U.S. Department of Energy
FreedomCAR & Vehicle Technologies Program

Hybrid Electric and Pure Electric Vehicle Testing
(Advanced Vehicle Testing Activity)

Jim Francfort
Discovery Center of Idaho - September 2005
HEV & EV Testing Presentation Outline

• Testing partners
• Hybrid electric vehicles
  – Performance
  – Fuel economy
  – Maintenance & repairs
  – Life-cycle costs
  – MPG in fleets, controlled testing & EPA results
• Neighborhood electric vehicles
• Urban electric vehicles
• Airport Ground Support Equipment testing
• WWW location
Current AVTA Testing Partners

- U.S. Department of Energy’s Idaho National Laboratory
- Qualified Vehicle Testers (50/50 cost share)
  - Electric Transportation Applications (lead)
  - Arizona Public Service, Bank One of Arizona & Red Cross
  - Ford Motor Company
  - Luke AFB & Camp Pendleton
  - New York Power Authority, Southern California Edison & Salt River Project
  - Cites of Palm Springs, Palm Valley, Phoenix, Vacaville & San Diego, & UC Irvine
HEV Testing Methods

• Baseline performance testing (dynamometer & closed track testing)
  – Acceleration, max speed, braking, handling, & two fuel economy tests (SAE J1634 drive cycle - air conditioning on & off)
• Fleet & accelerated reliability (AR) testing
  – Fuel use, maintenance & operations (M&O), miles, mission, & life-cycle costs
  – Two of each HEV model accumulate 160,000 miles
• End of life (160,000 miles) testing
  – Rerun two SAE J1634 tests, & conduct battery capacity (Hybrid Pulse Power Characterization) & power testing (Static Capacity)
HEV Baseline Performance Testing

- 2002 test vehicles
  - Insight
  - Civic
  - Gen I Prius

- 2005 test vehicles
  - Accord
  - Gen II Prius
  - Silverado (2WD)
  - Escape (2WD)
  - Lexus RX400h (to be tested)
  - Toyota Highlander (to be tested)
HEV Acceleration (0 to 50 & 0 to 60 MPH)

*0 to 50 mph for Insight, Civic and Gen I Prius. 0 to 60 mph for others
HEV Maximum Speed in ¼ Mile

Max Speed in 1/4 mile

<table>
<thead>
<tr>
<th>Car</th>
<th>Miles per Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civic</td>
<td>70</td>
</tr>
<tr>
<td>Insight</td>
<td>70</td>
</tr>
<tr>
<td>Gen I Prius</td>
<td>70</td>
</tr>
<tr>
<td>Gen II Prius</td>
<td>80</td>
</tr>
<tr>
<td>Silverado</td>
<td>90</td>
</tr>
<tr>
<td>Escape</td>
<td>80</td>
</tr>
<tr>
<td>Accord</td>
<td>90</td>
</tr>
</tbody>
</table>
HEV Maximum Speed @ 6% Grade

Maximum Speed @ 6% Grade

Civic | Insight | Gen I Prius | Gen II Prius | Silverado | Escape | Accord

Miles per Hour

0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110
HEV Braking

Braking (Controlled Dry) from 60 mph

- Civic
- Insight
- Gen I Prius
- Gen II Prius
- Silverado
- Escape
- Accord

Feet
HEV Fuel Economy (SAE J1634)

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

- Insight
- Gen I Prius
- Civic
- Gen II Prius
- Silverado
- Accord
- Escape
HEV - MPG Difference (Air on/off SAE J1634)

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

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

Insight  Gen I Prius  Civic  Gen II Prius  Silverado  Accord  Escape  Average
HEV MPG New Vs. MPG @ End-of-Life (~160,000 miles) SAE J1634

New Vs. End of Life (E-of-L) HEV Fuel Economy

J1634 - Air On  J1634 - Air Off

Miles per Gallon

[Bar chart showing fuel economy comparison between new and end-of-life HEVs, including Civic, Prius, and Insight models.]
28 HEVs - Fleet Testing Status

