U.S. Department of Energy, Vehicle Technologies Program

AVTA Electric Drive Vehicle Testing Activities & Infrastructure Requirements – NAFA (March 2010)

Jim Francfort
Advanced Vehicle Testing Activity (AVTA)
National Association of Fleet Administrators
Seattle, WA. March 2010

This presentation does not contain any proprietary or sensitive information
AVTA Description

• AVTA background
• BEVs, HEVs, PHEVs, NEVs, HICEs, and EREVs
  – How they work
  – Advantages / disadvantages
  – Testing results / performance
• Charging infrastructure
  – Terms
  – Safety
  – Levels
  – Smart Charging
• eTec/Nissan/INL charging infrastructure project
• Future vehicle announcements
• Vehicle deployment considerations
AVTA Description

• The Idaho National Laboratory (INL) and Electric Transportation Engineering Corporation (eTec) conduct the AVTA for DOE’s Vehicle Technologies Program

• The AVTA tests light-duty whole vehicle systems and fueling infrastructures that employ / support:
  – 100% Electric and dual-fuel electric drive systems
  – Advanced energy storage systems
  – Some ICE 100% Hydrogen and HCNG blended fuels
  – Advanced control systems (i.e., start/stop hybrids)

• Provide benchmarked vehicle data to R&D programs, modelers, manufacturers, and target/goal setters (DOE)

• Assist early adaptor fleet managers and the general public in making informed vehicle purchase, deployment and operating decisions
  – Reports, fact sheets, and presentations
AVTA Testing by Technology

- Plug-in hybrid electric vehicles (PHEVs)
  - 12 models, 259 vehicles, 1.5 million test miles
- Hybrid electric vehicles (HEVs)
  - 18 models, 47 vehicles, 5 million test miles
- Neighborhood electric vehicles (NEVs)
  - 23 models, 200,000 test miles
- Hydrogen internal combustion engine (ICE) vehicles
  - 7 models, 500,000 test miles
- Full-size battery electric vehicles (BEVs)
  - 41 EV models, 5+ million test miles
- Urban electric vehicles (UEVs)
  - 3 models, 1 million test miles

13 million test miles have been accumulated on 1,600 electric drive vehicles representing 97 different electric drive models.
AVTA Vehicle Testing Approach

• Depending on vehicle technology and capabilities, vehicles are tested via:
  – Closed test tracks
  – Dynamometer testing
  – Laboratory testing (batteries)
  – Accelerated testing, using dedicated drivers and other methods to accumulate miles and cycles
  – Fleet testing, uses unstructured vehicle utilization
  – Different testing methods are used to balance testing control/repeatability, sample size, and costs

• Publish testing results in relevant ways to accurately
  – Document real-world petroleum reduction potentials
  – Document fuel and infrastructure use
  – Document life-cycle risks and costs
Battery Electric Vehicle (BEVs) Technology

- BEVs only have a battery onboard the vehicle for storing energy – no other onboard energy source
- Energy from the battery is used to power one or more electric motors
- Must be charged from an off-board electricity source, mostly from power plants via the electric grid
- Also captures energy during regenerative braking: electric motor(s) acts as a generator to slow the BEV
- There are no emissions from the vehicle. However, depending on the power plant, there maybe be offboard related emissions unless renewables are used
- Examples include the Nissan Leaf, Mitsubishi iMiEV, BMW Mini-E, and Tesla Roadster
BEV Advantages and Disadvantages

• BEV advantages
  – No vehicle-based emissions
  – Domestically produced fuel
  – May lower overall electricity costs via higher power plant utilization rates
  – Lower fuel and operating costs

• BEV Disadvantages
  – Need to understand and install public charging infrastructure
  – Limited range per charge = “Range anxiety”
  – Battery improvements still needed
  – Long-term battery performance unknown
  – No large scale domestic battery industry
  – No large scale component industry
Hybrid EV (HEVs) Technology

• Usually uses both a small onboard battery and an ICE as energy sources
• Generally uses parallel design, but may include other designs
• Most HEV batteries last 150,000+ miles and hundreds of thousands of cycles due to narrow battery charge / discharge range. Only 20 to 30% maximum SOC swing
• No offboard charging required
• HEV battery charged from the ICE and regenerative braking
• Hydraulic hybrids used by some medium duty trucks such as refuse haulers
• Most OEMs offer HEVs or plan to in near-term
HEV Advantages and Disadvantages

• HEV advantages
  – Reduced gasoline fuel use and vehicle emissions
  – Recovers regenerative braking energy (up to ~80%)
  – Uses existing gas station infrastructure
  – Optimized use of electric propulsion
  – No need to connect to the electric grid for battery charging
  – No range anxiety

