U.S. Department of Energy's Vehicle Technologies Program

Jackson Hole - EV 101 & INL's EV and Charging Infrastructure Experience

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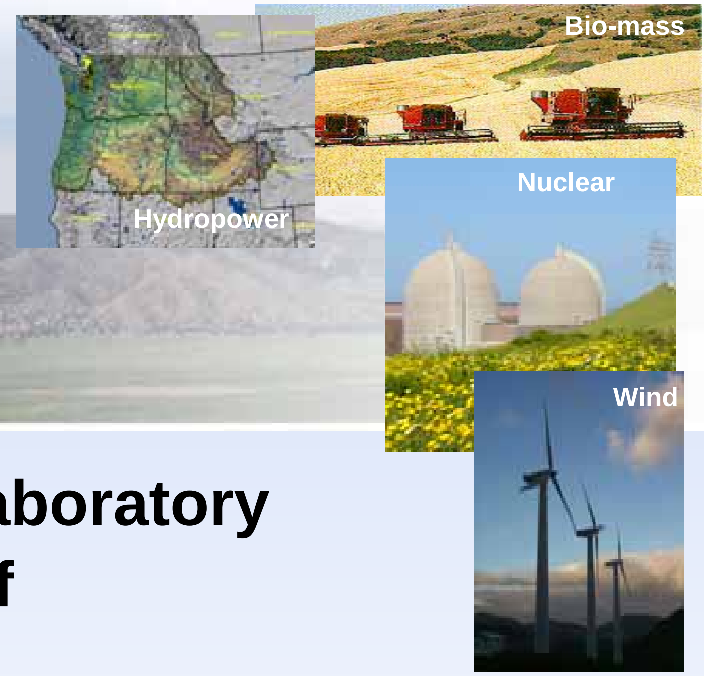
This presentation does not contain any proprietary or sensitive information

Idaho National Laboratory

Presentation Outline

- **INL's Vehicle Technology Experience and General Data Collection Methods**
- **Comparing Electric Drive Vehicle Technologies**
- **Grid Connected Vehicle Charging Infrastructure Overview**
- **EV Project & National Results**
- **EV Project EVSE and DCFC – Usage, Deployment, Costs, and Some Lessons Learned**
- **Other Testing Activities**
- **Acknowledgements and Sources**
- **A little comic relief**

