Idaho National Laboratory: AVTA's Grid Connected Vehicle and Infrastructure Testing Activities

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Ketchum Area Energy Advisory Group
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Vehicle / Infrastructure Testing Experience

- **144 million test miles accumulated on 11,700 electric drive vehicles and 17,500 units**
- **EV Project: 8,228 Leafs, Volts and Smarts, 12,363 EVSE and DCFC**
- **Charge Point: 4,253 EVSE reporting 1.5 million charges**
- **PHEVs: 15 models, 434 PHEVs, 4 million test miles**
- **EREVs: 2 model, 156 EREVs, 2.3 million test miles**
- **HEVs: 24 models, 58 HEVs, 6.4 million test miles**
- **Micro hybrid (stop/start) vehicles: 3 models, 7 MHVs, 608,000 test miles**
- **NEVs: 24 models, 372 NEVs, 200,000 test miles**
- **BEVs: 48 models, 2,000 BEVs, 5 million test miles**
- **UEVs: 3 models, 460 UEVs, 1 million test miles**
- **Other testing includes hydrogen ICE vehicle and infrastructure testing**

INL Vehicle/EVSE Data Management Process

Process Driven by Disclosure Agreements

HICEVs

HEVs

PHEVs

BEVs & EREVs

EVSE & DCFC

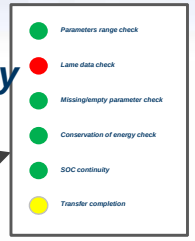
File server

SQL Server data warehouse

Report generator

INL Vehicle Data Management System

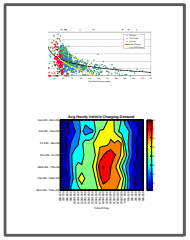
Data quality reports



Individual vehicle reports

Fleet summary Reports - Public

Focused technical analyses and custom reports



Modeling and simulation input

AVTA's Vehicle Data Parameters

- **Different vehicle technologies broadcast multiple data parameters, so staff engineers crack OEM CAN Codes**
- **One PEV model provided 97 parameters at 1 Hz and 65 are used by INL for analysis and report generation. Examples include:**

A/C Power Factor (Calculated)	Onboard charger mode	Charge duration time
AC Input to Charger – Current	Odometer Reading	Cumulative charge time
AC input to Charger – Voltage	Latitude, Longitude	Brake status switch
Accelerator Pedal Position	Vehicle Speed	Planned end SOC for HVB
A/C Compressor Watts	Engine Coolant Temperature	Propulsion system status
Accessory Power Consumption	Engine RPM	Watt hours per charge event
Average Ambient Temperature	Traction battery temperature	Total miles driven in EV mode
Average Filtered Fuel – Liters	Active charging time	Trip distance
12V Battery Voltage	High voltage battery current	Long term mpg (PHEVs)
DC Output of Charger – Current	High voltage battery (HVB) SOC	Short term mpg (PHEVs)
DC Output of Charger – Voltage	High voltage battery voltage	Charge start time
Distance traveled regen energy	J1772 Status	Charge end time
Charge Sustaining Mode Status	Cumulative kWh charge HVB	% EV miles (PHEVs)
Ignition Switch Status	Cumulative kWh discharge HVB	Regen energy recovered

AVTA Testing Methods

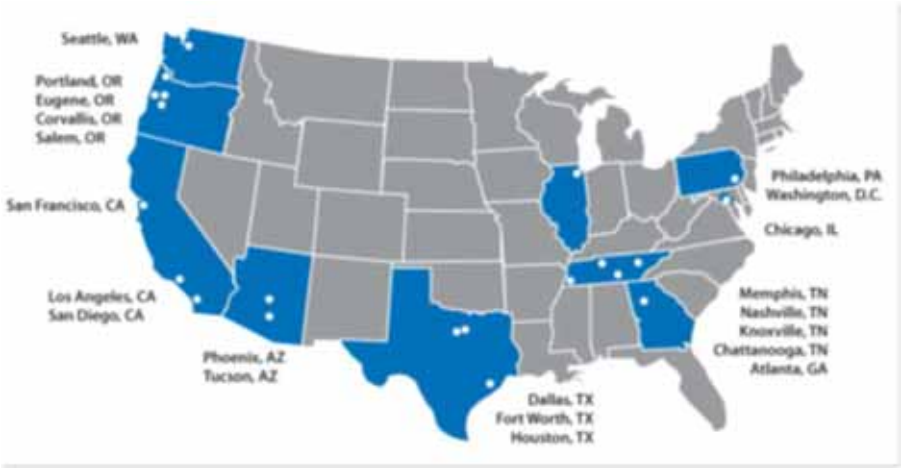
- **Combinations of testing methods are used to characterize each respective vehicle technology. Normally the testing process includes:**
  - **4,000 miles are used to "break-in" a vehicle**
  - **Track testing establishes the coastdown coefficients used for dynamometer testing and includes range tests at various speeds, acceleration, braking, with energy use benchmarked**
  - **Dynamometer testing uses industry standard drive cycles**
  - **Accelerated fleet testing on AVTA-owned vehicles, with up to 195,000 test miles per vehicle within 30 months. Establishes real-world maintenance, fuel use, and lifecycle costs**
  - **Other fleet testing involves partnering with private, commercial or government fleets**
  - **All testing is data logger based**

