Ford Plug-In Project: Bringing PHEVs to Market

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Overview

Timeline

- Start: October, 2008
- Finish: December, 2013
- 75% Complete (Vehicle Build – 100%)

Budget

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

DOE funds have been fully obligated.

Partners

- Electric Power Research Institute
- 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

Barriers

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

Relevance

2007

Ford
- Collaboration with SCE
- Examine future of PHEVs
- System: Vehicle, Home & Grid

2008

EPRI
- Electric Power Research Institute joined
- Expanded project access to utilities nationwide

DOE
- DOE Conditional Award announced
- Targeted to identify a sustainable pathway toward mass production

2009

Fleet Build
- PHEV Technology Demonstration
- Vehicle Design & Development
- Battery & Controls
- 21 Vehicle Fleet

Testing
- Deployment & Testing
- Data Collection
- Data Availability
- Service & Updates

DOE/INL
- DOE sponsored fuel economy testing
- Data correlation & algorithm validation
- Fleet Reports published on AVTA

Progression of Technology

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 System Design
  - Vehicle Controls
  - Two-way Communication
    - Vehicle to Meter
    - Meter to Vehicle

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	Continue vehicle demonstrations from Phase III and demonstrate advanced metering interface: - Continue demonstration of PHEV fleet and support of public information activities - Continue vehicle development and testing; Continue battery and controls development - Continue in-field service and support - Continue data acquisition, analysis and reporting	Phase IV - In progress

Technical Accomplishments

2011 Completed Milestones

Project Management	- Over 65 nationwide public outreach activities supported
Support Vehicle Operations	- Bi-weekly customer action team meetings with partners/customers ongoing - Monthly meetings with DOE on-going - Vehicle Issue Diagnosis & Resolution ongoing
Battery Controls & Development	- Battery software validated and installed on fleet. Additional updates identified and provided to production team - Vehicle operation software continues to be refined based on customer feedback and field operation data - PCM calibration revised and installed on PHEV-05 for testing
Vehicle Controls & Development	- SAE J1772 compatible charge port design/development/testing completed to allow vehicles charging using level II 240V EVSE. *Level I 120V charging still possible per project requirements* - SAE J1772 compatible port fleet implementation begun - PHEV-05 upgraded with electric air conditioning, instrument cluster software (for e-a/c), low voltage charger cooling fans and 57 mph all-electric operation

Technical Accomplishments

2011 Completed Milestones

AMI/V2G/G2V Interface & Communications	- Electric Power Research Institute (EPRI) conducted field demonstration of Smart Meter communication at utility partner locations - Interface testing work has validated the ability to perform utility charge control direct to vehicle
Testing & Data Acquisition	- Over 238,000 fleet miles accumulated in 2011 CY with data acquisition systems in place and collecting real world PHEV usage and performance data - SAE J1772 charge port testing on PHEV-05 Ford engineering vehicle ongoing
Data Analysis & Reporting	- Ford and INL data correlation and algorithm validation completed to support INL Ford Escape PHEV public reporting - INL baseline and monthly summary fleet reports now available via AVTA website

