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2010 DOE Vehicle Technologies Program Review Presentation

Bi-directional dc-dc Converter

Including Vehicle System Study to determine Optimum Battery and DC Link Voltages

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Project ID #APE021

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Overview

Timeline

- Start: September 2007
- End: September 2010
- 80% Complete

Barriers

Barriers addressed

- Reduce the cost of battery for EV and PHEV for commercialization
- Efficiency of the converter
- Power Density, Size of Converter for vehicle packaging (volume and Weight)

Budget

- Total project funding
  - DOE $1,113,691
  - Contractor: $ 668,732
- Funding for FY09 $ 360,139
- Funding for FY10 $ 160,272

Project Target Performance

- High inlet and ambient temperatures (>105°C)
- High efficiency (> 95 %, originally 90%)
- High power density (20 – 50 W/in3, achieved 54W/in^3)
- Low cost (≤ $75 /kW)

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The Challenge

- PHEV requires high power density battery/energy storage for hybrid operation and high energy density battery for EV mode range.
- Battery Technologies to maximize power density and energy density simultaneously, are not commercially feasible.
- The use of bi-directional dc-dc converter allow use of multiple energy storage, and the flexible dc-link voltages can enhance the system efficiency and reduce component sizing.

The Objective

Design a bi-directional dc-dc converter and fabricate a 8kW POC unit to demonstrate the following;

- High inlet and ambient temperatures (> 105 °C)
- High efficiency (> 95 %, originally 90%)
- High power density (20 – 50 W/in3, achieved 54W/in^3)
- Low cost (≤ $75 /kW)

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Milestones

Month/Year	Milestone or Go/No-Go Decision
OCT 08	**Determine the optimum vehicle system design.** **Determine the cost saving for dual battery system** **Determine the range increase for dual battery system**
May 09	**Determine the cost saving for dual battery system** **Determine the range increase for dual battery system** **Determine the power density of bi-directional dc-dc converter**
Oct-09	**Determine Efficiency of the bi-directional dc-dc converter** **Determine the cost of bi-directional dc-dc converter**

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Approach/Strategy

- Multi phase bi-directional dc-dc converter topology with High bandwidth control.
- Custom power module and packaging to allow high temperature operation.
- Integrated sensors to reduce size and cost.
- Enhanced custom magnetic to increase switching frequency and efficiency.

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Major Accomplishments

1. Developed a vehicle level simulation modeling, with dual battery system and the dc-dc converter for characterizing vehicle drive cycles for various vehicle system configuration and drive cycles and vehicle platforms (Economy, Compact, Sedan and SUV)
2. Developed an FEA parametric model and analysis techniques to characterize the magnetic and thermal behavior of the dc-dc converter critical components.
3. Developed a vehicle level power and energy management.
4. Developed and implemented converter level modeling to determine the operation trade off and control system.
5. The dynamic and static behavior of the dc-dc converters were validated with actual unit, including the converter system control.

