Electric Drive Vehicle and Charging Infrastructure Research at Idaho National Laboratory

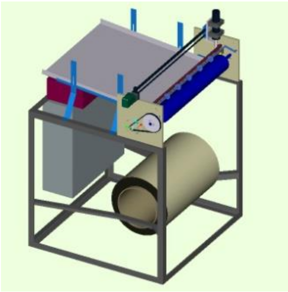
John Smart

University of Washington Civil & Env. Engineering Department
May 19-20, 2015

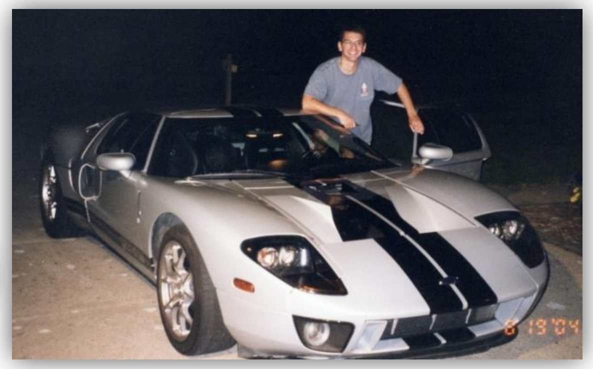
INL/MIS-15-35583

Personal Background

- BSME from Brigham Young University, 2001
- Internships and senior design project during undergraduate program



- Ford Motor Company 2001 – 2007
  - Product design engineer in Powertrain Product Development



- Idaho National Laboratory 2007 – present
  - Group leader, Advanced Vehicles and Fueling Infrastructure research group

Idaho National Laboratory

- 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
  - Renewables and Hybrid Energy Systems
  - Advanced Vehicles, Batteries, Fuels, and Infrastructure
  - Unmanned Aerial Systems and Autonomous Vehicles
  - Cyber Security

Primer on Electric Drive Vehicles

Transportation Oil Dependency

Areas of concern

- Energy security
  - Insufficient domestic supply of easily obtainable oil forces us to rely on imports

www.kotc.com.kw/fleetlist.html

- Global climate change
  - Tailpipe and smoke stack green house gas emissions

www.greentechmedia.com/articles/read/epa-grants-california-emissions-waiver

- Economic stability
  - Unbalanced supply and demand affect all levels of the economy (global, national, personal)

Electric Drive Vehicles as a Solution to Oil Dependency

Advantages of Plug-in Electric Vehicles

- Displace petroleum consumption with electricity
- Enable ***alternatives***
  - Use domestically generated electricity from a variety of sources
  - Use existing infrastructure
  - Leverage nuclear and renewable energy sources (wind, solar, hydro, geothermal)

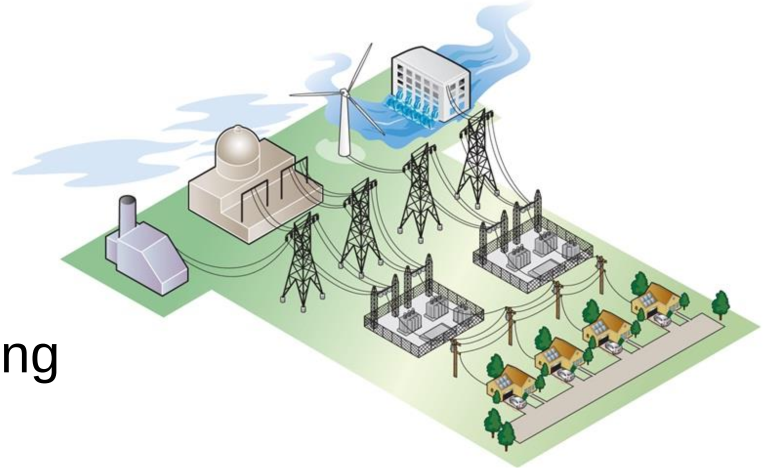
Pre-production image of Chevrolet Spark with Clipper Creek level 2 charging unit from http://www.chevrolet.com/spark-ev-electric-vehicle.html

Electric Drive Vehicles as a Solution to Oil Dependency

Challenges with Plug-in Electric Vehicles

- Complex ,or at least new, designs affecting:
  - Product development
  - Service
  - Procedures for first responders
- Current technology limitations (batteries!)
- Some infrastructure required
  - Charging stations (short term)
  - Communication between vehicles and electric grid (mid term)
  - Additional electricity generation/transmission/distribution (long term)
- Consumer acceptance

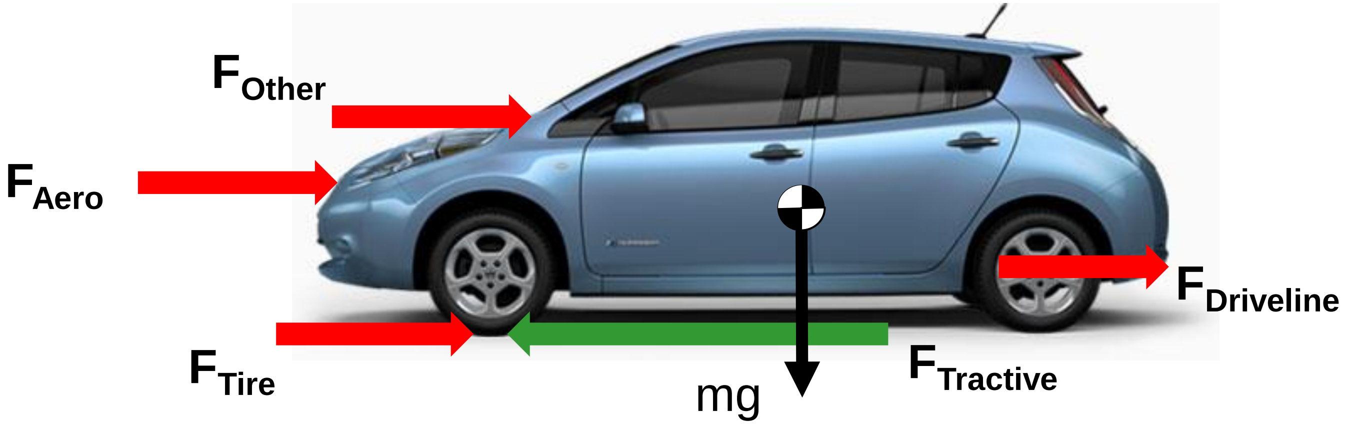
From Danish newspaper Ekstra Bladet, Oct 24, 2009
http://ekstrabladet.dk/biler/bil_nyheder/article1243890.ece



sce-smartgrid.com/content/
edison-internationals-smart-grid-vision

Underlying Physics Principles

- Conservation of energy – it has to come from somewhere
- How much energy does it take to get from point A to point B?



<u>Find the power (P) required to maintain a speed of V</u>

$F_{inertial\ accel} = m_{vehicle} * a_{vehicle}$

$F_{aero} = ½\ C_D\ A_{frontal}\ \rho_{air}\ (V_{vehicle})^2$

$F_{tire\ rolling\ resistance} = C_{RR}\ m_{vehicle}\ g$

$F_{tractive} = F_{inertial\ accel} + F_{aero} + F_{driveline} + \ldots + F_{other}$

$P_{wheel} = F_{tractive} * V_{vehicle}$

<u>Find energy required to get from point A to point B</u>

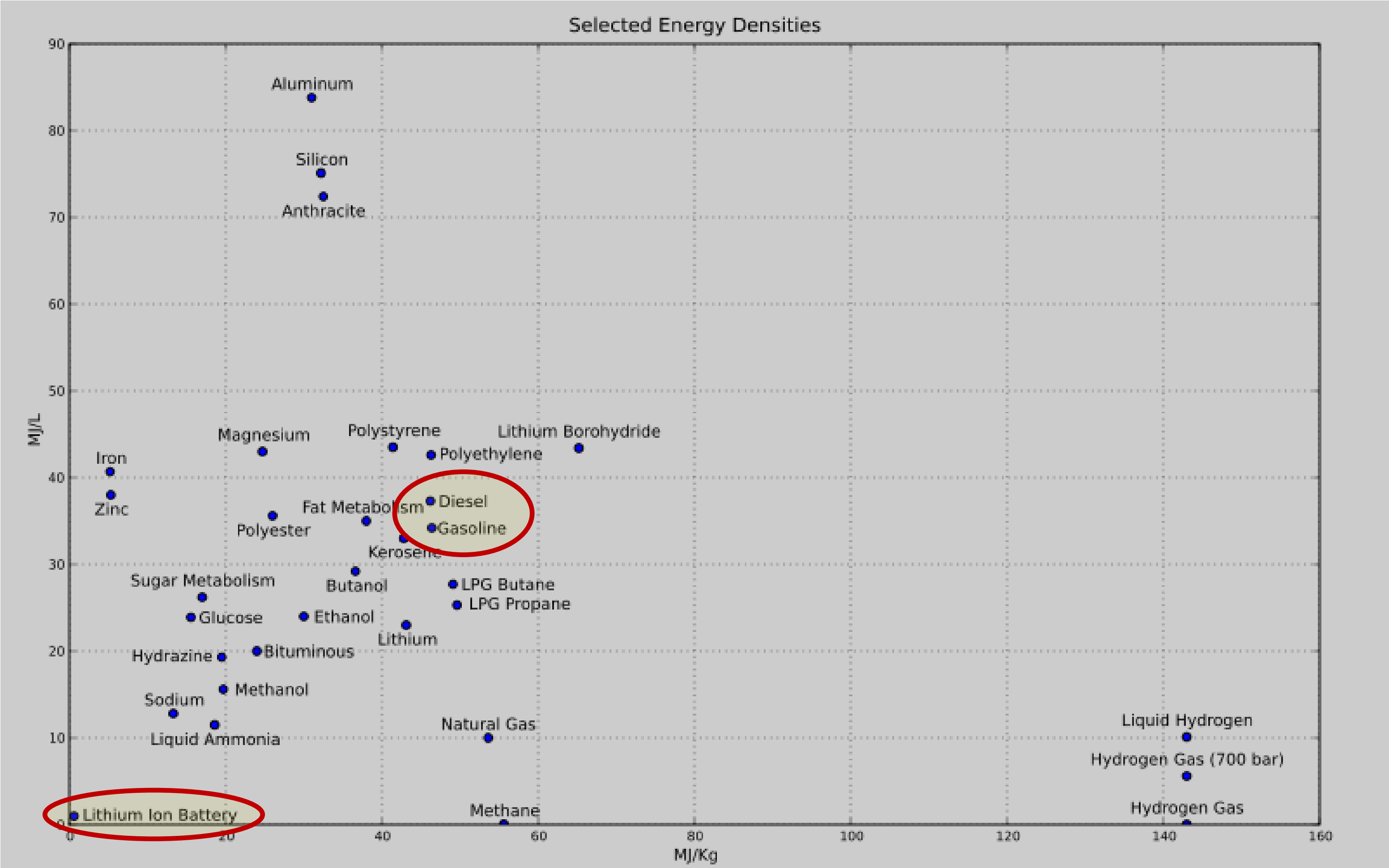
$$E_{wheel} = \int_a^b P_{wheel}\, dt$$

*** Assume Rotational Inertias are negligible**

Comparison of Energy Density of Fuels

- Onboard energy storage is the constraint

Volumetric energy density (MJ / Liter)

