Advancing Transportation Through Vehicle Electrification - PHEV

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Chrysler Group LLC

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Project ID # ARRAVT067

Overview

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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

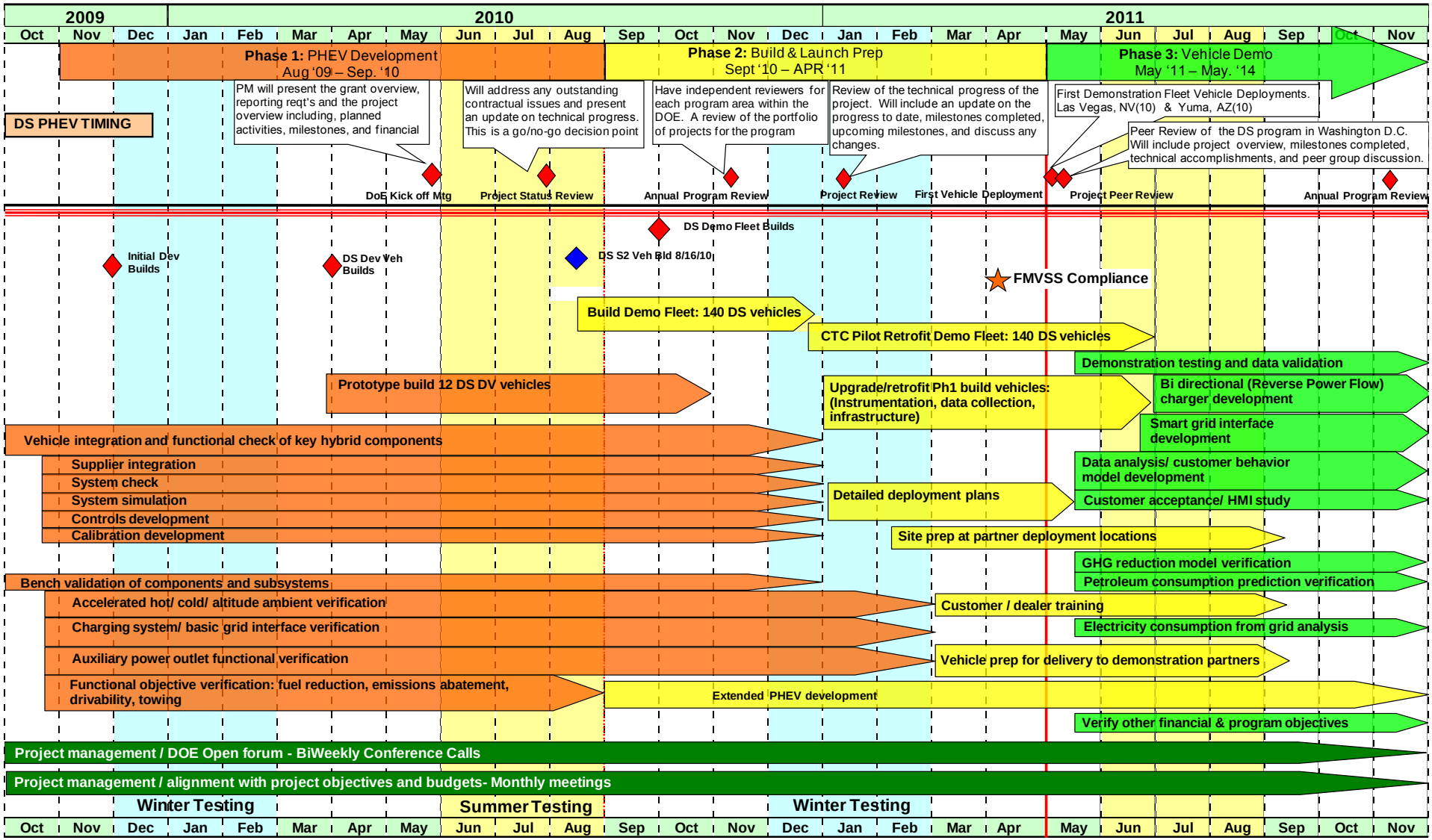
Demonstration Partners

• 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

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

Project Overview : Approach & Timing



Technical Approach

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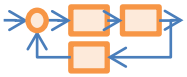
120V / 240V AC Power Panel 6.6 Kw

