Advancing Transportation Through Vehicle Electrification - PHEV

Abdullah A. Bazzi
Chrysler Group LLC
May 9, 2011
Project ID # ARRAVT067

This presentation does not contain any proprietary, confidential, or otherwise restricted information
### Timeline
- Project Start: September, 2009
- Project Complete: June, 2014
- 45% Complete

### Budget
- Total Project Funding
  - DOE: $48,000,000
  - Chrysler $49,408,996
- Funding received FY09: $0
- Funding received FY10: $9.79M
- Funding received FY11: $9.13M

### Barriers
- Battery performance across extreme ambient conditions
- Thermal Management Integration
- Charging System Integration
- Understanding customer acceptance and usage patterns for PHEV technology

### Development Partners & Key Suppliers
- Behr America • Electrovaya • Hitachi • Delphi • TDI • Continental • CASCO Products • EPRI • Austin Energy • ERCOT • Michigan State University • University of Michigan • Sacramento Municipal Utility District (SMUD) • NextEnergy • UC Davis

### Demonstration Partners
- Sacramento Municipal Utility District (SMUD) • State of Colorado, DOT • State of North Dakota • New York State Energy Research and Development Authority (NYSERDA) • Commonwealth of Massachusetts • Austin Energy • State of Michigan • City of Kansas City, Missouri • Clark Co., NV • City of Yuma, AZ • Hawaii State Energy Office (in cooperation with US Military) • City and County of San Francisco

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DS Program Objectives - Relevance

- Demonstrate 140 pickup trucks in diverse geographies and climates, spanning from North Dakota to Arizona & Hawaii to Massachusetts, and across a range of drive cycles and consumer usage patterns applicable to the entire NAFTA region.
- Verify plug-in charging mode performance based on charger and battery model.
- Verify AC power generation mode.
- Prove product viability in “real-world” conditions.
- Develop bi-directional (communication and power) charger interface.
- Support the creation of “Green” Technology jobs and advance the state of PHEV technology for future production integration.
- Develop an understanding of Customer Acceptance & Usage patterns for PHEV technology.
- Quantify the benefits to customers and to the nation.

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### Project Overview: Approach & Timing

<table>
<thead>
<tr>
<th>Year</th>
<th>Phase 1: PHEV Development</th>
<th>Phase 2: Build &amp; Launch Prep</th>
<th>Phase 3: Vehicle Demo</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>Aug '09 – Sep. '10</td>
<td>2010 – APR '11</td>
<td>May '11 – May. '14</td>
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<tr>
<td>2010</td>
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<td>2011</td>
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**DS PHEV TIMING**

- **Initial Dev**
- **DS Dev Veh Builds**
- **Prototype build 12 DS DV vehicles**
- **Vehicle integration and functional check of key hybrid components**
  - Supplier integration
  - System check
  - System simulation
  - Controls development
  - Calibration development
- **Bench validation of components and subsystems**
  - Accelerated hot/ cold/ altitude ambient verification
  - Charging system/ basic grid interface verification
  - Auxiliary power outlet functional verification
  - Functional objective verification: fuel reduction, emissions abatement, drivability, towing
- **Prototype build 12 DS DV vehicles**
- **DS Demo Fleet builds**
- **CTC Pilot Retrofit Demo Fleet: 140 DS vehicles**
- **FMVSS Compliance**

**Vehicle Prep**

- **Extended PHEV development**
- **Vehicle prep for delivery to demonstration partners**
- **Verify other financial & program objectives**
- **Customer acceptence/ HMI study**
- **Customer / dealer training**
- **Electricity consumption from grid analysis**
- **Petroleum consumption prediction verification**
- **GHG reduction model verification**

**Project Management**

- **Project management / DOE Open forum - BiWeekly Conference Calls**
- **Project management / alignment with project objectives and budgets - Monthly meetings**

**Winter Testing**

<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
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**Summer Testing**

