Advanced Vehicle and Fueling Infrastructure Evaluation

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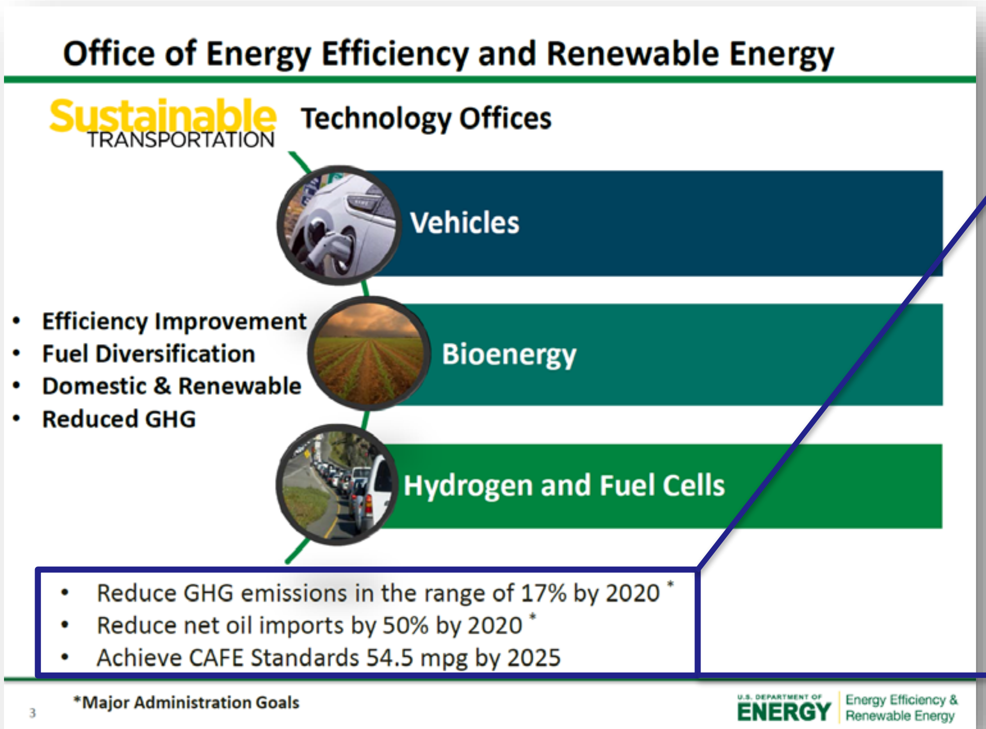
INL/MIS-15-35328

INL Tech-to-Market (T2M) Workshop *May 19-20, 2015*

Idaho National Laboratory

Advanced Transportation Core Customer:
U.S. Department of Energy's Office of Energy Efficiency & Renewable Energy (EERE) Sustainable Transportation

- **EERE is split into three areas:**
  - **Renewable Energy: $370M**
  - **Energy Efficiency: $664M**
  - **Sustainable Transportation: $558M**



Drivers of Technology:

- **Reduce GHG emissions by 15% by 2020**
- **Reduce net oil imports by 50% by 2020**
- **Achieve 54.5 mpg CAFE standard by 2025**

Additional (Larger) Drivers for Advanced Transportation

Regulation at the State Level

California Air Resource Board (CARB) introduced the Zero Emission Vehicle (ZEV) mandate starting in 1990 in order to:

California Environmental Protection Agency
Air Resources Board

1. **Reduce smog**
2. **Reduce greenhouse gas**
3. **Promote cleanest cars**
4. **Provide fuels for cleanest cars (electricity & hydrogen)**

Zero Emission Vehicle (ZEV) mandate drives sales in California

- **7500 ZEVs 2012-2014;   25,000 ZEVs 2015-2017**

10 other states will mandate the same:

- **Connecticut, Maine, Maryland, Massachusetts, New Jersey, New Mexico, New York, Oregon, Rhode Island, and Vermont**

ZEV credits have their own market…

Advanced Transportation: Drivers & Gaps

Drivers

- **High level goals at the federal Level - DOE-EERE:**
  - **Reduce GHG emissions by 15% by 2020**
  - **Reduce net oil imports by 50% by 2020**
  - **Achieve CAFE standards 54.5 mpg by 2025**

