U.S. Department of Energy, Vehicle Technologies Program

Advanced Vehicle Testing Activity (AVTA) – North American and Seattle PHEV Testing and Demonstrations

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AVTA Principle Investigator
Seattle Chamber of Commerce
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Idaho National Laboratory

- Eastern Idaho based U.S. Department of Energy (DOE) Federal laboratory
- 890 square mile site with 3,600 staff
- Support DOE’s strategic goal:
  - Increase U.S. energy security and reduce the nation's dependence on foreign oil
- Multi-program DOE laboratory
  - Nuclear Energy
  - Fossil, Biomass, Wind, Geothermal and Hydropower Energy
  - Advanced Vehicles and Battery Development
  - Energy Critical Infrastructure Protection
AVTA Background and Goals

• The Advanced Vehicle Testing Activity (AVTA) is part of DOE’s Vehicle Technologies Program

• The Idaho National Laboratory (INL) and Electric Transportation Engineering Corporation (ETEC) conduct the AVTA. Argonne National Laboratory performs dynamometer testing

• The AVTA goals:
  – Provide benchmark data to technology modelers, research and development programs, vehicle manufacturers (via VSATT), and target and goal setters
  – Assist fleet managers in making informed early adaptor vehicle purchase, deployment and operating decisions

AVTA Testing History

• Plug-in hybrid electric vehicles (PHEV)
  – 12 models, ~150 vehicles, 360,000 fleet test miles

• Hybrid electric vehicles (HEV)
  – 14 models, 4+ million test miles

• Hydrogen ICE (internal combustion engine) vehicles
  – 7 models, 400,000 test miles

• Full-size electric vehicles
  – 40 EV models, 5+ million test miles

• Neighborhood electric vehicles
  – 21 models, 200,000 test miles

• Urban electric vehicles
  – 3 models, 1 million test miles
PHEV Questions

• What are the petroleum savings and electricity demands?
• Will fleets and the public adapt to plugging in (charging) PHEVs to maximize mpg?
• Is a two-fuel scenario a difficult transition?
• What are the charging infrastructure needs, including 110V versus 220V? Fast charging?
• V2Grid – economic and technical benefit or liability to the vehicle operator?
• Are PHEVs technically and economically feasible as a transportation option?
• To answer these questions, the AVTA is testing and demonstrating 12 different PHEV models (by battery), their batteries, and the charging infrastructure.

12 PHEVs Models in Testing/Demonstrations

• Hymotion Prius (A123Systems)
• Hymotion Escape (A123Systems)
• Ford E85 Escape (Johnson Controls/Saft)
• EnergyCS Prius, 2 models (Valance and Altair Nano)
• Electrovaya Escape (Electrovaya)
• Hybrids Plus Escape, 2 models (Hybrids Plus and K2 Energy Solutions)
• Hybrids Plus Prius (Hybrids Plus)
• Manzanita Prius (lead acid)
• Manzanita Prius (Thunder Sky)
• Renault Kangoo (Saft NiCad)
• (All batteries are Lithium unless noted)
PHEV Testing Objectives

- Perform independent testing of PHEVs, using:
  - Baseline performance testing – closed test tracks and dynamometers
  - Accelerated testing – dedicated drivers operating on defined onroad loops
  - Fleet testing – everyday unstructured \ non-directed fleet and public use, with onboard data loggers
  - Laboratory testing of PHEV batteries
- Document battery life, charging patterns and profiles
- Document vehicle operations, fuel use (electricity and gasoline) and infrastructure requirements (110V versus 220V; Levels 1 and 2, offpeak, and V2Grid charging)
- Document driver influences on fuel use
- Document individual PHEV models and PHEV concept
- Document PHEV life-cycle costs

PHEV Baseline Performance Testing

- ETEC conducts initial track testing near Phoenix, AZ
  - Includes coastdown (determination of dynamometer coefficients), acceleration, top speed, braking, charging, and durability testing
- Argonne 5-day dynamometer testing regime includes:
  - Charge depleting and sustaining test cycles, as well as hot and cold starts
  - At least 26 UDDS (Urban Dynamometer Driving Schedule) and HWFEDS (Highway Fuel Economy Driving Schedule) dynamometer test cycles
Hymotion Prius Gen I – UDDS Fuel Use

- 5 kWh A123Systems (Li) and Prius packs (AC kWh)

