U.S. Department of Energy - Vehicle Technologies Program
2008 Annual Merit Review

Advanced Vehicle Testing Activity (AVTA) - PHEV Evaluations and Data Collection

Vehicle Systems Merit Review
Jim Francfort – INL AVTA Principle Investigator
Lee Sle Zack – DOE Sponsor

February 2008, Bethesda, Maryland

This presentation does not contain any proprietary or confidential information
AVTA Participants

- The Idaho National Laboratory (INL) supports the ATVA’s overall execution, collects and analyzes the data, and disseminates the testing results.
- The Clarity Group (Phoenix, AZ) provides track and onroad testing and technical support, Don Karner is the PI for the Clarity Group (d.b.a. Electric Transportation Engineering Corporation - ETEC).
- National Energy Technology Laboratory manages the Clarity Group contract.
- Argonne National Laboratory performs dynamometer vehicle testing for the AVTA.
- Public and private fleet test partners provide vehicle mission diversity and provide leveraged funding.
- FY08 budget is $9 million, with ~$675k spent to date ($7 million for PHEV Demonstration).
Historical Testing Accomplishments

- Full-size electric vehicles (started early 1990’s)
  - 40 EV models, 5+ million test miles
- Neighborhood electric vehicles (ongoing)
  - 15 NEV models, 200,000 test miles
- Urban electric vehicles
  - 3 models, 1 million test miles
- 100% Hydrogen and HCNG internal combustion engine (HICE) vehicles (ongoing)
  - 6 models, 400,000 test miles
- Hybrid electric vehicles (ongoing)
  - 13 HEV models, 3.5 million test miles
- Testing methods and procedures continue to evolve to match vehicle technology advancements
AVTA’s PHEV Testing Objectives

• Provide benchmark Plug-in Hybrid Electric Vehicle (PHEV) data to technology modelers, target setters, and research and development programs

• Assist early-adapter fleet managers in making informed vehicle purchase, deployment and operating decisions
  – Document the performance of PHEVs in test-track, dynamometer, accelerated, and real-world applications
  – Reduce the uncertainties about vehicle and battery performance and life
  – Document fuel (petroleum and electricity) use over various distances
  – Document charging infrastructure requirements, use, performance and costs
  – Document operator influence on charging times, patterns, and frequencies
AVTA’s PHEV Testing Objectives – cont’d

- Collect onboard vehicle operations data via data loggers
- Collect vehicle maintenance costs
- Document real-world PHEV life-cycle costs
- Continue to use established testing facilities and fleet-testing relationships to maximize knowledge and value to DOE
FY07 Testing Accomplishments

• Developed 400-page PHEV testing specifications and procedures document that incorporated comments from other national laboratories, industry and other stakeholders

• Obtained and benchmarked one PHEV from an OEM and two from PHEV conversions companies (only available) by performing:
  – Baseline performance track and laboratory tests
  – Initiated accelerated onroad tests

• Performed due diligence on PHEV models to determine suitability as test candidates
FY07 Testing Accomplishments - cont’d

- Initiated cooperative testing agreements that provide access to non-DOE owned PHEVs operating in demonstration fleets. Partners include:
  - New York State Energy Research Development Agency (NYSERDA)
  - City of Seattle, King County, Port of Seattle, Puget Sound Clean Air Agency
  - Tacoma Power
  - National Rural Electric Cooperative Association
  - PHEV conversion companies
    - Hymotion
    - EnergyCS
Baseline Performance Testing

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

• Five day dynamometer testing regime performed at Argonne
  – Testing includes at least 26 drive cycle tests
  – Charge depleting & sustaining test cycles
  – UDDS & HWFED cycles reported
  – Includes air conditioning (A/C) off & on cycles
RESS Baseline Performance Testing

• If vehicle option, conduct Rechargeable Energy Storage System (RESS) only testing with & without the air conditioning (A/C):
  – Day 1, RESS Only mode – A/C off
    • UDDS, UDDS, HWFEDS, HWFEDS
    • UDDS, UDDS, HWFEDS, HWFEDS
    • Repeat as able, than charge traction battery
  – Day 2, RESS Only mode – A/C on
    • UDDS, UDDS, HWFEDS, HWFEDS
    • UDDS, UDDS, HWFEDS, HWFEDS
    • Repeat as able
FY07 Testing Results
FY07 EnergyCS Prius – UDDS Fuel Use

- 9 kWh Valence lithium pack – AC kWh

EnergyCS PHEV Prius MPG & kWh - UDDS Testing

Each Bar = 1 UDDS Test Cycle. Labeled by Cumulative Miles
FY07 EnergyCS Prius – HWFET Fuel Use

