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Presentation Outline

• Advanced Vehicle Testing Activity (AVTA) background, vehicle technologies, and testing methods

• PHEV demonstrations and testing
  – Background and methodology
  – Vehicle energy consumption and sensitivities
  – Vehicle charging demand and location
  – Controlled charging study findings

• Future outlook
Advanced Vehicle Testing Activity (AVTA) is part of DOE’s Vehicle Technologies Program. Conducted by:

- **Idaho National Laboratory (INL)**
  - Program execution in support of DOE goals
  - Conducts engineering, data analysis, and reporting

- **Ecotality North America (formerly eTec)**
  - Private company based in Phoenix, AZ with access to numerous testing facilities / tracks
  - Conducts vehicle test operations and engineering

- **ANL and ORNL** provide AVTA dynamometer testing support and vehicle data acquisition support (ANL)
AVTA Description – cont’d

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

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

• Assist early adopter fleet managers and the general public in making informed vehicle purchase, deployment and operating decisions. Presentations to industry groups, including via DOE’s Clean Cities Coalitions

• DOE’s only light-duty vehicle testing activity of new technologies deployed in whole-vehicle systems operated in real-world fleet environments
AVTA Testing by Technology

- Plug-in hybrid electric vehicles (PHEV)
  - 12 models, 259 vehicles, 1.5 million test miles
- Hybrid electric vehicles (HEV)
  - 18 models, 47 vehicles, 5 million test miles
- Full-size battery electric vehicles (BEVs)
  - 40 EV models, 5+ million test miles
- Neighborhood & Urban electric vehicles
  - 26 models, 1.2 million test miles
- Hydrogen internal combustion engine vehicles
  - 7 models, 500,000 test miles

14 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 on-road testing
  – Fleet deployment and evaluation

• Graded approach (from the lab to the field) used to balance testing control, realism, sample size, and costs

• Publish testing results to simply and accurately
  – Document real-world petroleum reduction potentials
  – Document fuel and infrastructure use
  – Document life-cycle risks and costs
PHEV Testing

12 PHEV models tested to date

- Hymotion Prius (A123 Systems)
- Hymotion Escape (A123 Systems)
- EnergyCS Prius, 2 models (Valence and Altairnano)
- Electrovaya Escape (Electrovaya)
- Hybrids Plus Escape, 2 models (Hybrids Plus and K2 Energy Solutions)
- Hybrids Plus Prius (Hybrids Plus)
- Manzanita Prius, 2 models (lead acid and Thunder Sky)
- Renault Kangoo (Saft NiCad)
- Ford E85 Escape (Johnson Controls/Saft)

(Lithium-ion unless noted)

Testing focus is on the PHEV technology concept and batteries, and driver and environmental impacts on fuel efficiencies and charging rates, not on individual PHEV conversions
PHEV Testing Partners

• 259 PHEVs in 26 states, Canada, and Finland
• 1.5 million miles
• 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
• 2,500+ automated monthly PHEV 3-page summary reports have been generated and disseminated to testing partners, 1,176 reports disseminated just in FY09
  – 9 City governments
  – 10 Universities
  – 2 Clean Air Agencies
Most Vehicle Conversions
- Prius & Escapes
- Li-ion Batteries

Public + Private Partners

INL: Data analysis & Reporting

Total:
- 294 Total
- 247 Operating
- 35 Coming ‘10
- 12 Out of Service
INL is maintaining and enhancing automated data warehousing, analysis, and reporting process for fleet data

• Accommodates 6 different data transfer methods from a multitude of vehicle/data logger combinations:
  – 9 PHEV, 1 BEV, 1 EREV, 8 HEV, and 1 HICE models
  – 5 data logger makes/models in use, with development efforts started for 3 more

• PHEV reporting formats include 71 metrics describing energy use, driving patterns, and charging patterns

• Developed quality assurance/exploratory analysis tools

• Created flexible automated report generation processes for individual and multiple vehicle reports

• The PHEV onboard data collection system is growing at approximately 60 million records per month
**Vehicle Data Management Process**

