INL Retired Employees Association – Electric Drive Vehicles

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Retired INL Employees Association
Idaho Falls, Idaho
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This presentation does not contain any proprietary or sensitive information

Presentation Outline

- Advanced Vehicle Testing Activity (AVTA) background
- Comparison of Internal combustion engine (ICE), hybrid electric (HEV), plug-in hybrid electric (PHEV), and battery electric (BEV) vehicle technologies
- Grid connected vehicle charging infrastructure and charging levels
- INL / AVTA electric drive vehicle testing
- EV Project data collection
- OEM PHEV data reporting
- OEM electric drive vehicle deployment announcements
- Acknowledgement and AVTA WWW Address
AVTA Description

- Advanced Vehicle Testing Activity (AVTA) is conducted by the Idaho National Laboratory (INL) for DOE’s Vehicle Technologies Program, which is part of EERE
- INL’s AVTA tests light-duty vehicles, energy storage systems, and the fueling infrastructures that support:
  - 100% Electric and dual-fuel electric drive systems
  - Advanced energy storage systems
  - Advanced control systems (i.e., micro hybrid vehicles)
  - 100% Hydrogen and HCNG blended ICE vehicles
- Benchmarked testing results customers include:
  - DOE and industry R&D programs, modelers, battery manufacturers, OEMs, and target/goal setters
  - Assist early adaptor fleet managers and the public in making informed vehicle / infrastructure purchase, deployment and operating decisions
  - Presentations / webinars to industry groups and Clean Cities’ groups

Comparison of Vehicle Technologies
Comparison of Vehicle Technology

• Conventional vehicle with internal combustion engine (ICE) only

Comparison of Vehicle Technology

• Hybrid Electric Vehicle (HEV) with ICE and electric drive
• Does not plug in to electric grid
Comparison of Vehicle Technology

- Plug-in Hybrid Electric Vehicle (PHEV) with ICE and electric drive

Comparison of Vehicle Technology

- Battery Electric Vehicle (BEV) with electric drive only
Conceptual Comparison of Vehicle Operation

- Hypothetical 15 mile drive cycle
Vehicle Electrification: Grid Impacts

- In the U.S., current grid capacity could supply electricity for 70% of our vehicles without adding capacity, but assumes:
  - Vehicles would only charge off-peak
  - “Perfect” distribution of electricity
  - No local impacts such as overburdening neighborhood transformers
- EVs and PHEVs will not cause a grid “meltdown” but we clearly need to work fast to reduce vehicle rollout impacts
- Smart charging will be key to lowering costs and minimizing impacts
- Time of day pricing also important
- Administration Goal: 1 Million Plug-in Vehicles by 2015
Build-out of Charging Infrastructure

- Key today: Home Charging
  - Need to get the cost and installation process right. Currently a significant barrier
- Public Charging
  - Expansive if not well utilized
  - Expansive to fully cover full driving patterns
- Ideally need market pull to determine public infrastructure build-out
  - PHEVs may be key to help initiate market pull for public infrastructure

Innovative Approaches

- Battery swapping
  - Requires OEM buy-in
- Fast Charging (becoming less innovative)
- Innovative Financing
- Secondary use of batteries
  - Utility ancillary services
  - Bulk energy storage
  - Present value
- Vehicle to Grid (V2G)
Level 1 Charging Level

- This method allows broad access to change an EV or PHEV by plugging into the most common grounded electrical outlet in the U.S.
- AC energy transfer to onboard charger
- Typical hardware includes portable cord set that must utilize a vehicle connector UL approved for the purpose, a GFCI, and otherwise meet NEC 625 requirements and SAE standards, including the J1772 connector:
  - Separate circuit
  - Standard 120V/15A or 20A
  - Current 12 amps or 16 amps (80% of amp breaker)
  - Power 1.44 kW
- Charge Times (general approximation)
  - Battery EV 14 hours (20 kWh battery) to 39 hours (56 kWh battery)
  - PHEV 3 to 8 hours

