U.S. Department of Energy’s Vehicle Technologies Program -

Plug-in Electric Vehicle (PEV) Real-World Data from DOE’s AVTA (IWC, Tempe, AZ)

Jim Francfort – Idaho National Laboratory
EPRI – Infrastructure Working Council
Tempe, AZ
December 2011

This presentation does not contain any proprietary or sensitive information
Outline

• Background, participants, testing experience
• Data process and security
• EV Project
  – Description and data parameters
  – Leaf and EVSE results (bulk of presentation)
• PEV charging as a percent of U.S. generation
• Volt results
• Ford Escape Advanced Research Vehicle results
• Chrysler Ram PHEV results
• ChargePoint American results
• Hymotion Prius results
• Other vehicle and EVSE testing
• Summary
Idaho National Laboratory

• Eastern Idaho based U.S. Department of Energy (DOE) Federal laboratory
• 890 square mile site with 4,000 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
  – Homeland Security and Cyber Security
AVTA Participants and Goals

• Participants
  – The Advanced Vehicle Testing Activity (AVTA) is part of DOE’s Vehicle Technologies Program (EERE)
  – The Idaho National Laboratory (INL) conducts the light-duty vehicle portion of the AVTA per DOE guidance
  – Many of these testing activities are conducted with ECOtality North American
  – Support also provided to DOE Clean Cities and FEMP

• The AVTA goal - Petroleum reduction and energy security
  – 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 vehicle and infrastructure purchase, deployment and operating decisions
Vehicle / Infrastructure Testing Experience

- 24 million test miles accumulated on 5,500 electric drive vehicles representing 111 models
- Plug-in hybrid electric vehicles: 14 models, 430 PHEVs, 4 million test miles
- Extended Range Electric Vehicles: 1 model, 125 EREVs, 250,000 test miles
- Hybrid electric vehicles: 19 models, 50 HEVs, 6 million test miles
- Micro hybrid (stop/start) vehicles: 3 models, 7 MHVs, 300,000 test miles
- Neighborhood electric vehicles: 24 models, 372 NEVs, 200,000 test miles
- Battery electric vehicles: 47 models, 4,000 BEVs, 12 million test miles
- Urban electric vehicles: 3 models, 460 UEVs, 1 million test miles
- 4,000 EVSE and first hydrogen generation/dispensing station in United States
INL Vehicle Data Management Process

Process Affected by Disclosure Agreements

HICEVs
HEVs
PHEVs
BEVs & EREVs
EVSE & Chargers

File server
SQL Server data warehouse
Report generator

INL Vehicle Data Management System

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

Data quality reports
Parameters range check
Lame data check
Missing/empty parameter check
Conservation of energy check
SOC continuity

Trip Fuel Economy (mpg)

CD/Cs trips
Log. (CD trips)
Log. (CD/Cs trips)

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

0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
### Example: Vehicle/Infrastructure Data Sources

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

**Managing 26 different data models**
Data Security and Protection

- All raw vehicle and EVSE data, and personal information protected by NDAs (Non Disclosure Agreements) or a CRADAs (Cooperative Research And Development Agreements), resulting in:
  - Limitations on how the proprietary data can be distributed, stored, and used
  - No raw data can or will be distributed by INL
  - Raw data, in both electronic and printed formats, cannot be shared with DOE in order to avoid exposure to FOIA

- Vehicle and EVSE data collection would not occur unless the above limitations are strictly adhered by INL
- INL can bin data results into usable information formats for analysis in research partnerships
- No raw data can be shared by INL
EV Project Locations (Largest World-Wide PEV and EVSE Data Collection Activity)

The EV Project at a glance:

- Seattle, WA
- Portland, OR
- Eugene, OR
- Corvallis, OR
- Salem, OR
- San Francisco, CA
- Los Angeles, CA
- San Diego, CA
- Phoenix, AZ
- Tucson, AZ
- Dallas, TX
- Fort Worth, TX
- Houston, TX
- Memphis, TN
- Nashville, TN
- Knoxville, TN
- Chattanooga, TN
EV Project Residential Infrastructure

• Deploy 8,300 battery electric vehicles with data loggers
  – 5,700 Nissan Leaf BEVs
  – 2,600 Chevrolet Volt EREV