**Process Affected by Disclosure Agreements**

- **HICEVs**
- **HEVs**
- **PHEVs**
- **BEVs**
- **EVSE & Chargers**

**INL Vehicle Data Management System**

- **File server**
- **SQL Server data warehouse**
- **Report generator**

**Data quality reports**
- Individual vehicle reports
- Fleet summary reports to public
- Focused technical analyses and custom reports

**Inputs to modeling and simulation**
### North American PHEV Demonstration

**Fleet Summary Report:** Hymotion Prius (V2Green data logger)

**Number of vehicles:** 182

**Reporting Period:** Apr 08 - Feb 10

#### All Trips Combined

- **Overall gasoline fuel economy (mpg):** 49
- **Overall AC electrical energy consumption (AC Wh/mi):** 1
- **Overall DC electrical energy consumption (DC Wh/mi):** 2
- **Total number of trips:** 125,328
- **Total distance traveled (mi):** 1,161,489

#### Trips in Charge Depleting (CD) mode

- **Gasoline fuel economy (mpg):** 62
- **DC electrical energy consumption (DC Wh/mi):** 4
- **Number of trips:** 57,053
- **Percent of trips city / highway:** 86% / 14%
- **Distance traveled (mi):** 261,411
- **Percent of total distance traveled:** 23%

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

- **Gasoline fuel economy (mpg):** 53
- **DC electrical energy consumption (DC Wh/mi):** 6
- **Number of trips:** 10,749
- **Percent of trips city / highway:** 47% / 53%
- **Distance traveled (mi):** 278,541
- **Percent of total distance traveled:** 24%

#### Trips in Charge Sustaining (CS) mode

- **Gasoline fuel economy (mpg):** 43
- **Number of trips:** 57,526
- **Percent of trips city / highway:** 74% / 26%
- **Distance traveled (mi):** 625,034
- **Percent of total distance traveled:** 54%

#### Notes:


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### Gasoline Fuel Economy by Trip Type

<table>
<thead>
<tr>
<th>Fuel Economy (mpg)</th>
<th>CD/CS</th>
<th>CD</th>
<th>CS</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
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### Distance Traveled by Trip Type

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### Miles Logged by Month This Year

<table>
<thead>
<tr>
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<th>CD/CS</th>
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PHEV 3-Page Report

• Report fuel use by highway/city cycles and driver style

  • CD city, 60 mpg (62%+), 165 DC Wh/mi
  • CD highway, 66 mpg (47%+), 109 DC Wh/mi
  • CS city, 37 mpg
  • CS highway, 45 mpg
  • Less aggressive driving (0 to 20%) averages ~80 mpg
    – (Aggressiveness = accelerator pedal position)
• Report charging stats, time of day driving, and charging profiles

• Average 1 charging event per day when PHEV driven
• 44.8 miles between charge events
• 4.8 trips between charge events
• 2.8 hours per charge
• 20.9 hours time plugged in per charge
• 2.6 AC kWh per charge event
Driver Aggressiveness

- With increase in driver aggressiveness
  - Fuel consumption increases
  - Wh/mi slightly decreases

![Graph showing impact of driver aggressiveness on fuel and electrical energy consumption by average trip speed.](image)
Route Type

• Discernable by
  – Average Vehicle Speed
  – Stops per mile
  – % time stopped

• For typical driving
  • Strong correlation between average speed and stops per mile
Route Type

• Inflection point around 35 kph and 2 stops/mile

• Lower average speed results in higher fuel consumption and higher electrical consumption

• Higher average speed also results in higher fuel consumption BUT lower electrical consumption
Accessory Utilization – Air Conditioner

- As A/C compressor speed (and load) increases
  - CD: Wh/mi increases, minimal change to fuel consump.
  - CS: Fuel consumption increases
Engine Warm-up / Start-up

- Total energy consumption dramatically decreases as initial engine temperature increases
- Longer trip duration reduces fuel consumption due to greater time driving with warm engine (less start-up effect)
PHEV Ambient Temperature MPG Impacts

Hymotion Prius Fleet Fuel Economy

Average Ambient Temperature [°C]

- Average Fuel Economy [MPG]

- All Trips
- CD
- CD/CS
- CS

Average Ambient Temperature

- <20C
- -20C to -10C
- -10C to 0C
- 0C to 10C
- 10C to 20C
- 20C to 30C
- 30C to 40C
- >40C
Engine Operation is a Main Factor for PHEV Fuel Economy Changes
Usable Battery Capacity is Slightly Effected by Temperature