• HEV Disadvantages
  – Complexity and cost of two powertrains
  – Components such as batteries, powertrains and power electronics are still not produced in very large numbers
  – Generally higher initial costs
Plug-in HEV (PHEV) Technology

- Uses both an onboard battery and an ICE as energy sources
- Can have a series or parallel design
- In parallel mode, both the ICE and the battery/electric motor power the vehicle, usually through the transmission. The ICE may also recharge the battery
- Uses the electric grid to recharge and balance the propulsion battery and accepts regenerative braking energy
- Original equipment manufacturer (OEM) designs are anticipated to have a single PHEV propulsion battery
- Some conversions (Hymotion) keep the original HEV battery and add a second “mule” PHEV battery. The mule battery can only be recharged from the grid
- Includes buses, trucks, and light-duty vehicles
- Most OEMs have PHEV plans. Ford built a limited number of Escape PHEVs
PHEV Advantages and Disadvantages

• PHEV Advantages
  – Reduced petroleum consumption and vehicle emissions
  – Smaller battery pack (versus BEV) to buy and manage
  – Gas fueling infrastructure portion exists
  – Minimal electric grid changes needed - add connector and electric vehicle supply equipment (EVSE)
  – At home battery charging, well below cost of gasoline
  – Potential for off-peak charging

• PHEV Disadvantages
  – Cost, complexity and added weight of two powertrains
  – Higher initial cost
  – Drivers adapting to dual-fueling scenario
  – Component availability: batteries, powertrains, power electronics
PHEV Operating Modes

- **Charge sustaining (CS) mode**: from start to finish of a single trip, there is no energy available for electric drive propulsion in the PHEV battery. The battery state-of-charge (SOC) is **sustained**.

- **Charge depleting (CD) mode**: from start to finish of a single trip, there is energy available for partial or full electric drive propulsion in the PHEV battery. The battery SOC is being **depleted** during the entire trip.

- **Mixed CD/CS mode**: there is energy in the battery pack at the start of a single trip, but the PHEV battery is fully depleted before the trip ends.

- **Electric propulsion**: is either in the form of all-electric or electric-assist (the ICE provides propulsion power).

- **Some PHEV designs** have as many as eight operating modes, making fuel use measurement and reporting uniformly very difficult.
Extended Range EVs (EREVs)

- EREVs have an onboard battery and an ICE as the second energy source
- Operates in series mode: ICE charges the battery and the battery powers the electric motor(s)
- Normally will operate in all-electric mode until battery is discharged, then ICE turns on to charge the battery. No propulsion energy goes directly from the ICE to the vehicle wheels
- Must be plugged into the electric grid to fully recharge and balance its propulsion battery
- Captures energy during regenerative braking
- Examples include the Chevrolet Volt and Renault Kangoo (2003 model)
- Similar advantages and challenges as PHEVs
# Purchase and Fuel Costs per Mile

<table>
<thead>
<tr>
<th></th>
<th>MSRP ($$$)</th>
<th>MPG Gas</th>
<th>kWh / Mile</th>
<th>Gas Cost / Mile (Cents)</th>
<th>Electricity Cost / Mile (Cents)</th>
<th>Capital Cost / Mile (Cents)</th>
<th>Total Cost / Mile (Cents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICEV</td>
<td>21,825</td>
<td>25</td>
<td>11.0</td>
<td></td>
<td></td>
<td>14.6</td>
<td>25.6</td>
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<tr>
<td>HEV</td>
<td>22,800</td>
<td>45</td>
<td>6.1</td>
<td></td>
<td></td>
<td>15.2</td>
<td>21.3</td>
</tr>
<tr>
<td>BEV</td>
<td>35,000</td>
<td></td>
<td>0.290</td>
<td>2.9</td>
<td></td>
<td>23.3</td>
<td>26.2</td>
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<tr>
<td>PHEV Conversion</td>
<td>34,800</td>
<td>70</td>
<td>0.125</td>
<td>3.9</td>
<td>1.25</td>
<td>23.3</td>
<td>28.45</td>
</tr>
</tbody>
</table>

**Notes**
- ICEV, HEV, and PHEV conversion capital costs are based on known costs. BEV capital cost is an educated guess. PHEV conversion cost includes base vehicle capital cost.
- All capital costs per mile are based on 150,000 miles of straight depreciation, with zero financing costs assumed.
- Gasoline cost of $2.75 / gallon and electricity cost of 10 cents / kWh used.
- Battery life is unknown. Other maintenance costs are not included. BEV maintenance costs should be lower, but no documentation currently exits.
Battery Chemistries

- **Lead Acid** used for applications where weight and space limitations are outweighed by cost considerations. BEV battery of choice in early to mid 1990’s. Historically, limited cycle life of 600 to 1,000 cycles.

- **Advanced Lead Acid** R&D activities are suggesting a possible revival of lead chemistries due to new production processes, materials, and cost advantages.