• Install 8,300 level 2 residential EVSE with data loggers
EV Project Commercial Infrastructure

• Install ~5,000 level 2 EVSE with data loggers
  – Retail locations
  – Municipal locations
  – Employer locations

• Deploy 200+ Dual Port DC Fast Chargers with data loggers
EV Project – Data Parameters Collected per Charge Event

• Date/Time Stamp
• Unique ID for Charging Event
• Unique ID Identifying the EVSE – may not change
• Connect and Disconnect Times
• Start and End Charge Times
• Maximum 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 – Data Parameters Collected per Start/Stop Event

- Date/Time Stamp
- Vehicle ID
- Event type (key on / key off)
- Odometer
- Battery state of charge
- GPS (longitude and latitude)
- Recorded for each key-on and key-off event
### EV Project – Overview Report

#### Overview

- **Vehicles and charging infrastructure deployed to date (Sept 2011)**
  - 2,990 units installed
  - 177,962 charging events
  - 1,273 AC MWh

- **Vehicles**
  - 2,822 Leafs & Volts enrolled
  - 6.2 million miles

- **Results provided nationally & regionally**

#### Charging Infrastructure

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of EV Project Charging Units Installed To Date</th>
<th>Number of Charging Events Performed</th>
<th>Electrically Consumed (AC MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phoenix, AZ Metropolitan Area</td>
<td>254</td>
<td>14,240</td>
<td>88.85</td>
</tr>
<tr>
<td>Tucson, AZ Metropolitan Area</td>
<td>66</td>
<td>4,414</td>
<td>28.10</td>
</tr>
<tr>
<td>Los Angeles, CA Metropolitan Area</td>
<td>234</td>
<td>14,686</td>
<td>100.06</td>
</tr>
<tr>
<td>San Diego, CA Metropolitan Area</td>
<td>536</td>
<td>41,846</td>
<td>318.48</td>
</tr>
<tr>
<td>San Francisco, CA Metropolitan Area</td>
<td>665</td>
<td>33,442</td>
<td>295.64</td>
</tr>
<tr>
<td>Washington, D.C. Metropolitan Area</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Oregon</td>
<td>328</td>
<td>19,452</td>
<td>132.75</td>
</tr>
<tr>
<td>Chattanooga, TN Metropolitan Area</td>
<td>35</td>
<td>1,366</td>
<td>10.88</td>
</tr>
<tr>
<td>Knoxville, TN Metropolitan Area</td>
<td>73</td>
<td>3,320</td>
<td>24.45</td>
</tr>
<tr>
<td>Memphis, TN Metropolitan Area</td>
<td>13</td>
<td>354</td>
<td>4.06</td>
</tr>
<tr>
<td>Nashville, TN Metropolitan Area</td>
<td>223</td>
<td>9,254</td>
<td>62.07</td>
</tr>
<tr>
<td>Dallas/Ft. Worth, TX Metropolitan Area</td>
<td>10</td>
<td>97</td>
<td>0.41</td>
</tr>
<tr>
<td>Houston, TX Metropolitan Area</td>
<td>8</td>
<td>29</td>
<td>0.10</td>
</tr>
<tr>
<td>Washington State</td>
<td>545</td>
<td>38,606</td>
<td>243.33</td>
</tr>
</tbody>
</table>

