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

Maui Energy Expo - PHEV Operations and Performance

Jim Francfort

Maui Energy Expo
Maui, Hawaii – September 2009

This presentation does not contain any proprietary or sensitive information
AVTA Background and Goals

- The Advanced Vehicle Testing Activity (AVTA) is part of DOE’s Vehicle Technologies Program
- The Idaho National Laboratory (INL) and Electric Transportation Engineering Corporation (ETEC) conduct the AVTA. Argonne National Laboratory performs dynamometer testing

- The AVTA goals:
  - Provide benchmark data to technology modelers, research and development programs, vehicle manufacturers (via VSATT), and target and goal setters
  - Assist fleet managers in making informed early adaptor vehicle purchase, deployment and operating decisions
AVTA Testing by Technology

- **Plug-in hybrid electric vehicles (PHEV)**
  - 12 models, 187 vehicles, 850,000 fleet test miles

- **Hybrid electric vehicles (HEV)**
  - 17 models, 45 vehicles, 4.5 million test miles

- **Neighborhood electric vehicles**
  - 23 models, 200,000 test miles

- **Hydrogen ICE (internal combustion engine) vehicles**
  - 7 models, 500,000 test miles

- **Full-size battery electric vehicles (BEVs)**
  - 40 EV models, 5+ million test miles

- **Urban electric vehicles**
  - 3 models, 1 million test miles
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 on defined onroad loops
  – Fleet testing: everyday unstructured \ non-directed fleet and public use, with onboard data loggers
  – Laboratory testing of PHEV batteries

• Testing used to document:
  – Battery life, charging patterns and profiles
  – Vehicle operations, fuel use (electricity and gasoline) and infrastructure requirements
  – Driver influences on fuel use
  – Individual PHEV models and PHEV concepts
  – PHEV life-cycle costs
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) 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 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.
Hymotion Prius Gen I – UDDS Fuel Use

- 5 kWh A123Systems (Li) and Prius packs (AC kWh)

Hymotion PHEV Prius MPG & kWh - UDDS Testing

Each Bar - 1 UDDS Test Cycle, Labeled by Cumulative Miles
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>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
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<td>0</td>
<td>4</td>
<td>60</td>
<td>600</td>
<td>37%</td>
<td>11%</td>
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<tr>
<td>20</td>
<td>1</td>
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<td>8</td>
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<td>12</td>
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<td>Total</td>
<td>2,340</td>
<td>3,100</td>
<td>1,344</td>
<td>162</td>
<td>5,440</td>
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</tr>
<tr>
<td>Average</td>
<td>43%</td>
<td>57%</td>
<td>8.3</td>
<td>18</td>
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## Hymotion Prius Gen I – Accelerated Testing

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<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 Gals</th>
<th>MPG</th>
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<tr>
<td>10</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>60</td>
<td>600</td>
<td>136.33</td>
<td>4.81</td>
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<td>8</td>
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<td>122.02</td>
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<td>4</td>
<td>12</td>
<td>10</td>
<td>600</td>
<td>55.33</td>
<td>8.98</td>
<td>68.9</td>
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<td>12</td>
<td>8</td>
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<td>43.99</td>
<td>11.36</td>
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<td>11.02</td>
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<td><strong>2340</strong></td>
<td><strong>3100</strong></td>
<td><strong>1404</strong></td>
<td><strong>167</strong></td>
<td><strong>5,440</strong></td>
<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>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>8.88</td>
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<td>600</td>
<td>33.38</td>
<td>10.54</td>
<td>58.8</td>
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<td>80</td>
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<td>8</td>
<td>640</td>
<td>41.38</td>
<td>10.71</td>
<td>61.8</td>
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<td>100</td>
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<td>12</td>
<td>6</td>
<td>600</td>
<td>26.48</td>
<td>10.91</td>
<td>56.5</td>
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<td>3</td>
<td>600</td>
<td>16.01</td>
<td>10.41</td>
<td>57.7</td>
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<td><strong>Total</strong></td>
<td><strong>2340</strong></td>
<td><strong>3100</strong></td>
<td><strong>1404</strong></td>
<td><strong>167</strong></td>
<td><strong>7,840</strong></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg
Hymotion Prius Gen II – Accelerated Testing

- 40 mile city/highway loops – high ambient temperatures results in incomplete charging
PHEV Fleet Testing Partners

