U.S. Department of Energy’s Vehicle Technologies Program

Oregon E.V. Road Map - Electric Drive Vehicle (PHEVs) Testing Activities and Results

Jim Francfort

E.V. Road Map – Preparing Oregon for the Introduction of Electric Vehicles
November 2009

This presentation does not contain any proprietary or sensitive information
Idaho National Laboratory (INL)

- Eastern Idaho based U.S. Department of Energy (DOE) Federal research laboratory
- 890 square mile site with 3,600 staff
- Support DOE’s strategic goal:
  - Increase U.S. energy security and reduce the nation’s dependence on foreign oil
- Multi-program DOE laboratory
  - Nuclear Energy
  - Fossil, Biomass, Wind, Geothermal and Hydropower Energy
  - Advanced Vehicles and Battery Development
  - Energy Critical Infrastructure Protection
AVTA Background

• INL’s PHEV and other vehicle testing is conducted for DOE’s Advanced Vehicle Testing Activity (AVTA). The AVTA is part of DOE’s Vehicle Technologies Program.
• INL and the Electric Transportation Engineering Corporation (eTec) jointly conduct the AVTA.

AVTA Goal

• Provide benchmark data for DOE technology modeling, simulations, research and development activities, and to fleet managers and the general public to support their vehicle purchase, operations, and infrastructure deployment decisions.
  – Accomplished via the development of cost-shared partnerships with public, private, and regional groups to test, deploy and demonstrate advanced vehicle and infrastructure technologies.
AVTA Testing by Technology

- Plug-in hybrid electric vehicles (PHEVs)
  - 12 models, 216 vehicles, 1.1 million test miles
- Hybrid electric vehicles (HEVs)
  - 18 models, 47 vehicles, 4.7 million test miles
- Neighborhood electric vehicles (NEVs)
  - 23 models, 200,000 test miles
- Hydrogen internal combustion engine (ICE) vehicles
  - 7 models, 500,000 test miles
- Full-size battery electric vehicles (BEVs)
  - 40 EV models, 5+ million test miles
- Urban electric vehicles (UEVs)
  - 3 models, 1 million test miles

Total of 12 million test miles accumulated on 1,600 electric drive vehicles representing 96 different electric drive models
12 PHEVs Models in Testing/Demonstrations

- Hymotion Prius (A123Systems)
- Hymotion Escape (A123Systems)
- Ford E85 Escape (Johnson Controls/Saft)
- EnergyCS Prius, 2 models (Valance and Altair Nano)
- Electrovaya Escape (Electrovaya)
- Hybrids Plus Escape, 2 models (Hybrids Plus and K2 Energy Solutions)
- Hybrids Plus Prius (Hybrids Plus)
- Manzanita Prius (lead acid)
- Manzanita Prius (Thunder Sky)
- Renault Kangoo (Saft NiCad)
- (All batteries are Lithium unless noted)
PHEV Testing Methods and Objectives

• Perform independent testing of PHEVs, using:
  – **Baseline performance testing**: closed test tracks and dynamometers
  – **Accelerated testing**: dedicated drivers operating vehicles on defined onroad loops
  – **Fleet testing**: everyday unstructured \ non-directed fleet and public use, with onboard data loggers
  – **Laboratory testing** of batteries

• Testing used to document:
  – Battery life, charging patterns and profiles and infrastructure requirements
  – Vehicle operations, fuel use (electricity and gasoline)
  – Driver and environmental influences on fuel use
  – Document the PHEV technology concept as well as PHEV batteries and models
PHEV Operating Modes

• **Charge sustaining (CS) mode**: from start to finish of a single trip, there is no energy available for electric drive propulsion in the PHEV battery. Therefore, the battery state-of-charge (SOC) at 0% is **sustained**.

• **Charge depleting (CD) mode** – from start to finish of a single trip, there is energy available for partial or full electric drive propulsion in the PHEV battery. Therefore, the battery SOC is being **depleted** during the entire trip.

• **Mixed CD/CS mode** – there is energy in the battery pack at the start of a single trip, but the PHEV battery is **fully depleted** before the trip ends.
PHEV Fleet Testing Partners

- 75+ U.S., Canadian and Finnish testing partners
  - 38 Electric utilities and 2 clean-air agencies
  - 13 City, county, state and national governments
  - 7 Private companies and advocacy organizations
  - 8 Universities and colleges, and 4 Canadian provinces
  - 2 PHEV companies 1 sea port and 1 DOD facility