**Total**: 2,990 units installed - 177,962 charging events - 1,273 AC MWh

#### Vehciles

<table>
<thead>
<tr>
<th>Region</th>
<th>Nissan Leafs Enrolled to Date</th>
<th>Chevrolet Volts Enrolled to Date</th>
<th>Distance Driven (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phoenix, AZ Metropolitan Area</td>
<td>170</td>
<td>405,926</td>
<td>431,926</td>
</tr>
<tr>
<td>Tucson, AZ Metropolitan Area</td>
<td>57</td>
<td>128,633</td>
<td>128,633</td>
</tr>
<tr>
<td>Los Angeles, CA Metropolitan Area</td>
<td>292</td>
<td>962,152</td>
<td>962,152</td>
</tr>
<tr>
<td>San Diego, CA Metropolitan Area</td>
<td>594</td>
<td>1,305,134</td>
<td>1,305,134</td>
</tr>
<tr>
<td>San Francisco, CA Metropolitan Area</td>
<td>739</td>
<td>1,928,294</td>
<td>1,928,294</td>
</tr>
<tr>
<td>Washington, D.C. Metropolitan Area</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oregon</td>
<td>294</td>
<td>936,452</td>
<td>936,452</td>
</tr>
<tr>
<td>Chattanooga, TN Metropolitan Area</td>
<td>23</td>
<td>42,754</td>
<td>42,754</td>
</tr>
<tr>
<td>Knoxville, TN Metropolitan Area</td>
<td>48</td>
<td>106,405</td>
<td>106,405</td>
</tr>
<tr>
<td>Memphis, TN Metropolitan Area</td>
<td>8</td>
<td>11,910</td>
<td>11,910</td>
</tr>
<tr>
<td>Nashville, TN Metropolitan Area</td>
<td>19</td>
<td>209,630</td>
<td>209,630</td>
</tr>
<tr>
<td>Dallas/Ft. Worth, TX Metropolitan Area</td>
<td>1</td>
<td>5</td>
<td>3,182</td>
</tr>
<tr>
<td>Houston, TX Metropolitan Area</td>
<td>480</td>
<td>1,967,492</td>
<td>1,967,492</td>
</tr>
<tr>
<td>Washington State</td>
<td>2,801</td>
<td>21</td>
<td>6,174,091</td>
</tr>
</tbody>
</table>

**Total**: 2,822 Leafs & Volts enrolled - 6.2 million miles

**Note**: EV Project charging units may be used by vehicles that are not part of the EV Project. Likewise, EV Project vehicles may connect to non-EV Project charging units. Therefore vehicle and charging infrastructure usage shown on this report are not directly comparable.

1. Licensed region includes the Los Angeles, San Diego, and San Francisco metropolitan areas.
2. Washington region includes the Greater Seattle and Olympia metropolitan areas.
3. Vehicle enrollment numbers refer to the EV Project only. Numbers do not reflect total regional or national vehicles sales or production.
EV Project – # EVSE & Vehicles 3rd Quarter

Number of Leafs, Volts & EVSE Reporting Data

- Charging Units Reporting
- Leafs
- Volts

Cities: PHX, Tuscon, LA, San D., San Fran, Oregon, TN Chat, TN Knx, TN Nash, TN Memph, Wash St, TX DFW, TX Houst
EV Project – Nissan Leaf Usage Report

- July - Sept 2011 only
- See following slides
- 1 page nationally
- Plus 1 additional page for each region with more than 10 vehicles
- Subset of 2,394 vehicles as this report requires matching Leaf and charging data
EV Project – Nissan Leaf Usage Report

- Vehicle Usage – 3rd quarter 2011
  - Number of Trips: 536,548
  - Total distance traveled (miles): 3,718,272 mi
  - Ave trip distance: 6.9 mi
  - Ave distance per day when driven: 30.8 mi
  - Ave # trips between charging events: 4.3
  - Ave distance traveled between charging events: 30.1 mi
  - Ave # charging events per day when a vehicle was driven: 1.0
  - Vehicle petroleum used: 0 gallons
EV Project – Nissan Leaf Usage

EV Project Leafs: Average Miles/Trip, Trips/Charge, Charges/Day

- **Ave Miles / Trip**
- **Trips per Charge**
- **Charges / Day**

<table>
<thead>
<tr>
<th>Location</th>
<th>Ave Miles / Trip</th>
<th>Trips per Charge</th>
<th>Charges / Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nation</td>
<td>5.6</td>
<td>3.4</td>
<td>0.5</td>
</tr>
<tr>
<td>PHX</td>
<td>5.8</td>
<td>3.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Tuscon</td>
<td>5.7</td>
<td>3.3</td>
<td>0.5</td>
</tr>
<tr>
<td>LA</td>
<td>5.5</td>
<td>3.4</td>
<td>0.5</td>
</tr>
<tr>
<td>San D.</td>
<td>5.4</td>
<td>3.3</td>
<td>0.5</td>
</tr>
<tr>
<td>San Fran</td>
<td>5.3</td>
<td>3.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Oregon</td>
<td>5.2</td>
<td>3.1</td>
<td>0.6</td>
</tr>
<tr>
<td>TN Chat</td>
<td>6.0</td>
<td>4.0</td>
<td>1.0</td>
</tr>
<tr>
<td>TN Knx</td>
<td>6.5</td>
<td>4.5</td>
<td>1.5</td>
</tr>
<tr>
<td>TN Nash</td>
<td>6.8</td>
<td>5.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Wash St</td>
<td>7.2</td>
<td>5.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>
EV Project – Nissan Leaf Usage

