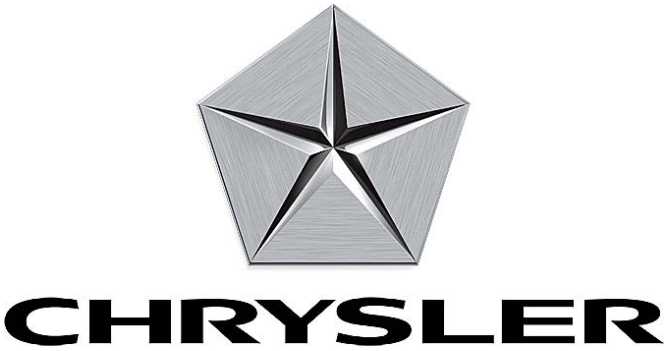
Advancing Plug In Hybrid Technology and Flex Fuel Application on a Chrysler Minivan PHEV DOE Funded Project



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May 17, 2012

Project ID # VSS063

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Minivan Project - Overview

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Timeline

- Project Start: September, 2009
- Project Complete: June, 2014
- 40% Complete

Budget

- Total Project Funding
  - DOE: $10,000,000
  - Chrysler: $15,791,697
- Funding received FY09: $0
- Funding received FY10: $0
- Funding received FY11: $3,452,740
- Funding received FY12: $3,859,999
- Chrysler/Partner Share*: $10,408,155

*As of March 31, 2012

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) • Duke Energy, NC • City of Auburn Hills, Mi • DTE, Mi• City of Yuma, Az. • Argonne National Labs

Targets :

• Range : Equivalent All Electric Range (EAER) of 22 miles

• Emissions : Tier II Bin 5 Compliance (w/ both MS8004 & E85 Fuel)

• Fuel Economy : Charge Depleting City – 53 mpg

Minivan Program Objectives – Relevance

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- Demonstrate 25 Minivans in diverse geographies and climates, spanning from Michigan, California, and North Carolina 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

Minivan Program Impact – Relevance

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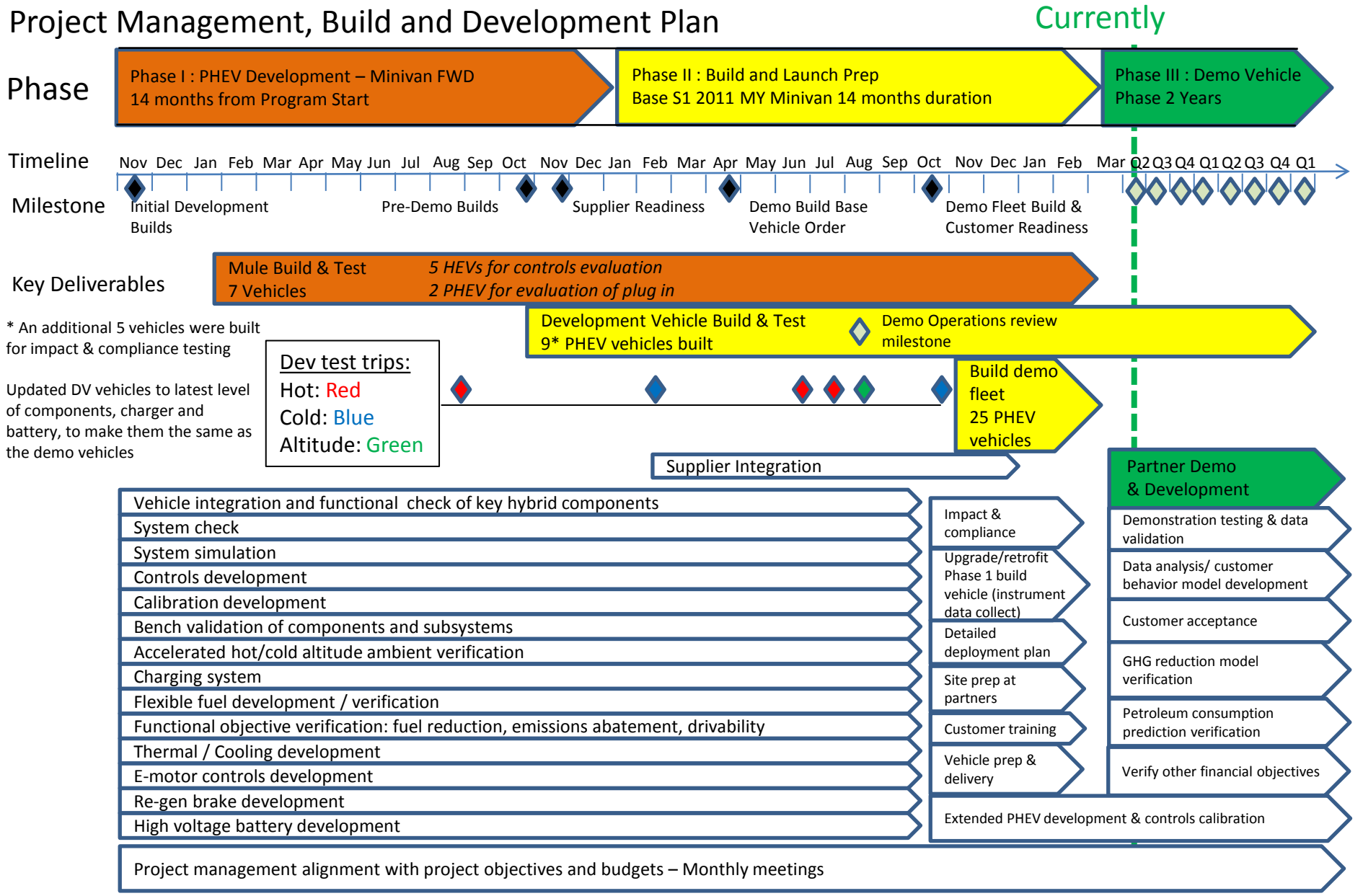
Objective	Target	Status	Procedure	R/G/Y
RANGE	Equivalent All Electric Range (EAER) of 22 miles	20 miles EAER; at launch	California Exhaust Emission Standards And Test Procedures, as amended December 2, 2009	YELLOW
EMISSIONS	Tier II Bin 5 Compliance (with both MS8004 & E85 Fuels)	• Complete and passing for T2 Bin 5 with MS 8004 fuel • E85 Testing yielded acceptable levels without margin	CFR Title 40: Part 86 – Control of Emissions from New and In-Use Highway vehicles and Engines; Subpart S.	GREEN YELLOW
FUEL ECONOMY	Charge Depleting City -53 MPG (MS8004 Fuel)	**MS 8004 Fuel:** CD CITY Unadjusted: **55 MPG** CD Hwy Unadjusted: 46 MPG CS City Unadjusted: 25 MPG CS Hwy Unadjusted: 34 MPG **E85 Fuel:** CD CITY Unadjusted: 40 MPG CD Hwy Unadjusted: 36 MPG CS City Unadjusted: 18 MPG CS Hwy Unadjusted: 24 MPG	SAE J 1711, Date Published: 2010-06-08. For Test Procedure Guidance. *Reported FE is – Fuel used in CD mode/CD Distance	GREEN