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<th>Jun</th>
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<th>Sep</th>
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**Winter Testing**

<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
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<th>Sep</th>
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Technical Approach

120V / 240V AC
Power Panel 6.6 Kw

J1772
Charge Port
Level I / II

HV Battery Li-Ion
12.9 kWhr
Liquid Cooled

6.6 Kw Charger / Inverter

Electric Motors

2-Mode Hybrid Transmission
• 2 EVT Modes
• 4 Fixed Gears
• 65 Kw Motors

Controls
• E Motors
• Battery
• Hybrid Vehicle
• Transmission

5.7 L Hemi V-8 Engine
• 345 hp Gas Engine
• 399 hp Total Hybrid System

Thermal Systems

Power Electronics
Inverter and DC / DC
Technical Specifications - Accomplishments

**Plug-in Hybrid Technical Specifications**

**Hybrid Drive System Technology**
- Next Generation Lithium Ion Battery

**Charge Times**
- 2hrs at 220V
- 5hrs at 110V
- Full Hybrid system function w/o Plug-in

**Fuel Economy (City)**
- Charge Depleting 32MPG

**Electric Drive Range (City)**
- 20 miles equivalent

**Range**
- 655 miles

**Transmission**
- Advanced Technology Plug-in Hybrid

**Brakes**
- Regenerative Brake System

**Auxiliary Power**
- 6.6kW Continuous Through:
  - Power Panel
  - Pickup Bed
  - 2 – 120V, 20A duplex
  - 1 – 240V, 20A plug

**Cabin Receptacle**
- Center Console
- 1 – 120v, 20A plug

**Power On-The-Fly**
- 120V / 240V, 60Hz AC

**Silent Mode**
- 120V / 240V, 60Hz AC

**Exterior Dimensions**

**Vehicle Length**
- 227.5"

**Overall Height**
- 74.8"

**Body Width**
- 79.4"

**Ground Clearance**
- 7.7" @ Curb Weight

**Approach / Departure**
- 19.2° / 21.9°

**Breakover**
- 15.2°

**Track**
- 68.1" Front
- 67.5 Rear

**Turning Diameter**
- 45.3’ Curb to Curb

**Wheelbase**
- 140"

**Powertrain Engine Size / Type**
- 5.7L Hemi V8

**Maximum Power**
- 399 Horsepower

**Maximum Torque**
- 390 ft-lb @ 4300 rpm

**Transfer Case**
- 4x4

**Axles**
- 3.27 Axle Ratio
- 9.25 Light Duty Rear Axle
- Automatic Front Axle Disconnect (enhances fuel economy)

**Capacities / Weights**

**Curb**
- 6,192 lbs

**Fuel Tank Capacity**
- 26 gallons

**GCWR**
- 12,100 lbs

**GVWR**
- 7,200 lbs

**Payload**
- 1,000 lbs

**Towing Capacity**
- 6,000 lbs

**Cargo Box**
- 5’7” with Ram Box

**Wheels / Tires**

**Wheels**
- 17” x 7.0” Aluminum

**Wheels (Steel Spare)**
- P265/70R17 BSW All Season Tires

**Tires**
- Full Size Spare Tire

**Interior Dimensions**

**Passenger Volume**
- 120.9 Cubic Feet

**Seating Capacity**
- 6 Passenger 3F/3R

**Safety**

**Electronic Stability Program**
- Traction Control
- ABS
- Brake Assist
- Electronic Roll Mitigation
- Hill Start Assisted
- Trailer Sway Control

**Air Bags**
- Advanced Multistage Front
- Supplemental Side Curtain
- Supplemental Front and Rear Curtain

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Technical Accomplishments – Vehicle Build & Test

- Development and validation utilized the standard Chrysler Group LLC Vehicle Development Process for a production intent program.
  - Designed and built all development and test vehicles
  - Augmented development process with modified testing procedures to address specific plug in Hybrid Technologies
- **Facility Based Testing:** hot static cell, hot drive cell, cold static cell, cold drive cell, altitude chamber, engine dynamometer, transmission dynamometer, NHV cell, EMC cell, end of line; bench Testing: vibration, SOC, thermal, charge / discharge cycling
- **Impact Testing:** Successfully Completed for FMVSS compliance
- **Road trips:** development testing and verification: hot trip to 125F, cold trip to -20F, altitude trip to 12,000 ft
- **Durability testing:** powertrain, high mileage, two charge cycles per day.