Technical Accomplishments

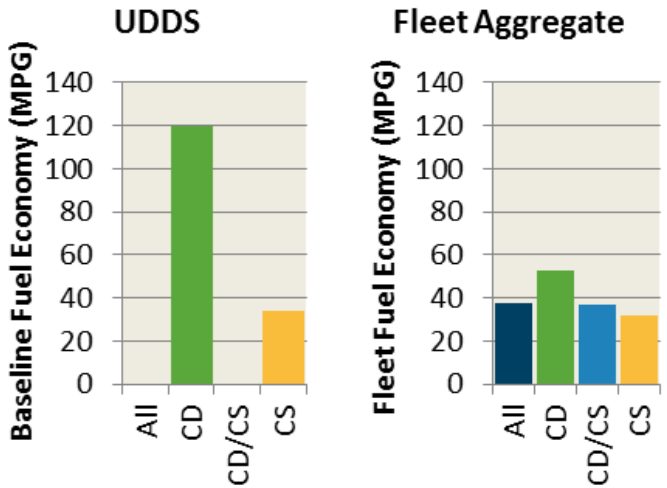
2012 (1st Qtr) Completed Milestones

Vehicle Controls & Development	- SAE J1772 compatible charge port implementation completed
	- DOE approval for demonstration of using advanced information systems in an intelligent PHEV system to:
	  - Use cloud based computing and off board information to enhance the fuel economy and drivability of the vehicle
	  - Maximize EV experience and fuel economy through use of predictive information
	  - Improve drivability by providing EV mode at the right time and right location
	  - Determine requirements on external data to obtain vehicle improvements

Testing & Data Acquisition	- Vehicle testing, data acquisition and testing on-going - As of end of March – fleet has accumulated over 668K miles; with data recorded for over 22K drive events and 34K charge events
Production Validation Evaluation	- DOE approval for validation evaluation on two production PHEVs by the DOE with data collection occurring from January to December 2013

Technical Progress

Ford has worked closely with INL to correlate and assess fleet data …

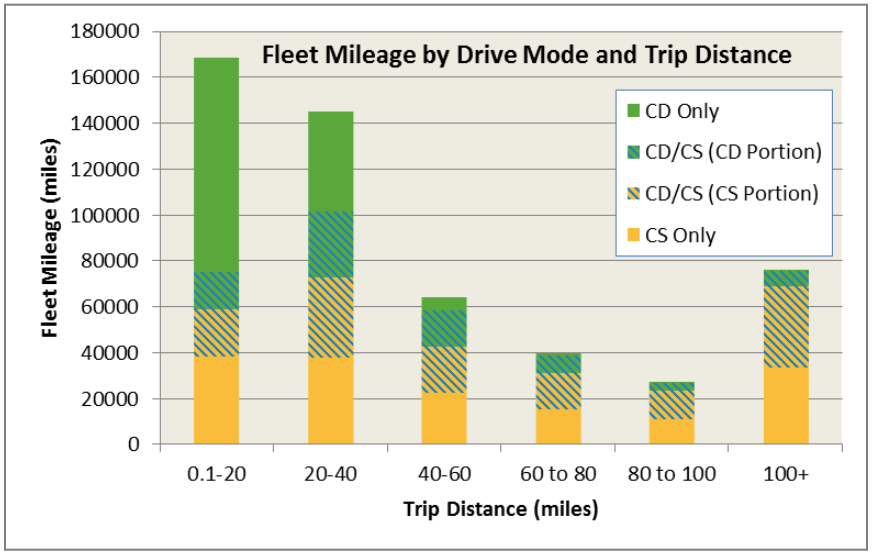


- INL conducted baseline fuel economy testing over the EPA standard urban drive (UDDS) and Highway (HWFET) drive cycles on one Escape PHEV
- Significantly higher fuel economy results achieved in baseline testing versus that realized by the fleet in the field

Note: *Baseline testing done with E-85 (typically results in 20-25% lower FE than regular gasoline)*

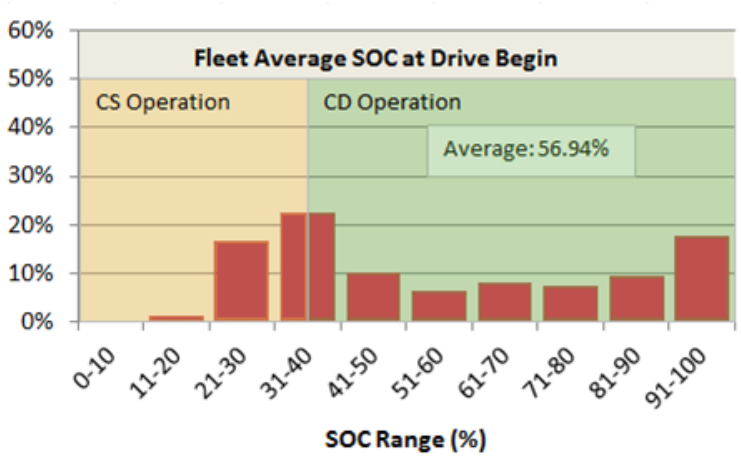
- Factors contributing to fuel economy in the field can be grouped into two general categories:
  - Reduction of Charge Depleting (CD) operation
  - General energy consumption increase