- **Based on Fuel Economy enablers, result is 20 miles EAER vs. a target of 22 miles; which will be contained through continuous improvements and exceed 53 MPG CD City Fuel Economy**
- **E85 Emission testing at the acceptable level without margin was in the Charge Sustaining Mode. The mitigation plan is to enhance the catalyst efficiency through calibration**

Minivan Project Plan - Approach

Project Management, Build and Development Plan



Minivan Project Milestones – Approach

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Month / Year	Milestone or Go/No-Go Decision	Description	Status
Feb 2012	Milestone	Complete testing for certification: durability, impact, road trips and facility based testing	Complete
March 2012	Milestone	Complete vehicle builds for the 25 demonstration vehicles	Complete
March 2012	Milestone	Complete functional test on each vehicle before they are deployed to the partners	Complete
March 2012	Go/No-Go Decision	Start vehicle deployment to partners	On schedule
March 2012	Milestone	Complete participating dealer training	Complete
April 2012	Milestone	Start capturing deployment fleet data to support calibration and controls enhancements	On schedule
April 2012	Milestone	Begin to analyze the fleet data	On schedule

Minivan Plug-in Hybrid Tech. Specs. - Approach

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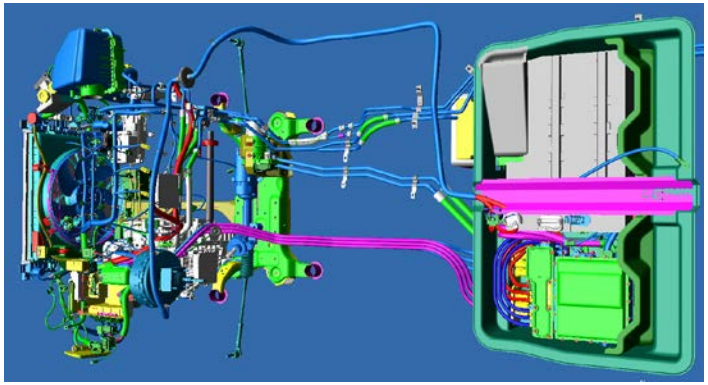
Chrysler Town & Country Touring Plug-In Hybrid Electric Vehicle

Key Features
- PHEV Minivan with Flex Fuel
- Scheduled Charging

Limitations:
- Four passengers due to weight restriction impacting tire rating and cradle structure



*Charge times will vary based on state of charge (SOC) of the vehicle.