- 6 - 2001 Honda Insights: Aug/01 - March/05
- 6 - 2002 Gen I Toyota Prius: Nov/01 - April/05
- 4 - 2003 Honda Civics: May/02 - April/05
- 2 - 2004 Gen II Toyota Prius: Nov/03 - ongoing
- 2 - 2004 Chevrolet Silverado: Sept/04 - ongoing
- 2 - 2005 Honda Accord: Jan/05 - ongoing
- 2 - 2005 Ford Escape: April/05 – ongoing
- 2 - 2005 Lexus RX400h SUVs: May/05 – ongoing
- 2 - 2006 Toyota Highlander SUVs: Oct/05 start
HEV 1.4 Million Fleet Testing Miles

All HEVs - Miles Driven

- Monthly Mileage (right axis)
- Cumulative Mileage (left axis)
1.4 Million Testing Miles By HEV Model

HEV Total Fleet / AR Test Miles

- Insight
- Civic
- Gen I Prius
- Gen II Prius
- Silverado
- Accord
- Escape
- Lexus

Miles
HEV Fleet Testing Fact Sheets

- Summarize:
  - Vehicle use
  - Major operations & maintenance events
  - Mileage profile
  - Cumulative fuel economy
  - Life cycle operating costs
Insight Fleet Testing Monthly MPG

Honda Insights - Monthly Fuel Economy

Miles per Gallon

Monthly Fuel Economy
Cumulative Fuel Economy
HEV Fleet Testing MPG Hot & Cool Months

HEV MPG - Hot Vs. Cool 3 Months
(Cool - Dec, Jan, Feb & Hot - June, July, Aug)

<table>
<thead>
<tr>
<th>Model</th>
<th>Hot 3 Months</th>
<th>Cool 3 Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insight</td>
<td>10.5% &amp; 4.9</td>
<td>11.5% &amp; 4.6</td>
</tr>
<tr>
<td>Civic</td>
<td>11.5% &amp; 4.6</td>
<td>10.6% &amp; 4.6</td>
</tr>
<tr>
<td>Gen I Prius</td>
<td>10.6% &amp;</td>
<td>0.4% &amp;</td>
</tr>
<tr>
<td></td>
<td>4.6 mpg</td>
<td>0.2 mpg</td>
</tr>
<tr>
<td>Gen II Prius</td>
<td>8.16% &amp;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.6 mpg</td>
<td></td>
</tr>
</tbody>
</table>

Average: 8.16% & 3.6 mpg
HEV MPG – Fleet SAE J1634, & EPA

Drive Cycle, Feet/AR & EPA Miles Per Gallon

- Fleet/AR Testing
- J1634 - Air On
- J1634 - Air Off
- EPA City
- EPA Highway

Miles per Gallon

Civic | Insight | Gen I Prius | Gen II Prius | Accord | Silverado | Escape | Lexus
HEV Maintenance & Repairs Fact Sheets