PHEVs and Demonstration Locations

Most Vehicle Conversions
- Prius & Escapes
- Li-ion Batteries

Gov’t, Public + Private Partners

Data analysis & Reporting

INL

UV

Canada

30 + 18 = 48

34

5

UCD

59 + 37 = 96

NREL

1

1 + 1 = 2

ANL

13

1

OSU

1

ORNL

15

1

1 in CT

1 in DC

UV

Oslo

2

2

1

5

2

3

3

1

18

2

1

1

6

6

3

3

3

1

6

204 Operating

71 Coming ‘09

12 Out of Service

287 Total PHEVs
Vehicle Data Management Process

Process Affected by Disclosure Agreements

- HICEVs
- HEVs
- PHEVs
- BEVs
- EVSE & Chargers

INL Vehicle Data Management System

- File server
- SQL Server data warehouse
- Report generator

- Data quality reports
- Individual vehicle reports
- Fleet summary Reports - Public
- Focused technical analyses and custom reports
- Modeling and simulations

INL Database

Focused technical analyses and custom reports

Individual vehicle reports

Fleet summary Reports - Public

Modeling and simulations

Data quality reports
Hymotion Prius Gen I – UDDS Fuel Use

- 5 kWh A123Systems (Li) and Prius packs (AC kWh)
Hymotion Prius Gen I – HWFEDS Fuel Use

- 5 kWh A123Systems (Li) and Prius packs (AC kWh)
PHEV Accelerated Testing

- Accelerated testing in Phoenix over 5,440 onroad miles
- GPS units track distance, average and maximum speeds

<table>
<thead>
<tr>
<th>Cycle (mi)</th>
<th>Urban (10 mi)</th>
<th>Highway (10 mi)</th>
<th>Charge (hr)</th>
<th>Reps (N)</th>
<th>Total (mi)</th>
<th>Reps (%)</th>
<th>Miles (%)</th>
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<td>Total</td>
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<td>Average</td>
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<td>57%</td>
<td>8.3</td>
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# Hymotion Prius Gen I – Accelerated Testing

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<th>Highway (10 mi)</th>
<th>Charge (hr)</th>
<th>Reps (N)</th>
<th>Total (mi)</th>
<th>Electricity AC kWh</th>
<th>Gasoline Gals</th>
<th>MPG</th>
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<td><strong>1404</strong></td>
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<td><strong>Weighted Average</strong></td>
<td><strong>79.5</strong></td>
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Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg
# Hymotion Prius Gen II – Accelerated Testing

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<th>Total (mi)</th>
<th>Electricity AC kWh</th>
<th>Gasoline Gals</th>
<th>MPG</th>
<th>Recalculated without incomplete charges</th>
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<td>8</td>
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<td>600</td>
<td>16.01</td>
<td>10.41</td>
<td>57.7 I</td>
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| Total      | 2340          | 3100           | 1404        | 167      | 7,840       | Weighted Average   |               |     |                                       |

Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg.
E = experienced HEV driver, I = inexperienced driver
High ambient temperatures impact charge completion

ETEC Hymotion Prius: 40 mi City/Hwy Loops

Complete Charge Max Batt Cell Temperature [degF]
Incomplete Charge Max Batt Cell Temperature [degF]
Engine Operations by Ambient Temperatures

Hymotion Prius Fleet - Percentage of Miles with Engine On

-20°C to 0°C
0°C to 10°C
10°C to 20°C
20°C to 30°C
30°C to 40°C
>40°C

Percent Miles Engine On [%]

Average Ambient Temperature [°C]

All Trips
CD
CD/CS
CS
Monthly Fleet Testing MPG Results

Hymotion Prius PHEVs with GridPoint (V2Green) data loggers – 731,000 miles of data from 108 vehicles (as of September 2009)
Hymotion Prius PHEVs with GridPoint (V2Green) data loggers – 731,000 miles of data from 108 vehicles (as of September 2009)
PHEV Fleet Testing Reports

• Summary reports posted monthly on the www
• Individual vehicle reports only go to the respective fleet owners each month, 1,340+ reports to date (Oct. 2009)
• 157 Hymotion Prius PHEVs, 981,000 miles, 108,297 trips, 26,000 charging events, 58,400 kWh used. GridPoint (V2Green) and Kvaser data loggers
Hymotion Prius (GridPoint Log.) Fleet Tests

- March 2008 to Oct. 1, 2009. 116 PHEVs, 712,000 miles, 77,500 trips, 16,800 charging events and 44,000 kWh
Hymotion Prius PHEVs – CS Trips

- MPG and aggressive driving impacts March ‘08 – May ‘09

MPG & Driver Aggressiveness for 17,300 CS Trips, 275,000 miles (15.9 miles average trip distance)

Data from 150 Hymotion Prius with V2Green and Kvaser loggers
Hymotion Prius PHEVs – CS/CD Mixed Trips

- MPG and aggressive driving impacts March ‘08 – May ‘09

Data from 150 Hymotion Prius with V2Green and Kvaser loggers
Hymotion Prius PHEVs – CD Trips

