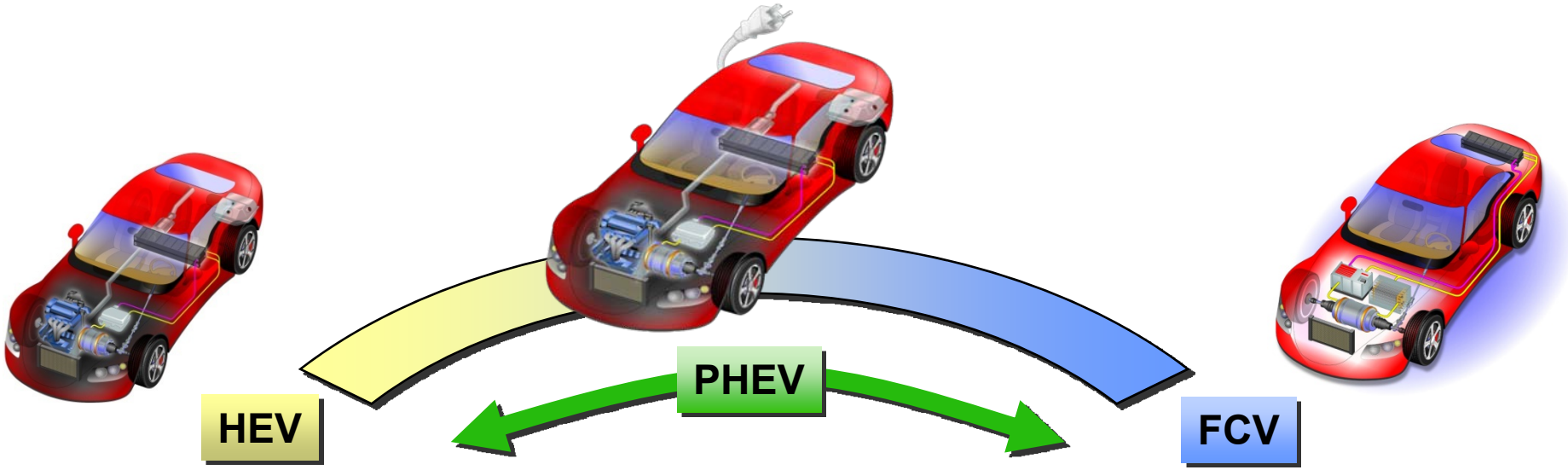
Motors
- permanent magnet (PM) motors
- high performance non-PM motors
- permanent magnets

PEEM Thermal Control
- heat transfer techniques
- materials
- area enhancement
- alternative coolants

Integrated Traction Drive System
- benchmarking technologies
- innovative system designs

