Ford Plug-In Project: Bringing PHEVs to Market

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Overview

Timeline

- Start: October, 2008
- Finish: December, 2013
- 90% Complete
  - Fleet Build and Testing: 100%
  - Advanced Information Systems demonstration: 25%

Budget

- Total Project Funding
  - DOE: $ 7,547,748
  - Ford: $ 7,575,540

DOE funds have been fully obligated.

Partners

- Electric Power Research Institute (EPRI)
- Southern California Edison
- Detroit Edison
- NY Power Authority
- Consolidated Energy
- NY State Energy Research & Development Authority
- Progress Energy
- Southern Company
- National Grid
- American Electric Power
- Pepco Holdings Inc.
- Hydro-Quebec
- Nokia

Barriers

- Battery Cost
- Battery Charge Time
- Extreme Temperature Operation
- Lack of Uniform Codes & Standards

Relevance

Objectives:

Identify a sustainable pathway toward accelerated and successful mass production of Plug-in Hybrids (PHEVs)

- Launch a 21 vehicle demonstration fleet
  - Provide real-world usage data
  - Provide laboratory data
- Support a customer-valued PHEV production program
  - Propulsion and Control System Design
  - Two-way Charger Communication
- Leverage Connectivity to Improve Vehicle Operation
  - New data sources, new opportunities
  - Intelligent, adaptive, and personalized

Approach

Phase	Activity	Status
I	Validate and demonstrate plug-in technology on a new, more fuel efficient engine	Completed in 2009 CY – Included engineering and development of 11 vehicles
II	Progress battery/controls closer to production intent and demonstrate bi-directional communication and flex-fuel capability	Completed in 2010 CY – Included engineering, development and delivery of additional 10 PHEV's with E85 flexibility
III	Demonstrate plug-in technology in fleet operation and perform data analysis	Completed 1QTR 2011 – Included completion Ford/INL fleet data correlation and algorithm validation
IV (Demo. Fleet)	Continue vehicle demonstrations from Phase III and demonstrate advanced metering interface:	Completed in 2012 – All demonstration vehicles returned.
V (Adv Info Sys)	Demonstrate the benefit of using advanced information systems in an intelligent PHEV system	Initiated 2012 – Developing concepts using simulation and prototype hardware.