EV Project Leafs: Average Miles Per Day and Miles Per Charge

- Ave Miles per Day
- Ave Miles / Charge

Miles

Nation, PHX, Tuscon, LA, San D., San Fran, Oregon, TN Chat, TN Knx, TN Nash, Wash St
EV Project – Nissan Leaf Usage

Percentage Charging Locations

- Home Charging
- Away Charging
- Unknown

EV Project – Nissan Leaf Usage

National

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

PHX

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

Tucson

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

LA

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

WA

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

KnoxTN

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

SD

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

OR

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

NashTN

Battery State of Charge (SOC) at the Start of Charging Events
EV Project – Nissan Leaf Usage

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

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

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

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

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

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

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

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

NashTN
- Battery State of Charge (SOC) at the End of Charging Events
- Percent of Charging Events
### EV Project – EVSE Infra. Summary Report

- **Residential & Public EVSE usage**
- **Percent EVSE with a vehicle connected by time of day**
- **Percent EVSE with energy transferred by time of day**
- **Range of aggregate electricity demand versus time of day**
- **National and regional information**

#### Charging Unit Usage

<table>
<thead>
<tr>
<th></th>
<th>Residential Level 2</th>
<th>Private Nonresidential Level 2</th>
<th>Publicly Available Level 2</th>
<th>Publicly Available DC Fast</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of charging units¹</td>
<td>2,413</td>
<td>0</td>
<td>170</td>
<td>0</td>
<td>2,583</td>
</tr>
<tr>
<td>Number of charging events²</td>
<td>118,239</td>
<td>0</td>
<td>2,258</td>
<td>0</td>
<td>120,497</td>
</tr>
<tr>
<td>Electricity consumed (AC MWh)</td>
<td>852.17</td>
<td>0.00</td>
<td>14.15</td>
<td>0.00</td>
<td>866.31</td>
</tr>
<tr>
<td>Percent of time with a vehicle connected by vehicle connected by time of day</td>
<td>29%</td>
<td>0%</td>
<td>7%</td>
<td>0%</td>
<td>29%</td>
</tr>
<tr>
<td>Percent of time with a vehicle drawing power from charging unit</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
<td>0%</td>
<td>2%</td>
</tr>
</tbody>
</table>

#### Charging Availability: Range of Percent of Charging Units with a Vehicle Connected versus Time of Day³

![Chart of Charging Availability](image)

- Max percentage of charging units connected across all days
- Min percentage of charging units connected across all days
- Percentage of charging units connected on single calendar day with highest demand

#### Charging Demand: Range of Aggregate Electricity Demand versus Time of Day⁴

![Chart of Charging Demand](image)

- Max electricity demand across all days
- Max electricity demand across all days
- Electricity demand on single calendar day with highest peak

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¹ Includes all charging units that were in use by the end of the reporting period

² A charging event is defined as the period when a vehicle is connected to a charging unit, during which period some power is transferred

³ Considers the connection status of all charging units every minute

⁴ Based on 15 minute rolling average power output from all charging units
EV Project – EVSE Infra. Summary Report

- National data. All 2,413 R2 EVSE. July-Sept 2011
- Power demand range for any time during reporting quarter
- Yellow line is daily profile for the day with quarterly peak demand
- Both graphs in AC MW
- Based on 15 minute rolling average MW demand
EV Project – EVSE Infra. Summary Report

- National data. All 2,413 R2 EVSE. July-Sept 2011
- Range of charging units with a vehicle connected
- Yellow line is for day with peak power demand
- Both graphs percent of charging units
EV Project – EVSE Infra. Summary Report

- National data. All 170 P2 EVSE. July-Sept 2011
- Power demand range for any time during reporting quarter
- Yellow line is daily profile for the day with quarterly peak demand
- Both graphs in AC MW
- Based on 15 minute rolling average MW demand
EV Project – EVSE Infra. Summary Report

- National data. All 170 P2 EVSE. July-Sept 2011
- Range of charging units with a vehicle connected
- Yellow line is for day with peak power demand
- Both graphs percent of charging units
EV Project – EVSE Infra. Summary Report