- All events - date, mileage, description & cost/warranty

<table>
<thead>
<tr>
<th>Date</th>
<th>Mileage</th>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/10/2012</td>
<td>5,011</td>
<td>Change oil and rotate tires</td>
<td>$27.00</td>
</tr>
<tr>
<td>8/28/2012</td>
<td>9,519</td>
<td>Change oil and rotate tires</td>
<td>$28.62</td>
</tr>
<tr>
<td>3/6/2013</td>
<td>15,023</td>
<td>15,000 mile service</td>
<td>$231.21</td>
</tr>
<tr>
<td>3/24/2013</td>
<td>15,705</td>
<td>Repair spark plug damage to let light (not included in maintenance costs)</td>
<td>$1,222.24</td>
</tr>
<tr>
<td>10/6/2012</td>
<td>20,142</td>
<td>Change oil and rotate tires</td>
<td>$20.99</td>
</tr>
<tr>
<td>10/6/2012</td>
<td>26,147</td>
<td>Change oil and rotate tires</td>
<td>$30.97</td>
</tr>
<tr>
<td>12/5/2013</td>
<td>33,019</td>
<td>Change oil and rotate tires</td>
<td>$31.07</td>
</tr>
<tr>
<td>2/10/2013</td>
<td>43,290</td>
<td>45,000 mile service</td>
<td>$34,128</td>
</tr>
<tr>
<td>2/14/2013</td>
<td>43,850</td>
<td>Repair brake to damage to rear bumper (not included in maintenance costs)</td>
<td>$834.42</td>
</tr>
<tr>
<td>3/15/2013</td>
<td>53,390</td>
<td>Change oil and rotate tires</td>
<td>$30.64</td>
</tr>
<tr>
<td>4/2/2013</td>
<td>62,973</td>
<td>Change oil and rotate tires</td>
<td>$30.64</td>
</tr>
<tr>
<td>5/23/2013</td>
<td>69,090</td>
<td>Change oil and rotate tires</td>
<td>$30.65</td>
</tr>
<tr>
<td>6/6/2013</td>
<td>74,969</td>
<td>90,000 mile service</td>
<td>$304.15</td>
</tr>
<tr>
<td>6/24/2013</td>
<td>77,835</td>
<td>Replace front and rear final wheels</td>
<td>$185.33</td>
</tr>
<tr>
<td>6/16/2013</td>
<td>77,839</td>
<td>Clock Eight left light failed. Drive reset, no problem found.</td>
<td>$189.39</td>
</tr>
<tr>
<td>7/17/2013</td>
<td>80,416</td>
<td>Change oil and rotate tires</td>
<td>$31.14</td>
</tr>
<tr>
<td>7/17/2013</td>
<td>80,416</td>
<td>Clock Eight left light failed. Drive reset, no problem found.</td>
<td>$189.39</td>
</tr>
<tr>
<td>8/3/2013</td>
<td>86,363</td>
<td>90,000 mile service</td>
<td>$274.13</td>
</tr>
<tr>
<td>9/4/2013</td>
<td>86,369</td>
<td>Change oil and rotate tires</td>
<td>$31.03</td>
</tr>
<tr>
<td>9/12/2013</td>
<td>90,597</td>
<td>Clock Eight right light failed. Updated PCMU software installed by dealer.</td>
<td>$50.00</td>
</tr>
<tr>
<td>10/1/2013</td>
<td>93,015</td>
<td>95,000 mile service</td>
<td>$50.00</td>
</tr>
<tr>
<td>10/2/2013</td>
<td>93,912</td>
<td>Change oil and rotate tires</td>
<td>$140.22</td>
</tr>
<tr>
<td>11/29/2013</td>
<td>26,000</td>
<td>Clock Eight right light failed. Driver replaced the PHEV OBD pin to pin sensor</td>
<td>$50.00</td>
</tr>
<tr>
<td>1/1/2014</td>
<td>96,506</td>
<td>Trims in passenger area trim panel replaced</td>
<td>$202.53</td>
</tr>
<tr>
<td>1/5/2014</td>
<td>97,735</td>
<td>Clock Eight right light failed. Canopy cargo trim replaced</td>
<td>$202.53</td>
</tr>
<tr>
<td>3/24/2014</td>
<td>103,501</td>
<td>15,000 mile service</td>
<td>$250.53</td>
</tr>
<tr>
<td>4/4/2014</td>
<td>113,685</td>
<td>90,000 mile service</td>
<td>$454.09</td>
</tr>
<tr>
<td>4/15/2014</td>
<td>115,814</td>
<td>Replace motors</td>
<td>$112.38</td>
</tr>
<tr>
<td>6/2/2014</td>
<td>119,610</td>
<td>Change oil and rotate tires</td>
<td>$31.03</td>
</tr>
</tbody>
</table>
HEV Maintenance & Repairs Summary

- **Civic & Insight** - 6 continuously variable transmission (CVT) failures in 4 vehicles @ 97k, 99k, 89k & 77k miles. Again @ 157k & 146k miles

- **Insight battery control module & traction battery replaced @ 72k**

- **Insight & Civic** - 7 software upgrades & 2 catalytic converters replaced

- **Gen I Prius** - rack & pinion replacements 1st Prius @ 106k, & 2nd Prius @ 25k & 32k miles

- **Gen II Prius** – oil changes, tires, normal service @ 42k & 27k miles

- **Other HEVs** – normal maintenance @ low mileages
HEV Life-Cycle Costs (high mileage HEVs)

