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

Vehicle Systems Merit Review
Jim Francfort – INL AVTA Principle Investigator
Lee Slezak – 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

#### PHEV America

**Base Vehicle Description**
- **Make:** Toyota
- **Model:** Prius
- **Year:** 2007
- **VIN:** 3TFEY32752083813
- **Number of Passengers:** 5
- **Hybrid Configuration:** Series/Parallel

#### Energy GS Plug-In Hybrid

**Specifications**
- **Battery System:** Nickel Metal Hydride (NiMH)
- **Rated Voltage:** 24V
- **Power:** 9.3kW
- **Energy:** 14 kWh
- **EPA Combined Consumption:** 114.2 kW-h/100 mi
- **EPA Combined CO2 Emissions:** 168.0 g/mi

**Vehicle Test Results**

<table>
<thead>
<tr>
<th>Distance (mi)</th>
<th>Fuel Economy (mpg)</th>
<th>E/C Energy Consumed (kWh)</th>
</tr>
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<tr>
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<td>1.8</td>
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<td>117.6</td>
<td>3.65</td>
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**Test Notes:**
- The data for this fuel economy and E/C energy consumption is based on the EPA test cycle.
- The test results are valid for the vehicle configuration and powertrain as specified by the manufacturer.
- The measurements were conducted under controlled conditions and may not reflect real-world driving conditions.
- **E/C Energy Consumed** refers to the energy consumed by the electric system to drive the vehicle.

**HWHFET Fuel Economy**

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**Pedal Hybrid**

**Specifications**
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- **Rated Voltage:** 24V
- **Power:** 9.3kW
- **Energy:** 14 kWh
- **EPA Combined Consumption:** 114.2 kW-h/100 mi
- **EPA Combined CO2 Emissions:** 168.0 g/mi

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**Hymotion Plug-In Hybrid**

**Specifications**
- **Battery System:** Nickel Metal Hydride (NiMH)
- **Rated Voltage:** 24V
- **Power:** 9.3kW
- **Energy:** 14 kWh
- **EPA Combined Consumption:** 114.2 kW-h/100 mi
- **EPA Combined CO2 Emissions:** 168.0 g/mi

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- The measurements were conducted under controlled conditions and may not reflect real-world driving conditions.
- **E/C Energy Consumed** refers to the energy consumed by the electric system to drive the vehicle.
FY07 EnergyCS Prius – UDDS Fuel Use

- 9 kWh Valence lithium pack – AC kWh

![Graph showing EnergyCS PHEV Prius MPG & kWh - UDDS Testing](image)

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

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

- 5 kWh A123 lithium & Prius packs – AC kWh

![Graph showing Hymotion Prius MPG & kWh - UDDS Testing](image-url)
FY07 Hymotion Prius – HWFET Fuel Use

- 5 kWh A123 lithium & Prius packs – AC kWh

![](chart.png)

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

Fuel Cost per Mile

- ECS UDDS $ per Mile Gas
- ECS UDDS $ per Mile kWh
- ECS HWY $ per Mile Gas
- ECS HWY $ per Mile kWh
- ECS UDDS Combined $$ PER MILE
- ECS HWY Combined $$ PER MILE
FY07 Hymotion Prius – Fuel Costs

Hymotion PHEV Prius UDDS & FWHET Fuel Cost per Mile

- HYM UDDS $ per Mile Gas
- HYM UDDS $ per Mile kWh
- HYM HWY $ per Mile Gas
- HYM HWY $ per Mile kWh
- HYM UDDS Combined $$ PER MILE
- HYM HWY Combined $$ 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

Hymotion - Pack 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

<table>
<thead>
<tr>
<th>Test Cycle</th>
<th>AC kWh per Mile</th>
<th>Miles per Gallon</th>
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<tbody>
<tr>
<td>Battery Only - UDDS</td>
<td>0.268</td>
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</tr>
<tr>
<td>Battery Only - HWFET</td>
<td>0.155</td>
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<tr>
<td>Battery Only @ Constant 45 mpg</td>
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<tr>
<td>Battery &amp; Gas Cold UDDS</td>
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<td>Battery &amp; Gas Hot UDDS</td>
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<tr>
<td>Battery &amp; Gas Hot HWFET</td>
<td>0.042</td>
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FY08 Hymotion Escape – UDDS Fuel Use

