Advancing Plug In Hybrid Technology and Flex Fuel Application on a Chrysler Mini-Van PHEV DOE Funded Project

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RT Project Overview

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Timeline

- Project Start: September, 2009
- Project Complete: June, 2014
- 20% Complete

Budget

- Total Project Funding
  - DOE: $10,000,000
  - Chrysler $15,791,697
- Funding received FY09: $0
- Funding received FY10: $0
- Funding received FY11: $1,846,175
- Chrysler Program Total: $5,006,976

*Figures stated are As of: Feb 28, 2011

Barriers

- Battery performance across extreme ambient conditions
- Thermal Management Integration
- Charging System Integration
- Flex Fuel Controls and Calibration for PHEV
- Understanding customer acceptance and usage patterns for PHEV technology

Development Partners :

- Behr America • Electrovaya

Demonstration Partners:

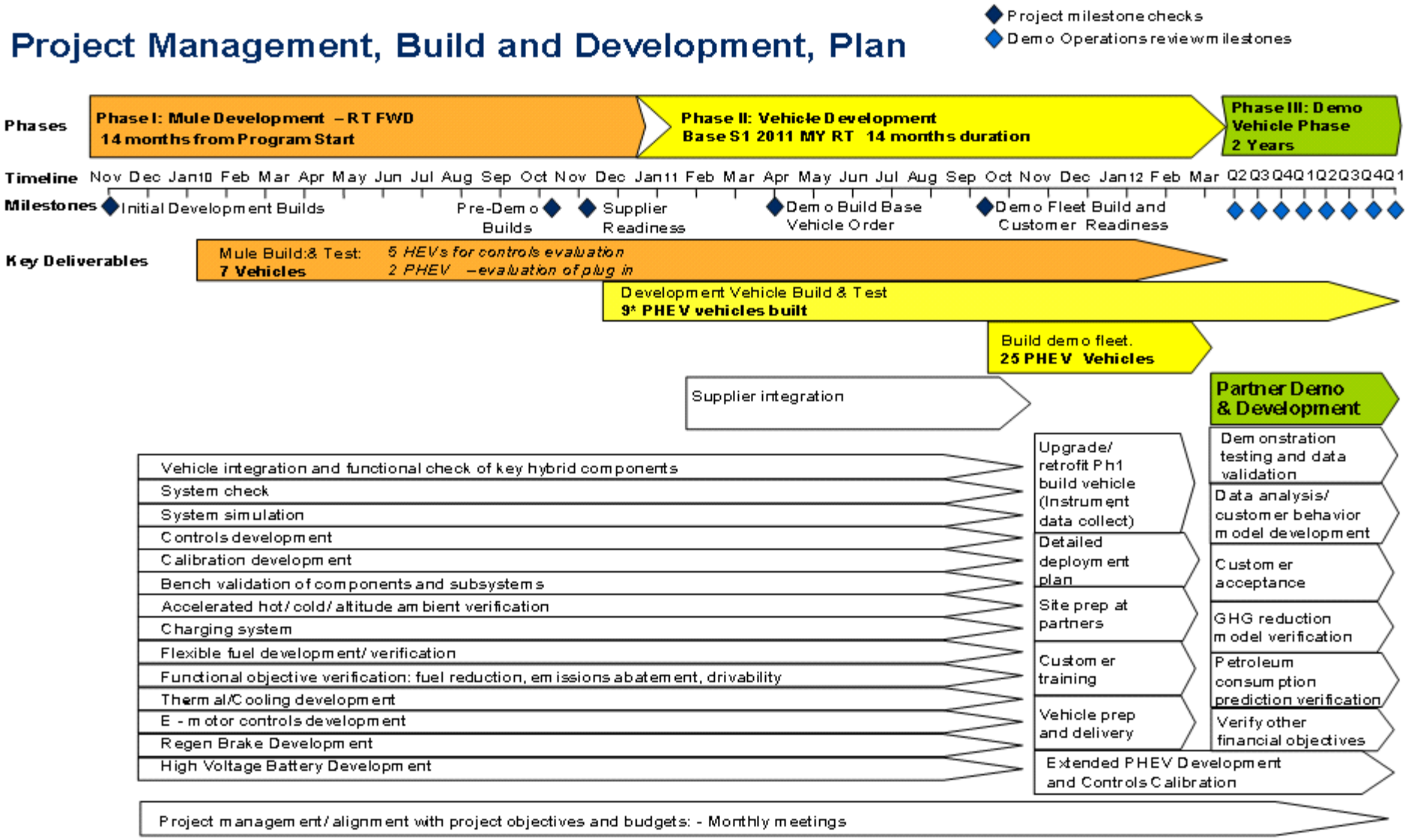
- Sacramento Municipal Utility District (SMUD)
- Austin Energy • State of Michigan
- Argonne National Labs