Hybrid Drive System
Technology
- Next Generation Lithium Ion Battery

Charge Times
- 2-4 hrs at 220V
- 8-15 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

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”

Powertrain
Engine
- 3.6L V6

Fuel
- Flex Fuel (E85) capability

Maximum Power
- 290 Horsepower

Additional Features
- Dual Power Sliding Doors
- 2nd Row Battery /Charger
- Satellite / Navigation Radio

Capacities / Weights
Curb
- 5401 lbs.

Fuel Tank Capacity
- 20.5 gallons

GVWR
- 6,001 lbs.

Payload
- 600 lbs.

Towing Capacity
- N/A

Wheels / Tires
Wheels
- 17” x 6.5” Aluminum

Tires
- 225/65 R17

Interior Dimensions
Cargo Capacity (behind front seat)
- 140.1 Cubic Feet

Passenger Volume
- 156.1 Cubic Feet

Seating Capacity
- 4 Passenger

Safety
Electronic Stability Program
- Traction Control
- ABS
- Brake Assist
- Electronic Roll Mitigation
- Hill Start Assisted

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

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Mini-Van Technical - Approach

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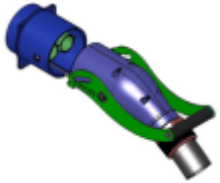
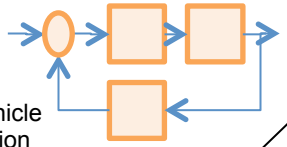
Charge Port



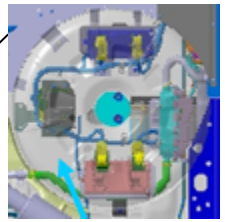
HMI changes:
DVIC display and Tell Tales

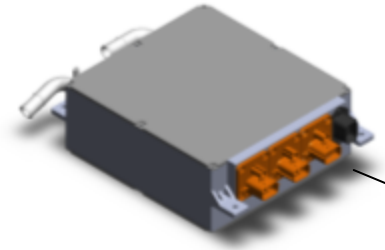
Controls

- E- Motor
- Battery
- Hybrid Vehicle
- Transmission

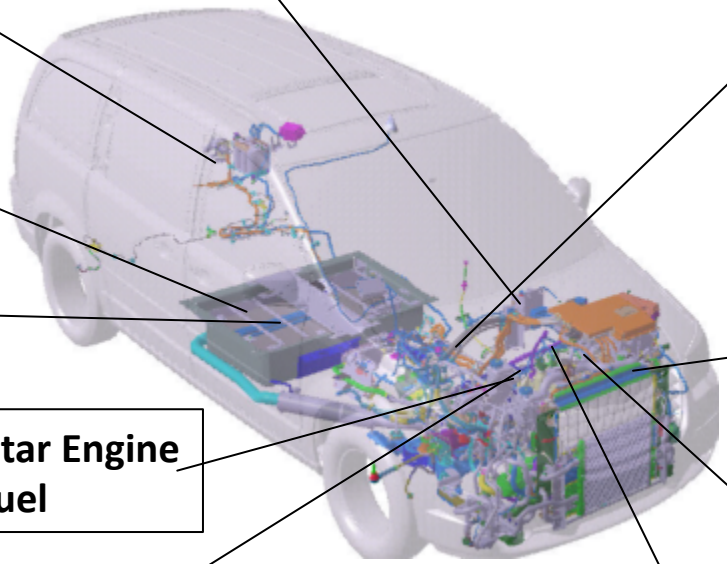


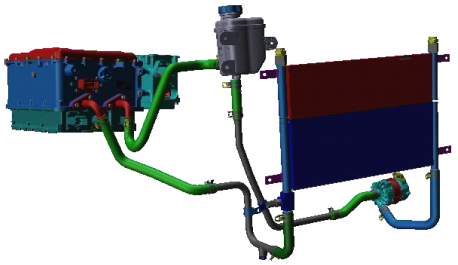
Mounted Under Spare Tire Tub



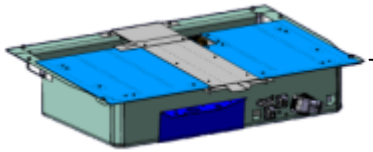


Charger



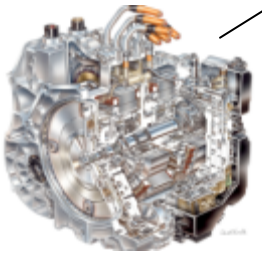


Thermal Systems



HV Battery Li-Ion

3.6L PentaStar Engine With Flex Fuel

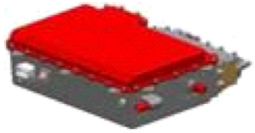


2-Mode Hybrid Transmission

Electric Motors

DC/DC

Power Electronics



Inverter

Minivan Technical Accomplishments (previous)