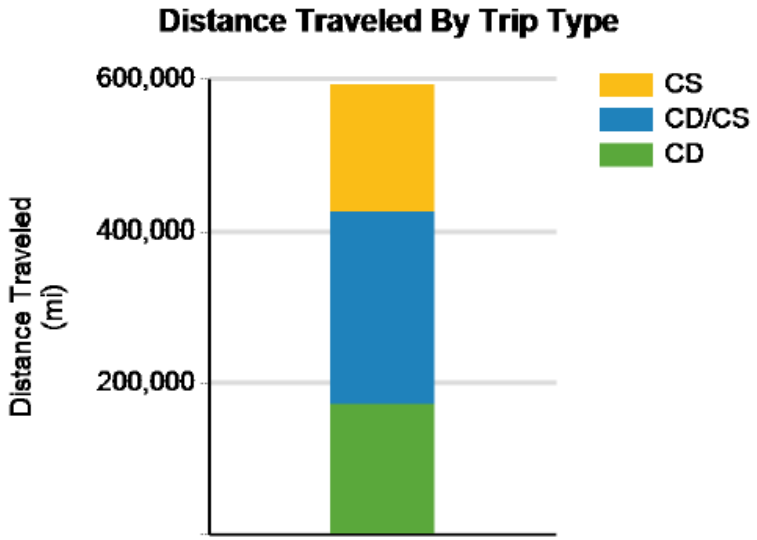
Technical Accomplishments 1 of 7

2012 Demonstration Fleet Completed Milestones

Complete demonstration of PHEV Fleet	- 21 Unit Escape Plug-In Hybrid Demonstration Fleet completed with total accumulation of over 800,000 miles with data acquisition systems in place and collecting real-world PHEV(includes Ford development miles) - Over 300 nationwide public outreach activities supported (auto shows, educational displays and government events) over life of fleet
Complete vehicle development and testing	- Ford Escape PHEV Fleet demonstration completed December 2012 - EPRI has completed their analysis of the on-road data - providing insight into vehicle and driver behavior, the feasibility of bi-directional communication (vehicle <->:charging infrastructure), as well as the potential for vehicle impact on the grid through the creation of a fleet charging aggregator simulation tool.
Complete in-field vehicles service and support	- Updates to the on-board vehicle chargers gave the fleet access to Level II 240V EVSE through the installation of SAE J1772 compatible charge ports - Level I 120V charging still possible per project requirements - Fleet upgrades were completed in 1st Qtr 2012
Complete data acquisition, analysis and reporting	- All data collected during fleet demonstration has been made available to Idaho National Laboratories with summary reports available to the public on the AVTA website. http://avt.inl.gov/phev.shtml - Reports include monthly summary results as well as consolidated summaries for Jan. – Nov. 2012 and Nov. 2009 – Dec.2012

Technical Accomplishments 2 of 7

Form Nov. 2009 through Dec. 2012, the Ford Escape PHEV demonstration fleet …

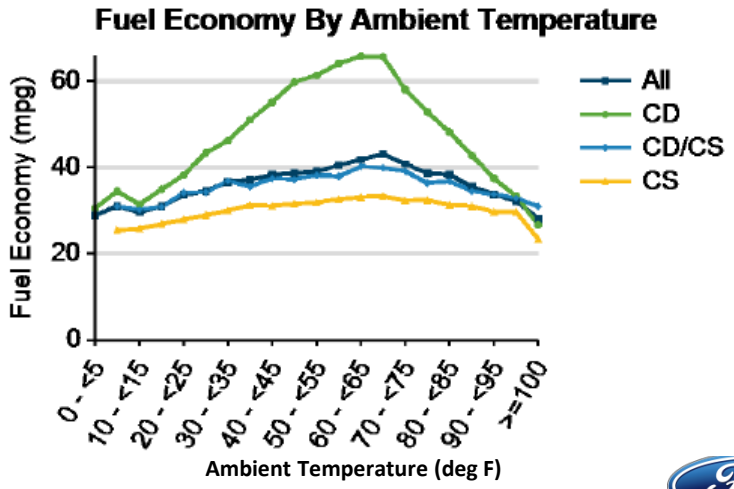


- 593,114 of the miles traveled were analyzed by INL with results made public on the INL AVTA website
- Of the 49,849 trip events – 29% are reported in Charge Depleting, 28% in Charge Sustaining (typical hybrid operation), and 43% in both modes
- Of the 19,514 charge events - Vehicles were found to be charged an average of 2.2 hours, resulting in only a partial SOC increase. (*This fleet experienced a pattern of short, infrequent charges, which limited the ability to realize the potential benefits of the PHEV system)*

- Fuel Economy in Charge Depleting mode was the most sensitive to ambient temperature

NOTE:

- *Majority of demonstration prototype* vehicles were not equipped with electronic A/C
- *Purpose of fleet was to demonstrate vehicle/grid interaction and customer duty cycles; vehicles were not optimized to provide maximum potential fuel economy*



Technical Accomplishments 3 of 7

2012 , 2013Q1 Advanced Information System Completed Milestones

Prototype Hardware Acquired and Deployed for Development	- Escape PHEV prototype repurposed for Smart and Connected technology development - Updated with PC, 4G modem, Touch Screen, Precision GPS - Tablet to Vehicle integration through OpenXC system
Defined Vehicle to Cloud Connectivity Architecture and Software	- Defined overall vehicle to cloud system architecture - Implemented Windows 7 + .net framework - Designed and implemented shared services (Location, Route, Zones, Controller Area Network, and more) - Demonstrated in an Escape PHEV
Ongoing Algorithm Development	- Path Forecasting for Optimal Energy Management (Use preview of route and topography to improve fuel economy) - Trip Profiling - Cloud Based Battery Calculations (Off boarding of large scale computation) - Location based (Geo fenced) energy management