RT Program Objectives – Relevance

- Demonstrate 25 minivans (RT) in diverse geographies and climates, spanning from Michigan, California, and Texas and across a range of drive cycles and consumer usage patterns applicable to the entire NAFTA region
- Run the vehicles for 2 years with relevant data collected to prove the product viability under real-world conditions
- Quantify the benefits to customers and to the nation
- Develop & demonstrate charging capability
- Develop and demonstrate Flex Fuel (E85) capability with PHEV technology.
- 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
- Integration of PHEV technology with Renewable energy generation

RT Project Plan

Project Management, Build and Development, Plan



* An additional 5 vehicles will be built for impact and compliance testing

Plug-in Hybrid Technical Specifications

Chrysler Town & Country Touring

The only minivan to boast a plug-in hybrid powertrain in combination with Flex Fuel (E85) capability

Hybrid Drive System

Technology
- Next Generation Lithium Ion Battery

Charge Times
- 2-4 hrs at 220V
- 6-8 hrs at 110V
- Full Hybrid system function w/o Plug-in

Fuel Economy (City)
- Charge Depleting 53 MPG

Electric Drive Range (City)
- 22 miles equivalent

Range
- 700 miles

Brakes
- Regenerative Brake System

Powertrain

Engine
- 3.6L V6

Fuel
- Flex Fuel (E85) capability

Maximum Power
- 290 Horsepower

Wheels / Tires

Wheels
- 16" x 6.5" Aluminum

Tires
- 225/65 R16 BSW All Season

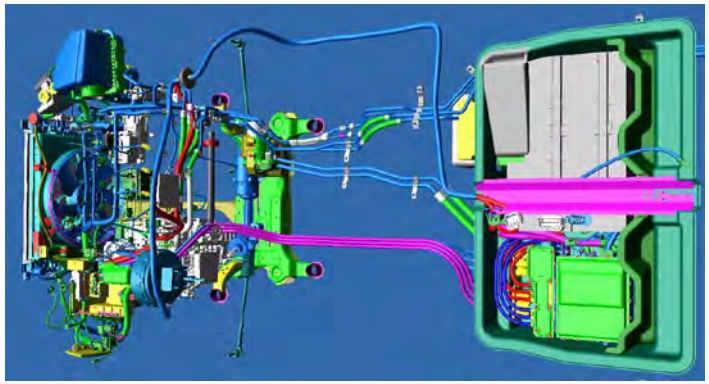
Additional Features
- Dual Power Sliding Doors
- 2nd Row Stow 'N Go
- 3rd Row Stow 'N Go
- Satellite / Navigation Radio
- Engine Block Heater

Interior Dimensions

Cargo Capacity (behind front seat)
- 140.1 Cubic Feet

Passenger Volume
- 156.1 Cubic Feet

Seating Capacity
- 7 Passenger



Exterior Dimensions

Vehicle Length
- 202.5"

Overall Height
- 68.9"

Body Width
- 76.9"

Ground Clearance
- 6.1" @ Curb Weight

Track
- 65.5" Front
- 64.8" Rear

Turning Diameter
- 38.0' Curb to Curb

Wheelbase
- 121.2"

Capacities / Weights

Curb
- 5446 lbs

Fuel Tank Capacity
- 20.5 gallons

GCWR
- 9,050 lbs

GVWR
- 6,250 lbs

Payload
- 1,200 lbs

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

Technical Approach

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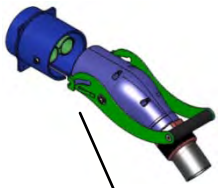
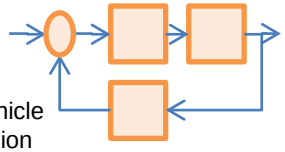
J1772 Charge Port Level I / II

