On Road Fuel Economy Performance of Hybrid Electric Vehicles

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Outline

• Energy Drivers

• DOE FreedomCAR and 21st Century Truck Goals

• Vehicle systems analysis and testing

• Field testing and evaluation of light-duty hybrid electric vehicles

• Information resources
Increasing fuel economy dampens oil use for next 2 decades, but does not offset long-term growth in consumption.
Economics of Oil

U.S. Imported Crude Oil (Million Barrels per Day)

<table>
<thead>
<tr>
<th>Year</th>
<th>Imports (in millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>9.6</td>
</tr>
<tr>
<td>2010</td>
<td>11.6</td>
</tr>
<tr>
<td>2020</td>
<td>14.9</td>
</tr>
<tr>
<td>2025</td>
<td>16.2</td>
</tr>
</tbody>
</table>

Annual Cost of U.S. Crude Oil Imports (Billions 2002 $)

<table>
<thead>
<tr>
<th>Year</th>
<th>Cost (Billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>$77.7</td>
</tr>
<tr>
<td>2010</td>
<td>$102.1</td>
</tr>
<tr>
<td>2020</td>
<td>$141.5</td>
</tr>
<tr>
<td>2025</td>
<td>$159.3</td>
</tr>
</tbody>
</table>

Source: DOE/EIA, Annual Energy Outlook 2004
DOE FreedomCAR and 21st Century Truck Goals

Transition to Hydrogen Vehicle Technology

- **H₂ Fuel**
  - Fuel Cell Hybrid
  - Advanced ICE Hybrid
  - H₂-Enhanced Fuel Advanced ICE Hybrid

- **Gasoline/Diesel**
  - ICE Hybrid
  - ICE Conventional

- **Requirements & Impacts Analysis**
  - (OFCVT & OHFCIT)

- **Technology Development and Validation**
  - (OFCVT, OHFCIT & Industry)

- **System Development & Validation**
  - (OFCVT and Industry)

- **Fuel Cell Technology**

- **Hydrogen Engines, Production & Storage Technology**

- **Advanced Fuels & Engine Technology**

- **Power Electronics & Energy Storage Technology**

- **Technology Development**
  - and Validation

- **System Development**
  - & Validation

- **Requirements & Impacts Analysis**
  - (OFCVT & OHFCIT)
Vehicle Systems
Analysis & Testing

Technology Requirements & Targets
- Vehicle systems simulation & analysis
- Technical targets development
- Benchmarking

Technology Development
- Advanced propulsion & vehicle efficiency
- Electrochemical energy storage
- Power electronics & electric machines
- Advanced combustion engines
- Materials
- Fuels
- Fuel cells and H₂ storage (OHFCIT)

Validation & Introduction
- Laboratory testing & validation
- Field testing & evaluation
- Technology introduction

SAE
Field Testing and Evaluation of Light Duty Hybrid Electric Vehicles (HEV)

- Baseline performance, fleet & accelerated reliability testing
  - 6 MY 2001 Honda Insights
  - 4 MY 2003 Honda Civics
  - 6 MY 2002 Gen I Toyota Prius
  - 2 MY 2004 Gen II Toyota Prius
  - 2 MY 2004 Chevrolet Silverado (2 & 4WD)
  - 2 MY 2005 Honda Accord
  - 2 MY 2005 Ford Escape (2 & 4WD)
HEV Testing Methods

• Baseline Performance testing (dynamometers & closed tracks)
  – Acceleration, max speed, braking, handling & two fuel economy tests (SAE J1634 drive cycle - with & w/o air conditioning)

• Fleet & accelerated reliability (AR) testing
  – Bank One, Red Cross, Arizona Public Service, ETA
  – Collect fuel use, maintenance & operations (M&O), miles & costs
  – 2 of each HEV model accumulate 160,000 miles

• End of life (160,000 miles) SAE J1634 tests & battery capacity & power testing
HEV Baseline Performance Testing

* The 1 mile Max Speed for the Silverado and Escape exceeded 100 mph
HEV Baseline Performance MPG

Baseline Performance MPG - J1634 With and W/O Air

- Insight
- Gen I Prius
- Civic
- Gen II Prius (Not QA'd)
- Silverado (Not QA'd)
- Accord (Not QA'd)
- Escape (Not QA'd)

Miles per Gallon

SAE
HEV J1634 MPG Difference (Air on/off)

Baseline Performance MPG % Decrease - J1634 With and W/O Air (W/O Base)