Prototype Hardware Development

Escape PHEV from demonstration fleet as baseline vehicle

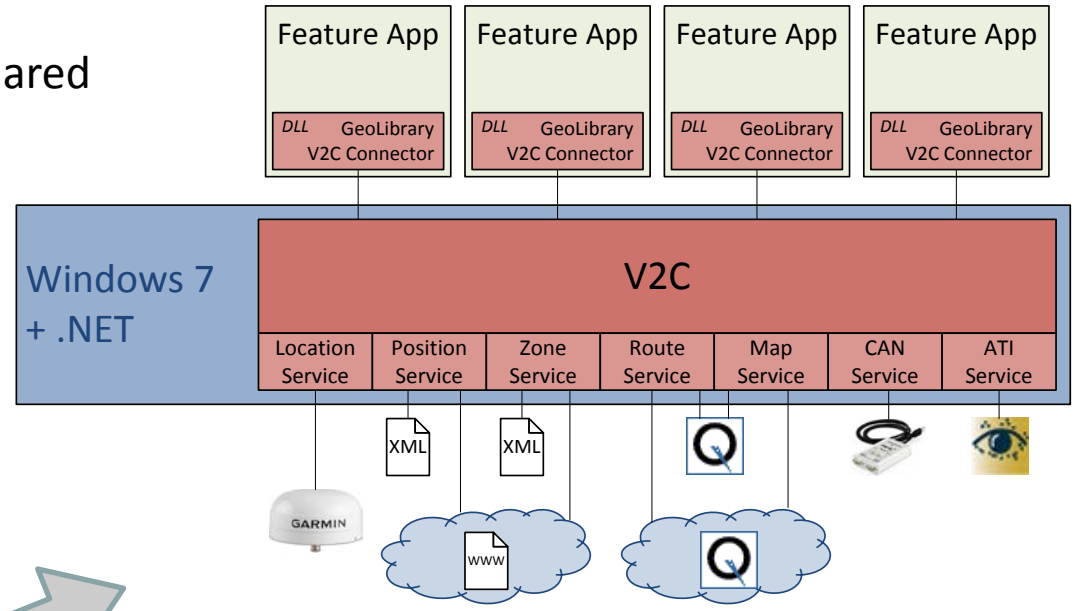
- CarPC installed in the trunk
- Touch-Screen for driver
- 4G Connectivity
- Prototype Control Module for Powertrain Controls Development

- Open XC hardware provides link between tablet and vehicle
- Tablet provide development platform for HMI experiences

Connectivity System Architecture

3 Layered Expandable Structure

- Feature Apps
- Vehicle to Cloud Framework with Shared Services
- External Systems
  - Map Data
  - GPS
  - Route
  - Communication Bus
  - …