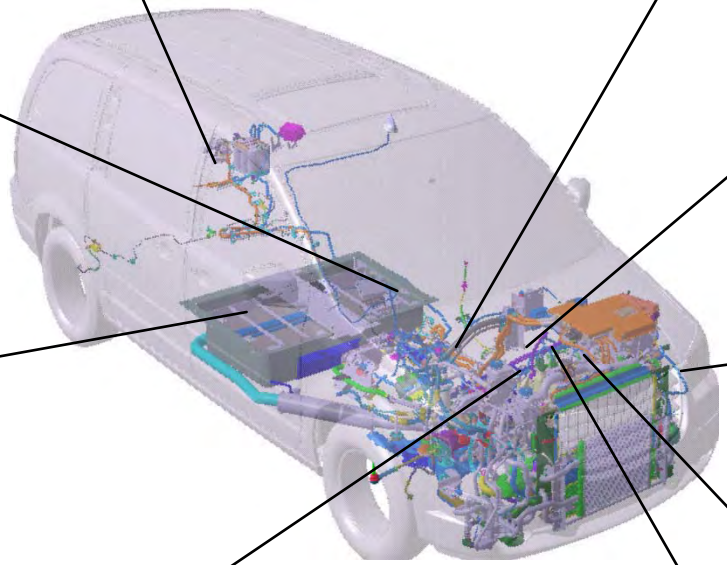


Plug In Hybrid Controls

- E- Motor
- Battery
- Hybrid Vehicle
- Transmission



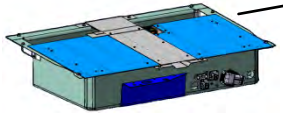
6.6 Kw Charger



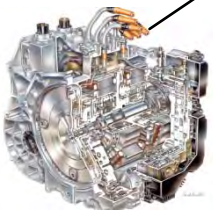
3.6 L Pentastar V-8 Engine

- **290 hp Gas Engine**
- **345 hp Total Hybrid System**

Thermal Systems



HV Battery Li-Ion
12.9 kWhr
Liquid Cooled



2-Mode Hybrid Transmission

Electric Motors

Power Electronics Inverter DC/DC

Phase I – Technical Actions

- Design & Package PHEV Components
- Virtual modeling & Simulation of PHEV technology
- Component level Bench Testing of new PHEV components, software and calibrations
- Retrofit Base Gas Vehicle with PHEV Technology
  - i. Design, Package, and Install Li-Ion Battery
  - ii. Design, Package, and Install Charger
  - iii. Design, Package, and Install controls for battery thermal module, and Power Electronics
  - iv. Develop controls and calibration for PHEV
  - v. Update remaining thermal system components for PHEV
  - vi. Design, Package, and Install LV & HV Wiring
  - vii. Modify 3.6L Pentastar Engine to accept Hybrid Componentry
  - viii. Retrofit Vehicle with 2-Mode Hybrid Transmission
  - ix. Instrument vehicle for PHEV testing & validation

RT - Milestones

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Phase I: PHEV Development – 2009/10/11

☑ Simulate key systems to confirm sub-system technical specifications

Built 7 Mini-Vans for Mule Level Engineering Development

- HV Battery System (2 Early Vintage – 5 New Architecture)
- Thermal System (5)
- 2 Mode Hybrid Transmission (all)
- Re-Generative Brake System (5)
- Engine Controls / Power Electronics (all)
- Hybrid System Controls (all)

☑ Successfully Completed Summer Hot Weather Development Trip Testing

Southwest Quadrant U.S. (Death Valley, Stove Pipe, Bakers Grade, Las Vegas (City Cycle), Phoenix (Chrysler APG)

☑ 1st week: Successfully completed vehicle shake down and APG Testing

☑ 2nd week: Successfully completed testing and calibration modifications

☑ 3rd week: Successfully validated software calibration packages

RT - Milestones

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Phase 2: Refine Vehicle Verification Objectives

Build 9 Development (DV) Vehicles + 5 Impact Vehicles = 14 DV Vehicles

- ☑ Finalize PHEV component and sub-system designs
- ☑ Supplier selection and component sourcing
- ☑ Perform Vehicle packaging & Structural Enhancements
- ☑ Confirm Key features and functionalities
- ☑ Define system level and vehicle level test plans
- ☑ Develop tooling and procure required equipment
- ☑ Procure Instrumentation equipment
- ☑ Order carrier vehicles for DV Mini-Van Build

  HV Battery Packs, HV&LV Wiring , 2 mode Hybrid Transmissions, Power Electronics, Re-Gen Brakes, Thermal Management Components, Charging System Components, Structural Components

- ☑ Procure all components required for the 14 Development vehicles and build 14 Mini-Vans
- ☑ Perform Vehicle level testing on the Mini-Van as part of the PHEV system controls development.

