U.S. DOE Advanced Vehicle Testing Activity

PHEV Testing Activities and Fleet Demonstrations

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Portland, Oregon
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This presentation does not contain any proprietary or sensitive information
Presentation Outline

• Background - Idaho National Laboratory and DOE’s Advanced Vehicle Testing Activity
• AVTA testing history
• PHEV baseline performance and accelerated onroad testing methods and results
• PHEV demonstration partners and data collection
• PHEV charging infrastructure examples
• Other PHEV testing studies
• Unofficial market status of PHEVs by converter and OEM
Idaho National Laboratory

- Eastern Idaho based U.S. Department of Energy (DOE) multi-program laboratory
- 890 square-mile site with 3,600 staff
- Support implementation of DOE’s strategic goals, both nationally and regionally, including
  - Diversity of supply and use
  - Reduced environmental impact
  - Flexible, reliable energy infrastructure
  - Energy security
AVTA Background

• The Advanced Vehicle Testing Activity (AVTA) is part of The U.S. Department of Energy’s Vehicle Technologies Program

• The Idaho National Laboratory (INL) and Electric Transportation Engineering Corporation (ETEC) conduct the AVTA light-duty vehicle testing; Argonne National Laboratory provides dynamometer testing support

AVTA Goal

• Provide benchmark data to technology modelers, research and development programs, and target and goal setters

• Assist fleet managers in making informed vehicle purchase, deployment and operating decisions
AVTA Test History

- PHEVs - 8 different models in testing / demonstrations
- Hybrid electric vehicles
  - 14 models, 42 vehicles, 3.7 million test miles
- Hydrogen ICE (internal combustion engine) vehicles
  - 7 models, 400,000 test miles
- Full-size electric vehicles
  - 40 EV models, 5+ million test miles
- Neighborhood electric vehicles
  - 20 models, 200,000 test miles
- Urban electric vehicles
  - 3 models, 1 million test miles
PHEV Testing 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 use

• Document battery life, charging patterns and demand profiles

• Document vehicle operations, fuel use (both gasoline and electricity) and infrastructure requirements

• Document PHEV life-cycle costs
PHEV Baseline Performance Testing

- ETEC conducts initial track testing near Phoenix, AZ
  - Includes coastdown (determination of dynamometer coefficients), acceleration, top speed, braking, charging, and durability testing
- Argonne 5-day dynamometer testing regime includes:
  - Charge depleting and charge sustaining test cycles
  - At least 26 UDDS (Urban Dynamometer Driving Schedule) and HWFEDS (Highway Fuel Economy Driving Schedule) dynamometer test cycles
  - Includes hot and cold test starts
Baseline Performance Testing Results

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**Energy CS Plug-In Hybrid**

**Vehicle Specifications**
- **Engine**: 152kW
- **Charge Depleting**: Acceleration 0-60 MPH: 7.3 seconds, Maximum Speed: 105 MPH
- **Charge Sustaining**: Acceleration 0-60 MPH: 11.3 seconds, Maximum Speed: 79 MPH

**UDDS Fuel Economy**
- **Distance (miles)**: 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200
- **Fuel Economy (mpg)**: 118.0, 137.6, 124.7, 94.7, 99.8, 77.9, 160.3, 117.4, 99.4, 88.8, 83.7
- **Energy Consumed (kWh)**: 1.87, 5.65, 5.5, 5.65, 6.4, 5.92, 3.31, 3.59, 3.58, 3.58, 3.58

**HWFET Fuel Economy**
- **Distance (miles)**: 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200
- **Fuel Economy (mpg)**: 104.6, 116.4, 99.9, 85.7, 75.2, 66.6, 85.7, 75.2, 66.6, 59.2, 53.9
- **Energy Consumed (kWh)**: 1.77, 3.45, 5.46, 5.92, 5.29, 5.93, 5.29, 5.93, 5.93, 5.93, 5.93

**Test Notes**
1. Distance at constant speed
2. Time starts from zero
3. See UDDS and HWFET Test Procedure Specifications
4. Measurement is based on the average of three tests
5. Charging efficiency is based on the average of three tests
6. A/C energy not included in measured energy efficiency