J1772 Charge Port Level I / II

Controls

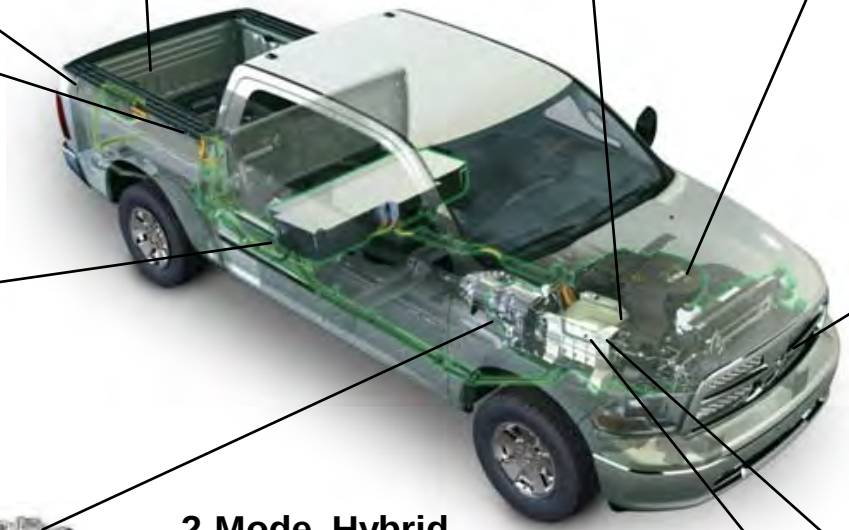
- E Motors
- Battery
- Hybrid Vehicle
- Transmission



5.7 L Hemi V-8 Engine

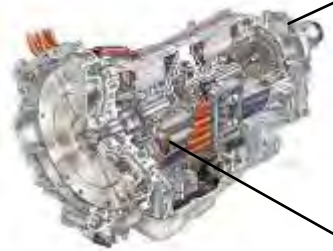
- 345 hp Gas Engine
- 399 hp Total Hybrid System

6.6 Kw Charger / Inverter



HV Battery Li-Ion
12.9 kWhr
Liquid Cooled

Thermal Systems



2-Mode Hybrid Transmission

- 2 EVT Modes
- 4 Fixed Gears
- 65 Kw Motors

Electric Motors

Power Electronics Inverter and DC /DC

Technical Specifications - Accomplishments

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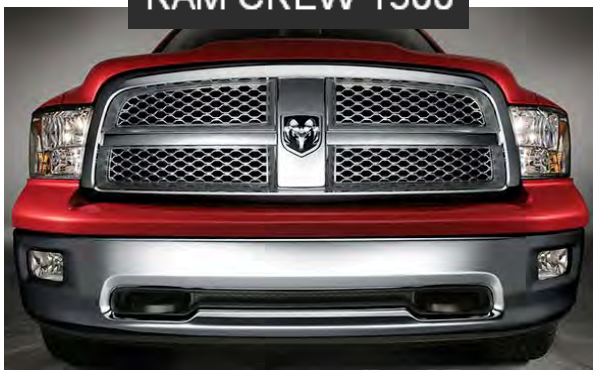
RAM CREW 1500



- 6000 pounds towing and 32% grade capability.
- Only full size truck with Advanced Technology Partial Zero Emissions

- Features the unique utility and functionality of on-board AC power
- Is a low cost alternative to aftermarket commercial grade diesel generators
- Eliminates the need for a separate generator fuel supply

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
- 19.2º / 21.9º

Breakover
- 15.2º

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)

Tires
- P265/70R17 BSW All Season 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

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:** 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.