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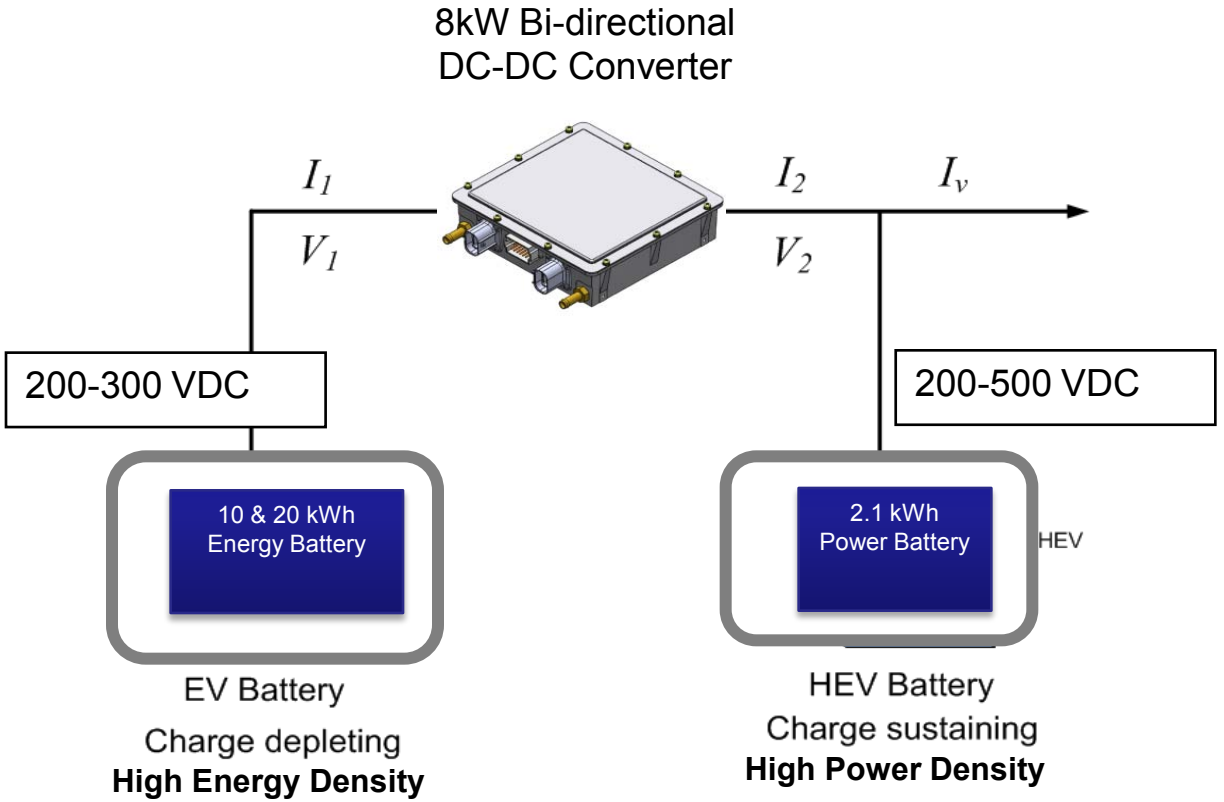
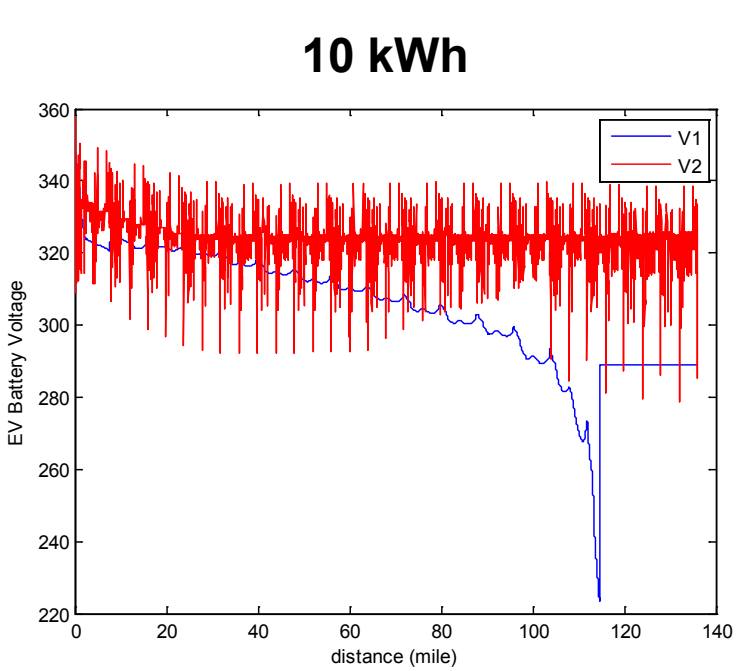
Major Accomplishments Cont.