Level 2 Charging Level

- Expected to be most common method for residential and commercial charging
- EVSE (electric vehicle supply equipment) for AC energy transfer to onboard charger
- Permanently attached wall box, GFCI, some vehicle communication, UL approved, NEC 625 requirements and SAE standards, including J1772 connector:
  - 240V single phase up to 100A
  - Current up to 80A (80% of amp breaker)
  - Power up to 19.2 kW
  - 3.3 kW or 6.6 kW more typical initially
- Charge Times (general approximation)
  - 20 kWh Battery EV 3 hours (at 6.6 kW) to 56 kWh battery in 8.5 hours (at 6.6k kW)
  - PHEV 3 to 8 hours
Level 3 Charging Level

• This charge level is NOT “FAST Charge” as currently used
• Typically would be 480VAC energy transfer to an onboard charger
• Current up to 400 amps
• Typically 60 kW to 120 kW, but can be up to 200 kW
• HOWEVER, no light-duty original equipment vehicle manufacturer plans to use onboard chargers at these energy levels

Fast Charging

• Expected to be used in an intercity grid pattern or along travel routes between cities in commercial settings
• Off-board charger (high cost, large volume and weight)
• Used for DC energy transfer to vehicle
• Requires most charger-to-vehicle communication and control
• No current U.S. SAE standard connector, however, U.S. fast chargers are using Japanese TEPCO (Tokyo Electric Power Company) connector per CHAdeMO protocol
• Up to 500VDC and 125A. 60 kW likely
• Charge Times are dependant on battery size
  – BEV intent is 50% recharge in 15 minutes and 80% recharge in 30 minutes
  – Charge times dependant on charger / battery relative sizing
  – Generally not used for PHEVs due to relatively small battery sizes
INL / AVTA Electric Drive Vehicle Testing

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
- Current INL staff has used onboard data loggers to document vehicle and charging operations since 1993
- 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
Vehicle Testing Experience

- Plug-in hybrid electric vehicles: 14 models, 430 PHEVs, 5+ million (ml) miles
- Extended Range Electric Vehicles: 1 model, 150 EREVs, 400+ thousand (k) miles
- Hybrid electric vehicles: 19 models, 50 HEVs, 6+ ml miles
- Micro hybrid vehicles: 3 models, 7 MHVs, 200+ k miles
- Neighborhood electric vehicles: 24 models, 372 NEVs, 200k miles
- Hydrogen internal combustion engine vehicles, 7 models, 18 HICEVs, 500k miles
- Battery electric vehicles 47 models, 2,300 BEVs, 5+ million miles (includes 500+ USPS BEVs)
- Urban electric vehicles: 3 models, 460 UEVs, 1 million miles
- 18+ million test miles accumulated on 2,300 electric drive vehicles representing 110 models

Vehicle Data Management Process

Process Affected by Disclosure Agreements

INL Vehicle Data Management System

File server
SQL Server data warehouse
Report generator

Data quality reports
Individual vehicle reports
Fleet summary
Reports - Public
Focused technical analyses and custom reports
Modeling and simulations

EVSE & Chargers
PHEVs
BEVs / EREVs
HEVs
HICEVs
## Vehicle and Infrastructure Data Sources

<table>
<thead>
<tr>
<th>Vehicle and Infrastructure Data Sources</th>
<th>HEV: 12 vehicle models, 1 data logger</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>HICE: 1 vehicle model, 1 data logger</td>
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<tr>
<td>Conversion PHEVs: 8 vehicle models, 3 data loggers</td>
<td>Ford Escape PHEV, Ford wireless logger</td>
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<td>Chrysler Ram PHEV, Chrysler wireless logger</td>
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<td>Vehicle event data (key-on, key-off)</td>
<td>Nissan Leaf, Nissan telematics</td>
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<td>Chevrolet Volt, OnStar telematics</td>
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<tr>
<td>Charger event and 15 min time-history data</td>
<td>ECoTality Blink networked level 2 EVSE, DC/fast chargers</td>
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<td>Coulomb ChargePoint networked level 2 EVSE</td>
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### Managing 26 different data models

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## INL Data Management System - Push

(Nissan, GM, Chrysler, Coulomb)

