Plug-In Electric Vehicles

Introduction and Real-World Data from DOE's Advanced Vehicle Testing Activity

January 2012

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www.inl.gov

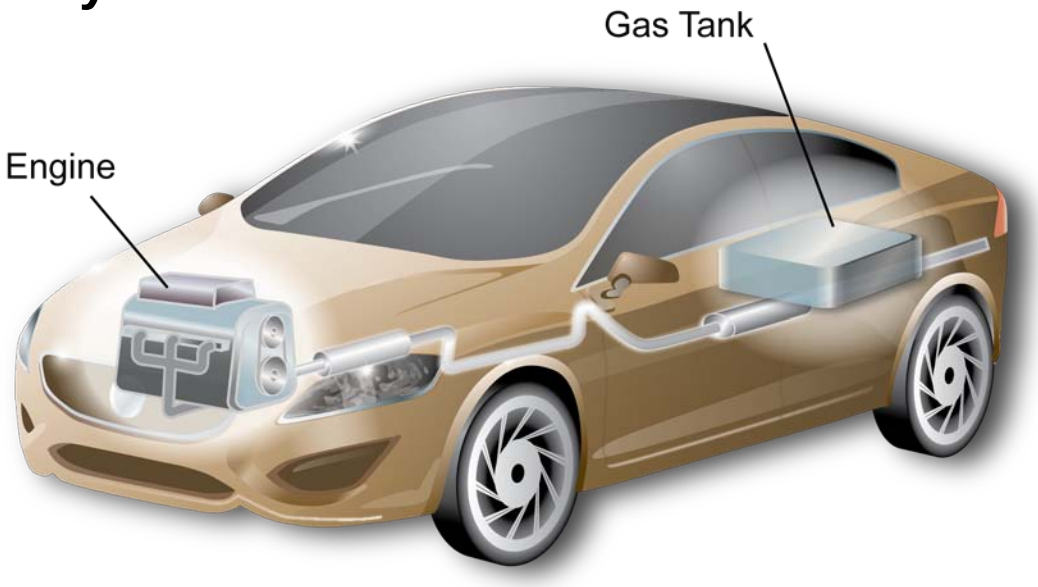
Idaho National Laboratory

Outline

- Comparison of Vehicle Technology
- AVTA Data Collection and Reporting
- EV Project
- GM Volt Vehicle Demo
- Ford Escape PHEV Advanced Research Vehicle
- Chrysler RAM PHEV Vehicle Demo
- Summary

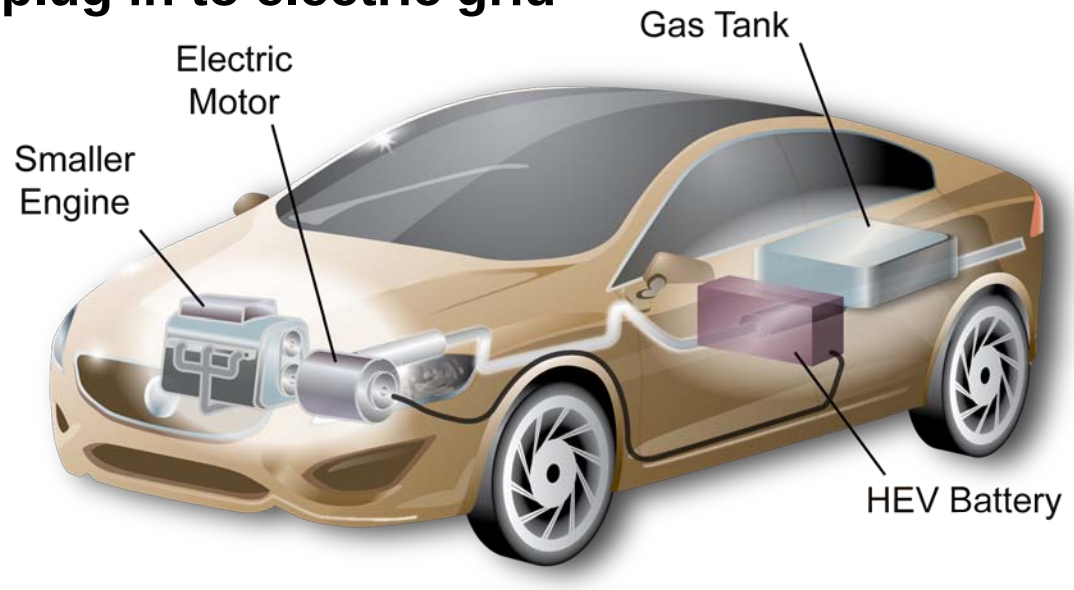
Comparison of Vehicle Technology

Conventional vehicle with internal combustion engine (ICE) only



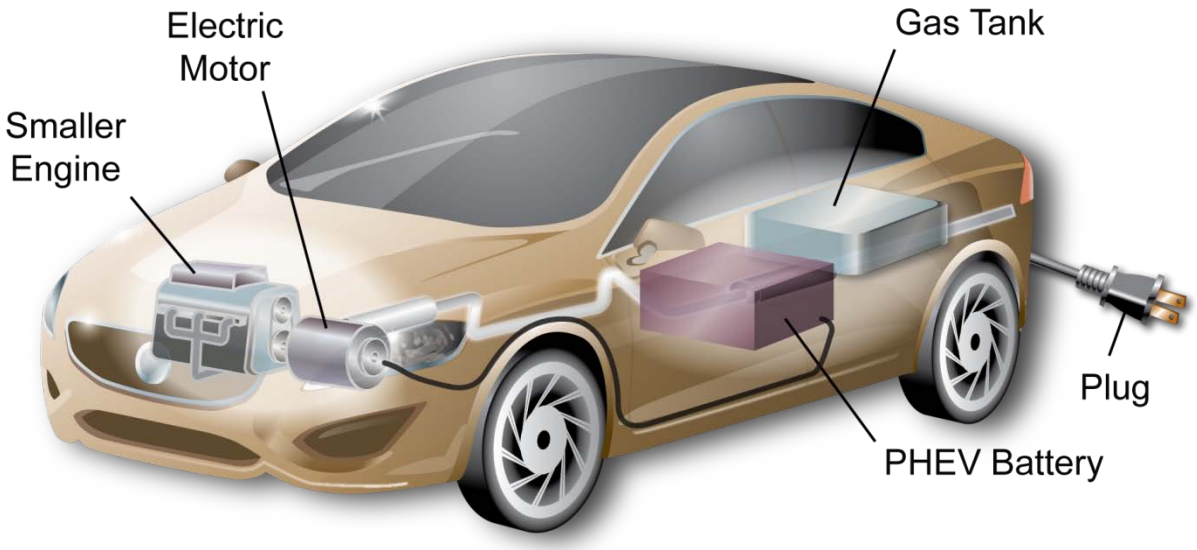
Comparison of Vehicle Technology

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



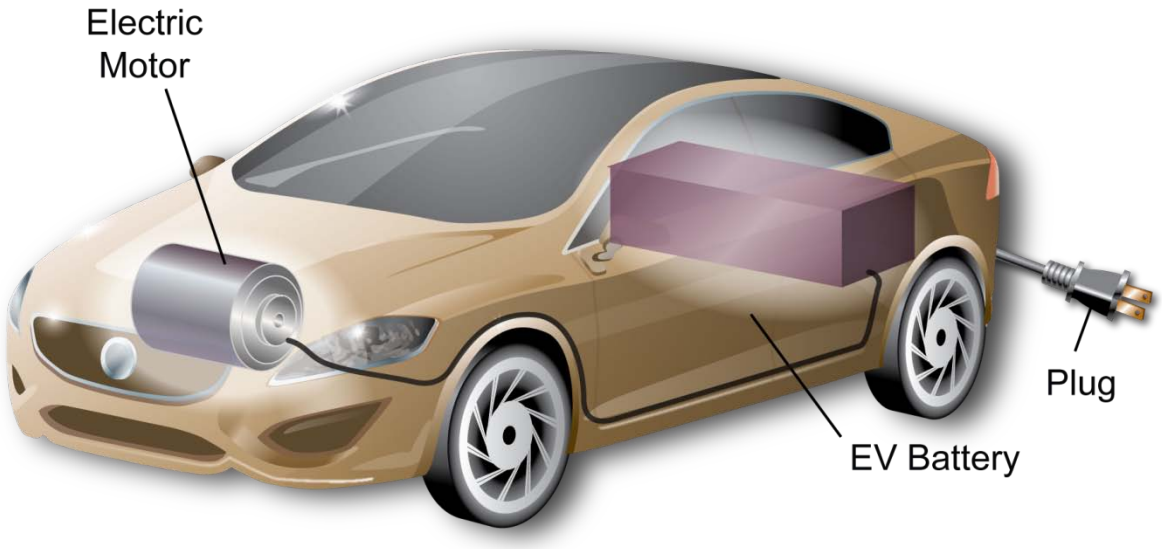
Comparison of Vehicle Technology

- **Plug-in Hybrid Electric Vehicle (PHEV) with ICE and electric drive**



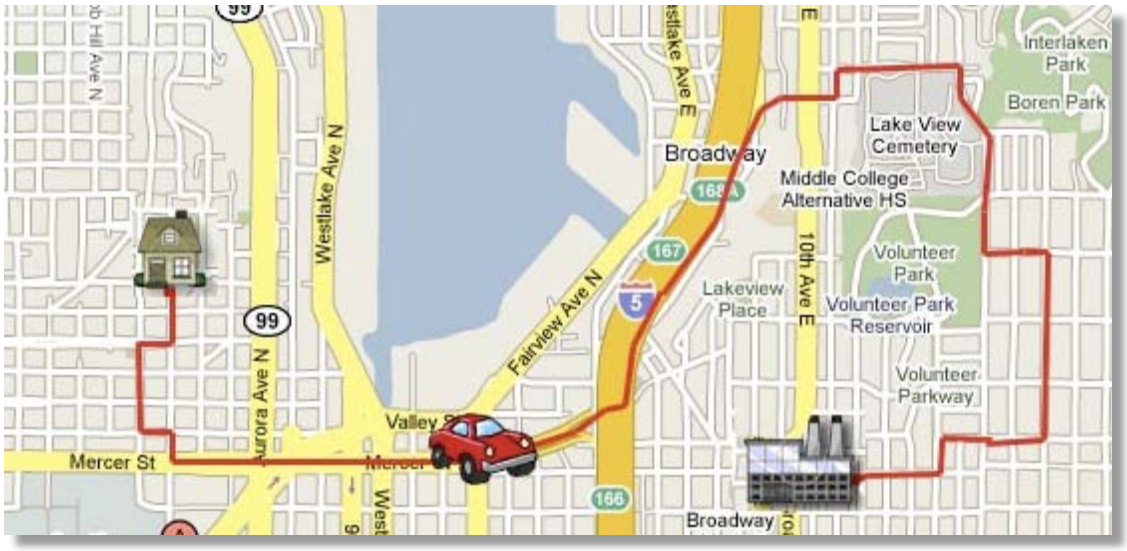
Comparison of Vehicle Technology

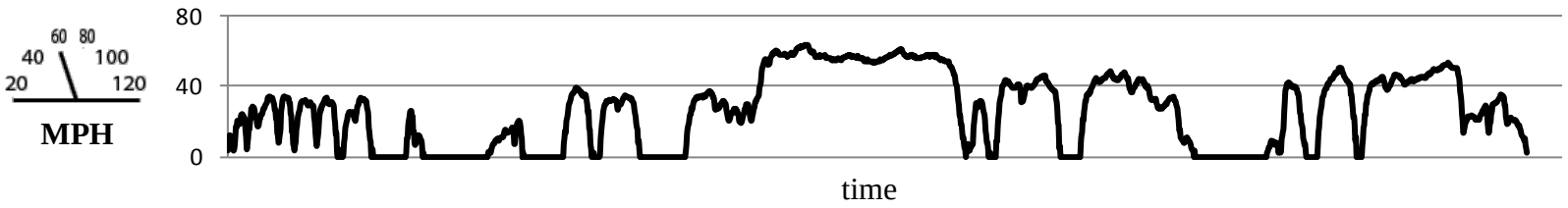
- **Battery Electric Vehicle (BEV) with electric drive only**



