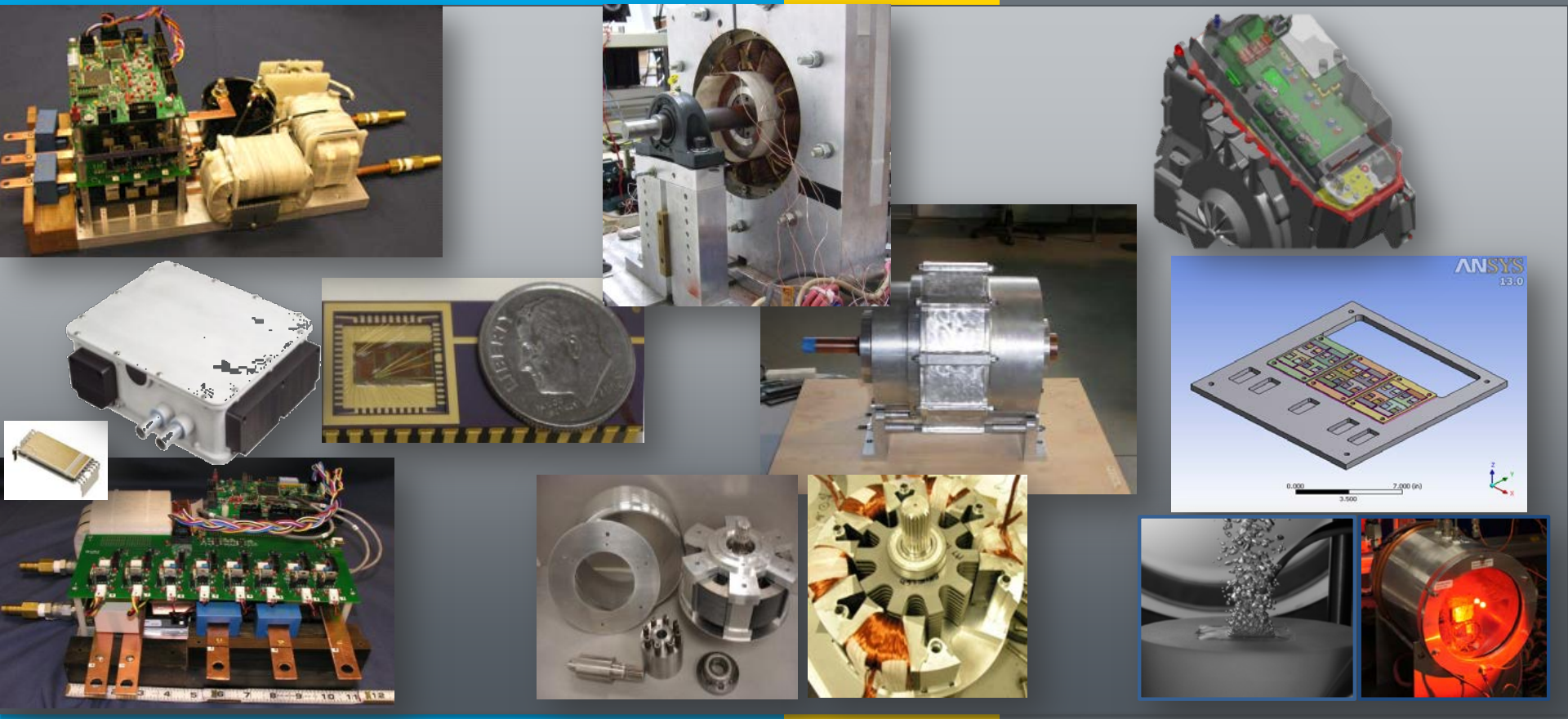
VEHICLE TECHNOLOGIES PROGRAM

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



Advanced Power Electronics & Electric Motors R&D Overview

May 15, 2012

Susan Rogers
Advanced Power Electronics and Electric Motors (APEEM) R&D
Vehicle Technologies Program
U. S. Department of Energy