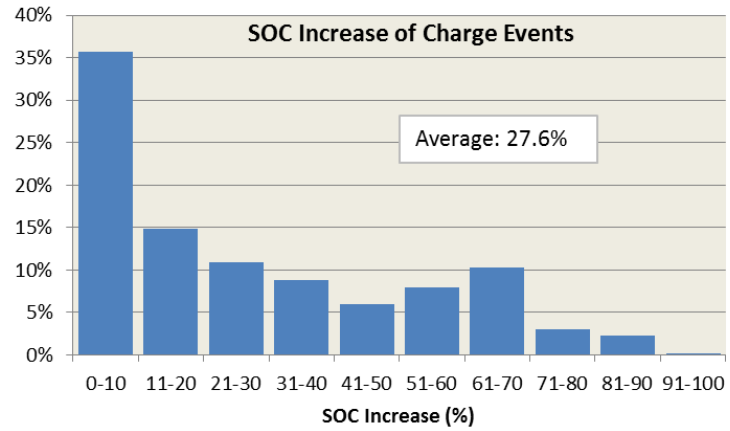
Note: Purpose of fleet was to demonstrate vehicle/grid interaction and customer duty cycles; vehicles were not optimized to provide maximum potential fuel economy



Technical Progress

Infrequent/incomplete fleet vehicle charging has reduced CD operation ….





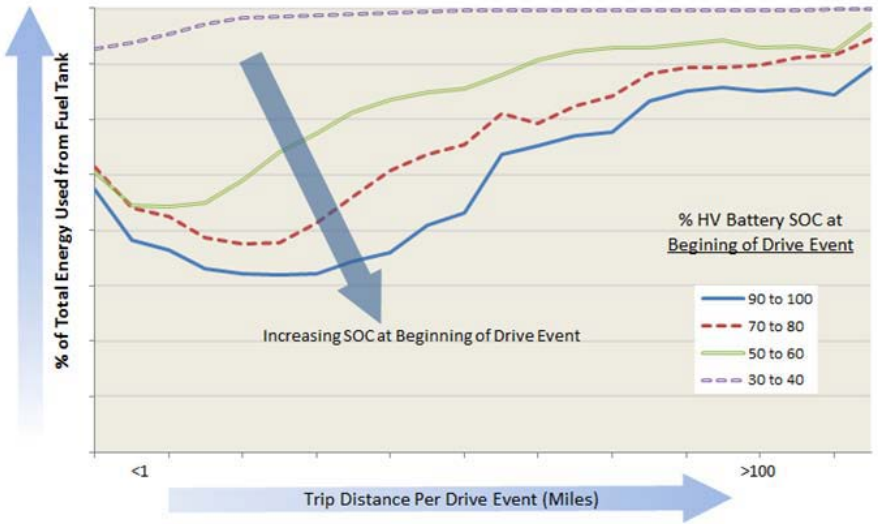
- The average HV battery state of charge (SOC) at the beginning of a fleet drive event is 57%
- Fleet drive events begin with a full HV battery SOC less than 20% of the time (full charge => 90% or greater)
- More than 40% of all trips begin with a SOC of 40% or less – giving minimal or zero CD range

