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

Advanced Vehicle Testing Activity’s HEV, NEV, HICE, and PHEV Testing Results and Resources

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Clean Cities National Leadership Retreat
Big Sky, Montana – September 2008

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

• The Advanced Vehicle Testing Activity (AVTA) is conducted for DOE (Lee Slezak) by the Idaho National Laboratory (INL) and Electric Transportation Engineering Corporation (ETEC), with Argonne National Laboratory providing testing support

• AVTA Goal
  – Provide vehicle and fueling infrastructure benchmark data to technology modelers, research and development programs, and target and goal setters
  – Assist fleet managers (often the early adaptors of alternative fuel vehicles) in making informed vehicle purchase, deployment and operating decisions
AVTA Testing History

- Plug-in hybrid electric vehicles
  - 9 models, ~75 vehicles
- Hybrid electric vehicles
  - 14 models, 4 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
  - 16 models, 200,000 test miles
- Urban electric vehicles
  - 3 models, 1 million test miles
# Hybrid Electric Vehicles (HEVs) in Testing

<table>
<thead>
<tr>
<th>Model</th>
<th>QTY</th>
<th>Status</th>
</tr>
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<tbody>
<tr>
<td>2001 Honda Insight</td>
<td>6</td>
<td>Completed</td>
</tr>
<tr>
<td>2002 Gen I Toyota Prius</td>
<td>6</td>
<td>Completed</td>
</tr>
<tr>
<td>2003 Gen I Honda Civic</td>
<td>4</td>
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</tr>
<tr>
<td>2004 Chevrolet Silverado (2- &amp; 4-WD)</td>
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<tr>
<td>2004 Gen II Toyota Prius</td>
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<td>2005 Ford Escape (front &amp; 4-WD)</td>
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<td>2005 Honda Accord</td>
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<td>Completed</td>
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<td>2006 Lexus RX 400h (front &amp; 2 AWD)</td>
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<td>2006 Toyota Highlander (AWD)</td>
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<td>Ongoing</td>
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<tr>
<td>2006 Gen II Honda Civic</td>
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<tr>
<td>2007 Saturn Vue</td>
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<td>Ongoing</td>
</tr>
<tr>
<td>2007 Toyota Camry</td>
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<td>Ongoing</td>
</tr>
<tr>
<td>2008 Nissan Altima</td>
<td>2</td>
<td>Ongoing</td>
</tr>
<tr>
<td>2008 GM 2-mode Tahoes</td>
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<td>Ongoing</td>
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<tr>
<td>Total</td>
<td>39</td>
<td>to date</td>
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HEVs Baseline Performance Tested

Baseline Performance MPG (J1634 With & W/O Air)

- Insight
- Gen I Prius
- Gen I Civic
- Gen II Prius
- Silverado
- Accord
- Escape
- Highlander
- RX400h
- Gen II Civic
- Camry
- Vue
- Altima
- Tahoe
- Average

Miles per Gallon

- MPG SAE J1634 Air On
- MPG SAE J1634 Air Off
Percent HEV MPG Decrease - A/C on

Percent MPG Difference (J1634 With & W/O Air)

-30%  -25%  -20%  -15%  -10%  -5%  0%  5%  10%  15%

-25%  -20%  -15%  -10%  -5%  0%  5%  10%  15%  20%

Insight  Gen I Prius  Gen I Civic  Gen II Prius  Silverado  Accord  Escape  Highlander  RX400h  Gen II Civic  Camry  Vue  Altima  Tahoe  Average
4 Million HEV Test Miles – MPG by model

HEV Fleet / Accelerated Reliability Testing MPG - By HEV Model

<table>
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<tr>
<th>Model</th>
<th>MPG</th>
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<td>Insight</td>
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<td>Gen I Prius</td>
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<td>Silverado</td>
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<tr>
<td>Accord</td>
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<td>Gen II Prius</td>
<td>44.2</td>
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<tr>
<td>Escapes</td>
<td>26.7</td>
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<tr>
<td>Lexus RX400h</td>
<td>23.4</td>
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<tr>
<td>Highlander</td>
<td>24.5</td>
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<tr>
<td>Camry</td>
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<td>Gen II Civic</td>
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<td>Saturn Vue</td>
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<tr>
<td>Altima</td>
<td>30.8</td>
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<tr>
<td>Tahoe</td>
<td>24.9</td>
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</table>
AVTA HEV Fleet MPG and EPA MPG