APEEM Charter & Budget

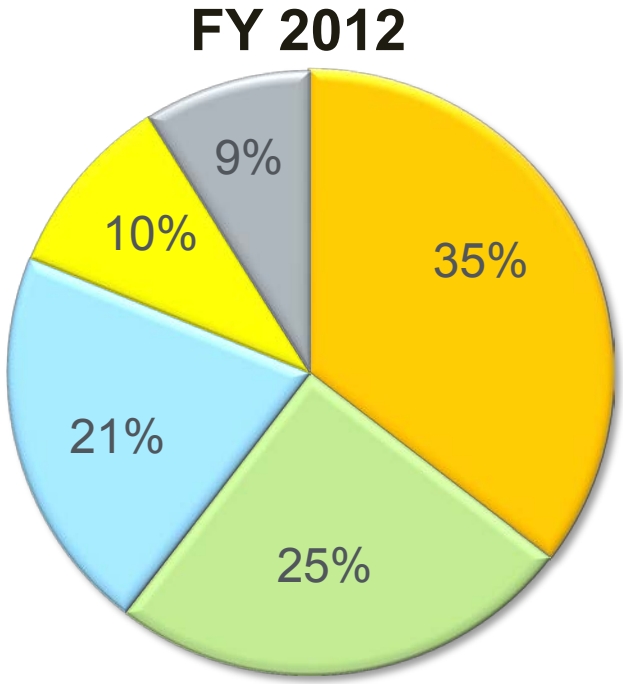
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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*



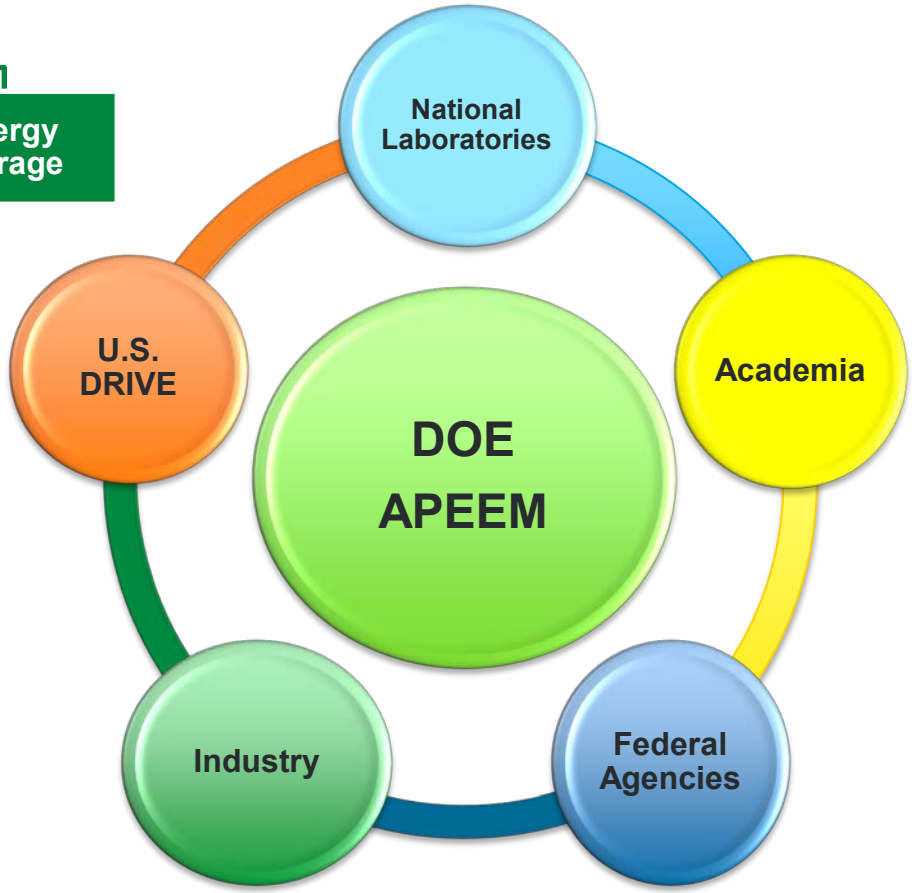
FY	Budget
2011	$22.4M
2012	$28.8M

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



APEEM Collaboration

- Department of Energy
- U.S. DRIVE Electrical & Electronics Tech Team
- National Laboratories
- Other Federal Agencies & IAPG
- Industry
- Universities