- **Nickel Metal Hybrid** is used primarily as power battery in HEVs, with 300,000 to 500,000+ cycle life. HEVs are an accepted technology due to NiMH durability.

- **Lithium** is viewed as the most commercially viable future energy storage option due to its potential for much higher energy and power densities. Economically viable demonstration successes are needed before a large penetration of PHEVs and a full transition to BEVs can take place.
Charging Levels

- **Level I** – 110 / 120 VAC, 15 amp (12 amp continuous). Maximum 1.44 kW continuous. Onboard charger. Currently NEMA5-15R receptacle, with GFCI is used. However by NEC code, SAE J1722 connector should be used.

- **Level II** – greater than Level I, with 208-240 VAC and up to 40 amp (32 amp continuous). Maximum 9.6 kW (7.68 kW continuous). Generally onboard charger. Electric vehicle supply equipment (EVSE), mated to AC input and SAE J1722 connector should be used per code.

- **Level III** – greater than Level II, generally off-board charger supporting more than one vehicle. Energy to vehicle can be 440 VDC or higher.
Charging Terms / Considerations

- **Fast Charge** – Not definitively defined. Generally returns 50% of a battery’s capacity in ~10 minutes. Large batteries require Level III charging

- **SAE J1722** – Defines standard connector up to ~70 amps

- **EVSE** - Some “chargers” are not chargers at all, but electric vehicle supply equipment (EVSE). If a charger is onboard the vehicle, the EVSE houses the connector (plug) and cord set offboard, and hopefully some intelligence, communication, and metering capability. EVSE bridges the gap between the vehicle charge post and the electric grid

- A vehicle can have an onboard Level II charger and also be capable of being fast charged from an offboard charger via the same or a second charge port
Smart Charging

• Ranges from simple “lamp timer” to electric utility controlled charging events
• Charging interruption similar to interrupting hot water heaters, air conditioners, other electric loads
• Goal is to push charging to off-peak periods, with excess generation capacity, such as at night
• Studies indicate night time generation capacity for charging 10’s of millions of vehicles. With increased plant utilization, may result in lower overall kWh costs
• Most sophisticated smart charging devices require the EVSE / charger to have bidirectional communications via PLC, zigbee, cellular or WiFi; and the ability to turn on/off remotely; and hopefully have a utility-grade meter
Safety / Standards

• SAE standards are used to insure all OEMs equip their vehicles with the same on-vehicle charge port and communications, so they can be connected and charged at any SAE compliant charger. SAE standards are not a prerequisite for market sales.

• “UL Listing” by Underwriters Laboratory certifies an offboard charger or EVSE as compliant to a set of standards. Only UL Listed charging infrastructure should be installed for safety and legal reasons. Other U.S. certification companies also provide similar “UL Listing”.

• National Electric Code (NEC) or NFPA 70, is the U.S. standard for safe installation of electrical wiring and equipment. It is followed non-uniformly by thousands of local and regional building inspectors. When installing charging infrastructure, the NEC should be followed for safety and legal reasons.
Installing Charging Infrastructure

- If specific EVSE requirements are unknown during new building construction, install service panels and conduit in anticipation of 240 Volt, Level II charging
- If charging requirements are known
  - Install SAE J1722 compliant connectors and UL Listed EVSE and offboard chargers
  - Follow the local NEC requirements for electrical wiring and equipment (EVSE and chargers)
  - Match infrastructure to vehicle requirements
- Level I, 120 Volt may be suitable for small PHEV battery packs
- Level II, 240 volt or higher is required for BEVs due to their large energy storage (kWh) and the time required to charge them
- Public infrastructure should be at least Level II
AVTA PHEV Testing

- 12 PHEV models tested to date
  - Hymotion Prius (A123Systems)
  - Hymotion Escape (A123Systems)
  - Ford E85 Escape (Johnson Controls/Saft)
  - EnergyCS Prius, 2 models (Valance and Altair Nano)
  - Electrovaya Escape (Electrovaya) - done
  - 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) - done
  - (Lithium unless noted)
AVTA PHEV Testing – cont’d

- 259 PHEVs in 23 states, Canada and Finland, 1.5 million miles - AVTA only purchased 2 vehicles and 12 conversions. Highly leveraged testing activity
- 93 PHEV testing partners include:
  - 38 Electric utilities
  - 10 County governments
  - 4 State governments
  - 10 Canadian government groups
  - 3 Sea ports and military bases
  - 2 PHEV conversion companies
  - 5 Private companies and advocacy organizations
- 2,000+ monthly PHEV 3-page summary reports have been generated and disseminated to testing partners
AVTA PHEVs and Demonstration Locations