- 9 kWh Valence lithium pack – AC kWh

![EnergyCS PHEV Prius MPG & kWh - HWFET Testing](chart)

Each Bar = 1 HWFET Test Cycle. Labeled by Cumulative Miles.
FY07 Hymotion Prius – UDDS Fuel Use

- 5 kWh A123 lithium & Prius packs – AC kWh

Hymotion PHEV Prius MPG & kWh - UDDS Testing

Each Bar - 1 UDDS Test Cycle, Labeled by Cumulative Miles
FY07 Hymotion Prius – HWFET Fuel Use

- 5 kWh A123 lithium & Prius packs – AC kWh

Hymotion PHEV Prius MPG & kWh - HWFET Testing

Each Bar - 1 HWFET Test Cycle, Labeled by Cumulative Miles
FY07 EnergyCS Prius – Fuel Costs

EnergyCS PHEV Prius UDDS & HWFET Fuel Cost per Mile

Each Data Point Labeled by HWFET and UDDS Tests, uneven miles. Gas $3.25 gallon & kWh $0.10
FY07 Hymotion Prius – Fuel Costs

Hymotion PHEV Prius UDDS & FWHET Fuel Cost per Mile

Each Data Point Labeled by HWFET and UDDS Tests, uneven miles. Gas $3.25 gallon & kWh $0.10
FY07 Hymotion Battery Charge Profile

A123 Systems Lithium Ion Battery - DC kWh
FY07 Hymotion Cell Charge Profile

A123 Systems Lithium Ion Battery – DC kWh
FY07 EnergyCS Battery Charge Profile

Valence Lithium Ion Battery – DC kWh
FY07 EnergyCS Cell Charge Profile

Valence Lithium Ion Battery – DC kWh
FY07 Kangoo Test Results

- Renault Kangoo – Series PHEV with 9.6 kWh (usable) Saft NiCad pack & 650cc gasoline engine

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<tr>
<th>Test Cycle</th>
<th>AC kWh per Mile</th>
<th>Miles per Gallon</th>
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<td>Battery Only - HWFET</td>
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FY08 Hymotion Escape – UDDS Fuel Use

- 8.5 kWh A123 lithium & Prius packs – AC kWh

Hymotion PHEV Escape MPG & kWh - UDDS Testing

Each Bar = 1 UDDS Test Cycle. Labeled by Cumulative Miles
FY08 Hymotion Escape – HWFET Fuel Use

- 8.5 kWh A123 lithium & Prius packs – AC kWh

Hymotion PHEV Escape MPG & kWh - HWFET Testing

Each Bar = 1 HWFET Test Cycle. Labeled by Cumulative Miles
FY08 Hymotion Escape – Fuel Costs

Each data point labeled by HWFEDS and UDDS tests, uneven miles. Gas $3.25 gallon & kWh $0.10
FY08 Accelerated Onroad Testing

- Uses dedicated drivers
- Predetermined and repeatable drive cycles
- Combinations of urban and highway loops
- 5,440 total onroad test miles per PHEV model
- 162 drive and charging cycles that include 1,344 hours of charging - can not be economically performed on a dynamometer
- Not as controlled as dynamometer, but compliments controlled dynamometer testing by allowing a broader view of fuel use over many more miles and charging events
- Test PHEV batteries at completion of accelerated testing and at 25k, 50k and ? miles
FY08 PHEV Accelerated Testing

- Accelerated testing in Phoenix over 5,440 miles
- GPS units track distance, average & maximum speeds

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<tr>
<th>Cycle (mi)</th>
<th>Urban (10 mi)</th>
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<th>Reps (N)</th>
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| Total      | 2,340         | 3,100           | 1,344       | 162      | 5,440      |          |          |
| Average    | 43%           | 57%             | 8.3         | 18       |            |          |          |
## FY08 EnergyCS Prius – Accelerated Testing

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* Being rerun to 600 miles
### FY08 Hymotion Prius – Accelerated Testing

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* Being rerun to 600 miles
## FY08 Renault Kangoo – Accelerated Testing

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Weighted Average
FY07 / FY08 PHEV Fuel Costs per Mile

2 Hymotions, EnergyCS, & Electrovaya PHEVs (UDDS & HWFEDS) & Other Vehicles

- ECS UDDS Combined $\$ PER MILE
- ECS HWY Combined $\$ PER MILE
- HYM UDDS Combined $\$ PER MILE
- HYM HWY Combined $\$ PER MILE
- HEV Prius 45 MPG
- ICE Gas 30 MPG
- ICE Gas 20 MPG
- ECS Prius Accelerated Testing
- Eltro UDDS Combined $\$ PER MILE
- Eltro HWY Combined $\$ PER MILE
- HYM Escape UDDS Combined $\$ PER MILE
- HYM Escape HWY Combined $\$ PER MILE

