2009 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review: 
**Advanced Vehicle Benchmarking of HEV’s and PHEV’s**

Richard “Barney” Carlson, Mike Duoba, Forrest Jehlik, Ted Bohn, Dan Bocci
*Argonne National Laboratory*
Sponsored by Lee Slezak

vss_03_carlson
DOE Merit Review
May 19, 2009

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Project Overview

Timeline

- HEV Benchmarking
  - Tahoe Hybrid: 2\textsuperscript{nd} Qtr 2008
  - Altima Hybrid: 3\textsuperscript{rd} Qtr 2008
  - 2010 Honda Insight: 3\textsuperscript{rd} Qtr 2009
  - 2010 Toyota Prius: 4\textsuperscript{th} Qtr 2009
  - 2010 Fusion Hybrid: 4\textsuperscript{th} Qtr 2009
  - 2010 Saturn Vue Hybrid: 4\textsuperscript{th} Qtr 2009
- PHEV Benchmarking
  - Three Escape PHEV conversions: FY08
  - Two Prius PHEV conversions: FY09

Budget

- Advanced Vehicle Benchmarking
  - FY08: $ 300k
  - FY09: $ 370k

Barriers

- Obtaining advanced technology vehicles is difficult due to proto-type nature of PHEV’s
- Expense of Detailed vehicle instrumentation

Partners

- Idaho National Lab
  - AVTA Program
Objectives

- Benchmark advanced technology vehicles and disseminate that information to U.S. OEM’s, National Labs, and Universities

Milestones

- **HEV**
  - GM Tahoe Hybrid benchmarking completed (Level 1+ instrumentation)
    - Full instrumentation of Level 2 except for invasive engine torque sensor
  - Nissan Altima Hybrid
- **PHEV’s Benchmarked**
  - Three Escape PHEV conversion
  - Two Prius PHEV conversion
  - One OEM PHEV
- **Dynamometer Data Acquisition**
  - Developed a more robust and streamlined CAN bus data acquisition system
Chevrolet Tahoe Hybrid - 2Mode

- Engine: 6.0L V8 gasoline
  - Pushrod 2 valves per cylinder
  - Variable camshaft timing with late intake valve closing
  - Cylinder Deactivation (8 cyl. or 4 cyl.)

- Transmission: 2-Mode
  - Dual, 60kW permanent magnet, electric motors
  - 2 EVT modes (power-split)
  - 4 fixed gear ratios (parallel)

- Battery: Panasonic NiMH
  - 1.8 kWh (rated) / 0.5 kWh (usable)
  - Air cooled from cabin air
  - Typical peak power: 30kW
  - Instantaneous peak power: 60kW at WOT engine start

Source: General Motors
2 Mode Transmission Combines Benefit of CVT and Step Gear

- 2 Modes (Low and High)
  - Power-split Hybrid
- 4 Fixed Gear Ratios
  - Parallel operation
  - More efficient at high speeds
  - Enables trailer towing of large mass
  - Enormous controls flexibility

![Graph showing GM Tahoe Hybrid 2 Mode Ratios - US06](image)
Full Regen Capability in RWD Tahoe Hybrid

- Full Regen Braking capability up to:
  - battery power limit of 30kW
  - driveshaft torque of -500Nm
  - 29 mph

- EV operation capable up to 28 mph
**Tahoe Hybrid 2-Mode:**

**Very Low Tail Pipe Emissions except for NMOG on UDDS**

- Tailpipe emissions for most tests were within SULEV
- UDDS NMOG (cold and hot start) was within ULEV limits (not SULEV)
**Nissan Altima Hybrid**

- Same powertrain as Camry Hybrid except larger engine (2.5L) produced by Nissan
  - Same transmission and power electronics
  - Same NiMH battery
- Fuel economy comparison
  - Altima Hybrid: better city fuel economy
  - Camry Hybrid: better Hwy fuel economy
- Altima Hybrid attained SULEV emissions

