Power Electronics and Electric Machines

"Plug-In Hybrid Electric Vehicle Power Electronics and Electric Machines Research and Development Activities"

Presented to
U.S. Department of Energy: PHEV Stakeholder Workshop

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Power Electronics and Electric Machines for PHEVs

- Along with batteries, power electronics and electrical machines constitute the propulsion system for PHEVs

- All elements must meet targets to produce cost-effective solutions

Scope of PEEM Activities

Application	Power Electronics	Electric Machines
Traction Drive System	Inverter & Boost Converter (if needed)	Motor/Generator
Vehicle Power Management	Bi-directional DC-DC Converter	
PHEV-Specific	On-Board Charging	

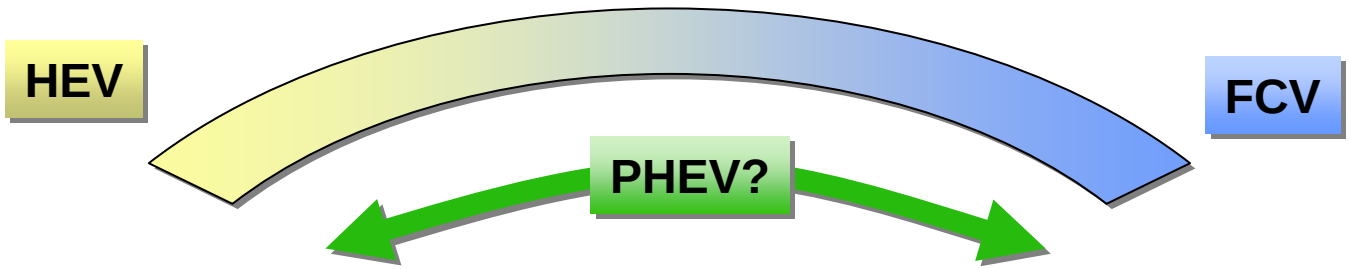
PEEM Program Structured to Meet PHEV R&D Plan Schedule

- **Current R&D Portfolio is Appropriate for Broad Range of Vehicle Electrification**
- **Vehicle Assessments to be Performed in FY08**
  - PHEV designs will emerge
  - PHEV requirements will be more fully developed
  - PHEV R&D efforts can be more sharply focused as targets emerge
- **Advanced Technology from R&D Activities will Support PHEV Plan Technology Milestones**

PHEV Challenges

- **Electric Traction Drive**
  - Current 100 kW system cost is about $3,500
  - Cost is critical issue
  - Volume is also important issue
- **Power Management**
  - PHEV charge depleting mode will require dc/dc converter to provide stiff voltage source
  - Accommodate widely varying battery output
    - load regulation
    - line regulation
- **Charging**
  - On-board charging system