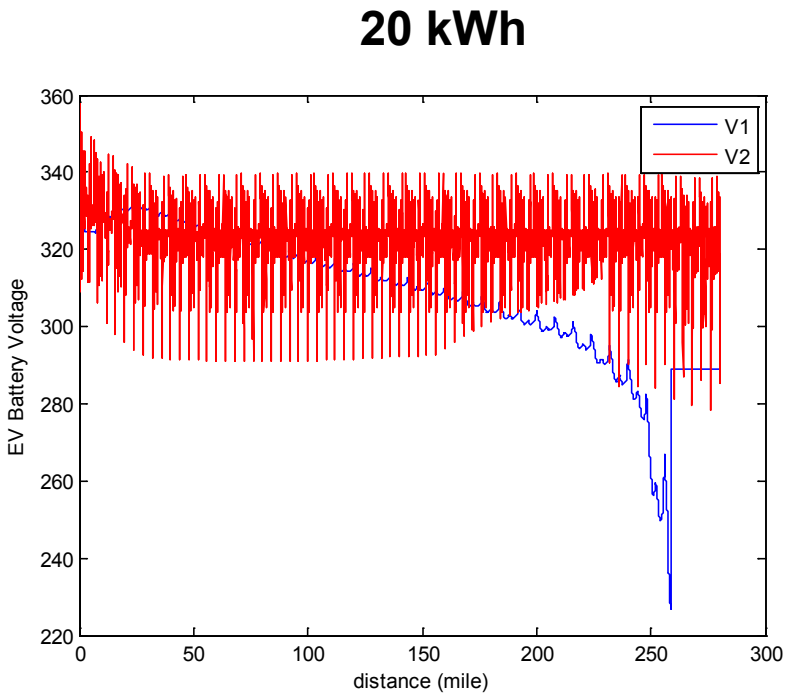
6. Demonstrated High efficiency (meeting and exceeding the target > 95 %).
7. Custom Silicon packaging with 1200V NPT fast IGBT and 1200V SIC diode with high coolant temperature of 105 °C.
8. Has been able to demonstrate high power density of 54 W/in^3,(Enhanced the EMI Filter), exceeding the program target of (20 – 50 W/in^3).
9. Demonstrated low cost ($\leq$ $62.5 /kW) for quantities of 10k/year, based on actual BOM and suppliers cost data with automated testing.
10. The dual battery system provides 14% increase in range, while
11. Reducing the weight by 13% and
12. Reducing the total cost by 5%, not including the life extension of the battery.

Vehicle level modeling with Dual Battery and Bidirectional dc-dc Operation



Vehicle level performance (Voltage)