Technical Accomplishments – Vehicle Build & Test

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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:** Planned 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**: Planned for powertrain, high mileage, two charge cycles per day.

Technical Accomplishments (Cont.)

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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^{o}F to 125^{o}F while providing predictable and reliable vehicle performance
- **Developed charging system** capable of charging up to 6.6Kw
- **PHEV systems integrated** cold start, cold drive, EV Drive, start/stop, thermal management, battery SOC operational boundaries, level 1 & level 2 torque security validation, transmission dynamometer for E-Motor PHEV drive cycle

Technical Accomplishments – FE & Emissions

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<table>
<tr><th></th><th>Proposal</th><th>Status</th><th>Procedure</th></tr>
<tr><td>RANGE</td><td>Equivalent All Electric Range (EAER) of 22 miles</td><td>Simulation results have shown that 20+ miles EAER can be achieved.</td><td>California Exhaust Emission Standards And Test Procedures, as amended December 2, 2009</td></tr>
<tr><td>EMISSIONS (SIMS Only)</td><td>Tier 2 Bin5 Compliance with Indolene & E-85</td><td>Standards and Internal Goals for FTP
<table>
<tr><th rowspan="2">Tier 2 Standard</th><th colspan="3">Emission Limits at 50,000 miles</th><th colspan="3">Emission Limits at Full Useful Life (120,000 miles)</th></tr>
<tr><th>NOx (g/mi)</th><th>NMOG (g/mi)</th><th>CO (g/mi)</th><th>NOx (g/mi)</th><th>NMOG (g/mi)</th><th>CO (g/mi)</th></tr>
<tr><td>Fed Bin 5</td><td>0.05</td><td>0.075</td><td>3.4</td><td>0.07</td><td>0.09</td><td>4.2</td></tr>
</table>
<table>
<tr><th rowspan="2">Chrysler Minivan PHEV Target</th><th colspan="3">Emission Limits at 50,000</th><th colspan="3">Emission Limits at Full</th></tr>
<tr><th>NOx (g/mi)</th><th>NMOG (g/mi)</th><th>CO (g/mi)</th><th>NOx (g/mi)</th><th>NMOG (g/mi)</th><th>CO (g/mi)</th></tr>
<tr><td>0.033</td><td>0.053</td><td>1.7</td><td>0.046</td><td>0.063</td><td>2.1</td></tr>
</table></td><td>Procedures as listed in TITLE 40--Protection of Environment
CHAPTER I--ENVIRONMENTAL PROTECTION AGENCY
SUBCHAPTER C--AIR PROGRAMS
PART 86--CONTROL OF EMISSIONS FROM NEW AND IN-USE HIGHWAY VEHICLES AND ENGINES.</td></tr>
<tr><td>FUEL ECONOMY</td><td>Charge Depleting City 53 MPG</td><td>– FE CITY: Simulation results – 47.7 MPG + 16.07 kWh/100mi
» Utility Factors (SAE J 2841) based - CD & CS are combined and reported as one number; Fuel Energy & Electrical Energy reported separately (no MPGe).
» Vehicle kWh/100mi was calculated using a nominal charging system efficiency of 88%.</td><td>SAE J 1711, Date Published: 2010-06-08.</td></tr>
</table>

Key Facilities & Equipment Used by Chrysler and Demonstration Partners at Development & Demo Sites

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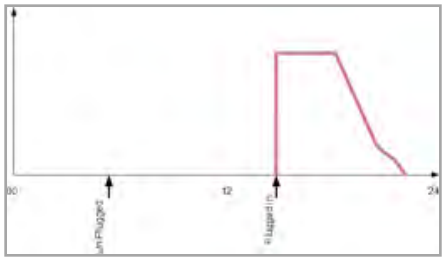
	Facilities / Infrastructure	Equipment : All New
Chrysler	**All Existing:** • Windsor Assembly plant, Windsor, MI • Chrysler Technical Center – Auburn Hills, MI – Fuel Economy Testing, Altitude chamber, Static Hot/Cold cell, Environmental Drive cell • Chelsea Proving Grounds – Chelsea, MI – Sled-impact testing site, Covered crash barrier, Skid traction area, Mileage accumulators, Emissions certification Center, Wind tunnel	• ETAS Hardware – Automotive Electronic Control Unit (ECU) calibration • ETK – ECU Interface • ES – Measurement and Network Modules • INCA Software – ETAS software for ECU calibration • Matlab Simulink – General engineering data computation and analysis software • CANoe Software – ECU simulation software • CANalyzer Software – Analysis tool for data networks and distributed systems • 25 EVSE Level 2 Charging Units Deployed to Partner Locations
Partners		
Austin Energy	• New: Charging Station Infrastructure	
Behr	• Existing: Wind Tunnel, Performance lab	• Existing: System Calorimeter
Electrovaya		• New: Module impact assembly fixtures
SMUD	• New: Charging Station Infrastructure • Existing: Advanced Metering Infrastructure	
State of Michigan	• New: Charging Station Infrastructure	