PEEM Traction Drive R&D Responsive to Full Spectrum of Electric Vehicles

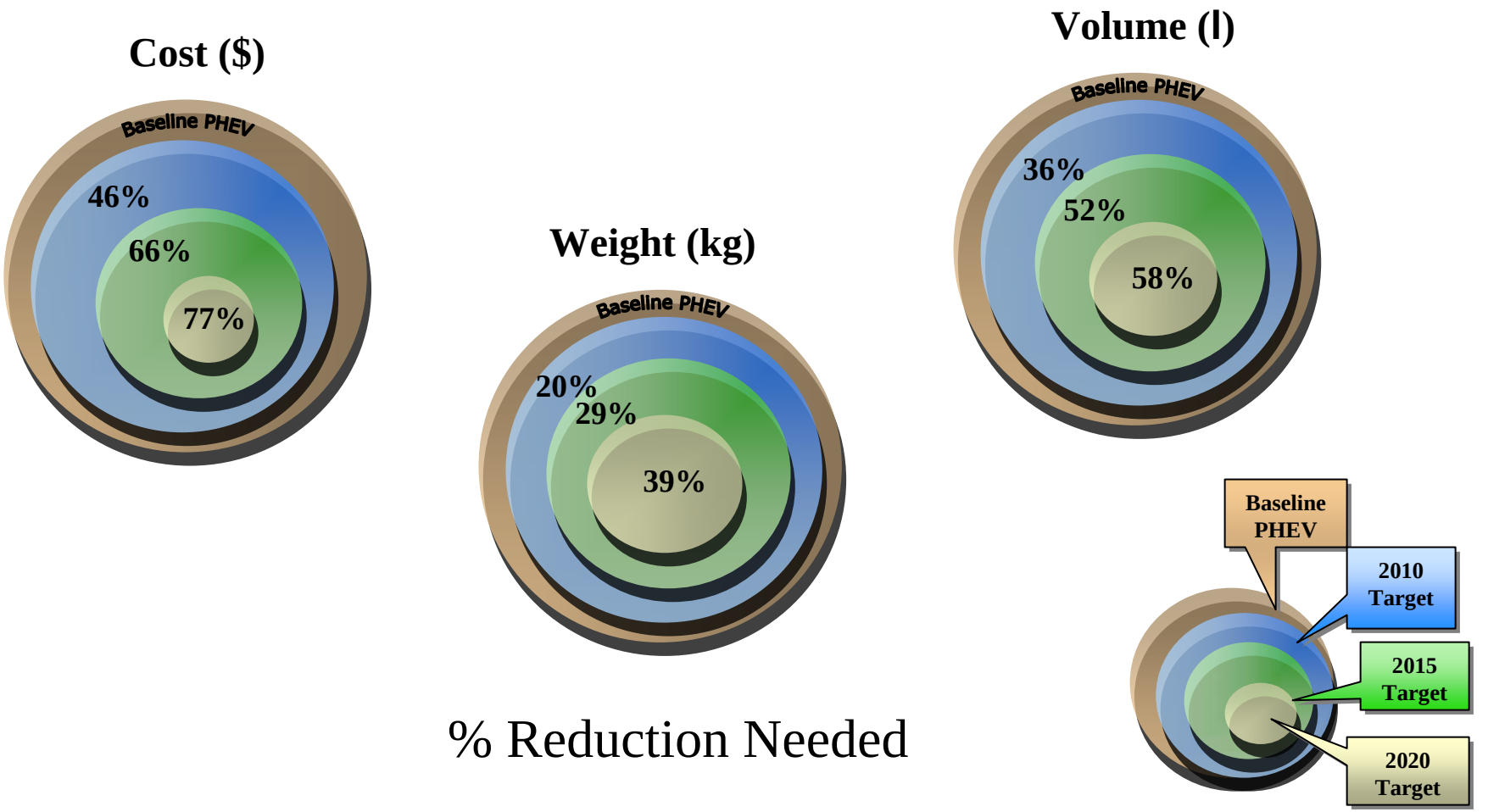


Blended ICE/Electric
– Power Requirement ≥ 55 kW
– Parallel architecture
– Intermittent short operation

Sized for Electric Only
– Power required increases (up to 200 kW)
– Series architecture
– Always "on"

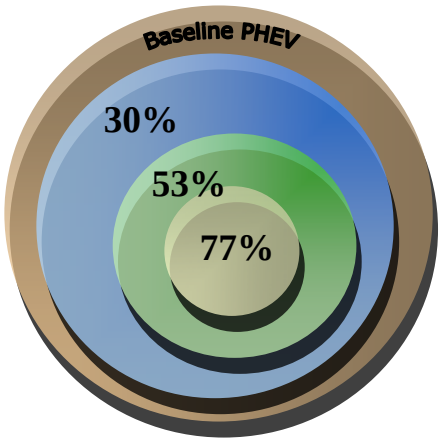
PHEV Position in Spectrum Depends on Design

Electric Propulsion System PEEM Targets are Aggressive

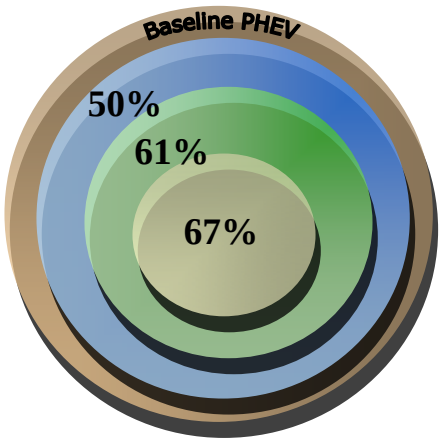


Power Management DC-DC Targets are Similarly Aggressive

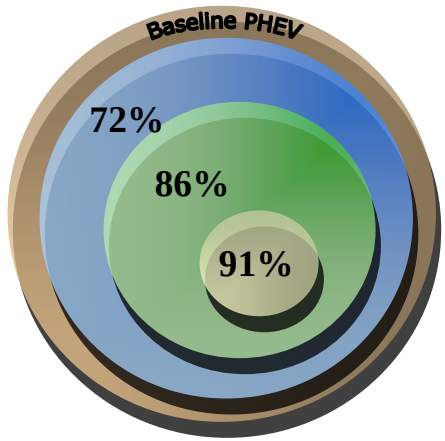
Cost ($)

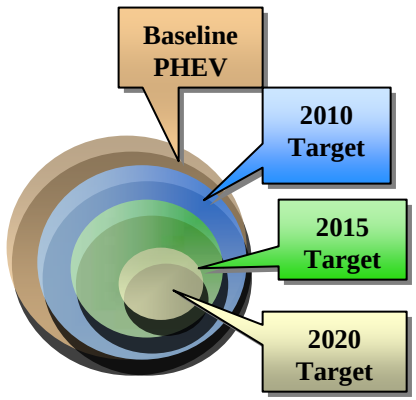


Weight (kg)