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 a PHEV truck capable of 7200 GVW & 12,100 GCWR capable of operating over temperature -20^{o}F to 125^{o}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

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	Proposal	Status	Procedure
RANGE	Equivalent All Electric Range (EAER) of 20 miles	20+ miles EAER achieved	California Exhaust Emission Standards And Test Procedures, as amended December 2, 2009
EMISSIONS	ATPZEV Compliance	– SULEV TP emissions demonstrated for » Charge Depleting (CD) City and Hwy Cycles. » Charge Sustaining (CS) City, Hwy, US06,and ColdCO cycles. – Based on testing with prior development test vehicles , SULEV TP emissions requirements can be met for 50F test and SC03 cycle. – Met the PZEV Evap Emissions requirements for » Rig Test, based on the purge volume measurements during the 3bag City Cycle. Based on testing with prior development test vehicles , PZEV Evap emission requirements can be met for whole vehicle SHED test, ORVR and Running loss.	California Exhaust Emission Standards And Test Procedures, as amended December 2, 2009
FUEL ECONOMY	Charge Depleting City 32 MPG	– FE CITY: Exceeded 32 MPG » 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%. Charger development ongoing.	SAE J 1711, Date Published: 2010-06-08.

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

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

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Facilities / Infrastructure

All Existing:

- Warren Truck Assembly plant, Warren 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

Equipment : All New

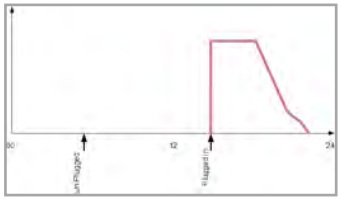
- ETAS Hardware – Automotive Electronic Control Unit (ECU) calibration
- ETK – ECU Interface
- ES – Measurement and Network Modules
- INCA Software – ETAS software for ECU calibration
- Matlab Simulink – General engineering data computation and analysis software
- CANoe Software – ECU simulation software
- CANalyzer Software – Analysis tool for data networks and distributed systems
- 140 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
Clark County	• Existing: Flex Fuel stations, Charging Stations	
Colorado	• Existing: Charging Station Infrastructure	
Electrovaya		• New: Module impact assembly fixtures
MSU	• Existing: Engine Dynamometers, Fuel Spray Lab, Controls Lab	• Existing: Single Cylinder Firing and Optical Engines
NextEnergy	• New: MicroGrid Power Test Pavilion	
SMUD	• New: Charging Station Infrastructure • Existing: Advanced Metering Infrastructure	
UM-D	• Existing: Power Electronics and Electric Drive Lab, Inst. of Advanced Veh Systems, Electromagnetic Capability Lab, Hybrid vehicle powertrain Lab	• New: Various Software and Hardware, see budget for detailed list

Vehicle Charging Functionality

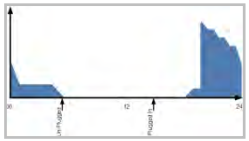
CHARGE NOW

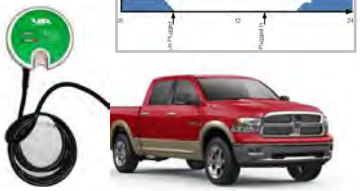


- No Customer Input
- Minimal System Input
- Highest Charging rate
- **Fleet Vehicle May 2011 Implementation**