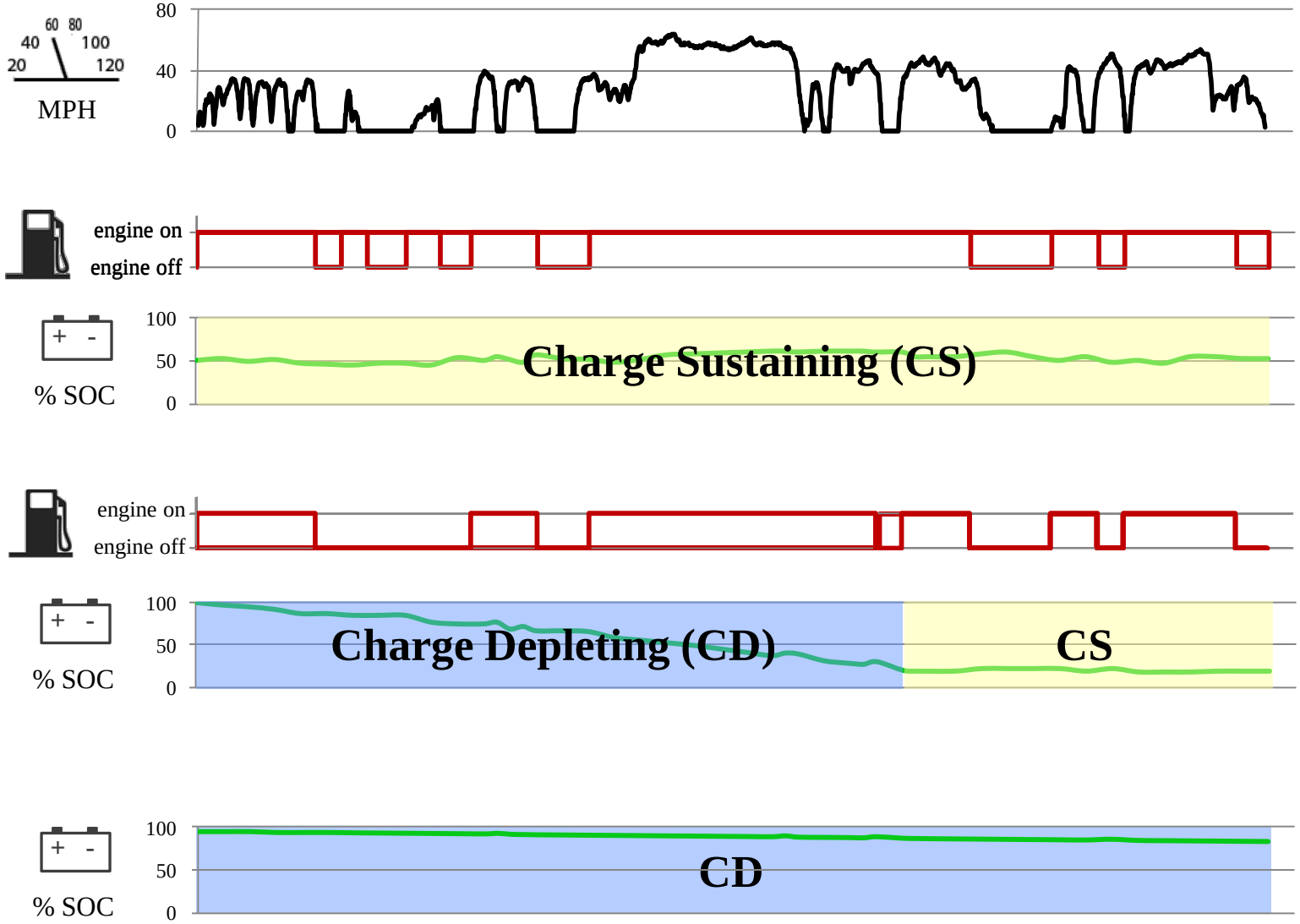
Conceptual Comparison of Vehicle Operation

Hypothetical 15 mile drive cycle





Conceptual Comparison of Vehicle Operation



Timeline of Advanced Electric Vehicle Availability



Production OEM HEVs

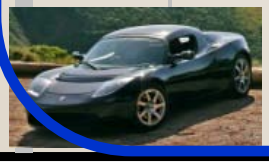
Conversion PHEVs

AVTA has done extensive testing of vehicles available to date

Production OEM PHEVs*


AVTA is testing OEM PHEVs and BEVs. HEV and conversion PHEV testing continues.

Production OEM BEVs*




* Refers to PHEVs and BEVs produced for the mass market. OEMs have produced PHEVs and BEVs in low volume intermittently since the 1990's.