- **Vehicle and Charger Data**
- **OEM Data Management Systems**
- **Protected Data**
  - EV Project Team
  - Internal data quality reports
  - EV Project FTP/SFTP Server
  - INL pulls with encrypted transmission
  - Access restricted by firewall rules
- **OEM pushes using FTP/SFTP**
- **INL transmits reports to DOE And OEMs**
- **INL Protect Enclave - EV Project member access only**
- **INL Internal firewall**
- **INL DMZ Firewall – Public has access to AVT.INL.GOV**
- **Fleet summary reports - public**
- **AVT.INL.GOV**

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INL transmits reports to DOE And OEMs
INL Data Management System - Pull
(ECOtality, Ford, conversion PHEVs, HEVs, HICEs)

- Vehicle and Charger Data
- OEM Data Management Systems
- Protected Data
- EV Project Team

INL pulls with encrypted transmission
- Parameters range check
- Lame data check
- Missing/empty parameter check
- Conservation of energy check
- SOC continuity
- Transfer completion

INL transmits reports to DOE and OEMs

INL Internal firewall
INL DMZ Firewall – Public has access to AVT.INL.GOV
INL Protect Enclave – EV Project member access only

Reports posted on WWW
AVT.INL.GOV

PHEV Conversion Testing Partners

- 267 PHEV conversions in 26 states, Canada and Finland, 3 million miles - AVTA only purchased 2 PHEVs and conducted 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
- 3,000+ automated monthly 3-page summary reports have been generated and disseminated to testing partners
FY-10 PHEV Conversion Demonstrations

Public + Private Partners

INL Data analysis & Reporting

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

Canada

Finland

267 Total
255 Operating
12 Out of Service

PHEV 3-Page Report

• Reports 2.6 million Hymotion Prius test miles and 281,000 trips
• Report by charge mode:
  – Charge depleting (CD)
  – Charge sustaining (CS)
  – Mixed (CD/CS)
• All trips, 47 mpg, 52 AC Wh/mi & 38 DC Wh/mi
• CD, 62 mpg & 141 DC Wh/mi
• CD/CS, 53 mpg & 49 DC Wh/mi
• CS, 43 mpg
PHEV 3-Page Report

- Report fuel use by highway/city cycles and driver style
- CD city, 60 mpg, 165 DC Wh/mi
- CD highway, 66 mpg, 109 DC Wh/mi
- CS city, 36 mpg
- CS highway, 46 mpg
- Less aggressive driving (0 to 20%) averages ~100 mpg
  - (Aggressiveness = accelerator pedal position)

PHEV 3-Page Report

- Report charging stats, time of day driving, and charging profiles
- Average 0.9 charging event per day when PHEV driven
- 52 miles between charge events
- 5.5 trips between charge events
- 2.8 hours per charge
- 34.3 hours time plugged in per charge
- 2.7 AC kWh per charge event
PHEV Ambient Temperature MPG Impacts

Engine Operation is a Main Factor for PHEV Fuel Economy Changes
Hymotion Prius PHEVs – CD Trips

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

Data from 150 Hymotion Prius with V2Green and Kvaser loggers

Usable Battery Capacity is Slightly Effected by Temperature

Hymotion Prius Battery Energy Capacity
PHEV Fleet Results from Full Charge Trip Sequences
HEV and MHV Testing

- 6 million total HEV testing miles
- 22 HEV models and 56 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
  - 2, Honda CRZ
  - 3, 2010 Smart Fortwo Pure Coupe
  - 2, 2010 MazDA 3 Hatchback
  - 2, 2010 Volkswagen Golf TDI.

- HEV testing includes beginning and high mileage HEV traction battery testing – HPPC, Static Capacity tests, as well as acceleration and fuel economy tests.
HEV Air Conditioning use MPG Impacts

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

-5% 0% -24.0% -19.6% -21.6% -14.9% -18.5% -22.1% -21.7% -22.1% -14.6% -24.4% -23.1% -8.0% -17.8% -21.8%

Gen I Insight
Gen I Prius
Gen II Civic
Silverado
Accord
Escape
Highlander
Gen II Civic
Carry
Vue
Altezza
Tahoe
Gen II Prius
Ford Fusion
Mercedes S400
Average

HEV Maintenance Sheets

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

<table>
<thead>
<tr>
<th>Date</th>
<th>Mileage</th>
<th>Description</th>
<th>Cost</th>
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1-Page HEV Fleet Summary Sheets
- Life-cycle ownership costs per mile includes:
  - Purchase cost
  - Sales cost
  - Maintenance costs
  - Operating costs (insurance, fuel, taxes, registration, etc.)