• 75+ testing partners in the U.S. and Canada:
  – 36 Electric utilities and 2 clean-air agencies
  – 10 City, county and state 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

• Testing partners include:
PHEVs and Demonstration Locations

228 Total
177 Operating
41 Coming in ‘09
10 Out of Service

30+18 - Canada

1 in DC
PHEV Fleet Testing Reports

- Summary reports posted monthly on web
- Individual vehicle reports only go to the respective fleets each month, 1,060+ reports to date (August 1, 2009)
- 153 Hymotion Prius PHEVs, 780,000 miles, 86,000 trips, 20,500 charging events, 47,000 kWh used. V2Green and Kvaser data logger reports
Hymotion Prius (V2Green Logger) Fleet Tests

- March 01/08 to July 01/09. 110 PHEVs, 498,000 miles, 54,000 trips, 12,400 charging events and 31,000 kWh used
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

MPG & Driver Aggressiveness for 5,900 CD/CS Trips, 149,000 miles (25.3 miles average trip distance)

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
Ambient Temperature MPG Impacts

Hymotion Prius Fleet Fuel Economy

Average Fuel Economy [MPG]

Average Ambient Temperature [C]

- <20°C
- 20°C to -10°C
- -10°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

All Trips
CD
CD/CS
CS
Engine Operations by Ambient Temperatures

Hymotion Prius Fleet - Percentage of Miles with Engine On

<table>
<thead>
<tr>
<th>Average Ambient Temperature [°C]</th>
<th>Percent Miles Engine On [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; -20°C</td>
<td>All Trips</td>
</tr>
<tr>
<td>20°C to -10°C</td>
<td>CD</td>
</tr>
<tr>
<td>-10°C to 0°C</td>
<td>CD/CS</td>
</tr>
<tr>
<td>0°C to 10°C</td>
<td>CS</td>
</tr>
<tr>
<td>10°C to 20°C</td>
<td></td>
</tr>
<tr>
<td>20°C to 30°C</td>
<td></td>
</tr>
<tr>
<td>30°C to 40°C</td>
<td></td>
</tr>
<tr>
<td>&gt; 40°C</td>
<td></td>
</tr>
</tbody>
</table>

Average Ambient Temperature [°C] vs. Percent Miles Engine On [%]

Graph showing the percentage of miles with the engine on for different ambient temperature ranges, with labels for All Trips, CD, CD/CS, and CS.
Monthly Fleet Testing MPG Results

Monthly MPG by Operating Mode

- MPG - All
- MPG CD
- MPG CD/CS
- MPG CS

Graph showing Monthly MPG by Operating Mode from April 2008 to July 2009.
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
- Haw aii 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

0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100
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

<table>
<thead>
<tr>
<th>Level 1 Residential</th>
<th>Labor</th>
<th>Material</th>
<th>Permits</th>
<th>Total</th>
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<tr>
<td>EVSE (charge cord)</td>
<td>-</td>
<td>$250</td>
<td>-</td>
<td>$250</td>
</tr>
<tr>
<td>Residential circuit installation (20A branch circuit, 120 VAC/1-Phase)</td>
<td>$300</td>
<td>$131</td>
<td>$85</td>
<td>$516</td>
</tr>
<tr>
<td>Administration costs</td>
<td>$60</td>
<td>$43</td>
<td>$9</td>
<td>$112</td>
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<tr>
<td>Total Level 1 Cost</td>
<td>$360</td>
<td>$424</td>
<td>$94</td>
<td>$878</td>
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</tbody>
</table>

Report @ http://avt.inl.gov/pdf/phev/phevInfrastructureReport08.pdf
AVTA Webpage Use and Gasoline Costs

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

Visitors (left axis)
Gasoline Cost (right axis)
Linear (Gasoline Cost (right axis))
Linear (Visitors (left axis))

Number of Monthly Visitors
$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

All Grades Gasoline Costs - End of Month
$1.25
$1.75
$2.00
$2.25
$2.50
$2.75
$3.00
$3.25
$3.50
$3.75
$4.00
$4.25

May '02
June
July
Aug
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Nov
Dec '02
Jan '03
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Dec '03
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Jan '09
Feb
Acknowledgement

This work is supported by the U.S. Department of Energy’s Vehicle Technologies Program

Additional Information

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