Hymotion Prius Gen I – HWFEDS Fuel Use

- 5 kWh A123Systems (Li) and Prius packs (AC kWh)
EnergyCS Prius Valence – UDDS Fuel Use

- 9 kWh Valence (Li) pack only (AC kWh)

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

Each Bar = 1 UDDS Test Cycle. Labeled by Cumulative Miles

EnergyCS Prius Valence – HWFEDS Fuel Use

- 9 kWh Valence (Li) pack only (AC kWh)

![EnergyCS PHEV Prius MPG & kWh - HWFEDS Testing](image)

Each Bar = 1 HWFEDS Test Cycle. Labeled by Cumulative Miles
Hymotion Escape – UDDS Fuel Use
• 8.5 kWh A123Systems (Li) and Escape packs (AC kWh)

Hymotion PHEV Escape MPG & kWh - UDDS Testing
Each Bar = 1 UDDS Test Cycle. Labeled by Cumulative Miles

Hymotion Escape – HWFEDS Fuel Use
• 8.5 kWh A123Systems (Li) and Escape packs (AC kWh)

Hymotion PHEV Escape MPG & kWh - HWFEDS Testing
Each Bar = 1 HWFET Test Cycle. Labeled by Cumulative Miles
Electrovaya Escape – UDDS Fuel Use
• 12 kWh Electrovaya (Li) and Escape packs (AC kWh)

Electrovaya PHEV Escape MPG & kWh - UDDS Testing

Electrovaya Escape – HWFEDS Fuel Use
• 12 kWh Electrovaya (Li) and Escape packs (AC kWh)

Electrovaya PHEV Escape MPG & kWh - HWFEDS Testing
Hybrids Plus Escape – UDDS Fuel Use

- 12 kWh Hybrids Plus (Li) pack (AC kWh)

Hybrids Plus Escape – HWFEDS Fuel Use

- 12 kWh Hybrids Plus (Li) pack (AC kWh)
### Renault Kangoo Test Results

- First OEM series PHEV with 9.6 kWh (usable) Saft NiCad pack and 650cc gasoline engine

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<td>Battery Only - HWFEDS</td>
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<td>Battery Only @ Constant 45 mpg</td>
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<td>Battery and Gas Hot UDDS</td>
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<td>Battery and Gas Hot HWFEDS</td>
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### PHEV Accelerated Testing

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

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<th>Urban (10 mi)</th>
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<th>Charge (hr)</th>
<th>Reps (N)</th>
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Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg

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### Hymotion Prius Gen II – Accelerated Testing

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Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg
### EnergyCS Prius Val. – Accelerated Testing

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Each total distance slightly greater than 600 miles. HEV version = 44 mpg.

### Renault Kangoo – Accelerated Testing

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* Testing ended when gasoline engine and inverter failed. Each total distance slightly greater than 600 miles.
### Hymotion Escape – Accelerated Testing

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<td>18</td>
<td>12</td>
<td>3</td>
<td>600</td>
<td>26.09</td>
<td>17.72</td>
<td>33.5</td>
</tr>
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<td><strong>Total</strong></td>
<td>2340</td>
<td>3100</td>
<td>1344</td>
<td>162</td>
<td><strong>5440</strong></td>
<td></td>
<td><strong>Weighted Average</strong></td>
<td>42.5</td>
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</table>

Each total distance slightly greater than 600 miles. HEV version = 27 mpg

---

### Electrovaya Escape – 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 (AC kWh)</th>
<th>Gasoline (Gals)</th>
<th>MPG</th>
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</thead>
<tbody>
<tr>
<td>10</td>
<td>1</td>
<td>0</td>
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<td>600</td>
<td>135.24</td>
<td>9.55</td>
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<td>20</td>
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<td>2</td>
<td>12</td>
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<td>600</td>
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<td>12</td>
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<td>20.73</td>
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<td>42.72</td>
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<td>19.01</td>
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<tr>
<td><strong>Total</strong></td>
<td>2340</td>
<td>3100</td>
<td>1344</td>
<td>162</td>
<td><strong>5440</strong></td>
<td></td>
<td><strong>Weighted Average</strong></td>
<td>36.7</td>
</tr>
</tbody>
</table>

Each total distance slightly greater than 600 miles. HEV version = 27 mpg
Hymotion Joint Data Collection