- **State level mandates driving sales - CARB:**
  - **Reduce Smog / Reduce greenhouse gas**
  - **Promote Cleanest Cars /Provide Fuels for Cleanest Cars (electricity & hydrogen)**
  - **7500 ZEVs between 2012 - 2014; 25,000 ZEVs between 2015 - 2017**

Gaps

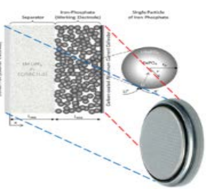
1. **Cost of vehicle is prohibitive to consumer**
2. **Vehicle does not meet the precieved needs of the consumer (range, fueling time, infrastructure accessibility / cost / convenience)**
3. **Infrastructure / fuel is cost-prohibitive or does not exist**

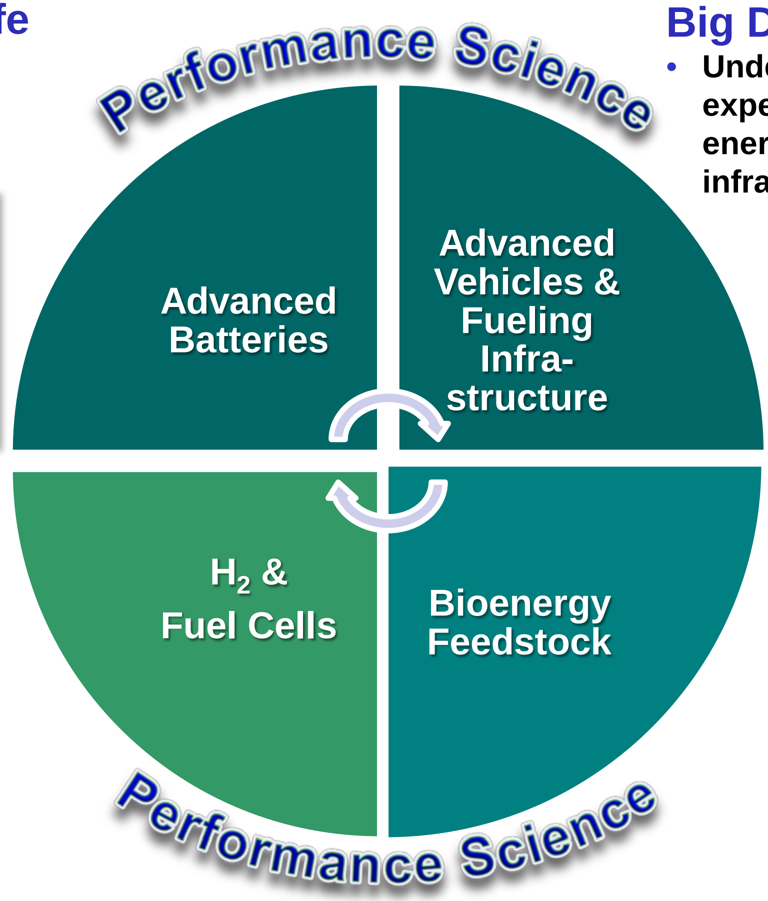
INL’s Advanced Transportation Activities

- Attacking the key challenges of cost, consumer acceptance, and infrastructure to overcome barriers to alternative-energy vehicle adoption

Battery Performance & Life Testing and Diagnostics

- Cost reduction
- Safety and life improvements





Big Data

- Understanding consumer experience with alternative-energy vehicles and infrastructure

Electric Vehicle Charging Infrastructure

- Supporting the development of global standards

Real-time Power and Energy Systems Emulation & Simulation

- Added-value hydrogen production

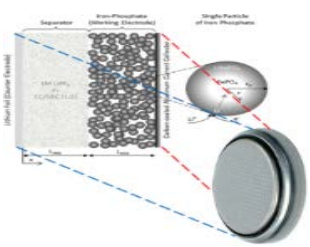
Bioenergy Feedstocks

- Cost reduction
- Quality improvement
- Scale-up and integration

Battery Test Center and Advanced Vehicles

Development of next-generation low cost / reliable batteries

- **Leverage unique INL capabilities in Performance Science**
- **Foundation: Battery Testing Center & Advanced Vehicle Testing data collection**
- **Growth through strong partnerships with:**
  1. **DOE-EERE (USABC)**
  2. **OEMs**
  3. **Battery Developers**
- **Impact: Enabling and accelerating next gen-batteries**



Half-Cell / Coin

Pouch / Cell

Pack

Vehicle

Expansion of Performance Science lifecycle modeling

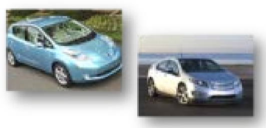
Advanced Vehicles & Fueling Infrastructure