2-Page HEV Fleet Testing Fact Sheets
- Number of vehicles
- Total miles
- Average trip distance
- Stop time with engine idling
- Trip type: city/highway
- Fuel economy by vehicle speed
NEV Testing

- CARB requires all NEVs be tested by AVTA to be eligible for incremental funding – 25 models tested to date

**NEV Maximum Speed and Range Test Results**

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

HICE Testing
Accomplishments
- 12 H₂ internal combustion engine vehicles
- Averaged 13.5 miles per gasoline gallon equivalent (mpgge)
- 80,899 test miles
- 14,074 fleet trips
- Very low-cost data collection effort as no DOE funds were used to purchase, fuel, maintain or operate the HICE vehicles
- Task completed
INL Data Collection Activities in Support of DOE’s Vehicle Electrification Projects

INL ARRA / TADA Data Collection Support

- INL tasked with data collection, analysis and reporting for five light-duty vehicle and infrastructure deployment projects funded by DOE via ARRA and Technology Acceleration and Demonstration Activity (TADA):
  - EV Project: 8,300 Leaf EVs and Volt EREVVs, and 15,300 eTec Level 2 EVSE and fast chargers. All 23,600 pieces of equipment are equipped with data loggers (DLs)
  - 140 Chrysler Ram PHEV Pickups with DLs
  - 125 General Motors EREV Volts with DLs
  - 21 Ford Escape PHEV SUVs with DLs
  - 4,000 Level 2 EVSE deployed by Coulomb with DLs
- Raw data and personal information protected by numerous NDAs (Non Disclosure Agreements) with participant partners
EV Project - Overview

• $230 million total project funded by a US Department of Energy grant ($115 million) via the American Recovery and Reinvestment Act (ARRA)
• Partners cost share match greater than $115 million
• Lead by Electric Transportation Engineering Corporation (eTec) (renamed Ecotality NA)
• Data will be collected by INL via data streams from eTec (charging infrastructure), and Nissan and General Motors/OnStar (vehicles)
• EV Project purpose is to build and study mature electric vehicle charging infrastructure in eight regions – 16 cities
• Product: Take the lessons learned from the deployment of these first 8,300 EVs and the 15,300 charging infrastructure units supporting them, to enable the streamlined deployment of the next 5,000,000 EVs
EV Project - Infrastructure Data Collected per Charge Event

- Date/Time Stamp
- Unique ID for Charging Event
- Unique ID Identifying the EVSE – may not change
- Connect and Disconnect Times (plugged in and out)
- Start and End Charge Times
- Max Instantaneous Peak Power
- Average Power
- Total energy (kWh) per charging event
- Rolling 15 Minute Average Peak Power
- And other non-dynamic EVSE information (GPS, ID, type, contact info, etc.)

EV Project - Vehicle Data Collected per each Start / Stop Event

- Vehicle ID
- Date/Time Stamp
- Event type (key on / key off)
- Odometer
- Battery state of charge
- GPS (longitude and latitude)
- Liquid fuel consumption (some vehicles)
- Recorded for each key-on and key-off event
EV Project – Nissan Leaf Reporting

Battery State of Charge (SOC) at the Start of Charging Events

Battery State of Charge (SOC) at the End of Charging Events

EV Project – Nissan Leaf Reporting

Weekdays

Electricity Demand (AC MW)