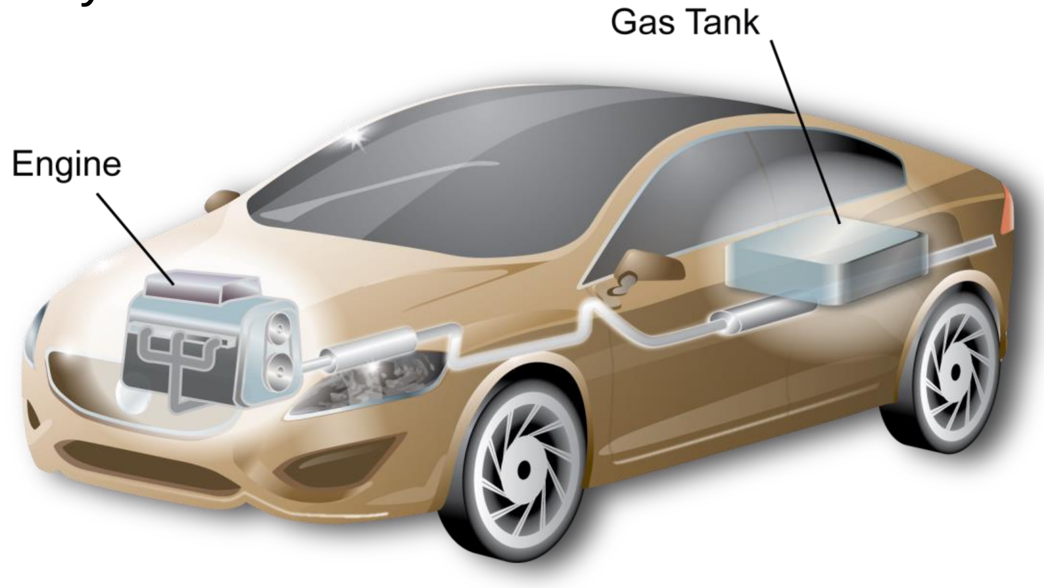


Gravimetric energy density (MJ / kg)

http://en.wikipedia.org/wiki/File:Energy_density.svg accessed July 2010

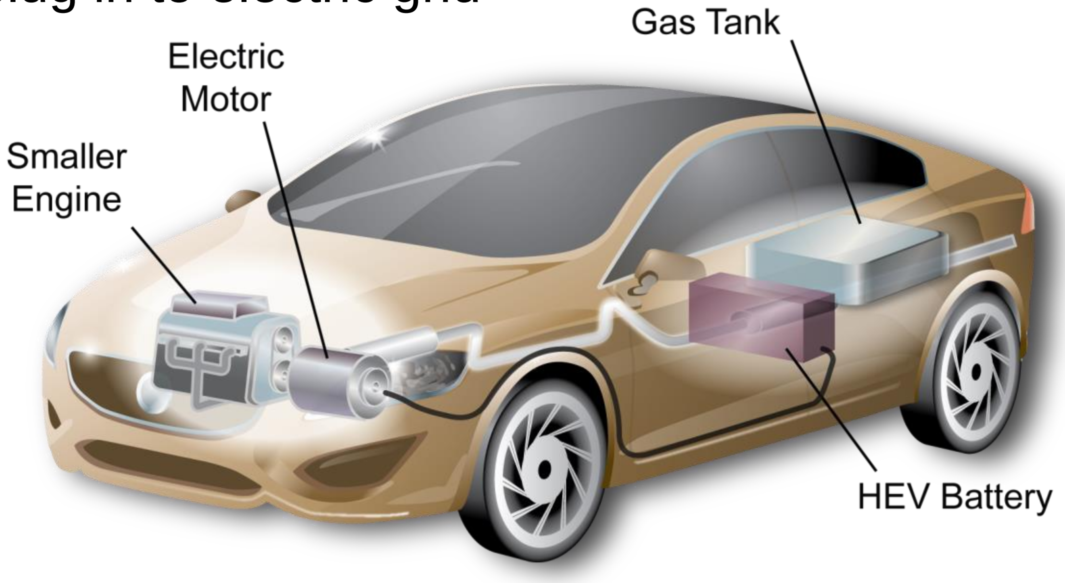
Comparison of Vehicle Technology

Conventional vehicle with internal combustion engine (ICE) only



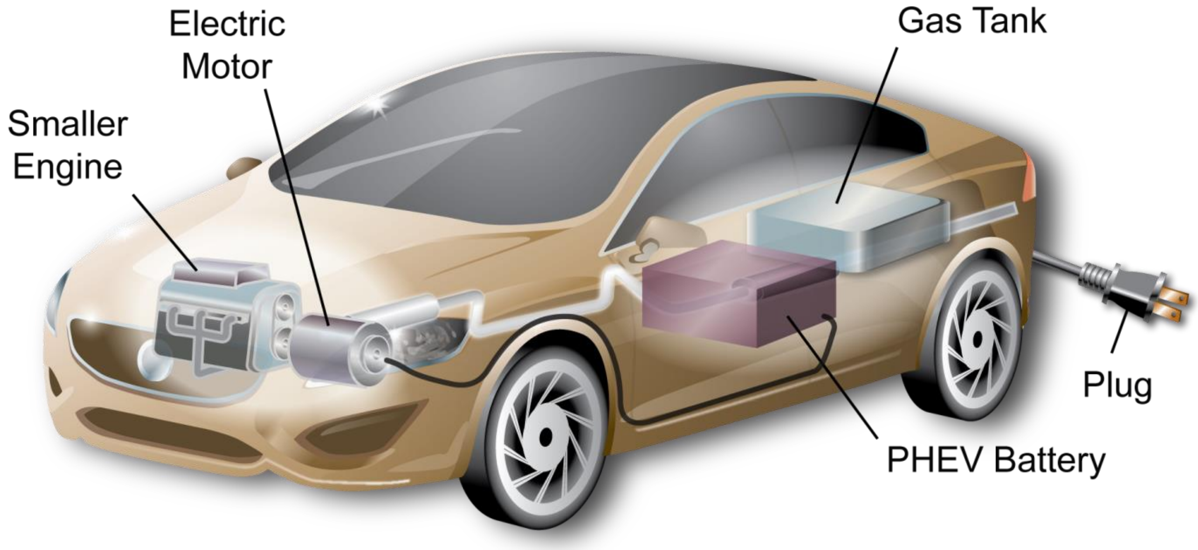
Comparison of Vehicle Technology

- Hybrid Electric Vehicle (HEV) with ICE and electric drive
- Does not plug in to electric grid



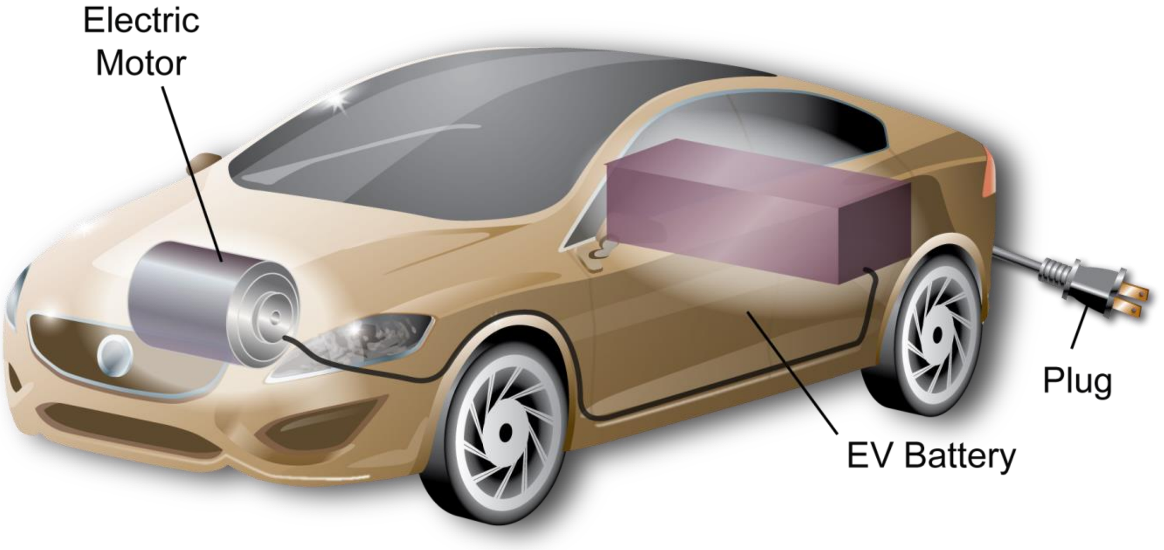
Comparison of Vehicle Technology

- Plug-in Hybrid Electric Vehicle (PHEV) or Extended Range Electric Vehicle (EREV) with ICE and electric drive