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**HybriBM Plug-In Hybrid**

**Vehicle Specifications**
- **Engine**: 260kW
- **Charge Depleting**: Acceleration 0-60 MPH: 6.9 seconds, Maximum Speed: 100 MPH
- **Charge Sustaining**: Acceleration 0-60 MPH: 12.6 seconds, Maximum Speed: 55 MPH

**UDDS Fuel Economy**
- **Distance (miles)**: 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200
- **Fuel Economy (mpg)**: 154.8, 160.3, 124.7, 94.7, 99.8, 77.9, 160.3, 117.4, 99.4, 88.8, 83.7
- **Energy Consumed (kWh)**: 1.65, 3.31, 5.58, 5.38, 5.38, 3.58, 3.31, 3.58, 3.58, 3.58, 3.58

**HWFET Fuel Economy**
- **Distance (miles)**: 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200
- **Fuel Economy (mpg)**: 87.48, 95.27, 86.11, 75.79, 67.36, 61.05
- **Energy Consumed (kWh)**: 1.30, 2.24, 3.20, 3.92, 3.92, 3.30

**Test Notes**
1. Distance at constant speed
2. Time starts from zero
3. See UDDS and HWFET Test Procedure Specifications
4. Measurement is based on the average of three tests
5. Charging efficiency is based on the average of three tests
6. A/C energy not included in measured energy efficiency
EnergyCS Prius – UDDS Fuel Use

- 9 kWh Valence (Li) pack only (AC kWh)

![EnergyCS PHEV Prius MPG & kWh - UDDS Testing graph]

*Each Bar = 1 UDDS Test Cycle. Labeled by Cumulative Miles*
EnergyCS Prius – HWFETS Fuel Use

• 9 kWh Valence (Li) pack only (AC kWh)
Hymotion Prius – UDDS Fuel Use

- 5 kWh A123Systems (Li) V1 and Prius packs (AC kWh)

![Hymotion PHEV Prius MPG & kWh - UDDS Testing](chart.png)

Each Bar - 1 UDDS Test Cycle, Labeled by Cumulative Miles
Hymotion Prius – HWFETS Fuel Use

- 5 kWh A123Systems (Li) V1 and Prius packs (AC kWh)

Each Bar - 1 HWFET Test Cycle, Labeled by Cumulative Miles
Hymotion Escape – UDDS Fuel Use

- 8.5 kWh A123Systems (Li) and Escape packs (AC kWh)
Hymotion Escape – HWFETS Fuel Use

- 8.5 kWh A123Systems (Li) and Escape packs (AC kWh)

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

Each Bar = 1 HWFET Test Cycle. Labeled by Cumulative Miles

Drive Cycle Fuel Economy
Cumulative AC kWhrs
Cumulative Fuel Economy
Electrovaya Escape – UDDS Fuel Use

- 12 kWh Electrovaya (Li) and Escape packs (AC kWh)

![Electrovaya PHEV Escape MPG & kWh - UDDS Testing](chart.png)

Each Bar = 1 UDDS Test Cycle. Labeled by Cumulative Miles

- **MPG per UDDS Test**
- **Cumulative AC kWh**
- **Cumulative UDDS MPG**
Electrovaya Escape – HWFETS Fuel Use

- 12 kWh Electrovaya (Li) and Escape packs – (AC kWh)
Renault Kangoo Test Results

- First OEM series PHEV with 9.6 kWh (usable) Saft NiCad pack and 650cc gasoline engine

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<th>Test Cycle</th>
<th>AC kWh per Mile</th>
<th>Miles per Gallon</th>
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PHEV Accelerated Testing

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

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Total 2,340 3,100 1,344 162 5,440

Average 43% 57% 8.3 18
### EnergyCS Prius – Accelerated Testing

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*Rerun to 600 miles. **Software updated and cells replaced. May rerun. Each total distance slightly greater than 600 miles. HEV version = 44 mpg.*
# Hymotion Prius – Accelerated Testing

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Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg
### Renault Kangoo – Accelerated Testing

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* Test ended when gasoline engine and inverter failed. Each total distance slightly greater than 600 miles.
## Hymotion Escape – Accelerated Testing