Each data point labeled by HWFEDS and UDDS Tests, Uneven Miles. Gas $3.25 gallon & kWh $0.10
FY08 PHEV Onroad Demonstrations and Data Collection Activities
FY08 Hymotion Joint Data Collection

• Kvaser data loggers installed on 45 PHEVs in North America fleets, will include 100 vehicles by end of 2008
• Onboard data includes performance, fuel use, and charging and driving profiles (up to 45 parameters)
• Offboard data includes fuel use, maintenance and mission description
• Fleet testing agreement requires the INL to:
  – On a monthly basis, collect data from fleets via INL ftp site or regular mail
  – Perform AVTA, operating fleet, and Hymotion required data reduction and analysis
  – Report testing results monthly
• To date, 96% of 26 North American fleets with data loggers installed have agreed to participate
FY08 Hymotion Joint Data Collection – cont’d

- Participates include electric utilities, water agencies, universities, county and provincial governments, and a private company in geographically diverse regions:
  - East / South East: Toronto, Virginia, South Carolina, North Carolina, Kentucky, Florida
  - North / Central: Wisconsin, North Dakota, Indiana, Manitoba
  - Southwest: Arizona, Texas
  - West Coast: California (5 fleets), Oregon

- New battery version available 1st half 2008, currently in crash testing; will maintain SULEV certification
FY08 HyMotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges (single PHEV)

**Time at start of charging**

- **AC energy in per charging event (kWh)**

- **Length of charging time per charging event**

- **3 months, 2212 miles, 35 charges (single PHEV)**
FY08 Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges (single PHEV)

**Plug-in battery SOC prior to charging**

**Plug-in battery SOC after charging**

**Number of trips since last charging event**

**Total distance since last charging event (mi)**
FY08 Hymotion Prius MPG Vs. Speed

- 3 months, 2212 miles (single PHEV)

Fuel Economy vs. Average Vehicle Speed

- CD only avg speed
- CD / CS avg speed
- CS only avg speed
- Poly. (CD only avg speed)

CD – charge depleting, S - sustaining
FY08 Hymotion Prius MPG Vs. Trip Distance

- 3 months, 2212 miles (single PHEV)

**Fuel Economy vs. Distance**

- CD only dist
- CD / CS dist
- CS only dist

CD – charge depleting, S - sustaining
FY08 EnergyCS Joint Data Collection

• EnergyCS provided onboard data for seven vehicles operating in fleets in Canada, Arizona, and California

• Data collection methods are being modified to allow the collection of data via WiFi modems directly to INL servers

• Some reduction in battery performance due to software and pack balance problems

• AVTA / EnergyCS discussing replacement batteries
FY08 EnergyCS Onboard Data
FY07 / FY08 NYSERDA

The AVTA is testing all six of the New York State Energy Research and Development Agency’s PHEV conversions. Models and test status:

<table>
<thead>
<tr>
<th>Model</th>
<th>Baseline Testing</th>
<th>Accelerated Testing</th>
<th>Delivery Status</th>
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<td>Hymotion Prius</td>
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<tr>
<td>Hymotion Escape</td>
<td>Started</td>
<td>After baseline</td>
<td></td>
</tr>
<tr>
<td>Electovaya Escape</td>
<td>Problems</td>
<td>Starting</td>
<td>4 deliveries required</td>
</tr>
<tr>
<td>HybridsPlus Escape</td>
<td>Awaiting shipment</td>
<td></td>
<td>Delivered twice</td>
</tr>
</tbody>
</table>

Probable fleet testing of 30 PHEVs later CY08
FY08 Seattle-Area Demonstration

- 13 Hymotion Prius PHEV demonstration with:
  - The City of Seattle (4)
  - King County (4)
  - Port of Seattle (2)
  - Puget Sound Clean Air Agency (3)
- 1 Green Car Company lead acid Prius at King County
- Fleets will operate PHEVs in various missions
- Using V2Green cellular data loggers and GPS units to collect onboard data (45 parameters)
- Obtain offboard fuel use, maintenance requirements, and mission descriptions from fleets
- Start April 2008
- Likely partner in charge demand study with Seattle City Light
FY08 Tacoma Power

- Tacoma Power obtained two lead acid battery Prius PHEVs from the Green Car Company
- One Hymotion Prius on order (April 2008)
- Conduct cooperative testing of vehicles and charging infrastructure
- Lead acid PHEVs are supposed to be the first PHEVs deployed with an all-electric range of 10 to 15 miles
- Testing will include charging and driving profiles as well as charging infrastructure analysis
- Using V2Green cellular data loggers and GPS units
- Started 1st quarter CY08
- AVTA considering baseline and accelerated testing of lead acid PHEV conversions
FY08 National Rural Electric Cooperative Association (NRECA)