Vehicle Charging Functionality

CHARGE NOW

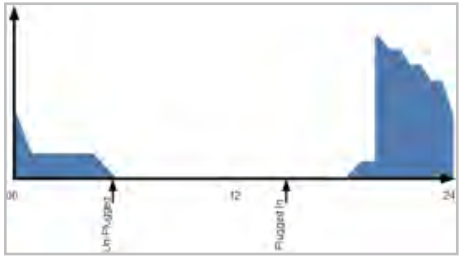


REPORTS

DATA

SERVER

OPTIMIZED CHARGE



REPORTS

DATA

SERVER

Improvements to Charge Efficiency

- No Customer Input
- Minimal System Input
- Highest Charging rate
- **Fleet Vehicle March 2012 Implementation**

- Customer Input
- Max System Input
- Most Efficient Charge Rate
- Data Collection & Reporting
- Development Start May 2011
- **March 2012 Implementation**

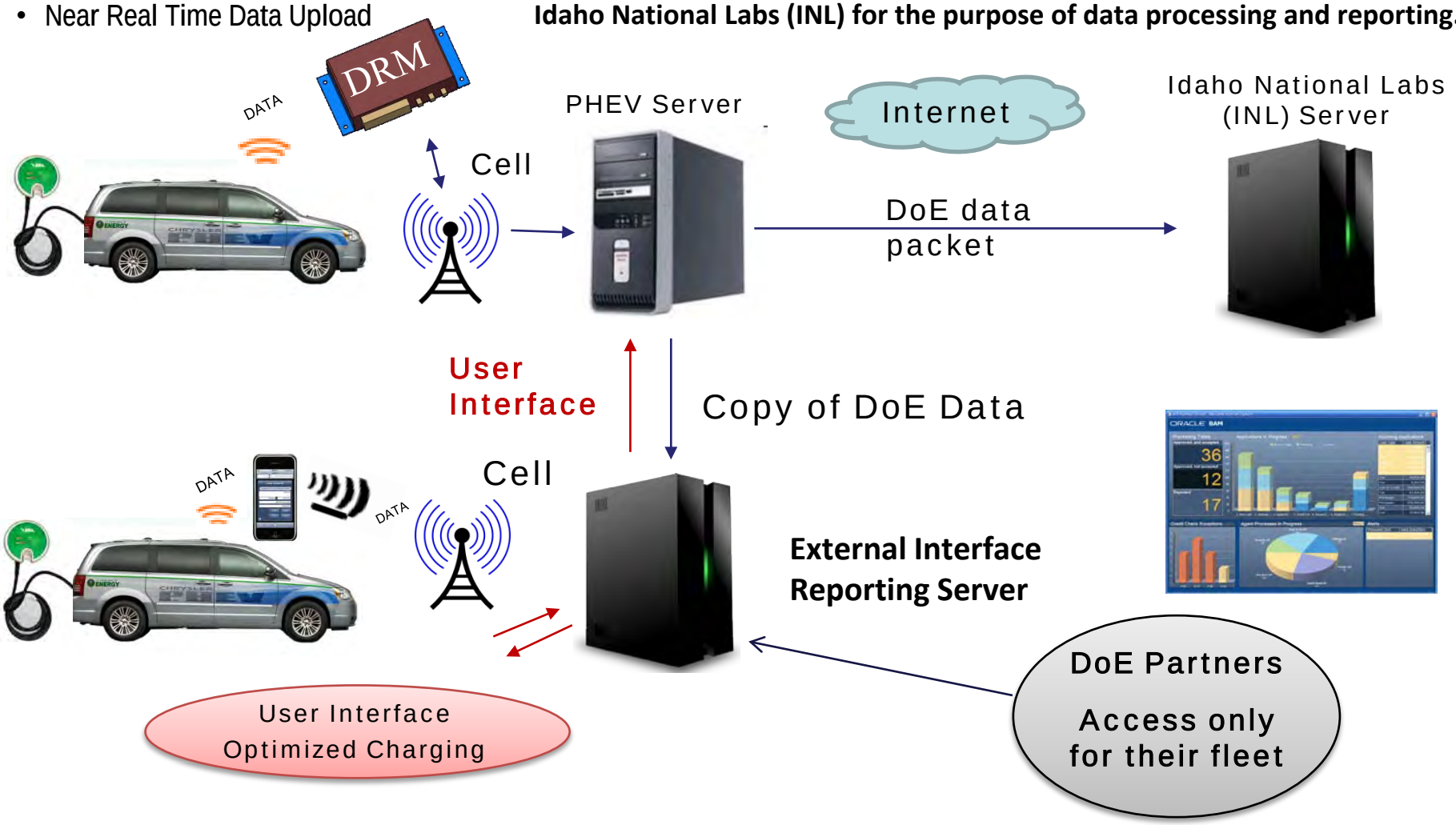
Data Reporting – Technical Accomplishments