Hymotion Prius Battery Energy Capacity
PHEV Fleet Results from Full Charge Trip Sequences

Average Ambient Temperature [°C]

Battery Discharge Energy [DC kWh]

Usable SOC [%]

Discharge Energy

Usable SOC
Hymotion Li-Ion Battery Internal Resistance Change with Temperature
PHEV Time of Day Charging Demand

Personal-use Vehicles in Private Households (UC Davis Study)

- Data from last week of charging at 67 households
- Uncontrolled charging

Weekday peak occurs between X:00 and X:00

Weekend peak occurs around midnight

Peak day has peak in X:00 hour
PHEV Time of Day Charging Demand

Commercial-use Fleet Vehicles

- Data from 6 randomly sampled weeks during 2009
- 138 distinct vehicles

Weekday peak occurs between 2:00 and 5:00

Weekend peak occurs around midnight

Peak day has peak in 5:00 hour
PHEV Charging Location
Personal-use Vehicles in Private Households
(UC Davis Study)

Percent of Time Driving, Plugged in, and Parked while Unplugged by Location

- Driving
- Parked at Primary Charging Location
- Parked at Non-Primary Charging Location
- Parked at Location with No Charging History
- Parked at Unknown Location (No GPS Fix)
- Plugged in at Primary Charging Location
- Plugged in at Non-Primary Charging Location
- Plugged in at Unknown Location (No GPS Fix)
PHEV Charging Location
Commercial-use Fleet Vehicles

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- Plugged in at Unknown Location (No GPS Fix)
Seattle Area PHEV Smart Charging Trials

• 13 Hymotion PHEVs using GridPoint’s *Electric Vehicle Management Solution*

• Types of trials conducted with GridPoint and Seattle City Light (project lead):
  – **Time of Day Charging** – Vehicle charging only allowed during certain hours of the day
  – **Goal Based Charging** – Normalize power demand for vehicle charging around a kW goal load
  – **Economic Charging** – Allow vehicle charging only when the price of electricity is below a threshold

• GridPoint Vehicle Connectivity Modules (VCM) used to control charging as directed by GridPoint’s server and to log vehicle charging and driving data

• VCM requests the pack to wait to charge or to charge at a specified power level - no physical circuit interruption

• INL analyzed the data collected from the vehicles
Typical Charge, Single Vehicle - No External Control

Charging
\[ P_{\text{avg}} = 1100 \text{ W} \]

Post Charge
\[ P_{\text{avg}} = 6 \text{ W} \]

End-of-Charge

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

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

**Typical Charge, Single Vehicle - 10am to 4pm Charging**

- **Charging**
  - $P_{avg} = 897 \text{ W}$
- **Post Charge**
  - $P_{avg} = 5 \text{ W}$
- **Standby**
  - $P_{avg} = 40 \text{ W}$

Vehicle Plugged In ~10 PM

Charging Begins

Charging Ends
Results of Time of Day Charging Trials

- 35% 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>
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<tbody>
<tr>
<td><strong>Charging in Window</strong></td>
</tr>
<tr>
<td><strong>Charging out-of Window</strong></td>
</tr>
<tr>
<td>151.6, 65%</td>
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<tr>
<td>33.7, 14%</td>
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</tbody>
</table>
AVTA is collaborating with auto makers to begin testing OEM PHEVs and BEVs. HEV and conversion PHEV testing continues.

AVTA has done extensive testing of vehicles available to date.

* Refers to PHEVs and BEVs produced for the mass market. OEMs have produced PHEVs and BEVs in low volume intermittently since the 1990's.
AVTA Grid-connected Vehicle Testing

FY10

• Tested first BEV from OEM in 10+ years
• Ford Escape PHEV Prototype
• USPS LLV BEV conversions

FY11 outlook includes:

• Nissan Leaf BEV
• Chevrolet Volt EREV
• Mitsubishi iMiEV BEV
• THINK City BEV
• Ford Transit Connect, Focus BEVs
• Toyota Prius PHEV
• Others as they become available
AVTA Summary – WWW Visitors
Acknowledgement

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Additional Information

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