AVTA Testing Emphasis

- **Testing is vehicle / fueling infrastructure based, the AVTA focuses:**
  - **Energy storage system performance, life, cycle throughput, charge acceptance, auxiliary loads, and safety**
  - **Grid impacts and demands by PEV and charger technologies**
  - **Petroleum use reductions from electric drive vehicle technologies and charging practices**
  - **Charging technologies and profiles at private and public locations and how grid impacts can be lessened via distributed energy storage and economic incentives**
  - **Focus on providing testing based factual results to DOE, industry and regulatory groups, fleets, and the general public**

EV Project

- **EV Project data produced by 8,200 plug-in electric vehicles (PEVs) and 12,300 EVSE and DC Fast Chargers (DCFC)**
  - **Largest ever accumulation of vehicle and charging profile data**
  - **4.2 million charge events, 124 million test miles. At one point, 1 million test miles every 5 days**
  - **Benchmarks Time of Use rate impacts on charging start times**
  - **Benchmarks work place charging profiles**
  - **Benchmarks use profiles for BEVs and EREVs**
  - **Benchmark public charging fee impacts**



EV Project Vehicle Profiles *(4th quarter 2013 data)*

	Leafs	Volts
• Number of vehicles	*3,499*	*1,611*
• Number of Trips	*781,062*	*559,680*
• Distance (million miles)	*5.3*	*4.7*
• Average (Ave) trip distance	*6.7 mi*	*8.2 mi*
• Ave distance per day	*26.7 mi*	*39.8 mi*
• Ave number (#) trips per charge event	*3.6*	*3.3*
• Ave distance between charging events	*23.9 mi*	*27.2 mi*
• Ave # charging events per day	*1.1*	*1.5*

EV Project Vehicle Charging *(4th quarter 2013 data)*

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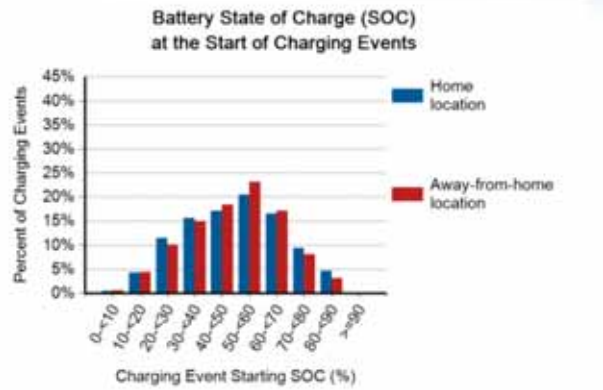
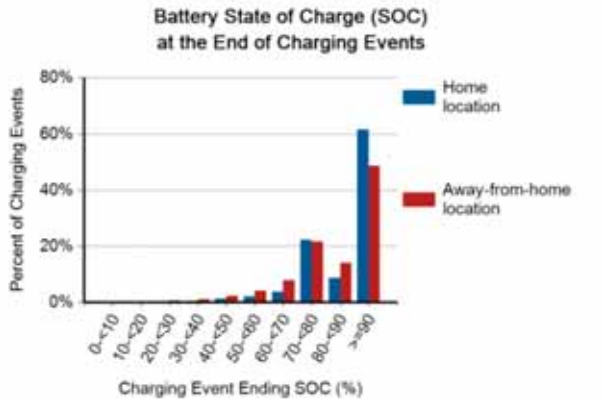
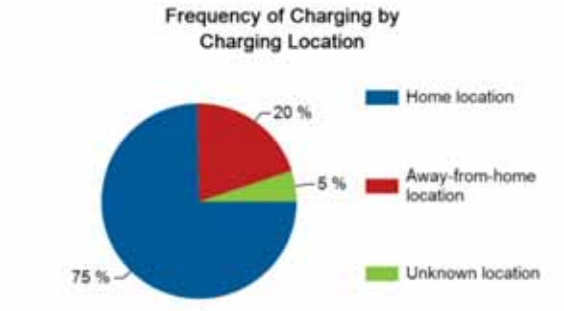
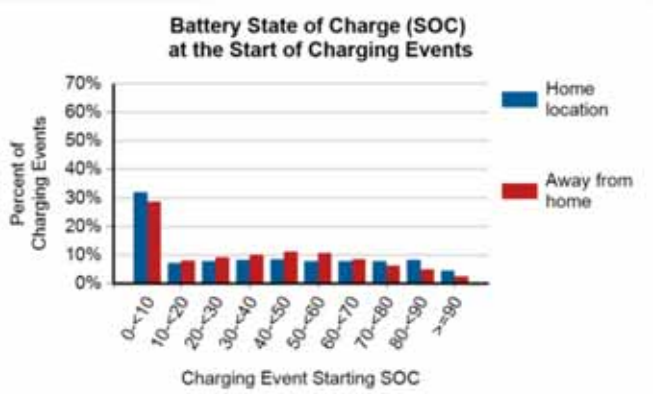
Leafs