2004 2006 2008 2010 2012 2014

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

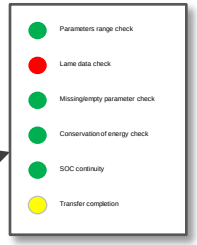
File server

SQL Server data warehouse

Report generator

INL Vehicle Data Management System

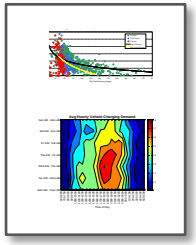
Data quality reports



Individual vehicle reports

Fleet summary Reports - Public

Focused technical analyses and custom reports



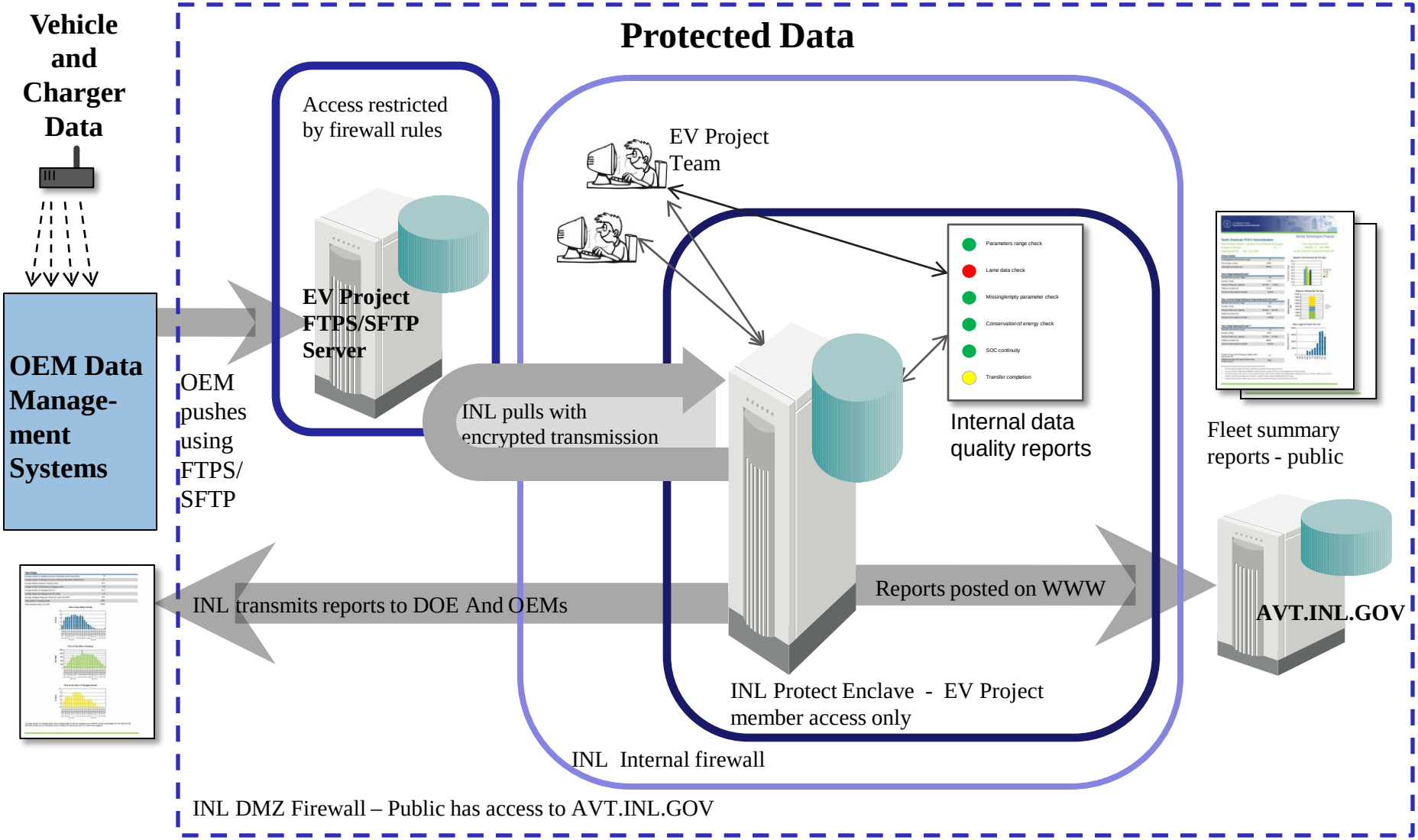
Modeling and simulations

Example: Vehicle/Infrastructure Data Sources

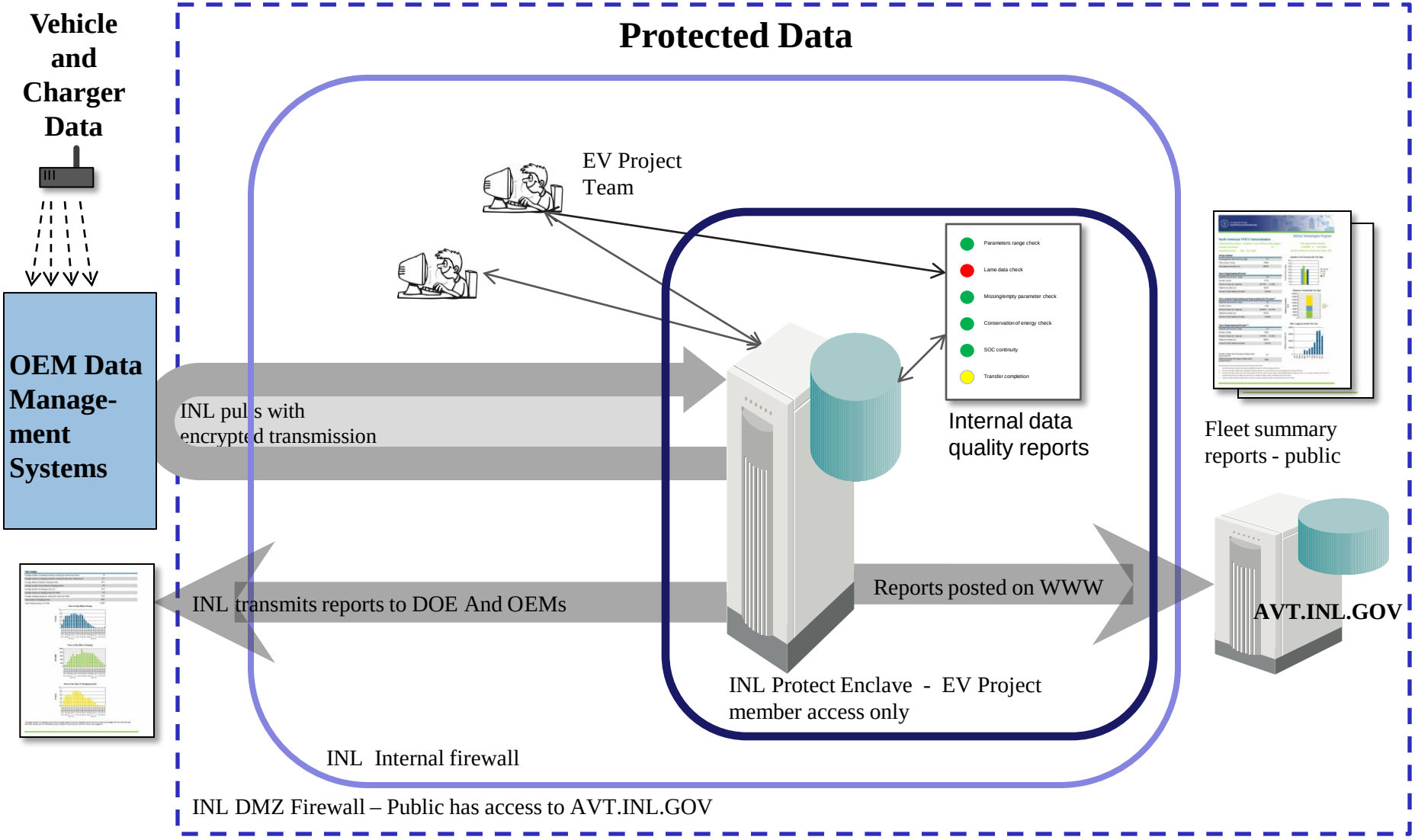
Vehicle time-history data (second-by-second)	HEV: 12 vehicle models, 1 data logger
	HICE: 1 vehicle model, 1 data logger
	Conversion PHEVs: 8 vehicle models, 3 data loggers
	Ford Escape PHEV, Ford wireless logger
	Chrysler Ram PHEV, Chrysler wireless logger
Vehicle event data (key-on, key-off)	**Nissan**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

Managing 26 different data models

INL Data Management System - Push
(Nissan, GM, Chrysler, Coulomb)



INL Data Management System - Pull
(ECOtality, Ford, conversion PHEVs, HEVs, HICEs)



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**

EV Project Locations (Largest World-Wide PEV and EVSE Data Collection Activity)

EV Project Residential Infrastructure

- **Deploy 8,300 battery electric vehicles with data loggers**
  - **5,700 Nissan Leaf BEVs**
  - **2,600 Chevrolet Volt EREVs**
- **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 EVSE and Fast Charger Data Parameters Collected per Charge Event

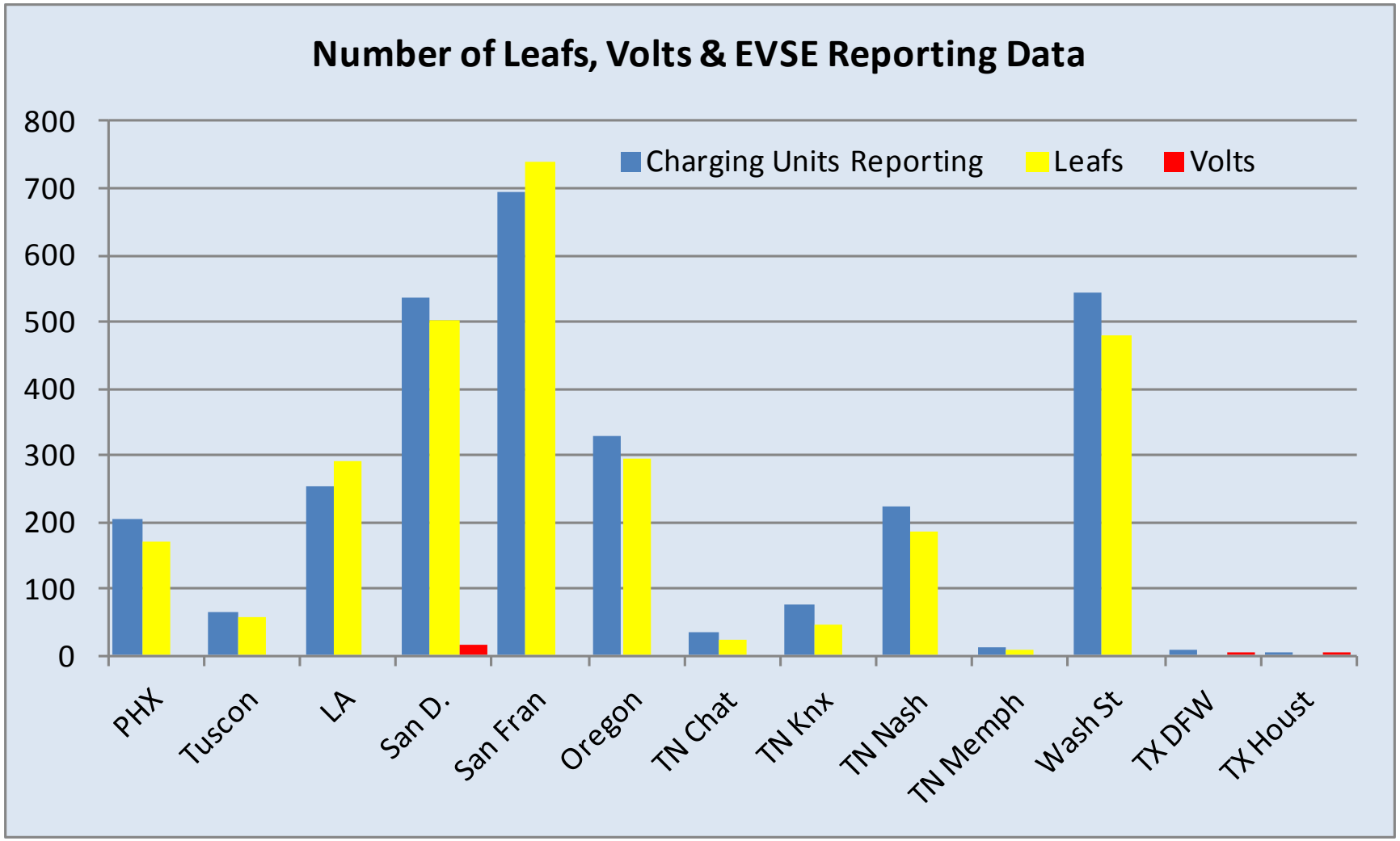
- Date/Time Stamp
- Unique ID for Charging Event
- Unique ID Identifying the EVSE – may not change
- Connect and Disconnect Times
- Start and End Charge Times
- Maximum Instantaneous Peak Power
- Average Power
- Total energy (kWh) per charging event
- Rolling 15 Minute Average Peak Power
- And other non-dynamic EVSE information (GPS, ID, type, contact info, etc.)

EV Project Vehicle Data Parameters Collected per each Key-on Key-off Event

- **Date/Time Stamp**
- **Vehicle ID**
- **Event type (key on / key off)**
- **Odometer**
- **Battery state of charge**
- **GPS (longitude and latitude)**

EV Project Number EVSE & Vehicles

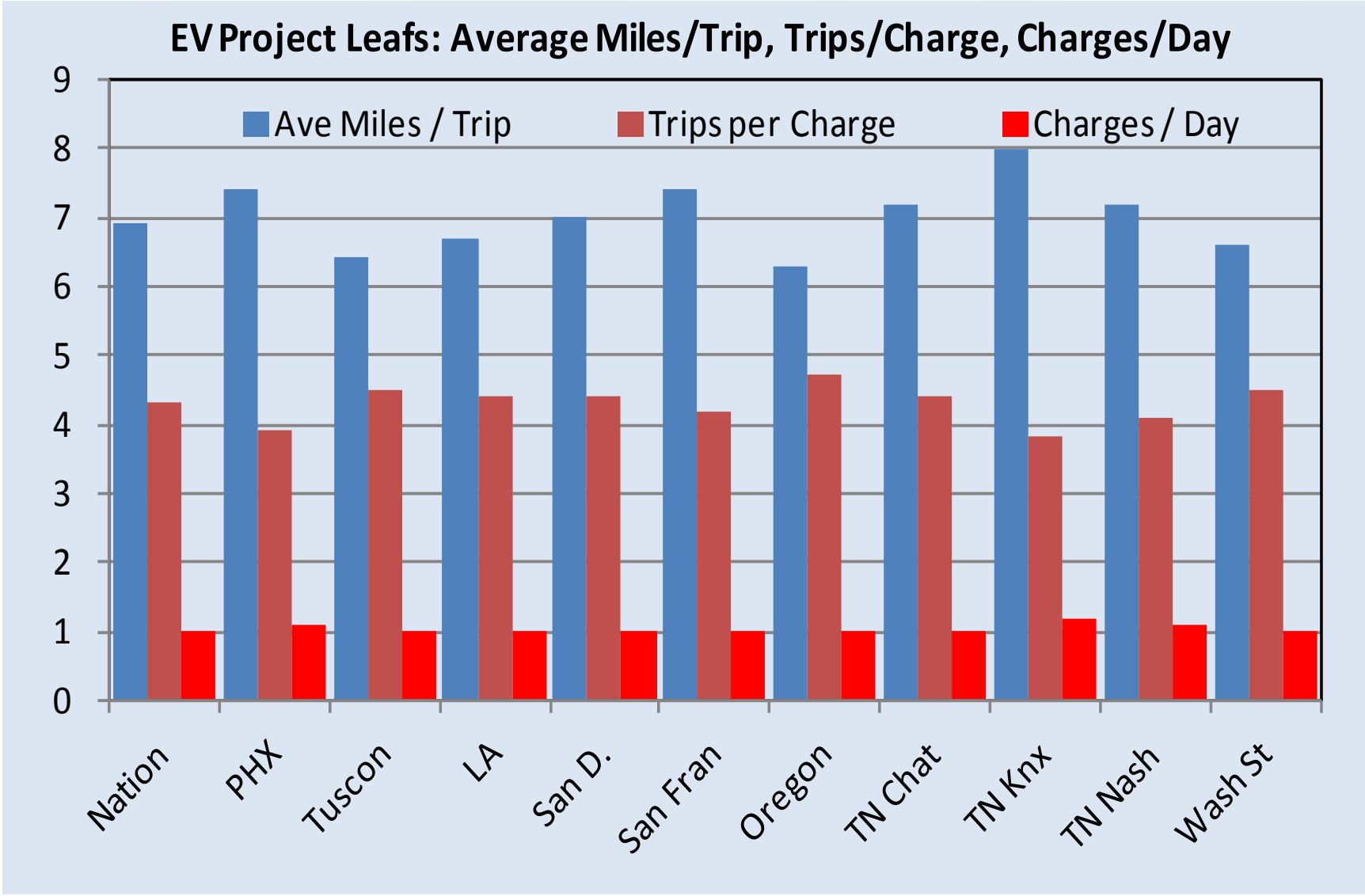
- **2,822 Leafs and Volts, and 2,990 EVSE Reporting data 3rd Qtr 2011**