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Technical Accomplishments (Cont.)

PHEV Specific Feature Development:

• Thermal management of Li-ion battery system capable of heating the high voltage battery in extreme cold, and cooling the high voltage battery in extreme hot ambient temperatures, optimizing the operating temp range.

• Developed powertrain control system to operate within the power limitations of the Li-ion battery over ambient temperature range of -20°F to 125°F while providing predictable and reliable vehicle performance.

• Developed a PHEV truck capable of 7200 GVW & 12,100 GCWR capable of operating over temperature -20°F to 125°F

• Developed charging system capable of charging in excess of 6.6kW

• Developing the inverter system to support power panel, V2G, and micro-grid functions up to 6.6 kW

• PHEV systems integrated cold start, cold drive, EV Drive, start/stop, thermal management, battery SOC operational boundaries, torque security validation, transmission dynamometer for E-Motor PHEV duty cycle.
## Technical Accomplishments – FE & Emissions

<table>
<thead>
<tr>
<th>Proposal</th>
<th>Status</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RANGE</strong></td>
<td>Equivalent All Electric Range (EAER) of 20 miles</td>
<td>20+ miles EAER achieved</td>
</tr>
<tr>
<td><strong>EMISSIONS</strong></td>
<td>ATPZEV Compliance</td>
<td>SULEV TP emissions demonstrated for&lt;br&gt;» Charge Depleting (CD) City and Hwy Cycles.&lt;br&gt;» Charge Sustaining (CS) City, Hwy, US06,and ColdCO cycles.&lt;br&gt;Based on testing with prior development test vehicles, SULEV TP emissions requirements can be met for 50F test and SC03 cycle.&lt;br&gt;Met the PZEV Evap Emissions requirements for&lt;br&gt;» Rig Test, based on the purge volume measurements during the 3bag City Cycle.&lt;br&gt;Based on testing with prior development test vehicles, PZEV Evap emission requirements can be met for whole vehicle SHED test, ORVR and Running loss.</td>
</tr>
<tr>
<td><strong>FUEL ECONOMY</strong></td>
<td>Charge Depleting City 32 MPG</td>
<td>FE CITY: Exceeded 32 MPG&lt;br&gt;» Utility Factors (SAE J 2841) based - CD &amp; CS are combined and reported as one number; Fuel Energy &amp; Electrical Energy reported separately (no MPGe).&lt;br&gt;» Vehicle kWh/100mi was calculated using a nominal charging system efficiency of 88%. Charger development ongoing.</td>
</tr>
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</table>

* Range, Emissions and Fuel Economy deliverables listed in the FOA 28 proposal, Submitted May 12, 2009

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### Key facilities & equipment used by Chrysler and demonstration partners at development & demo sites