Initial Fleet Deployment Implementation – March 2012

- 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.**



PHEV Mini-Van Demonstration
Partner Vehicle Deployment Plan

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Partner	Fleet Activity	Qty	Deployment Date
State of Michigan	Cold Climate Diverse use	4	Mar-12
SMUD (Sacramento Municipal Utility District)	Diverse drive cycle and use	10	Mar-12
Austin Energy - ERCOT - UT Austin	Pool vehicles for the city of Austin	10	Mar-12
Argonne National Lab	Technology Evaluation and Testing	1	Mar-12

Future Work

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Phase I: PHEV Development

- Complete Cold Weather Validation of vehicle software, calibration and component tests
- Complete vehicle durability and validation
- Calibration/Controls Development
- Charging system
- HMI
  i. Hybrid Human Machine Interface (HMI) Display
  ii. Plug-In Charging HMI Display
- Functional objective verification
  i. Fuel reduction
  ii. Flex Fuel Capability
  iii. Drivability

Phase II: Build and Launch Prep

- Site preparation – Ship Level 2 EVSE Units for installation at Demonstration Partner Deployment Locations
- Customer/Dealer training
- Build the 25 Mini-Van demonstration fleet
- Vehicle Prep and Delivery

Phase III: PHEV Vehicle Demonstration

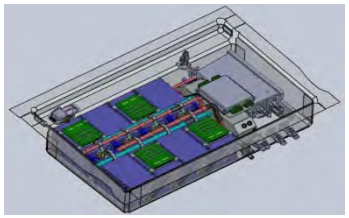
- Data Capture / Analysis / Continue Modifications & Optimizations
- Enhance Data Reporting Capabilities
- Optimize Charge Development and Calibration
- Customer Interface Server

Summary

- Official Award received from the DOE October 2010
- Management process established.
- Successful Upgrade of 7 Mule Vehicles
- Successful Hot Trip Testing
- On track to meet program milestones and project deliverables.
- Successful development, execution, and validation of the PHEV technology on engineering level vehicles.
- Successfully demonstrated the PHEV 22 miles All Electric Equivalent drive cycle.
- Scheduled FE Testing to support the target fuel economy level of 53 mpg in charge depleting cycle (electric equivalent range EAER).
- On track to meet program milestones and project deliverables.
- Created “Green” core competency jobs and have a plan in place to sustain them toward future development of electrification programs.

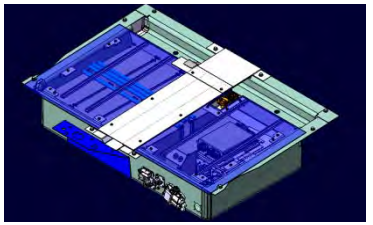
Technical Back-Up Slides

RT MiniVan PHEV – Battery System Summary



Electrovaya - Major Contributions

- Design/Engineering /Simulation/Testing/Packaging
- Cell manufacturing in Mississauga, Ontario.
- Battery Pack manufacturing in Malta, NewYork



RT – MiniVan Battery Specification

Cell Specs:	**96 cells in series**	**360 V nominal pack voltage**
Cell Chemistry:	33.3 Ah Prismatic pouch cell	Lithium NCM blended cell chemistry
Energy:	12 kWh overall pack energy	8 kWh useable energy for Charge Depleting cycle
Charge Capacity:	Charging at up to 6 kW rate	35 kW discharge power during charge depleting cycle
Thermal System:	Liquid cooled with glycol/water coolant	Unique “Heli-cool” battery modules with integrated cooling loop
Packaging:	The battery is packaged in the “Stow-n-Go” tub space.	Located between the first and second row seats.

