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

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Chrysler Group LLC
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Project ID # VSS063

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RT Project Overview

**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

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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

Phases
- Phase I: Mule Development - RT FWD
  14 months from Program Start
- Phase II: Vehicle Development
  Base S1 2011 MY RT  14 months duration
- Phase III: Demo Vehicle Phase
  2 Years

Timeline
- Nov Dec Jan10 Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan11 Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan12 Feb Mar
- Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1

Milestones
- Initial Development Builds
- Pre-Demo Builds
- Supplier Readiness
- Demo Build Base Vehicle Order
- Demo Fleet Build and Customer Readiness

Key Deliverables
- Mule Build & Test: 5 HEVs for controls evaluation
- 7 Vehicles
- 2 PHEV - evaluation of plug in

Development Vehicle Build & Test
- 9 PHEV vehicles built

Build demo fleet.
- 25 PHEV Vehicles

Supplier integration

Vehicle integration and functional check of key hybrid components
- System check
- System simulation
- Controls development
- Calibration development
- Bench validation of components and subsystems
- Accelerated hot/cold/altitude ambient verification
- Charging system
- Flexible fuel development/verification
- Functional objective verification: fuel reduction, emissions abatement, drivability
- Therm a/c cooling development
- E - motor controls development
- Regen Brake Development
- High Voltage Battery Development

Partner Demo & Development
- Upgrade/retrofit Ph1 build vehicle (Instrument data collect)
- Detailed deployment plan
- Site prep at partners
- Customer acceptance
- GHG reduction model verification
- Customer training
- Petroleum consumption prediction verification
- Vehicle prep and delivery
- Verify other financial objectives
- Extended PHEV Development and Controls Calibration
- Demonstration testing and data validation
- Data analysis/customer behavior model development

Project management/alignment with project objectives and budgets: - Monthly meetings

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

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### 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

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#### 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

#### Capacities / Weights
- **Curb**
  - 5446 lbs
- **Fuel Tank Capacity**
  - 20.5 gallons
- **GCWR**
  - 9,050 lbs
- **GVWR**
  - 6,250 lbs
- **Payload**
  - 1,200 lbs

#### 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”

#### Fuel Economy (City)
- Charge Depleting 53 MPG
- Electric Drive Range (City)
  - 22 miles equivalent
- Range
  - 700 miles
- Brakes
  - Regenerative Brake System

#### 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

#### 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

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

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6.6 Kw Charger

HV Battery Li-Ion
12.9 kWh
Liquid Cooled

2-Mode Hybrid Transmission

Electric Motors

3.6 L Pentastar V-8 Engine
• 290 hp Gas Engine
• 345 hp Total Hybrid System

J1772 Charge Port
Level I / II

Plug In Hybrid Controls
• E-Motor
• Battery
• Hybrid Vehicle
• Transmission

Thermal Systems

Power Electronics Inverter
DC/DC

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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

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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
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.

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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.)

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 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

<table>
<thead>
<tr>
<th>RANGE</th>
<th>Proposal</th>
<th>Status</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td></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>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EMISSIONS (SIMS Only)</th>
<th>Proposal</th>
<th>Status</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 2 Bin5 Compliance with Indolene &amp; E-85</td>
<td>Standards and Internal Goals for FTP</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>
<td></td>
</tr>
</tbody>
</table>

### Tier 2 Standard

<table>
<thead>
<tr>
<th>Fed Bin 5</th>
<th>Emission Limits at 50,000 miles</th>
<th>Emission Limits at Full Useful Life (120,000 miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NOx (g/mi)</td>
<td>NMOG (g/mi)</td>
</tr>
<tr>
<td>Fed Bin 5</td>
<td>0.05</td>
<td>0.075</td>
</tr>
</tbody>
</table>

### Chrysler Minivan PHEV Target

<table>
<thead>
<tr>
<th>Emission Limits at 50,000</th>
<th>Emission Limits at Full Useful Life (120,000 miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx (g/mi)</td>
<td>NMOG (g/mi)</td>
</tr>
<tr>
<td>0.033</td>
<td>0.053</td>
</tr>
</tbody>
</table>

## FUEL ECONOMY

<table>
<thead>
<tr>
<th>Proposal</th>
<th>Status</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<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 &amp; CS are combined and reported as one number; Fuel Energy &amp; 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>
</tbody>
</table>
### Key Facilities & Equipment Used by Chrysler and Demonstration Partners at Development & Demo Sites

<table>
<thead>
<tr>
<th>Facilities / Infrastructure</th>
<th>Equipment: All New</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chrysler</strong></td>
<td></td>
</tr>
<tr>
<td><strong>All Existing:</strong></td>
<td></td>
</tr>
<tr>
<td>• Windsor Assembly plant, Windsor, MI</td>
<td>• ETAS Hardware – Automotive Electronic Control Unit (ECU) calibration</td>
</tr>
<tr>
<td>• Chrysler Technical Center – Auburn Hills, MI</td>
<td>• ETK – ECU Interface</td>
</tr>
<tr>
<td>— Fuel Economy Testing, Altitude chamber, Static Hot/Cold cell, Environmental Drive cell</td>
<td>• ES – Measurement and Network Modules</td>
</tr>
<tr>
<td>• Chelsea Proving Grounds – Chelsea, MI</td>
<td>• INCA Software – ETAS software for ECU calibration</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>
</tr>
<tr>
<td></td>
<td>• CANoe Software – ECU simulation software</td>
</tr>
<tr>
<td></td>
<td>• CANalyzer Software – Analysis tool for data networks and distributed systems</td>
</tr>
<tr>
<td></td>
<td>• 25 EVSE Level 2 Charging Units Deployed to Partner Locations</td>
</tr>
<tr>
<td><strong>Partners</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Austin Energy</strong></td>
<td><strong>Behr</strong></td>
</tr>
<tr>
<td>• New: Charging Station Infrastructure</td>
<td>• Existing: Wind Tunnel, Performance lab</td>
</tr>
<tr>
<td><strong>Electrovaya</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Existing: System Calorimeter</td>
</tr>
<tr>
<td><strong>SMUD</strong></td>
<td></td>
</tr>
<tr>
<td>• New: Charging Station Infrastructure</td>
<td>• New: Module impact assembly fixtures</td>
</tr>
<tr>
<td>• Existing: Advanced Metering Infrastructure</td>
<td></td>
</tr>
<tr>
<td><strong>State of Michigan</strong></td>
<td></td>
</tr>
<tr>
<td>• New: Charging Station Infrastructure</td>
<td></td>
</tr>
</tbody>
</table>
Vehicle Charging Functionality

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

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

Improvements to Charge Efficiency

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Initial Fleet Deployment Implementation – March 2012

**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

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## PHEV Mini-Van Demonstration
### Partner Vehicle Deployment Plan

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

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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
## Electrovaya - Major Contributions

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

## RT – MiniVan Battery Specification

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