PEEM Activity Covers the Full Range of Vehicle Electrification Applications

APEEM is a critical system of all HEVs/PHEVs/FCVs

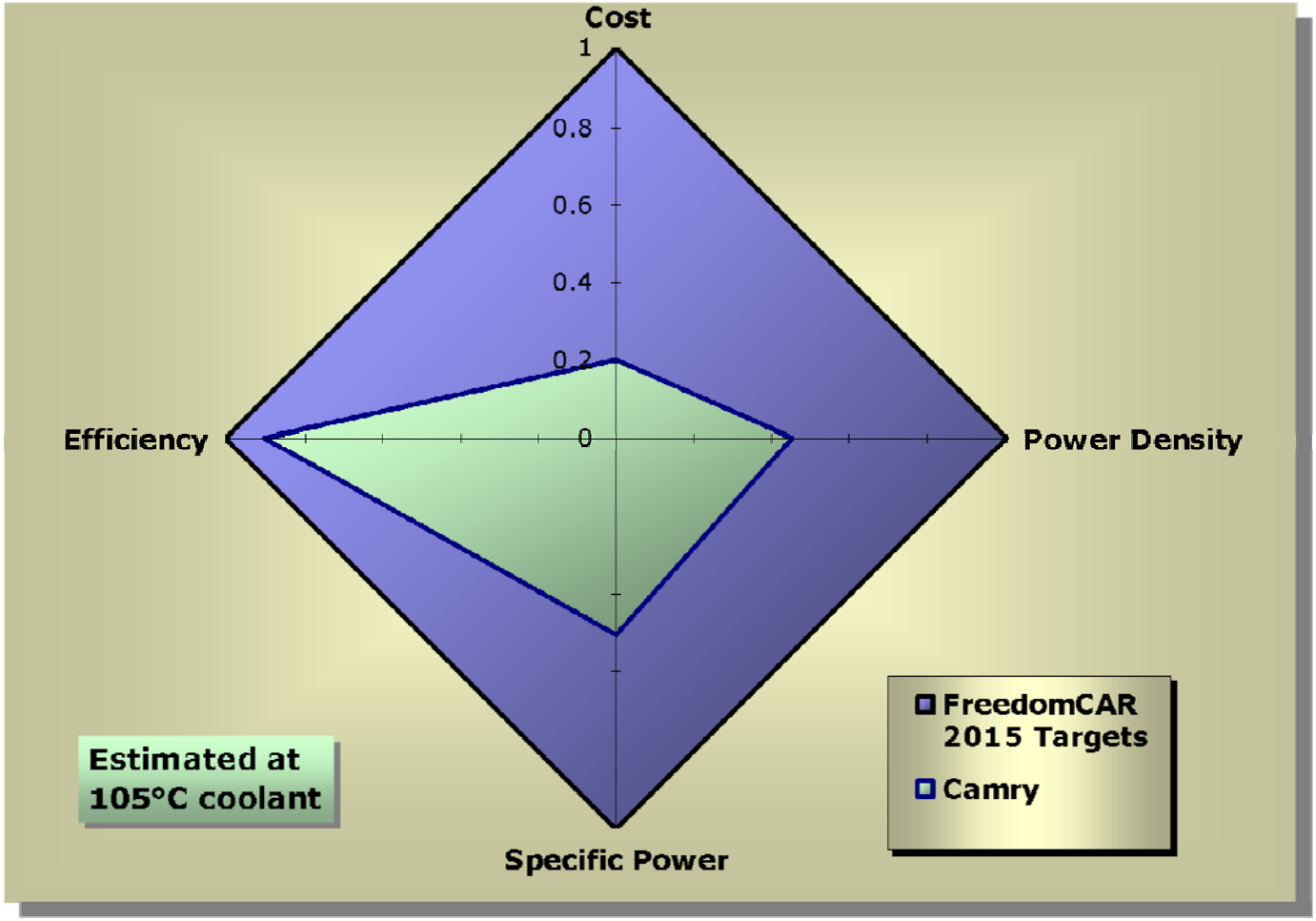


Blended ICE/Electric
- Power requirement ≥ 55 kW
- Parallel architecture
- Intermittent short operation

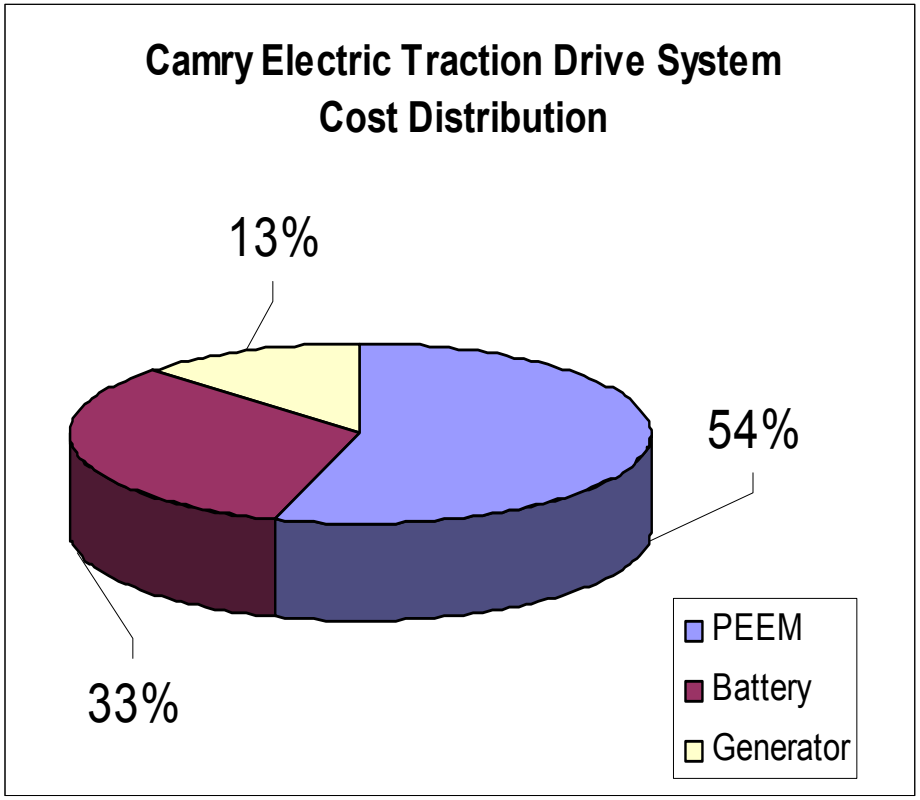
Sized for Electric Only
- Power required increases (up to 200 kW)
- Series architecture
- Always “on”