- Kvaser data loggers installed onboard ~50 Hymotion Prius PHEVs in North America
  - Requires manually pulling data cards and downloading via web or mailing cards in
  - About 70% response rate, with data lags
- Onboard data includes vehicle performance, fuel use, and charging and driving profiles
- Started 2007

Single Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges
Single Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges

<table>
<thead>
<tr>
<th>Charge / Operating Mode</th>
<th>Number of Trips</th>
<th>Distance Traveled (Miles)</th>
<th>Miles per Gallon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge Depleting (CD)</td>
<td>3,073</td>
<td>14,820</td>
<td>59</td>
</tr>
<tr>
<td>Mixed CD / CS</td>
<td>404</td>
<td>11,121</td>
<td>49</td>
</tr>
<tr>
<td>Charge Sustaining (CS)</td>
<td>1,358</td>
<td>16,059</td>
<td>40</td>
</tr>
<tr>
<td>All trips combined</td>
<td>4,835</td>
<td>42,000</td>
<td>48</td>
</tr>
</tbody>
</table>

26 Hymotion Prius - January thru May 2008

- Below averages do NOT tell the whole PHEV energy-use potential – see following slides
13 Hymotion Prius in May 2008 - MPG

- Below averages do NOT tell the whole PHEV energy use potential – see following slides

<table>
<thead>
<tr>
<th>Charge / Operating Mode</th>
<th>Number of Trips</th>
<th>Total Distance (Miles)</th>
<th>Average Trip Distance (miles)</th>
<th>MPG</th>
<th>DC kWh per Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge Depleting (CD)</td>
<td>575</td>
<td>3,040</td>
<td>5.3</td>
<td>72.0</td>
<td>0.138</td>
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<tr>
<td>Mixed CD / CS</td>
<td>67</td>
<td>1,840</td>
<td>27.5</td>
<td>52.1</td>
<td>0.050</td>
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<tr>
<td>Charge Sustaining (CS)</td>
<td>133</td>
<td>1,411</td>
<td>10.6</td>
<td>40.2</td>
<td></td>
</tr>
<tr>
<td>Electric vehicle only (EV)</td>
<td>137</td>
<td>127</td>
<td>0.9</td>
<td></td>
<td>0.236</td>
</tr>
<tr>
<td>Total</td>
<td>912</td>
<td>6,417</td>
<td>7.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD, CS, CD/CS results (excludes EV results)</td>
<td>775</td>
<td>6,291</td>
<td>8.1</td>
<td>55.9</td>
<td></td>
</tr>
</tbody>
</table>

13 Hymotion Prius MPG Vs. Speed

![Trip Fuel Economy vs. Trip Average Speed - May 2008](chart)
13 Hymotion Prius MPG Vs. Distance

Trip Fuel Economy vs. Trip Distance

0 5 10 15 20 25 30 35 40 45 50

Trip Distance (mi)

0 50 100 150 200 250 300

Trip Fuel Economy (mpg)

CD trips
CD/CS trips
CS trips

13 Hymotion Prius and Aggressive Driving

MPG vs. Trip Aggressiveness (Percent of time above the 40% accelerator pedal position)

0 25 50 75 100 125 150 175 200 225 250 275 300

Trip Fuel Economy (mpg)

0% 10% 20% 30% 40% 50% 60%

Aggressiveness Factor

CD trips
CD/CS trips
CS trips
Log. (CD trips)
Log. (CD/CS trips)
61 Hymotion Prius and Aggressive Driving

Hymotion Prius Fleet Fuel Economy vs. Aggressiveness
10,459 trips from 61 cars with V2Green 112,749 miles. Mar - Dec 2008

NYSERDA Testing Partnership

- AVTA is testing New York State Energy Research and Development Agency’s PHEV conversions, stated 2007
- Fleet testing of 20 PHEVs started 1st quarter CY09

<table>
<thead>
<tr>
<th>Model</th>
<th>Baseline Testing</th>
<th>Accelerated Testing</th>
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</thead>
<tbody>
<tr>
<td>EnergyCS Prius</td>
<td>Completed</td>
<td>Completed</td>
</tr>
<tr>
<td>Hymotion Prius</td>
<td>Completed</td>
<td>Completed</td>
</tr>
<tr>
<td>Hymotion Escape</td>
<td>Completed</td>
<td>Completed</td>
</tr>
<tr>
<td>Electovaya Escape</td>
<td>Completed</td>
<td>Completed (But…)</td>
</tr>
<tr>
<td>HybridsPlus Escape</td>
<td>Suspended (?)</td>
<td>Suspended (?)</td>
</tr>
</tbody>
</table>
EnergyCS Prius Data Collection

