Recent Results from INL’s EV Project Analysis and Advanced Vehicle Testing

GITM meeting
2/11/2015

John Smart
Outline

• Plug-In electric vehicle gasoline tax revenue analysis
• Corridor DC fast charger usage on the West Coast Electric Highway
• Chevy Volt charging system power quality testing
• Chevy Volt on-road cold weather testing
Plug-In Electric Vehicle Gas Tax Revenue Analysis

- Plug-in electric vehicles do a portion or all of their driving using electricity from the grid.
- Drivers are not purchasing gas to drive those miles and are not paying road tax.
- INL electric vehicle miles traveled (eVMT) analysis from over 21,000 privately-owned PEVs enables estimation of lost gas tax revenue:
  - Nissan Leaf, Honda Fit, Ford Focus EV
  - Chevrolet Volt, Ford Fusion Energi, Ford Cmax Energi, Honda Accord PHEV, Toyota Prius Plug-in
  - Information was previously published on VMT and eVMT.
**Annual eVMT by Vehicle Type**

**BEV**

<table>
<thead>
<tr>
<th></th>
<th>Nissan LEAF</th>
<th>Ford Focus Electric</th>
<th>Honda Fit EV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicles</td>
<td>4,039</td>
<td>2,193</td>
<td>645</td>
</tr>
<tr>
<td>eVMT</td>
<td>9,697</td>
<td>9,548</td>
<td>9,680</td>
</tr>
</tbody>
</table>

- **Weighted average annual eVMT per BEV = 9,648**

**PHEV/EREV**

<table>
<thead>
<tr>
<th></th>
<th>Chevorlet Volt</th>
<th>Ford CMax Energi</th>
<th>Ford Fusion Energi</th>
<th>Honda Accord PHEV</th>
<th>Toyota Prius Plug-in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicles</td>
<td>1,867</td>
<td>5,368</td>
<td>5,803</td>
<td>189</td>
<td>1,523</td>
</tr>
<tr>
<td>eVMT</td>
<td>9,112</td>
<td>4,069</td>
<td>4,337</td>
<td>3,336</td>
<td>2,484</td>
</tr>
</tbody>
</table>

- **Weighted average annual eVMT per PHEV = 4,640**
## Fuel Economy of Comparative Gasoline Vehicles

<table>
<thead>
<tr>
<th>PEV Models</th>
<th>Comparative ICE Model</th>
<th>EPA Combined Fuel Economy (MPG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nissan Leaf</td>
<td>2014 Nissan Versa</td>
<td>35</td>
</tr>
<tr>
<td>Chevrolet Volt</td>
<td>2014 Chevrolet Cruze</td>
<td>30</td>
</tr>
<tr>
<td>Ford Focus BEV</td>
<td>2014 Ford Focus</td>
<td>31</td>
</tr>
<tr>
<td>Ford CMax Energi</td>
<td>2014 Ford Fiesta</td>
<td>34</td>
</tr>
<tr>
<td>Ford Fusion Energy</td>
<td>2014 Ford Fusion</td>
<td>28</td>
</tr>
<tr>
<td>Honda Fit EV</td>
<td>2014 Honda Civic HEV</td>
<td>30</td>
</tr>
<tr>
<td>Honda Accord PHEV</td>
<td>2014 Honda Accord</td>
<td>29</td>
</tr>
<tr>
<td>Toyota Prius Plug-in</td>
<td>2014 Toyota Prius</td>
<td>50</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td><strong>33.4</strong></td>
</tr>
</tbody>
</table>
Estimated Equivalent Annual Fuel Tax for PEVs

- **ICE Vehicles**
  - Idaho gasoline fuel tax is $0.25/gal
  - The national average fuel tax is $0.24/gal
  - At 33.4 MPG, average vehicle pays $0.007485 in fuel tax per mile

- **BEVs**
  - Average 9,648 annual eVMT
  - Equivalent BEV fuel tax = \$72.22 annually