Percent EPA MPG > or < AVTA Fleet MPG

- New EPA > AVTA
- Old EPA > AVTA

10'03 Civic
6'01 Insights
6'02 & '03 Prius
1'04 Silverado
1'04 2WD Silverado
2'05 Accord
2'04 Prius
1'05 4WD Escape
1'05 2WD Escape
1'06 AWD Lexus RX400h
2'06 AWD Lexus RX400h
2'06 AWD Highlander
2'07 Camry
2'06 Civic
2'07 Saturn Vue
2'07 Altima
2'07 Tahoe 2WD
Average

08 Tahoe - no old EPA Ratings
HEV Maintenance and Repairs

**FreedomCAR & Vehicle Technologies Program**

**HEV Fleet Testing**

**Advanced Vehicle Testing Activities**

**Maintenance Sheet for 2006 – Highlander**

VIN # JFEEDW21A160006395

<table>
<thead>
<tr>
<th>Date</th>
<th>Mileage</th>
<th>Description</th>
<th>Cost</th>
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<td>51.578</td>
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<tr>
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<td>90.270</td>
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**U.S. Department of Energy**

Energy Efficiency and Renewable Energy

Doing it right, it’s cleaner, greener, better.
NEV America Testing – 21 models tested

- CARB now requires all Neighborhood Electric Vehicles (NEVs) be tested by the AVTA
- 5 NEVs completed testing in 2008
  - 2 Miles Automotive: sedan & pickup
  - 1 Zen sedan
  - 2 GEMs
- 15 NEVs previously tested:
  - 8 Gems, 2 Th!nk Neighbors, 2 Frazier Nashes, 2 ParCars, 1 Katech
NEVAmerica Testing Includes

• NEV test variables
  – Acceleration 0 to 20 mph
  – Maximum speed
  – Range per charge at maximum speed
  – Braking from 20 mph
  – Gradeability
  – Charging Efficiency (Wh-AC/mile and cents/mile)
  – Level 1 and 3 (if equipped) charger
    • Maximum AC and DC current and demand
    • Time to recharge to 80%, 100% and complete
• Vehicle specifications
  – Batteries, tires, charger, dimensions, and weights
NEV Testing Results – Range per Charge

NEVs - Range @ Maximum Speed

Miles per Recharge

2001 Frazer-Nash City Car
2001 Frazer-Nash Pickup
2002 Ford/Think Neighbor 2 Pass
2002 Ford/Think Neighbor 4 Pass
2002 GEM 2 Passenger
2002 GEM 4 Passenger
2002 ParCar 4 Passenger
2002 ParCar 2 Passenger
2002 GEM Long Bed Utility
2002 GEM Short Bed Utility
2005 GEM 2 Passenger
2005 GEM 4 Passenger
2007 GEM 6 Passenger
2008 Miles 4 Passenger Sedan
2008 Miles Utility Bed
2008 Zenn 2 Passenger
NEV Testing Results – Maximum Speed

NEVs - Maximum Speed at 170 lbs Payload

Miles per Hour
NEV Testing Results – Wh per Mile

NEVs - Charging Efficiency, Wh per Mile (Level 1 Charging)
Hydrogen Internal Combustion Engine (HICE) Vehicle Testing

• Assess HICE vehicle safety, reliability and operating characteristics

• Identify any engine or vehicle system degradations

• Eight 100% HICE pickups (Roush CNG conversions), equipped with data loggers, fueled at the Integrated Waste Hydrogen Utilization Project in Vancouver, BC

• 7 HICE and HCNG models tested to date

• Operating APS Alternative Fuel Pilot Plant since 2002
HICEVAmerica Roush Testing Fact Sheet

- 22 seconds 0 to 60 mph acceleration
- 27 miles/GGE at 45 mph constant speed
- SAE J1634 17.7 miles/GGE AC off and 15.2 miles/GGE AC on
- 79 mph maximum speed at 1 mile
- Three carbon fiber wrap / aluminum lined fuel tanks
  - 5000 psi nominal
  - 10.5 gasoline gallon equivalents (GGE)
9 PHEVs Models in Testing/Demonstrations

- Most equipped with lithium traction batteries
- Hymotion Prius
- Hymotion Escape
- EnergyCS Prius
- Electrovaya Escape
- Hybrids Plus Escape
- Hybrids Plus Prius
- Manzanita Prius (lead acid)
- Ford Escape
- Renault Kangoo (NiCad)
Hymotion Prius – UDDS Fuel Use

• 5 kWh A123 lithium & Prius packs – AC kWh

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

• 5 kWh A123 lithium & Prius packs – AC kWh

Hymotion PHEV Prius MPG & kWh - HWFET Testing

Each Bar - 1 HWFET Test Cycle, Labeled by Cumulative Miles
## Hymotion Prius – 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 kWh</th>
<th>Gals</th>
<th>MPG</th>
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<td>10</td>
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Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg
### EnergyCS Prius – Accelerated Testing