• MPG and aggressive driving impacts March ‘08 – May ‘09

MPG & Driver Aggressiveness for 22,700 CD Trips, 151,000 miles (6.7 miles average trip distance)

Data from 150 Hymotion Prius with V2Green and Kvaser loggers
MPG Results - Charge Depleting (CD) Mode

Percent of 22,700 CD Trips and 151,000 CD Miles by MPG Grouping

Data from 150 Hymotion Prius with V2Green and Kvaser loggers
Testing Results by Fleet

Percent Miles Driven by Fleet and Operating Mode

- WA State 31
- California 18
- All V2Green 112
- Hawaii 6
- Canada 14
Testing Results by Fleet – cont’d

Percent Trips Taken by Fleet and Operating Mode

- WA State 31
- California 18
- All V2Green 112
- Hawaii 6
- Canada 14
Testing Results by Fleet – cont’d

Charging Statistics

- WA State 31
- California 18
- All V2Green 112
- Hawaii 6
- Canada 14

Ave Charging Event/Vehicle/Month
Ave Charging Event/Vehicle/Day
Ave Distance (mi) per charge
Ave kWh/Charge
Ave kWh/Month
Testing Results by Fleet – cont’d

MPG by Fleet and Operating Mode

- WA State 31
- California 18
- All V2Green 112
- Hawaii 6
- Canada 14

CD MPG, CS MPG, CD/CS MPG, All Modes MPG, CD/CS % Improvement
Seattle Area PHEV Smart Charging Trials

• 13 Hymotion PHEVs, sponsored by Seattle City Light using GridPoint’s *Electric Vehicle Management Solution*

• Types of Trials:
  – **Time of Day Charging** – Vehicle charging only allowed during certain hours of the day
  – **Goal Based Charging** – Normalize power demand for vehicle charging around a kW goal load
  – **Economic Charging** – Allow vehicle charging only when the price of electricity is below a threshold

• GridPoint Vehicle Connectivity Modules (VCM) used to control charging as directed by GridPoint’s server and to log vehicle charging and driving data

• VCM requests the pack to wait to charge or to charge at a specified power level - no physical circuit interruption

• INL analyzed the data collected from the vehicles
Charging – No Control

Typical Charge, Single Vehicle - No External Control

AC Power [Watts]

Charging
P_{avg} = 1100 W

Post Charge
P_{avg} = 6 W

End-of-Charge

Hymotion Prius PHEV battery from A123 Systems
Results of Time of Day Charging Trials

- VCM establishes communication with control server, requests charging only between 10pm & 4am

**Typical Charge, Single Vehicle - 10am to 4pm Charging**

- **Standby**: $P_{avg} = 40$ W
- **Charging**: $P_{avg} = 897$ W
- **Post Charge**: $P_{avg} = 5$ W

Vehicle Plugged In ~10 PM
Charging Begins
Charging Ends
Results of Time of Day Charging Trials

• Rogue AC kWh – energy drawn outside of allowable charging window:
  – Communication not established or lost - charging occurs
  – Cumulative standby energy draw when not charging
Results of kW Goal Charging Trials

- Vehicle charging controlled to normalize the resource load around 3 kW (Typical 7 Vehicle Max, 13 Possible)

![Typical Charge, Single Vehicle - 3kW Normalized Load](image)

- Charge: $P_{avg} = 702 \text{W}$ (8 Segments)
- Standby: $P_{avg} = 37 \text{W}$ (7 Segments)
- Post Charge: $P_{avg} = 6 \text{W}$
Results of Economic ($/kWh) Charging Trials
• Artificial price signal supplied and vehicles only charged when energy price < $.08/kWh
Commercial fleet
67 Hymotion Prius PHEVs
May 2009
1,218 Level I charging events
Commercial Fleet Average Charge Demand

Avg Hourly Vehicle Charging Demand

Time of Day

Mon AM - Tues AM
Tue AM - Wed AM
Wed AM - Thu AM
Thu AM - Fri AM
Fri AM - Sat AM
Sat AM - Sun AM
Sun AM - Mon AM
Commercial Fleet Average Charge Demand

**Weekday**

- Weekday period goes from Mon 6:00 AM to Sat 5:59 AM

**Weekend**

- Weekend period goes from Sat 6:00 AM to Mon 5:59 AM
Private Fleet Average Charging Demand

Private fleet
39 Hymotion Prius PHEVs
Jan – Sep 2009
1,014 charging events
Private Fleet Average Charging Demand

Weekday period goes from Mon 6:00 AM to Sat 5:59 AM
Weekend period goes from Sat 6:00 AM to Mon 5:59 AM
Vehicle to Grid (V2G) Regulatory Study