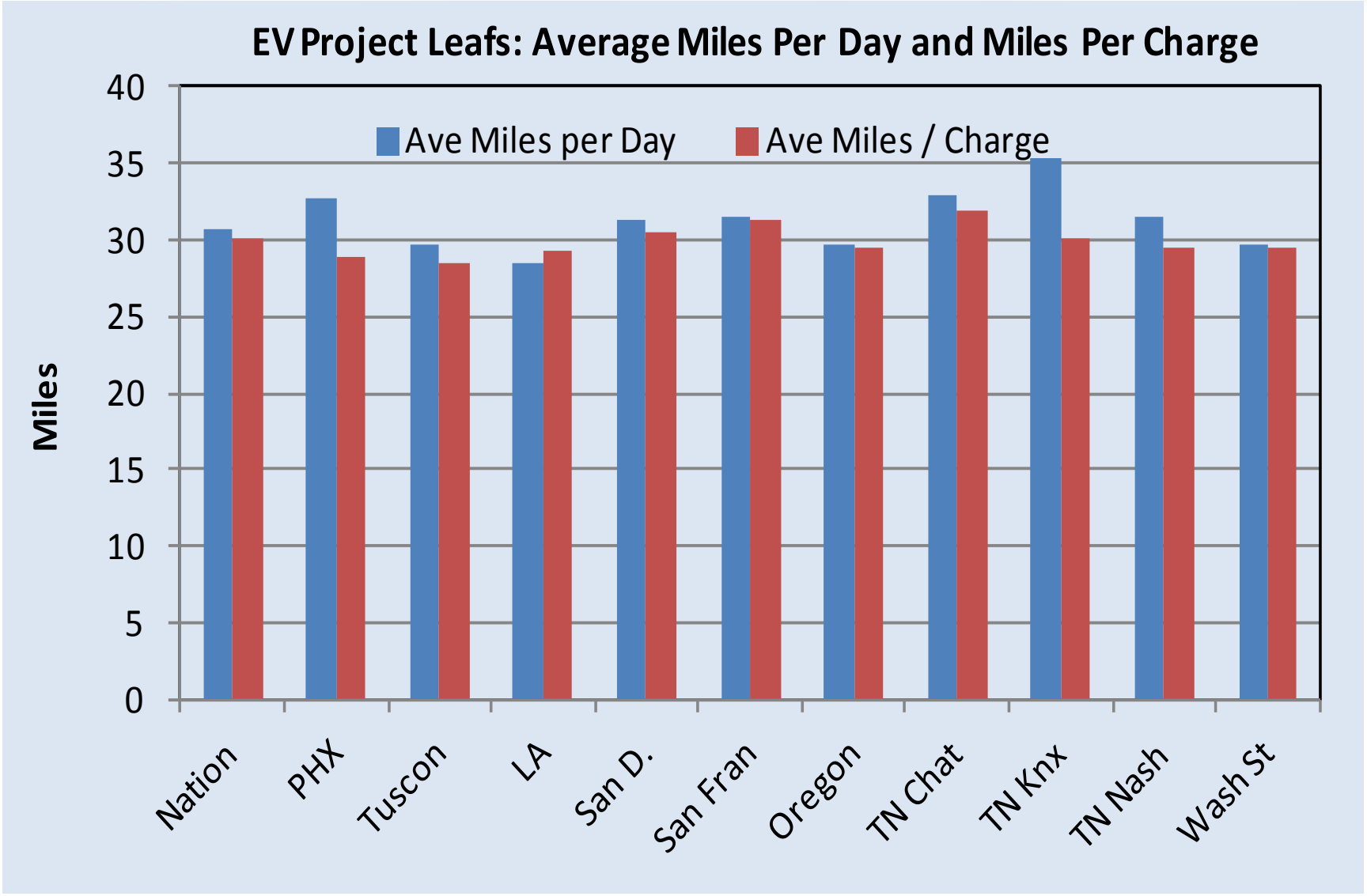
EV Project – Nissan Leaf Usage

- **Vehicle Usage – 3st 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**

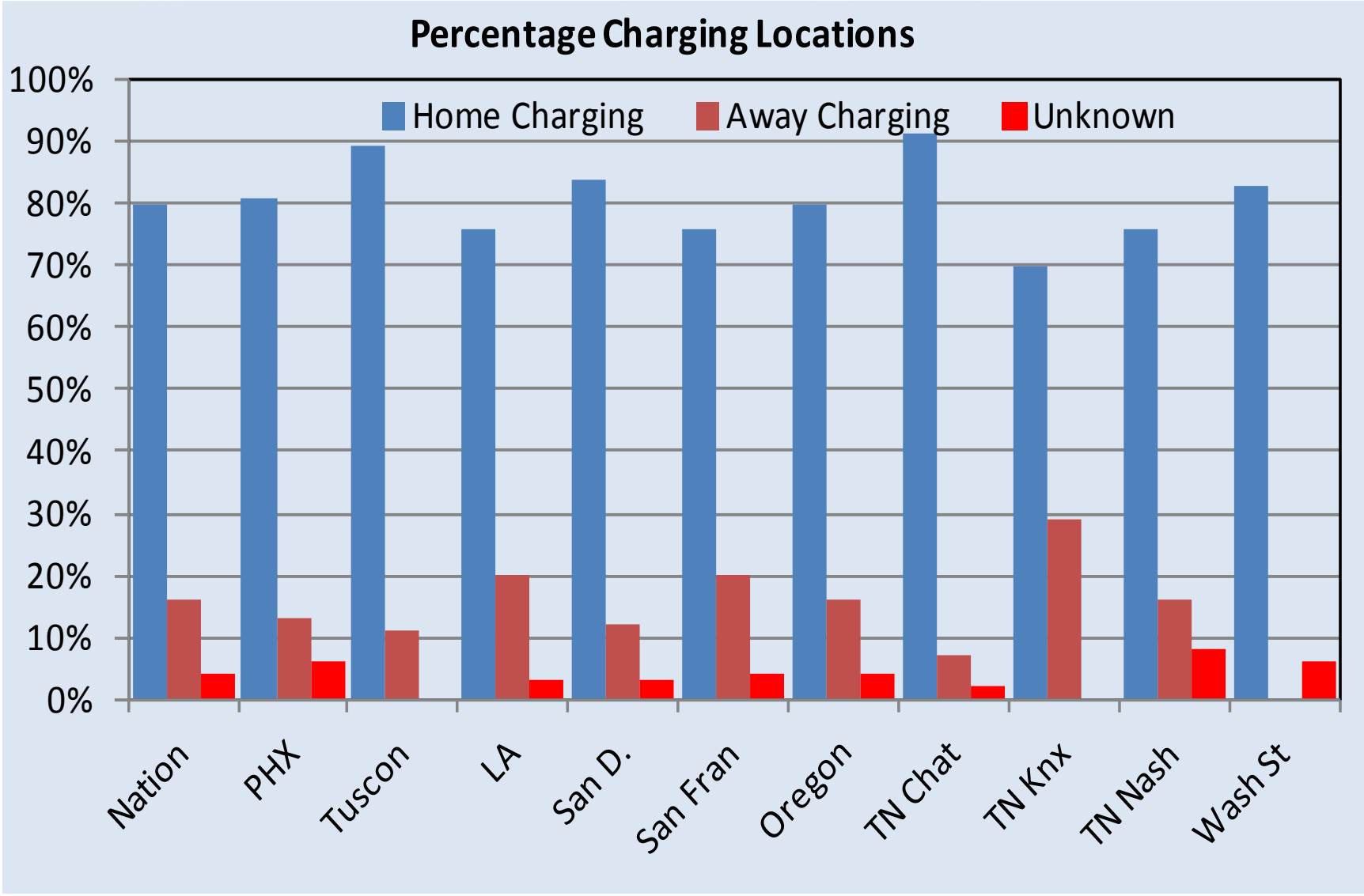
EV Project – Nissan Leaf Usage



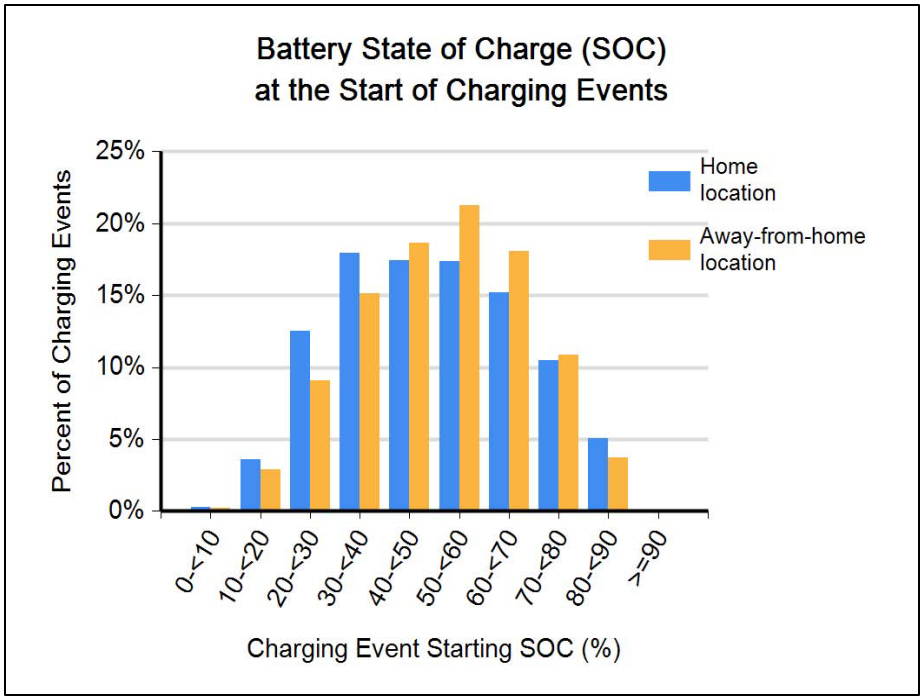
EV Project – Nissan Leaf Usage

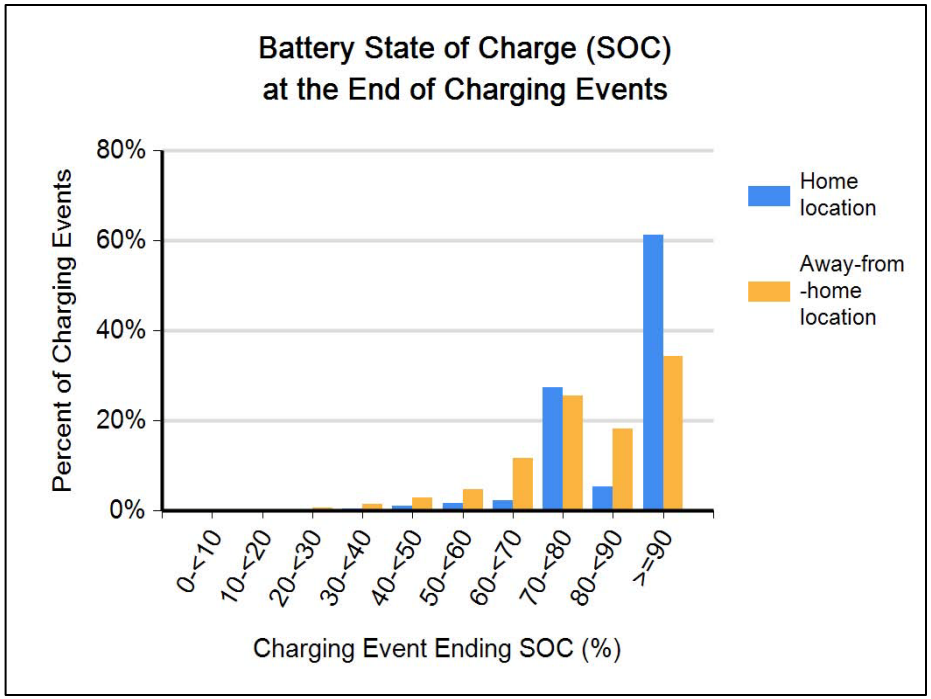


EV Project – Nissan Leaf Usage

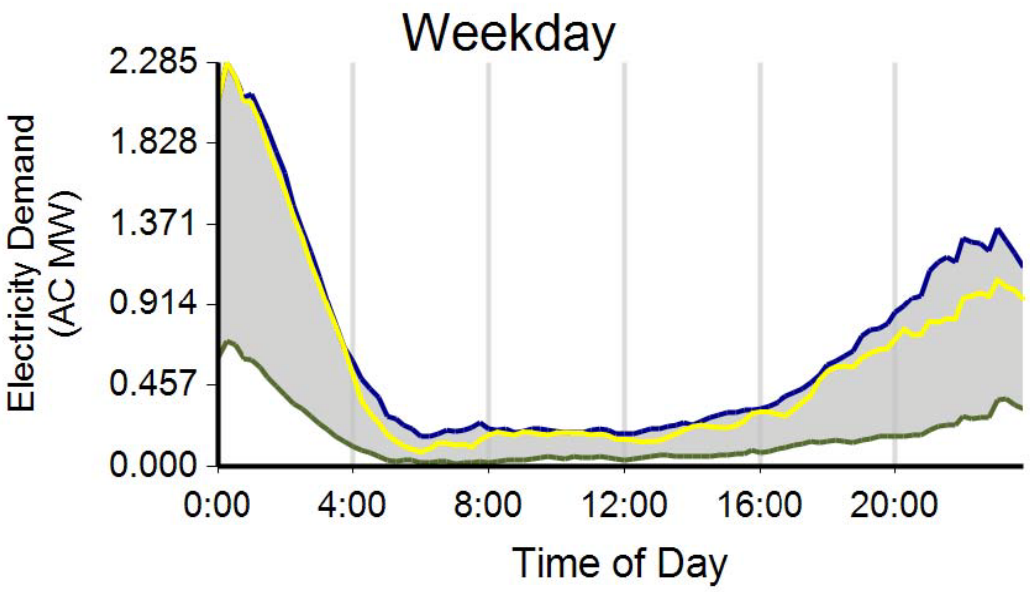


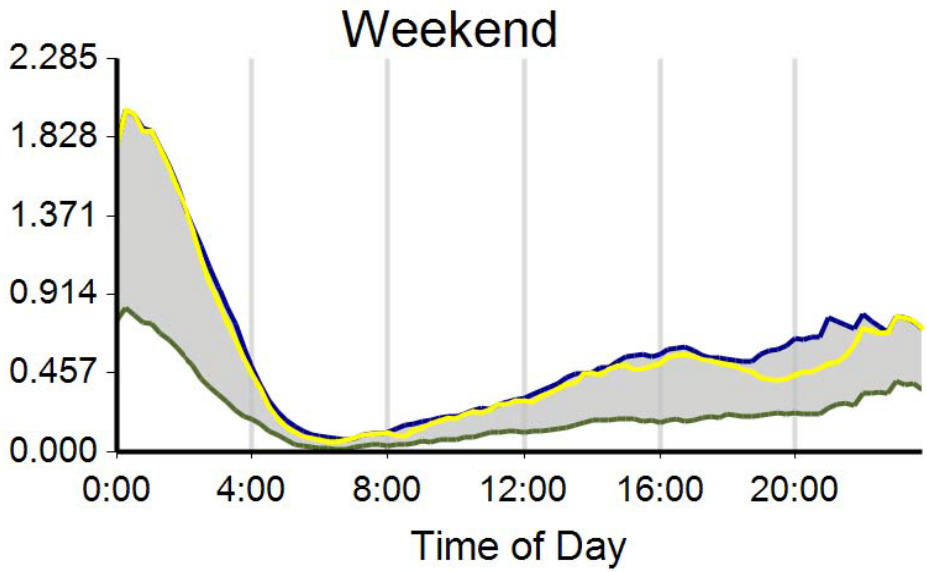
