U.S. Department of Energy - Advanced Vehicle Testing Activity

PHEV Field Test Plans and Testing Results

DOE PHEV Annual Review Meeting - Washington DC. June 2007

Jim Francfort (INL)
Don Karner (ETA)
Presentation

• Background & goal
• Test plan development
• Test methods
• PHEVs in testing
• Testing results to date
  – Gasoline & electricity use
  – Combined fuel costs on a per mile basis
• PHEV payback based on fuel cost savings
• PHEV potential petroleum reductions
• Future PHEV activities
AVTA Background & Goal

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

• The AVTA is primarily conducted by the Idaho National Laboratory (INL) & Electric Transportation Applications (ETA - Phoenix, AZ), with Argonne National Laboratory performing dynamometer testing

• AVTA Goal
  – Provide benchmark data to technology modelers, & research & development programs
  – Also assist fleet managers in making informed vehicle purchase, deployment & operating decisions
AVTA Testing History

• Hybrid electric vehicles
  – 12 models, 3 million test miles
• Hydrogen ICE (internal combustion engine) vehicles
  – 6 models, 400,000 test miles
• Full-size electric vehicles
  – 40 EV models, 5+ million test miles
• Neighborhood electric vehicles
  – 15 models, 200,000 test miles
• Urban electric vehicles
  – 3 models, 1 million test miles
• Oil bypass filters
  – 2 models, 1.3 million test miles
PHEV Test Plan Development

- Developed 400-page vehicle specifications & test procedures document for:
  - Baseline performance testing (closed track & dyno)
  - Accelerated testing (defined onroad testing)
  - Battery testing (after baseline & accelerated testing)
  - Fleet testing

- Developed with the anticipation of testing PHEVs from converters & OEMs
  - Initial draft reviewed by ANL & NREL, with two PHEVs tested to validate procedures
  - Second draft being commented on by OEMs, PHEV converters, FeedomCAR Tech Teams, & others
  - Third draft to be distributed all PHEV Stakeholders
PHEV Baseline Performance Testing

• Initial track testing conducted by ETA near Phoenix
  – Testing includes coastdown (determination of dynamometer coefficients), acceleration, top speed, charging, & durability

• Five day dynamometer testing regime performed at Argonne
  – Testing includes at least 26 drive cycle tests
  – Charge depleting & sustaining test cycles
  – UDDS, HWFEDs & US06 cycles
  – Includes air conditioning (AC) off & on cycles
PHEV Baseline Performance Testing – cont’d

- If vehicle option, conduct Rechargeable Energy Storage System (RESS) Only mode baseline performance testing with & without A/C:
  - Day 1, RESS Only mode – A/C off
    - UDDS, UDDS, HWFEDS, HWFEDS
    - UDDS, UDDS, HWFEDS, HWFEDS
    - Repeat as able, then charge traction battery
  - Day 2, RESS Only mode – A/C on
    - UDDS, UDDS, HWFEDS, HWFEDS
    - UDDS, UDDS, HWFEDS, HWFEDS
    - Repeat as able
**PHEV Accelerated Testing**

- Accelerated testing in Phoenix over 4,240 miles
- GPS units track distance, average & maximum speeds

<table>
<thead>
<tr>
<th>Cycle (mi)</th>
<th>Urban (10 mi)</th>
<th>Highway (10 mi)</th>
<th>Charge (hr)</th>
<th>Charge Reps (N)</th>
<th>Total (mi)</th>
<th>Reps Total (mi)</th>
<th>Reps Total (%)</th>
<th>Miles Total (%)</th>
<th>Cum. (mi)</th>
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<td><strong>Average</strong></td>
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<td><strong>59%</strong></td>
<td><strong>7.5</strong></td>
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AVTA PHEVs Currently Being Tested

• EnergyCS Prius – 9 kWh Valence lithium pack
  – Completed baseline performance testing
  – Completed 1,000 miles of accelerated testing
• Hymotion Prius – 5 kWh A123 lithium (& Prius pack)
  – Completed baseline performance testing
  – Started accelerated testing
• Renault Kangoo - 9.6 kWh (measured usable) NiCad pack & 650 cc gasoline engine (series hybrid)
  – Completed baseline performance testing
  – Completed 600 miles of accelerated testing
• Additional vehicles in cooperation with NYSERDA
NYSERDA PHEVs Testing Status

• Support NYSERDA’s PHEV deployment by conducting baseline performance & accelerated testing on six PHEV conversion models
  – EnergyCS Prius: testing AVTA vehicle as surrogate. Vehicle delivered to New York
  – Hymotion Prius: testing AVTA vehicle as surrogate. Vehicle delivered to New York
  – Hymotion Civic: June delivery
  – Hymotion Escape: June delivery
  – Electovaya Escape: June delivery
  – HybridsPlus Prius: July delivery
  – Some rolling delivery delays
EnergyCS Prius – UDDS Fuel Use