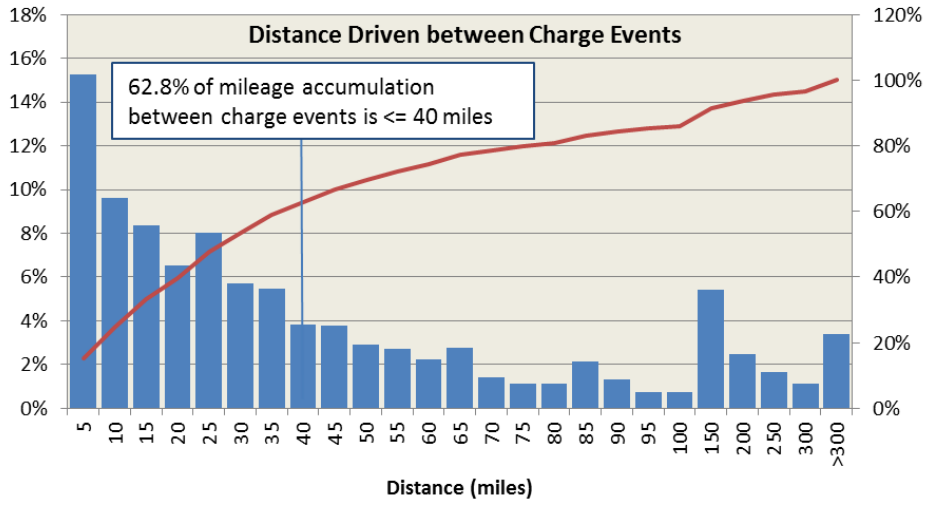
- Fleet vehicles are being charged roughly 3 times per week
- Charge events are typically less than 2 hours, resulting in an average battery SOC increase of only 27%
- This pattern of short, infrequent charges results in the fleet vehicles routinely operating with low SOC, limiting the ability to realize the potential benefits of the PHEV system

Technical Progress

Analysis of drive events reveal the impact this reduced CD operation has had on fleet performance …

- The Escape PHEV advanced research fleet was designed to have a 40 mile CD range when starting with a full SOC – and then to transition to Charge Sustaining (CS) mode
- Roughly 2/3 of all charge events have 40 miles or less accumulated before recharging



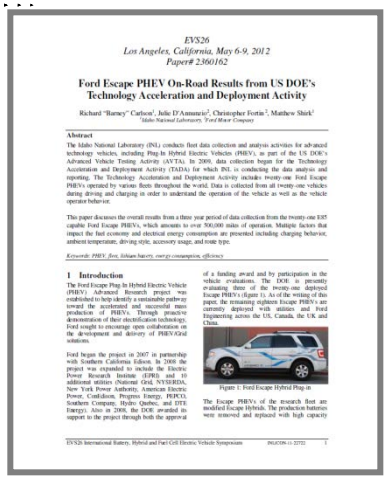


- If the fleet was regularly allowed to fully charge, CD operation would drastically increase
- A vehicle which starts off with a full SOC typically requires less liquid fuel over the drive event – with the maximum benefit of fully charging the HV battery realized in the 10-40 mile trip range

Technical Progress

Fleet data also indicates how general energy consumption contributes to aggregate fleet fuel economy ….

- INL has identified several factors which influence the vehicles general energy consumption and thus contribute to the fleets realized fuel economy:
  - Ambient temperature
  - AC usage
  - Driver aggressiveness
  - Petroleum displacement



EVS26
Los Angeles, California, May 6-9, 2012
Paper# 2360162

Ford Escape PHEV On-Road Results from US DOE's Technology Acceleration and Deployment Activity

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Abstract

The Idaho National Laboratory (INL) conducts fleet data collection and analysis activities for advanced technology vehicles, including Plug-In Hybrid Electric Vehicles (PHEV), as part of the US DOE's Advanced Vehicle Testing Activity (AVTA). In 2009, data collection began for the Technology Acceleration and Deployment Activity (TADA) for which INL is conducting the data analysis and reporting. The Technology Acceleration and Deployment Activity includes twenty-one Ford Escape PHEVs operated by various fleets throughout the world. Data is collected from all twenty-one vehicles during driving and charging in order to understand the operation of the vehicle as well as the vehicle operator behavior.

This paper discusses the overall results from a three year period of data collection from the twenty-one E85 capable Ford Escape PHEVs, which amounts to over 500,000 miles of operation. Multiple factors that impact the fuel economy and electrical energy consumption are presented including charging behavior, ambient temperature, driving style, accessory usage, and route type.