Most Vehicle Conversions
• Prius & Escapes
• Li-ion Batteries

Public + Private Partners

Data analysis & Reporting

294 Total
247 Operating
35 Coming ‘10
12 Out of Service
## Hymotion Prius PHEV – 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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<tbody>
<tr>
<td>10</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>60</td>
<td>600</td>
<td>111.43</td>
<td>5.205</td>
<td>117.6 E</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>124.50</td>
<td>8.105</td>
<td>80.1 I</td>
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<tr>
<td>40</td>
<td>4</td>
<td>0</td>
<td>12</td>
<td>15</td>
<td>600</td>
<td>71.28</td>
<td>9.8</td>
<td>62.1 I</td>
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<tr>
<td>40</td>
<td>4</td>
<td>0</td>
<td>12</td>
<td>15</td>
<td>600</td>
<td>44.97</td>
<td>7.2</td>
<td>84.2 E</td>
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<tr>
<td>40</td>
<td>2</td>
<td>2</td>
<td>12</td>
<td>15</td>
<td>600</td>
<td>64.36</td>
<td>9.70</td>
<td>64.3 I</td>
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<tr>
<td>40</td>
<td>2</td>
<td>2</td>
<td>12</td>
<td>15</td>
<td>600</td>
<td>75.14</td>
<td>6.20</td>
<td>99.8 E</td>
</tr>
<tr>
<td>40</td>
<td>2</td>
<td>2</td>
<td>12</td>
<td>15</td>
<td>600</td>
<td>70.98</td>
<td>6.83</td>
<td>90.6 I</td>
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<tr>
<td>40</td>
<td>0</td>
<td>4</td>
<td>12</td>
<td>15</td>
<td>600</td>
<td>75.18</td>
<td>6.10</td>
<td>103.3 E</td>
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<td>40</td>
<td>0</td>
<td>4</td>
<td>12</td>
<td>15</td>
<td>600</td>
<td>63.46</td>
<td>8.88</td>
<td>70.8 I</td>
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<tr>
<td>60</td>
<td>2</td>
<td>4</td>
<td>12</td>
<td>10</td>
<td>600</td>
<td>33.38</td>
<td>10.54</td>
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<tr>
<td>80</td>
<td>2</td>
<td>6</td>
<td>12</td>
<td>8</td>
<td>640</td>
<td>41.38</td>
<td>10.71</td>
<td>61.8 I</td>
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<tr>
<td>100</td>
<td>2</td>
<td>8</td>
<td>12</td>
<td>6</td>
<td>600</td>
<td>26.48</td>
<td>10.91</td>
<td>56.5 I</td>
</tr>
<tr>
<td>200</td>
<td>2</td>
<td>18</td>
<td>12</td>
<td>3</td>
<td>600</td>
<td>16.01</td>
<td>10.41</td>
<td>57.7 I</td>
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<tr>
<td>Total</td>
<td>2340</td>
<td>3100</td>
<td>1404</td>
<td>167</td>
<td>7,840</td>
<td>Weighted Average</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg.
E = experienced HEV driver, I = inexperienced driver
Hymotion Prius PHEV – Accelerated Testing

- High ambient temperatures impact charge completion
PHEV Ambient Temperature MPG Impacts

Hymotion Prius Fleet Fuel Economy

- Average Fuel Economy [MPG]
- Average Ambient Temperature [°C]

- All Trips
- CD
- CD/CS
- CS
PHEV Engine Ops by Ambient Temperatures

Hymotion Prius Fleet - Percentage of Miles with Engine On

<table>
<thead>
<tr>
<th>Average Ambient Temperature [C]</th>
<th>Percent Miles Engine On [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; -20°C</td>
<td>100%</td>
</tr>
<tr>
<td>-20°C to 10°C</td>
<td>80%</td>
</tr>
<tr>
<td>-10°C to 0°C</td>
<td>60%</td>
</tr>
<tr>
<td>0°C to 10°C</td>
<td>40%</td>
</tr>
<tr>
<td>10°C to 20°C</td>
<td>20%</td>
</tr>
<tr>
<td>20°C to 30°C</td>
<td>0%</td>
</tr>
<tr>
<td>30°C to 40°C</td>
<td>0%</td>
</tr>
<tr>
<td>&gt; 40°C</td>
<td>0%</td>
</tr>
</tbody>
</table>

Legend:
- All Trips
- CD
- CD/CS
- CS
Hymotion Prius PHEVs – CD Trips

• MPG and aggressive driving impacts March ‘08 – May ‘09

MPG & Driver Aggressiveness for 22,700 CD Trips, 151,000 miles (6.7 miles average trip distance)

Data from 150 Hymotion Prius with V2Green and Kvaser loggers
### North American PHEV Demonstration