APEEM Technical Targets

Reduce Dependence on Oil
Via Vehicle Electrification

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

Technical Targets

Traction Drive System				
Impacts →	**Reduce Cost**	**Reduce Weight**	**Reduce Volume**	**Reduce Energy Storage Requirements**
Year	**Cost ($/kW)**	**Specific Power (kW/kg)**	**Power Density (kW/l)**	**Efficiency**
2010*	19	1.06	2.6	>90%
2012	17	1.08	3.0	>91%
2015	12	1.2	3.5	>93%

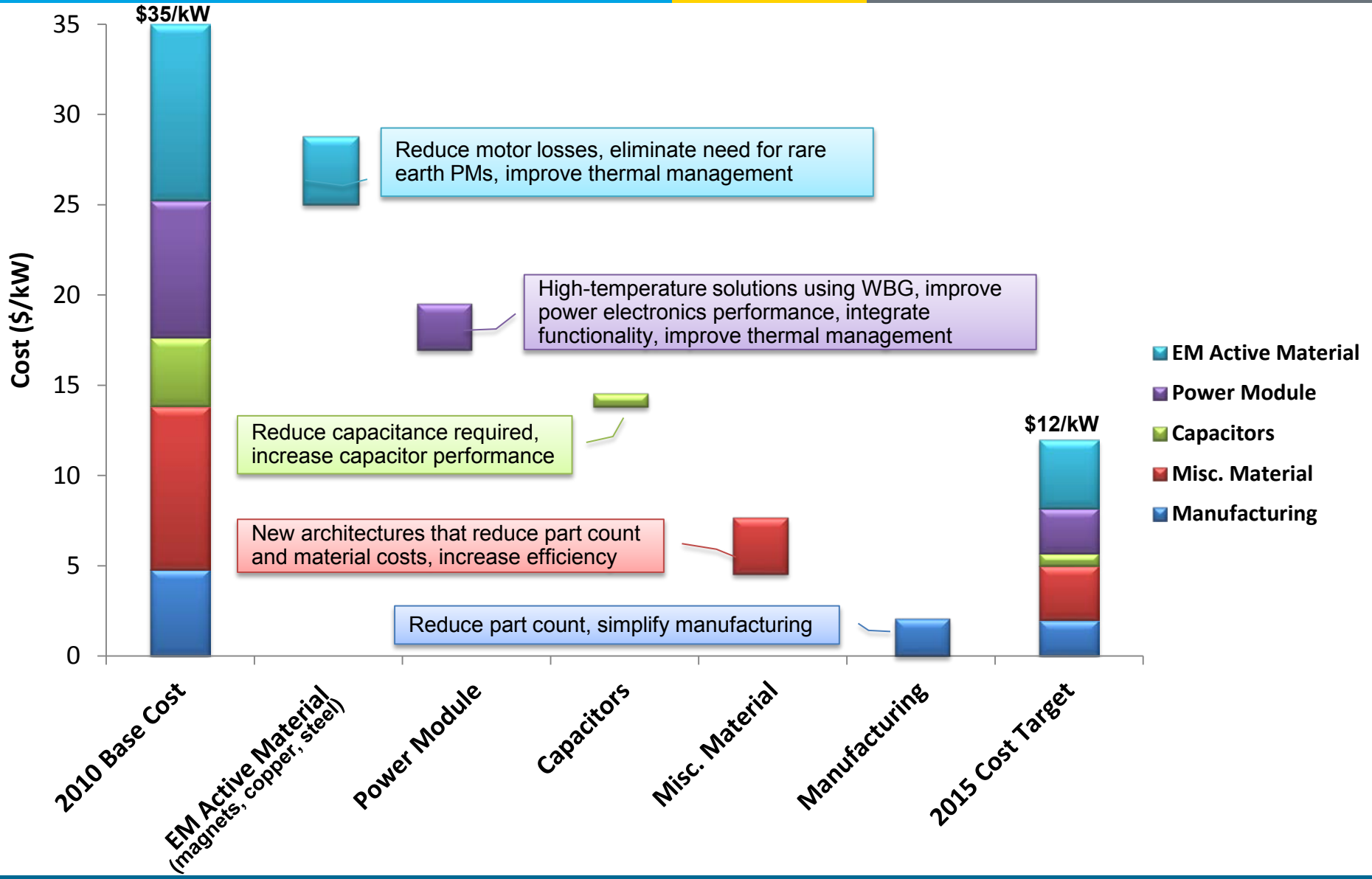
Power Electronics		
($/kW)	**(kW/kg)**	**(kW/l)**
7.9	10.8	8.7
7	11.2	10
5	12	12