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<td><strong>1344</strong></td>
<td><strong>162</strong></td>
<td><strong>5440</strong></td>
<td><strong>Weighted Average</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Each total distance slightly greater than 600 miles. HEV version = 27 mpg
### Electrovaya 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>
<th>Total (mi)</th>
<th>Electricity AC kWh</th>
<th>Gasoline Gals</th>
<th>MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>60</td>
<td>600</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>20</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>30</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>4</td>
<td>0</td>
<td>12</td>
<td>15</td>
<td>600</td>
<td>71.3</td>
<td>16.42</td>
<td>37.3</td>
</tr>
<tr>
<td>40</td>
<td>2</td>
<td>2</td>
<td>12</td>
<td>15</td>
<td>600</td>
<td>69.8</td>
<td>14.34</td>
<td>43.1</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
<td>4</td>
<td>12</td>
<td>15</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>2</td>
<td>4</td>
<td>12</td>
<td>10</td>
<td>600</td>
<td>44.8</td>
<td>16.64</td>
<td>37.3</td>
</tr>
<tr>
<td>80</td>
<td>2</td>
<td>6</td>
<td>12</td>
<td>8</td>
<td>640</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>2</td>
<td>8</td>
<td>12</td>
<td>6</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>2</td>
<td>18</td>
<td>12</td>
<td>3</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2340</strong></td>
<td><strong>3100</strong></td>
<td><strong>1344</strong></td>
<td><strong>162</strong></td>
<td><strong>5440</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Each total distance slightly greater than 600 miles. HEV version = 27 mpg
EnergyCS Prius – Fuel Costs

Each data point labeled by HWFEDS and UDDS tests, uneven miles. Gas $4.00 gallon & kWh $0.10
Hymotion Prius – Fuel Costs

Hymotion PHEV Prius UDDS & HWFEDS Fuel Cost per Mile

Each data point labeled by HWFEDS and UDDS tests, uneven miles. Gas $4.00 gallon & kWh $0.10
Hymotion Escape – Fuel Costs

Hymotion PHEV Escape UDDS & HWFEDS Fuel Cost per Mile

Each data point labeled by HWFEDS and UDDS tests, uneven miles. Gas $4.00 gallon & kWh $0.10
Electrovaya Escape – Fuel Costs

Electrovaya PHEV Escape UDDS & HWFEDS Fuel Cost per Mile

Each data point labeled by HWFEDS and UDDS tests, uneven miles. Gas $4.00 gallon & kWh $0.10
PHEV Vs. HEV and ICE Fuel Costs per Mile

Each data point labeled by HWFEDS and UDDS Tests, Uneven Miles. Gas $4.00 gallon & kWh $0.10
Onroad Demonstration Partners and Fleet Data Collection Activities
Hymotion Joint Data Collection

- Kvaser data loggers installed 50 PHEVs North America
- Onboard data includes vehicle performance, fuel use, and charging and driving profiles
- Participants include electric utilities, water agencies, universities, county and provincial governments:
  - East / South East: Toronto, Virginia, South Carolina, North Carolina, Kentucky, Florida
  - North / Central: Wisconsin, North Dakota, Indiana, Manitoba
  - Southwest: Arizona, Texas
  - West Coast: California, Oregon
- Started 2007
Single Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges
Single Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges

- Plug-in battery SOC prior to charging
- Total distance since last charging event (mi)
- Number of trips since last charging event
- Plug-in battery SOC after charging
Single Hymotion Prius MPG Vs. Speed

- 3 months, 2212 miles

CD – charge depleting, S - sustaining
Single Hymotion Prius MPG Vs. Distance

- 3 months, 2212 miles

CD – charge depleting, S - sustaining
26 Hymotion Prius - January thru May 2008

- Below averages do NOT tell the whole PHEV energy-use potential – see following May-only slides

<table>
<thead>
<tr>
<th>Charge / Operating Mode</th>
<th>Number of Trips</th>
<th>Distance Traveled (Miles)</th>
<th>Miles per Gallon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge Depleting (CD)</td>
<td>3,073</td>
<td>14,820</td>
<td>59</td>
</tr>
<tr>
<td>Mixed CD / CS</td>
<td>404</td>
<td>11,121</td>
<td>49</td>
</tr>
<tr>
<td>Charge Sustaining (CS)</td>
<td>1,358</td>
<td>16,059</td>
<td>40</td>
</tr>
<tr>
<td>All trips combined</td>
<td>4,835</td>
<td>42,000</td>
<td>48</td>
</tr>
</tbody>
</table>
13 Hymotion Prius in May 2008 - MPG