• Provided AVTA onboard data for 12 vehicles operating in fleets in the U.S. and Canada with Valence packs
• Going forward, EnergyCS is using lithium batteries from various manufacturers (including Altair Nano)
• ~ 30 vehicles deployed (15 No. America and 15 Europe)
• AVTA supporting data logger improvements

Washington State Demonstrations

• 13 Hymotion Prius in Seattle area:
  – City of Seattle and King County
  – Port of Seattle and Puget Sound Clean Air Agency
  – Initial use of V2Green data loggers, GPS and cellular communications, used in all PHEV fleets going forward
• Tacoma Power
  – 2 Manzanita lead acid Prius
  – 2 Hymotion Prius
• Washington State-wide, Port of Chelan leading, with 14 Hymotion Prius with:
  – Benton County PUD, Chelan County Public Works, City of Wenatchee, Douglas County PUD, Energy Northwest, Green IT Alliance, McKinstry, Port of Chelan, University of Washington, Walla Walla Community College and Wenatchee Valley College
Fleet Demonstration Partners – cont’d

• University of California Davis, with 13 Hymotion Prius
  – Up to 70 AAA of California public drivers will each operate a Hymotion Prius for ~2 months
  – First study of public use of PHEVs, charging practices and locations, started April 2008

• Oregon State Government fleets
  – Three Hymotion Prius

• National Rural Electric Cooperative Association
  – Total of ten Prius and Escape PHEVs from Hymotion, EnergyCS, and Hybrids Plus
  – Problems with vehicle recalls and a fire

• Above all using V2Green data loggers

Fleet Demonstration Partners – cont’d

• Hawaii, 6 Hymotion Prius on Maui and Oahu

• 75+ Total testing partners in the U.S. and Canada:
  – 36 Electric utilities and 2 clean-air agencies
  – 6 City, 2 County and 2 state governments
  – 8 Universities and colleges
  – 7 Private companies and advocacy organizations
  – 4 Canadian provinces, 1 sea port and 1 DOD
  – 2 PHEV conversion companies
### Canada Specific Activities

- Testing/Demo activities with 20 Canadian universities, governments, private companies and energy companies
- PHEV data collection activities include
  - 20 Hymotion Prius PHEVs with data loggers currently in Canadian fleet operations
  - Adding 28 more Hymotion Prius PHEVs with data loggers, mostly in British Columbia
  - AVTA will provide PHEV data to University of Victoria
- Hydrogen ICE activities in Vancouver BC area
  - Eight HICE pickups with data loggers fueled at IWHUP
  - Studying HICE specific maintenance/repair issues
- BC Hydro PHEV and data logger procurement support, and developing charging infrastructure guidelines for BC PHEV deployment and future electric drive deployments

### PHEVs and Demonstration Locations

- 211 Total
- 137 Operating
- 60 Coming '09
- 14 Out of Service

![Map of PHEV and Demonstration Locations](image)
Fleet Data Collection \ Reporting Processes

• Along with testing partners, implemented onboard data logging for 150+ PHEVs, 16 HEVs, 8 HICE vehicles
• Created automated data warehousing, analysis, and reporting process for fleet data
• Accommodates 4 different data transfer methods from a multitude of vehicle / data logger combinations:
  – 8 PHEV, 8 HEV and 1 HICE models
  – 4 data logger manufacturers / designs
• Reporting formats include 69 metrics describing energy use, driving and charging patterns, and status monitors
• Developed quality assurance \ exploratory analysis tools
• Created flexible automated report generation processes for individual and multiple vehicle reports

Database Statistics

• As of December 2008, the data warehouse has grown to:
  – 5 different databases
  – 80 GB of vehicle data
  – Approximately 1 billion records
  – Approximately 120 vehicles (95 Hymotion Prius PHEVs) representing 700,000 vehicle miles and 53,000 trips (only includes downloaded and processed data from the onboard data loggers)
• The fleet onboard data collection system is growing at approximately 40 million records per month
Database Generated PHEV Reports

- Summary reports posted monthly on web
- Individual vehicle reports only goes to respective fleets each month