• National Data – 3rd quarter 2011
  – Ave time vehicle connected R2 WD 9.9 hours
  – Ave time vehicle connected R2 WE 10.0 hours
  – Ave time vehicle drawing power R2 WD 2.0 hours
  – Ave time vehicle drawing power R2 WE 1.8 hours
  – Ave energy per charge event R2 WD 7.5 AC kWh
  – Ave energy per charge event R2 WE 6.5 AC kWh
  – Ave time vehicle connected P2 All 6.8 hours
  – Ave time vehicle drawing power P2 All 1.7 hours
  – Ave energy per charge event P2 All 6.3 AC kWh

• R: residential, P: public, WD: weekday, WE: weekend, All: weekday/weekend combined
EV Project – EVSE Infra. Summary Report

Hours Connected & Drawing Power, & Average AC kWh

HRs Connected per Charge
HRs drawing Power
Ave AC kWh

R2 WD
R2 WE
R2 Overall
P2 WD
P2 WE
P2 Overall
Average Number of Charging Events Started per EVSE per Day

- **WD**
- **WE**
- **Overall**

The chart shows the average number of charging events started per EVSE per day across different sites and regions. Each bar represents a different site or region, with the height indicating the average frequency of charging events.

The sites and regions include:
- All R2
- All P2
- PHX R2
- PHX P2
- Tuscon R2
- LA R2
- SDR2
- SD P2
- SF R2
- OR R2
- OR P2
- TN Chart R2
- TN Knox R2
- TN Nash R2
- Wash ST R2
- Wash ST P2
EV Project – Other Reports to date include:

- Infrastructure reports by each utility service area are produced by overlaying GIS service area data with EV Project data
- Various billing support reports
- Shown - San Diego infrastructure report

1 Includes all charging units that were in use by the end of the reporting period
2 A charging event is defined as the period when a vehicle is connected to a charging unit, during which period some power is transferred
3 Considers the connection status of all charging units every minute
4 Based on 15 minute rolling average power output from all charging units
The number of Leafs that can be charged at 5.538 kWh per day using a percentage of existing electricity generation

<table>
<thead>
<tr>
<th>Total 2009 Generation kWh</th>
<th>Number of Nissan Leafs that can be charged at 5.538 kWh per day (2021.37 kWh per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,950,331,000,000</td>
<td>2009 kWh generation</td>
</tr>
<tr>
<td>39,503,310,000</td>
<td>1% 2009 kWh generation</td>
</tr>
<tr>
<td>79,006,620,000</td>
<td>2% 2009 kWh generation</td>
</tr>
<tr>
<td>118,509,930,000</td>
<td>3% 2009 kWh generation</td>
</tr>
<tr>
<td>158,013,240,000</td>
<td>4% 2009 kWh generation</td>
</tr>
<tr>
<td>197,516,550,000</td>
<td>5% 2009 kWh generation</td>
</tr>
</tbody>
</table>

http://205.254.135.24/cneaf/electricity/epa/epates.html
Chevrolet Volt DOE ARRA Project

- July – Sept 2011
- 110 Chevy Volts
- 208,165 test miles
- All trips, 74.8 mpg, 185 AC Wh/mi
- EV mode, 369 AC Wh/mi no gasoline, 50.3% all miles
- Extended range mode, 37.2 mpg
- Average trip distance 7.4 miles city and 45.6 miles highway driving
Chevrolet Volt DOE ARRA Project

• 110 Volt 3rd quarter report
  – Average charging events per month 17
  – Average # charging events per vehicle day 1.3
  – Average miles per charging event 44 miles
  – Average trips between charging events 3.3
  – Average time connected per event 3.4 hours
  – Average energy per charge event 7.1 AC kWh
  – Average charging energy per vehicle 119 AC kWh month
Chevrolet Volt DOE

Battery State of Charge at End of Charging Prior to Driving

- Number of Events
- Percent State of Charge

Battery State of Charge at End of Drive Prior to Plugging In

- Number of Events
- Percent State of Charge

Percent Distance Traveled By Operating Mode (EV/ERM)

- Percent of Total Dist. Traveled (%)
- Trip Distance (mi)

Time of Day When Driving

- Local Time of Day
- Percent of Total Dist. Traveled (%)