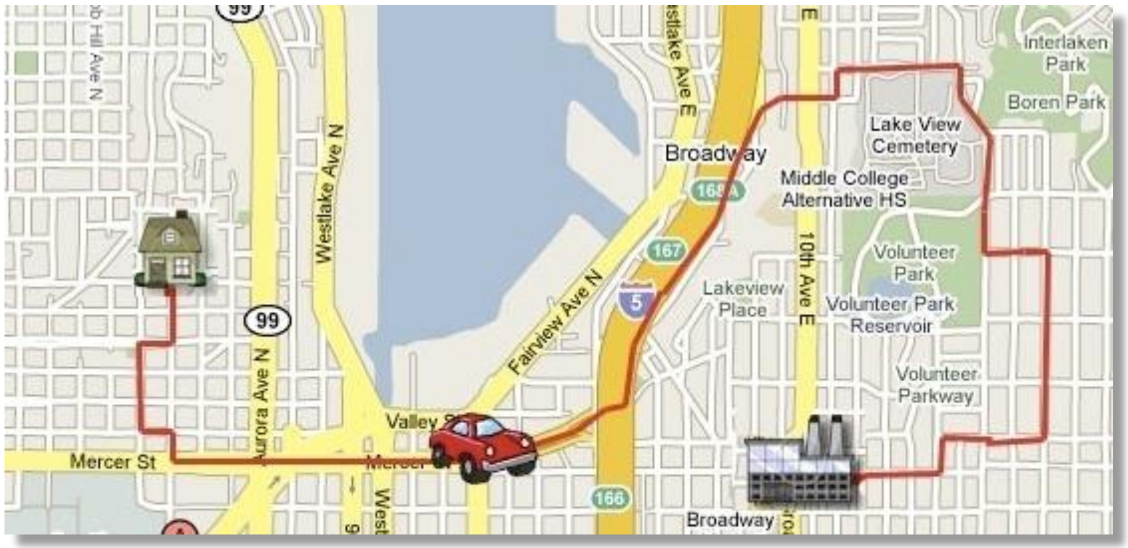
Comparison of Vehicle Technology

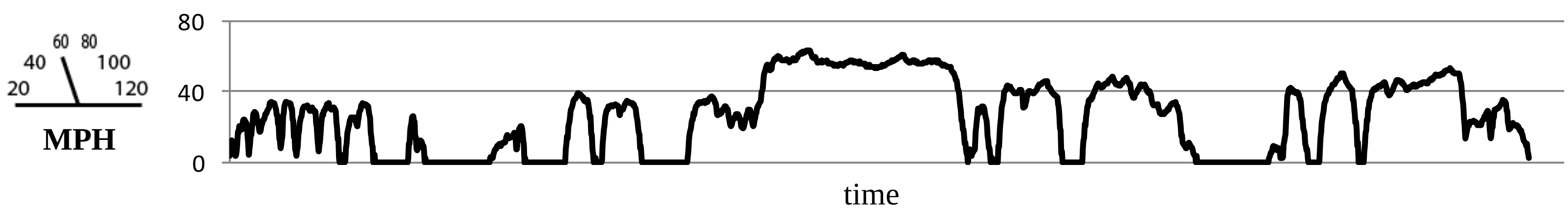
- Battery Electric Vehicle (BEV) with electric drive only



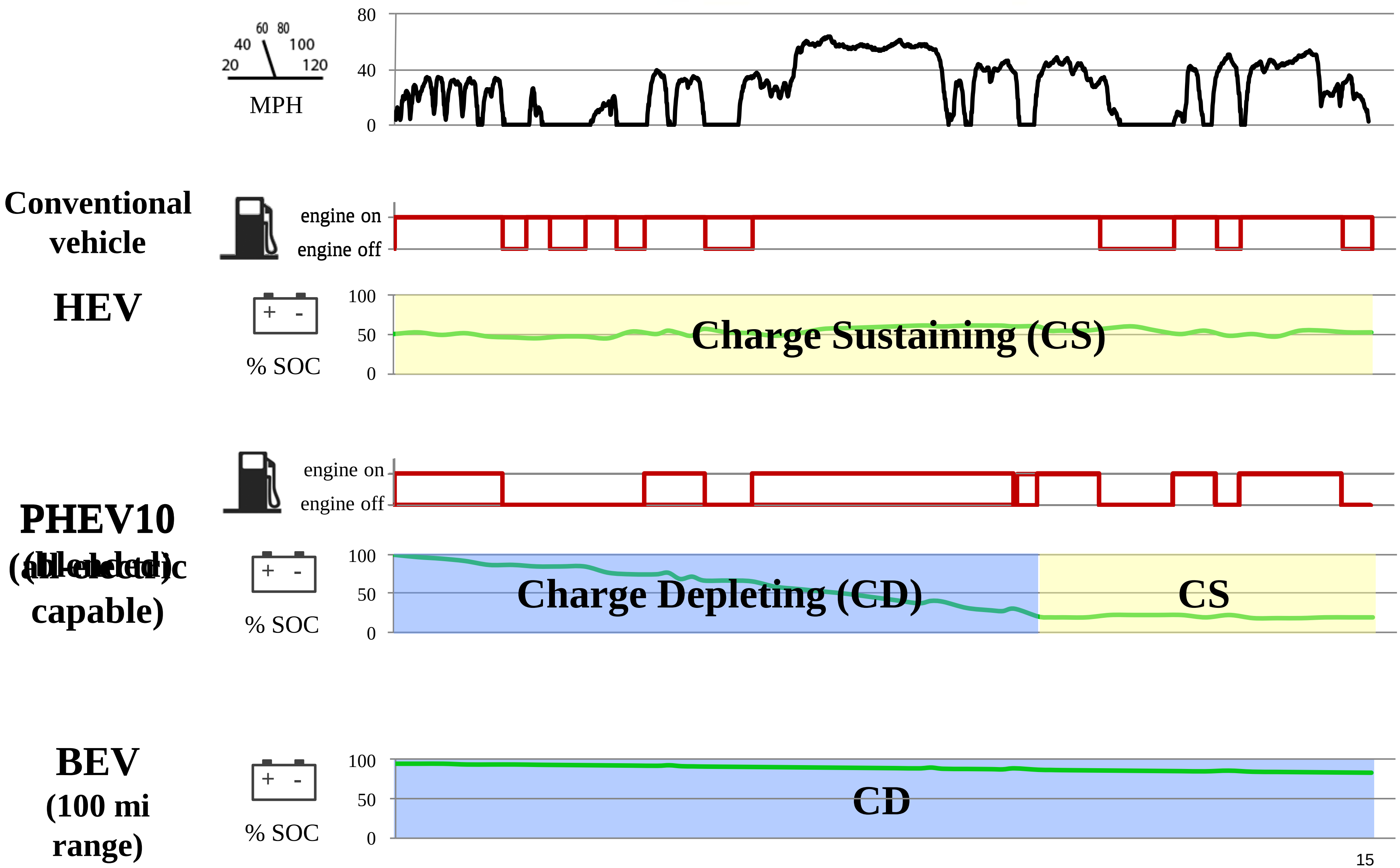
Conceptual Comparison of Vehicle Operation

Hypothetical 15 mile drive cycle





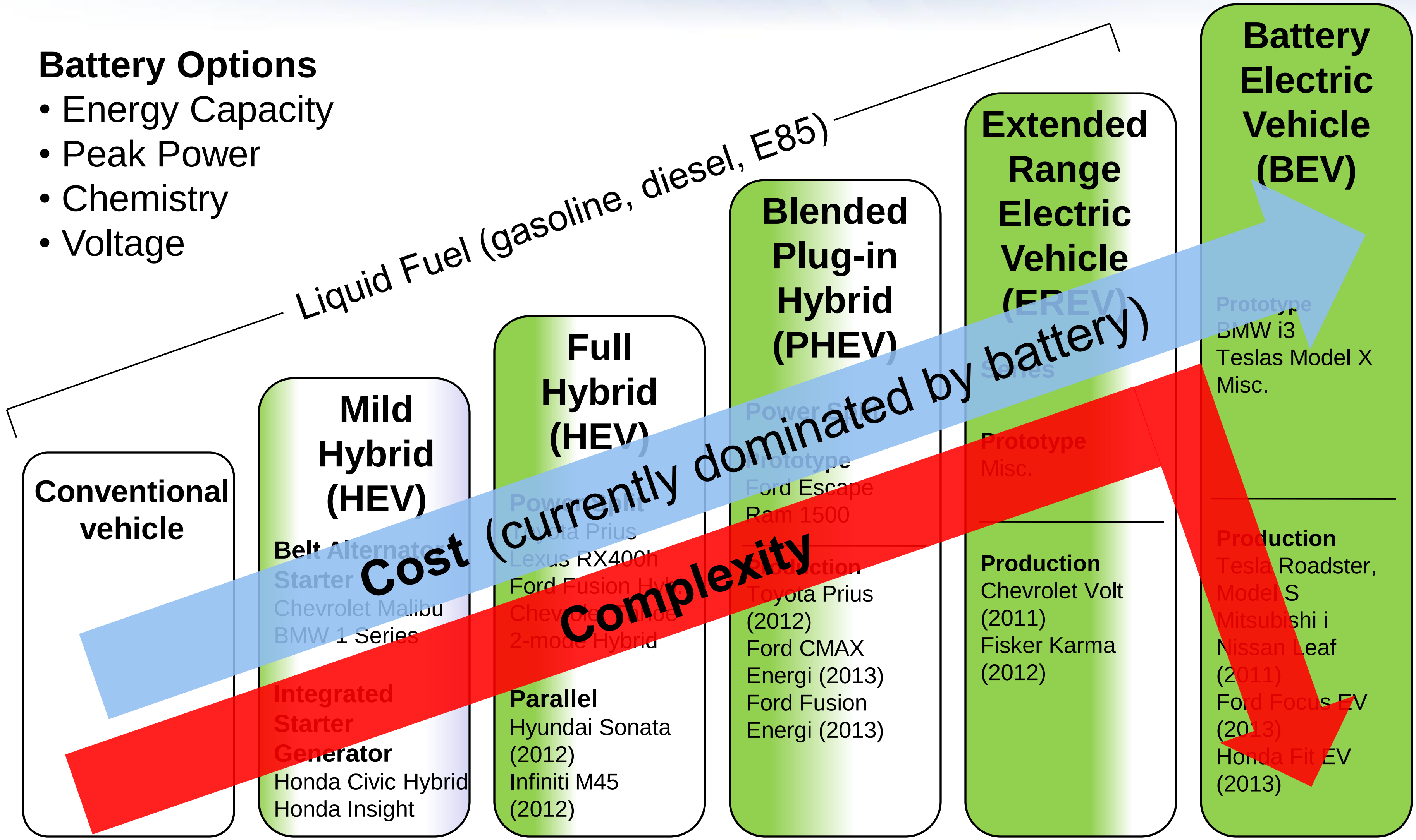
Conceptual Comparison of Vehicle Operation