Improvements to Charge Efficiency

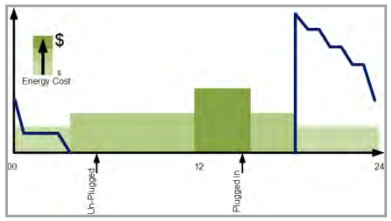
OPTIMIZED CHARGE





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

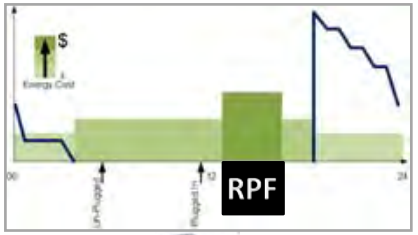
SMART GRID INTERFACE

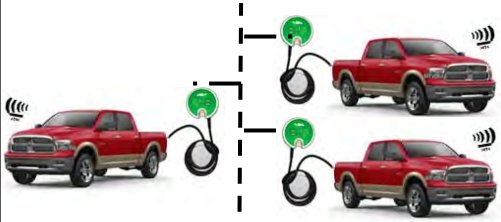


- Utility Interface
- Time of Use Rates
- Achieve Optimized Charge @ Lowest Cost
- Minimize effect on Grid
- **September 2011 Implementation**

REVERSE POWER FLOW

AMI





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

Data Reporting – Technical Accomplishments

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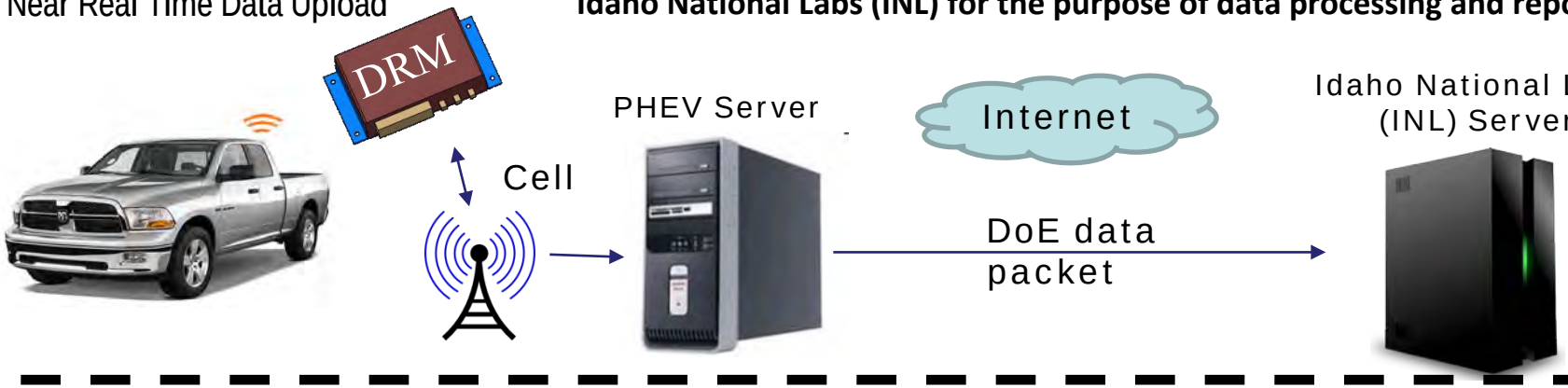
Initial Fleet Deployment Implementation – May 2011