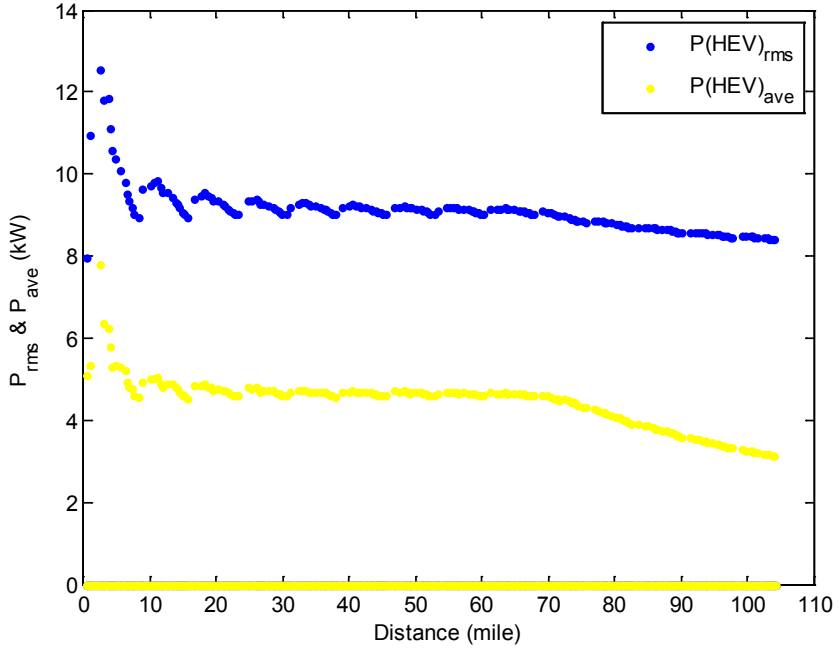




Single and Dual Battery Load Comparison

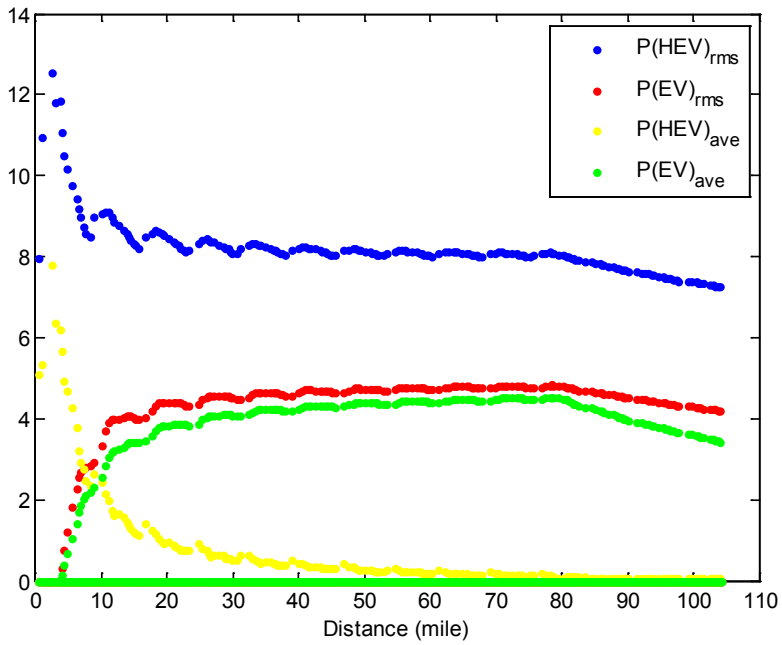
Single battery

(high rms and average current)



Dual battery

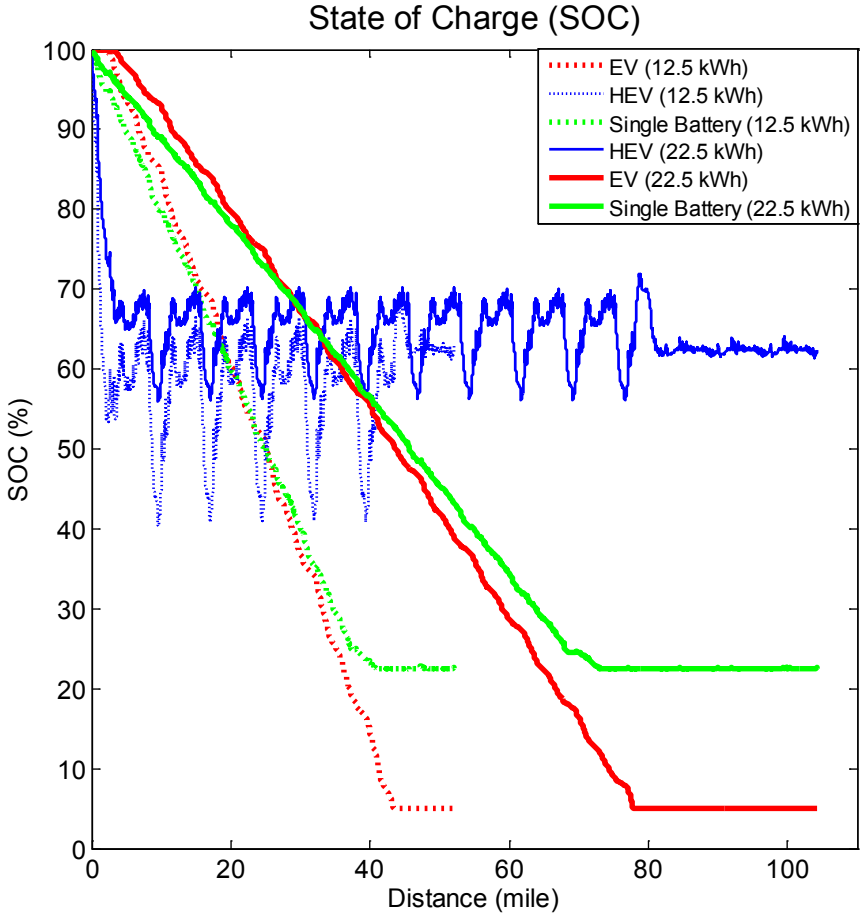
Power battery has high rms and zero average and Energy battery has only average current)