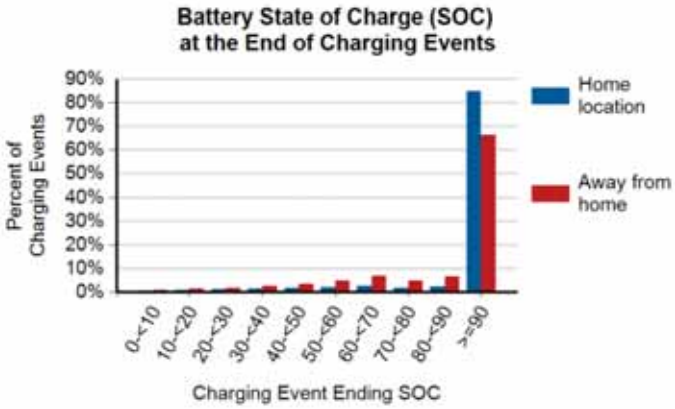


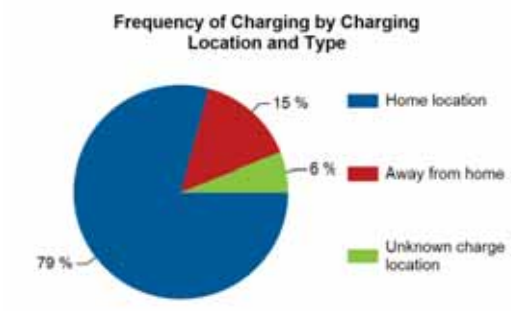




Volts



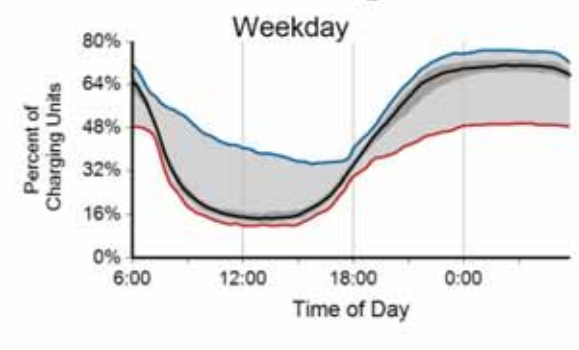




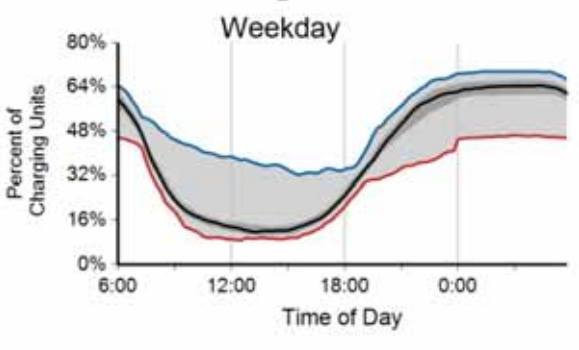
EV Project Residential Level 2 EVSE Connect *(4th quarter 2013)*

- **San Diego and San Francisco, with Residential L2 Time-of-Use (TOU) rates, are similar to other regional EVSE (Electric vehicle supply equipment) connect profiles. Weekday data**

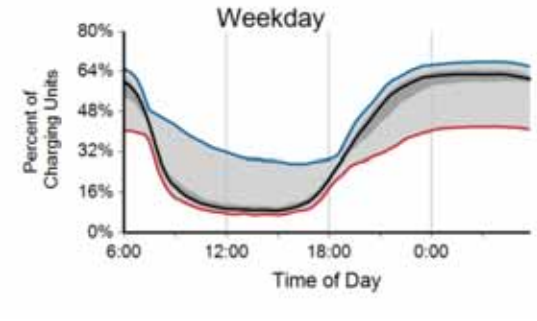
San Diego



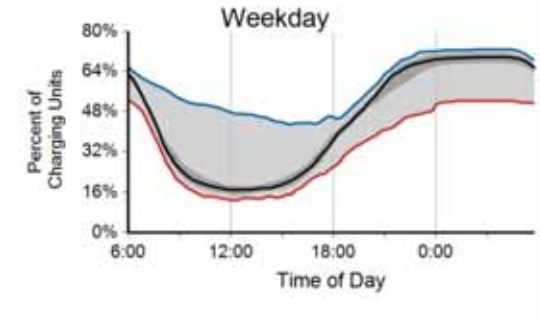
Los Angeles



San Francisco



Washington State

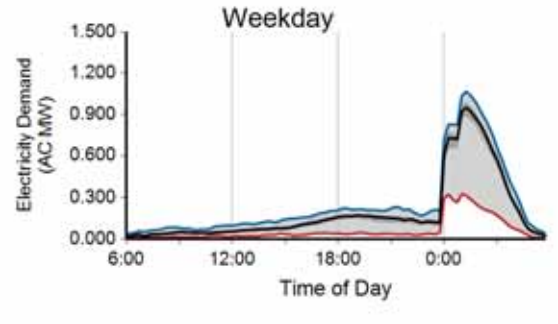


Legend: 92 day reporting quarter. Data is max (blue line), mean (black line) and minimum (red line), for the reporting period. Dark gray shaded is plus and minus 25% quartile.