EV Project – Nissan Leaf Usage





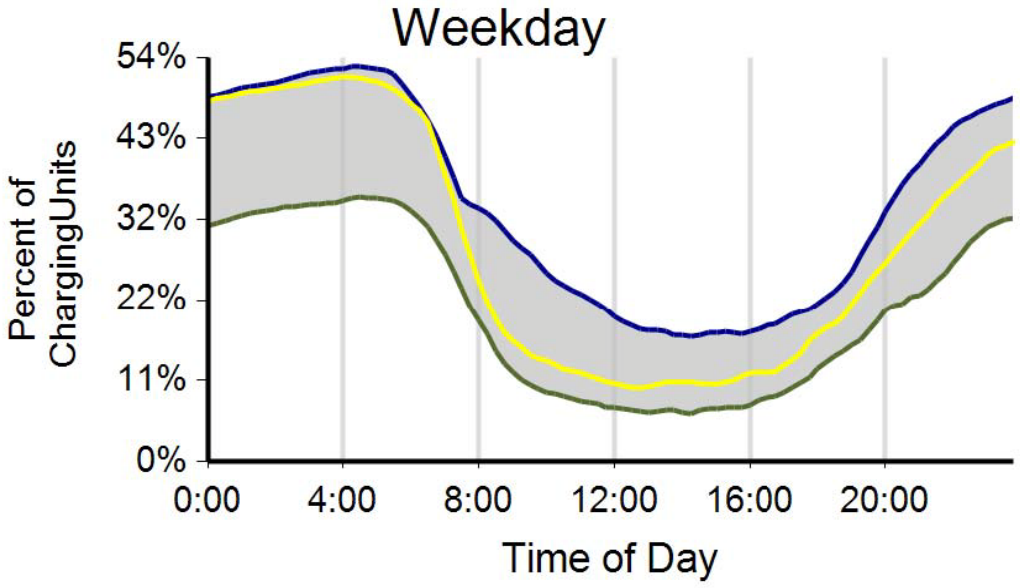
EV Project – Residential EVSE

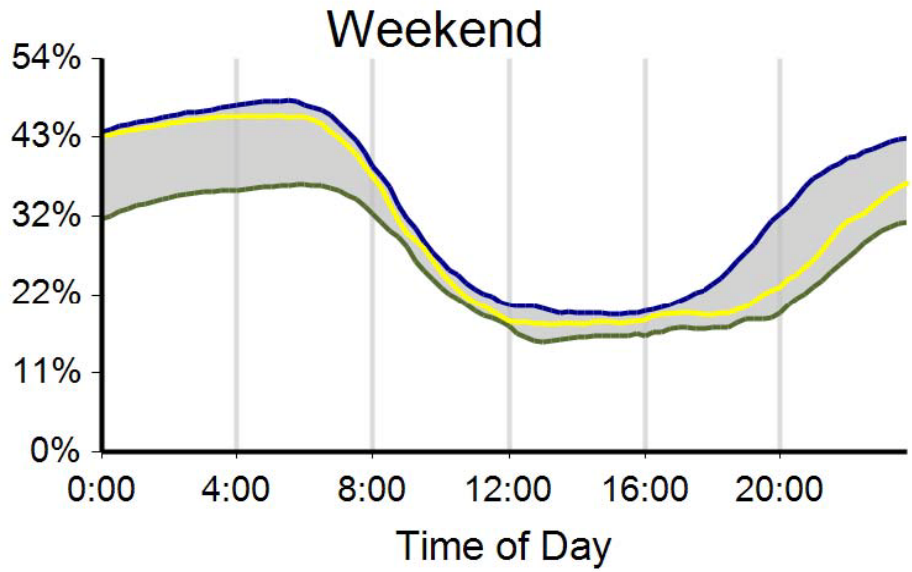




- **Power demand range for any time during reporting quarter**
- **Yellow line is daily profile for the day with quarterly peak demand**
- **Both graphs in AC MW**
- **Based on 15 minute rolling average MW demand**
- **National data. All 2,413 Residential Level 2 EVSE. July-Sept 2011**