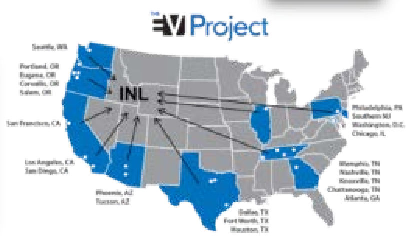
Understand the consumer experience with alternative-energy vehicles

- Leverage unique INL capabilities in Big Data analysis
- Foundation: Advanced Vehicle Testing & EV Infrastructure Laboratory
- Growth: Steward to DOE-EERE, OEMs, SAE & CARB
- Impact: Increasing return on investment for alt-energy infrastructure development and deployment

The EV Project

- 8,000 Nissan Leafs and Chevrolet Volts
- 8,000 level 2 residential EVSE
- 5,000 level 2 commercial EVSE
- Up to 200 DC fast chargers
- 19 US cities





Big Data Analysis

Heat maps of EV charging locations

Global standardization of wireless charging with SAE & OEMs

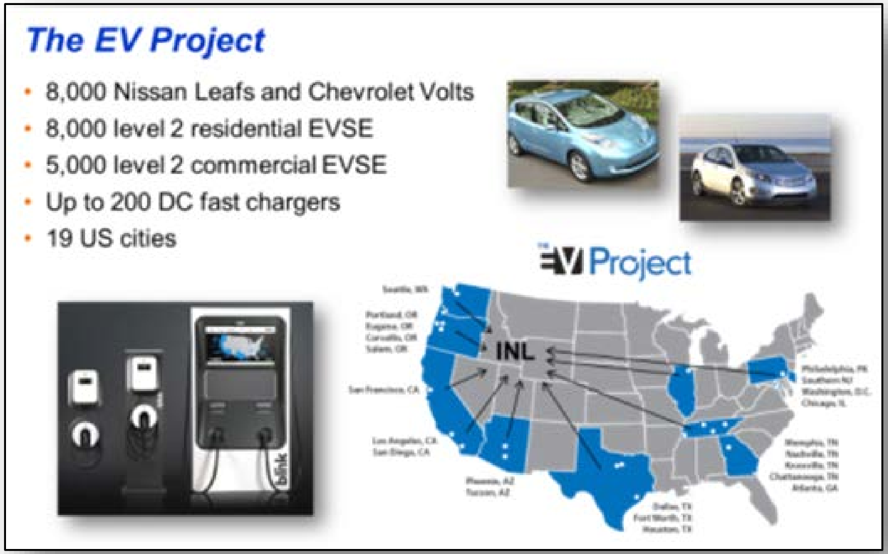
Alt-energy corridor analysis

Advanced Vehicle Testing Experience

- **Since 1994, INL and its partners have benchmarked PEVs in the lab, on the track, and on the road**
  - **INL has collected data from 232 million miles of driving and 44,300 AC MWh of charging from 27,400 electric drive vehicles and 17,000 charging units**