+

Electric Motors		
($/kW)	**(kW/kg)**	**(kW/l)**
11.1	1.2	3.7
10	1.24	4
7	1.3	5

* **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.

Achieving 2015 Traction Drive Cost Target



APEEM Research & Focus Areas

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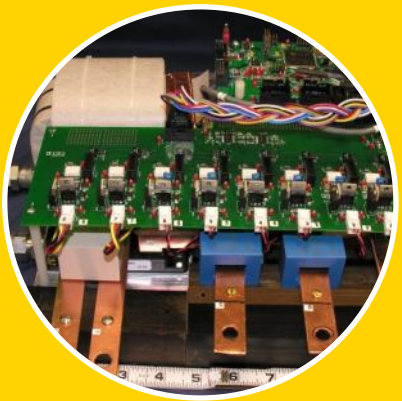
TRL 4 & 5

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

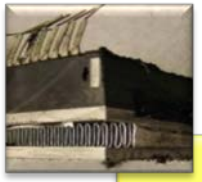
- Non-permanent magnet (PM) motors
- PM motors
- New magnetic materials
- Motor materials

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

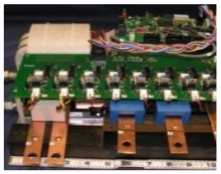
Testing, evaluation, and assessments provide current technology status and trajectory as motivation for setting R&D priorities.

Innovative system designs

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

Key to achieving 2020 targets

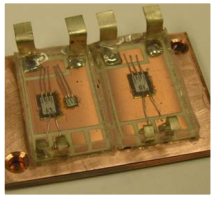
APEEM Power Electronics R&D



Electrical Architecture

Cost, performance, weight & volume

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

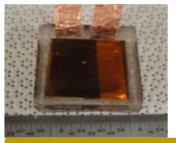


Packaging

Volume, cost & thermal management

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

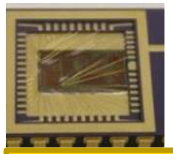
WBGs → high temperature operation



Capacitors

High-temperature capability & cost

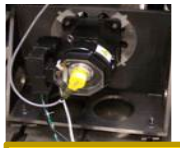
- Improves reliability & volume



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

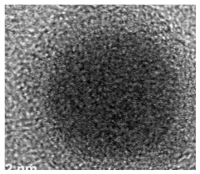
Reduce cost and size while enhancing efficiency

APEEM Electric Motors R&D

Non-permanent magnet (PM) motors

Cost, performance, weight & volume

- Eliminate PMs → reduce cost
- System level improvements → enable PE cost reduction



Magnetic materials

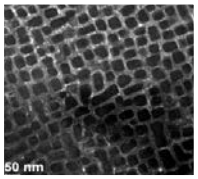
Cost Reduction

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

PM motors

Cost & performance

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



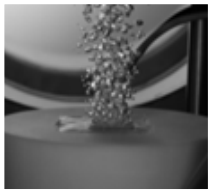
New materials

Cost & efficiency

- Increase temperature capability:
  - laminations
  - insulation
  - potting

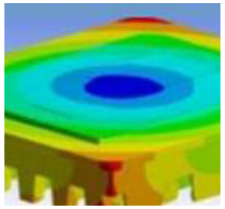
Improve motor designs and eliminate rare earth magnets to reduce cost