**Fleet Summary Report:** HyMotion Plus (V2Green data logger)

**Number of vehicles:** 180

**Reporting Period:** Apr 08 - Dec 09

### All Trips Combined

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall gasoline fuel economy (mpg)</td>
<td>49</td>
</tr>
<tr>
<td>Overall AC electrical energy consumption (AC Wh/mi)</td>
<td>59</td>
</tr>
<tr>
<td>Overall DC electrical energy consumption (DC Wh/mi)</td>
<td>44</td>
</tr>
<tr>
<td>Trips</td>
<td></td>
</tr>
<tr>
<td>Total number of trips</td>
<td>105,249</td>
</tr>
<tr>
<td>Total distance traveled (mi)</td>
<td>917,420</td>
</tr>
</tbody>
</table>

### Trips in Charge Depleting (CD) mode

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline fuel economy (mpg)</td>
<td>54</td>
</tr>
<tr>
<td>DC electrical energy consumption (DC Wh/mi)</td>
<td>44</td>
</tr>
<tr>
<td>Number of trips</td>
<td>48,367</td>
</tr>
<tr>
<td>Percent of trips city / Highway</td>
<td>86% / 14%</td>
</tr>
<tr>
<td>Distance traveled (mi)</td>
<td>200,864</td>
</tr>
<tr>
<td>Percent of total distance traveled</td>
<td>22%</td>
</tr>
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</table>

### Trips in Charge Depleting and Charge Sustaining (CD/CS) modes

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Gasoline fuel economy (mpg)</td>
<td>53</td>
</tr>
<tr>
<td>DC electrical energy consumption (DC Wh/mi)</td>
<td>49</td>
</tr>
<tr>
<td>Number of trips</td>
<td>9,296</td>
</tr>
<tr>
<td>Percent of trips city / Highway</td>
<td>48% / 53%</td>
</tr>
<tr>
<td>Distance traveled (mi)</td>
<td>206,967</td>
</tr>
<tr>
<td>Percent of total distance traveled</td>
<td>24%</td>
</tr>
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</table>

### Trips in Charge Sustaining (CS) mode

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline fuel economy (mpg)</td>
<td>43</td>
</tr>
<tr>
<td>Number of trips</td>
<td>47,596</td>
</tr>
<tr>
<td>Percent of trips city / Highway</td>
<td>74% / 26%</td>
</tr>
<tr>
<td>Distance traveled (mi)</td>
<td>517,076</td>
</tr>
<tr>
<td>Percent of total distance traveled</td>
<td>53%</td>
</tr>
<tr>
<td>Number of trips when the plug-in battery pack was turned off for the vehicle operator</td>
<td>2415</td>
</tr>
<tr>
<td>Distance traveled with plug-in battery pack turned off by the vehicle operator (mi)</td>
<td>93,839</td>
</tr>
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**Notes:** 1 - 9 Please see http://avt.nerl.gov/phevreportnotes for an explanation of all PHEV Fleet Testing Report notes.
In addition to charge mode, the 3-Page PHEV Fact Sheets provide fuel use by drive cycle and driver style (aggressiveness)

<table>
<thead>
<tr>
<th>Trips in Charge Depleting (CD) mode</th>
<th>City</th>
<th>Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline fuel economy (mpg)</td>
<td>82</td>
<td>87</td>
</tr>
<tr>
<td>DC electrical energy consumption (DC Wh/mi)</td>
<td>167</td>
<td>109</td>
</tr>
<tr>
<td>Percent of miles with internal combustion engine off</td>
<td>30%</td>
<td>8%</td>
</tr>
<tr>
<td>Average trip aggressiveness (on scale 0 – 10)</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Average trip distance (mi)</td>
<td>2.9</td>
<td>4.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trips in both Charge Depleting and Charge Sustaining (CU/CS) modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline fuel economy (mpg)</td>
</tr>
<tr>
<td>DC electrical energy consumption (DC Wh/mi)</td>
</tr>
<tr>
<td>Percent of miles with internal combustion engine off</td>
</tr>
<tr>
<td>Average trip aggressiveness (on scale 0 – 10)</td>
</tr>
<tr>
<td>Average trip distance (mi)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trips in Charge Sustaining (CS) mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline fuel economy (mpg)</td>
</tr>
<tr>
<td>Percent of miles with internal combustion engine off</td>
</tr>
<tr>
<td>Average trip aggressiveness (on scale 0 – 10)</td>
</tr>
<tr>
<td>Average trip distance (mi)</td>
</tr>
</tbody>
</table>

Effect Of Driving Aggressiveness on Fuel Economy This Year

Aggressiveness factor is based on accelerator pedal position. The more time spent during a trip at higher accelerator pedal position, the higher the trip aggressiveness.