<table>
<thead>
<tr>
<th>Chrysler</th>
<th>Facilities / Infrastructure</th>
<th>Equipment : All New</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All Existing:</strong></td>
<td></td>
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<tr>
<td>• Warren Truck Assembly plant, Warren MI</td>
<td>• ETAS Hardware – Automotive Electronic Control Unit (ECU) calibration</td>
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<tr>
<td>• Chrysler Technical Center – Auburn Hills, MI</td>
<td>• ETK – ECU Interface</td>
<td></td>
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<tr>
<td>— Fuel Economy Testing, Altitude chamber, Static Hot/Cold cell, Environmental Drive cell</td>
<td>• ES – Measurement and Network Modules</td>
<td></td>
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<tr>
<td>• Chelsea Proving Grounds – Chelsea, MI</td>
<td>• INCA Software – ETAS software for ECU calibration</td>
<td></td>
</tr>
<tr>
<td>— Sled-impact testing site, Covered crash barrier, Skid traction area, Mileage accumulators, Emissions certification Center, Wind tunnel</td>
<td>• Matlab Simulink – General engineering data computation and analysis software</td>
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<tr>
<td></td>
<td>• CANoe Software – ECU simulation software</td>
<td></td>
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<tr>
<td></td>
<td>• CANalyzer Software – Analysis tool for data networks and distributed systems</td>
<td></td>
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<tr>
<td></td>
<td>• 140 EVSE Level 2 Charging Units Deployed to Partner Locations</td>
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<thead>
<tr>
<th>Partners</th>
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<tbody>
<tr>
<td>Austin Energy</td>
<td>• New: Charging Station Infrastructure</td>
</tr>
<tr>
<td>Behr</td>
<td>• Existing: Wind Tunnel, Performance lab</td>
</tr>
<tr>
<td>Clark County</td>
<td>• Existing: Flex Fuel stations, Charging Stations</td>
</tr>
<tr>
<td>Colorado</td>
<td>• Existing: Charging Station Infrastructure</td>
</tr>
<tr>
<td>Electrovaya</td>
<td>• New: Module impact assembly fixtures</td>
</tr>
<tr>
<td>MSU</td>
<td>• Existing: Engine Dynamometers, Fuel Spray Lab, Controls Lab</td>
</tr>
<tr>
<td>NextEnergy</td>
<td>• Existing: Single Cylinder Firing and Optical Engines</td>
</tr>
<tr>
<td>SMUD</td>
<td>• New: Various Software and Hardware, see budget for detailed list</td>
</tr>
<tr>
<td>UM-D</td>
<td>• New: Various Software and Hardware, see budget for detailed list</td>
</tr>
</tbody>
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Vehicle Charging Functionality

**CHARGE NOW**
- No Customer Input
- Minimal System Input
- Highest Charging rate
- Fleet Vehicle May 2011 Implementation

**OPTIMIZED CHARGE**
- Customer Input
- Max System Input
- Most Efficient Charge Rate
- Data Collection & Reporting
- Development Start May 2011
- September 2011 Implementation

**SMART GRID INTERFACE**
- Utility Interface
- Time of Use Rates
- Achieve Optimized Charge @ Lowest Cost
- Minimize effect on Grid
- September 2011 Implementation

**REVERSE POWER FLOW**
- Reverse Power Flow
- Smart Grid Comm.
- Micro Grid Development
- Emergency Load Curtailment
- May 2012 Implementation

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Data Reporting – Technical Accomplishments

Initial Fleet Deployment Implementation – May 2011

- Remote Software Flash
- Remote Diagnostics
- Near Real Time Data Upload

STATUS:
- Chrysler’s PHEV server sends the DoE required Unlimited Rights data to Idaho National Labs (INL) for the purpose of data processing and reporting.

Remote Software Flash
Remote Diagnostics
Near Real Time Data Upload

PHEV Server

DoE data packet

Idaho National Labs (INL) Server

External Interface

User Interface

Optimized Charging
Smart Grid Charging
Reverse Power Flow

DoE Partners
Access only for their fleet

Copy of DoE Data

4th Quarter 2011 Implementation

User Interface

Internet

Cell

KNX Hub
Partner and Vehicle Allocation

Sacramento Municipal Utility District (SMUD) – (14)
California State University, Sacramento
City of San Francisco –(14)
UC Davis PHEV Research Ctr.
EPRI
HNEI, U of Hawaii
U.S. Military

State of Colorado, DOT – (14)
State of N. Dakota, DOT – (14)
Univ. of North Dakota
City of Yuma (10)
N. Arizona Univ, Yuma Ariz Westrn College