APEEM Thermal Management



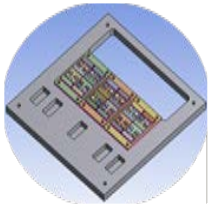
Heat Transfer Technologies

- 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



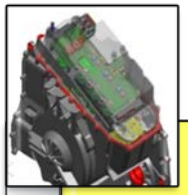
Thermal Systems Integration

- 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



Traction Drive System

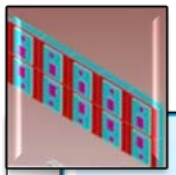
- Cost
- Packaging
- Systems Integration
- Reliability

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

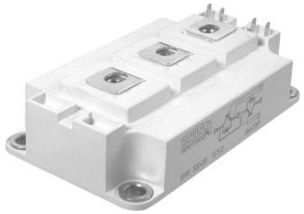
GM Fuel Cell Vehicle

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

Ford Fusion

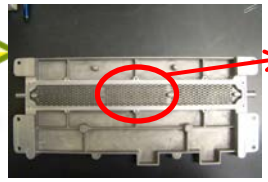
- **Semikron Power Device Attachment**
  - Sintering technology achieved higher reliability; used in all Semikron power modules

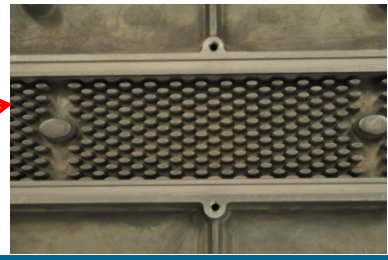
Semikron IGBT module



- **Liquid-Cooled Heat Exchanger**
  - New pin-fin shape improved thermal performance

Semikron inverter heat exchanger





Commercialization Activities
Existing Vehicle/Product Line

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

GM Fuel Cell Vehicle

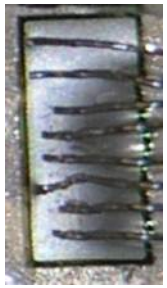
- **Brushless, External Field Coil Motor Architecture**
  - Improved performance and decreased operating costs by adapting electric drive technology for vehicle alternators

Fleet vehicles

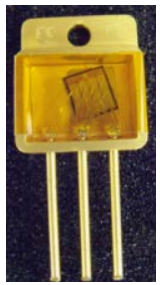
Commercialization Activities
Future Vehicle Applications

- **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

1200 V, 50 A SiC Schottky diode



1,200 V, 100 A MOSFET



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

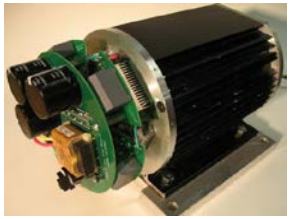
Delphi high-temperature inverter

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

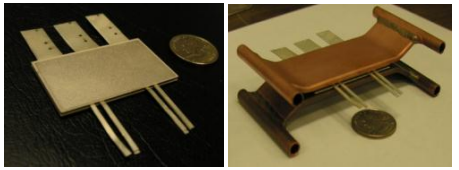


Integrated Traction Drive

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



200 A/1,200 V phase-leg power module - double sided planar interconnection (left) & integrated heat exchangers (right)

Electric Motors

Scalable, High Performance IPM Motor (GE)

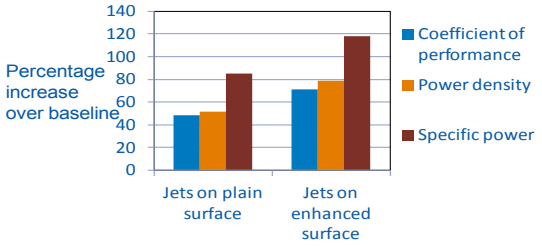
- High energy permanent magnets minimized losses, increased efficiency and power density, and reduced manufacturing costs

High Performance IPM Motor

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

Information Sources

- **FY 2011 Advanced Power Electronics and Electric Motors Annual Progress Report**
  - http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/2011_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

Contact Information

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