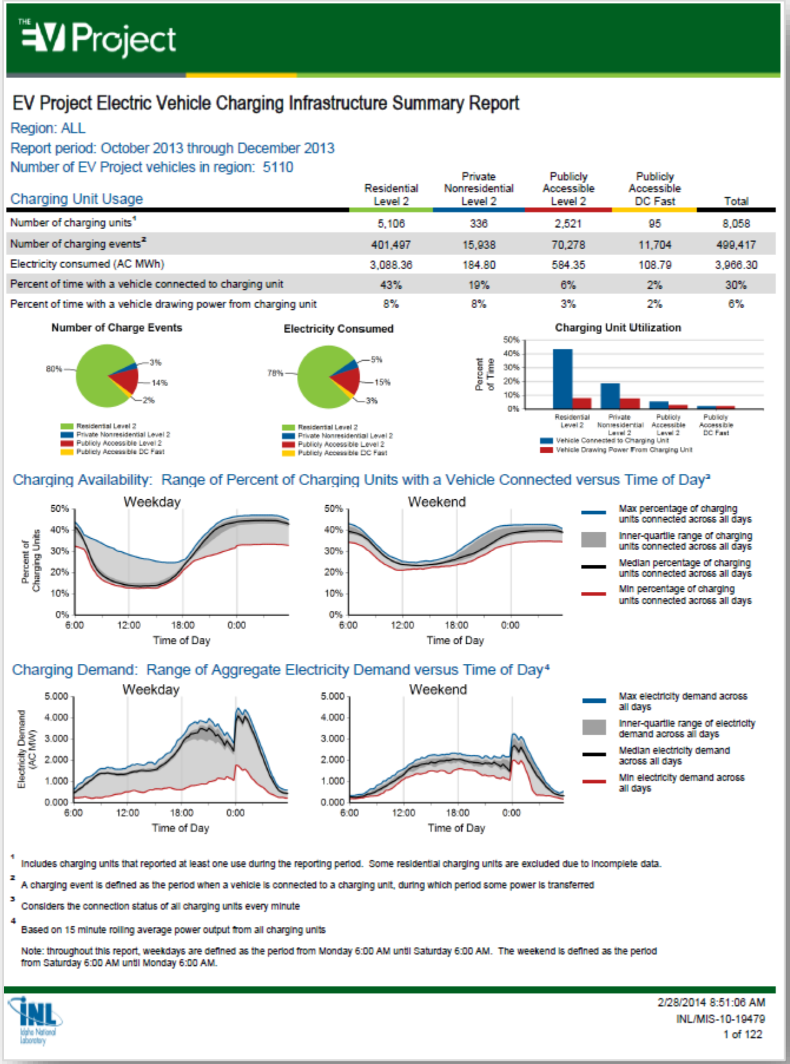
Example: The EV Project

- **8,228 Leafs, Volts and Smart ED's**
  - **124 million test miles**
  - **At one point, 1 million test miles every 5 days**
- **12,363 EVSE and DCFC**
  - **4.2 million charge events**



Driving and Charging Behavior

- Analysis of driving behavior
  - Energy consumption
  - Usage patterns
  - Common parking locations
- Analysis of charging behavior
  - Utilization by time of day, location, and power level
    - Home vs. away from home
    - AC Level 1/2 vs. DC fast charge
  - Aggregate power demand
  - Impact of time-of-use electricity rates


THE EV Project

EV Project Electric Vehicle Charging Infrastructure Summary Report

Region: ALL

Report period: October 2013 through December 2013

Number of EV Project vehicles in region: 5110

Charging Unit Usage	Residential Level 2	Private Nonresidential Level 2	Publicly Accessible Level 2	Publicly Accessible DC Fast	Total
Number of charging units[1]	5,106	336	2,521	95	8,058
Number of charging events[2]	401,497	15,938	70,278	11,704	499,417
Electricity consumed (AC MWh)	3,088.36	184.80	584.35	108.79	3,966.30
Percent of time with a vehicle connected to charging unit	43%	19%	6%	2%	30%
Percent of time with a vehicle drawing power from charging unit	8%	8%	3%	2%	6%

Charging Availability: Range of Percent of Charging Units with a Vehicle Connected versus Time of Day[3]

Charging Demand: Range of Aggregate Electricity Demand versus Time of Day[4]

[1] Includes charging units that reported at least one use during the reporting period. Some residential charging units are excluded due to incomplete data.

[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

Note: throughout this report, weekdays are defined as the period from Monday 6:00 AM until Saturday 6:00 AM. The weekend is defined as the period from Saturday 6:00 AM until Monday 6:00 AM.