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Phase I: PHEV Development – completed prior to May 2011

- 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
  - ✓ Design, Package, and Install Li-Ion Battery
  - ✓ Design, Package, and Install Charger
  - ✓ Design, Package, and Install controls for battery thermal module & Power Electronics
  - ✓ Develop controls and calibration for PHEV
  - ✓ Update remaining thermal system components for PHEV
  - ✓ Design, Package, and Install LV & HV Wiring
  - ✓ Modify 3.6L Phoenix Engine to accept Hybrid Componentry
  - ✓ Retrofit Vehicle with 2-Mode Hybrid Transmission
  - ✓ Instrument vehicle for PHEV testing & validation

The above technical accomplishments were completed prior to May 2011

Minivan Technical Accomplishments

Phase I: PHEV Development – completed after May 2011

- 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
- Completed 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
- Completed Impact Testing for FMVSS compliance
- Completed PHEV system controls and calibrations: Created, developed and verified control systems and supporting calibrations to achieve program targets for Minivan PHEV vehicle
- Completed Road trips: development testing and verification: hot trip to 125F, cold trip to -20F, altitude trip to 12,000 ft
- Completed Durability testing: Planned for powertrain, high mileage, two charge cycles per day.
- Flex Fuels: Developed PHEV Torque Model to accommodate Flex Fuels (E0 to E85) operations

The above technical accomplishments were completed between May 2011 and March 2012.

Minivan Technical Accomplishments

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Phase II: Build and Launch Prep – completed after May 2011

- Completed the initial build of the demonstration fleet vehicles (25 vehicles in total)
- Developed and implemented a procedure for off-line, end of line testing to verify that the vehicle is operational
- Accumulated 1,800 miles on each vehicle as a pre-deployment verification(In process as of 3/5/12 – estimated completion 3/30/12)
- Conducted engineering evaluation of each vehicle (In process as of 3/12/12 – estimated completion 3/30/12)

The above technical accomplishments were completed between May 2011 and March 2012.

Minivan Technical Accomplishments

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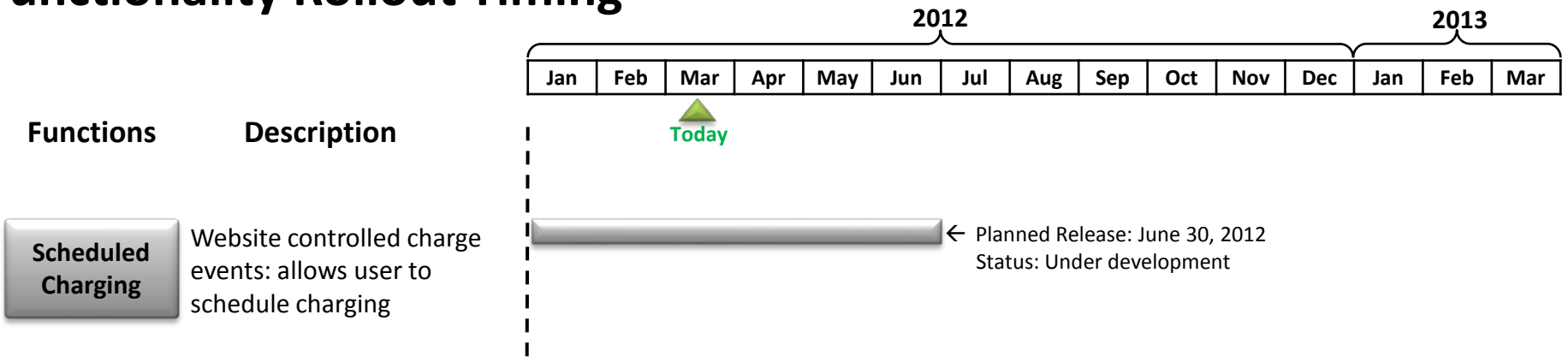
Phase III: Demonstration Vehicle Phase – completed after May 2011

- Completed participating Dealer Training
- Completed DRM (Data Recording Module) data collection and data storage development
- Identified participating partners for Minivan program
- Developed data analysis tools and data storage (Performant/ MicroStrategy)