Time of Day When Charging

- Local Time of Day
- Percent of Total Charging Energy (%)

- ERM
- EV
Ford Escape Adv. Research Vehicle

- 21 Ford Escape PHEVs
- 395,000 test miles and 31,000 trips
- All trips, 38 mpg, 101 AC Wh/mi & 66 DC Wh/mi
- Charge Depleting (CD), 53 mpg & 165 DC Wh/mi
- Charge Sustaining (CS), 32 mpg
- Plugging in = 66% increase in overall MPG when comparing CD to CS trips


Since these vehicles are flex-fuel capable, some driving events are conducted with E-85, which may decrease fuel economy results

*The Ford Escape Advanced Research Fleet was designed as a demonstration of customer duty cycles related to plug-in electric vehicles. The vehicles used in this demonstration have not been optimized to provide the maximum potential fuel economy.*
**Ford Escape Adv. Research Vehicle**

- **CD city**, 49 mpg, 166 DC Wh/mi
- **CD highway**, 58 mpg, 164 DC Wh/mi
- **CS city**, 30 mpg
- **CS highway**, 32 mpg
- **Plugging in** = 63% increase in city MPG and 81% increase in highway MPG (compare CD to CS)

### Trips in Charge Depleting (CD) mode

<table>
<thead>
<tr>
<th></th>
<th>City</th>
<th>Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline fuel economy (mpg)</td>
<td>49</td>
<td>58</td>
</tr>
<tr>
<td>DC electrical energy consumption (DC Wh/mi)</td>
<td>166</td>
<td>164</td>
</tr>
<tr>
<td>Percent of miles with internal combustion engine off</td>
<td>38%</td>
<td>12%</td>
</tr>
<tr>
<td>Average trip driving intensity (Wh/mi)</td>
<td>280</td>
<td>306</td>
</tr>
<tr>
<td>Average trip distance (mi)</td>
<td>4</td>
<td>10</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>City</th>
<th>Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline fuel economy (mpg)</td>
<td>43</td>
<td>35</td>
</tr>
<tr>
<td>DC electrical energy consumption (DC Wh/mi)</td>
<td>75</td>
<td>51</td>
</tr>
<tr>
<td>Percent of miles with internal combustion engine off</td>
<td>30%</td>
<td>5%</td>
</tr>
<tr>
<td>Average trip driving intensity (Wh/mi)</td>
<td>279</td>
<td>326</td>
</tr>
<tr>
<td>Average trip distance (mi)</td>
<td>9</td>
<td>40</td>
</tr>
</tbody>
</table>

### Trips in Charge Sustaining (CS) mode

<table>
<thead>
<tr>
<th></th>
<th>City</th>
<th>Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline fuel economy (mpg)</td>
<td>30</td>
<td>32</td>
</tr>
<tr>
<td>Percent of miles with internal combustion engine off</td>
<td>23%</td>
<td>4%</td>
</tr>
<tr>
<td>Average trip driving intensity (Wh/mi)</td>
<td>266</td>
<td>321</td>
</tr>
<tr>
<td>Average trip distance (mi)</td>
<td>4</td>
<td>30</td>
</tr>
</tbody>
</table>

---

**Effect Of Driving Intensity (Wheel Energy) on Fuel Economy This Month**

**Trip Fuel Economy Distribution By Trip Type**

- **City** - 38% CD and 23% CS miles engine off
- **Highway** - 12% CD and 4% CS miles engine off
Ford Escape Advanced Research Vehicle

- 18.9 miles per charge event
- 1.5 trips per charge event
- 3.0 charge events per vehicle day
- 6.1 average hours plugged in per charge
- 1.4 average hours drawing power per charge event
- 1.9 kWh average energy per charge event
- 44 average charge events / vehicle / month when driven
### Chrysler Ram PHEV Project

- **70 Chrysler Ram PHEVs**
- **70,000 test miles and 11,000 trips**
- **All trips, 18 mpg, 115 AC Wh/mi & 69 DC Wh/mi**
- **CD, 23 mpg & 248 DC Wh/mi**
- **CS, 17 mpg**
- **Plugging in = 35% increase in overall MPG when comparing CD to CS trips**