State of Michigan – (4)
MSU
U of M
NextEnergy
NYSERDA – (14)
SUNY, Stony Brook

State of – (14) Massachusetts
UMass. Lowell, Dartmouth Amherst

City of Kansas City, Missouri – (4)

State of –(14)

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<table>
<thead>
<tr>
<th>Partner</th>
<th>Fleet Activity</th>
<th>Qty</th>
<th>Deployment Date</th>
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</thead>
<tbody>
<tr>
<td>Clark Co. Automotive Division - Nevada Energy</td>
<td>City and Rural cycles, Hot Climate, High Mileage</td>
<td>10</td>
<td>May-11</td>
</tr>
<tr>
<td>City of Yuma, Arizona - Univ. of Arizona, Yuma</td>
<td>Hot Climate, Diverse drive cycle and use</td>
<td>10</td>
<td>May-11</td>
</tr>
<tr>
<td>Commonwealth of Massachusetts - U of Mass, Amherst</td>
<td>Diverse drive cycle and use</td>
<td>14</td>
<td>Jun-11</td>
</tr>
<tr>
<td>NYSERDA - SUNY, Stony Brook</td>
<td>Diverse use, City and rural</td>
<td>14</td>
<td>Jun-11</td>
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<tr>
<td>State of Michigan</td>
<td>Cold Climate, Diverse use</td>
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<td>Jul-11</td>
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<tr>
<td>State of Colorado</td>
<td>High Altitude exposure, City and Rural cycles</td>
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<td>Jul-11</td>
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<tr>
<td>City Of Kansas City, Missouri</td>
<td>Diverse drive cycle and use</td>
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<td>Jul-11</td>
</tr>
<tr>
<td>State of North Dakota DOT - U of North Dakota</td>
<td>Cold Climate, On and Off road, Rural use of AC</td>
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<td>Aug-11</td>
</tr>
<tr>
<td>SMUD (Sacramento Municipal Utility District)</td>
<td>Diverse drive cycle and use</td>
<td>14</td>
<td>Aug-11</td>
</tr>
<tr>
<td>City of San Francisco - UC Davis</td>
<td>Diverse use</td>
<td>14</td>
<td>Aug-11</td>
</tr>
<tr>
<td>Austin Energy - ERCOT - UT Austin</td>
<td>Pool vehicles for the city of Austin</td>
<td>14</td>
<td>Sep-11</td>
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<tr>
<td>State of Hawaii - U.S. Army - HNEI, UofHawaii Manoa</td>
<td>Diverse use</td>
<td>14</td>
<td>Sep-11</td>
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<tr>
<td>Argonne National Lab</td>
<td>Technology Evaluation and Testing</td>
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<td>TBD</td>
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Future Work

**Phase I: PHEV Development**
- Continue Hot & Cold Weather Validation of vehicle software
- Complete extended vehicle durability and validation
- Continue Calibration/Controls Development and Optimize Fully Integrated Systems
- Charging system / Implement Optimized Smart Charging, and Basic Vehicle to Grid (V2G) interface
- HMI - Hybrid Human Machine Interface (HMI) Display
  - Plug-In Charging HMI display
  - Power Panel HMI Display
  - Functional objective verification
- Fuel Usage Reduction
  - Emissions abatement
  - Driveability
  - Towing

**Phase II: Build and Launch Prep**
- Site preparation – Ship Level 2 EVSE Units for installation at Demonstration Partner Deployment Locations
- Customer/Dealer Service Training
- Build the 140 truck demonstration fleet
  - Install Remaining Batteries
  - Install Remaining Chargers

**Phase III: PHEV Vehicle Demonstration**
- Deploy Vehicles
- Capture Deployed Fleet Data to support Calibration and Controls development
- Enhance Data Reporting Capabilities
- Smart Grid & Reverse Powerflow
- Customer Interface Server

