US Department of Energy and Idaho National Laboratory
PHEV Activity Overview

Ohio Rural Electric Cooperatives 2008 Fall
Marketing, Member Services and
Communication Conference

Columbus, OH
November 6, 2008

John Smart

INL/CON-08-15046
US Department of Energy
Vehicle Technologies Program
PHEV Research and Development Areas

System / component level activities include:

• Energy storage
  – Advanced battery cells, packs and full systems
    • Cost, life, low temperature performance, tolerance abuse and safety
  – Monitoring of all technologies (capacitors, flywheels, etc)

• Power electronics and electric Motors
  – Cost, size, thermal control, integrated systems development

• Definition of PHEV component requirements
US Department of Energy
Vehicle Technologies Program
PHEV Research and Development Areas

Vehicle Technology Analysis and Evaluation activities include:

• Modeling and Simulation
  – Reference Vehicle Definition
  – Analytical Tool Development
  – Technology Verification

• Integration and Validation
  – Hardware-in-the-Loop System Integration
  – Technology Validation

• Laboratory and Field Evaluation
  – Vehicle / Component Testing
  – Model Validation
US Department of Energy
PHEV Testing Partners

Cooperative testing agreements provide access to non-DOE owned PHEVs operating in demonstration fleets. Partners include:

- New York State Energy Research Development Agency (NYSERDA)
- City of Seattle, King County, Port of Seattle, Puget Sound Clean Air Agency
- Tacoma Power
- State of Hawaii
- National Rural Electric Cooperative Association
- University of California-Davis
- PHEV conversion companies
  - Hymotion
  - EnergyCS
  - others
US Department of Energy
PHEV Technology Acceleration and Deployment Activity (TADA)

• Funding opportunity for vehicle manufacturers to put prototype PHEVs in field over next three years
• Proposals selected for negotiation from:
  – General Motors
  – Ford Motor Co.
  – Chrysler / General Electric
Idaho National Laboratory

- Eastern Idaho based U.S. Department of Energy (DOE) multi-program 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
- The INL has managed DOE’s Advanced Vehicle Test Activity since the late 1980’s
Advanced Vehicle Testing Activity (AVTA)

• Part of the U.S. Department of Energy’s Vehicle Technologies Program
• INL and Electric Transportation Engineering Corporation (ETEC) conduct the AVTA’s light-duty vehicle testing, with Argonne National Laboratory performing dynamometer testing

AVTA Goals

• Determine actual petroleum displacement and overall operating cost of advanced technology vehicles
• Provide benchmark data to industry and government research and development programs
• Assist consumers in making informed vehicle purchase, usage, and operating decisions
AVTA Testing History

• Plug-in hybrid electric vehicles
  – 9 models, ~70 vehicles in fleets
• Hybrid electric vehicles
  – 14 models, 4+ million test miles
• Hydrogen ICE (internal combustion engine) vehicles
  – 6 models, 400,000 test miles
• Full-size electric vehicles
  – 40 EV models, 5+ million test miles
• Neighborhood electric vehicles
  – 16 models, 200,000 test miles
• Urban electric vehicles
  – 3 models, 1 million test miles
PHEV Models Tested by AVTA

Nine different PHEV models are in or have completed various testing / demonstration activities

- Hymotion Prius
- EnergyCS Prius
- Hymotion Escape
- HybridsPlus Escape
- HybridsPlus Prius
- Manzanita lead acid Prius
- Electrovaya Escape
- Ford E85 Escape
- Renault Kangoo

- Daimler Sprinter expected to start testing in Spring 2009
PHEV Testing Objectives
Perform independent testing of PHEVs using:

• Baseline performance testing
  – closed test tracks and dynamometers

• Accelerated on-road testing
  – dedicated drivers operating on defined routes

• Fleet testing
  – monitor everyday uncontrolled use with onboard data loggers

• Lab and field off-board charging / grid interaction studies
PHEV Testing Objectives

Study and document

• How the vehicles are driven
• How the vehicles are charged
• The effect on
  – Gasoline and electricity fuel use
  – Battery life
  – Facility / grid demand and energy profiles
• Charging infrastructure requirements
• Cost / benefit of fast charging, vehicle-to-grid charging
• Overall PHEV life-cycle costs
PHEV Baseline Performance Testing

- These and other test results at http://avt.inl.gov
Toyota Prius with Hymotion PHEV conversion – EPA City Test