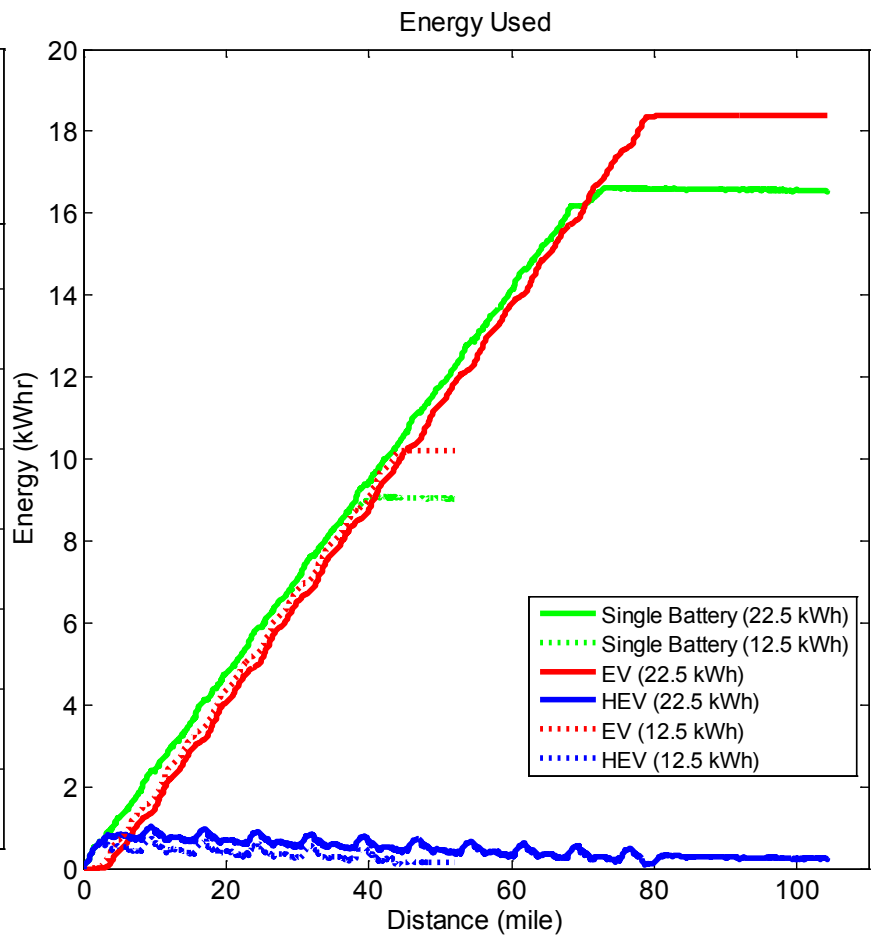


Battery rms and average power for single and dual battery system with Bi-directional dc-dc converter with optimum control strategy

State of Charge (SOC) & Energy

Dual Battery and bi-directional dc-dc converter range improvement over single battery





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Weight and cost reduction and the range increase for the dual battery

Cost Saving

22.5 kWh	+17%
12.5 kWh	+5%

Fuel Saving

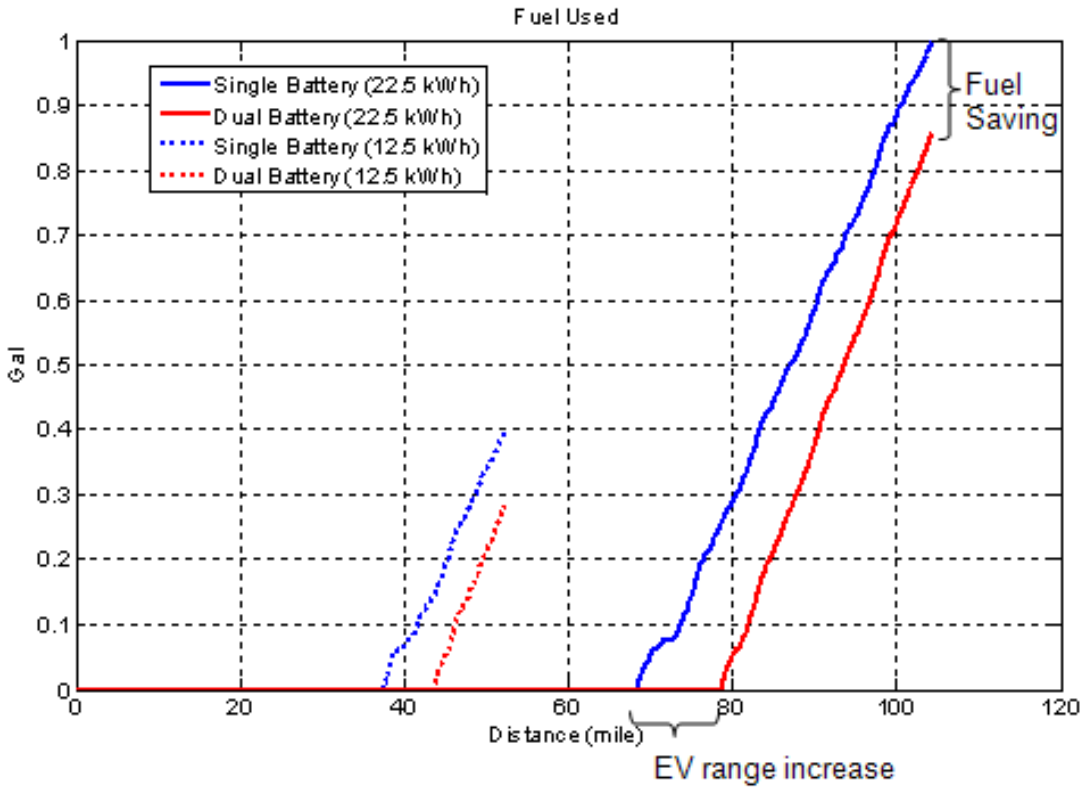
22.5 kWh (100 miles)	+14%
12.5 kWh (50 miles)	+30%