Idaho National Laboratory

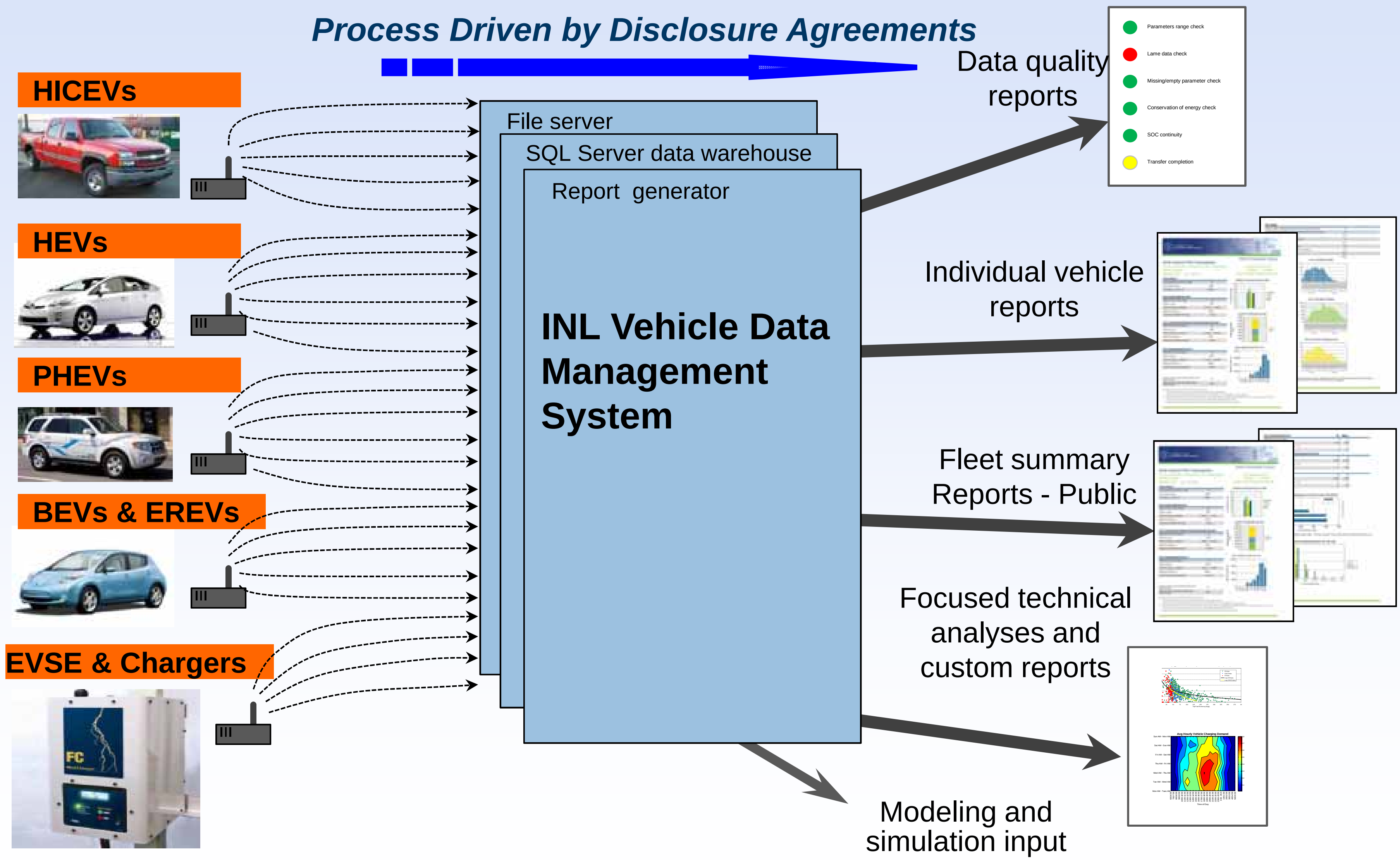


- U.S. Department of Energy (DOE) laboratory
- 890 square mile site with 4,000 staff
- Support DOE's strategic goal:
  - Increase U.S. energy security and reduce the nation's dependence on foreign oil
- Multi-program DOE laboratory
  - Nuclear Energy
  - Fossil, Biomass, Wind, Geothermal and Hydropower Energy
  - Advanced Vehicles and Battery Development
  - Homeland Security and Cyber Security

Vehicle / Infrastructure Testing Experience

- **120 million test miles accumulated on 11,600 electric drive vehicles and 16,800+ EVSE and DCFC**
- **EV Project: 8,110 Leafs, Volts and Smart EVs, 12,604 EVSE and DC Fast Chargers (DCFC), 100 million test miles. 1 million miles of data every 6 days**
- **Charge Point: 4,217 EVSE reporting 997,000 charge events**
- **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



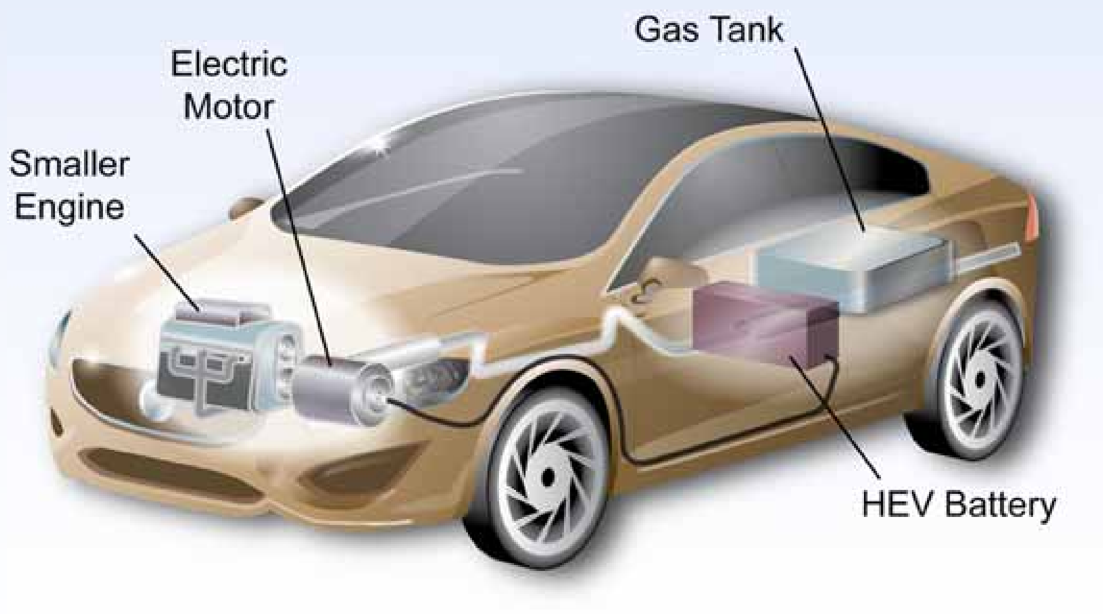
Comparing Electric Drive Vehicle Technologies