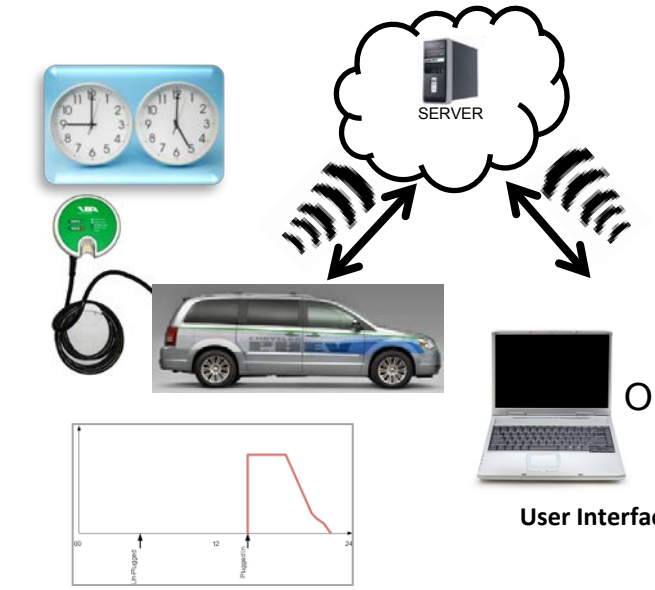
The above technical accomplishments were completed between May 2011 and March 2012.

Minivan Technical Accomplishments-in progress

Functionality Rollout Timing



Scheduled Charging Overview



User Interface Screen

Description
• Web site control of the starting and duration of vehicle charging • Allows users to schedule charging events as necessary • Minimal customer input required (Date, Start Time, End Time, Desired SOC) • Minimal system input

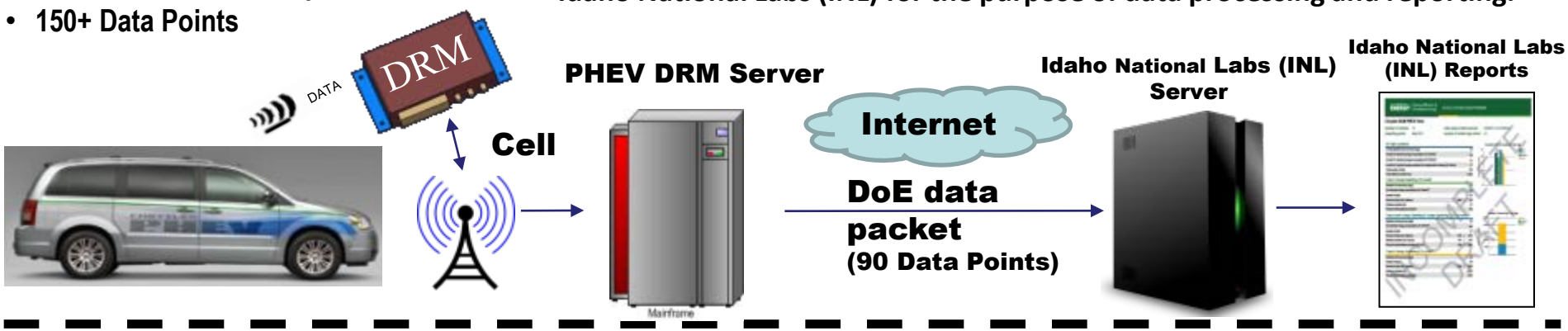
New functionality will be rolled out throughout calendar year 2012

Technical Accomplishments – Data Reporting

- Remote Software Flash
- Remote Diagnostics
- Near Real Time Data Upload
- 150+ Data Points

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.

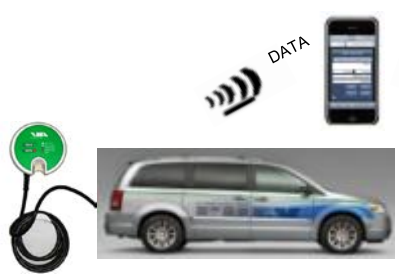


Enhanced Data Reporting Server

Copy of DoE Data

Plus Engineering Only Data

2nd Quarter 2012 Implementation



Dashboard User Interface

External Reporting Server Temporary Hosting on Performant Dev. Server

User Interface
***Scheduled Charging**
***Smart Grid Charging**

Demo Partners Access only DOE Data for their fleet

Engineering Full Access to Fleet Data

Minivan Collaborations with other Institutions

Idaho National Laboratory Data: Cumulative as of April 30, 2012

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy — VEHICLE TECHNOLOGIES PROGRAM

Chrysler Town & Country PHEV Fleet

Number of vehicles: 22
Reporting period: April 2012
Date range of data received: 4/2/2012 to 4/30/2012
Number of vehicle days driven: 150

All Trips Combined

Overall gasoline fuel economy (mpg)	28
Overall AC electrical energy consumption (AC Wh/mi)[1]	80
Overall DC electrical energy consumption (DC Wh/mi)[2]	66
Overall DC electrical energy captured from regenerative braking (DC Wh/mi)	30
Total number of trips	725
Total distance traveled (mi)	7,008