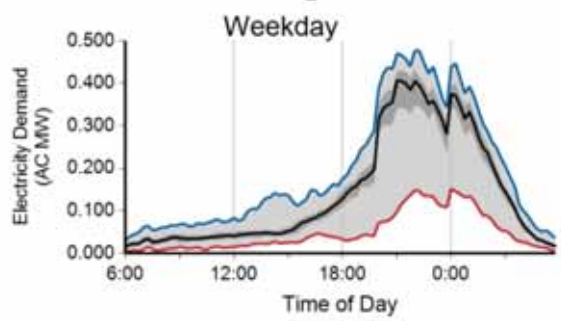
EV Project Residential Level 2 EVSE Connect (4th quarter 2013

- **Time of use rates in San Diego and San Francisco clearly impact when vehicle charging times are set**

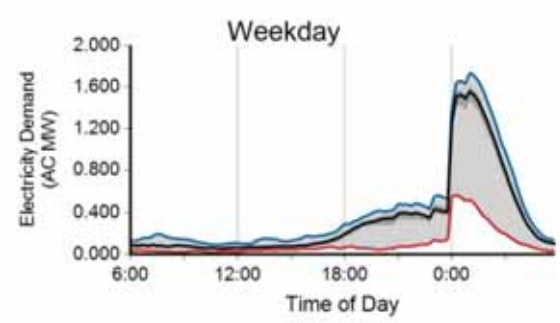
San Diego



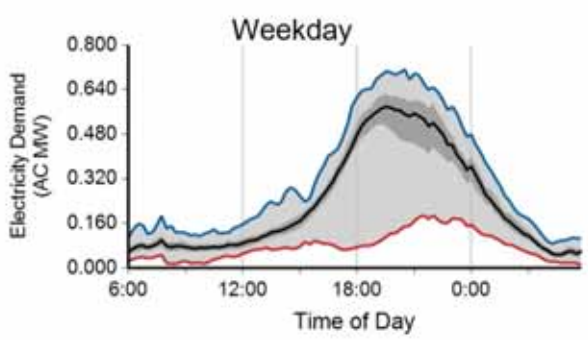
Los Angeles



San Francisco



Washington State



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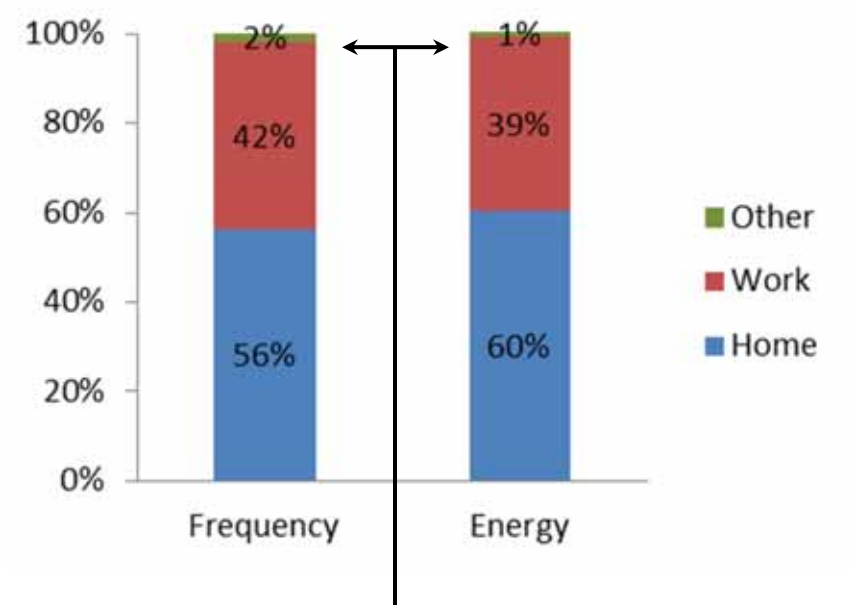
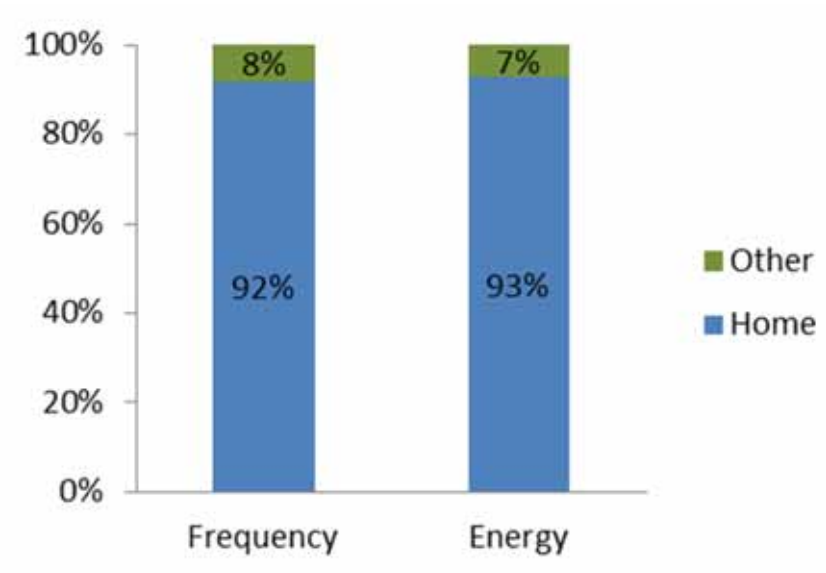
EV Project Charging Location Preference for Nissan Leaf drivers