- kWh – A/C at the wall

EnergyCS PHEV Prius MPG & kWh - UDDS Testing

Each Bar = 1 UDDS Test Cycle. Labeled by Cumulative Miles
EnergyCS Prius – HWFET Fuel Use

- kWh – A/C at the wall

EnergyCS PHEV Prius MPG & kWh - HWFET Testing

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

- kWh – A/C at the wall
Hymotion Prius – HWFET Fuel Use
• kWh – A/C at the wall

Hymotion PHEV Prius MPG & kWh - HWFET Testing

Each Bar - 1 HWFET Test Cycle, Labeled by Cumulative Miles
EnergyCS Prius – Fuel Costs

- kWh – A/C at the wall

Each Data Point Labeled by HWFET and UDDS Tests, uneven miles. Gas $3.25 gallon & kWh $0.10
Hymotion Prius – Fuel Costs

- kWh – A/C at the wall

Hymotion PHEV Prius UDDS & FWHET Fuel Cost per Mile

<table>
<thead>
<tr>
<th>Fuel Cost per Mile</th>
<th>HYM UDDS $ per Mile Gas</th>
<th>HYM UDDS $ per Mile kWh</th>
<th>HYM HWY $ per Mile Gas</th>
<th>HYM HWY $ per Mile kWh</th>
<th>HYM UDDS Combined $$ PER MILE</th>
<th>HYM HWY Combined $$ PER MILE</th>
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<tbody>
<tr>
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Each Data Point Labeled by HWFET and UDDS Tests, uneven miles. Gas $3.25 gallon & kWh $0.10
## EnergyCS Prius Accelerated Testing

<table>
<thead>
<tr>
<th>Cycle (mi)</th>
<th>Urban (10 mi)</th>
<th>HWY (10 mi)</th>
<th>Charge (hr)</th>
<th>Reps (N)</th>
<th>Total (mi)</th>
<th>Actual (mi)</th>
<th>MPG</th>
<th>Miles / kWh</th>
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<td>2</td>
<td>2</td>
<td>12</td>
<td>5</td>
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<td>206</td>
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<td>621</td>
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<td>1,035</td>
<td>109.1</td>
<td>8.82</td>
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</table>

<table>
<thead>
<tr>
<th>Cycle (mi)</th>
<th>Urban (10 mi)</th>
<th>HWY (10 mi)</th>
<th>Charge (hr)</th>
<th>Reps (N)</th>
<th>Total (mi)</th>
<th>Gas $ / Mile</th>
<th>kWh $ / Mile</th>
<th>Total Fuel $ / Mile</th>
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<tbody>
<tr>
<td>40</td>
<td>2</td>
<td>2</td>
<td>12</td>
<td>5</td>
<td>200</td>
<td>$0.023</td>
<td>$0.015</td>
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<td>2</td>
<td>4</td>
<td>12</td>
<td>10</td>
<td>600</td>
<td>$0.031</td>
<td>$0.010</td>
<td>$0.041</td>
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<tr>
<td>Weighted Average - (miles)</td>
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<td></td>
<td>$0.031</td>
<td>$0.012</td>
<td>$0.043</td>
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</table>

- Assumes gasoline $3.25 / gallon & $0.10 kWh
## Kangoo – Test Results

<table>
<thead>
<tr>
<th>Test Cycle</th>
<th>A/C kWh per Mile</th>
<th>Miles per Gallon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Only - UDDS</td>
<td>0.268</td>
<td></td>
</tr>
<tr>
<td>Battery Only - HWFET</td>
<td>0.155</td>
<td></td>
</tr>
<tr>
<td>Battery Only @ Constant 45 mpg</td>
<td>0.271</td>
<td></td>
</tr>
<tr>
<td>Battery &amp; Gas Cold UDDS</td>
<td>0.144</td>
<td>42.3</td>
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<tr>
<td>Battery &amp; Gas Hot UDDS</td>
<td>0.110</td>
<td>39.4</td>
</tr>
<tr>
<td>Battery &amp; Gas Hot HWFET</td>
<td>0.042</td>
<td>40.9</td>
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<tr>
<td>60 Battery Only 10-mile Accelerated Cycles</td>
<td>0.481</td>
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</table>
Kangoo – Fuel Cost per Mile

Kangoo Fuel Cost per Mile

- Battery Only - UDDS
- Battery Only - HWFET
- Battery Only @ Constant 45 mph
- Battery & Gas Cold UDDS
- Battery & Gas Hot UDDS
- Battery & Gas Hot HWFET
- 60 Battery Only - 10-mile Accelerated Cycles