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<th>Cycle (mi)</th>
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* Rerun to 600 miles  **Software updated and cells replaced. May be rerun. Each total distance slightly greater than 600 miles. HEV version = 44 mpg
## 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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Each total distance slightly greater than 600 miles. HEV version = 27 mpg
Electrovaya Escape – Accelerated Testing

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<th>Highway Charge (10 mi)</th>
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<th>Gasoline MPG</th>
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<td>2</td>
<td>2</td>
<td>12</td>
<td>15</td>
<td>600</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>In testing</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>2</td>
<td>4</td>
<td>12</td>
<td>10</td>
<td>600</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>16.30</td>
<td>40.8</td>
</tr>
<tr>
<td>100</td>
<td>2</td>
<td>8</td>
<td>12</td>
<td>6</td>
<td>600</td>
<td>21.17</td>
<td>29.2</td>
</tr>
<tr>
<td>200</td>
<td>2</td>
<td>18</td>
<td>12</td>
<td>3</td>
<td>600</td>
<td>20.85</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><strong>Weighted Average</strong></td>
<td></td>
</tr>
</tbody>
</table>

Each total distance slightly greater than 600 miles. HEV version = 27 mpg
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

- Time at start of charging
  - Graph showing frequency of charging events by time.

- Length of charging time per charging event
  - Graph showing frequency of charging events by time length:
    - 1 - 2, 2 - 4, 4 - 6, 6 - 8, 8 - 10, 10 - 12, 12 - 14, 14 - 16, 16 - 18, 18 - 20, 20 - 22, 22 - 24 hours.

- AC energy in per charging event (kWh)
  - Graph showing frequency of charging events by energy:
    - 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4 kWh.

- Kilowatt Hours
  - Graph showing frequency of charging events by kilowatt hours:
    - 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5 kWh.

- More
Single Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges
13 Hymotion Prius in May 2008 - MPG

- Below averages do NOT tell the whole PHEV energy use potential – see following slide

<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>Total</td>
<td>912</td>
<td>6,417</td>
<td>7.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD, CS, CD/CS results (excludes EV results)</td>
<td>775</td>
<td>6,291</td>
<td>8.1</td>
<td>55.9</td>
<td></td>
</tr>
</tbody>
</table>
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)
AVTA is testing New York State Energy Research and Development Agency’s PHEV conversions, stated 2007

Fleet testing of ~20 PHEVs later CY08
EnergyCS Prius Data Collection

- Provided AVTA onboard data for 12 vehicles operating in fleets in the U.S. and Canada
- Going forward, EnergyCS is using lithium batteries from various manufacturers
- ~30 vehicles deployed (~15 North America and ~15 Europe)
Seattle Area Demonstration

- 13 Hymotion Prius operations in partnership with:
  - City of Seattle (4)
  - King County (4)
  - Port of Seattle (2)
  - Puget Sound Clean Air Agency (3)
  - Started 4/2008, five vehicles converted to date, remainder September 2008

- City of Seattle lead time-of-day charging demonstration on above 13 Seattle area PHEVs. Includes INL battery impact analysis. Uses V2Green wireless charging control

- These and all future demonstration PHEVs are using V2Green onboard data loggers with cellular data transfer and GPS
Tacoma Power Demonstration

• Vehicle demonstration using
  – 2 Manzanita lead acid Prius, 1st quarter 2008
  – 2 Hymotion Prius adding late 2008

• Charging infrastructure study
  – After 4 PHEVs in operation, collect data on one section of administration building (800 amp, 480 volt, 3 phase load) and PHEV charging infrastructure
  – Document demand and energy profiles of PHEV charging as portion of facility profiles
  – WiFi local energy meter (LEM) data collection system
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 Sept. 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
  – 13 vehicles recently completed conversions
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
Total PHEV Demonstrations

69 w/data loggers
64 adding CY08
? In discussion
133 Total end of CY08
Other PHEV Testing

• Hymotion/A123Systems V2 Prius battery hot weather vehicle/battery testing, summer 2008
• PHEV charging studies at three commercial facilities (Tacoma Power is one). Started 5/2008
• 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
• Conduct vehicle/battery testing on PHEVs when received via DOE’s OEM PHEV solicitation
• Will consider other suitable PHEV conversions for vehicle/battery testing
PHEV Charging Infrastructure

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

• NEC being updated
AVTA Webpage Use and Gasoline Costs
Acknowledgement

This 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/