EV Range Increase

22.5 kWh	+12%
12.5 kWh	+14%

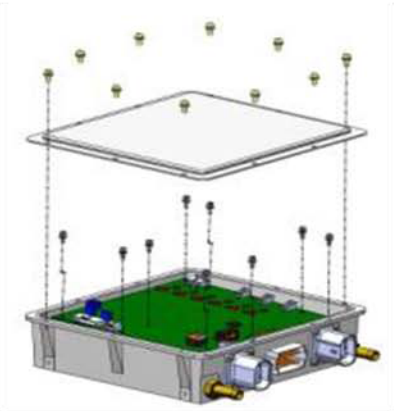
Weight Reduction

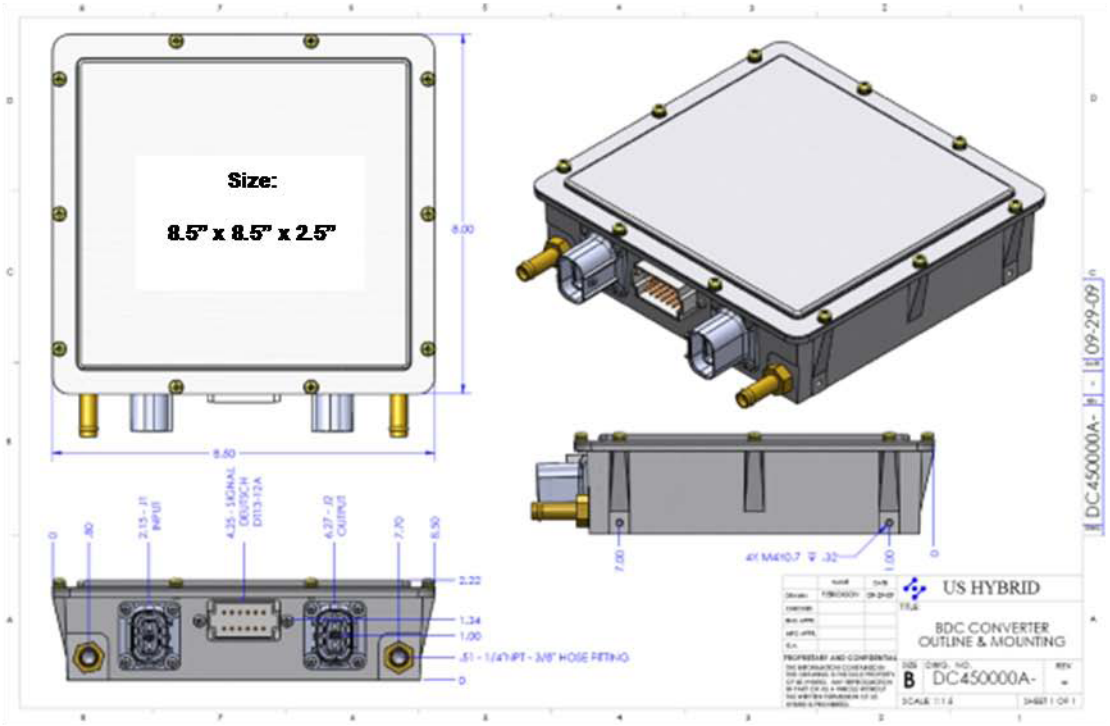
22.5 kWh	-17%
12.5 kWh	-13%



The cost and weight reduction and range extension of the dual battery system.