- 8.5 kWh A123 lithium & Prius packs – AC kWh
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

Hymotion PHEV Escape UDDS & HWFEDS Fuel Cost per Mile

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

<table>
<thead>
<tr>
<th>Cycle (mi)</th>
<th>Urban (10 mi)</th>
<th>Highway (10 mi)</th>
<th>Charge (hr)</th>
<th>Reps (N)</th>
<th>Total (mi)</th>
<th>Reps (%)</th>
<th>Miles (%)</th>
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## FY08 EnergyCS Prius – Accelerated Testing

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<th>Electricity (kWh)</th>
<th>Gasoline (Gals)</th>
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<td><strong>4840</strong></td>
<td><strong>Weighted Average 81.7</strong></td>
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<td>132</td>
<td></td>
<td>Weighted Average</td>
<td>70.6</td>
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</table>

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

<table>
<thead>
<tr>
<th>Cycle (mi)</th>
<th>Urban (10 mi)</th>
<th>Highway (10 mi)</th>
<th>Charge (hr)</th>
<th>Reps (N)</th>
<th>Total (mi)</th>
<th>Electricity kWh</th>
<th>Mi/kWh</th>
<th>Gasoline Gals</th>
<th>MPG</th>
</tr>
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<tbody>
<tr>
<td>10</td>
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<td>60</td>
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<td>359.60</td>
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<tr>
<td>20</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>30</td>
<td>600</td>
<td>131.96</td>
<td>4.55</td>
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<tr>
<td>40</td>
<td>4</td>
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<td>12</td>
<td>5</td>
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<td>5.59</td>
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<td>2</td>
<td>12</td>
<td>5</td>
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<td>6.02</td>
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<tr>
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<td>4</td>
<td>12</td>
<td>5</td>
<td>200</td>
<td>28.60</td>
<td>6.99</td>
<td>0</td>
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</tr>
<tr>
<td>60</td>
<td>2</td>
<td>4</td>
<td>12</td>
<td>10</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>2</td>
<td>6</td>
<td>12</td>
<td>8</td>
<td>640</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>2</td>
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<td>12</td>
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<td>200</td>
<td>2</td>
<td>18</td>
<td>12</td>
<td>3</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1740</td>
<td>2500</td>
<td>984</td>
<td>132</td>
<td>4,240</td>
<td></td>
<td></td>
<td>Weighted Average</td>
<td></td>
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</tbody>
</table>
FY07 / FY08 PHEV Fuel Costs per Mile

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

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)
FY08 Hymotion Prius Charging Profiles

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

-插在电池SOC充电前
-插在电池SOC充电后
-自上次充电事件以来的行程数
-自上次充电事件以来的总里程
FY08 Hymotion Prius MPG Vs. Speed

- 3 months, 2212 miles (single PHEV)

**Fuel Economy vs. Average Vehicle Speed**

![Graph showing fuel economy vs. average vehicle speed]

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

$R^2 = 0.7962$

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

- 3 months, 2212 miles (single PHEV)

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

EnergyCS Prius - 678 Miles of Several Drives and Charging Events

- RPM
- Ah In
- Ah Out
- Speed
- Voltage

RPM, Ah In and Ah Out vs. Voltage and Speed (mph)
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>
</tr>
</thead>
<tbody>
<tr>
<td>EnergyCS Prius</td>
<td>Completed</td>
<td>Near completion</td>
<td></td>
</tr>
<tr>
<td>Hymotion Prius</td>
<td>Completed</td>
<td>ongoing</td>
<td></td>
</tr>
<tr>
<td>Hymotion Civic</td>
<td></td>
<td></td>
<td>Not yet delivered</td>
</tr>
<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

This work is supported by DOE’s Vehicle Technologies Program

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/

INL/CON-08-13848