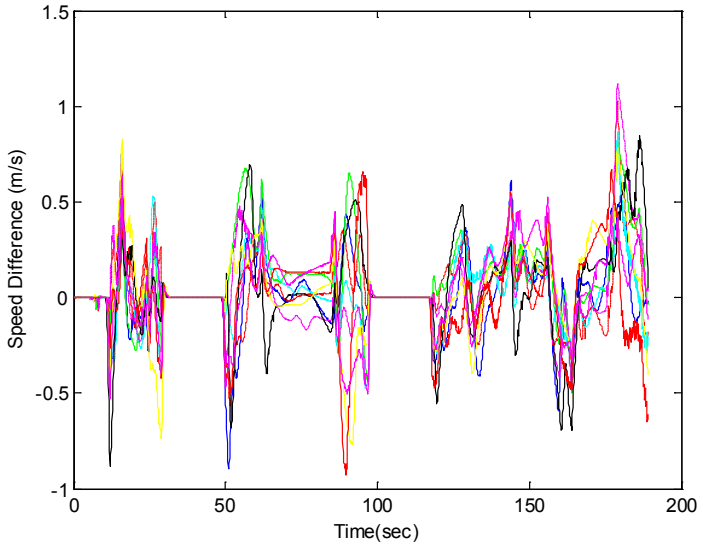
Implemented and Demo'd in Escape PHEV

Technical Accomplishments 6 of 7

Path Forecasting Controls

Use preview information to improve Fuel Economy

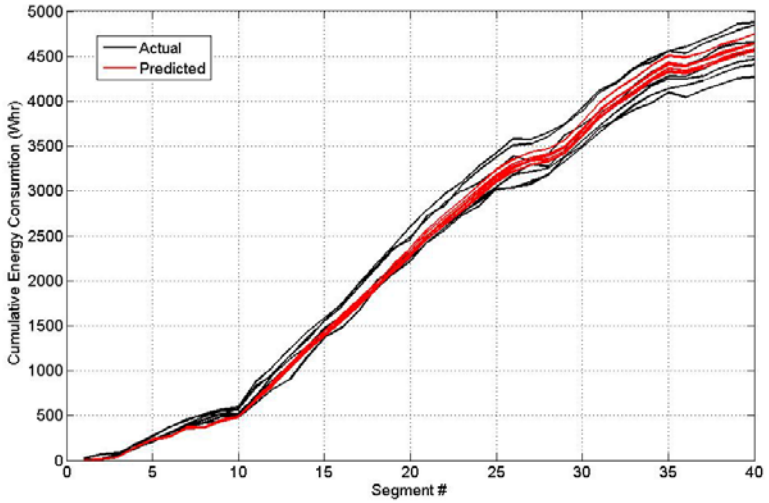
- Route based algorithm, uses receding horizon control concept
- Expanded algorithm to consider alternative drive cycles
- Robustness study initiated to consider deviations from target speed profile



Trip Profiling

Developed New Trip Profiling Algorithms

- Energy Usage Models
- Destination Prediction
- Common Route Recognition
- Online GPS segmentation

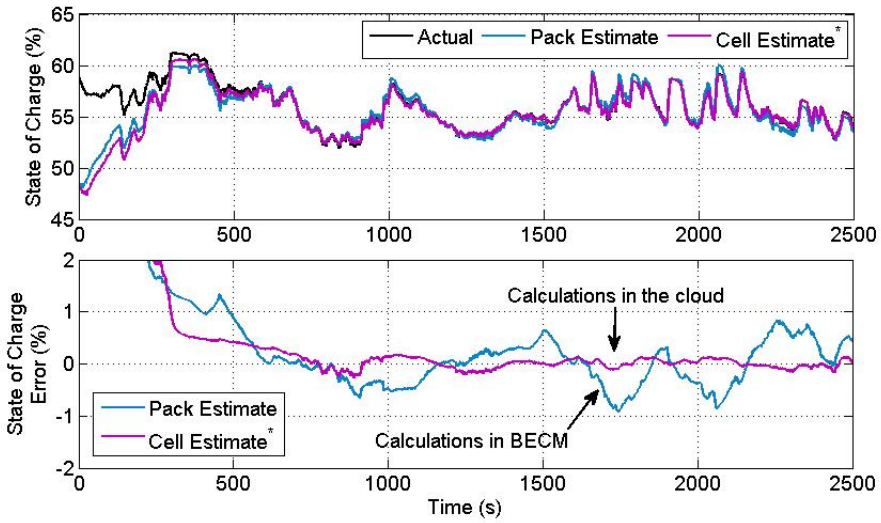


Technical Accomplishments 7 of 7

Cloud Based Battery Calcuations

Use off-board computing capability to improve accuracy of battery system models

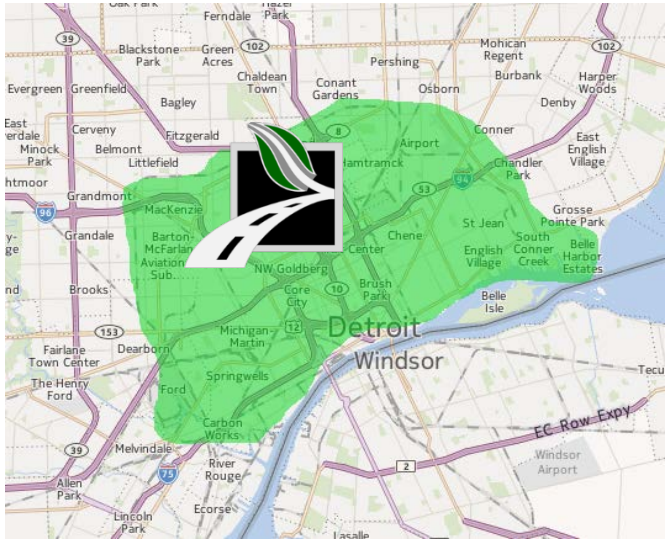
- Cell level modeling vs. Pack level modeling shows improvement in SOC accuracy
- Studied effect of low bandwidth connectivity and loss of data



Location Based Energy Mgmt

All Electric Driving is important for PHEVs

- Customers want control of where and when they prioritize EV driving.
- Automatic location based energy usage concept using customer defined geo-fenced areas has been designed and implemented in the Escape PHEV Prototype.