---

#### All Trips Combined

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall gasoline fuel economy (mpg)</td>
<td>16</td>
</tr>
<tr>
<td>Overall AC electrical energy consumption (AC Wh/mi)</td>
<td>162</td>
</tr>
<tr>
<td>Overall DC electrical energy consumption (DC Wh/mi)</td>
<td>94</td>
</tr>
<tr>
<td>Total number of trips</td>
<td>3,443</td>
</tr>
<tr>
<td>Total distance traveled (mi)</td>
<td>13,911</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of trips</td>
<td>1,310</td>
</tr>
<tr>
<td>Percent of trips city</td>
<td>66%</td>
</tr>
<tr>
<td>Percent of trips highway</td>
<td>2%</td>
</tr>
<tr>
<td>Distance traveled (mi)</td>
<td>3,779</td>
</tr>
<tr>
<td>Percent of total distance traveled</td>
<td>27%</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of trips</td>
<td>175</td>
</tr>
<tr>
<td>Percent of trips city</td>
<td>66%</td>
</tr>
<tr>
<td>Percent of trips highway</td>
<td>14%</td>
</tr>
<tr>
<td>Distance traveled CD</td>
<td>1,232</td>
</tr>
<tr>
<td>Distance traveled CS</td>
<td>1,433</td>
</tr>
<tr>
<td>Percent of total distance traveled CD</td>
<td>9%</td>
</tr>
<tr>
<td>Percent of total distance traveled CS</td>
<td>10%</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of trips</td>
<td>1,968</td>
</tr>
<tr>
<td>Percent of trips city</td>
<td>98%</td>
</tr>
<tr>
<td>Percent of trips highway</td>
<td>2%</td>
</tr>
<tr>
<td>Distance traveled (mi)</td>
<td>7,505</td>
</tr>
<tr>
<td>Percent of total distance traveled</td>
<td>53%</td>
</tr>
</tbody>
</table>

---

#### Effect of Driving Aggressiveness on Fuel Economy

<table>
<thead>
<tr>
<th>Driving Aggressiveness</th>
<th>Effect on Fuel Economy (mpg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>8-10</td>
</tr>
<tr>
<td>1</td>
<td>6-8</td>
</tr>
<tr>
<td>2</td>
<td>4-6</td>
</tr>
<tr>
<td>3</td>
<td>0-2</td>
</tr>
</tbody>
</table>

---

**Notes:**
- Vehicles and may not necessarily demonstrate optimized performance.

---
**Chrysler Ram PHEV Pickups**

- 44% of Ram driving and stopped time, gas engine is stopped
- 54.4 miles per charge event
- 8.5 trips per charge event
- 0.64 charge events per vehicle day
- 1.9 average hours per charge event
- 6.3 kWh average energy / charge
- 240 L1 and 1,029 L2 charge events
- 14% at L1 & 86% at L2 total energy
- 29.8 hrs at L1 & 2.3 hrs at L2 to charge from 20% to 100% SOC
ChargePoint America (Coulomb) Project

- 893 EVSE installed (May – August 2011)
- 39,000 charge events
- 237 AC MWh consumed
- 444 Residential, 37% of time a vehicle is connected
- 83 Private commercial, 15% of time a vehicle is connected
- 365 Public, 4% of time a vehicle is connected
- 1 Not specified, 48% of time a vehicle is connected
North American PHEV Demonstration
Fleet Summary Report: Hymotion Prius (V2Green data logger)
Number of vehicles: 184
Reporting Period: Apr 08 - May 11