- Below averages do NOT tell the whole PHEV energy use potential – see next 3 slides

<table>
<thead>
<tr>
<th>Charge / Operating Mode</th>
<th>Number of Trips</th>
<th>Total Distance (Miles)</th>
<th>Average Trip Distance (miles)</th>
<th>MPG</th>
<th>DC kWh per Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge Depleting (CD)</td>
<td>575</td>
<td>3,040</td>
<td>5.3</td>
<td>72.0</td>
<td>0.138</td>
</tr>
<tr>
<td>Mixed CD / CS</td>
<td>67</td>
<td>1,840</td>
<td>27.5</td>
<td>52.1</td>
<td>0.050</td>
</tr>
<tr>
<td>Charge Sustaining (CS)</td>
<td>133</td>
<td>1,411</td>
<td>10.6</td>
<td>40.2</td>
<td></td>
</tr>
<tr>
<td>Electric vehicle only (EV)</td>
<td>137</td>
<td>127</td>
<td>0.9</td>
<td></td>
<td>0.236</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>912</strong></td>
<td><strong>6,417</strong></td>
<td><strong>7.0</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CD, CS, CD/CS results (excludes EV results)</strong></td>
<td><strong>775</strong></td>
<td><strong>6,291</strong></td>
<td><strong>8.1</strong></td>
<td><strong>55.9</strong></td>
<td></td>
</tr>
</tbody>
</table>
13 Hymotion Prius MPG Vs. Speed

Trip Fuel Economy vs. Trip Average Speed - May 2008

Trip Fuel Economy (mpg)

Trip Average Speed (mph)

- CD trips
- CD/CS trips
- CS trips
13 Hymotion Prius MPG Vs. Distance

Trip Fuel Economy vs. Trip Distance

- CD trips
- CD/CS trips
- CS trips
13 Hymotion Prius and Aggressive Driving

MPG vs. Trip Aggressiveness (Percent of time above the 40% accelerator pedal position)

- CD trips
- CD/CS trips
- CS trips
- Log. (CD trips)
- Log. (CD/CS trips)
NYSERDA Testing Partnership

- AVTA is testing New York State Energy Research and Development Agency’s PHEV conversions, stated 2007
- Fleet testing of ~20 PHEVs later CY08

<table>
<thead>
<tr>
<th>Model</th>
<th>Baseline Testing</th>
<th>Accelerated Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>EnergyCS Prius</td>
<td>Completed</td>
<td>Near completion, restarted</td>
</tr>
<tr>
<td>Hymotion Prius</td>
<td>Completed</td>
<td>Completed</td>
</tr>
<tr>
<td>Hymotion Escape</td>
<td>Completed</td>
<td>Ongoing</td>
</tr>
<tr>
<td>Electovaya Escape</td>
<td>Completed (problems)</td>
<td>Restarted</td>
</tr>
<tr>
<td>HybridsPlus Escape</td>
<td>Not started</td>
<td>Suspended</td>
</tr>
</tbody>
</table>
EnergyCS Prius Joint Data Collection

- Provided AVTA onboard data for 11 vehicles operating in fleets in Canada, Arizona, Georgia and California
- Going forward, EnergyCS is using lithium batteries from various manufacturers
- ~30 vehicles deployed (~15 North America and ~15 Europe)
Fleet Demonstration Partners

- Seattle-area, using 13 Hymotion Prius with:
  - City of Seattle (4)
  - King County (4)
  - Port of Seattle (2)
  - Puget Sound Clean Air Agency (3)
  - Started 4/2008, 1 converted to date, more 8/2008

- Tacoma Power
  - 2 current Green Car Company lead acid Prius – potential battery problems
  - 2 Hymotion Prius adding 11/2008

- These and all future demonstration PHEVs are using V2Green onboard data loggers with cellular data transfer and GPS
Fleet Demonstration Partners – cont’d