- **PHEVs**
  - Average 4,640 annual eVMT
  - Equivalent PHEV fuel tax = \$34.73 annually

To access the full report on the INL website, go to:
avt.inl.gov/pdf/phev/PEVandPHEVeVMTforIAH.pdf

INL/MIS-14-34029
West Coast Electric Highway Corridor DC Fast Charger Usage
West Coast Electric Highway

• WCEH was designed to support long distance EV travel in WA, OR, and CA

• Analysis included 45 AeroVironment and 12 Blink DCFC located in Oregon and Washington

• Using EV Project data, we can look at Leaf charging at these fast chargers
  – 1,589 EV Project Leafs in Oregon and Washington
  – 319 used at least one of the 57 DCFC in the study

• Driving was analyzed based on “outings” – all trips taken between leaving home and returning home
DCFC Usage Frequency

9/1/2012 to 1/1/2014

- Most highly used DCFC were in large cities and along interstate between them (Seattle, Portland)
  - Used 2 to 5 times per day, or more

- Usage tends to decrease as DCFC get farther from I-5
  - Also drops off south of Eugene

- DCFCs along the coast and east of I-5 were used a few times per week
  - This low frequency does not provide high value to DCFC owner
  - But each charge may be highly valued by the Leaf owner!
Median Outing Distance

9/1/2012 to 1/1/2014

- DCFC in cities were used in much shorter outings (usually less than full charge range of Leaf)
- As distance from DCFC to cities increases, outing distance increases
- Many DCFC along I-5 were used 2 to 4 times per day for outings over 150 miles
  - Some >225 miles
  - Regularly being used for outings that require 2,3, or more full charges to complete

Full report is being reviewed for publication
INL/EXT-15-34337
Steady State Power Quality Test Results – 2012 Chevrolet Volt

To access the full report on the INL website, go to:


INL/EXT-15-34055
Description and Key Insights

• Description
  – The steady state charging behavior of a 2012 Chevrolet Volt was tested at many different charge rates
  – Testing measured the efficiency and power quality of the vehicle charging
  – Vehicle charging is considered to be in steady state when the RMS current magnitude is not changing and the voltage source is close to nominal
  – Testing was done for both 120-volt Level 1 and 208-volt Level 2 charging

• Key Insights from Testing
  – Chevrolet Volt charging is most efficient and has the best power quality when charged at the maximum charge rate
  – When reducing the charging of a group of Chevrolet Volts, it is better to charge a subset of the vehicles at the maximum charge rate than to continue to charge all of the vehicles at a reduced charge rate
# Load Characteristics

- **Level 1 – 120 V Test**

<table>
<thead>
<tr>
<th></th>
<th>Min Charge Rate</th>
<th>Max Charge Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge Rate</td>
<td>0.65 kW</td>
<td>1.38 kW</td>
</tr>
<tr>
<td>Current</td>
<td>5.48 A</td>
<td>11.79 A</td>
</tr>
<tr>
<td>Efficiency</td>
<td>84.2%</td>
<td>86.6%</td>
</tr>
<tr>
<td>Power Factor</td>
<td>0.990</td>
<td>0.997</td>
</tr>
<tr>
<td>Current THD</td>
<td>14.41%</td>
<td>7.88%</td>
</tr>
</tbody>
</table>

- **Level 2 – 208 V Test**

<table>
<thead>
<tr>
<th></th>
<th>Min Charge Rate</th>
<th>Max Charge Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge Rate</td>
<td>1.15 kW</td>
<td>3.14 kW</td>
</tr>
<tr>
<td>Current</td>
<td>5.59 A</td>
<td>15.12 A</td>
</tr>
<tr>
<td>Efficiency</td>
<td>82.2%</td>
<td>88.5%</td>
</tr>
<tr>
<td>Power Factor</td>
<td>0.987</td>
<td>0.998</td>
</tr>
<tr>
<td>Current THD</td>
<td>13.73%</td>
<td>6.04%</td>
</tr>
</tbody>
</table>
Efficiency