Collaborations

With our Partners ….

- The demonstration Ford Escape PHEVs supported over events:
  - Auto shows, local green festivals, Presidential drives, utility conference meetings and public awareness events
  - Static Display and/or Drive events
- 2012 Bi-weekly Customer Action Team Meeting held
- Vehicle Data Analysis and Reporting
  - Summary reports were available in near real time for use by Ford and utility partners
  - INL published monthly fleet status summary reports on AVTA website
  - Ford and INL co-authored EVS-26 report presented May, 2012
- The Electric Power Research Institute (EPRI) concluded three affiliated collaboration projects:
  - analysis of infield results of the Escape PHEVs,
  - field demonstration of Smart Meter communication, and
  - creation of a model studying plug-in vehicles as a grid resource
- Partnered with Nokia to integrate map based data into on-board control system
  - Using route based data for trip profiling
  - Historic traffic information used for vehicle speed prediction
  - Integrated Advanced Driver Assistance Systems Rapid Prototyping software into Escape PHEV

Future Work

Planned work for Phase V ….

Target Completion

- DOE to evaluate the translation of demonstration fleet into production solutions:
  - Two production Ford C-MAX Energi PHEVs have been built for the Department of Energy evaluation
  - Data to be collected and made available to Idaho National Laboratories
- Continue to demonstrate the benefit of using advanced information systems in an intelligent PHEV system (E.g. enhanced fuel economy, drivability)
- Migrate Escape PHEV Prototype development platform to production Ford PHEVs: 2013 Ford Fusion Energi, 2013 Ford C-MAX Energi

Year End 2013

Summary

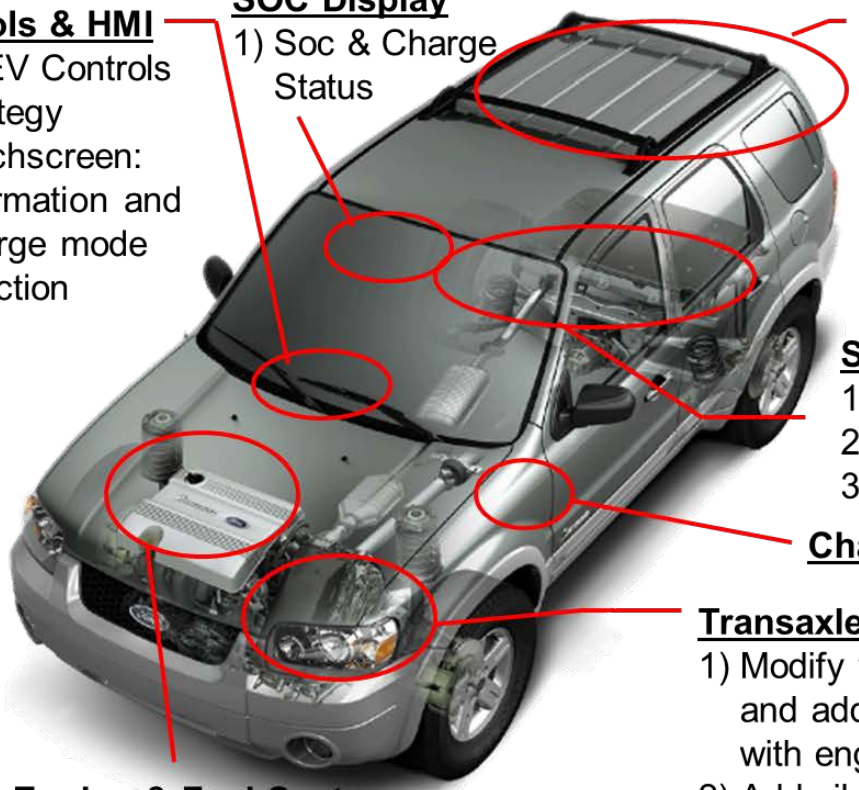
- This DOE sponsored program has:
  - Supported the announcement of two mass production PHEV programs in North America and Europe
  - Enabled a nationwide outreach effort including educational, community and industry/utility events
  - Facilitated a deeper understanding of the current and future potential impact of PHEVs on the grid
- The conclusion of the on-road Escape PHEV demonstration fleet includes:
  - 3+ years of on-road PHEV data collection covering more than 800,000 miles (including pre-deployment mileage accumulated during Ford vehicle development work)
  - With public summary reports made available through Idaho National Laboratories on over 590K miles, 49K trips and 19K charge events
- Demonstrated that using advanced information systems with PHEVs offers the possibility to improve vehicle attributes such as drivability and fuel economy.
- Collaboration with project sponsors and partners has both progressed the project and resulted in co-authored public presentation of results