Dollars / Mile

kWh $ / Mile
Gas $ / Mile

Electric Transportation Applications
Idaho National Laboratory
FreedomCAR & Fuel Partnership
Department of Energy
Combined ECS & Hymotion Fuel Costs
• kWh – A/C at the wall

Fuel Cost per Mile - Hymotion, EnergyCS (UDDS & HWFET) & Other Vehicles

<table>
<thead>
<tr>
<th>Fuel Cost per Mile</th>
<th>ECS UDDS Combined $</th>
<th>ECS HWY Combined $</th>
<th>HYM UDDS Combined $</th>
<th>HYM HWY Combined $</th>
<th>ICE Gas 45 MPG</th>
<th>ICE Gas 30 MPG</th>
<th>ICE Gas 20 MPG</th>
<th>PHEV Prius 45 MPG</th>
<th>ECS Prius Accelerated Testing</th>
</tr>
</thead>
</table>

Each Data Point Labeled by HWFET and UDDS Tests, Uneven Miles. Gas $3.25 gallon & kWh - $0.10
PHEV (ECS/HYM) Payback Assumptions

- Average gas & kWh costs - driving 40 & 60 miles / day
  - Both PHEVs in UDDS average: ~$0.039 / mile
  - Both PHEVs in HWFET average: ~$0.051 / mile
  - EnergyCS accelerated test: ~$0.043 / mile
- Versus HEV Prius @ 45 mpg: $0.072
- AVTA’s PHEVs cost from $15k to $40k ($40k includes data logger). Using $15 and $30k (assumes no data logger), average incremental PHEV cost is $22.5k
- Ignores additional battery replacement costs & any additional costs if a vehicle warranty is voided
- Payback = PHEV incremental cost compared to lower PHEV fuel cost per mile than HEV fuel cost per mile
## PHEV (ECS/HYM) Payback

<table>
<thead>
<tr>
<th>Miles Driven Per Day</th>
<th>Fuel Savings Per Mile</th>
<th>Conversion Cost</th>
<th>Miles to Payback</th>
<th>Years to Payback</th>
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<td>HWFET 60</td>
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<td>$22,500</td>
<td>1,071,429</td>
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<tr>
<td>UDDS 40</td>
<td>$0.033</td>
<td>$22,500</td>
<td>681,818</td>
<td>47</td>
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<tr>
<td>UDDS 60</td>
<td>$0.033</td>
<td>$22,500</td>
<td>681,818</td>
<td>31</td>
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</tbody>
</table>

- 40 miles / day = 14.6k miles / year. 60 miles / per day = 21.9k miles / year
- PHEV incremental cost = $22.5k. $3.25 gasoline & $0.10 kWh

- **Based on UDDS fuel savings & PHEV DC kWh use**
  - A 100,000-mile, 5-year payback, ~60 miles / day, = $3,300 battery with 3.1 to 4.7 usable DC kWh
  - Assuming 70% maximum DOD, no lifetime capacity loss, = battery with 4.4 to 6.7 DC kWh at $3,300
Potential Petroleum Displacement for a Single Vehicle, Over 100,000 Miles

Potential Petroleum Displacement Over 100,000 Miles - Single Vehicle

- ICE @ 20 mpg
- ICE @ 30 mpg
- HEV @ 45 mpg
- PHEV @ 100 mpg

Gallons Gasoline

0 1,000 2,000 3,000 4,000 5,000 6,000
Potential Annual Petroleum Displacement For Entire Federal Fleet of Passenger Cars

Potential Petroleum Reduction - Federal Fleet
(107k Sedans & Station Wagons, Driven 1.3 Billion Miles Annually)

Million Gallons Gasoline Per Year

- ICE @ 20 mpg
- ICE @ 25 mpg
- PHEV @ 100 mpg
Potential Annual Petroleum Displacement
For Entire U.S. Fleet of Passenger Cars

Potential Petroleum Reduction - U.S. Fleet of 135 Million Cars
(Assumes each car is driven 12,000 miles annually)

- ICE @ 20 mpg
- ICE @ 25 mpg
- PHEV @ 100 mpg

Million Gallons Gasoline per Year
PHEV Additional / Future Testing

- Working with EnergyCS to collect onboard fleet data for vehicles operating in California, Canada & Arizona
- Working with Hymotion to collect fleet data on their 30+ vehicles already deployed
- Work with NYSERDA to collect fleet data on PHEVs introduced into New York State fleets
- Collect fleet data on any AVTA-operated PHEVs
- Possibly collect fleet data with SCAQMD
- Exploring other PHEV data collection opportunities
- The AVTA will continue to obtain viable PHEVs for baseline performance, accelerated, fleet & battery testing
Acknowledgement

This work is supported by DOE’s FreedomCAR and Vehicle Technologies Program
Vehicle Systems Team Leader, Tien Duong
Project Leader and VSATT Lead, Lee Slezak

Additional Information
http://avt.inl.gov

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