Electric Drive Vehicle Powertrain Architectures

Battery Options

- Energy Capacity
- Peak Power
- Chemistry
- Voltage



Dates given are approx. year for start of production

HEV Examples

Chevrolet Tahoe Hybrid

Honda Insight

Toyota Prius V

Ford CMAX Hybrid

Infiniti M Hybrid

Hyundai Sonata Hybrid

All images downloaded from manufacturers' websites Mar 2013

PHEV / EREV Examples

Toyota Prius Plug-in Hybrid

Fisker Karma

Chevrolet Volt

Ford Fusion Energi

All images downloaded from manufacturers' websites Mar 2013

BEV Examples

Honda Fit EV

Tesla Model S

Ford Focus EV

Toyota RAV4 EV

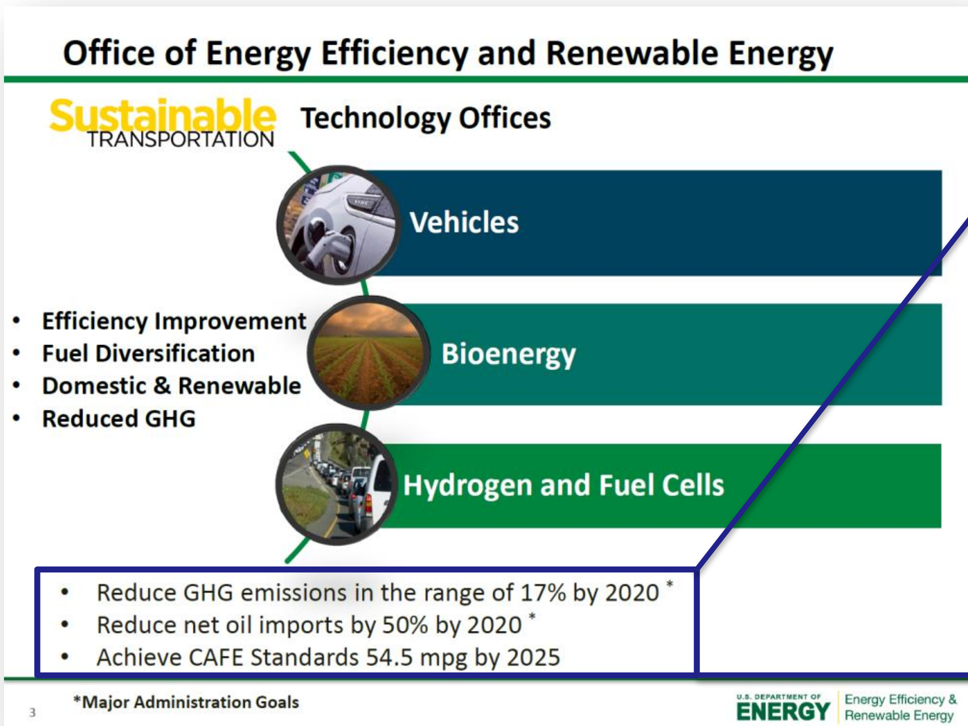
Nissan LEAF

All images downloaded from manufacturers' websites Mar 2013

Department of Energy and INL Research

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
  - Energy Efficiency
  - Sustainable Transportation



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

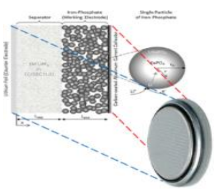
1. **Cost of vehicle is prohibitive to consumer**
2. **Vehicle does not meet the precieved needs of the consumer (range, fueling time, infrastructure accessibility / cost / convenience)**
3. **Infrastructure / fuel is cost-prohibitive or does not exist**

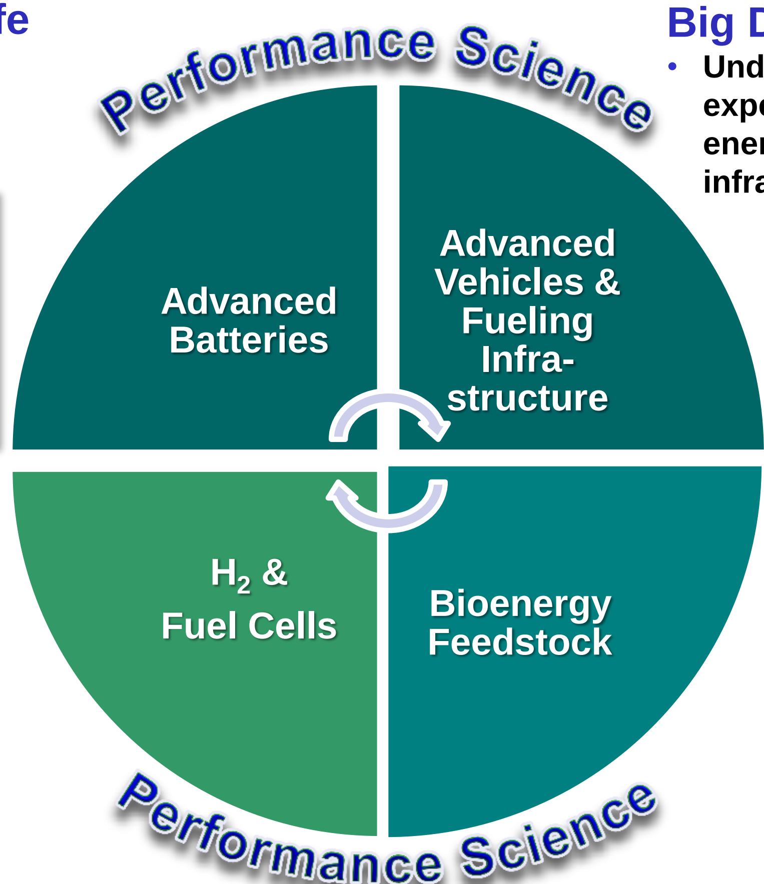
INL's Advanced Transportation Activities

- 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

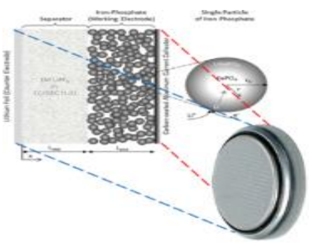
Bioenergy Feedstocks

- 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

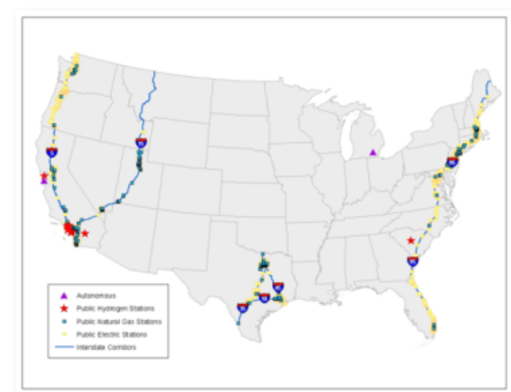
The EV Project

- 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

Building a Nationwide Living Laboratory

- In a competitively-awarded, cost-shared effort with industry partners, the U.S. Department of Energy supported the largest-ever demonstration of plug-in electric vehicles (PEV) and electric charging infrastructure
- Data collection and analysis led by Idaho National Laboratory (INL) has provided valuable insights to inform future deployment

The EV Project

- 12,000+ residential and public AC level 2 charging units
- 100+ DC fast chargers
- 8,000+ Electric drive vehicles
- INL data collection Jan 2011 – Dec 2013

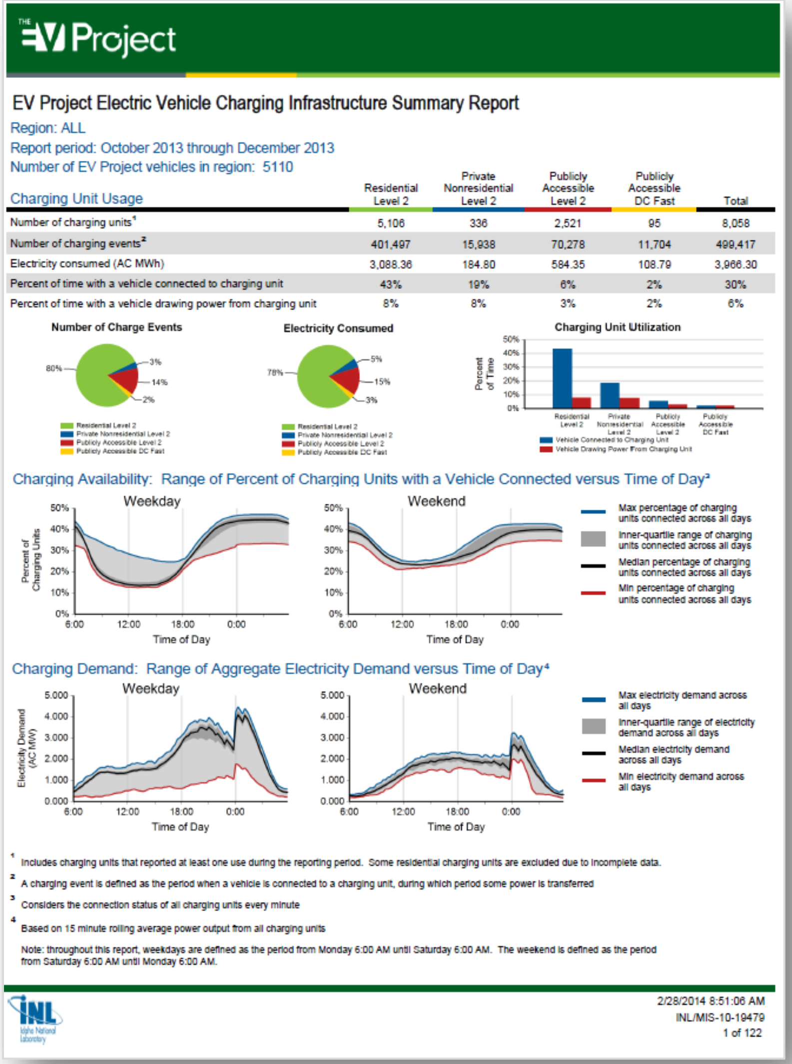
ChargePoint America

- 4,700+ residential and public AC level 2 charging units
- INL data collection May 2011 – Dec 2013

Project partners:

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%

Number of Charge Events

Electricity Consumed

Charging Unit Utilization

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.