Volume (l)





% Reduction Needed

Anticipating FY08 Assessment Results

- **Traction Drive**
  - Greater reduction in cost, volume, and weight required for PHEV (compared to HEV or FCV)
  - Tradeoffs between PEEM and batteries likely to require PEEM cost target < $8 kW and power density > 4 kW/l
- **Vehicle Power Management**
  - Bidirectional dc-dc converter will be required to provide stiff vehicle voltage
  - Likely targets
    - cost < $25/kW
    - power density > 3 kW/l
- **Vehicle Charging**
  - On-board charging system using traction drive PEEM may be most cost-effective solution

PEEM R&D Program Structure

- **Addresses Complete Application Spectrum**
  - Power levels from 55 to 200 kw
- **Technology Demonstrated at 55 kW Level**
  - Better performance parameters (e.g. $/kW, kW/kg, kW/l) at higher power since overheads spread over higher power
  - Ensures targets are met across entire spectrum of possible PHEV designs
- **Maintain Scalability to Meet Higher Power**

PEEM R&D Thrusts Directed at Achieving Targets
(example – cost target)

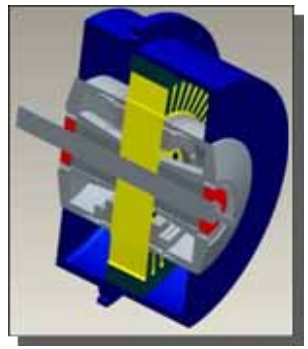
Long-term Cost Target for 55 kW System is $440

- **Elimination of Dedicated Coolant System**
  - Savings of ~$175
  - Use of on-board coolants

- **Elimination of Boost Converters**
  - Savings of ~$250
  - Motor design innovation to extend CPSR
  - For PHEV CD mode; converter still needed for voltage regulation so savings mitigated.

Research Pathways

- **Traction Drive EM**
  - Higher motor speed: increase power and performance parameters
  - Field weakening/strengthening: increase low-end torque, extend CPSR, and possibly eliminate boost converter
- **Charging PE**
  - Using PEEM system for battery charging to minimize cost



16,000 rpm with brushless field excitation

Research Pathways

- **Traction Drive PE**
  - Innovative topologies: decrease losses, decrease capacitor requirements, and high temperature operation
  - Utilize functional integration (e.g. converter and inverter): reduce part count and increase reliability
  - Novel heat management solution: allow reduction in size using high temperature components and enhanced heat transfer
  - Increase capacitor performance and decrease bus ripple current to decrease capacitor size
- **DC-DC Converter**
  - Innovative topologies: ensure efficiency, decrease cost, weight, and volume and allow high temperature operation

Integrated dual inverter for traction and compressor drive

6 kW, 3-phase dc-dc converter

PHEV PEEM Solicitation Addressed Four Areas of Interest

- High-Temperature Inverter
  - Requirements: 55kW peak; 15 year lifetime; coolant 105°C liquid or air
  - Targets: ≤4.6 L; ≤4.6 kg; ≤$275
- High-Speed Motor
  - Requirements: 55kW peak for 18 sec.; 30 kW continuous; 15-year life
  - Targets: ≤9.7 L; ≤ 35 kg; ≤ $275
  - Scaleable to 120 kW peak for 18 sec. and 65 kW continuous
- Traction Drive System
  - Requirements: 55 kW peak; 30 kW continuous; 15-year life
  - Targets: ≤16 L; ≤46 kg; ≤$660; coolant 105°C liquid
- Bi-directional DC/DC Converter
  - Phase I Study to establish optimal voltage for drive system
  - Phase II Hardware design and fabrication

Industrial Efforts Have Been Initiated

PEEM PHEV Solicitation Awards Announced

Projects total $33.8 million

Contract Negotiations On-going

- ***Team Lead: Delphi Automotive Systems***
  - Award: ≤ $4.9 million
  - Description: High temperature inverter (105°C coolant)
- ***Team Lead: Virginia Polytechnic Institute***
  - Award: ≤ $1.7 million
  - Description: Advanced soft switching inverter for reducing switching and power losses
- ***Team Lead: General Electric Global Research***
  - Award: ≤ $3.4 million
  - Description: Increasing traction motor power density and efficiency
- ***Team Lead: General Motors Corporation***
  - Award: ≤$7.9 million
  - Description: Integrated traction drive system
- ***Team Lead: U.S. Hybrid Corporation***
  - Award: ≤ $1.3 million
  - Description: Bi-directional dc-dc converter including vehicle system study to determine optimum battery and dc link voltages

PEEM Activity

- PEEM integral part of PHEV drive system
- Very challenging targets
- Targets likely to be further squeezed for PHEV application as PHEV designs more fully assessed
- PHEV R&D pathways identified (refined as PHEV targets emerge)
- Mix of national lab and industrial work will meet PHEV Plan milestone schedule