Group of 707 Nissan Leafs with Access to Workplace Charging 2012 – 2013

Days When Vehicles Were Parked at Work



Days When Vehicles Were Not Parked at Work

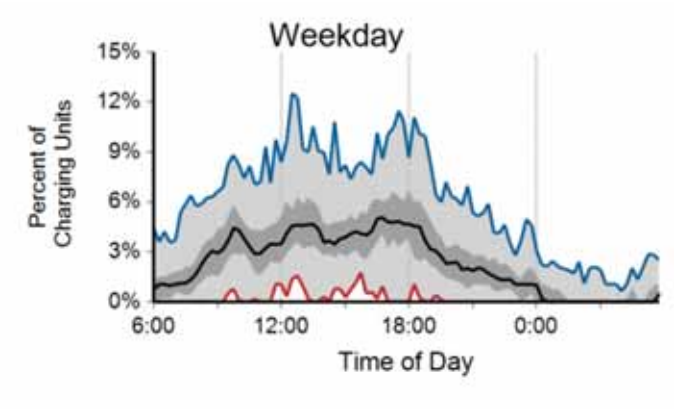


In aggregate, workplace vehicle drivers had little use for public infrastructure on days when they went to work

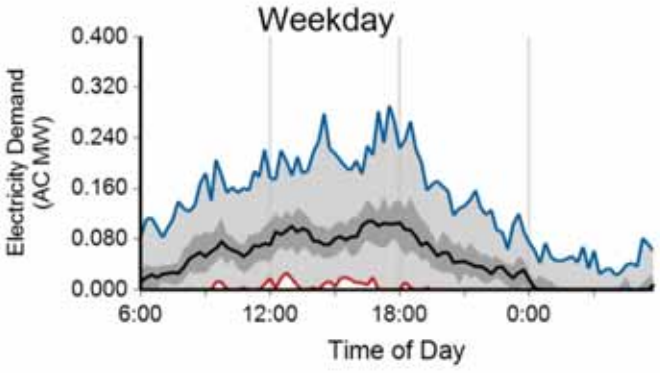
EV Project DC Fast Charger (DCFC) Use

- 4th quarter 2013, DCFC weekday use profiles
- 95 DCFC, 11,704 charge events, & 109 AC MWh

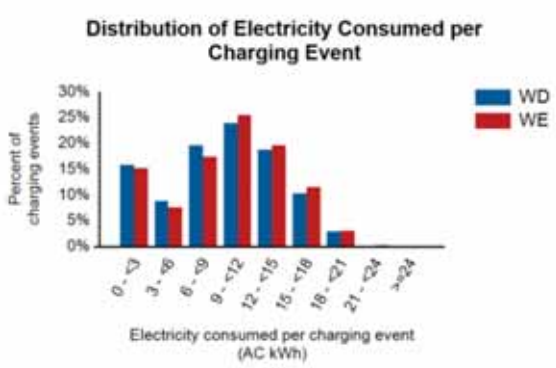
Weekday Connected Profile

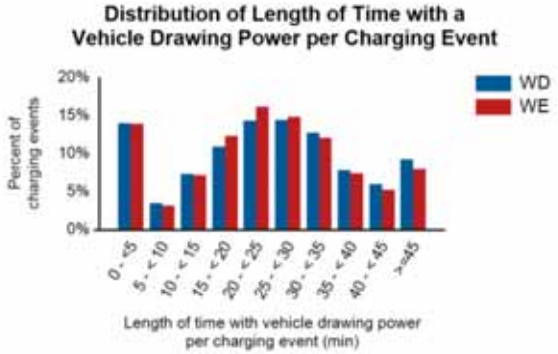


Weekday Demand Profile



- EV Project Leafs 18% charge events and 16% energy used
- 1.3 average charge events per day per DCFC
- 24.6 minutes average time connected
- 24.6 minutes average time drawing energy
- 9.3 kWh average energy consumed per charge