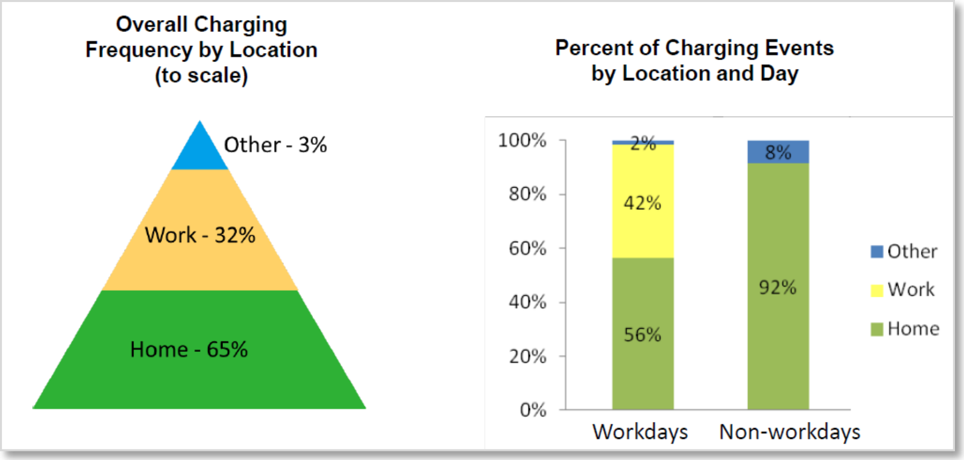
2/28/2014 8:51:06 AM
INL/MIS-10-19479
1 of 122

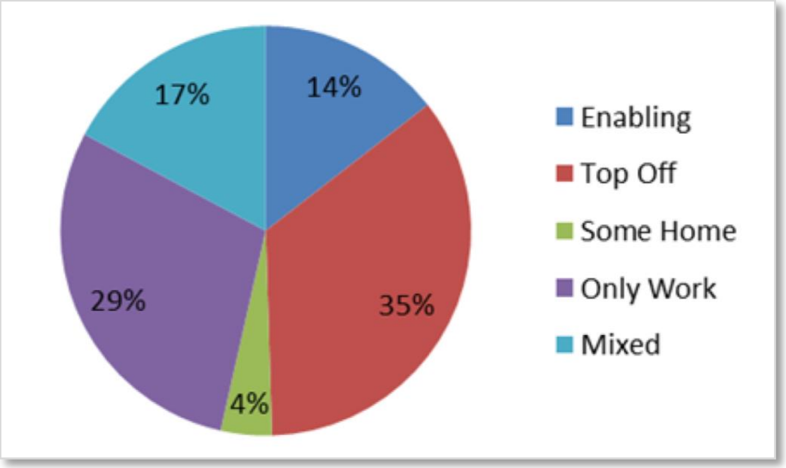
Workplace Charging Impact

- **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

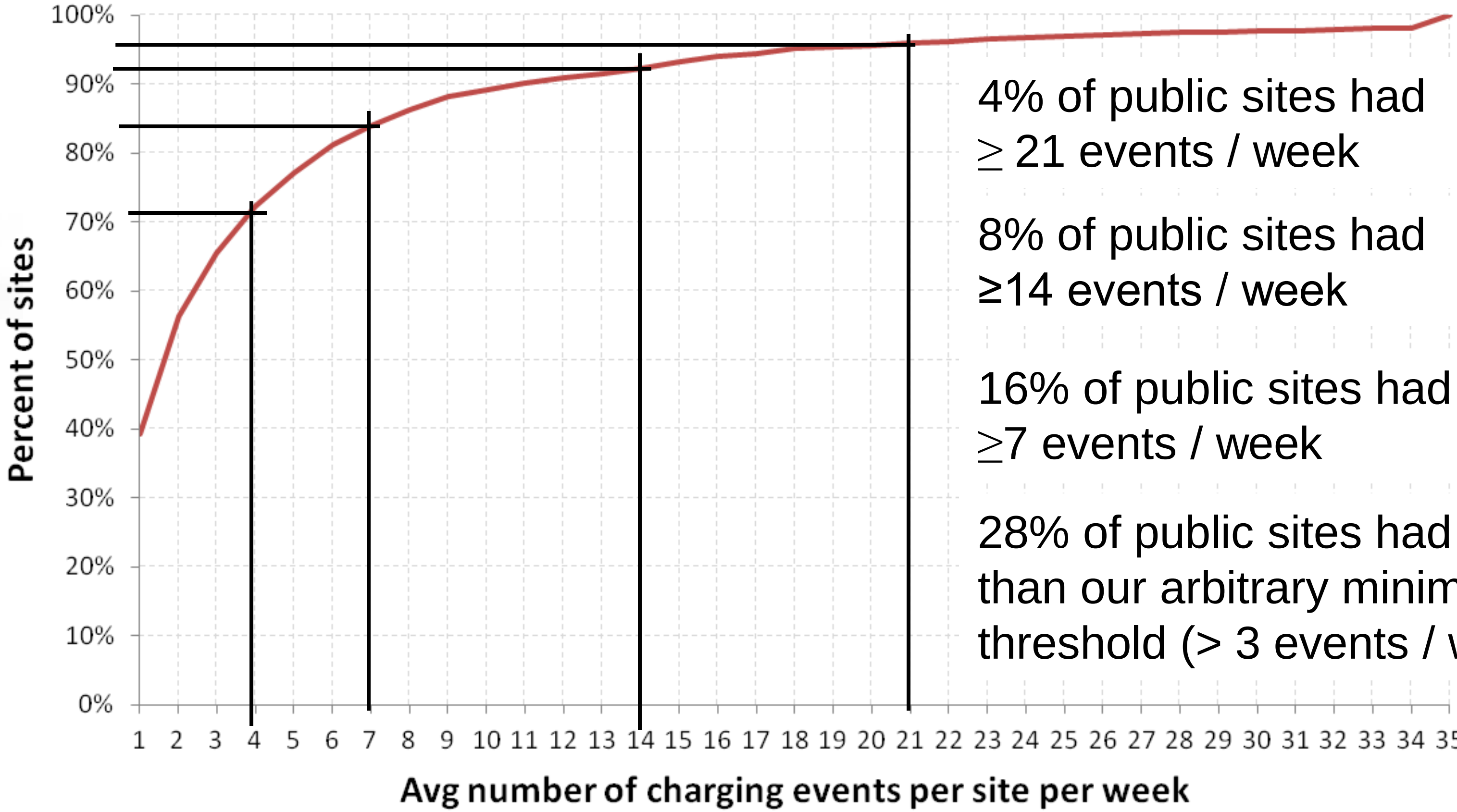




Which public charging sites are used most frequently?

Usage of Publicly Accessible Level 2 Sites

Cumulative Distribution of Charging Frequency of Blink and ChargePoint Level 2 Publicly Accessible Sites



4% of public sites had ≥ 21 events / week

8% of public sites had ≥14 events / week

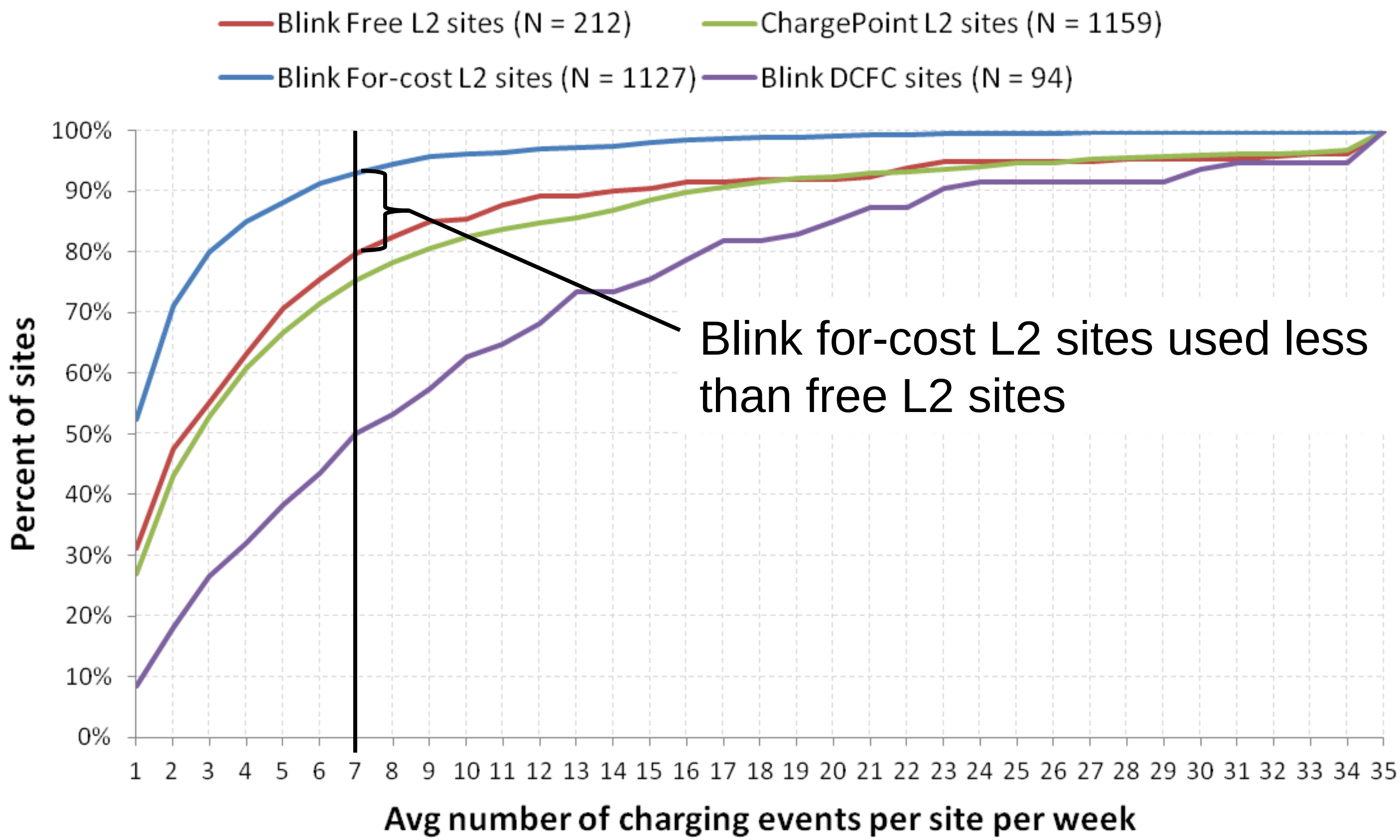
16% of public sites had ≥7 events / week