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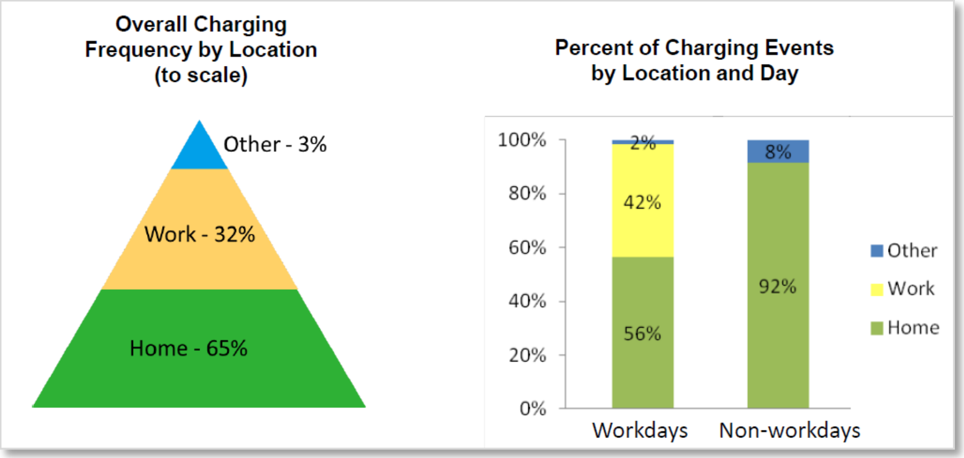
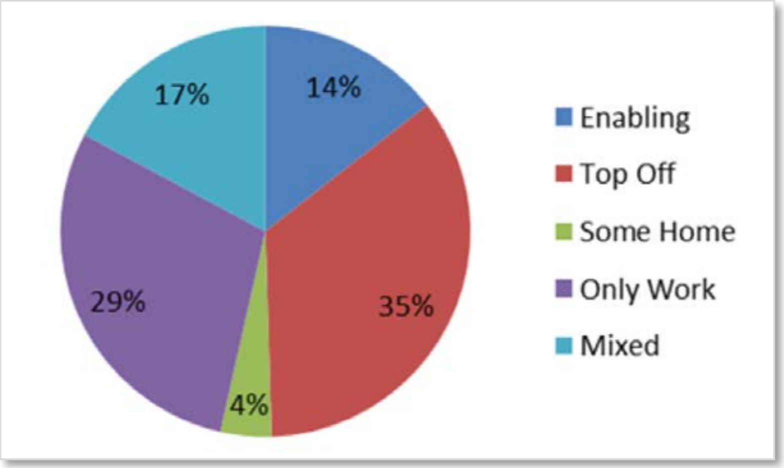
Workplace Charging Impact

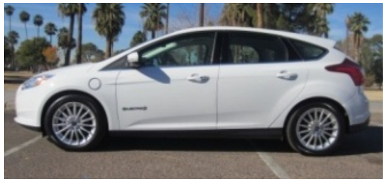
- **Most charging occurs at home and work**
- **Charging at "Other" locations may be critical to some drivers**
- **Workplace charging:**
  - **Enabled 14% of Leaf drivers to complete daily commutes that would have otherwise been impossible**
  - **Provided 15 mile average range increase on those days**
  - **Drivers averaged 12% more EV miles when they charged at work, regardless of need**

Sample of Nissan Leafs in The EV Project whose drivers had access to charging at home and work





BEV, EREV, HEV, PHEV…



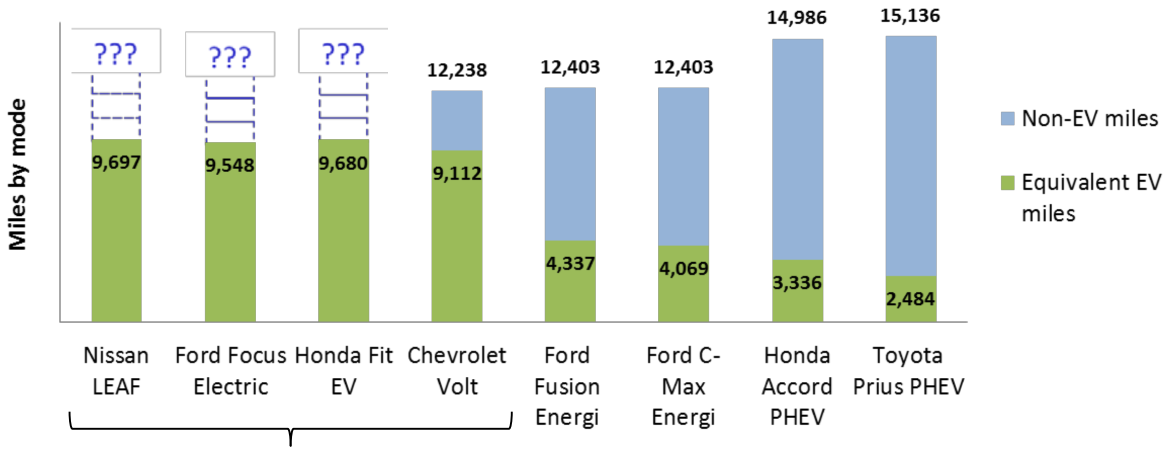
BEV (Battery Electric Vehicle):
Pure electric (no engine), charged by plugging in; typically with 75 - 100 mile electric range
Full ZEV

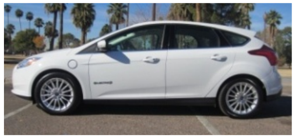
EREV (Extend Range Electric Vehicle):
Pure electric for 30 - 40 miles, then engine turns on for extended range
Partial ZEV… but is it?

