Ford Plug-In Project:  
Bringing PHEVs to Market

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

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

#### 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

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

DOE funds have been fully obligated.

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

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

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<tr>
<th>Technical Accomplishments</th>
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| 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](http://avt.inl.gov/phev.shtml)  
From 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.

*Form Nov. 2009 through Dec. 2012, the Ford Escape PHEV demonstration fleet...*
### Technical Accomplishments

#### 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

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

Escape PHEV from demonstration fleet as baseline vehicle

- 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**
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

Graphs showing speed difference and cumulative energy consumption.
Cloud Based Battery Calculations

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 ....

• 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
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
### Technical Back-Up Slides ...

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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

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

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
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