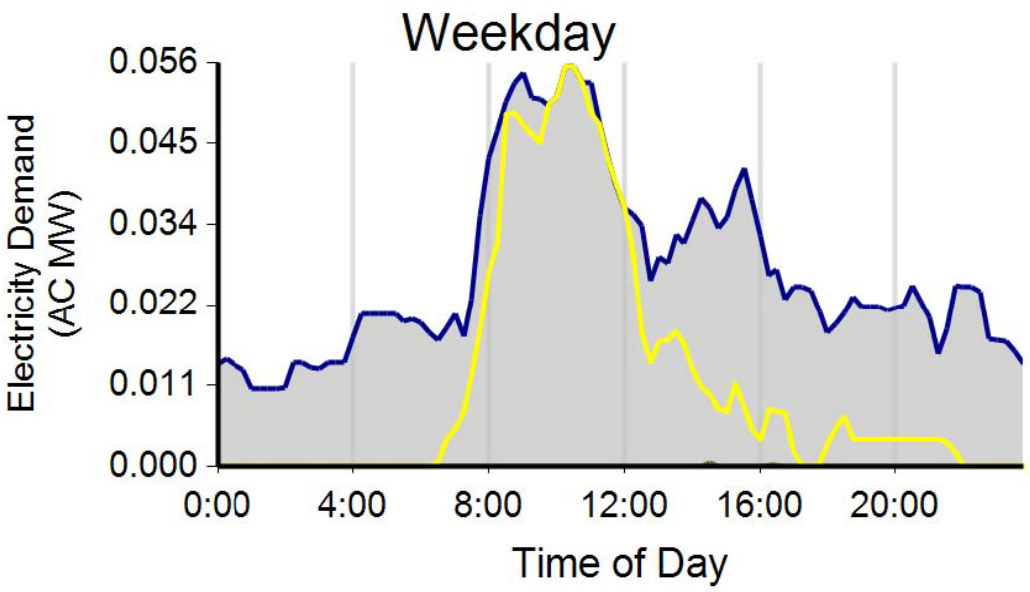
EV Project – Residential EVSE

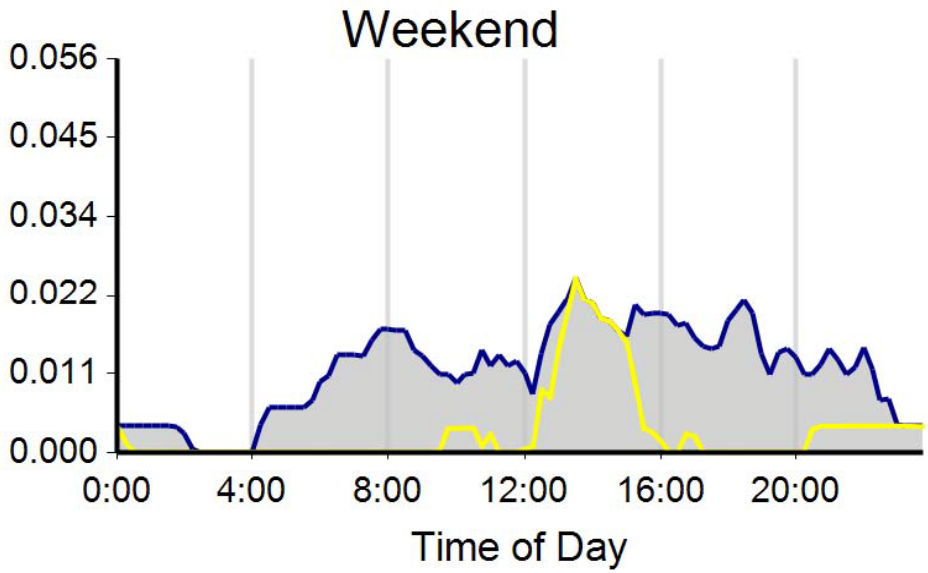




- **Percentage of charging units with a vehicle connected**
- **Yellow line is for day with peak power demand**
- **Both graphs percent of charging units**
- **Based on 15 minute increments**
- **National data. All 2,413 Residential Level 2 EVSE. July-Sept 2011**

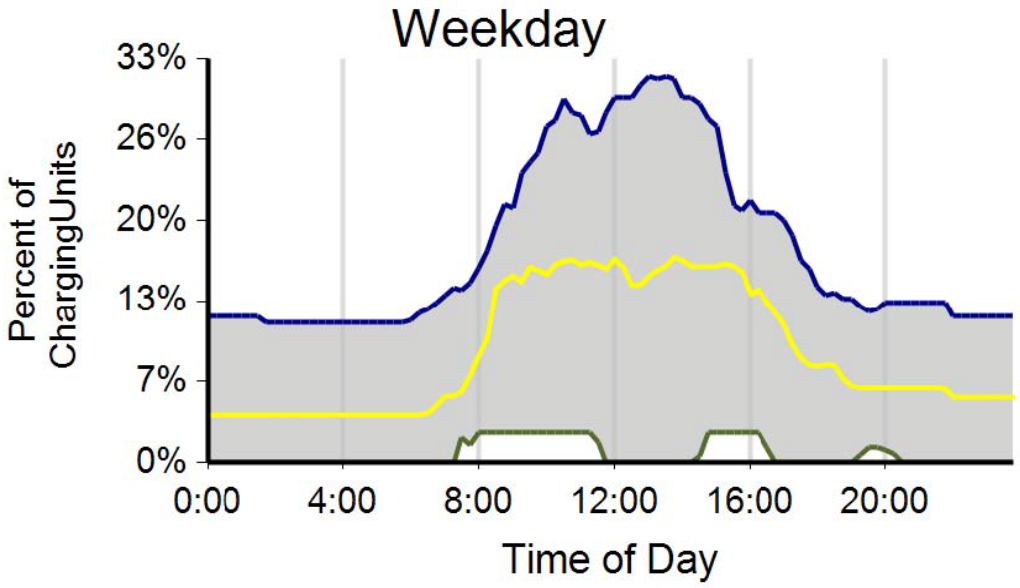
EV Project – Public EVSE

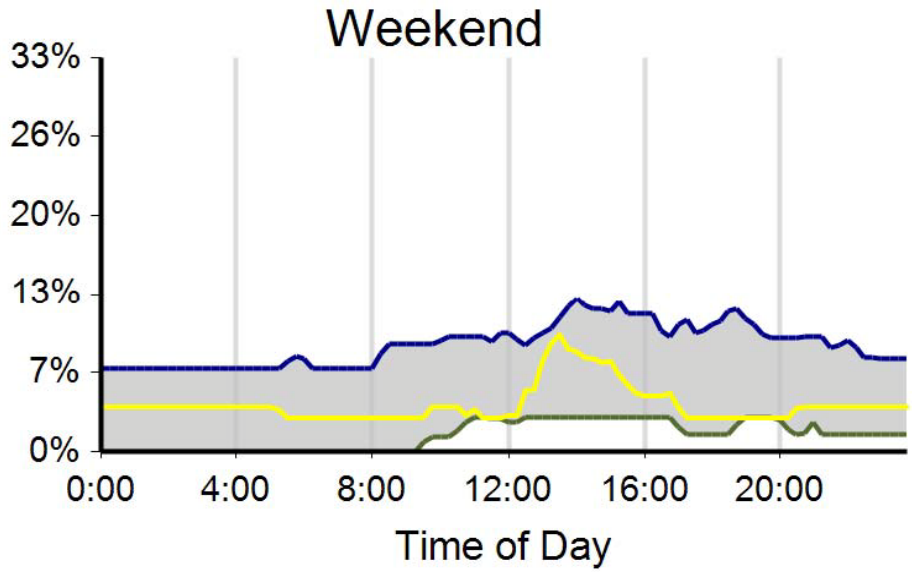




- **Power demand range for any time during reporting quarter**
- **Yellow line is daily profile for the day with quarterly peak demand**
- **Both graphs in AC MW**
- **Based on 15 minute rolling average MW demand**
- **National data. All 170 Public Level 2 EVSE. July-Sept 2011**

EV Project – Public EVSE





- **Percentage of charging units with a vehicle connected**
- **Yellow line is for day with peak power demand**
- **Both graphs percent of charging units**
- **National data. All 170 Public Level 2 EVSE. July-Sept 2011**