HEV (Hybrid Electric Vehicle): **Engine and battery power the wheels together. The battery is charged by the engine and regenerative braking**
PHEV (Plug-in Hybrid Electric Vehicle): **Similar architecture as HEV but battery can also be charged by plugging in; minimal all-electric range (5 - 20 miles)**
Both Partial ZEV

EV Miles Traveled (eVMT) Analysis Results

	BEV			EREV	PHEV				
	Nissan LEAF	Ford Focus Electric	Honda Fit EV	Chevrolet Volt	Ford Fusion Energi	Ford C-Max Energi	Honda Accord PHEV	Toyota Prius PHEV	Total
Number of Vehicles	4,039	2,193	645	1,867	5,803	5,368	189	1,523	21,627
Total Vehicle Miles Traveled *VMT* (miles)	28,520,792	10,043,000	4,912,920	20,950,967	33,098,000	39,376,000	1,794,494	19,772,530	158,468,703
Total Calculated Electric Vehicle Miles Traveled *eVMT* (miles)	28,520,792	10,043,000	4,912,920	15,599,508	11,572,000	12,918,000	399,412	3,224,981	87,190,613
Percent of EV-equivalent miles	100%	100%	100%	74%	35%	33%	22%	16%	
estimated Annual VMT	9,697	9,548	9,680	12,238	12,403	12,403	14,986	15,136	
estimated Annual eVMT	9,697	9,548	9,680	9,112	4,337	4,069	3,336	2,484	



