Hybrid Electric Vehicle Testing

Jim Francfort

Presentation Outline

• Background & goals
• Testing partners
• Hybrid electric vehicle testing
  – Baseline performance testing (new HEV models)
  – 1.5 million miles of HEV fleet testing (160k miles per vehicle in 36 months)
  – End-of-life HEV testing (rerun fuel economy & conduct battery testing @ 160k miles per vehicle)
  – Benchmark data: vehicle & battery performance, fuel economy, maintenance & repairs, & life-cycle costs
• WWW information location
Background

• Advanced Vehicle Testing Activity (AVTA) - part of the U.S. Department of Energy’s FreedomCAR and Vehicle Technologies Program

• AVTA Primary Goal - provide benchmark data for technology modeling, and research and development programs

• AVTA Secondary Goal - help fleet managers and other vehicle purchasers make informed purchase and operations decisions

• These activities are managed by the Idaho National Laboratory (INL also performs data analysis and reporting activities)
Testing Partners

- Qualified Vehicle Testers (50/50 cost share)
  - Electric Transportation Applications (lead)
  - Arizona Public Service
  - Bank One of Arizona
  - Red Cross
Testing Methods

• Baseline performance testing (dynamometer & closed track testing) – vehicle-to-vehicle comparisons
  – Acceleration, max speed, braking, handling, & two fuel economy tests - SAE J1634 drive cycle - air conditioning (AC) on & off

• Fleet (accelerated reliability) testing
  – Fuel use, miles, maintenance & repairs, & life-cycle costs in fleet operations
  – Two of each HEV model accumulate 160,000 miles

• End-of-life (at 160,000 miles) testing
  – Conduct battery capacity (Hybrid Pulse Power Characterization) & power testing (Static Capacity)
  – Rerun SAE J1634 tests (AC on & off)
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)
Acceleration

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

Max Speed in 1/4 mile

Civic | Insight | Gen I Prius | Gen II Prius | Silverado | Escape | Accord
--- | --- | --- | --- | --- | --- | ---
Miles per Hour
0 | 70 | 70 | 70 | 90 | 80 | 90
Max Speed @ 6% Grade

Max Speed 1/4 mile (mph)

Miles per Hour

Civic, Insight, Gen I Prius, Gen II Prius, Silverado, Escape, Accord
Braking (Controlled Dry) from 60 mph

- Civic: 150 feet
- Insight: 170 feet
- Gen I Prius: 150 feet
- Gen II Prius: 120 feet
- Silverado: 180 feet
- Escape: 140 feet
- Accord: 130 feet
Baseline Performance MPG

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

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

Miles per Gallon

- MPG SAE J1634 Air Off
- MPG SAE J1634 Air On
MPG (SAE J1634) - Air on/off Decrease

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

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

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

Insight  Gen I Prius  Civic  Gen II Prius  Silverado  Accord  Escape  Average
Normalized Discharge (SAE J1634)

Normalized Discharge During SAE J1634

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

Air Off
Air On
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 - ongoing
1.5 Million HEV Fleet Testing Miles

- Civic
- Insight
- Gen I Prius (Silverado)
- Accords
- Gen II Prius
- Escapes
- Lexus
- Highlander
Fleet Testing Fact Sheets

- Summarize real-world use:
  - Vehicle use
  - Major maintenance & repair events
  - Mileage profile
  - Cumulative fuel economy
  - Life cycle operating costs
Fleet Testing Average MPG

Cumulative MPG

- Civic
- Insight
- Gen I Prius
- Silverado
- Accords
- Gen II Prius
- Escapes
- Lexus
- Highlander
Fleet Testing Monthly MPG

HEV Monthly Fuel Economy

Miles per Gallon

Accord Monthly Fuel Economy
Insight Monthly Fuel Economy
Civic Monthly Fuel Economy
02 Prius Monthly Fuel Economy
04 Prius Monthly Fuel Economy
Silverado Monthly Fuel Economy
Escape Monthly Fuel Economy
Lexus Monthly Fuel Economy
Fleet Testing MPG Hot & Cool Months

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

- Insight 10.5% & 4.9 mpg
- Civic 11.5% & 4.6 mpg
- Gen I Prius 10.6% & 4.6 mpg
- Gen II Prius 0.4% & 0.2 mpg
- Average 8.16% & 3.6 mpg

Miles per Gallon
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

Cars compared:
- Civic
- Insight
- Gen I Prius
- Gen II Prius
- Accord
- Silverado
- Escape
- Lexus
### Maintenance & Repairs