-30.00%
-25.00%
-20.00%
-15.00%
-10.00%
-5.00%
0.00%

Insight  Gen I Prius  Civic  Gen II Prius (Not QA’d)  Silverado (Not QA’d)  Accord (Not QA’d)  Escape (Not QA’d)  Average

(W/O - With) / With/Out Air
HEV Fleet & AR Testing Status

- 6 MY 2001 Honda Insights: Aug/01 - March/05
- 6 MY 2002 Gen I Toyota Prius: Nov/01 - March/05
- 4 MY 2003 Honda Civics: May/02 - March/05
- 2 MY 2004 Gen II Toyota Prius: Nov/03 - ongoing
- 2 MY 2004 Chevrolet Silverado: Sept/04 - ongoing
- 2 MY 2005 Honda Accord: Jan/05 - ongoing
- 2 MY 2005 Ford Escape: April/05 - ongoing
HEV Fleet & AR Testing

- 1.33 million total HEV test miles
HEV Fleet & AR Cumulative MPG

HEV Cumulative Fuel Economy

Miles per Gallon

Insight Cumulative Fuel Economy
Civic Cumulative Fuel Economy
02 Prius Cumulative Fuel Economy
04 Prius Cumulative Fuel Economy
Silverado Cumulative Fuel Economy
Accord Cumulative Fuel Economy

Hybrid Electric Vehicle Testing

- Fleet and accelerated reliability testing

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**HEV Monthly Fuel Economy**

- **Miles per Gallon**

- **Dates:**

Legend:
- **Insight Monthly Fuel Economy**
- **Civic Monthly Fuel Economy**
- **02 Prius Monthly Fuel Economy**
- **04 Prius Monthly Fuel Economy**
- **Silverado Monthly Fuel Economy**
- **Accord Monthly Fuel Economy**
Hybrid Electric Vehicle Testing

- Fleet and accelerated reliability testing

**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
HEV Testing – All MPGs

Drive Cycle, Fleet/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 (Not QA'd), Accord (Not QA'd), Silverado 2WD (Not QA'd), Escape 2WD (Not QA'd)
HEV Life-Cycle Costs

<table>
<thead>
<tr>
<th>Cents per Miles</th>
<th>Ownership</th>
<th>Main/Repair</th>
<th>Registration</th>
<th>Gas ($1.80/gal)</th>
<th>Insurance</th>
</tr>
</thead>
<tbody>
<tr>
<td>03 Civic 161.5k miles</td>
<td>8.1294</td>
<td>4.9864</td>
<td>0.5263</td>
<td>4.8347</td>
<td>1.6842</td>
</tr>
<tr>
<td>03 Civic 161k miles</td>
<td>8.15</td>
<td>6.78</td>
<td>0.53</td>
<td>4.83</td>
<td>1.74</td>
</tr>
<tr>
<td>01 Insight 160k miles</td>
<td>9.0469</td>
<td>4.4613</td>
<td>0.5313</td>
<td>4.0038</td>
<td>1.8</td>
</tr>
<tr>
<td>Gen I Prius 165k miles</td>
<td>7.24</td>
<td>4.37</td>
<td>0.56</td>
<td>1.94</td>
<td>1.94</td>
</tr>
<tr>
<td>Gen I Prius 160k miles</td>
<td>7.0438</td>
<td>4.4513</td>
<td>0.5313</td>
<td>3.1238</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Ownership 20.16 cents/mi
Main/Repair 22.03 cents/mi
Registration 19.84 cents/mi
Gas ($1.80/gal) 16.05 cents/mi
Insurance 16.95 cents/mi
Future HEV Testing

• 2005: end-of-life (160,000 miles) SAE J1634, & battery capacity & power tests (HPPC)
  – Two each – Insight (maybe), Civic & Gen I Prius
• 2005: HEV testing candidates
  – Toyota Highlander & Lexus RX400H SUVs
• 2006 and beyond HEV testing
  – HEV end-of-life (160,000 miles) testing
  – HEV Hydrogen Prius (Quantum)
  – Plug-in HEV Dodge Sprinter (lithium)
  – Plug-in HEV Escape conversion (lithium)
  – Plug-in ALABC small SUV (EcoSport)
  – Other OEM HEVs?
For More Information

- FreedomCAR and Vehicle Technologies
  - www.eere.energy.gov/vehiclesandfuels

- Advanced Vehicle Testing Activity (AVTA)
  Test reports, fact sheets, and maintenance logs available via-
  - http://avt.inl.gov  or