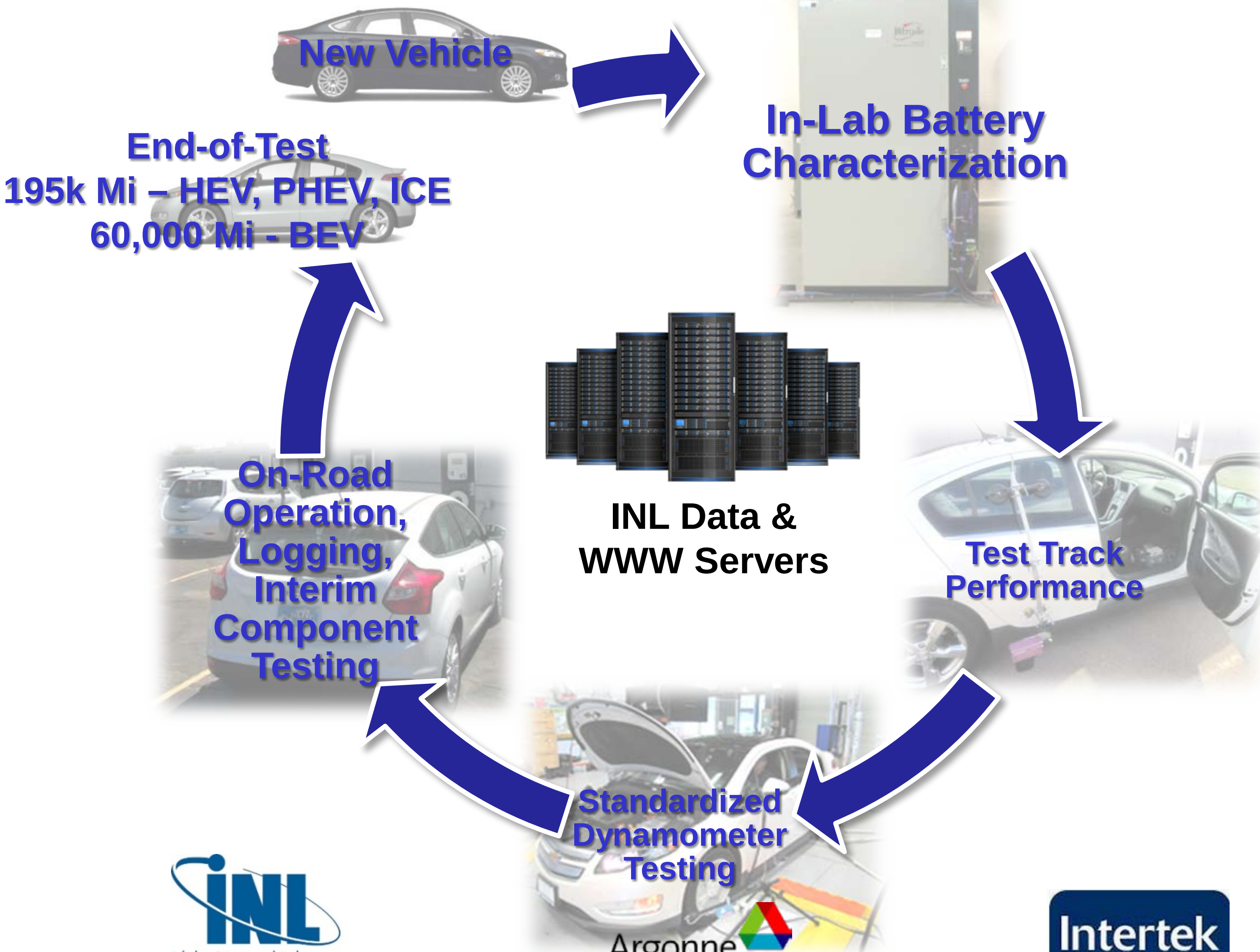





- EREV shows comparable eVMT as BEV
- Total VMT in households with BEV is unknown

Advanced Vehicle Testing Activity: On-road and Laboratory Testing and Evaluation

Advanced Vehicle Testing Process



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Intertek

High-mileage Fleet Evaluation Results

Information and results published to AVTA website

- Baseline performance testing
  - Specifications
  - Acceleration / braking
  - Test track energy consumption
- Battery test results
  - Capacity
  - Power capability
- Fleet fuel economy relative to use and conditions
  - Operation over vehicle life
- Operating costs
- Maintenance history

Advanced Vehicle Testing Activity

Idaho National Laboratory

Plug-In Hybrid Electric Vehicle Operation Data Summary for 2013 Chevrolet Volt VIN 1078

Reporting Period: November 2012 through September 2014

All Trips[1]

Overall gasoline fuel economy (mpg)[5]	41
Overall DC electrical energy consumption (DC Wh/mi)	59
Total distance driven (mi)	45,238
Average trip distance (mi)	7
Percent of miles city | highway	63% | 37%
Average ambient temperature (deg F)	94.9
Percent of miles driven with air conditioning selected	96%

EV Trips[2]

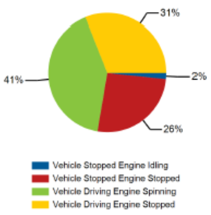
Overall gasoline fuel economy (mpg)[5]	N/A
Overall DC electrical energy consumption (DC Wh/mi)	295
Total distance driven (mi)	7,348
Average trip distance (mi)	5.0
Percent of miles city | highway	74% | 26%
Average ambient temperature (deg F)	82.0
Percent of miles driven with air conditioning selected	94%
Percent of total distance traveled	16%

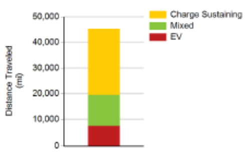
Mixed-Mode Trips[3]

Overall gasoline fuel economy (mpg)[5]	39
Overall DC electrical energy consumption (DC Wh/mi)	73
Total distance driven (mi)	12,135
Average trip distance (mi)	5.7
Percent of miles city | highway	62% | 38%
Average ambient temperature (deg F)	96.9
Percent of miles driven with air conditioning selected	96%
Percent of total distance traveled	27%

Charge Sustaining Trips[4]

Overall gasoline fuel economy (mpg)[5]	32
Overall DC electrical energy consumption (DC Wh/mi)	-15
Total distance driven (mi)	25,754
Average trip distance (mi)	8.7
Percent of miles city | highway	60% | 40%
Average ambient temperature (deg F)	96.9
Percent of miles driven with air conditioning selected	96%
Percent of total distance traveled	57%





1. Calculated from on-board electronic data logged over 45,238 miles, which may be a subset of total lifetime miles driven.
2. Trips where the vehicle was propelled by battery energy only, using no gasoline.
3. Trips where gasoline was consumed by the engine, and net electrical energy was consumed from the battery to propel the vehicle.
4. Trips where gasoline was consumed by the engine to propel the vehicle, while the net electrical energy consumed from the battery was less than 1% of the gasoline energy consumed.
5. Gasoline consumption calculated using Mass Air Flow and Commanded or Measured Air-Fuel Ratio read from OBD2 messages assuming AFR_{stoich} = 14.7 and $\rho_{gasoline}$ = 2819 g/gal.