Trips in Charge Depleting (CD) mode[3]

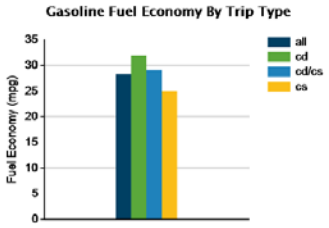
Gasoline fuel economy (mpg)	32
DC electrical energy consumption (DC Wh/mi)[4]	174
Number of trips	379
Percent of trips city | highway	94% | 6%
Distance traveled (mi)	2,267
Percent of total distance traveled	32%

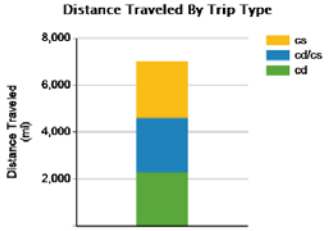
Trips in both Charge Depleting & Charge Sustaining (CD/CS) modes[5]

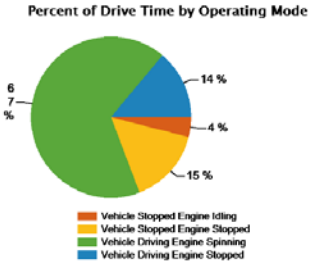
Gasoline fuel economy (mpg)	29
DC electrical energy consumption (DC Wh/mi)[6]	36
Number of trips	101
Percent of trips city | highway	72% | 28%
Distance traveled CD | CS (mi)	619 | 1,713
Percent of total distance traveled CD | CS	9% | 24%

Trips in Charge Sustaining (CS) mode[7]

Gasoline fuel economy (mpg)	25
Number of trips	245
Percent of trips city | highway	87% | 13%
Distance traveled (mi)	2,409
Percent of total distance traveled	34%







Minivan Highlights

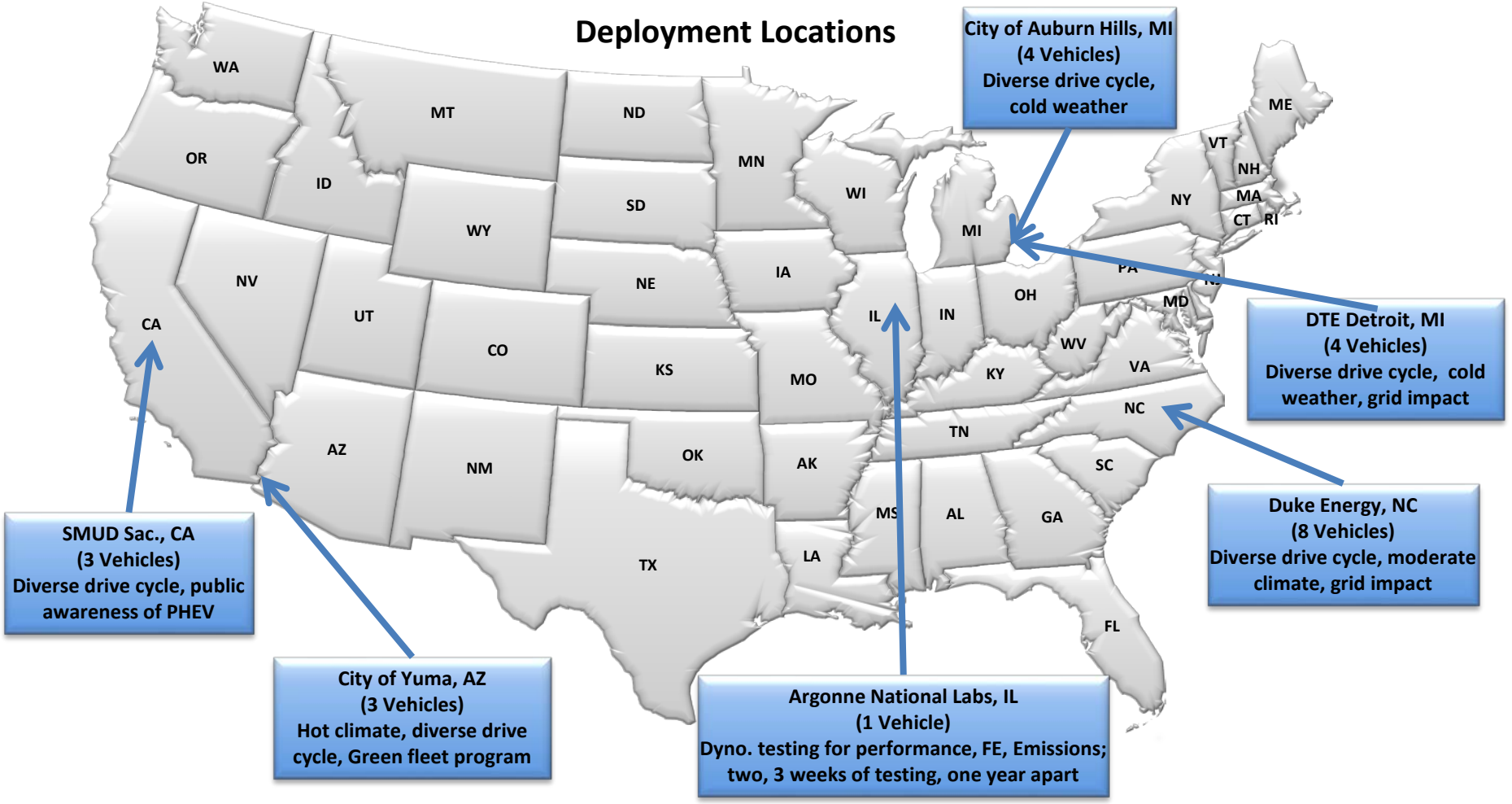
- Overall fuel economy = 28
- Charge depleting FE = 32
- Mixed CD / CS FE = 29
- Charge Sustaining FE = 25
- Charge Events = 0.73 (per day per vehicle when driven)
- Average charge event = 1.79 hrs.