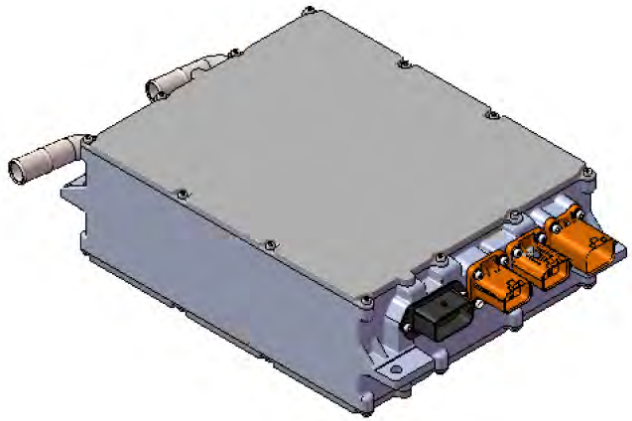
Charging System - Summary

Scope/Objective

- 6.6 KW On-board Charger

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 @ -40C to 70C
- 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
    - Vibration, Water Intrusion, Dust, Mechanical/Thermal Shock, High/Temp Endurance, Thermal Humidity.
- Reliability/Durability Requirements
- Assembly/Service/Packaging/Labels



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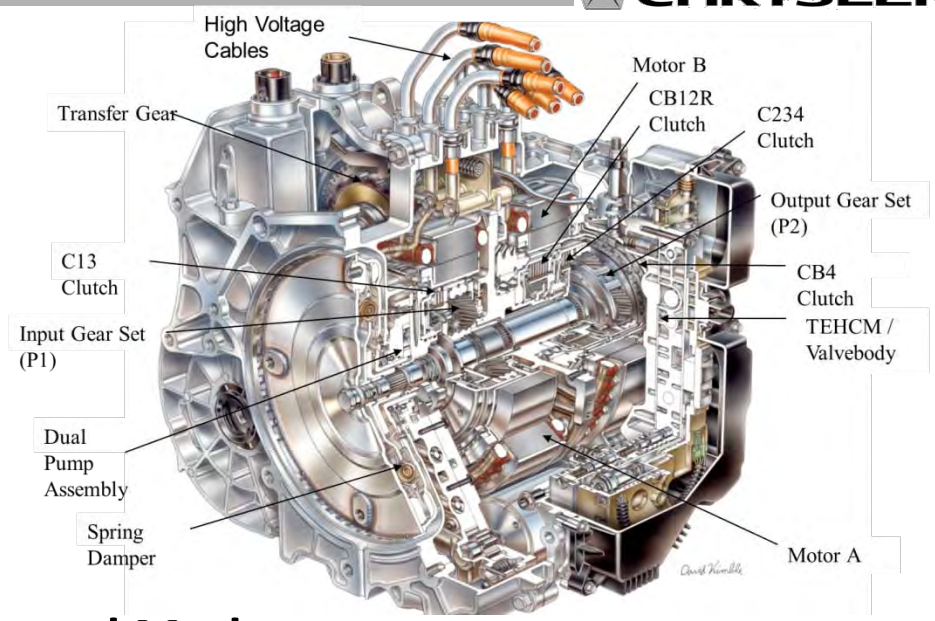
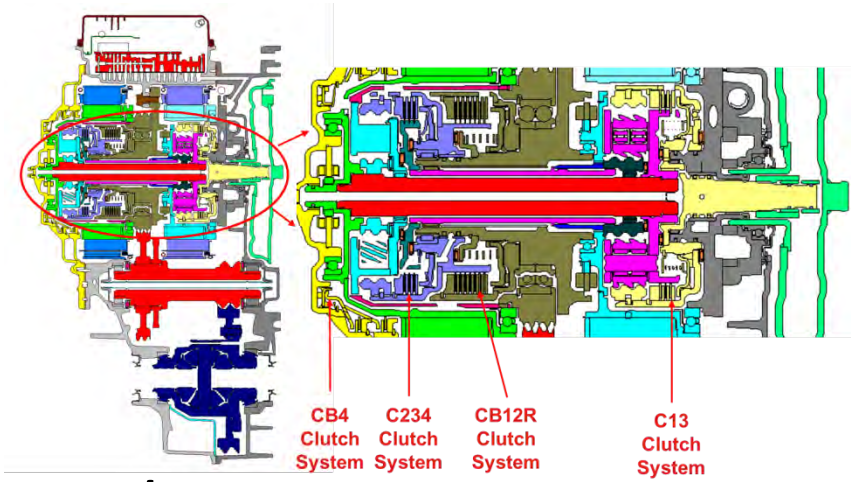
AHSF Information