- Total of seven Prius and Escape PHEVs from Hymotion, EnergyCS, and HybridsPlus will be / are operated by rural electric coop utilities
- Collect and process onboard data from the fleets, and provide individual vehicle and fleet operations data to NRECA and fleets
- Testing will include charging and driving profiles as well as charging infrastructure analysis
FY08 University of California Davis

- UCDavis will use 13 Hymotion Prius for public fleet demonstration
- Demonstration will include up to 100 drivers that are identified by AAA of California
- Each public driver will operate a vehicle for ~2 months
- V2Green cellular data loggers and GPS units will be used to track vehicle operations and performance, and charging practices and locations of the public
- AVTA will provide data collection, handling, analysis and dissemination support
- AVTA, UCDavis and AAA partnering to capture first study of public use of PHEVs
- Start ~April 2008
FY08 Washington State PHEV Demonstration

- Demonstrate 14 Hymotion Prius in coastal, desert, and island areas
- Testing partners include:
  - Port of Chelan (lead)
  - State of Washington
  - Five utilities
  - Three colleges
  - Port agencies, cities and counties
- Includes daily solar (photovoltaic array) charging of at least one PHEV
- Electricity costs as low as 2.5 cents/kWh (hydropower)
- Start early summer of 2008
- Use V2Green cellular data loggers and GPS units
FY08 Hawaii PHEV Demonstration

- Demonstrate six Hymotion Prius on Maui and Oahu
- Testing partners include:
  - State of Hawaii
  - University of Hawaii
  - Hawaiian Electric Company
  - Maui Electric Company
  - Maui County
  - U.S. Air Force
- Start late summer 2008
- Use V2Green cellular data loggers and GPS units
FY08 International Truck PHEV Bus Testing

- Conduct baseline performance testing of 40-foot PHEV school bus from International Truck with lithium pack
- Perform coastdown and dynamometer testing, likely use either or both the Manhattan driving cycle or the Orange County cycle
- With PHEV option on, 1st day of testing will include:
  - Cold start in charge deleting mode
  - Followed by hot starts in charge depleting modes
  - Followed by at least 2 charge-sustaining hot starts
  - In diesel engine only mode, 2nd day of testing will include 1 cold start, followed by several hot starts
- International completing internal testing
FY08 PHEV Technology Acceleration and Deployment Activity Financial Assistance

• DOE’s Vehicle Technologies Program seeks to accelerate development of PHEVs that:
  – Substantially reduce petroleum consumption
  – Are fully compliant with FMVSS
  – Meet all relevant emissions regulations
  – Can be economically massed produced
  – Have (minimum) 10-mile cumulative UDDS electric range

• Round I proposals were due 2/13/08, Round II 4/30/06

• Each awardee required to demonstrate 80 PHEVs over 3 years
  – 10 PHEVs 1st year, 20 in 2nd year, 50 in 3rd year

• $7 million first year, total of $30 million over 3 years
Summary PHEV Testing Activities

• Continue testing current and upcoming PHEVs and PHEV batteries
• Continue to perform due diligence to identify suitable PHEV candidates for testing
• Identify and determine the value of partnering in additional PHEV demonstrations
• Perform controlled accessory load testing for PHEV modelers
• Coordinate PHEV and charging infrastructure testing with industry and other DOE entities
• Explore possible vehicle to grid testing opportunities
• Supply charging behavior patterns and demands to PHEV infrastructure modelers at Oak Ridge and Pacific Northwest National Laboratories
Summary PHEV Testing Activities – cont’d

• Provide PHEV cost data to other DOE labs and OEMs

• Continue AVTA’s role as DOE’s sole independent tester of whole-vehicle technologies in field applications. By late summer, PHEVs will be demonstrated in:
  – 37 fleets
  – 18 states and 2 provinces

• The AVTA will provide testing and data collection support for DOE’s PHEV Technology Acceleration and Deployment Demonstration

• Provide PHEV testing results feedback to:
  – Domestic OEM industry, vehicle modelers and target setters, battery and other subsystem developers, DOE/Industry Technical Teams, and early fleet adaptors
Acknowledgement

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Hybrid Electric Systems Leader, Tien Duong
Vehicles and Systems Simulation and Testing Leader, Lee Slezak

Additional Information

http://avt.inl.gov
or
http://www1.eere.energy.gov/vehiclesandfuels/avta/

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