28% of public sites had greater than our arbitrary minimum threshold (> 3 events / week)

9/1/2012 to 1/1/2014 N = 2,498 sites

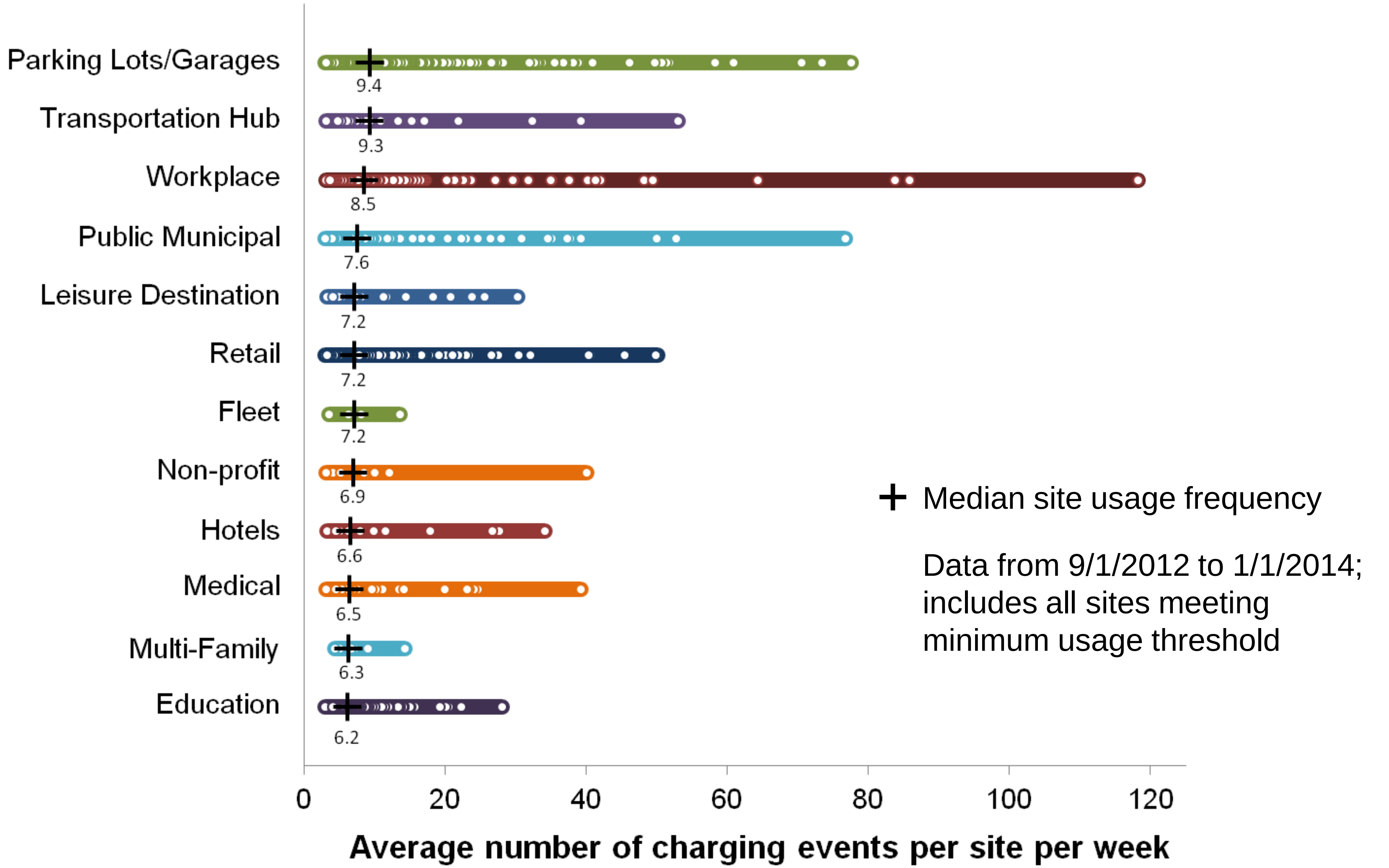
Usage of Publicly Accessible Level 2 Sites

Cumulative Distributions of Charging Frequency of Blink and ChargePoint Publicly Accessible Sites

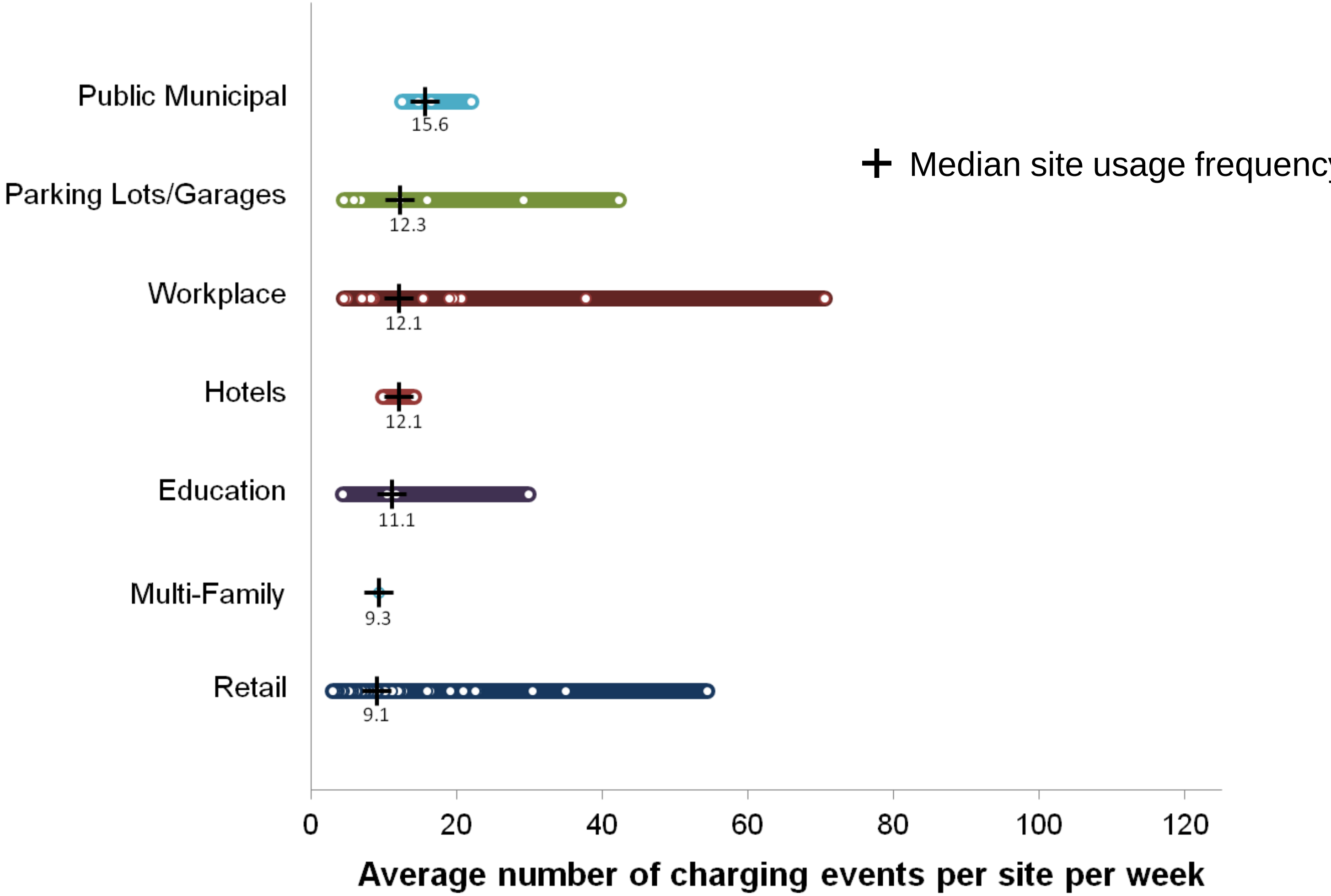


9/1/2012 to 1/1/2014

Distribution of Usage Frequency of Blink & ChargePoint Level 2 EVSE Sites by Venue



Distribution of Usage Frequency of Blink DCFC Sites by Venue

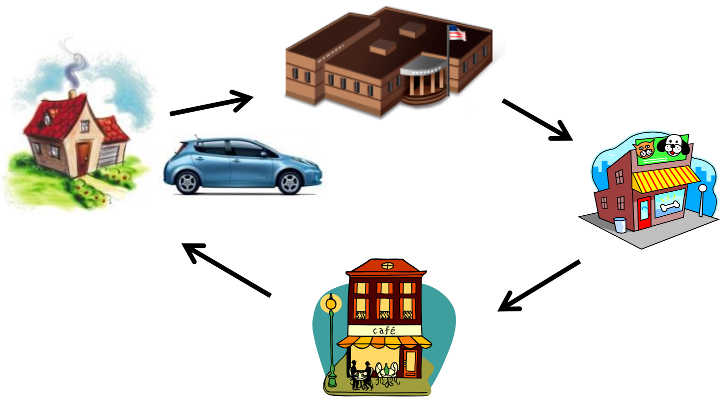


8/1/2013 to 1/1/2014 (after Blink network fees were instituted)