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• Successful development, execution, and validation of the PHEV technology on engineering vehicles.
• Successful completion and deployment of the first 20 demonstration fleet vehicles.
• Successfully demonstrated the PHEV 20-miles All Electric Equivalent drive cycle.
• Successfully overachieved the fuel economy target of 32 mpg in charge depleting cycle.
• Demonstrated capability to meet ATPZEV emission requirements.
• On track to meet program milestones and project deliverables.
• Created “Green” Technology jobs and have a plan in place to sustain them toward future development of electrification programs.
Technical Back-Up Slides

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RAM-1500 PHEV Battery System

Supplier: Electrovaya
Capacity
Pack: 12.9 kWhr
Cell: 33 Ahr used 85% BSOC range
Cell: 37.5 Ahr actual full capacity

Voltage
Pack 390-288 VDC

Technology
Lithium Ion SuperPolymer®
with MN-Series/Graphite chemistry

Validated Battery Characteristics

• State-of-charge (SOC) Estimation
• SOC Limits
• Voltage and Current Limits
• Power Limits
• Cell Balancing Strategy
• Contactor Control
• Diagnostics
Functionality:
• The Power Panel must be pre-enabled by remote starting the vehicle.
• Then, to turn the Power Panel On, press the ON/OFF button on the Power Panel (in the right rear Rambox bin). The green Ready light will illuminate on the Power Panel.
• To turn the Power Panel Off, press the ON/OFF button again.

Performance:
• Up to 6600 watts of total power is available through the combination of Power Panel outlets: (1) 240V/30A 4-prong outlet and (2) 120V/20A duplex outlets.
• The Power Panel has 20A circuit breakers for each of the 120V/20A duplex outlets.
• The OBCM provides protection for GFCI, short circuits, and 30A over-current for all the Power Panel outlets, and over-temperature protection for the inverters inside the OBCM. If any of these occurs, a red Fault light illuminates on the Power Panel.
• A warning (periodic horn chirp and lights flash) is emitted if the low fuel level warning occurs while the Power Panel is On.
• The propulsion system (gasoline and electric) and the Power Panel will be shut down if the fuel tank Distance to Empty (DTE) goes to “Low Fuel”.

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Charger / Inverter - Summary

Scope/Objective

• 6.6 KW OBC with an integrated Inverter for AC Power Generation

Testing and Validation

• Charging Capability under various ambient temperatures and voltage ranges
• Power Output:
  ➢ 6.6kW @ 220Vac
  ➢ 1.4kW @ 110Vac
• Efficiency >95%
• Output Voltage 250Vdc – 400Vdc
• Full Operating Temperature range @ -40°C to 70°C
• Air Cooled
• Level 1 & 2 J-1772 compliant
• CAN Vehicle communication interface:
  ➢ Network Management
  ➢ Flash/read application in vehicle
  ➢ I/O CAN Diagnostic
• Environmental & EMC Requirements:
  ➢ Vehicle Performance
  ➢ Component Performance
  ➢ Environmental Component Testing Specification
• Reliability/Durability Requirements
• Assembly/Service/Packaging/Labels

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Thermal System - Summary

Scope/Objective

• Maintain Optimal Thermal Conditions for PHEV systems efficient operation

Testing and Validation

• Thermal Systems
  • HVAC – Cabin heating and cooling performance maintained
  • A/C Refrigerant Compressor Variable Speed Control
  • Integration of Cabin Cooling and Battery Cooling Compressor Speed Control

• Battery Thermal
  • Battery Chiller & Heater Control Function, Pump Controls and Coolant Flow Confirmed

• Thermal System Controls
  • Cooling and Heating Calibrations (Aug ‘10 & Oct ‘10 respectively)
  • Thermal Management during Level II and I Battery Charging (Oct ‘10 & Nov ‘10 respectively)
  • System Pressure Drop, Battery Heat Rejection, Chiller Capacity, Refrigerant System Capacity - Module Correlation to after completion of vehicle testing

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