### Fuel Economy Comparison

<table>
<thead>
<tr>
<th></th>
<th>Altima Hybrid</th>
<th>Camry Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPA Reported Fuel Econ (mpg)</td>
<td>35 City 33 Hwy</td>
<td>33 City 34 Hwy</td>
</tr>
<tr>
<td>Dyno Test Results Fuel Econ (mpg)</td>
<td>33.5 City 32.3 Hwy</td>
<td>32.9 City 34.3 Hwy</td>
</tr>
<tr>
<td>Test Weight (lbs)</td>
<td>3750</td>
<td>4000</td>
</tr>
<tr>
<td>Engine Size [L]</td>
<td>2.5 L</td>
<td>2.4 L</td>
</tr>
<tr>
<td>Engine Comp Ratio</td>
<td>9.6:1</td>
<td>12.5:1</td>
</tr>
<tr>
<td>Engine-On Time Hot UDDS [%]</td>
<td>33.3</td>
<td>35.4</td>
</tr>
</tbody>
</table>
Three Escape PHEV Conversions

1. Hybrids-Plus Escape PHEV
   – Battery replacement conversion using A123 Li-Ion cells
2. Hymotion Escape PHEV
   – Battery add-on system using A123 Li-Ion cells and DC/DC converter to deliver power to powertrain
3. Electrovaya Escape PHEV
   – Battery add-on system using Electrovaya Li-Ion cells and Series Pass Regulator to deliver power to powertrain

All three Escape PHEV conversions attained SULEV

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrids-Plus</td>
<td>9.8</td>
<td>60</td>
<td>24.4</td>
<td>51.4</td>
<td>145</td>
</tr>
<tr>
<td>Hymotion</td>
<td>6.8</td>
<td>35</td>
<td>15.9</td>
<td>43.7</td>
<td>143</td>
</tr>
<tr>
<td>Electrovaya</td>
<td>6.0</td>
<td>60</td>
<td>15.0</td>
<td>39.6</td>
<td>148</td>
</tr>
</tbody>
</table>
Several PHEV Conversions Achieved SULEV Attainment
**Production Hymotion Prius PHEV**

- 5 kWh Li-Ion Battery System
- 3.6 kWh usable
- Utility Factor Weighted Fuel Economy
  - UDDS: 91 mpg / 98 AC Wh/mi
  - HWY: 84 mpg / 91 AC Wh/mi
  - US06: 50 mpg / 81 AC Wh/mi
  - LA92: 64 mpg / 94 AC Wh/mi
  - SC03: 50 mpg / 101 AC Wh/mi
- Charge Depletion Range: 30 mi
- Equivalent All-Electric Range: 15 mi
- Roundtrip Electrical Efficiency: 70%
Plug-In Conversions Corp. Prius PHEV

- Battery Replacement Conversion
  - 6.1 kWh rated NiMH Gold Peak batteries (30 Ah)
  - 3.8 kWh usable
- Utility Factor Weighted Fuel Economy
  - 89 mpg / 95 AC Wh/mi (UDDS)
  - 85 mpg / 100 AC Wh/mi (HWY)
  - 50 mpg / 95 AC Wh/mi (US06)
  - 64 mpg / 101 AC Wh/mi (LA92)
- Charge Depletion Range: 24 mi
- Equivalent All-Electric Range: 14 mi
- Roundtrip Electrical Efficiency: 70%
Future Work

- Proposed Upgrade APRF capability for Sub-Freezing FTP and Hot SC03 with solar heat load capabilities
  - For 5-cycle testing capability

- HEV’s to be benchmarked
  - 2010 Honda Insight
  - 2010 Toyota Prius
  - 2010 Saturn Vue 2Mode
  - 2010 Ford Fusion Hybrid

- PHEV’s to be benchmarked
  - Daimler Sprinter PHEV
Summary

- Benchmarking data use to validate PSAT vehicle models
  - Tahoe Hybrid 2-Mode
  - Hymotion Prius PHEV

- Recent Conversion PHEV have shown SULEV attainment with engine-on operation soon after key start (i.e. no EV range)

- Data from testing is available to the public on Argonne’s website database
  https://webapps.anl.gov/vehicle_data/