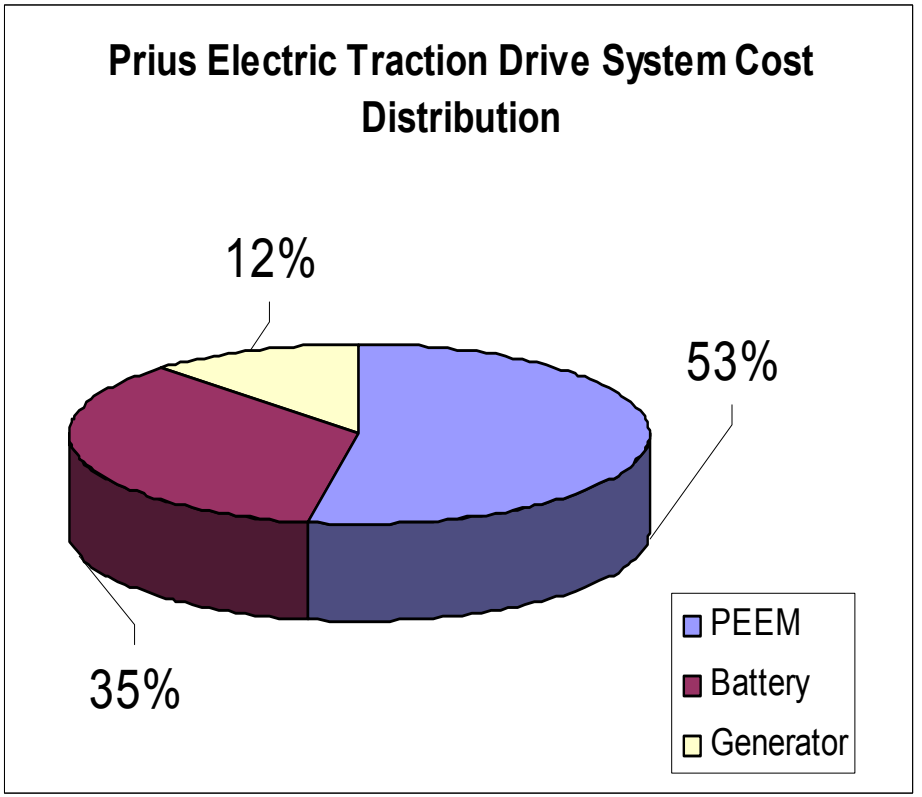
PHEV Position in Spectrum Depends on Design

Today's On-Road Technology Shows That Significant Challenges Exist



PEEM is Important Cost Component in Current HEVs





Sources:
1. K.G. Duleep, Technology and Cost of MY 2007 Toyota Camry HEV, ORNL/TM-2007/132, 2007
2. Rick McGill's Toyota, Knoxville, TN

FY09 Power Electronics Focus Responsive to Evolving Needs

- Initially power electronics (PE) focus was primarily on voltage source inverters
- Use of high-speed IPMs necessitated a boost converter
  - also aided in reducing current requirements and Si costs
- PHEV application added charging function
- Desire to reduce cost by eliminating separate cooling loop led to consideration of high-temperature coolants
- Elevated temperature operation led to increased capacitor requirements

FY09 Emphasis

- **Reduce Cost and Volume**
  - Eliminate separate boost converter
  - Reduce capacitor size
- **Enable High-Temperature Operation**
  - Packages and components
- **Charging System for PHEVs**

FY09 Approaches

- **Inverter Topologies**
  - Integrate multiple functionality into one unit
  - Minimize capacitance need
- **Inverter Packaging**
  - Design to use high-temp coolant
- **High-Temperature Components**
  - Gate drives, capacitors