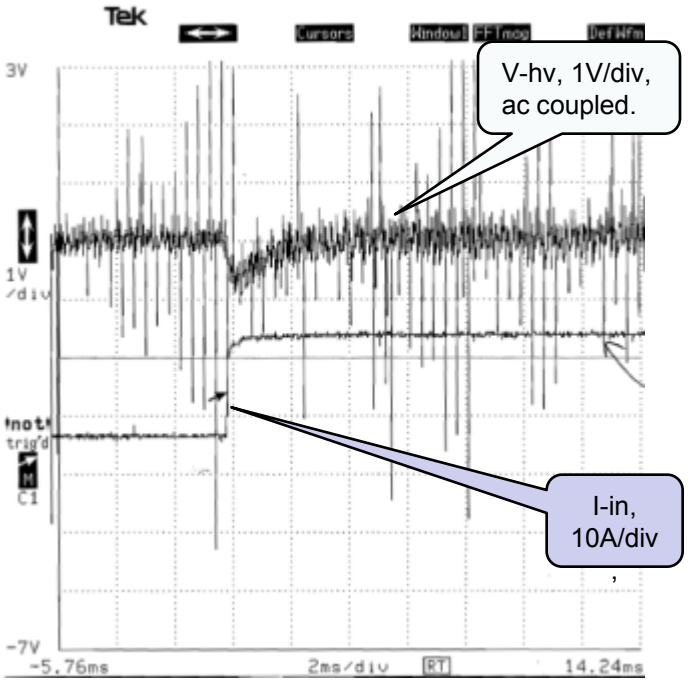
Packaging



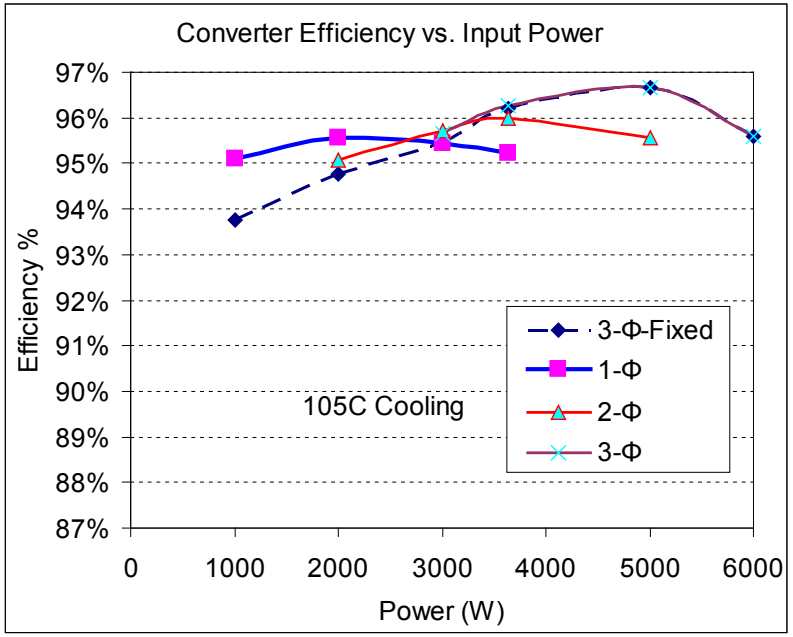


- **Demonstrated High efficiency (meeting and exceeding the target > 95 %).**
- **Custom Silicon packaging with 1200V NPT fast IGBT and 1200V SIC diode with high inlet and ambient temp of 105 °C.**
- **Demonstrates high power density of 54 W/in^3, (target 20 – 50 W/in^3).**
- **Demonstrated the low cost (≤ $62.5 /kW) for quantities of 10k/year (target $75/kW).**

Bi-directional dc-dc performance.



Converter dynamic Step load response. Vin=250V, Vout(hv)=350V, step load response with resistive load (5kW).



IGBT and SIC diode power converter operating at 50 kHz, Vin=250V and Vout=350V.

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The 2010 proposed work:

I. To design, develop and complete performance validations of the production intent prototype high power density power 8 kW bidirectional dc/dc boost converter. Vin=150V-300V, Vout=300V-500V and meets a DOE cost target of $75/kW

II. To demonstrate a power-conversion efficiency of 95% or more at a junction temperature of 130-150 °C corresponding to an inlet coolant temperature of 105 °C

III. To realize a power density of at least 1kW/l and a specific power of at least 0.8 kW/kg by operating the multi-phase converter at a modular switching frequency of 150 kHz.

IV. FMEA analysis and report

V. Production Planning.

Beyond FY10

The project is anticipated to go beyond FY10, by US Hybrid with following anticipated work and applications.