<table>
<thead>
<tr>
<th>All Trips Combined</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall gasoline fuel economy (mpg)</td>
<td>47</td>
<td>53</td>
</tr>
<tr>
<td>Overall AC electrical energy consumption (AC Wh/mi)</td>
<td>53</td>
<td>38</td>
</tr>
<tr>
<td>Total number of trips</td>
<td>287,310</td>
<td>2,891,319</td>
</tr>
<tr>
<td>Total distance traveled (mi)</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Trips in Charge Depleting (CD) mode</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Gasoline fuel economy (mpg)</td>
<td>53</td>
<td>49</td>
</tr>
<tr>
<td>DC electrical energy consumption (DC Wh/mi)</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>Number of trips</td>
<td>116,236</td>
<td></td>
</tr>
<tr>
<td>Percent of trips city / Highway</td>
<td>67% / 13%</td>
<td></td>
</tr>
<tr>
<td>Distance traveled (mi)</td>
<td>534,226</td>
<td></td>
</tr>
<tr>
<td>Percent of total distance traveled</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Trips in both Charge Depleting and Charge Sustaining (CD/CS) modes</td>
<td>53</td>
<td>49</td>
</tr>
<tr>
<td>Gasoline fuel economy (mpg)</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>DC electrical energy consumption (DC Wh/mi)</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Number of trips</td>
<td>150,320</td>
<td></td>
</tr>
<tr>
<td>Percent of trips city / Highway</td>
<td>77% / 23%</td>
<td></td>
</tr>
<tr>
<td>Distance traveled (mi)</td>
<td>1,019,064</td>
<td></td>
</tr>
<tr>
<td>Percent of total distance traveled</td>
<td>60%</td>
<td></td>
</tr>
<tr>
<td>Trips in Charge Sustaining (CS) mode</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Gasoline fuel economy (mpg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of trips</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent of trips city / Highway</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance traveled (mi)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent of total distance traveled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of trips when the plug-in battery pack was turned off by the vehicle operator</td>
<td>12,479</td>
<td></td>
</tr>
<tr>
<td>Distance traveled with plug-in battery pack turned off by the vehicle operator (mi)</td>
<td>274,084</td>
<td></td>
</tr>
</tbody>
</table>


Hymotion Prius PHEV Conversion
- 3.3 million total test miles
- CD 62 mpg and 142 DC Wh/mi
- CS 43 mpg
- Plugging in = 44% increase in overall MPG when comparing CD to CS trips
- Only 20% miles in CD trips
- 60% miles in CS trips
Hymotion Prius PHEV Conversion

- CD city, 60 mpg, 165 DC Wh/mi
- CD highway, 66 mpg, 109 DC Wh/mi
- CS city, 36 mpg
- CS highway, 46 mpg
- Plugging in = 67% increase in city mpg and 44% increase in highway mpg when comparing CD to CS
- CD trips 37% miles with engine off
- CS trips 30% miles with engine off
Ongoing INL Data Collection Projects

- 20 Lithium PHEV Escape Quantum conversions – same format as Ford Escapes
- Development of vehicle-based battery test-bed mule for testing emerging battery technologies
- Conducting mass impacts on fuel efficiency for HEV, ICEV and BEV technologies
- Developing fast charge study
  - Comparison of Fast versus Level 2 charging impacts on battery life in six-vehicle fleet and laboratory tests
Ongoing INL Data Collection Projects

- Initiated wireless and conductive charging infrastructure testing projects
  - Wireless EVSE energy efficiencies will be benchmarked
  - Cyber security testing of EVSE is being initiated
  - Five conductive Level 2 EVSE recently benchmarked and reports are being prepared
    - EVSE AC W consumption pre, post, and during charge
    - Efficiency during steady state charge
    - Unit specifications and features
Federal Fleet Data Collection Projects

- Five USPS electric long life vehicles (ELLV) conversions track, dynamometer, and fleet testing (with data loggers)
  - Stop & Go Trips ( >5 stops/mile)
    - 467 DC Wh/mi
    - 0.2 mile average trip distance
    - 5.3 mph average speed
    - 32.2 average stops per mile
    - 15% regenerative braking energy recovery
  - All trips 1.43 AC / DC Wh/mi ratio = 668 AC Wh/mi for above Stop & Go Trips
Summary – Based on Early Data

• Leaves: 31 miles per day, 30 miles per charge, 1 charge per vehicle day, 4.3 trips per charge, and 7.5 kWh per charge
• Most residential L2 EV Project charging occurs off-peak
• EV Project vehicles connected 5X’s longer than needed to recharge - opportunities to shift charging times
• San Diego: significant charge-starts occur at the midnight start of super off-peak kWh rates
• EV Project – accumulating ½ million test miles per week
• 1% of 2009 generation would charge 20 million PEVs (U.S. Min/Max average daily demand delta is 44%)
• Today’s grid-connected electric drive technologies result in 35% to 100% reductions in petroleum use
• EV Project plan did not include an earthquake, tsunami, fires, or reductions in economic activity and vehicle sales
• INL needs to collect data before reporting it
Acknowledgement

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

More Information
http://avt.inl.gov