Advanced Vehicle Testing Activity

Idaho National Laboratory

DC Fast Charge Effects on Battery Life and Performance Study – 50,000 Mile Update

Four model year 2012 Nissan Leaf battery electric vehicles were instrumented with data loggers and are being operated over a fixed on-road test cycle. Each vehicle is charged twice daily, with two vehicles charged at AC Level 2 (L2), and two DC fast charged (DCFC) with a 50kW charger. The traction battery packs are removed and tested when the vehicles were new, and at 10,000 mile intervals. Battery tests include constant current discharge capacity, electric vehicle power characterization, and low peak power tests[1]. The testing will continue to at least 50,000 miles at which point the battery testing results will determine if testing continues in additional 10,000 mile increments. This fact sheet summarizes the measured changes in capacity at 10,20,30,40, and 50 thousand miles relative to baseline test results.

	1011 L2	4582 L2	2183 DCFC	2078 DCFC
Baseline (New)	23.31	23.59	23.38	23.24
10,000 Miles	21.75	22.3	21.97	21.93
20,000 Miles	21.53	21.51	21.64	21.07
30,000 Miles	19.99	20.2	19.42	19.33
40,000 Miles	18.10	18.34	17.53	17.37
50,000 Miles	17.51	17.77	16.94	16.92

Table 1 - C_3 Energy capacity[2] (kWh)

	1011 L2	4582 L2	2183 DCFC	2078 DCFC
0-10k Miles (Oct-Jan)	28.6	28.6	32.7	32.5
10-20k Miles (Jan-Mar)	22.7	22.5	27.6	27.3
20-30k Miles (Apr-Jul)	35.7	36.0	39.8	39.5
30-40k Miles (Jul-Oct)	38.2	38.4	40.8	40.6
40-50k Miles (Oct-Mar)	23.2	23.6	27.3	26.8

Table 2 – Average pack temperature during all charging through mileage accumulation interval (°C)

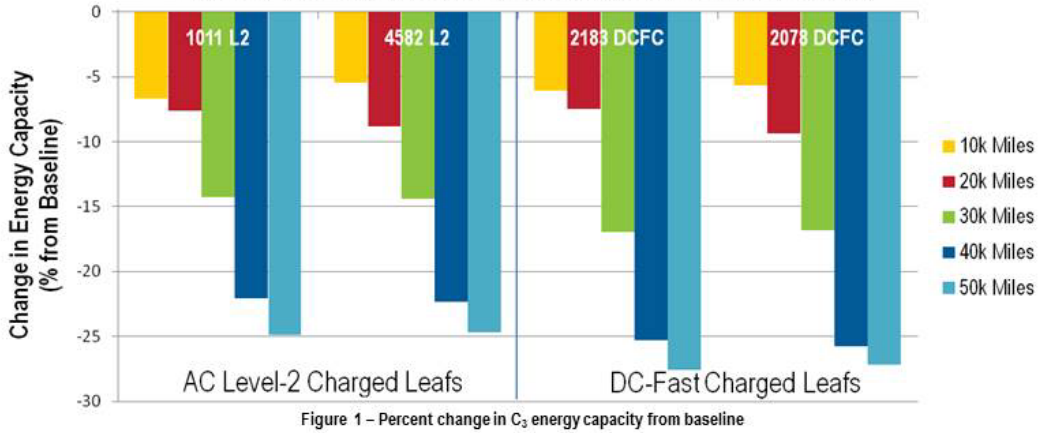


Figure 1 – Percent change in C_3 energy capacity from baseline

1. Capacity and Peak Power tests based on tests from USABC Electric Vehicle Battery Test Procedures Manual Revision 2. Electric Vehicle Power Characterization test adapted from the *Hybrid Pulse Power Characterization Test* from the FreedomCAR Battery Test Manual for Power-Assist Hybrid Electric Vehicles.
2. C_3 capacity reported is the mean value of 3 tests performed sequentially.