Additional Slides

Technical Back-Up Slides …

Technical Back-Up Slide

PHEV Features and Specifications …



Controls & HMI
1) PHEV Controls Strategy
2) Touchscreen: Information and Charge mode selection

SOC Display
1) Soc & Charge Status

Rear Cargo Area
1) Replace production high voltage battery with a ~11.5 kWh Li-Ion battery from JCS
2) Add 1.4 kW, 120V battery charger
3) Add Data Acquisition Module
4) Add ZigBee module (Bi-directional communication)

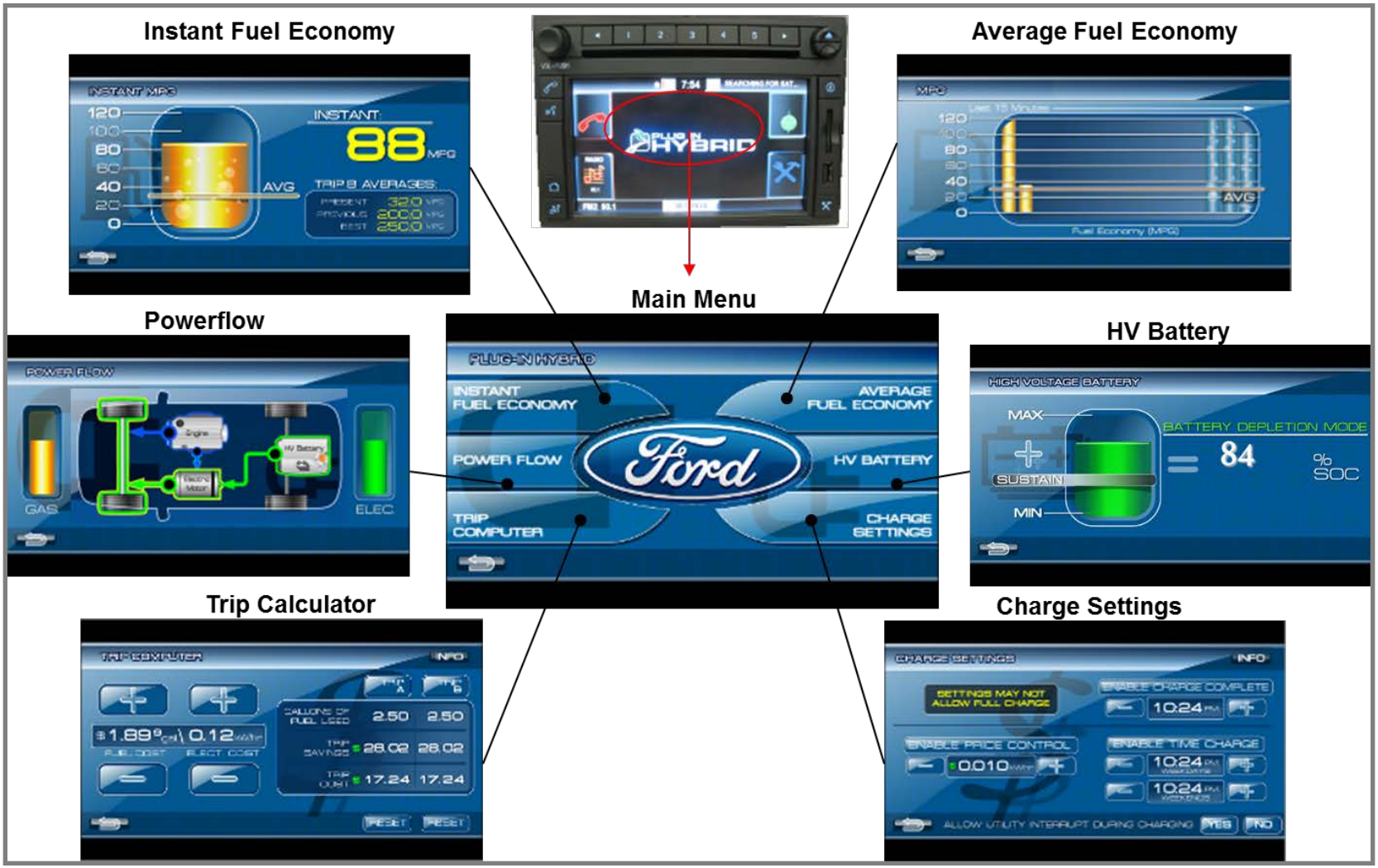
Structure and Suspension
1) Rear Suspension modifications
2) Structural enhancements
3) Exhaust System