FY09 Electrical Machines Focus Builds on Evolving Path

- **Initially induction motor favored due to cost consideration**
- **As volume became greater consideration IPM became motor choice because of high power density and efficiency**
- **PM cost and rare earth material supply uncertainty has resulted in reexamination of IPM**

FY09 Emphasis

- **Reduce motor cost and integrate voltage boost (which also reduces PE cost)**

FY09 Approaches

- **High-Speed designs using no PM material**
  - Assess potential for eliminating the boost
  - Eliminate cost/supply security concern of PM
  - High-speed results in smaller motor which due to lack of PMs grows
- **High performance IPM**
- **Magnet effort to reduce cost and improve temperature capability**

FY09 Thermal Control Focus Responsive to Developing Needs

- **Excessive heat can degrade the performance, life, and reliability of power electronic components**
- **Advanced thermal control technologies are critical to enabling higher power densities and lower system cost**

FY09 Emphasis

- Enable increased power density and lower system cost
- Increase the rate of heat transfer
- Decrease thermal resistance
- Evaluate impacts on life and reliability early in the development process

FY09 Approaches

- Conduct analysis of thermal stress and fatigue life of APEEM packages
- Characterize and develop advanced liquid cooling technologies
- Complete assessment of state-of-the-art TIMs
- Demonstrate advanced air-cooling heat transfer and system level performance

FY09 Integrated Systems Focus Moving to Demo Meeting 2010 Targets

FY09 Emphasis

- Document performance of current state-of-art PEEM systems at end-of-life
- Develop integrated traction drive system meeting 2010 targets

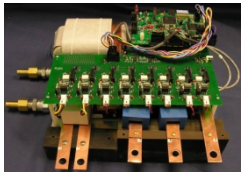
FY09 Approach

- Benchmark end-of-life Prius traction drive system and determine performance degradation
- Incorporate PE, EM, and thermal control advances into traction drive system design

Accomplishments

Power Electronics: Current Source Inverter

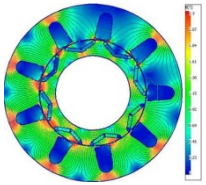
- A prototype of a 55kW CSI was successfully built and tested
  - Incorporated boost function
  - Reduced capacitor requirements from 2000uF to 195uF



Current Source Inverter

Electric Motors: Application of Concentrated Windings to Motors with Interior PMs

- Performed analysis and simulation of multiple IPM machines with concentrated and distributed winding
  - Determined design advantages ie. lower losses, higher power and increased torque for achieving high performance IPM machine designs



9/8 IPM one axis of symmetry

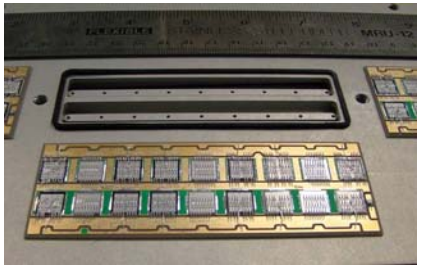
Lexus Power Control Unit

Systems: Benchmarking

- Completed module and component level evaluation of the Lexus LS600H
  - Through the analysis and recognition of technical trends within the marketplace more meaningful projects can be developed within the program.

Thermal Control: Low thermal-resistance structure for jet impingement cooling of power electronics

- Completed development and testing of “Low Thermal-Resistance Power Module Assembly” integrated with Semikron inverter.



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Program Flow Advances APEEM Technologies to the Marketplace

Advancing Power Electronics and Electric Machines

More Fuel Efficient Vehicles on the Road

- Chrysler
- Ford
- General Motors

FreedomCAR & Fuel Partnership

- Ames Laboratory
- Argonne National Laboratory
- Oak Ridge National Laboratory
- Sandia National Laboratory
- National Renewable Energy Laboratory

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Motors
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APEEM Thermal Control
- heat transfer techniques
- materials
- area enhancement

Integrated Traction Drive System
- benchmarking technologies

- General Motors
- Delphi Automotive Systems
- Virginia Tech University
- U.S. Hybrid
- GE Global

Power Electronics
- inverters and converters

Motors
- permanent magnet (PM) motors

Integrated Traction Drive System
- innovative system designs

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

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