Idaho National Laboratory Intertek

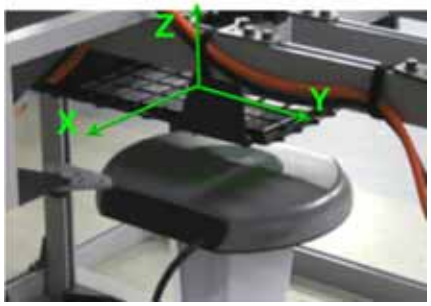
4/15/2014
INL/MIS-13-29877

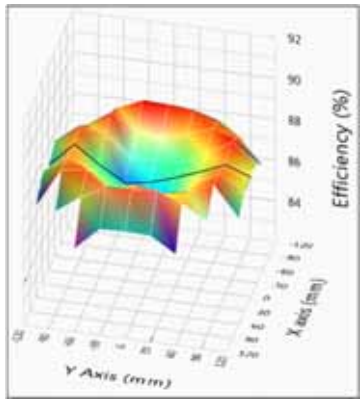
Idaho National Laboratory

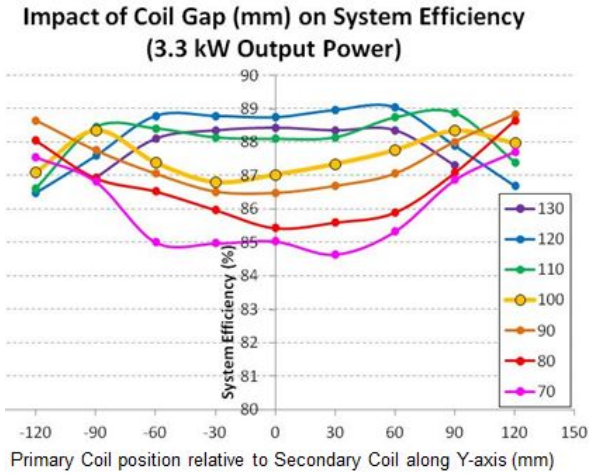
Nissan Leaf – Onroad DCFC & Level 2 Charging Results

Wireless Charging Testing

- **A prototype wireless power transfer (WPT) system has been both lab and in-vehicle tested; a production WPT system will be tested next**
- **Besides the obvious safety issue of misalignment of primary and secondary coils and resulting errant EMF fields and power quality issues, WPT system response to debris is tested, including:**
  - **Paper clips, soda can, aluminum foil, rebar (3/8”) which can be in the floor, coins, steel toe shoe, CD ROM disk, and other objects**







Additional Ongoing Projects

- **50 AVTA owned PHEVs, HEVs, CNGVs, direct injection diesel vehicles and BEVs, representing 13 models, are currently in testing**
- **Several hundred additional PHEV and HEV being added during 2014**
- **In discussions with Seattle to install data loggers in fleet vehicles**
- **Conducting I-5 DCFC study in Oregon and Washington**
- **Level 2 and DCFC testing – efficiency and power quality issues, and cyber security testing for vulnerabilities for EVSEs**
- **New York City based BEV taxi use benchmarking**
- **Federal fleet vehicles instrumented with data loggers**
- **ICE vehicle accessories load Study**
- **SAE interoperability testing**
- **DOD V2G (vehicle-to-grid) and base analysis and support**
- **The AVTA is "neck deep" in demonstrating PEV benefits**
- **INL's data sets of PEV and charging profiles is the largest in the world**

Vehicle Based Thermal Anomalies

- **In 20 years of testing, the AVTA has never experienced a thermal event with an OEM production vehicle while accumulating 144 million test miles on 11,700 vehicles, 6 million charging events and the use of 48,000 MWh for charging PEVs**
- **AVTA's direct experience with unintentional thermal events includes:**
  - **Passenger battery electric bus at the Grand Canyon**
  - **Conversion of a HEV sedan to a PHEV in South Carolina**
  - **Conversion of a HEV SUV to a PHEV in Phoenix**
  - **Preproduction PHEV in Idaho Falls**







Overall Vehicle Safety

PEVs Are Not Unique When it Comes to Vehicle Based Thermal Anomalies in the U.S.

- **According to the NFPA, between 1980 and 1982, there was an average of approximately 447,000 highway vehicle fires per year; between 2009 and 2011, there was an average of approximately 187,500 highway vehicle fires per year**
  (http://avt.inel.gov/pdf/energystorage/FinalReportNFPA.pdf)

Port of Newark, Sandy event
Impact of salt water flooding

NFPA Fire Suppression Project

Figure 72 Off gassing of Battery A3 approximately 22 hours after the conclusion of the test

- ***22 hours after testing – self reignition***
- ***At the conclusion of testing, an OEM's procedure for soaking PEV batteries in a salt bath were followed before shipping the six damaged battery packs. This method requires a minimum of 24 hours of submersion***

NFPA - Best Practices

A small sample of findings are listed below

- **Use standard vehicle firefighting equipment and tactics in accordance with department SOPs/SOGs**
- **All personnel should wear and utilize full PPE and SCBA as required at all vehicle fires**
- **Use water or other standard agents for PEV fires**
- **The use of water does not present an electrical hazard to firefighting personnel**
- **If a PEV battery catches fire, it will require a large, sustained volume of water**
  - **Battery A required 275 to 1,060 gallons**
  - **Battery B required 1,165 to 2,639 gallons**