West Coast Electric Highway Corridor DC Fast Charger Usage

West Coast Electric Highway

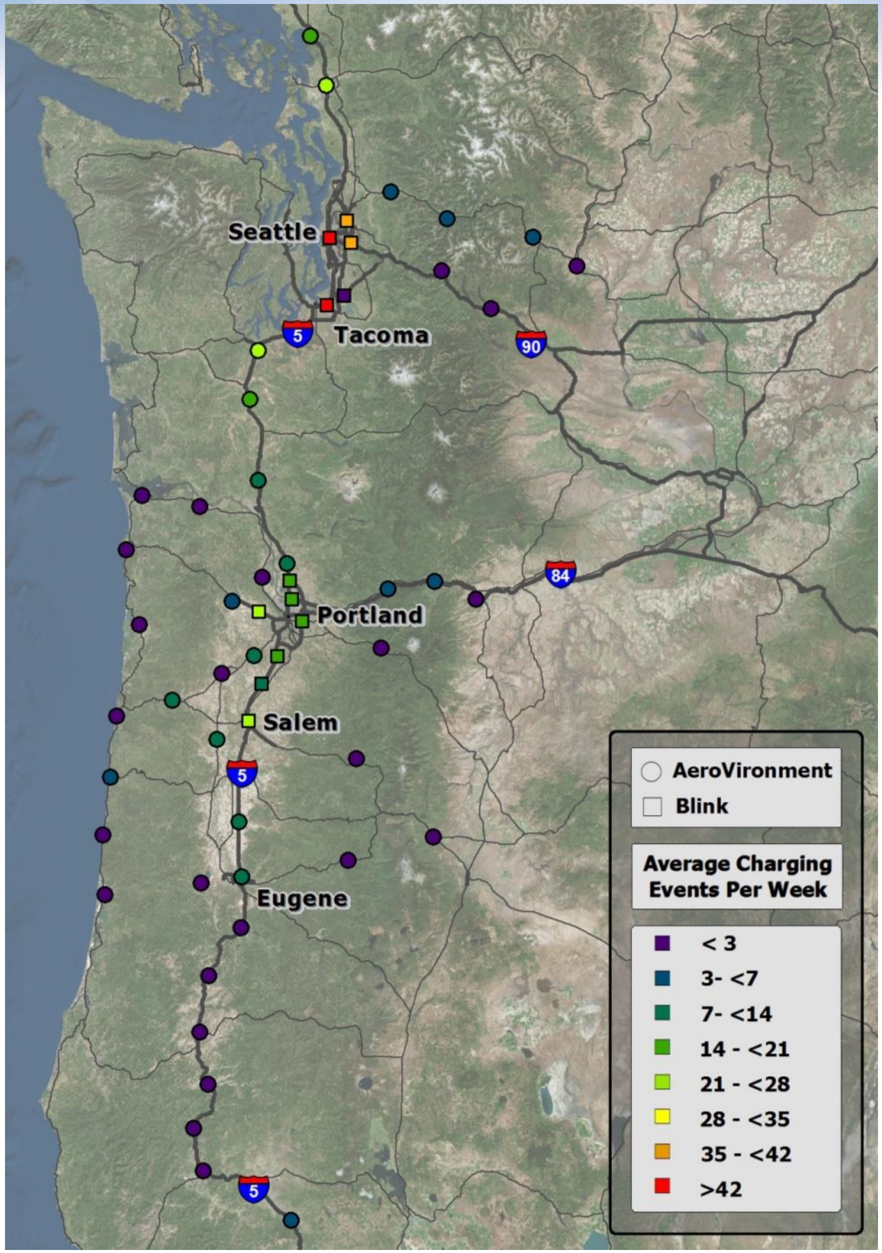
- WCEH was designed to support long distance EV travel in WA, OR, and CA
- Analysis included 45 AeroVironment and 12 Blink DCFC located in Oregon and Washington
- Using EV Project data, we can look at Leaf charging at these fast chargers
  - 1,589 EV Project Leafs in Oregon and Washington
  - 319 used 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

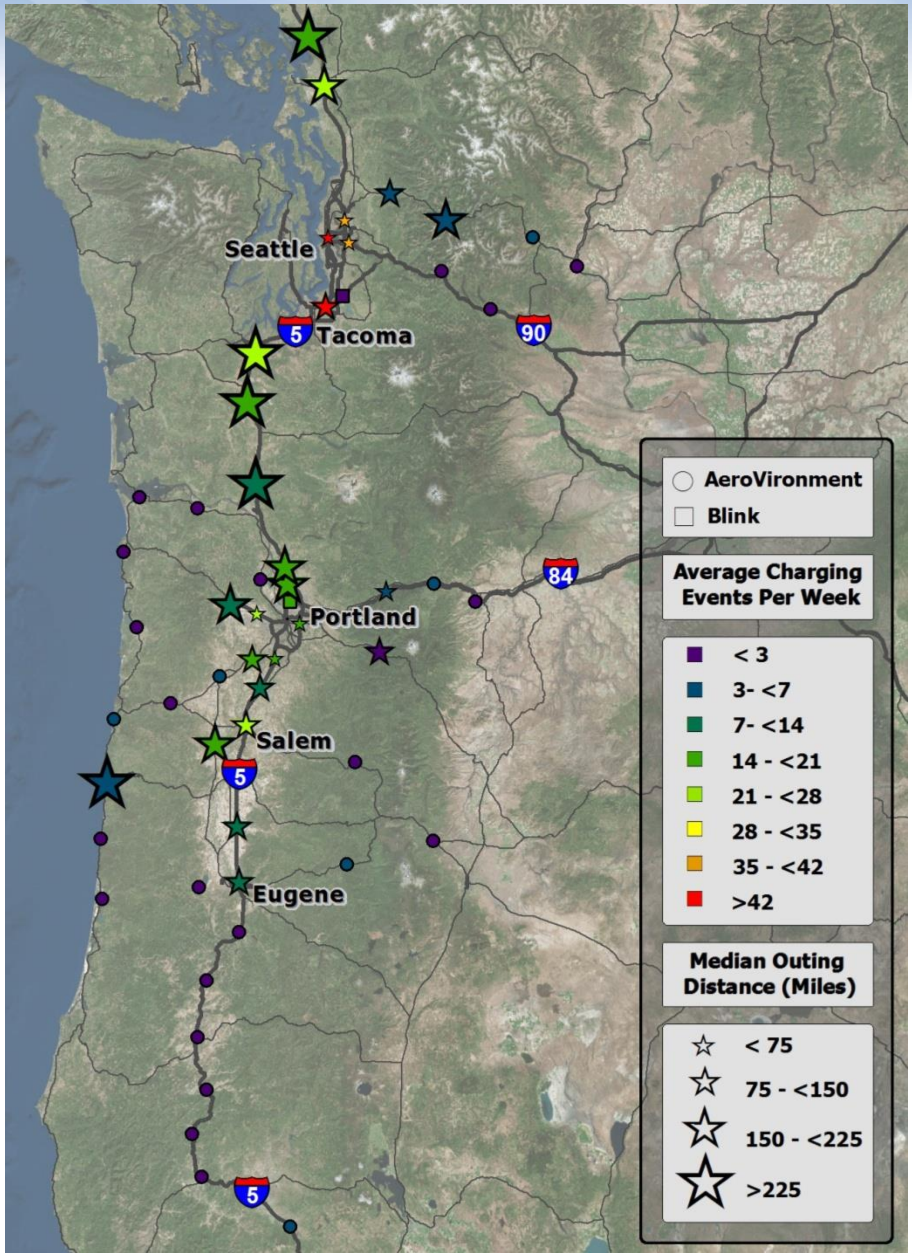
- Most highly used DCFC were in large cities and along interstate between them (Seattle, Portland)
  - Used 2 to 5 times per day, or more
- Usage tends to decrease as DCFC get farther from I-5
  - Also drops off south of Eugene
- DCFCs along the coast and east of I-5 were used a few times per week
  - 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