• Washington State-wide, Port of Chelan leading, with 14 Hymotion Prius with:
  – Benton County PUD, Chelan County Public Works, City of Wenatchee, Douglas County PUD, Energy Northwest, Green IT Alliance, McKinstry, Port of Chelan, University of Washington, Walla Walla Community College and Wenatchee Valley College
  – Started 4/2008, 1 converted to date, more 8/2008

• University of California Davis, with 13 Hymotion Prius
  – Up to 70 AAA of California public drivers will each operate a vehicle for ~2 months
  – First study of public use of PHEVs, charging practices and locations, started April 2008
  – 7 vehicles converted
Fleet Demonstration Partners – cont’d

• National Rural Electric Cooperative Association
  – Total of ten Prius and Escape PHEVs from Hymotion, EnergyCS, and Hybrids Plus operated by rural electric coop utilities, 6 converted to date, started 2007
  – Includes: Jackson Electric Membership Coop (GA), Salem Electric (OR), Four County Electric Membership Corp. (NC), Central Electric Power Coop (SC), Great River Electric (MN), and Buckeye Rural Electric Coop (OH)

• Hawaii, with 6 Hymotion Prius on Maui and Oahu
  – Planned start 11/2008
14 - Canada

65 w/data loggers
68 adding CY08
? In discussion
133 Total end of CY08
Charging Infrastructure

• National Electric Code requires
  – Dedicated branch circuit
  – GFCI (ground fault circuit interrupt)
  – “EV” extension cord
  – Unique connector “plug”

• NEC being updated
Other PHEV Testing

• Ford E85 Escape PHEV demonstration, started 6/2008
• Hymotion Prius with A123Systems V2 battery – conduct vehicle/battery testing, summer 2008
• PHEV charging at commercial facility studies - collecting data on PHEVs and commercial facilities to document energy profiles of recharging PHEVs as portion of facility profiles. Started 5/2008
• Defining time-of-day demand charging demonstration and battery analysis impacts on 13 PHEVs in Seattle
Other PHEV Testing – cont’d

- Defining bidirectional vehicle-to-grid (V2G) charging study with electric utilities participating
  - 6 kW and 20 kW levels, using two lithium battery PHEVs, cellular charging control, documenting infrastructure requirements and costs
- Daimler PHEV Sprinter – conduct vehicle/battery testing, start winter 2008/2009
- Conduct vehicle/battery testing on PHEVs when received via DOE’s original equipment manufacture’s PHEV solicitation
- Consider other PHEV conversions for vehicle/battery testing
PHEV Market Status - Converters

• Hymotion: About 85 Prius ($9995) and 5 Escapes
  – Prius only battery production ramp-up now, replacing all 67 Version 1 batteries. Recall Escapes
  – Prius crash-tested and obtaining CARB certification
  – Conversions and warranty work in Boston, Los Angeles, Minneapolis, San Francisco, and Seattle

• Hybrids Plus: 26 Prius and Escapes, ($21,600 to $36,150). Some operational issues

• EnergyCS: ~30 Prius (~$40,000). Some operational issues, only doing custom conversions in future

• Cal Cars: 8 Pius, believed to be all lead acid

• Green Car Company: 3(?) lead acid conversions ($12,000). Some operational issues. May do Hymotion conversions

• Electrovaya: 2 Escapes. Some operational issues

• Various single conversion “companies”
PHEV Market Status - OEMs

- Daimler Benz – 6 Sprinters late 2008, 1 to AVTA
- Ford: 20 Escapes in 2008/2009. 1 at AVTA for 6 months
- General Motors: Volt late 2010. Maybe Vue earlier
- Renault Kangoo: ~1,200 NiCad range-extenders in Europe (was 1 in U.S.), but shipped AVTA’s to Brussels for repair and sale
- Toyota: 20 Prius NiMH PHEVs in U.S., France and Japan, gaining operational knowledge. Maybe available in 2009
- Volvo and other OEMs have made various announcements
- DOE PHEV solicitation: Ford, GE/Chrysler and GM. AVTA to test products

- Note that OEM and converter statuses not necessarily “official” versions
Acknowledgement

This work is supported by the U.S. Department of Energy’s Vehicle Technologies Program:
Tien Duong, Lee Slezak and Ro Sullivan

Additional Information

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

INL/CON-08-14506