- Total number of trips (Key cycles) = 725
- Total distance traveled = 7,008 miles

- Vehicle stopped / engine stopped = 15%
- Vehicle driving / engine stopped = 14%

- **Real-world statistics will be used to capture customer behavior**

Minivan Collaborations with other Institutions



- Deployment of 22 vehicles has been completed as of the end of April 2012
- Initial customer data received from INL report
- Vehicles will be with partners for two years (March 2012 to March 2014)
- Assume approximately 15,000 miles per year per vehicle

Minivan Collaborations with other Institutions

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Development partners are participating in a variety of roles

- Behr has completed the thermal system design and parts delivery
- Electrovaya is nearing the completion of their work, based on budget; in discussion with continuing field support for critical issues

Collaborations & Partnerships

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Fleet Service: Servicing the fleet is conducted through a five step process(1)

1. Diagnosing the Issue
2. Kick off Problem Resolution (System focus)
3. Track Problem
4. Resolve Issue (System Focus)
5. Repair & Cascade to Fleet

Major Issues and Barriers Addressed

1. Battery Performance:
   Implemented a software feature that monitors battery cell temperatures. The feature then responds to those cell delta temperature differences, and then determines the optimal operating mode
2. Thermal Management Integration:
   Implemented a liquid and air cooling system. This system uses an air / liquid heat exchanger
3. Charging System Integration:
   Implemented fully integrated liquid cooled 6.6kW charger that works on both Levels 1 &2 EVSEs.
4. Understanding customer acceptance and usage patterns for PHEV technology:
   HMI and customer feedback analysis that focuses on the development of a customer behavior model. Analysis will be conducted throughout the demonstration period

Notes: (1) See first Technical Backup Slide in the Appendix for details

Future Work

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Phase I: PHEV Development

- Continue calibration/controls development and optimize fully integrated systems
- Complete extended vehicle durability and validation
- Continue hot & cold weather validation of vehicle software
- Charging system / implement scheduled charging
- Continue fuel usage reductions
  i. Emissions abatement for Flex fuel
  ii. Driveability
  iii. Deploy Scheduled Charging

Phase II: Build and Launch Prep

- Continue customer / dealer service training

Phase III: PHEV Vehicle Demonstration

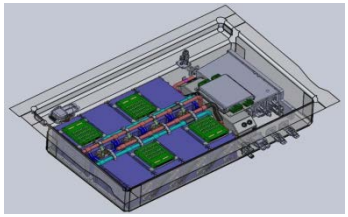
- Continue capturing deployed fleet data to support calibration and controls development
- Enhance data reporting capabilities
- Optimize charge development and calibration
- Update fleet partners customer interface server; allows the partners to interface directly with the server and access the vehicle data

Summary

- On track to meet program milestones and project deliverables; have a plan to contain the Fuel Economy EAER target gap through system optimization after launch
- Created “Green” core competency jobs and have a plan in place to sustain them toward future development of electrification programs.
- Built and deployed all demonstration fleet vehicles
- Continue to monitor and analyze data from the field

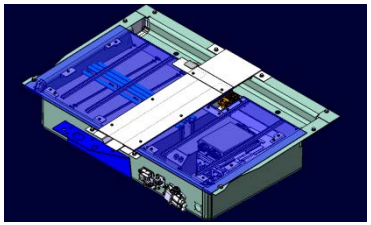
Technical Back-Up Slides

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.