Charge Plug J1772 modifications

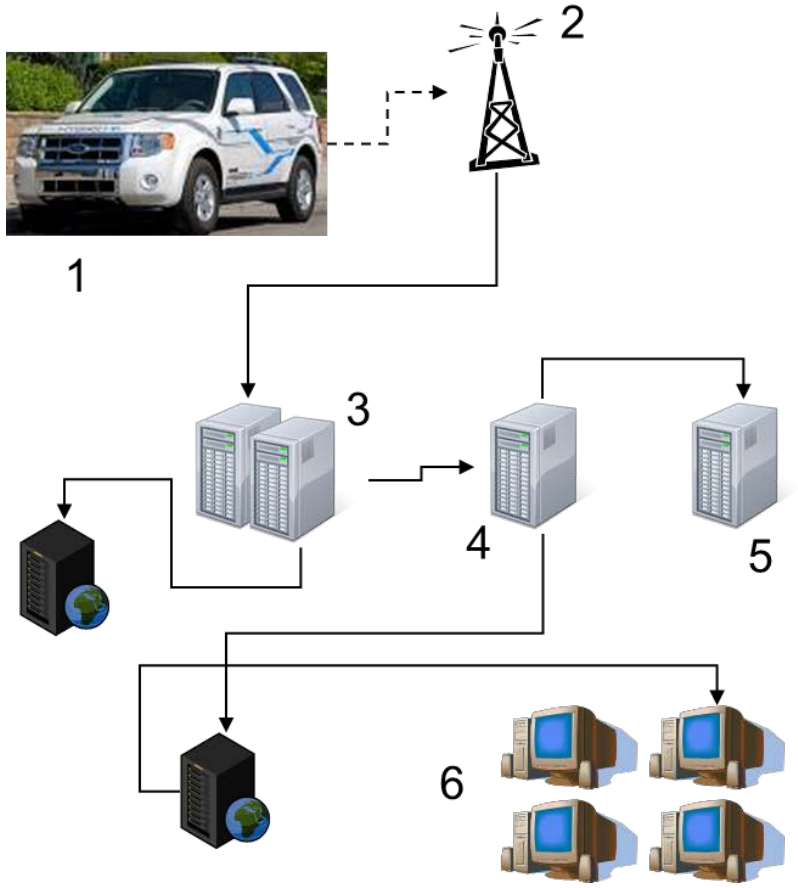
Transaxle Modifications
1) Modify transaxle oil lubrication/cooling circuit and add external electric oil pump for oil flow with engine off
2) Add oil to air heat exchanger to increase continuous operating capability of electric machines

Engine & Fuel System
1) Flex Fuel (E-85) hardware and software

Human Machine Interface (NAV system) …



Vehicle Data Collection and Reporting …



1. Data collected on vehicle.
2. Data received by broadband wireless network
3. Data archived in collection server
4. Data relayed to website server
5. Website server backed-up nightly
6. Data available to authorized users through web