Trip Fuel Economy Distribution By Trip Type

Percent of total miles in trip type
3-Page PHEV Fact Sheets provide charging stats, time of day driving, and charging profiles
PHEV Testing Results by Fleet

MPG by Fleet and Operating Mode

- WA State 31
- California 18
- All V2Green 112
- Hawaii 6
- Canada 14
Seattle PHEV Charging – No Control

**Typical Charge, Single Vehicle - No External Control**

- Charging: $P_{avg} = 1100 \text{ W}$
- Post Charge: $P_{avg} = 6 \text{ W}$

*Hymotion Prius PHEV battery from A123 Systems*
Seattle PHEV Time of Day Charging Trials

- VCM establishes communication with control server, requests charging only between 10pm & 4am

![Graph showing power consumption during charging trials]

- **Typical Charge, Single Vehicle - 10am to 4pm Charging**
  - **Standby** $P_{avg} = 40$ W
  - **Charging** $P_{avg} = 897$ W
  - **Post Charge** $P_{avg} = 5$ W

- Charging Begins ~10 PM

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Results of PHEV Time of Day Charging Trials

• Rogue AC kWh – energy drawn outside of allowable charging window:
  – Communication not established or lost - charging occurs
  – Cumulative standby energy draw when not charging

<table>
<thead>
<tr>
<th>Energy Consumption (kWh) by Type and Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging in Window</td>
</tr>
<tr>
<td>151.6, 65%</td>
</tr>
</tbody>
</table>
PHEV Commercial Fleets Charge Demand

Avg Hourly Vehicle Charging Demand

Time of Day

Avg Charging Demand per Vehicle (kW)

Mon AM - Tues AM
Tue AM - Wed AM
Wed AM - Thu AM
Thu AM - Fri AM
Fri AM - Sat AM
Sat AM - Sun AM
Sun AM - Mon AM
PHEV Private Fleets Charging Demand

Avg Hourly Vehicle Charging Demand

- Mon AM - Tues AM
- Tue AM - Wed AM
- Wed AM - Thu AM
- Thu AM - Fri AM
- Fri AM - Sat AM
- Sat AM - Sun AM
- Sun AM - Mon AM

Time of Day

Avg Charging Demand per Vehicle (kW)
AVTA HEV Testing

• 5 million total HEV testing miles
• 18 HEV models and 47 HEVs tested to date:
  – 6, 2001 Honda Insight
  – 6, 2002 Gen I Toyota Prius
  – 4, 2003 Gen I Honda Civic
  – 2, 2004 Chevrolet Silverado
  – 2, 2004 Gen II Toyota Prius
  – 2, 2005 Ford Escape
  – 2, 2005 Honda Accord
  – 3, 2006 Lexus RX 400h
  – 2, 2006 Toyota Highlander
  – 2, 2006 Gen II Honda Civic
  – 2, 2007 Saturn Vue
  – 2, 2007 Toyota Camry
  – 2, 2008 Nissan Altima
  – 2, 2008 GM 2-mode Tahoe
  – 2, 2010 Ford Fusion
  – 2, 2010 Toyota Prius
  – 2, 2010 Honda Insight
  – 2, 2010 Mercedes Benz S400
• Published 24 HEV battery testing reports to date
AVTA HEV Testing – cont’d

Baseline Performance (SAE J1634) and Fleet MPG

- Fleet/AR Testing
- MPG SAE J1634 Air On
- MPG SAE J1634 Air Off

Miles per Gallon

Gen I Insight, Gen I Prius, Gen I Civic, Silverado, Accord, Escape, Highlander, RX400h, Gen II Civic, Camry, Vue, Altima, Tahoe, Gen III Prius, Gen II Insight, Ford Fusion, Mercedes S400, Average
AVTA HEV Testing – cont’d

Percent MPG Difference (J1634 With & W/O Air)

-24.0%
-19.6%
-27.0%
-21.6%
-14.9%
-18.5%
-22.1%
-25.1%
-21.7%
-28.4%
-22.1%
-23.1%
-24.9%
-24.4%
-8.0%
-17.8%
-21.8%
-28.7%
-30%
-25%
-20%
-15%
-10%
-5%
0%
-25%
-20%
-15%
-10%
-5%
0%
AVTA HEV Testing – cont’d