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

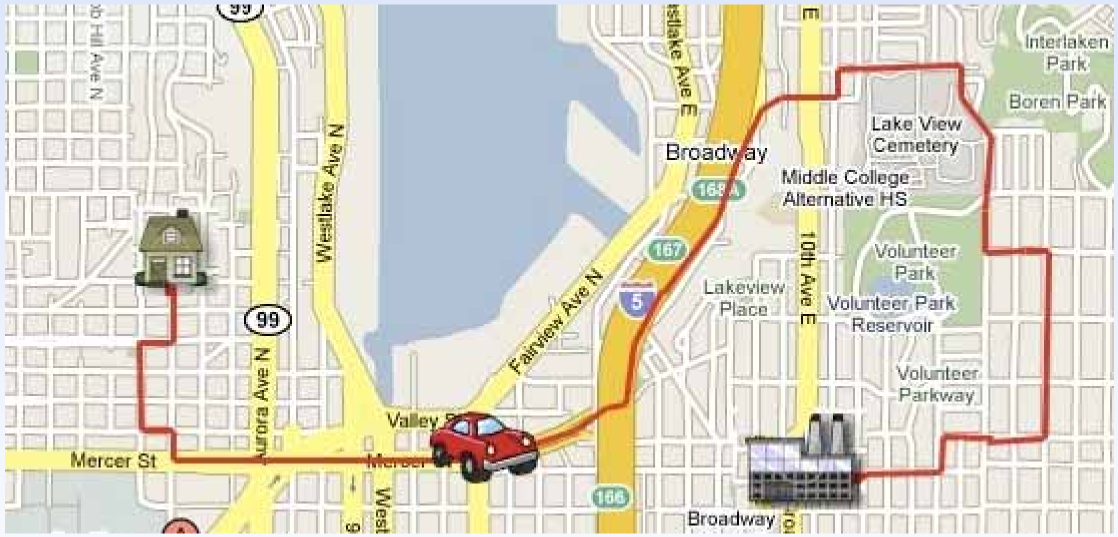
- **Plug-in Hybrid Electric Vehicle (PHEV) with ICE and electric drive**