- **Two (2) EVT Modes**
- **Four (4) Fixed Gears**
- **Two (2) Planetary Gear Sets**
  - One (1) Compound – Dual Planets
  - One (1) Single Planets



- **Synchronous Shifting between Gears and Modes**
- **Two (2) Pumps**
  - One (1) Mechanical – Engine Driven
  - One (1) Electric
- **Four (4) Wet Clutches**
  - Two (2) Brake
  - Two (2) Rotating



- **Damper Bypass Clutch for smooth engine start/stop**

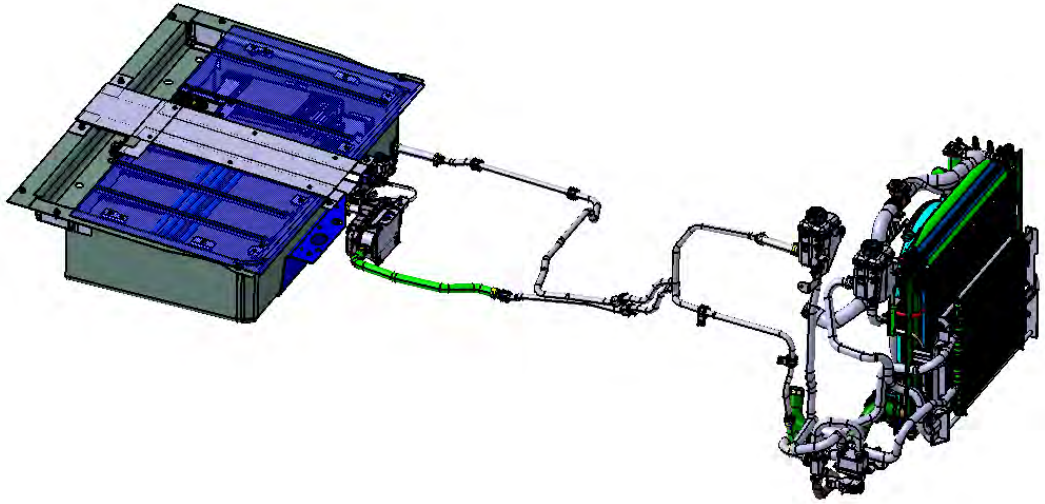
Behr America – Major Contributions

- 1D system simulation to size heat exchangers and pumps
- CAD packaging and design of major thermal system components
- Fabrication of all heat exchangers
- Sourcing of coolant and A/C hose & tube assemblies, coolant control valves
- Full system bench testing prior to vehicle installation

RT – MiniVan Thermal System Overview

Major Components

- Engine Cooling
- Battery Heating & Cooling
- Charging System Cooling
- Power Electronics Cooling



RT – Fuel Economy Targets

Base RT FE cert (4750 ETW)

Unadjusted City @ 20.60 Label 17 (MPG method)
Unadjusted Hwy @ 34.15 Label 25 (MPG method)

RT PHEV Targets (5500 ETW)

Charge Depleting : FE CITY: Simulation results – 47.7 MPG + 16.07 kWh/100mi

- Utility Factors (SAE J 2841) based - **CD & CS** are combined and reported as one number; Fuel Energy & Electrical Energy reported separately (no MPGe).
- Vehicle kWh/100mi was calculated using a nominal charging system efficiency of 88%.

Charge Sustaining

Unadjusted Charge Sustaining City @ 30.90 Unadj; Label 24 (MPG method)
Unadjusted Charge Sustaining Hwy @ 37.57 Unadj; Label 27 (MPG method)