- 5 kWh A123Systems (Li-ion) v1 and Prius packs (NiMH)
Toyota Prius with Hymotion PHEV conversion – EPA Highway Test

• 5 kWh A123Systems (Li-ion) v1 and Prius packs (NiMH)
## Hymotion Prius – On-road Accelerated Testing

<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>Electricity AC kWh</th>
<th>Gasoline Gal</th>
<th>MPG</th>
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Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg
Ford Escape Hybrid with HybridsPlus PHEV conversion – EPA City Test

- 10 kWh A123Systems (Li-ion)
Ford Escape Hybrid with HybridsPlus PHEV conversion – EPA Highway Test

- 10 kWh A123Systems (Li-ion)
Ford Escape Hybrid with Hymotion PHEV conversion – EPA City Test

- 8.5 kWh A123Systems (Li-ion) and Escape packs (NiMH)
Ford Escape Hybrid with Hymotion PHEV conversion – EPA Highway Test

- 8.5 kWh A123Systems (Li-ion) and Escape packs (NiMH)

![Graph showing Hymotion PHEV Escape MPG & kWh - HWFET Testing]
### Hymotion Escape – Accelerated Testing

<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>
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<td>162</td>
<td>5440</td>
<td>Weighted Average</td>
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</table>

Each total distance slightly greater than 600 miles. HEV version = 27 mpg
PHEVs and Demonstration Locations

14+34 - Canada

95 w/data loggers
59 adding
20+? In discussion
154 Total early 2009
Onroad Demonstration and Data Collection Partners

• ~75 Testing partners in the U.S. and Canada, including:
  – 36 Electric utilities (some via NRECA)
  – 6 City governments
  – 2 County governments
  – 2 State governments
  – 8 Universities and colleges
  – 2 Clean air agencies
  – 7 Private companies and advocacy organizations
  – 3 Governments of Canadian provinces
  – 2 Sea ports and U.S. military organizations
  – 2 PHEV conversion companies
PHEV Fleet Performance

- Data sampled from 28 Hymotion Prius vehicles
- Jan – Jun 2008
- 58,005 miles

**Combined Fleet Cumulative Gasoline Fuel Economy by Trip Type**

![Bar chart showing fuel economy by trip type]

**Distance Traveled by Trip Type**

![Bar chart showing distance traveled by trip type]

CD = Charge depleting
CS = Charge sustaining
PHEV Fleet Performance

- Data sampled from 4 conversion Escapes
  - 2 HybridsPlus, 2 Hymotion
- Jan – Aug 2008: 17,019 miles

Combined Fleet Cumulative Gasoline Fuel Economy by Trip Type

- Trips in CD mode
- Trips in CD/CS modes
- Trips in CS mode
- All trips

Distance Traveled by Trip Type

- Trips in CS mode
- Trips in CD/CS modes
- Trips in CD mode

CD = Charge depleting
CS = Charge sustaining
PHEV Fleet Performance

- Same 28 Hymotion Priuses, Jan – Jun 2008
- Range of monthly vehicle fuel economy results:

Some cars are achieving potential!
PHEV Fleet Performance

- Same 4 Escapes, Jan – Aug 2008
- Range of monthly vehicle fuel economy results:
PHEV Fleet Performance
• Same 28 Hymotion Priuses, Jan – Jun 2008
• Charging energy:

\[ \frac{3073 \text{ kWh}}{28185 \text{ mi}} = 108 \text{ Wh/mi} \]

\[ 58005 \text{ mi} \times 108 \text{ Wh/mi} = 6265 \text{ kWh} \]

Need > twice the electricity for 100% charge depleting miles (all other things equal)
PHEV Fleet Performance

- For better gasoline fuel efficiency, use more electricity!
- Battery capacity limited, so plug in more often

- Or put another way:
  For charge depleting operation, distance driven between charging events must be less than charge depleting range
Fleet Distance vs. Range

Hymotion Prius
23 cars
Jan – Jul 2008

Same cars, date range
Includes all segments that started with SOC > 95%, ended in CS mode.
CD range is CD distance for each segment.
Fleet Fuel and Electricity vs. Segment Distance

(42 EV-only segments not included)
“Actual Mileage May Vary”

- Even when in charge depleting mode, gasoline fuel efficiency, electrical energy efficiency, and charge depleting range vary widely depending on usage.