Keywords: PHEV, fleet, lithium battery, energy consumption, efficiency

1 Introduction

The Ford Escape Plug In Hybrid Electric Vehicle (PHEV) Advanced Research project was established to help identify a sustainable pathway toward the accelerated and successful mass production of PHEVs. Through this project, demonstration of their electrification technology, Ford sought to encourage open collaboration on the development and delivery of PHEV/Grid solutions.

Ford began the project in 2007 in partnership with Southern California Edison. In 2008 the project was expanded to include the Electric Power Research Institute (EPRI) and 10 additional utilities (National Grid, NYSERDA, New York Power Authority, American Electric Power, Con Edison, Progress Energy, PEPCO, Southern Company, Hydro Quebec, and DTE Energy). Also in 2008, the DOE awarded its support to the project through both the approval of a funding award and by participation in the vehicle evaluations. The DOE is presently evaluating three of the twenty-one deployed Escape PHEVs (figure 1). As of the writing of this paper, the remaining eighteen Escape PHEVs are currently deployed with utilities and Ford Engineering across the US, Canada, the UK and China.

Figure 1: Ford Escape Hybrid Plug-in

The Escape PHEVs of the research fleet are modified Escape Hybrids. The production batteries were removed and replaced with high capacity

EVS26 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium INL/CON-11-22722 1

- INL, in collaboration with Ford, has shared these findings in the EVS26 presentation ***Ford Escape PHEV On-Road Results from US DOE's Technology Acceleration and Deployment Activity*** report (May 6-9, 2012)

➢ Fleet data assessment indicates that while PHEV design, development and engineering can define a vehicle's electrification potential, other factors such as driving/charging patterns and real world usage environment greatly impact ability to fully take advantage of this technology

Collaborations

With our Partners ….

- To date, Ford Escape PHEVs have supported nearly 300 events:
  - 65 events supported in 2011
  - Auto shows, local green festivals, Presidential drives, utility conference meetings and public awareness events
  - Static Display and/or Drive events

National Grid
Northeastern University Event (1Q 2011)

- 2011 CY Collaboration Meetings
  - Bi-weekly Customer Action Team Meetings
    Location: Teleconferences, Host: Ford
  - November 29, 2011 Face-to-Face
    Location: White Plains, Host: EPRI
- Vehicle Data Analysis and Reporting
  - Vehicles equipped with data acquisition platforms which collect and transmit vehicle data while driving and charging
  - Summary reports are available in near real time for use by Ford and utility partners
  - DOE directed INL to identify fleet data collection parameters and reporting methods. In 2011 INL began publishing monthly fleet status summary reports on AVTA website
  - Ford and INL co-authored EVS-26 report presented May, 2012

Future Work

Planned work for Phase IV ….

Target Completion

- Continue and complete demonstration of PHEV fleet
- On-going service and support of PHEVs in field
- Continue and complete V2G/G2V communication demonstration
- Data acquisition, analysis and reporting
  - Continue and completed with vehicle data collection
  - Continue with vehicle data analysis and reports to DOE and partners
- Continue collaboration with DOE, INL, EPRI and Utility Partners
  - Continue bi-weekly Customer Action Team meetings
  - Face-To-Face Collaboration Meeting targeted Nov 2012
- Demonstrate the benefit of using advanced information systems in an intelligent PHEV system (enhanced fuel economy, drivability, etc.)

Year End 2012

Future Work

Planned work for Phase IV ….