- **If a Lithium Ion (Li-Ion) HV battery is involved in a fire, there is a possibility that it could reignite after extinguishment. If available, use thermal imaging to monitor the battery. Do not store a vehicle containing a damaged or burned Li-Ion HV battery in or within 50 feet of a structure or other vehicle until the battery can be discharged**

http://avt.inl.gov

Advanced Vehicle Testing Activity

INL Idaho National Laboratory

Chevrolet Volt Vehicle Demonstration

Fleet Summary Report

Reporting period: May 2011 through December 2013

Number of vehicles: 150

Number of vehicle days driven: 61,047

All operation

Overall gasoline fuel economy (mpg)	68.9
Overall AC electrical energy consumption (AC Wh/mi)	167
Average Trip Distance	12.3
Total distance traveled (mi)	3,531,534
Average Ambient Temperature (deg F)	63.0

Electric Vehicle mode operation (EV)

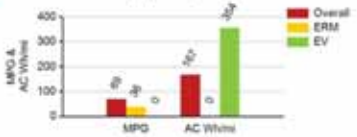
Gasoline fuel economy (mpg)	No Fuel Used
AC electrical energy consumption (AC Wh/mi)	354
Distance traveled (mi)	1,667,196
Percent of total distance traveled	47.2%
Average driving style efficiency (distance weighted)[1]	79%

Extended Range mode operation (ERM)

Gasoline fuel economy (mpg)	36.4
AC electrical energy consumption (AC Wh/mi)	No Elec. Used
Distance traveled (mi)	1,864,338
Percent of total distance traveled	52.8%
Average driving style efficiency (distance weighted)[1]	78%

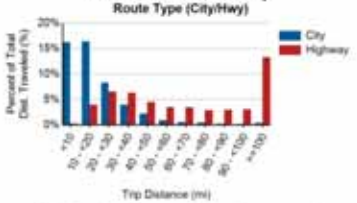
	City[3]	Highway[3]
Percent of miles in EV operation (%)	64.7%	29.5%
Percent Number of trips	86.0%	14.0%
Average trip distance (mi)	7.1	44.3
Average driving style efficiency (distance weighted)[1]	76%	81%

Fuel Economy & Electrical Consumption By Operating Mode

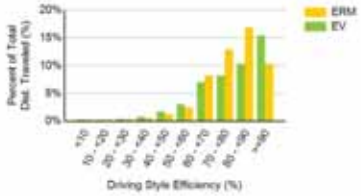


Percent Distance Traveled By Operating Mode (EV/ERM)

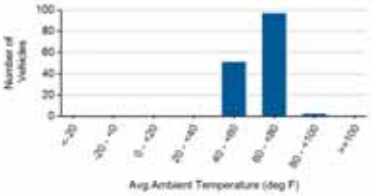
Percent Distance Traveled by Route Type (City/Hwy)



Percent Distance Driven for each Driving Style Efficiency



Distribution of Average Ambient Temperature[2]



1 The energy efficiency over the drive cycle is based on driving style. Driving in a more efficient manner results in a higher percentage for driving style

2 Plot shows average ambient temperature during all driving in the reporting period for each vehicle

3 City / Highway defined per SAE J2841

GM OnStar

Chevrolet Volt Vehicle Demonstration (continued)

Reporting period: May 2011 through December 2013

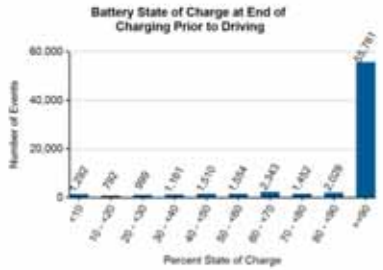
Charging Information

Average number of charging events per vehicle month*	18
Average number of charging events per vehicle day*	1.2
Average distance between charging events (mi)	46
Average number of trips between charging events	3.7
Average time charging per charging event (hr)	3.0
Average energy per charging event (AC kWh)	7.3
Average charging energy per vehicle month* (AC kWh)	129
Total charging energy (AC kWh)	590,696

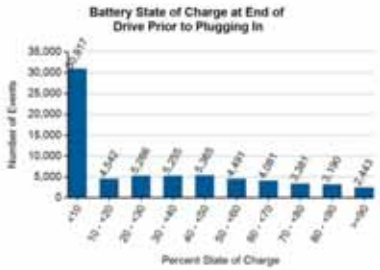
Time of Day When Driving

Time of Day When Charging

Battery State of Charge at End of Charging Prior to Driving



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



* month or day vehicle is driven

GM OnStar

Acronyms

- **AVTA - Advanced Vehicle Technology Activity**
- **BEV - battery EV**
- **CAN - controller area network**
- **DCFC - direct current fast charger**
- **DOD - Department of Defense**
- **DOE - Department of Energy**
- **EREV - extended range EV**
- **EV - electric vehicle**
- **EVSE - electric vehicle supply equipment**
- **HEV - hybrid EV**
- **Hz - Hertz**
- ***ICE - internal combustion engine***
- **INL - Idaho National Laboratory**
- **NEV - neighborhood EV**
- **NFPA - National Fire Protection Association**
- **OEM - original equipment manufacturer**
- **PEV - plug-in electric vehicle**
- **PHEV - plug-in hybrid EV**
- **TOU - time of use**
- **UEV - urban EV**
- **WPT - wireless power transfer**