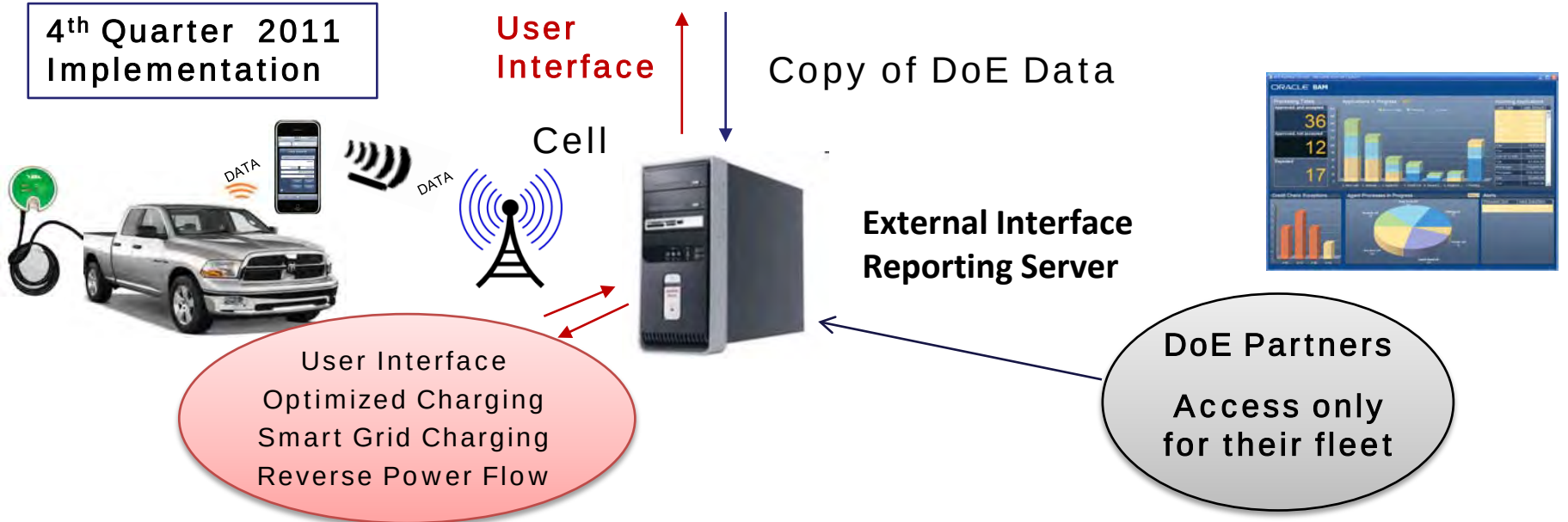
- Remote Software Flash
- Remote Diagnostics
- Near Real Time Data Upload

STATUS:

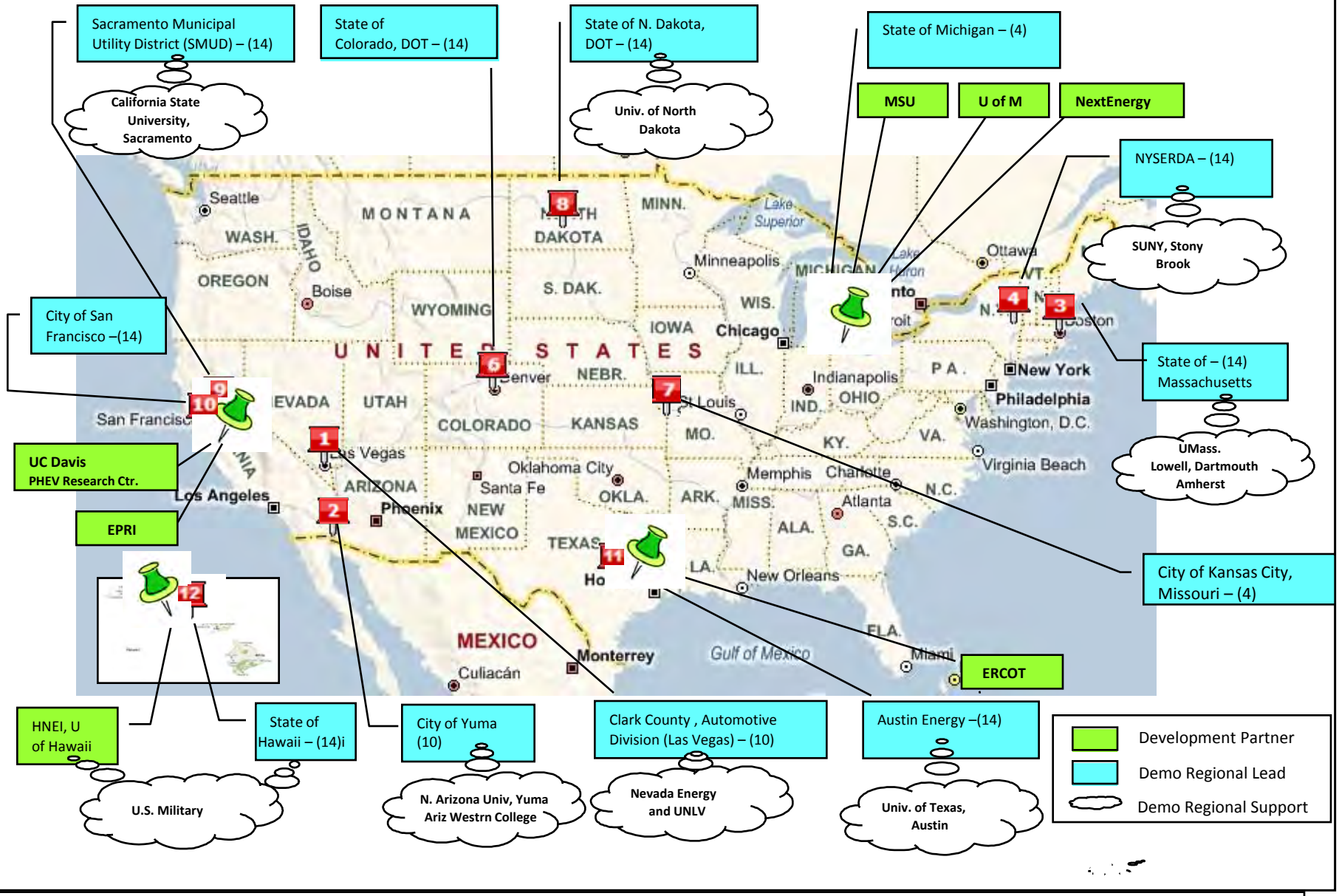
- **Chrysler's PHEV server sends the DoE required Unlimited Rights data to Idaho National Labs (INL) for the purpose of data processing and reporting.**