# HEV Fleet Testing
Advanced Vehicle Testing Activity
Maintenance Sheet for 2007 Nissan Altima

VIN #: 1N4CL21E27C177982

<table>
<thead>
<tr>
<th>Date</th>
<th>Mileage</th>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/3/2008</td>
<td>4,856</td>
<td>Changed oil</td>
<td>$25.45</td>
</tr>
<tr>
<td>2/1/2008</td>
<td>9,817</td>
<td>Changed oil</td>
<td>$32.04</td>
</tr>
<tr>
<td>4/8/2008</td>
<td>18,289</td>
<td>Changed oil and filter</td>
<td>$27.95</td>
</tr>
<tr>
<td>5/27/2008</td>
<td>30,947</td>
<td>Changed oil and filter</td>
<td>$30.24</td>
</tr>
<tr>
<td>7/7/2008</td>
<td>39,307</td>
<td>Changed oil and filter</td>
<td>$32.59</td>
</tr>
<tr>
<td>8/5/2008</td>
<td>48,243</td>
<td>Changed oil and filter, replaced air filter and cabin air filter, exchanged coolant, filled air conditioning coolant, and rotated tires</td>
<td>$259.08</td>
</tr>
<tr>
<td>9/22/2008</td>
<td>52,506</td>
<td>Changed oil and filter</td>
<td>$28.08</td>
</tr>
<tr>
<td>9/29/2008</td>
<td>58,349</td>
<td>Changed oil and filter</td>
<td>$28.71</td>
</tr>
<tr>
<td>10/25/2008</td>
<td>63,648</td>
<td>Changed oil and filter, exchanged coolant, replaced cabin air filter, and purchased tire life preventative maintenance package</td>
<td>$444.64</td>
</tr>
<tr>
<td>10/31/2008</td>
<td>66,826</td>
<td>Changed oil and filter</td>
<td>$28.08</td>
</tr>
<tr>
<td>11/1/2008</td>
<td>72,156</td>
<td>Changed oil and replaced, balanced, and aligned two front tires</td>
<td>$307.32</td>
</tr>
<tr>
<td>11/7/2008</td>
<td>73,172</td>
<td>Changed oil and filter</td>
<td>$28.08</td>
</tr>
<tr>
<td>12/4/2008</td>
<td>79,464</td>
<td>Changed oil and filter, replaced air filter</td>
<td>$35.10</td>
</tr>
<tr>
<td>1/14/2009</td>
<td>91,050</td>
<td>Changed oil and filter</td>
<td>$28.08</td>
</tr>
<tr>
<td>2/1/2009</td>
<td>99,340</td>
<td>Changed oil and air filter and balanced two tires</td>
<td>$368.34</td>
</tr>
<tr>
<td>2/25/2009</td>
<td>111,501</td>
<td>Changed oil and filter, replaced alternator belt and replaced wiper blades</td>
<td>$125.56</td>
</tr>
<tr>
<td>4/17/2009</td>
<td>117,676</td>
<td>Changed oil and filter, replaced front and back brake pads and shoes, and turned rear rotors</td>
<td>$414.26</td>
</tr>
<tr>
<td>5/1/2009</td>
<td>122,141</td>
<td>Changed oil and filter and replaced air filter</td>
<td>$48.96</td>
</tr>
<tr>
<td>5/27/2009</td>
<td>133,892</td>
<td>Changed oil and filter and installed and balanced two tires</td>
<td>$321.34</td>
</tr>
<tr>
<td>6/1/2009</td>
<td>142,317</td>
<td>Changed oil and filter</td>
<td>$28.21</td>
</tr>
<tr>
<td>7/9/2009</td>
<td>154,775</td>
<td>Changed oil and filter</td>
<td>$28.21</td>
</tr>
<tr>
<td>7/20/2009</td>
<td>154,986</td>
<td>Installed and balanced two tires</td>
<td>$275.10</td>
</tr>
</tbody>
</table>
2006 Toyota Highlander Hybrid

Final Fleet Testing Results

Operating Statistics
Number of Vehicles Tested: 2
Distance Driven: 297,852 mi
Average Trip Distance: 13.8 mi
Stop Time with Engine Idling: 23%
Trip Type City/Highway: 74%/26%

Operating Performance
Cumulative MPG: 24.4

Test Notes
2. Calculated from electronic data logged over a subset of total miles traveled equal to 118,836 miles.
3. Fuel economy calculated for this figure using mass airflow over dynamic vehicle operation.
2-Page HEV Fleet Testing Fact Sheets – cont’d
Hydrogen ICE Fact Sheet

- Twelve 2005 Chevrolet Silverado 1500HD pickups
- Operating in Canada and the U.S.
- Onboard data logger generated results
- 10.5 GGE ~100% H₂ onboard storage
- Low cost data monitoring activity
Hydrogen ICE Fact Sheet – cont’d

Notes:
1. Internal Combustion Engine
2. Data presented represents all electronically logged data, which is a subset of the overall fleet mileage
3. Percentage of total engine run hours
4. Miles per gallon gasoline equivalent (1 GGE = 1.012 kg H₂)
5. Average speed of vehicle when moving, idle time not included in calculation
AVTA NEV Testing

NEV Maximum Speed and Range Test Results

- Maximum Speed Test (mph) with 170 lbs Payload
- Range Test (miles) - tested at max speed
AVTA NEV Testing – cont’d