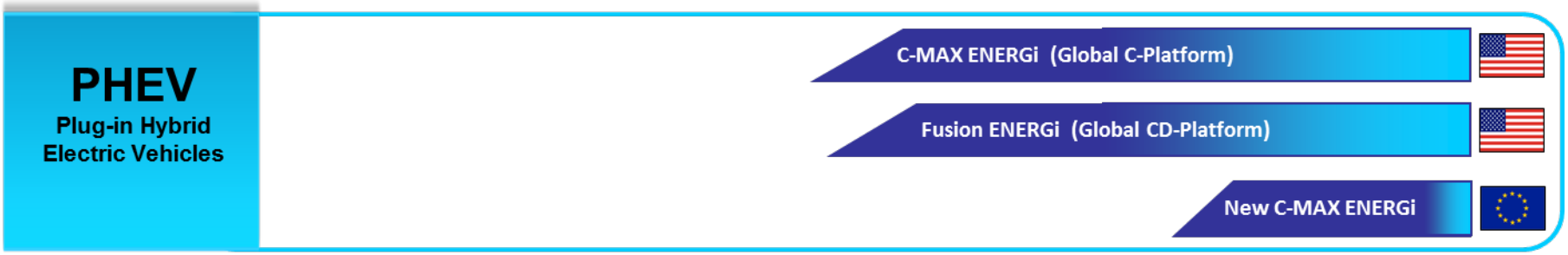
Target Completion

- Continue and complete advanced information systems demonstration
- DOE production validation evaluation

Year End 2013

Summary

- DOE-sponsored program supports the announcements of several 2012+ CY mass production PHEV programs in North America and Europe:



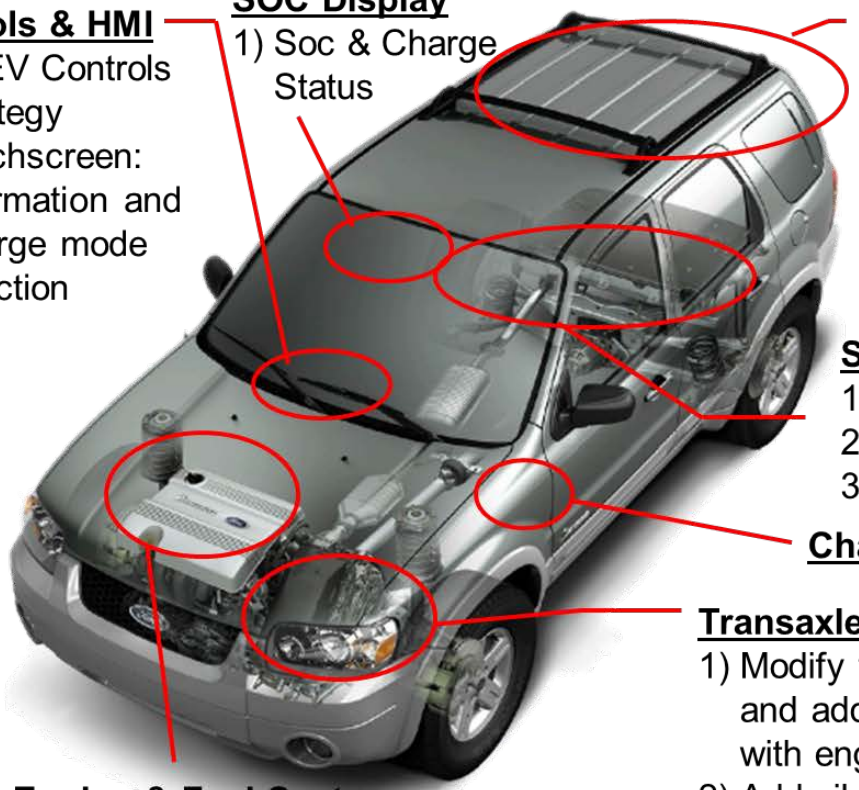
- Engineering development continues to drive production vehicle designs
- DOE-sponsored program has enabled nationwide outreach effort – educational, community and industry/utility events
- Strong interest from public
- Fleet customers are very satisfied with battery charging and driving experience
- Technical Accomplishments: Fleet data is being collected and analyzed with summary reports available on public website
- Collaboration: 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)