4th Quarter 2011 Implementation



Partner and Vehicle Allocation



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Partner Vehicle Deployment Plan

Partner	Fleet Activity	Qty	Deployment Date
Clark Co. Automotive Division - Nevada Energy	City and Rural cycles Hot Climate High Mileage	10	May-11
City of Yuma, Arizona - Univ. of Arizona, Yuma	Hot Climate Diverse drive cycle and use	10	May-11
Commonwealth of Massachusettes - U of Mass, Amherst	Diverse drive cycle and use	14	Jun-11
NYSERDA - SUNY, Stony Brook	Diverse useage City and rural	14	Jun-11
State of Michigan	Cold Climate Diverse use	4	Jul-11
State of Colorado	High Altitude exposure City and Rural cycles	14	Jul-11
City Of Kansas City, Missouri	Diverse drive cycle and use	4	Jul-11
State of North Dakota DOT - U of North Dakota	Cold Climate On and Off road Rural use of AC	14	Aug-11
SMUD (Sacramento Municipal Utility District)	Diverse drive cycle and use	14	Aug-11
City of San Francisco - UC Davis	Diverse use	14	Aug-11
Austin Energy - ERCOT - UT Austin	Pool vehicles for the city of Austin	14	Sep-11
State of Hawaii - U.S. Army - HNEI, UofHawaii Manoa	Diverse use	14	Sep-11
Argonne National Lab	Technology Evaluation and Testing	1	TBD

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
  - **i. Plug-In Charging HMI display**
  - **ii. Power Panel HMI Display**
  - **iii. Functional objective verification**
- **Fuel Usage Reduction**
  - **i. Emissions abatement**
  - **ii. Driveability**
  - **iii. 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

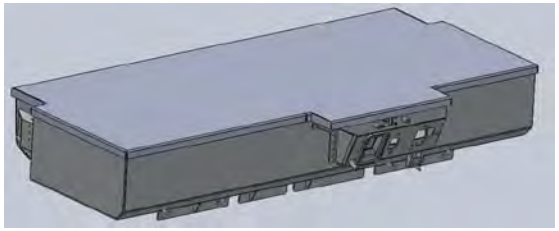
Summary

- 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

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

AC Power Panel - Summary

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”.

Charger / Inverter - Summary

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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 @ -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

Thermal System - Summary

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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