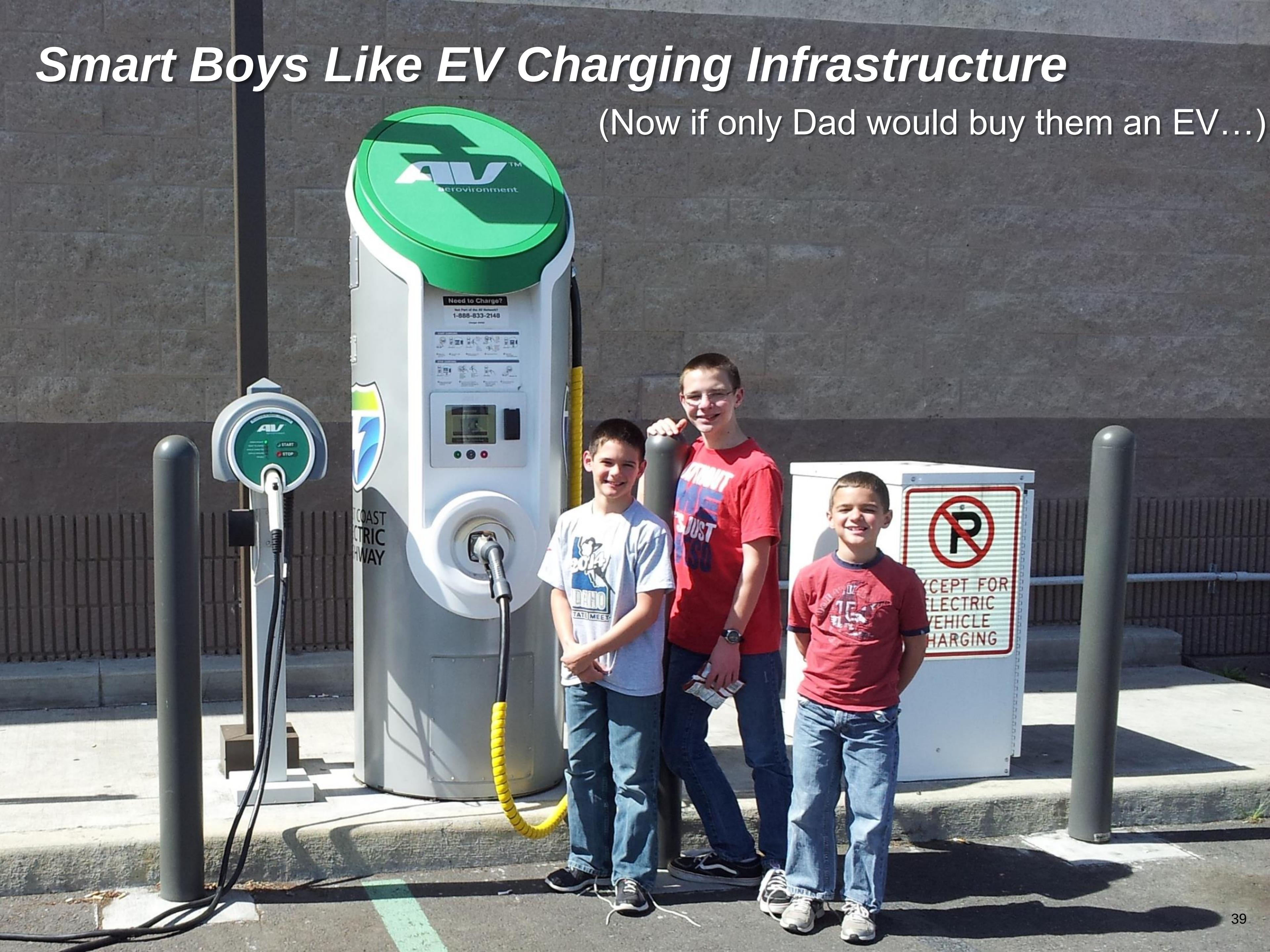
9/1/2012 to 1/1/2014

- 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



Smart Boys Like EV Charging Infrastructure

(Now if only Dad would buy them an EV…)



Electric Vehicle Miles Traveled

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 credit

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

EV Miles Traveled (eVMT) Analysis Results

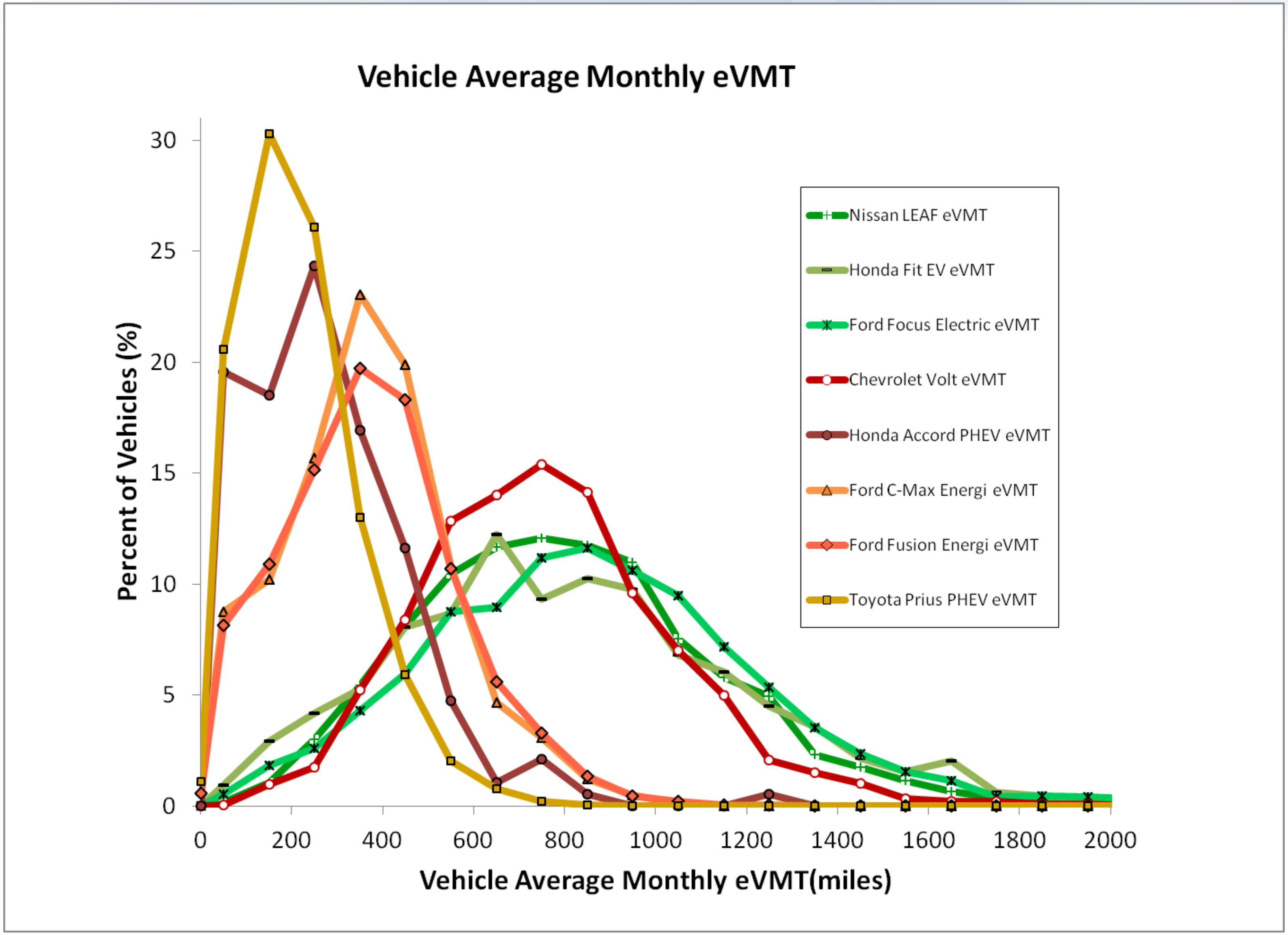
	BEV			EREV	PHEV				
	Nissan LEAF	Ford Focus Electric	Honda Fit EV	Chevrolet Volt	Ford Fusion Energi	Ford C-Max Energi	Honda Accord PHEV	Toyota Prius PHEV	Total
Number of Vehicles	4,039	2,193	645	1,867	5,803	5,368	189	1,523	21,627
Total Vehicle Miles Traveled *VMT* (miles)	28,520,792	10,043,000	4,912,920	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	





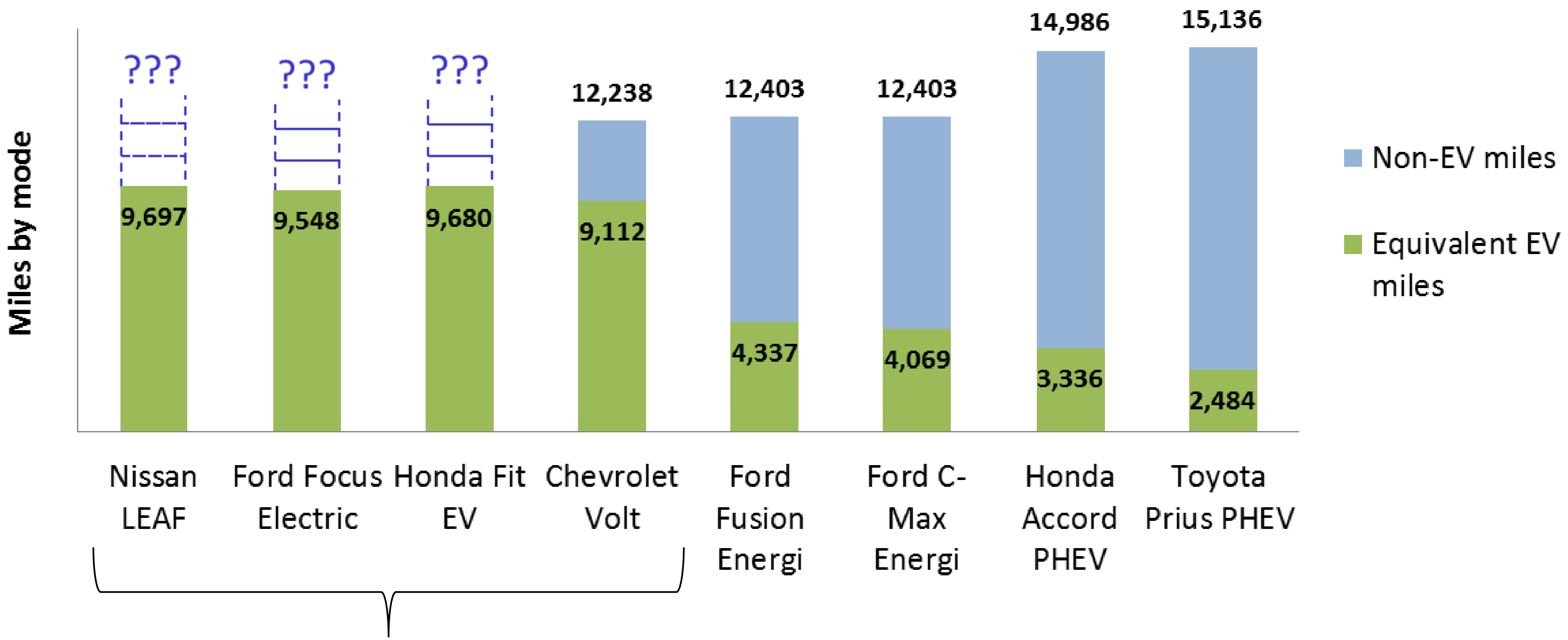


eVMT (monthly electric vehicle miles traveled)



Distance Bins: =0, >0 to 100, >100 to 200, >300 to 400, >400 to 500, etc.

eVMT Results



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

Motivation

"I think we have people in our nation and even in Texas that are really just anti-oil and gas. And they would like to see that production stopped. To those folks, I say, ride your horse to work every day."

- Todd Staples, president of the Texas Oil and Gas Association

"New Texas Law Makes Local Fracking Bans Illegal", NPR Morning Edition, May 20, 2015, http://www.npr.org/2015/05/20/408156948/new-texas-law-makes-local-fracking-bans-illegal

A Note About Partnerships

- Private companies (Ford / GM)
- National Labs / Universities

"Get ahead because of others,
not in spite of others"


INL
Idaho National Laboratory
john.smart@inl.gov
at.inl.gov