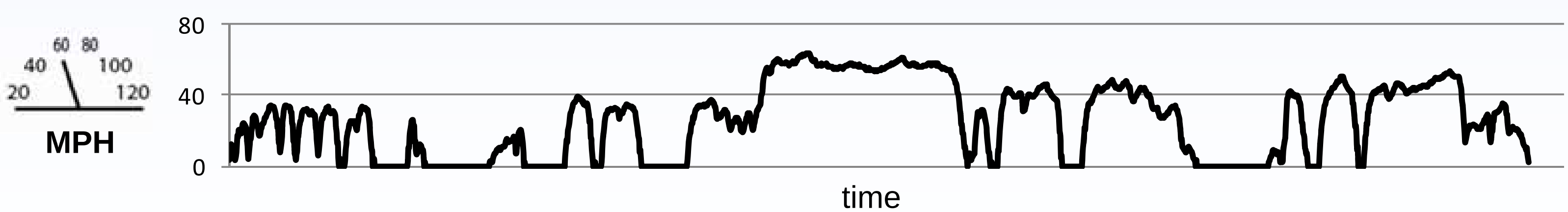
Comparison of Vehicle Technology

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

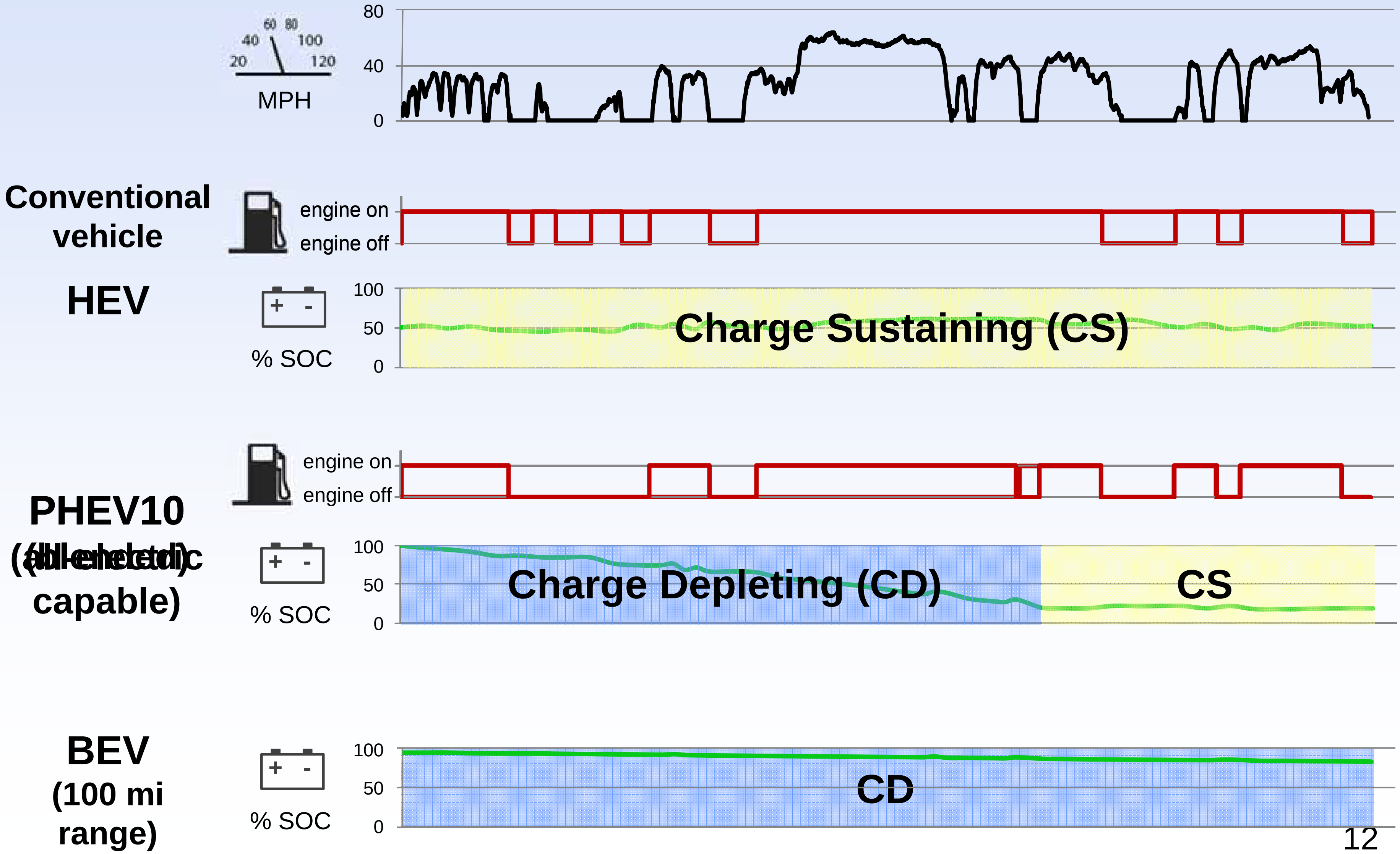
Conceptual Comparison of Vehicle Operation

Hypothetical 15 mile drive cycle





Conceptual Comparison of Vehicle Operation



Energy Efficiency

Drivetrain Efficiency – How much of the fuel energy gets to the road

Chemical or Electrical Energy (Gallons of gasoline, kWh of electricity, i.e. what you pay for)

Vehicle Engine & Drivetrain Efficiency (i.e. Engine, Transmission, Accessories)

Energy to the Wheels:
EV: 59-62%
Gasoline: 17-21%
PHEV: Somewhere in between…

Chassis Efficiency – How far does the wheel power move the car?

Energy to the wheels

Mass, Aerodynamic drag, Rolling Resistance, etc

Distance Travelled

Determines how much gasoline or electrical energy is used to drive some distance: i.e. MPG ratings.

Think Hummer vs. Civic

At the End of the Day, How Much $$$$?

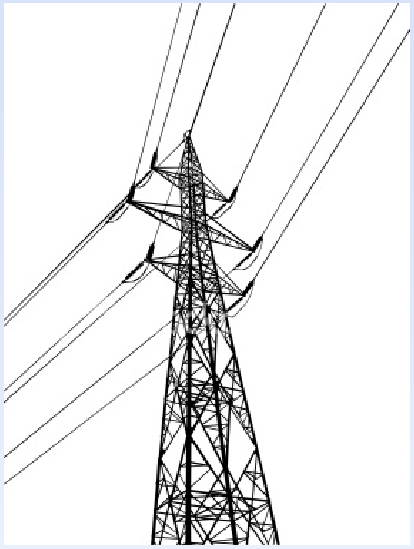
PEV Model	kWh / 100 Miles[1]	Cost to Travel 100 Miles[2]	ICE Model	MPG[1]	Gal / 100 Miles	Cost to Travel 100 Miles[2]
Chevrolet Volt	35	$3.85	Chevrolet Cruze	30	3.33	$12.17
Ford Focus EV	32	$3.52	Ford Focus	31	3.23	$11.77
Honda Fit EV	29	$3.19	Honda Fit	30	3.33	$12.17
Nissan Leaf (`12)	34	$3.74	Nissan Versa	35	2.86	$10.43
Average	32.50	$3.58	Average	31.5	3.17	$11.59