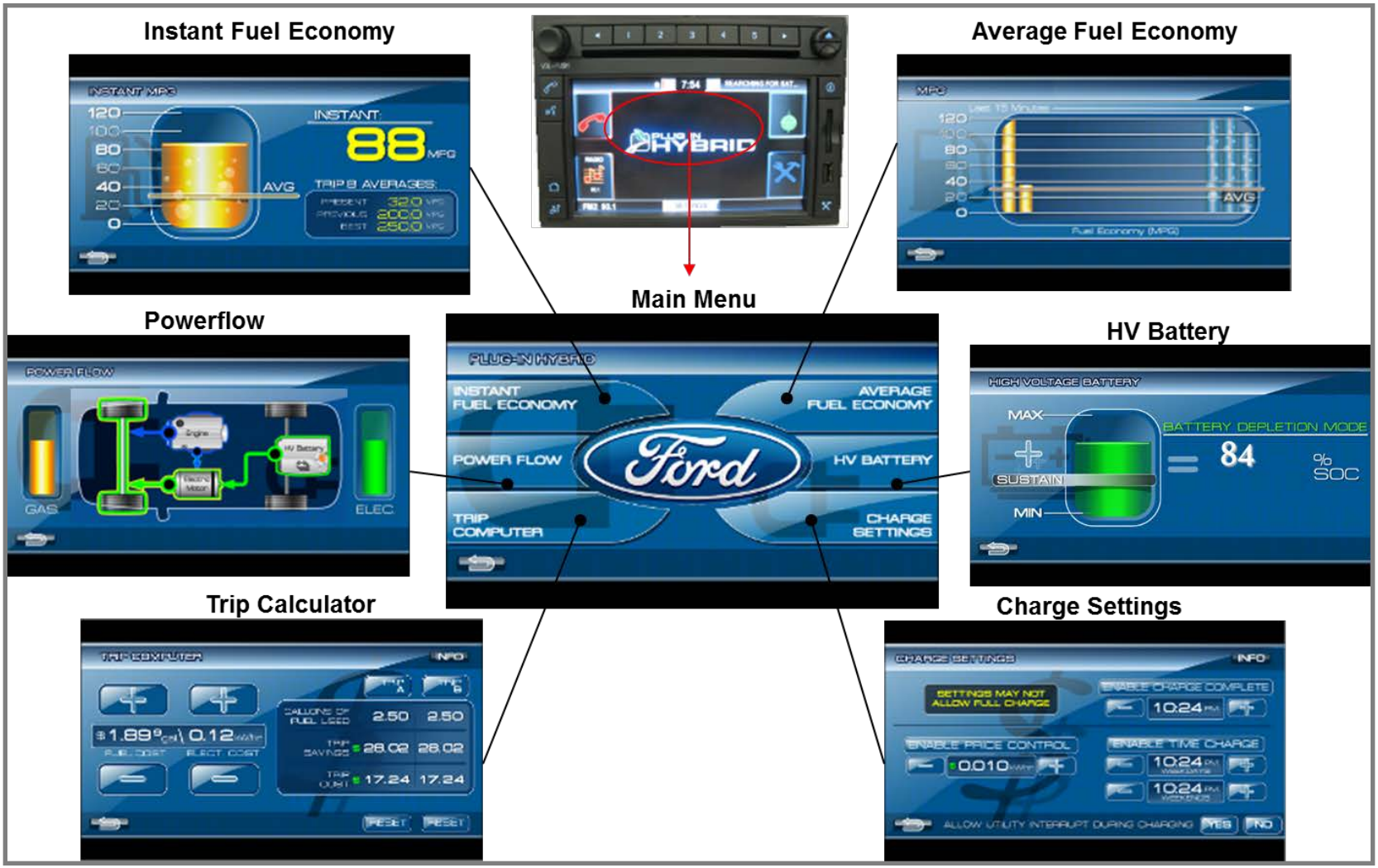
Structure and Suspension
1) Rear Suspension modifications
2) Structural enhancements
3) Exhaust System