<table>
<thead>
<tr>
<th></th>
<th>Ownership</th>
<th>Main/Repair</th>
<th>Registration</th>
<th>Gas ($2.50/gal)</th>
<th>Insurance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civic 161.5k miles</td>
<td>8.1</td>
<td>5.0</td>
<td>0.5</td>
<td>6.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Civic 161k miles</td>
<td>8.2</td>
<td>6.8</td>
<td>0.5</td>
<td>6.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Insight 160k miles</td>
<td>9.0</td>
<td>4.5</td>
<td>0.5</td>
<td>5.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Insight 111k miles</td>
<td>9.0</td>
<td>4.5</td>
<td>0.5</td>
<td>5.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Gen I Prius 165k miles</td>
<td>11.4</td>
<td>6.2</td>
<td>0.7</td>
<td>6.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Gen I Prius 160k miles</td>
<td>7.2</td>
<td>7.0</td>
<td>0.6</td>
<td>6.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Average</td>
<td>8.5</td>
<td>8.5</td>
<td>0.6</td>
<td>6.1</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Cents per Miles:
- Civic 161.5k miles: 22.0 cents/mi
- Civic 161k miles: 23.9 cents/mi
- Insight 160k miles: 21.4 cents/mi
- Insight 111k miles: 25.9 cents/mi
- Gen I Prius 165k miles: 17.7 cents/mi
- Gen I Prius 160k miles: 18.7 cents/mi
- Average: 21.6 cents/mi

(All 36 months of testing except 111k miles Insight - 29 months)
HEV Life-Cycle Costs (low mileage HEVs)

Low Mileage HEV Life Cycle Costs

<table>
<thead>
<tr>
<th>Model</th>
<th>Distance (mi)</th>
<th>Time (mo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gen I Prius</td>
<td>16k</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>18k</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>28k</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>70k</td>
<td>26</td>
</tr>
<tr>
<td>Insight</td>
<td>8k</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>16k</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>19k</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>73k</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>9k</td>
<td>15</td>
</tr>
<tr>
<td>Civic</td>
<td>28k</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>23k</td>
<td>20</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average cents per mile: 58.9
Additional Near-term HEV Testing

- HEV Hydrogen Prius (Quantum)
- Plug-in HEV Dodge Sprinter (lithium)
- Plug-in HEV Escape conversion (lithium)
- Other OEM HEVs?
Neighborhood Electric Vehicle (NEV) Testing

- Street legal ~40 states on ~35 mph speed limit streets
- 14 NEVs with lead acid batteries completed baseline performance testing (max speed, acceleration, range, braking, charging)
  - 8 GEM (DaimlerChrysler) - Deka gel & Trojan flooded
  - 2 ParCar - Trojan flooded
  - 2 TH!NK (Ford) - East Penn Gel
  - 2 Frazier Nash - Electrosource Glass Mat
NEV Range & Energy Efficiency Testing
Katech *Invita* Lithium Polymer Testing

- Onboard charger failed on arrival & several cells failed
- Constant speed range test (94 miles Kokam test)
  - Start at 80% SOC (offboard charger)
  - 47.9 miles, 91.3 A·H, 6.19 kWh, 4.25 to 3.0 V
  - 2 cells at 3.0 V (3.6 norm end-of-test)
- Two Kokum characterization tests (discharge to 2.7 V)
  - one cell failed each time @ 0.5 & 0.2 V
  - 102.21, 94.34, & 96.05 A·H
  - 98.34 & 98.11 A·H
NEVs Fleet Testing

- 90 NEVs in fleet testing (including fast charging)
  - San Diego Police Department
  - Luke Air Force Base
  - Palm Valley
  - Palm Springs

- Future NEV testing candidates
  - Ford Courier class NEV pickup from Roush
  - NEV(s) from Marsh Automotive
Urban Electric Vehicle (UEV) Testing

• Internet-based data collection of 100 Th!nk city UEVs in New York. Total & vehicle miles & missions, trip profiles, emissions, & gasoline avoidance collected. Partnered with New York Power Authority.

• In partnership with Ford Motor Company, tracked 276 additional Th!nk cities in CA, MI, GA, Canada, & Bermuda, including shared-car programs.
Urban Electric Vehicle (UEV) Testing

- Th!nk city UEVs used home to train stations & local errands – 180 to 230 miles per month
- Replaced 95% of gasoline vehicle trips
- Range 30 to 65 miles per 7 hour charge – participants wanted more range
- Zero to 30 mph 7.8 seconds & 50 mph in ¼ mile
- Continue fleet testing of 11 Nissan Hyperminis & 3 Toyota eComs
Airport Ground Support Equipment Testing

• Developed electric GSE (eGSE) specifications for pushback tractors, bag tractors & bag loaders
• Developing eGSE test procedures for same 3 vehicle classes
• Test (including fast charging) an FMC battery electric pushback tractor for 757-sized aircraft (fall 2005)
http://avt.inl.gov

AVTA Questions?