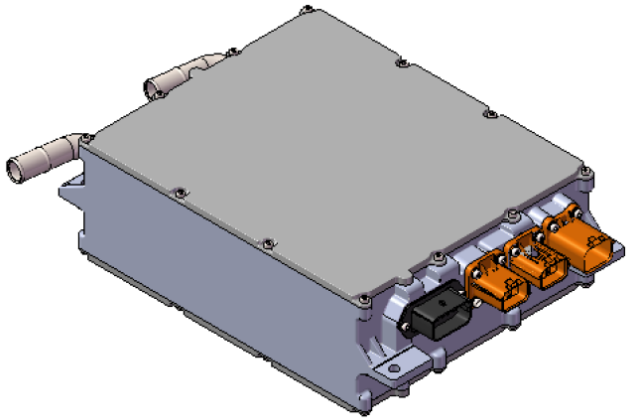
Charging System - Summary

Scope/Objective

- 6.6 KW On-board Charger

Testing and Validation

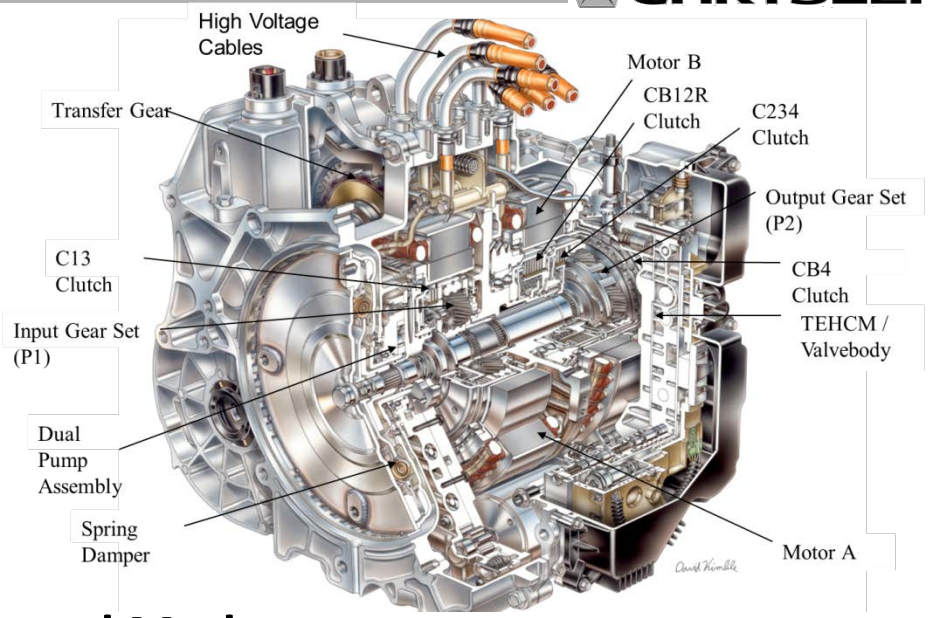
- Charging Capability under various ambient temperatures and voltage ranges
- Power Output:
  - 6.6kW @ 220Vac
  - 1.4kW @ 110Vac
- Efficiency >95%
- Output Voltage 250Vdc – 400Vdc
- Full Operating Temperature range @ -40C to 70C
- Air Cooled
- Level 1 & 2 J-1772 compliant
- CAN Vehicle communication 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



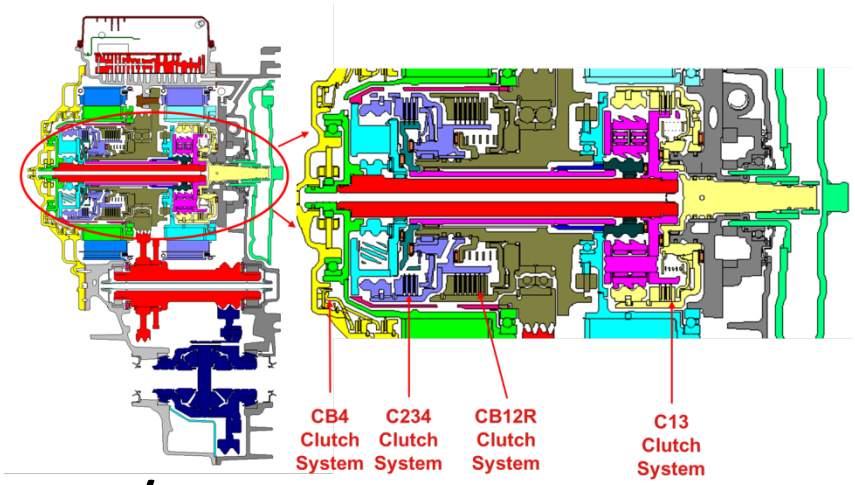
Technical Summary – 2 Mode Hybrid Transmission

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**

Minivan PHEV Thermal System Summary

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