FY09 R&D Budget

FY09 Budget: $17,358,000

- Power Electronics: 37%
- Electric Machines: 21%
- Thermal Control: 21%
- Integrated Systems: 21%
APEEM Components are Critical and Unique to Electrified-Driven Vehicles

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.

Current power electronics and electric machine technologies must advance to achieve lower cost, smaller and lighter footprints, and higher efficiency to meet marketplace demands.
### APEEM Research Targets, Challenges, and Focus Areas

#### Reduce Dependence on Oil

*Via Electrification of Vehicle Drives*

#### Technology Targets

<table>
<thead>
<tr>
<th>Year</th>
<th>Traction Drive System</th>
<th>Power Electronics</th>
<th>Motors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>($/kW)</td>
<td>(kW/kg)</td>
<td>(kW/l)</td>
</tr>
<tr>
<td>2010</td>
<td>19</td>
<td>1.06</td>
<td>2.6</td>
</tr>
<tr>
<td>2015</td>
<td>12</td>
<td>1.2</td>
<td>3.5</td>
</tr>
<tr>
<td>2020</td>
<td>8</td>
<td>1.4</td>
<td>4</td>
</tr>
</tbody>
</table>

#### 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

### Requirements:

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

### References:

- [U.S. Department of Energy](https://www.energy.gov)
- [Energy Efficiency and Renewable Energy](https://www.energy.gov/energy-efficiency)

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**Year**

- **2010**
- **2015**
- **2020**
APEEM is a critical system of all HEVs/PHEVs/FCVs

Blended ICE/Electric
- Power requirement $\geq$ 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

Estimated at 105°C coolant
PEEM is Important Cost Component in Current HEVs

Camry Electric Traction Drive System Cost Distribution

- PEEM: 33%
- Battery: 54%
- Generator: 13%

Prius Electric Traction Drive System Cost Distribution

- PEEM: 35%
- Battery: 53%
- Generator: 12%

Sources:
2. Rick McGill's Toyota, Knoxville, TN
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
• 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
• 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

**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

**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.
Program Flow Advances APEEM Technologies to the Marketplace

Advancing Power Electronics and Electric Machines

- Chrysler
- Ford
- General Motors

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

Power Electronics
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APEEM Thermal Control
- heat transfer techniques
- materials
- area enhancement

Integrated Traction Drive System
- benchmarking technologies

More Fuel Efficient Vehicles on the Road

- 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
EE Tech Team

Technology Development
National Laboratories

Module Development
Industry

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