Time of Day
EV Project – Nissan Leaf Reporting

- Reports 266,000 test miles and 21,000 trips
- Report by charge mode:
  - Charge depleting (CD)
  - Charge sustaining (CS)
  - Mixed (CD/CS)
- All trips, 38 mpg, 101 AC Wh/mi & 66 DC Wh/mi
- CD, 52 mpg & 169 DC Wh/mi
- CD/CS, 37 mpg & 56 DC Wh/mi
- CS, 31 mpg
Ford Escape PHEV 3-Page Report

- Report fuel use by highway/city cycles and driver style
- CD city, 47 mpg, 170 DC Wh/mi
- CD highway, 57 mpg, 167 DC Wh/mi
- CS city, 30 mpg
- CS highway, 32 mpg

Ford Escape PHEV 3-Page Report

- Report charging stats, time of day driving, and charging profiles
- Average 3.4 charging event per day when PHEV driven
- 16.6 miles between charge events
- 1.3 trips between charge events
- 1.2 hours per charge event
- 5.9 hours time plugged in per charge
- 1.7 AC kWh per charge event
Original Equipment Manufacturer (OEM)  
Electric Drive Vehicle Deployment  
Announcements

Some OEM EDV Announcements
• The below announcements and dates come from several sources and may change

<table>
<thead>
<tr>
<th>Introduction Year</th>
<th>Manufacturer / Model</th>
<th>Battery Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Nissan / Leaf</td>
<td>BEV</td>
</tr>
<tr>
<td>2010</td>
<td>GM / Volt</td>
<td>EREV</td>
</tr>
<tr>
<td>2011</td>
<td>Coda / Coda</td>
<td>BEV</td>
</tr>
<tr>
<td>2011</td>
<td>Ford / Focus</td>
<td>BEV</td>
</tr>
<tr>
<td>2011</td>
<td>Ford / Transit (Van)</td>
<td>BEV</td>
</tr>
<tr>
<td>2011</td>
<td>BYD / e6</td>
<td>BEV</td>
</tr>
<tr>
<td>2011</td>
<td>Fisker / Karma</td>
<td>BEV</td>
</tr>
<tr>
<td>2011</td>
<td>Mitsubishi / i-MiEV</td>
<td>BEV</td>
</tr>
</tbody>
</table>

BEV – Battery Electric Vehicle  
EREV – Extended Range Electric Vehicle  
PHEV – Plug-in Hybrid Electric Vehicle  
EDV – Electric Drive Vehicle
Some OEM EDV Announcements – con’td

- The below announcements and dates come from several sources and may change

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<tr>
<th>Introduction Year</th>
<th>Manufacturer / Model</th>
<th>Battery Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Smart / FORTWO</td>
<td>BEV</td>
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<tr>
<td>2012</td>
<td>Toyota / IQ-Based</td>
<td>BEV</td>
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<tr>
<td>2012</td>
<td>Tesla / S</td>
<td>BEV</td>
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<tr>
<td>2012</td>
<td>Toyota / Prius</td>
<td>PHEV</td>
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<tr>
<td>2012</td>
<td>Toyota-Tesla / RAV4</td>
<td>BEV</td>
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<tr>
<td>2012</td>
<td>Chrysler-Fiat / 500</td>
<td>BEV</td>
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<tr>
<td>2013</td>
<td>BMW / MegaCity</td>
<td>BEV</td>
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<tr>
<td>2013</td>
<td>Volkswagen / Eup</td>
<td>BEV</td>
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There have been another 50+ electric drive vehicle announcements beyond 2010 from Audi to Volvo.

Other INL Data Collection Projects

- Other OEM vehicles may be added to EV Project
- New EVs to be tested this year
- Five USPS electric long life vehicle (ELLV) conversions
  - ELLVs required five customized onboard data loggers
  - Testing to USPS and AVTA test procedures and cycles
- Start collecting data on SCAQMD’s 20 Lithium PHEV Escape conversions
- Development of vehicle-based battery test-bed mules
AVTA Summary – WWW Visitors

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

Visitors (left axis)
Gasoline Cost (right axis)
Linear (Visitors (left axis))
Linear (Gasoline Cost (right axis))

Acknowledgement and AVTA WWW Address

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

Additional AVTA Information, Reports, and Fact Sheets @ http://avt.inl.gov

INL/MIS-11-22115