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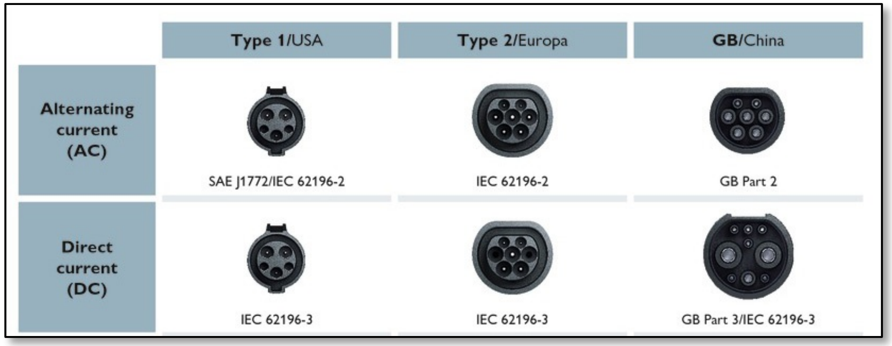
http://avt.inel.gov/phev.shtml

Vehicle Charge Connection International Standards

- **Plug-In Vehicles can be charged at different voltages**
- **Lack of plug commonality limits consumer acceptance & marketplace penetration**

AC Level 1 (120V)
Nissan Leaf: 10-12 hrs

AC Level 2 (240V)
Nissan Leaf: 4-6 hrs



	Type 1/USA	Type 2/Europa	GB/China
Alternating current (AC)	SAE J1772/IEC 62196-2	IEC 62196-2	GB Part 2
Direct current (DC)	IEC 62196-3	IEC 62196-3	GB Part 3/IEC 62196-3

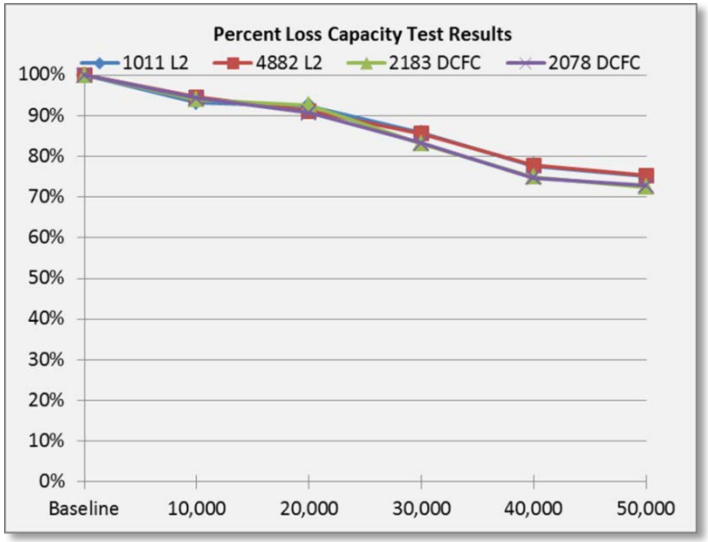
DC Fast Charge (480V)
Nissan Leaf: 80% ~20 mins

	System A CHAdeMO (Japan)	System B CATARC (PRC)	System C COMBO1 (US)	COMBO2
Connector				
Vehicle Inlet				
Communication Protocol	CAN		PLC	

DC Fast Charging Impact Study on 2012 Leafs

After 50,000 miles:

- **NO appreciable difference in capacity loss (~2%) between AC Level 2 and DC Fast Charged packs**



- **All Leafs were the same color – avoid unequal solar loading**
- **Leafs' climate control is set at 72ºF year round**

http://avt.inel.gov/pdf/energystorage/DCFC_Study_FactSheet_50k.pdf

Advance Sustainable Transportation Summary

- **With stretch targets to reduce green-house gas emission, improve CAFE mileages and decrease dependency on foreign oil, alternative-energy vehicles (electric, biofuel, hydrogen) will be continue to be developed regardless of the commodity price of oil**

- **Gaps towards achieving these targets are primarily around the cost of the alt-energy vehicle, its corresponding infrastructure / fuel and customer education**

- **INL is attacking these gaps across our Advanced Transportation activities**
  - **Reduction of battery costs**
  - **Consumer education with vehicles and fueling infrastructure**
  - **Fueling/charging infrastructure analysis and modeling**
  - **Fuel cost reduction of hydrogen / bio-fuels**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