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

#### HEV Fleet Testing - Maintenance Sheet
**2003 – Honda Civic Hybrid**

<table>
<thead>
<tr>
<th>Date</th>
<th>Mileage</th>
<th>Description</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>7/30/2002</td>
<td>5,085</td>
<td>Change oil and rotate tires</td>
<td>$27.00</td>
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<tr>
<td>8/6/2002</td>
<td>9,679</td>
<td>Change oil and rotate tires</td>
<td>$20.62</td>
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<td>9/9/2002</td>
<td>15,023</td>
<td>15,000 mile service</td>
<td>$231.36</td>
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<tr>
<td>9/24/2002</td>
<td>19,736</td>
<td>Repair accident damage to left front (not included in maintenance costs)</td>
<td>$1,223.34</td>
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<tr>
<td>10/8/2002</td>
<td>20,147</td>
<td>Change oil and rotate tires</td>
<td>$20.67</td>
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<tr>
<td>10/29/2002</td>
<td>26,147</td>
<td>Change oil and rotate tires</td>
<td>$31.07</td>
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<tr>
<td>12/20/2002</td>
<td>33,270</td>
<td>Change oil and rotate tires</td>
<td>$341.39</td>
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<tr>
<td>1/7/2003</td>
<td>40,290</td>
<td>Rear wheel bearing kits replaced, no problem found</td>
<td>$334.44</td>
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<tr>
<td>2/15/2003</td>
<td>53,301</td>
<td>Change oil and rotate tires</td>
<td>$20.67</td>
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<tr>
<td>4/23/2003</td>
<td>63,425</td>
<td>Change oil and rotate tires</td>
<td>$20.67</td>
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<td>5/23/2003</td>
<td>69,932</td>
<td>Change oil and rotate tires</td>
<td>$20.67</td>
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<tr>
<td>6/9/2003</td>
<td>74,353</td>
<td>20,000 mile service</td>
<td>$524.13</td>
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<tr>
<td>6/24/2003</td>
<td>77,628</td>
<td>Replace four tires and align front wheels</td>
<td>$186.33</td>
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<tr>
<td>9/15/2003</td>
<td>77,628</td>
<td>Check Engine light illuminated, dealer replaced, no problem found warranty</td>
<td>$31.07</td>
</tr>
<tr>
<td>7/23/2003</td>
<td>88,425</td>
<td>Change oil and rotate tires</td>
<td>$31.07</td>
</tr>
<tr>
<td>7/26/2003</td>
<td>92,434</td>
<td>Check Engine light illuminated, dealer repaired an intermittent problem with a valve sticking</td>
<td>$31.07</td>
</tr>
<tr>
<td>8/27/2003</td>
<td>99,304</td>
<td>90,000 mile service</td>
<td>$324.13</td>
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<tr>
<td>9/6/2003</td>
<td>99,304</td>
<td>Change oil and rotate tires</td>
<td>$21.08</td>
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<tr>
<td>9/17/2003</td>
<td>99,677</td>
<td>Coolant Engine light illuminated, updated PCM software installed by dealer</td>
<td>$54.09</td>
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<tr>
<td>10/9/2003</td>
<td>93,616</td>
<td>Steering wheel replaced</td>
<td>$60.09</td>
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<tr>
<td>10/24/2003</td>
<td>93,912</td>
<td>Change oil and replace brake pads</td>
<td>$146.22</td>
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<tr>
<td>11/20/2003</td>
<td>96,650</td>
<td>Check Engine light illuminated, dealer replaced the Throttle system pressure sensor</td>
<td>$146.22</td>
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<tr>
<td>1/5/2004</td>
<td>96,803</td>
<td>Transmission shifting electronics, transmission replaced</td>
<td>$3,993.62</td>
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<tr>
<td>1/25/2004</td>
<td>97,789</td>
<td>Check Engine light illuminated, catalytic converter replaced</td>
<td>$1,124.35</td>
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<tr>
<td>2/24/2004</td>
<td>103,901</td>
<td>15,000 mile service</td>
<td>$260.83</td>
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<tr>
<td>4/6/2004</td>
<td>113,665</td>
<td>50,000 miles service and accessory 12 volt battery replacement</td>
<td>$464.09</td>
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<tr>
<td>4/17/2004</td>
<td>115,699</td>
<td>Replace front tires</td>
<td>$112.33</td>
</tr>
<tr>
<td>5/20/2004</td>
<td>119,670</td>
<td>Change oil and rotate tires</td>
<td>$21.36</td>
</tr>
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</table>
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 miles
- Insight & Civic - 7 software upgrades & 3 catalytic converters replaced
- Gen I Prius - rack & pinion replacements 1\textsuperscript{st} Prius @ 106k, & 2\textsuperscript{nd} Prius @ 25k & 32k miles
- Other HEVs – normal maintenance @ lower mileages
Life-Cycle Costs (high mileage HEVs)