Charging Efficiency - AC Wh per Mile

AC Wh per Mile

0 25 50 75 100 125 150 175 200 225 250 275 300 325

2002 ParCar 2 passenger
2002 ParCar 4 passenger
2001 Frazer-Nash CityCar
2002 GEM short bed
2002 GEM long bed
2002 GEM 2 passenger
2002 GEM 4 passenger
2002 Ford/Think 2 pass
2002 Ford/Think 4 pass
2005 GEM long bed
2005 GEM short bed
2005 GEM 2 passenger
2005 GEM 4 passenger
2007 GEM 6 passenger
2007 Gem long bed
2007 Gem short bed
2007 Zenn 2 passenger
2008 Miles 4 passenger
2008 Miles pickup 2 pass
2009 Vantage pickup
2009 Vantage Van
2008 Roush pickup
Average
AVTA BEV Testing

- FY10 tested first BEV from OEM in 10+ years
- Additional FY10 BEVs: Tesla and THINK
- FY11 will include: Leaf, iMiEV, Transit, Focus, THINK, BMW, BYD E6
- FY11 will also include EREV Volt and PHEV Toyota Prius
eTec/Nissan/INL EV Infrastructure Project

- INL is a principle participant with eTec in the deployment of 4,700 battery electric Nissan Leaf vehicles in 5 states:
  - Oregon, Washington, California, Arizona and Tennessee

- Charging and vehicle data will be collected via data streams from eTec charging infrastructure, Nissan, and possibly 3rd party infrastructure providers

- INL will analyze and report on charging infrastructure utilization for ~11,000 Level II EVSE units, ~300 Level III chargers, and 4,700 Leafs

- INL will report on driver/vehicle charging patterns, and charging infrastructure utilization patterns

- Many of the 42 project partners are electric utilities with high interest in demand / smart charging controls

- Probable fast charge / grid energy storage test component
eTec/Nissan/INL EV Infrastructure Project

**eTec/Nissan/Regional Partners**

- Nashville, Chattanooga, Knoxville, ORNL
- Seattle
- Portland, Eugene, Corvallis, Salem, UCD
- San Diego, Phoenix, Tucson

**Data Analysis and Reporting**

11K+ Level II & III Chargers
4700 Nissan EV’s

**Battery** – 24+ kWh Li-ion, Projected 100 Mile Range
Announced BEV Introductions*

• 2009 Subaru 4 seat Stella or R1e (2 in New York now)
• 2009 Chrysler EVs (showing concepts)
• 2009 Smart for Two EV
• 2009 ZENN city BEV
• 2009 Chery (China, Berkshire Hathaway) BYD EV in China
• 2009 Tesla / Daimler Smart Car BEV
• 2010 BMW electric Mini (actually 2009 prototype)
• 2010 Chrysler EV
• 2010 Miles EV
• 2010 Mitsubishi \ Peugeot iMiEV BEV

(* Presenter makes no accuracy claim for the above dates and products. Some info based on media reports)

Announced BEV Introductions* – cont’d

• 2010 Nissan BEV
• 2010 Ford Battery Electric Van
• 2011 Tesla Model S sedan
• 2011 BYD e6 Electric Vehicle
• 2011 Ford Battery Electric Sedan
• 2011 Opel Ampera Extended Range BEV (Europe)
• 2012 Toyota EV sedan
• ? Volkswagen and Toshiba EV develop letter of intent
• (* Presenter makes no accuracy claim for the above dates and products. Some info based on media reports)

Announced PHEV Introductions*

- 2009 Fisker Karma S Plug-in Hybrid (maybe 2010)
- 2010 Saturn VUE Plug-in Hybrid
- 2010 Toyota Plug-in Hybrid (?)
- 2010 Chevrolet Volt Extended Range (actually EVRE)
- 2010 Kia LPG and Electric “hybrid”
- 2009 Chery (China, Berkshire Hathaway) BYD PHEV in Europe
- 2011 BYD F3DM Plug-in Hybrid
- 2012 Ford Escape Plug-in Hybrid
- 2012 Hyundai PHEV
- ? AFS Trinity SUV

(* Presenter makes no accuracy claim for the above dates and products. Some info based on media reports)

Vehicles Selection Considerations

- Is it an OEM Vehicle or a conversion? If a conversion ask:
  - Has the vehicle emissions been certified by CARB or the EPA, or received an exemption?
  - Has the vehicle been crashed tested and FMVSS certified per NHTSA reporting requirements?
  - Has the converter made the vehicle available to DOE’s AVTA or another group for independent testing?
  - Conversions need crash testing – Don’t believe “its (battery) just another piece of luggage in the trunk”

- Always match the vehicle capabilities to missions
  - Consider range requirements and operating environment, including ambient temperature, terrain, payload, passenger numbers
  - Consider recharging / fueling requirements
  - Install the fueling infrastructure(s) before vehicle delivery
AVTA Webpage Use and Gasoline Costs

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

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Additional Information

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