Efficiency vs Charge Rate (kW):
- L1 - 120 V
- L2 - 208 V

Efficiency vs Current (A):
- L1 - 120 V
- L2 - 208 V
Power Factor

![Graph 1: Power Factor vs Charge Rate (kW)]

![Graph 2: Power Factor vs Current (A)]
Total Harmonic Distortion in Current

Total Harmonic Distortion in Current

Charge Rate (kW)

Current THD

L1 - 120 V
L2 - 208 V

Total Harmonic Distortion in Current

Current (A)

Current THD

L1 - 120 V
L2 - 208 V
Harmonic Component

Level 1 - 120 V

- 5.4 A / 0.7 kW
- 8.4 A / 1 kW
- 11.8 A / 1.4 kW

Level 2 - 208 V

- 5.5 A / 1.2 kW
- 10.7 A / 2.2 kW
- 15.1 A / 3.1 kW
Cold Weather On-road Testing of a 2012 Chevrolet Volt
On-road testing of a 2012 Chevrolet Volt

- Testing was performed during the winter and spring months to determine the impact of cold temperature on driving and charging efficiency
- A single test vehicle was parked and charged overnight in an unsheltered parking stall and driven by a single driver in the morning along a specified route
- Both the vehicle and the charging equipment were instrumented to record energy consumption and other usage parameters during driving and charging
Test Route

- The 16.9 mile route included a mix of rural, city, and highway roads in the Idaho Falls, Idaho area

A typical profile of vehicle speed versus time for the Idaho Falls cold weather test route
Performance Metrics

• Ambient temperatures ranged from -17°F to 70°F during testing

• The following metrics were tracked:
  – Gasoline fuel economy (mpg)
  – Electrical energy consumption (Wh/mi)
  – Electric-only (EV) mode range (mi)
  – Charge depleting (CD) mode range (mi)

• All varied significantly as ambient temperature varied
Vehicle Driving Efficiency – Gasoline Fuel Economy

- As an all-electric capable vehicle, the Volt was able to complete the test route without consuming any gasoline, until the ambient temperature fell to 27°F
- At 27°F, the vehicle’s control system commands the engine to cycle on
- At even lower temperatures, the engine cycled on more frequently and fuel economy dropped further
- At -15°F, test fuel economy was 47 mpg, which approached charge sustaining operation fuel economy
Vehicle Driving Efficiency – Electrical Energy Consumption

- Electrical energy efficiency across all CD tests with cold starts ranged from 246 DC Wh/mi to 452 DC Wh/mi
- This 84% increase in consumption can be attributed to the effects of cold temperature and climate control load
- During the coldest CD test, electrical energy efficiency during this test was 311 DC Wh/mi
- Cold start test consumed more energy than hot starts
EV and CD Mode Range

- The Volt’s full-charge EV range dropped from 42.0 miles at 70°F to 19.7 miles at -15°F, a reduction of 53%.

- EV range fell off fairly linearly in tests averaging 50 to 25°F at a rate of 0.6 miles per deg F.

- CD range diverged from EV range in tests when temperatures were 27°F or less, because engine operation due to cold temperature also slowed the rate of battery depletion.

![EV Mode and CD Mode Ranges vs. Ambient Temperature](image)
Vehicle Charging Efficiency

• Energy consumption during overnight charging ranged from 12.53 to 13.73 AC kWh (10% increase)

• Energy consumption increased with decreasing temperature, but not at a consistent rate

• Additional instrumentation is required to determine the cause of this variation
Vehicle Charging Efficiency (cont.)

- The Volt draws power after charging to heat the battery.
- This post-charge power draw resulted in additional energy consumption of 3.56 AC kWh for the charging event shown.
- Naturally, the energy consumed due to post-charge power draw is a function of how long the vehicle remains plugged in.
- The short power spikes peaked between 1.8 to 2.6 kW and lasted for 10 to 25 minutes.

To access the full report on the INL website, go to: avt.inl.gov/pdf/phev/2012VoltColdWeatherTestReport.pdf