High Mileage HEV Life Cycle Costs

(All 36 months of testing except 146k miles Insight - 41 months)
Life-Cycle Costs (low mileage HEVs)

Low Mileage HEV Life Cycle Costs

- Ownership
- Main/Repair
- Registration
- Gas ($2.50/gal)
- Insurance

Cents per Mile

- Gen I Prius 16k mi & 15 mo
- Gen I Prius 18k mi & 15 mo
- Gen I Prius 70k mi & 26 mo
- Insight 73k mi & 12 mo
- Insight 9k mi & 15 mo
- Insight 19k mi & 15 mo
- Civic 28k mi & 15 mo
- Civic 23k mi & 20 mo
- Gen II Prius 43k mi & 23 mo
- Gen II Prius 60k mi & 13 mo
- 2W Silverado 29k mi & 13 mo
- 4WD Silverado 28k mi & 15 mo
- Average 58.9 cents/mi

Total - 131.3 cents
Cost Components – High & Low mileage

Life Cycle HEV Operations Costs

- High Mileage HEVs
- Lower Mileage HEVs

Cost per Mile

Insurance
Gas ($2.50/gal)
Registration
Main/Repair
Ownership
HEV Life-Cycle Costs (Weighted by Miles)

Costs include: Insurance, maintenance & repairs (excludes any collision costs), fuel @ $2.50 gallon, registration, & purchase – sales cost (or lease cost for Silverado)
## End of Life (160k miles) Battery Capacity

### End of Life Battery Capacity Test Findings

<table>
<thead>
<tr>
<th>Model</th>
<th>Nominal</th>
<th>C1 Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civic 1</td>
<td>6.0</td>
<td>4.1</td>
</tr>
<tr>
<td>Civic 2</td>
<td>6.0</td>
<td>4.1</td>
</tr>
<tr>
<td>Insight 1</td>
<td>6.5</td>
<td>5.6</td>
</tr>
<tr>
<td>Insight 2</td>
<td>6.5</td>
<td>5.4</td>
</tr>
<tr>
<td>Prius 1</td>
<td>6.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Prius 2</td>
<td>6.5</td>
<td>2.6</td>
</tr>
</tbody>
</table>

*Gen I Prius*
End-of-Life (160k miles) MPG - AC Off

New vs. End of Life J1634 Fuel Economy - Air Conditioning Off

*Gen I Prius
End-of-Life (160k miles) MPG - AC On

New vs. End of Life J1634 Fuel Economy - Air Conditioning On

*Gen I Prius
Percent Battery Capacity Used per Mile

*Gen I Prius*
# End-of-Life Phase II (SAE J1634) Vs. Onboard-Vehicle-Computer MPG

<table>
<thead>
<tr>
<th>End-of-life Phase II HEV MPG Testing</th>
<th>Onboard computer fuel economy percentage above Phase II SAE J1634 fuel economy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civic 1 AC off</td>
<td>+21.7%</td>
</tr>
<tr>
<td>Civic 1 AC on</td>
<td>+21.0%</td>
</tr>
<tr>
<td>Insight 1 AC off</td>
<td>+11.0%</td>
</tr>
<tr>
<td>Insight 1 AC on</td>
<td>+11.7%</td>
</tr>
<tr>
<td>Gen I Prius AC off</td>
<td>+15.7%</td>
</tr>
<tr>
<td>Gen I Prius AC on</td>
<td>+14.7%</td>
</tr>
</tbody>
</table>
Additional Near-term HEV Testing

- Hydrogen ICE HEV (HICEHEV) Hydrogen Prius from SCAQMD/Quantum
- Plug-in Diesel or Gas HEV (PIDHEV or PIGHEV) Dodge Sprinter (lithium) from Dodge
- PIGHEV Escape (lithium or lead) from vehicle converter Energy CS
- PIGHEV Gen II Prius conversion (Valence Li-Ion) from vehicle converter Energy CS
- Azure HEVs used by Purolator?
- Other OEM HEVs and/or Plug-ins?
http://avt.inl.gov