Advanced Power Electronics & Electric Motors R&D Overview

May 15, 2012
APEEM Charter & Budget

MISSION:
Develop Advanced Power Electronics & Electric Motor technologies to accelerate market penetration of hybrid & electric vehicles.

APEEM technologies must be:
• affordable
• smaller & lighter
• more efficient

FY 2012 Budget:
- Power Electronics: 35%
- Electric Motors: 25%
- Thermal Management: 21%
- Traction Drive System: 10%
- New Solicitation: 9%

FY 2011 & 2012 Budget:
- FY 2011: $22.4M
- FY 2012: $28.8M

FY 2015 Goal: Reduce cost of electric drive technologies. Demonstrate a cost of $12/ kW through data, simulation & modeling.
Hybrid and Electric Systems
David Howell, Team Lead

Vehicle Systems
Advanced Power Electronics & Electric Motors
Susan Rogers & Steven Boyd

Energy Storage

National Laboratories
Academia
U.S. DRIVE
DOE APEEM
Federal Agencies
Industry
APEEM Collaboration

- Department of Energy
- U.S. DRIVE Electrical & Electronics Tech Team
- National Laboratories
- Other Federal Agencies & IAPG
- Industry
- Universities
Traction Drive Requirements: 55 kW peak power for 18 sec; 30 kW continuous power; 15-year life

### Technical Targets

<table>
<thead>
<tr>
<th>Year</th>
<th>Cost ($/kW)</th>
<th>Specific Power (kW/kg)</th>
<th>Power Density (kW/l)</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010*</td>
<td>19</td>
<td>1.06</td>
<td>2.6</td>
<td>&gt;90%</td>
</tr>
<tr>
<td>2012</td>
<td>17</td>
<td>1.08</td>
<td>3.0</td>
<td>&gt;91%</td>
</tr>
<tr>
<td>2015</td>
<td>12</td>
<td>1.2</td>
<td>3.5</td>
<td>&gt;93%</td>
</tr>
</tbody>
</table>

* 2010 traction drive system cost target was achieved with development of the GM integrated traction drive system project; 2015 weight and size targets were also met.

### Power Electronics

<table>
<thead>
<tr>
<th></th>
<th>($/kW)</th>
<th>(kW/kg)</th>
<th>(kW/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>7.9</td>
<td>10.8</td>
<td>8.7</td>
</tr>
<tr>
<td>2012</td>
<td>7</td>
<td>11.2</td>
<td>10</td>
</tr>
<tr>
<td>2015</td>
<td>5</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

### Electric Motors

<table>
<thead>
<tr>
<th></th>
<th>($/kW)</th>
<th>(kW/kg)</th>
<th>(kW/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>11.1</td>
<td>1.2</td>
<td>3.7</td>
</tr>
<tr>
<td>2012</td>
<td>10</td>
<td>1.24</td>
<td>4</td>
</tr>
<tr>
<td>2015</td>
<td>7</td>
<td>1.3</td>
<td>5</td>
</tr>
</tbody>
</table>
Achieving 2015 Traction Drive Cost Target

- **2010 Base Cost**
  - EM Active Material (magnets, copper, steel)
  - Power Module
  - Capacitors
  - Misc. Material
  - Manufacturing

- **Cost ($/kW)**
  - $35/kW
  - $12/kW

- **Cost Breakdown**
  - Reduce motor losses, eliminate need for rare earth PMs, improve thermal management
  - High-temperature solutions using WBG, improve power electronics performance, integrate functionality, improve thermal management
  - Reduce capacitance required, increase capacitor performance
  - New architectures that reduce part count and material costs, increase efficiency
  - Reduce part count, simplify manufacturing

---

**Note:** The diagram illustrates the cost breakdown of various components in achieving the 2015 traction drive cost target. Each component is represented by a colored bar, indicating the cost per unit ($/kW). The target is set at $12/kW for 2015, aiming to reduce costs significantly from the 2010 base cost of $35/kW.
APEEM Research & Focus Areas

**TRL 4 & 5**
- Traction Drive System
  - Technology benchmarking
  - Innovative system designs

**TRL 2 & 3**
- Power Electronics
  - Wide bandgap devices
  - Capacitors
  - Electrical architectures
  - Packaging
  - Vehicle charging

**TRL 2 & 3**
- Electric Motors
  - Non-permanent magnet (PM) motors
  - PM motors
  - New magnetic materials
  - Motor materials

**TRL 2 to 5**
- Thermal Management
  - Heat transfer technologies
  - Thermal stress and reliability
  - Thermal systems integration

R&D required in all areas to achieve targets
Technology benchmarking

Testing, evaluation, and assessments provide current technology status and trajectory as motivation for setting R&D priorities.

Innovative system designs

Modular and integrated solutions to meet 2015 and 2020 size, weight, and cost targets.