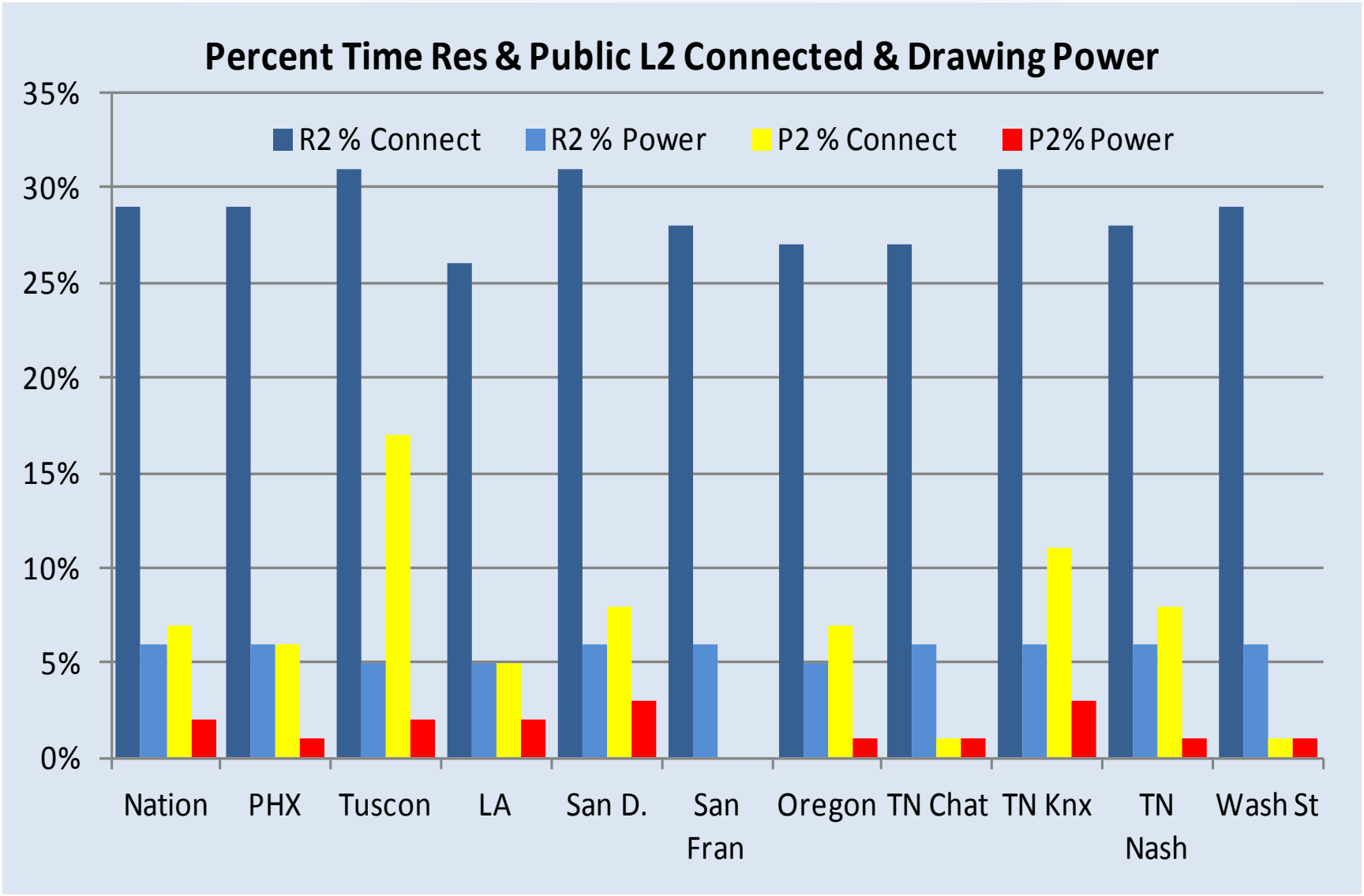
EV Project – EVSE Infra. Summary Report

- **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/end combined**

EV Project – EVSE Infra. Summary Report



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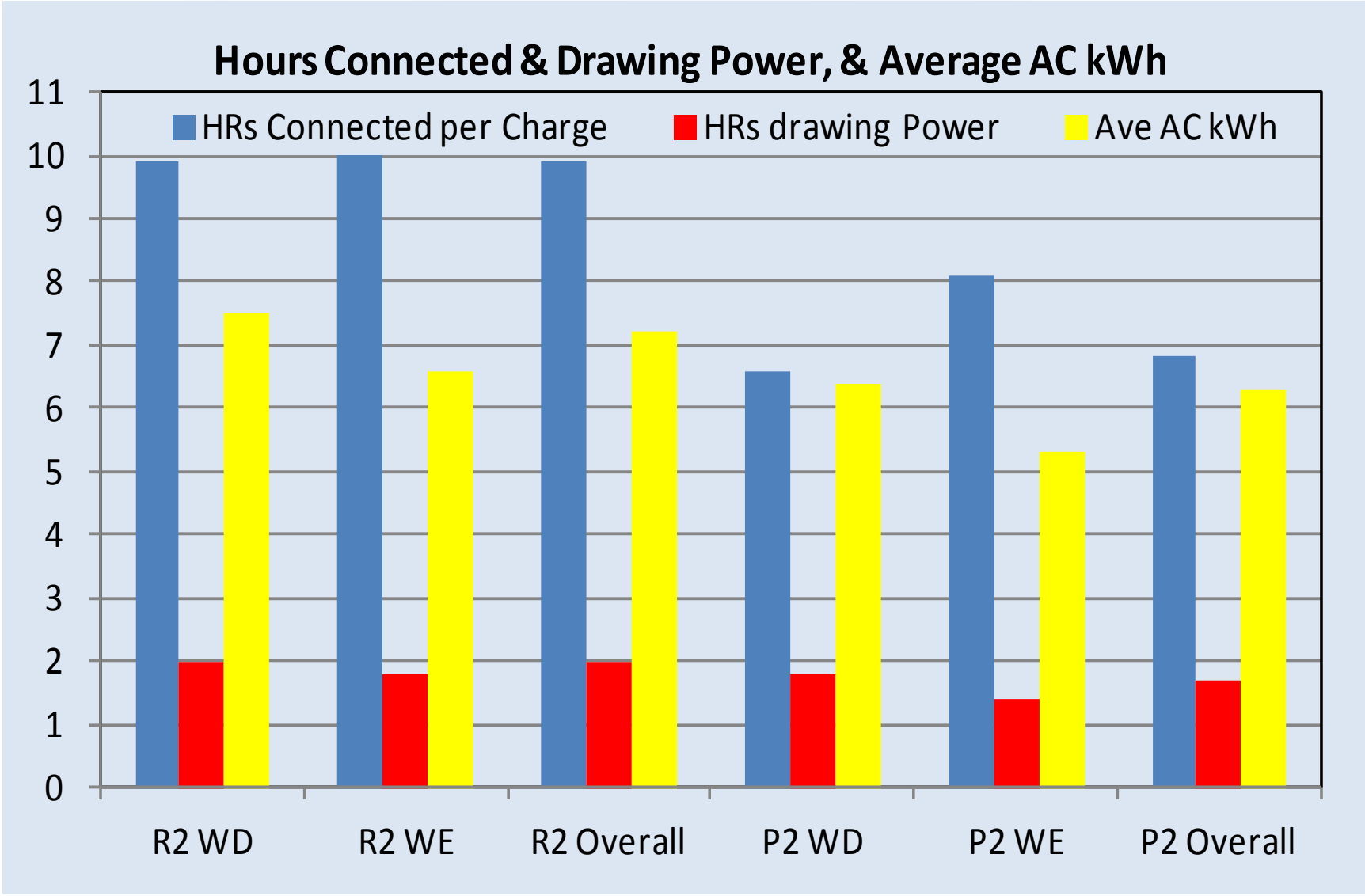

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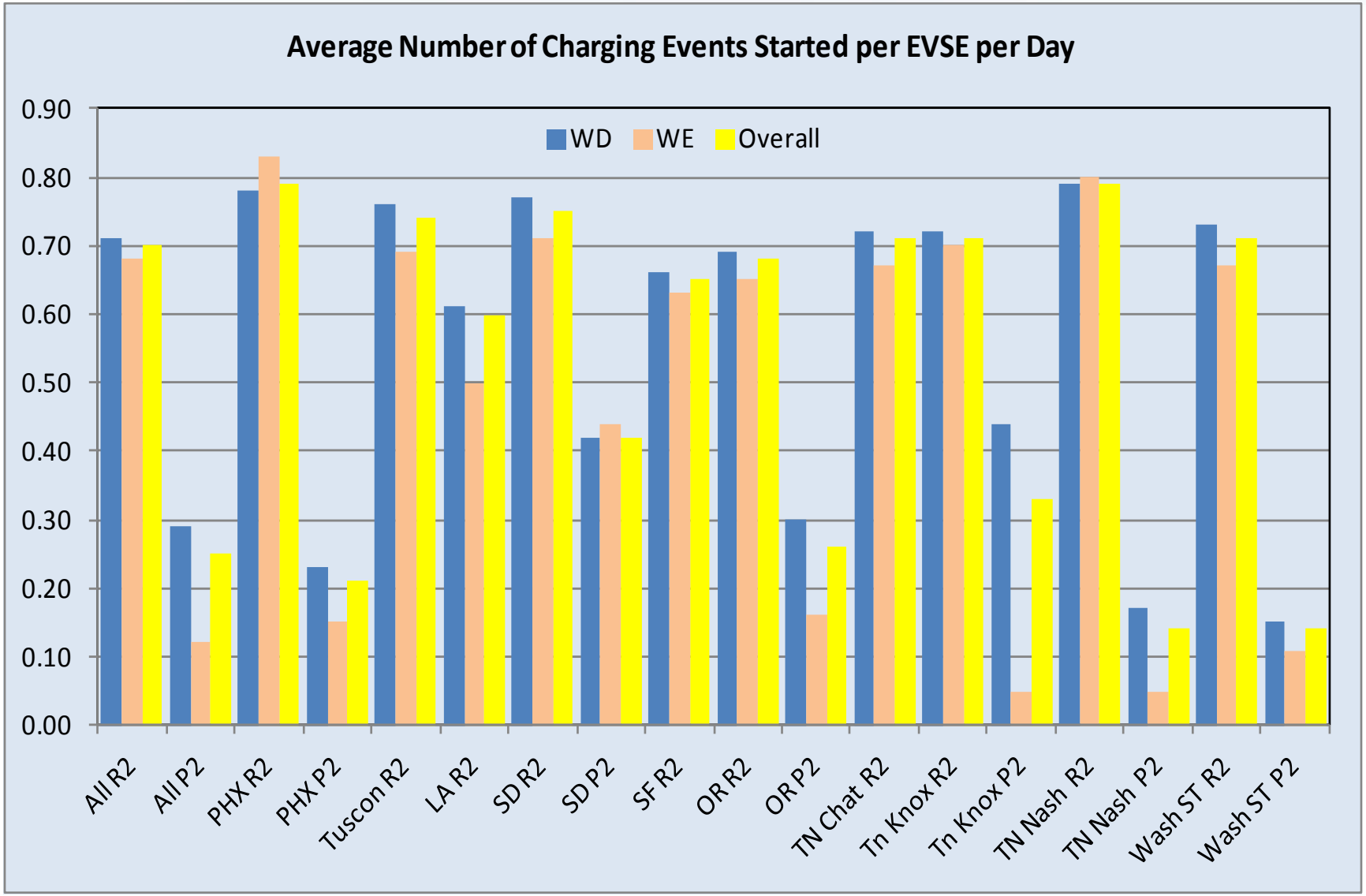
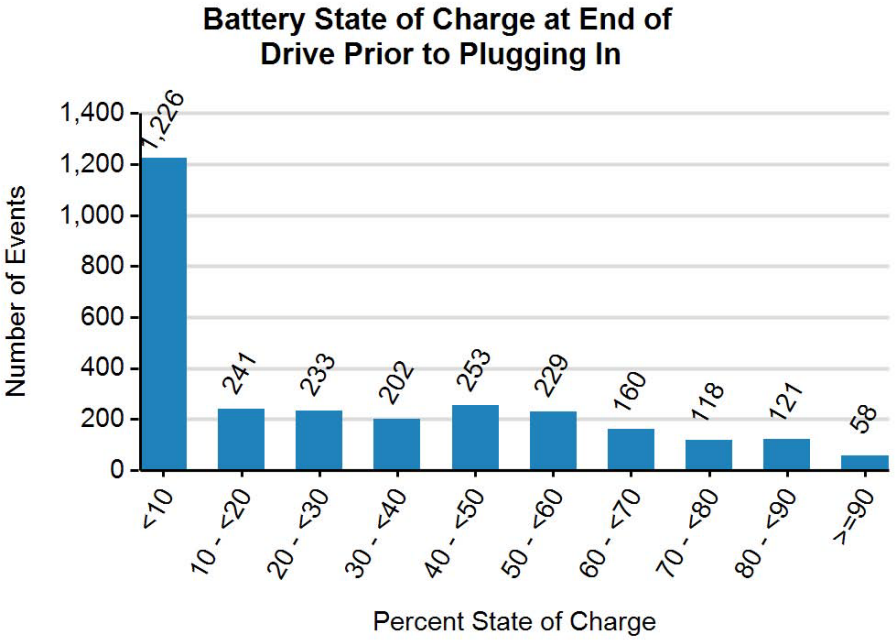


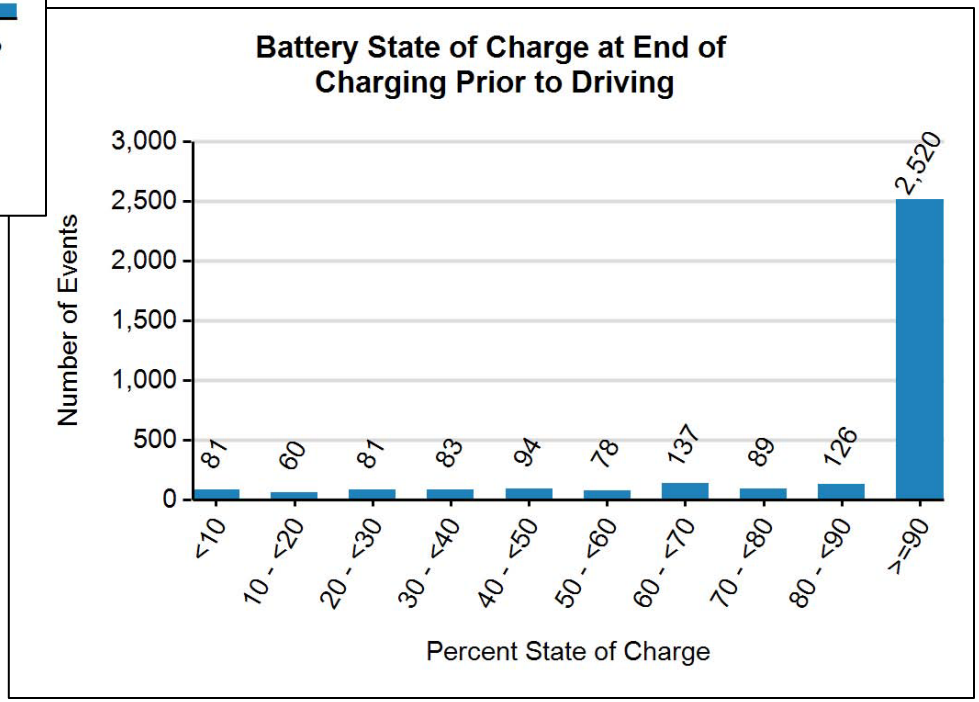
Chevrolet Volt DOE ARRA Project

- **110 Volts 3rd quarter report 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**