- FY11
  - Build Pilot production for PHEV, subject to customer demand.
  - Build pre-production units for Fuel cell industry.
- FY12
  - Build production for PHEV, subject to customer demand.
  - Build Production Units for Smart Grid.
  - Build production units for Fuel cell industry.

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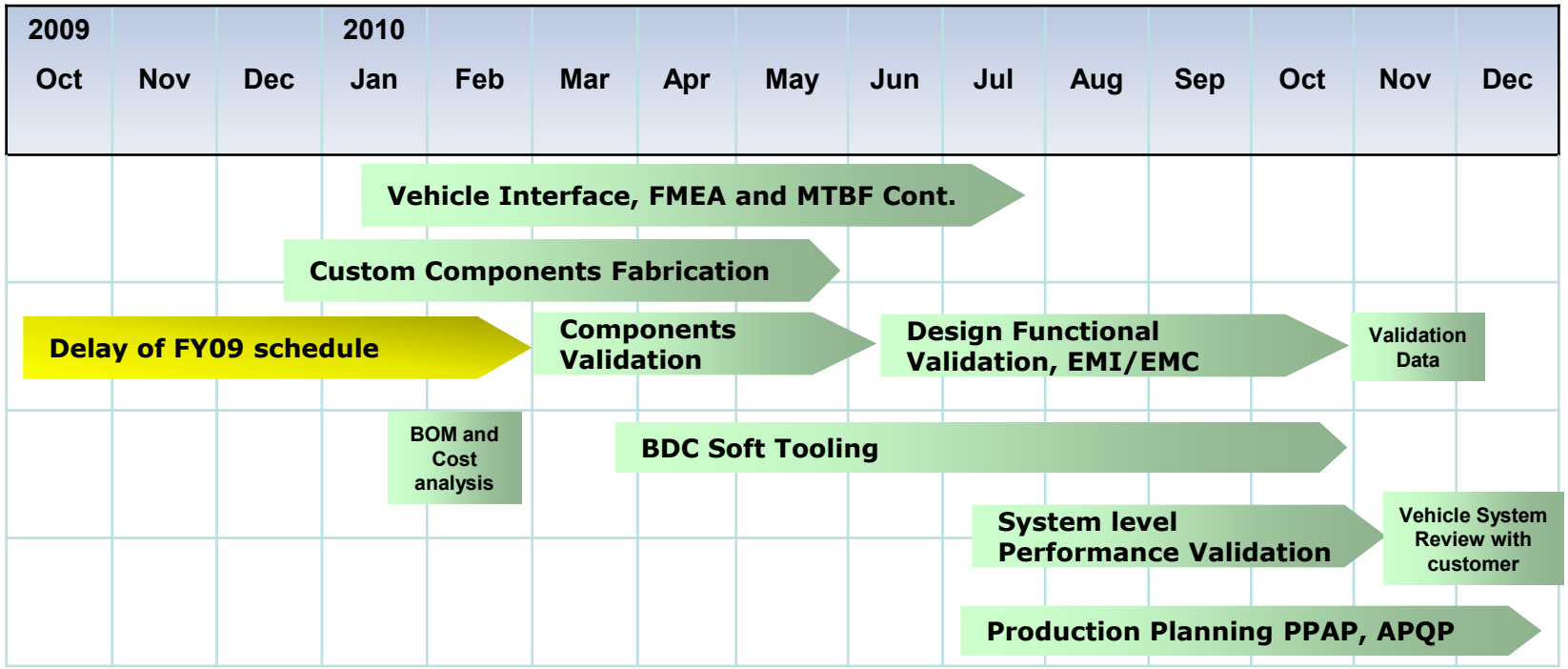
Summary

- The dual battery system for PHEV has proven to increase the range by 14% and reduce the weight by 13%, and the cost by 5%.
- The bidirectional dc-dc convert technology has met and exceeded the program requirements, following are a summary;
- Demonstrated High efficiency (meeting and exceeding the target > 95 %).
- Custom Silicon packaging with 1200V NPT fast IGBT and 1200V SIC diode with high inlet and ambient temp of 105 C.
- Demonstrates high power density of 54 W/in3, (target 20 – 50 W/in3).
- Demonstrated the low cost (≤ $62.5 /kW) for quantities of 10k/year (target $75/kW).

FY10 Time Line



Go No/Go Decision Point: Soft tooling vs. investment tooling and Automated end of line test equipment design and fabrication depends on customer purchase commitment.

Challenges/Barriers: Vehicle level system Validation Partner.