- Causes of variation
  - Driver aggressiveness
  - Location (city, rural, highway)
  - Temperature
  - Payload
  - Etc.
Driver Aggressiveness

Effect of Aggressiveness on Trip Fuel Economy

- Aggressiveness measured by time at accelerator pedal position
- The deeper the pedal, the higher the aggressiveness

28 Hymotion Priuses
Jan – Jun 2008
All trips with distance > 1 mi
Fuel Economy Seasonal Variation

Overall Gasoline Fuel Economy
Fleet Distribution by Month

Range of monthly vehicle fuel economy (mpg)

28 Hymotion Priuses
Jan – Jun 2008
## Plug-in Charging Patterns

<table>
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<tr>
<th>Metric</th>
<th>Value</th>
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<tbody>
<tr>
<td>Average number of charging events per vehicle per month</td>
<td>20</td>
</tr>
<tr>
<td>Average number of charging events per vehicle per day when vehicle driven</td>
<td>0.7</td>
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<tr>
<td>Average number of trips between charging events</td>
<td>3.9</td>
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<tr>
<td>Average distance driven between charging events (mi)</td>
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<tr>
<td>Average duration of charging event (hr)</td>
<td>2.4</td>
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<tr>
<td>Average energy per charging event (DC kWh)</td>
<td>1.8</td>
</tr>
<tr>
<td>Average charging energy per vehicle per month (DC kWh)</td>
<td>35.3</td>
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</table>
Plug-in Charging Patterns

Time of Day When Driving

<table>
<thead>
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<th>Time of Day</th>
<th>% of Occurrences</th>
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</thead>
<tbody>
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<td>6 - 6:59 AM</td>
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</tr>
<tr>
<td>8 - 8:59 AM</td>
<td>0%</td>
</tr>
<tr>
<td>10 - 10:59 AM</td>
<td>0%</td>
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<tr>
<td>12 - 12:59 PM</td>
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<td>12 - 12:59 AM</td>
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<tr>
<td>2 - 2:59 AM</td>
<td>0%</td>
</tr>
<tr>
<td>4 - 4:59 AM</td>
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</tr>
</tbody>
</table>

Time at the Start of Charging Events

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>% of Occurrences</th>
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</thead>
<tbody>
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<tr>
<td>8 - 8:59 AM</td>
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<tr>
<td>10 - 10:59 AM</td>
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<td>12 - 12:59 PM</td>
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<tr>
<td>2 - 2:59 PM</td>
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<td>0%</td>
</tr>
<tr>
<td>4 - 4:59 AM</td>
<td>0%</td>
</tr>
</tbody>
</table>
Plug-in Charging Patterns

Energy Consumed vs. Time of Day When Charging

DC kWh

0 50 100 150 200 250 300

6 - 6:59 AM 8 - 8:59 AM 10 - 10:59 AM 12 - 12:59 PM 2 - 2:59 PM 4 - 4:59 PM 6 - 6:59 PM 8 - 8:59 PM 10 - 10:59 PM 12 - 12:59 AM 2 - 2:59 AM 4 - 4:59 AM
PHEV/EV Impact on Electrical Grid

Basic questions to answer:

• How many PHEVs?
• What kind of PHEVs (energy capacity)?
• Where are they charging?
  – Population density
  – Type of service/circuit
• When are they charging?
• How are they charging (power demand)?
PHEV – Grid Interaction Testing

• Time-of-day charging study (Fall 2008)
  – Conducting charging demonstration with City of Seattle using 13 Seattle area PHEVs
  – Includes INL battery impact analysis
  – Uses V2Green wireless charging control

• Charging infrastructure and facility demand study (started May 2008)
  – Conducting charging demonstration with Tacoma Power to:
    • document charging infrastructure needs
    • determine demand and energy profiles of PHEV charging as portion of facility profiles
  – Using WiFi local energy meter (LEM) data collection system

• Bidirectional vehicle-to-grid (V2G) charging study with electric utilities participating (Fall 2008)
  – 6 kW and 20 kW levels, using two lithium battery PHEVs, V2Green cellular charging control, documenting infrastructure requirements and costs
Acknowledgement

INL/AVTA work is supported by the U.S. Department of Energy’s Vehicle Technologies Program
Pat Davis, Tien Duong, Lee Slezak and Ro Sullivan

Additional Information

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