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 month	119 AC kWh

Chevrolet Volt DOE ARRA Project





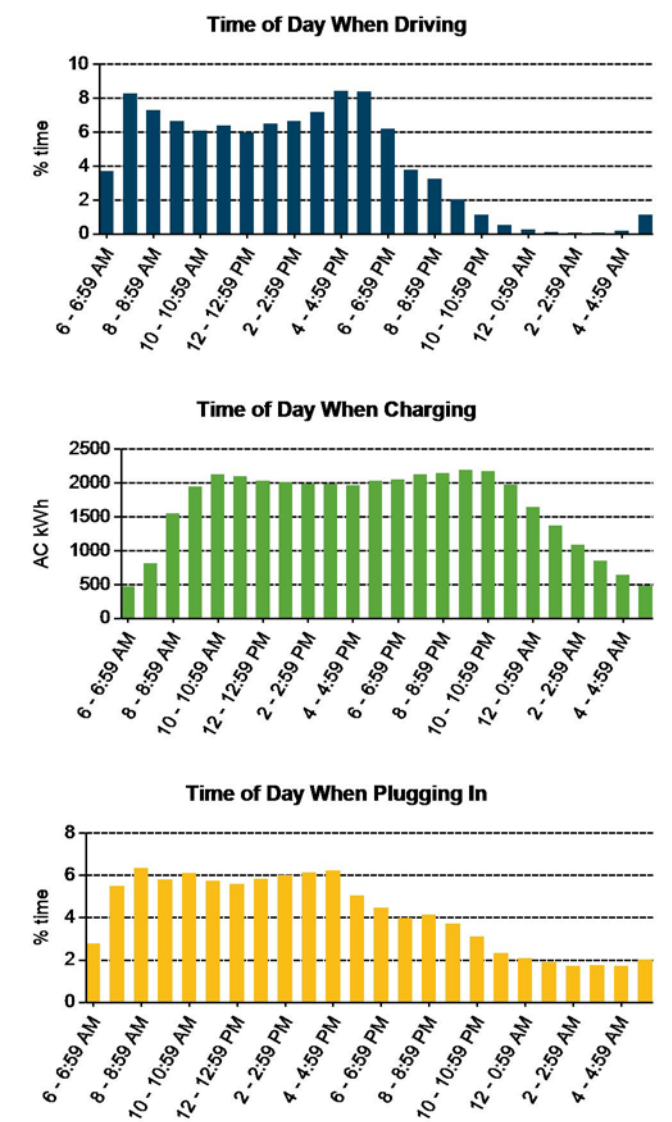
Ford Escape Advanced Research Vehicle

- 21 Ford Escape PHEVs (November 2009 – 2011)
- 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
- 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)
- 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



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy | VEHICLE TECHNOLOGIES PROGRAM

Chrysler RAM PHEV Fleet

Number of vehicles: 37
Reporting period: July 11 - Aug 11
Date range of data received: 7/1/2011 to 8/31/2011
Number of vehicle days driven: 615

All Trips Combined

Overall gasoline fuel economy (mpg)	16
Overall AC electrical energy consumption (AC Wh/mi)[1]	162
Overall DC electrical energy consumption (DC Wh/mi)[2]	94
Overall DC electrical energy captured from regenerative braking (DC Wh/mi)	53
Total number of trips	3,443
Total distance traveled (mi)	13,911

Trips in Charge Depleting (CD) mode[3]

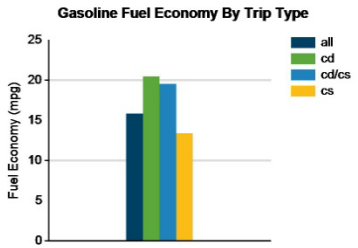
Gasoline fuel economy (mpg)			20
DC electrical energy consumption (DC Wh/mi)[4]			282
Number of trips			1,310
Percent of trips city | highway	98%	|	2%
Distance traveled (mi)			3,779
Percent of total distance traveled			27%

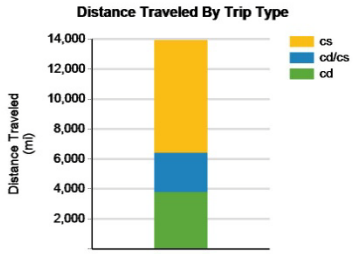
Trips in both Charge Depleting & Charge Sustaining (CD/CS) modes[5]

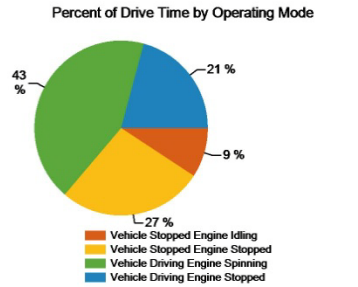
Gasoline fuel economy (mpg)			20
DC electrical energy consumption (DC Wh/mi)[6]			121
Number of trips			175
Percent of trips city | highway	86%	|	14%
Distance traveled CD | CS (mi)	1,232	|	1,433
Percent of total distance traveled CD | CS	9%	|	10%

Trips in Charge Sustaining (CS) mode[7]

Gasoline fuel economy (mpg)			13
Number of trips			1,958
Percent of trips city | highway	98%	|	2%
Distance traveled (mi)			7,505
Percent of total distance traveled			53%







Notes: 1 - 9. Please see http://avt.inl.gov/pdf/phev/chryslerreportnotes.pdf for an explanation of all PHEV Fleet Testing Report notes.

The Chrysler RAM PHEV Fleet was designed as a demonstration program of customer duty cycles related to plug-in electric vehicles and may not necessarily demonstrate optimized fuel economy.

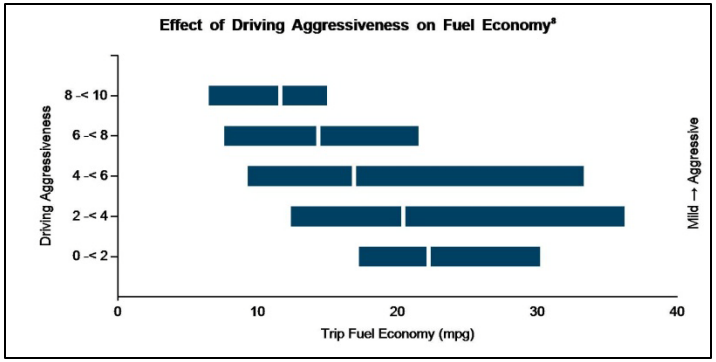
Vehicle fuel economy is based on customer usage and may not be representative of maximum potential fuel economy.

Idaho National Laboratory | CHRYSLER

Idaho National Laboratory

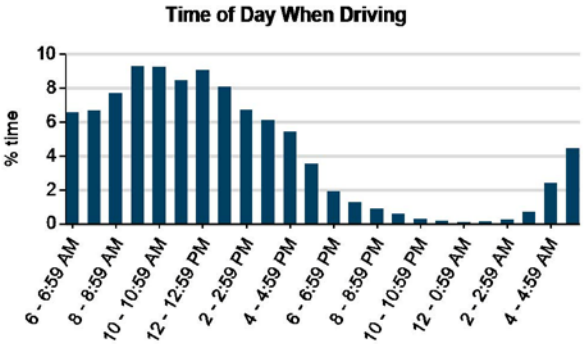
Chrysler Ram PHEV Project

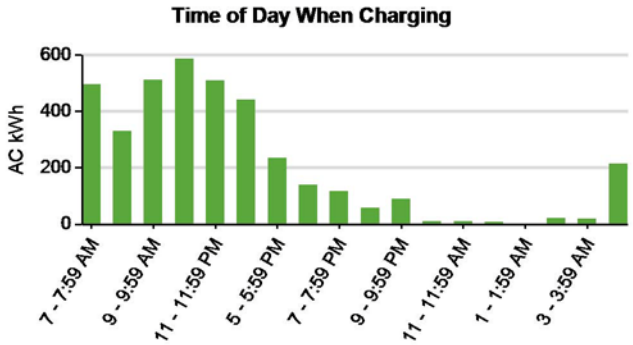
- 70 Chrysler Ram PHEVs
- 70,000 test miles and 11,000 trips
- All trips, 18 mpg, 115 AC Wh/mi & 69 DC Wh/mi
- CD, 23 mpg & 248 DC Wh/mi
- CS, 17 mpg
- Plugging in = 35% increase in overall MPG when comparing CD to CS trips

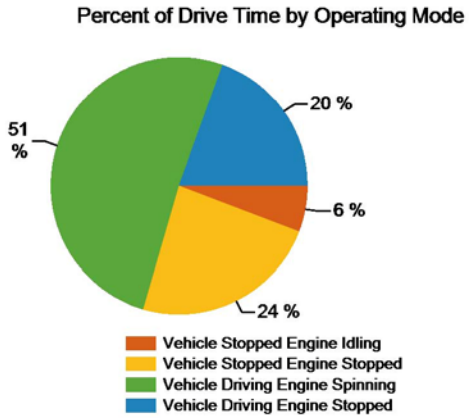


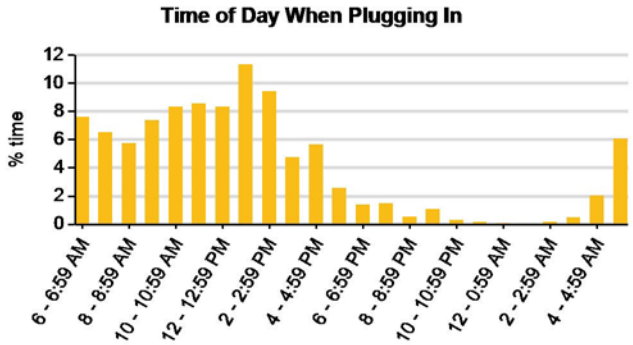
Chrysler Ram PHEV Pickups

- **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**









Summary – Based on Early Data

- **Leafs: 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 EV Project residential Level 2 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**
- **Today's grid-connected electric drive technologies result in 35% to 100% reductions in petroleum use**

Acknowledgement

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

More Information

http://avt.inl.gov

INL/MIS-12-24433