Key to achieving 2020 targets
APEEM Power Electronics R&D

Electrical Architecture

Cost, performance, weight & volume
- Reduce capacitance → reduces volume & cost
- Integrate functions → reduces size & cost; improve reliability
- Reduce Si content → reduces cost

Packaging

Volume, cost & thermal management
- Device level → improves reliability & performance; enable high temperature operation
- Module level → reduces cost & size; improve efficiency

WBGs → high temperature operation

Capacitors

High-temperature capability & cost
- Improves reliability & volume

Wide Bandgap Devices

Optimal utilization of ‘next generation’ devices
- Improves reliability & efficiency
- Enables high-temperature operation
- Reduces volume & weight

Charging

Diminish vehicle impact
- Reduce cost & weight

Reduce cost and size while enhancing efficiency
Non-permanent magnet (PM) motors

Cost, performance, weight & volume
- Eliminate PMs → reduce cost
- System level improvements → enable PE cost reduction

PM motors

Cost & performance
- Design improvements → reduce magnets required; enable use of new magnetic materials

Magnetic materials

Cost Reduction
- Stronger magnets → less magnetic material
- Higher-speed motors → less materials
- Increase temperature capability

New materials

Cost & efficiency
- Increase temperature capability:
  - laminations
  - insulation
  - potting

**Improve motor designs and eliminate rare earth magnets to reduce cost**
APEEM Thermal Management

Heat Transfer Technologies
- Develop, demonstrate and characterize performance of heat transfer technologies and interface materials → Results feed Thermal Systems Integration activities

Thermal Stress and Reliability
- Develop predictive thermal stress and reliability models
- Guide research decisions to reduce technology development time
- Develop technologies that achieve reliability and lifetime goals → Improve reliability

Thermal Systems Integration
- Confirm thermal research objectives and define thermal requirements
- Identify and facilitate thermal solutions for traction drive system
- Develop & characterize thermal technologies components
- Enable integrated vehicle thermal management

Reduce size, weight and cost

Improve reliability, and reduce size, weight and cost
Challenges

- Cost
- Packaging
- Systems Integration
- Reliability

Traction Drive System

- Cost
- Packaging
- Efficiency
- Reliability

Power Electronics

- Cost
- Packaging
- Efficiency
- Reliability

Electric Motors

- Cost
  - Rare Earth Magnets
- Efficiency
- Power Density
- Manufacturing
- Thermal Limitations

Thermal Management

- Cost
- Reliability
- Size and Weight
- Thermal Stress

Cost reduction required in every area
Commercialization Activities
Existing Vehicle/Product Line

- **Semikron Inverter Power Module**
  - Device level packaging innovations
    - reduced inverter cost and size

- **Ballard DC to DC Converter**
  - Converter design improvements
    - increased efficiency and reduced cost

- **Semikron Power Device Attachment**
  - Sintering technology achieved
    - higher reliability; used in all Semikron power modules

- **Liquid-Cooled Heat Exchanger**
  - New pin-fin shape improved
    - thermal performance
Commercialization Activities
Existing Vehicle/Product Line

- **Injection Molded Magnets**
  - Developed bonded magnets used in traction motor for cost reduction

- **Brushless, External Field Coil Motor Architecture**
  - Improved performance and decreased operating costs by adapting electric drive technology for vehicle alternators

GM Fuel Cell Vehicle

Fleet vehicles
Commercialization Activities
Future Vehicle Applications

- **Wide Bandgap (WBG) Performance Characterization**
  - Test results provided to manufacturers; enables performance improvements in packaging and WGB devices
  - Database of test results available to public

- **High Temperature Inverter**
  - Characterized interface material
  - Modeled thermal performance
  - Characterized advanced heat exchanger
Key Accomplishments

Traction Drive System

*Integrated Traction Drive* (ORNL/UW)
- Six phase, permanent magnet motor with an integrated inverter; high temperature silicon package can operate up to 200°C

Power Electronics

*Low Cost Power Module With Improved Power Density* (ORNL)
- Double sided planar interconnection and integrated heat exchangers
- Improved manufacturability
- Improved thermal resistance and efficiency

Electric Motors

*Scalable, High Performance IPM Motor* (GE)
- High energy permanent magnets minimized losses, increased efficiency and power density, and reduced manufacturing costs

Thermal Management

*Light-weight, Low-Cost, Design* (NREL/UQM Technologies Inc.)
- Liquid jets and enhanced surfaces on copper base plate
- Improved performance, power density and specific power
- Low cost enabled by using water-ethylene glycol and plastic manifold

Performance Results

- Coefficient of performance
- Power density
- Specific power

Percentage increase over baseline

0 20 40 60 80 100 120 140

Jets on plain surface
Jets on enhanced surface

Performance Results
Information Sources

• FY 2011 Advanced Power Electronics and Electric Motors Annual Progress Report

• 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
Contact Information

Susan Rogers
Advanced Power Electronics and Electric Motors
Susan.Rogers@ee.doe.gov

www.vehicles.energy.gov