Charge Plug J1772 modifications

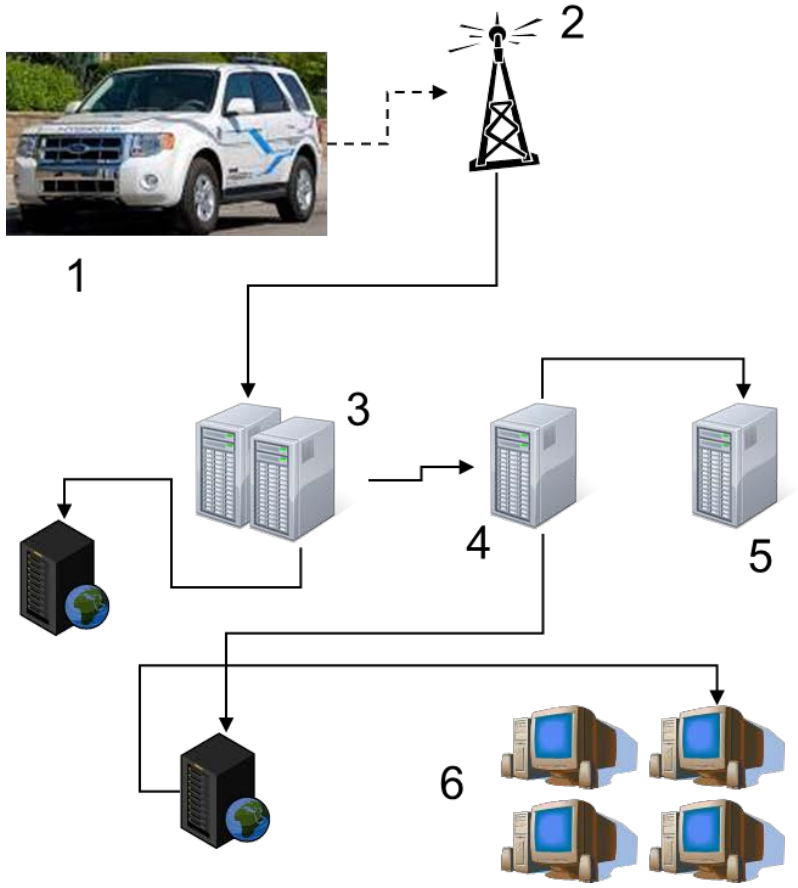
Transaxle Modifications
1) Modify transaxle oil lubrication/cooling circuit and add external electric oil pump for oil flow with engine off
2) Add oil to air heat exchanger to increase continuous operating capability of electric machines

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

Technical Accomplishments for Phase I …

- Vehicle & Design Build Updates
  - High Voltage (HV) Battery optimization
    - Improved power and State of Charge (SOC)
  - Implemented AC current and charger temperature controls
  - Low temperature robustness transaxle improvements
- Battery Controls and Development
  - LOS / Quit On Road Strategy completed and validated
  - Initial evaluations of vehicle battery management systems communications are completed
- Vehicle Controls & Development
  - Software modifications to allow Silent Key Start
  - Implemented a new charge port design
  - Engine and control system modifications have been made to allow for E-85 operation (08MY engine)
  - E-85 strategy and calibration under development for Phase II vehicles (09MY engine)
  - Sourced broadband on-vehicle data acquisition and transfer supplier
  - Sourced on-vehicle data organization and web-based access supplier
- Testing
  - FE testing completed at Argon National Labs
  - Pre-delivery NVH and Performance evaluations completed

Technical Accomplishments for Phase II …

- Vehicle & Design Build Updates
  - Provide Technology retrofits to vehicles 01-04 (upgrade structure and charge port, implement flex fuel E85 capability, improve trans cooling, and install data acquisition and Ford Works hardware)
  - Vehicle build 12-21 (complete vehicle build and battery integration, develop new model-year engine and fuel system hardware for flex fuel E-85, develop and implemented V2G/G2V communication hardware)
- Battery Controls and Development
  - LOS / Quit On Road Strategy completed and validated for JC-S supplied battery system
  - Developed and implemented V2G/G2V communication software
  - Completed software modifications for NAV system
- Vehicle Controls & Development
  - Software modifications to allow Silent Key Start on 2009MY vehicles
  - Completed E-85 strategy & calibration development for 2.5L engine in 2009MY vehicles
  - Implemented on-board data acquisition system on the vehicles
  - Implemented on-vehicle data organization, analysis and web-based access
- Testing
  - Completed baseline FE testing of Phase I vehicle Argonne National Labs
  - Pre-delivery NVH and Performance evaluations completed
  - Continued collecting field data, analysis and reporting