- Study of regulations, standards, and codes related to charging/discharging electric drive vehicles from/to the grid
  - Examine governmental regulations, standards and building code requirements potentially impacting V2G
  - Identify regulations, standards and codes requiring modification if V2G is implemented
  - Develop a common set of regulations, standards and codes for applying in a broad geographic area
  - Conducted with an OEM
- Base study on practices in Phoenix, Orlando, Boston, Detroit, Raleigh, Maui, San Diego, Dallas, Seattle, Washington DC, Portland OR, and New York
Other PHEV Testing

• Bidirectional vehicle-to-grid (V2G) charging study
  – 6 kW and 20 kW levels, using lithium PHEV batteries, V2Green cellular charging control. Document infrastructure requirements and costs for V2G

• Developing vehicle-based battery test bed research project for testing battery electric vehicle and PHEV batteries in various vehicle and charging operating scenarios, including:
  – High mileage applications that introduce testing uncertainties such as high heat, extreme cold, vibration, irregular charging profiles and the most dangerous influence of all – the vehicle operator
  – Testing will include dynamometer and battery laboratory testing
PHEV Charging Infrastructure Cost Report

- Analyzes PHEV infrastructure requirements in single and multi-family residential, and commercial facilities as well as driving trends. No site specific costs
- Charging infrastructure equipment/administrative costs:
  - Levels 1 (120V, 15 or 20 amp) and 2 residential
  - Levels 1 and 2 (208/240V ~40 amp) apartment complex
  - Level 2 commercial facility
- Battery sizes & charge times for various PHEV platforms
- Power electronics & battery costs for PHEV platforms

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<th>Level 1 Residential</th>
<th>Labor</th>
<th>Material</th>
<th>Permits</th>
<th>Total</th>
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<td>-</td>
<td>$250</td>
<td>-</td>
<td>$250</td>
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<tr>
<td>Residential circuit installation (20A branch circuit, 120 VAC/1-Phase)</td>
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<td>$360</td>
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eTec/Nissan EV Infrastructure Demonstration

- INL is a principle participant with eTec and Nissan in the deployment of 4,700 battery electric Nissan Leaf vehicles in 5 greater metropolitan statistical areas:
  - Portland OR., Seattle WA, San Diego CA, Phoenix / Tuscan AZ, and several Tennessee locals
  - INL will collect, analyze and report on charging infrastructure utilization for 11,000 Level II electric vehicle supply equipment (EVSE) and 260 Level III chargers
  - INL will report on vehicle charging patterns
eTec/Nissan EV Infrastructure Demonstration

**eTec/Nissan/Regional Partners**

- Seattle
- Portland, Eugene, Corvallis, Salem
- Nashville, Chattanooga, Knoxville
- San Diego
- Phoenix, Tucson
- INL
- OSU

**11K+ Level II & III Chargers**

**4700 Nissan EV’s**

**Data Analysis and Reporting**

**Battery – 24+ kWh Li-ion, Projected 100 Mile Range**
AVTA Webpage Use and Gasoline Costs

INL WWW Visitors & Gasoline Costs (all formulations, areas, and grades)

Number of Monthly Visitors

Visitors (left axis)

Gasoline Cost (right axis)

Linear (Gasoline Cost (right axis))

Linear (Visitors (left axis))

All Grades Gasoline Costs - End of Month

May '02 June July Aug Sept Oct Nov Dec '02 Jan '03 Feb March April May June July Aug Sept Oct Nov Dec '03 Jan '04 Feb March April May June July Aug Sept Oct Nov Dec '04 Jan '05 Feb March April May June July Aug Sept Oct Nov Dec '05 Jan '06 Feb March April May June July Aug Sept Oct Nov Dec '06 Jan '07 Feb March April May June July Aug Sept Oct Nov Dec '07 Jan '08 Feb March April May June July Aug Sept Oct Nov Dec '08

$1.25 $1.50 $1.75 $2.00 $2.25 $2.50 $2.75 $3.00 $3.25 $3.50 $3.75 $4.00 $4.25

$1.25 $1.50 $1.75 $2.00 $2.25 $2.50 $2.75 $3.00 $3.25 $3.50 $3.75 $4.00 $4.25
Summary

• INL/AVTA PHEV Demonstration has provided 1.1 million miles and 26,000 charging events of data (knowledge?)
• Driver behavior, charging frequency, and environmental conditions have significant impacts on electric drive vehicles’ 80-85% energy efficiencies and mpg results
• PHEV drive patterns suggest shorter distances per day driving patterns than previously documented
• PHEV operations often occur with minimal pre-trip charge events – “they run even if not plugged in”
• Non-charging energy use (hotel loads) may be significant
• The eTec/Nissan project will document more than 70 million miles of electric drive vehicle operations and more than 1.8 million charging events
• We (in this room) have the opportunity to help drive the future of electric drive transportation and infrastructure
Acknowledgement

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Additional Information:

http://avt.inl.gov
or
http://www1.eere.energy.gov/vehiclesandfuels/avta/