Database Generated PHEV Reports

- 61 Hymotion Prius PHEVs, 147,000 miles, 15,900 trips, 4,047 charging events – Mar/Dec 2008, V2Green collected
Database Generated PHEV Reports – cont’d

- 61 Hymotion Prius PHEVs, 147,000 miles, 15,900 trips, 4,047 charging events – Mar/Dec 2008, V2Green collected

Seattle PHEV Report – page 1

- 13, not 14 PHEVS
- V2Green data loggers
- 51 mpg all modes
- 59 mpg CD mode
- 54 mpg CD/CS mode
- 40 mpg CS mode
- 17,636 miles
- CD trips = 8,886 CD miles
- CD/CS trips = 2,877 miles & 1,586 CD mi.
- Total 10,472 CD miles
Seattle PHEV Report – page 2

- CD mode - 55 mpg city, 67 mpg highway
- CD/CS mode - 51 mpg city, 58 mpg highway
- CS mode - 37 mpg city, 46 mpg highway
- 0 to 20% aggressive driving = 100+ mpg
- Aggressive = percent of trip pedal position 40% or deeper
- Vehicle response controlled in future?

Seattle PHEV Report – page 3

- 17 charging events per vehicle per month when driven
- 797 charging events
- 2,082 kWh used
- 10,472 miles / 2,082 kWh = 5.03 miles/kWh
- 2.6 kWh average per charging event
- 35.5 kWh average per vehicle per month
- Lots of onpeak charging
Other PHEV Testing

- Hymotion/A123Systems Gen 2 Prius battery hot weather vehicle / battery testing
- Bidirectional vehicle-to-grid (V2G) charging study with electric utilities participating
  - 6 kW and 20 kW levels, using two lithium PHEV batteries, V2Green cellular charging control, documenting infrastructure requirements and costs
- Conduct vehicle/battery testing on PHEVs when received via DOE’s OEM PHEV Technology Assistance and Demonstration Activity
- Will consider other suitable PHEV conversions for vehicle/battery testing
- Developing batteries / mule vehicles testing regimes

PHEV Infrastructure Demonstrations

- City of Seattle lead time-of-day charging demonstration on 13 or more Seattle-area PHEVs. Includes INL battery impact analysis. Uses V2Green wireless charging control
- Charging infrastructure study
  - Tacoma - Collect data on one section of administration building (800 amp, 480 volt, 3 phase load) and PHEV charging infrastructure
  - Document demand and energy profiles of PHEV charging as portion of facility profiles
  - WiFi local energy meter (LEM) data collection system
PHEV Charging Infrastructure Costs Report

- Report analyzes PHEV infrastructure requirements in single family & multi-family residential, & commercial facilities as well as driving trends. No site specific costs
- Charging infrastructure equipment/administrative costs:
  - Levels 1 (120V, 15 or 20 amp) & 2 residential
  - Levels 1 & 2 (208/240V ~40 amp) apartment complex
  - Level 2 commercial facility
- Battery sizes & charge times for various PHEV platforms
- Power electronics & battery costs for PHEV platforms

<table>
<thead>
<tr>
<th>Level 1 Residential</th>
<th>Labor</th>
<th>Material</th>
<th>Permits</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>EVSE (charge cord)</td>
<td>- -</td>
<td>$250</td>
<td>- -</td>
<td>$250</td>
</tr>
<tr>
<td>Residential circuit installation (20A branch circuit, 120 VAC/1-Phase)</td>
<td>$300</td>
<td>$131</td>
<td>$85</td>
<td>$516</td>
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<tr>
<td>Administration costs</td>
<td>$60</td>
<td>$43</td>
<td>$9</td>
<td>$112</td>
</tr>
<tr>
<td>Total Level 1 Cost</td>
<td>$360</td>
<td>$424</td>
<td>$94</td>
<td>$878</td>
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</tbody>
</table>

Report @ http://avt.inl.gov/pdf/phev/phevInfrastructureReport08.pdf

Charging Infrastructure

- National Electric Code requires
  - Dedicated branch circuit
  - GFCI (ground fault circuit interrupt)
  - “EV” extension cord
  - Unique connector “plug”
- NEC being updated
AVTA Webpage Use and Gasoline Costs

INL WWW Visitors & Gasoline Costs (all formulations, areas, and grades)

Number of Monthly Visitors

INL/CON-09-15561

Acknowledgement
This work is supported by the U.S. Department of Energy’s Vehicle Technologies Program

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