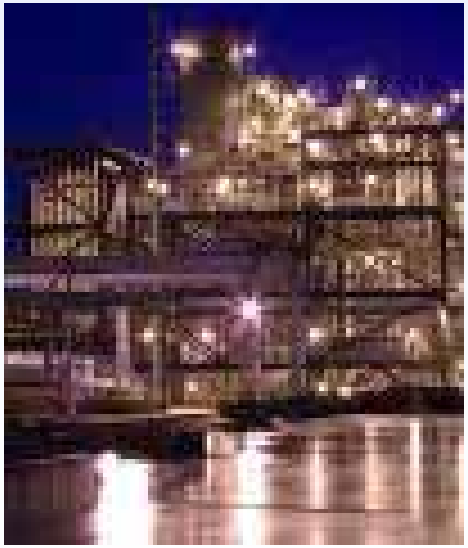
1 - Sources - 2013 Fuel Economy Guide Page
2 - Assumes 11 cents per kWh and $3.65 gallon

Grid Connected Vehicle Charging Infrastructure Overview

Vehicle Electrification: Grid Impacts

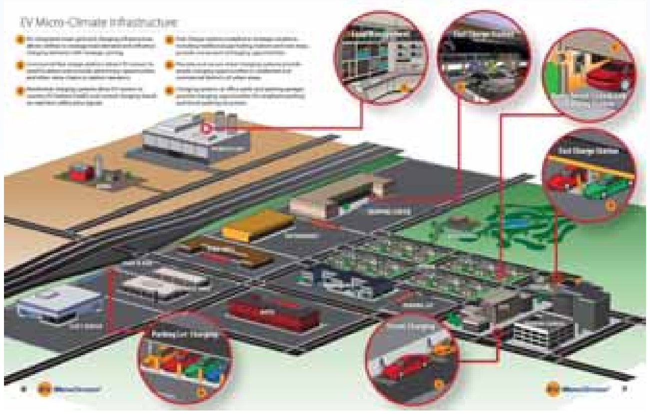
- In the U.S., current grid capacity could supply electricity for 70% of our vehicles without adding capacity, but assumes:
  - Vehicles would only charge off-peak
  - “Perfect” distribution of electricity
  - No local impacts such as overburdening neighborhood transformers
- EVs and PHEVs will not cause a grid “meltdown” but we clearly need to work to reduce vehicle rollout impacts
- Smart charging will be key to lowering costs and minimizing impacts
- Time of day pricing also important





Build-out of Charging Infrastructure

- Key today: Home "Location" Charging
  - Cost and installation process established at single family homes
  - Currently a significant barrier in multi unit housing
  - Fleet charging needs good planning
- Public Charging
  - Expensive if not well utilized
  - Expansive to fully cover full driving patterns
- Ideally need market pull to determine public infrastructure build-out
  - PHEVs may be key to help initiate market pull for public infrastructure



Innovative Approaches

- Battery swapping
  - Requires OEM buy-in
- Fast Charging (becoming less innovative)
- Innovative Financing
- Secondary use of batteries
  - Utility ancillary services
  - Bulk energy storage
  - Present value
- Vehicle to Grid (V2G)

Level 1 Charging Level

- This method allows broad access to change an EV or PHEV by plugging into the most common grounded electrical outlet in the U.S.
- AC energy transfer to onboard charger
- Typical hardware includes portable cord set that must utilize a vehicle connector UL approved for the purpose, a GFCI, and otherwise meet NEC 625 requirements and SAE standards, including the J1772 connector:
  - Separate, commercial-grade circuit and commercial-grade wall socket even at home
  - Standard 120V/15A or 20A
  - Current 12 amps or 16 amps (80% of amp breaker)
  - Power 1.44 kW
- Charge Times (general approximation)
  - Battery EV 14 hours (20 kWh battery) to 39 hours (56 kWh battery)
  - PHEV 3 to 8 hours

Level 2 Charging Level

- The most common method for residential and commercial charging
- EVSE (electric vehicle supply equipment) for AC energy transfer to onboard charger
- Permanently attached wall box, GFCI, some vehicle communication, UL approved, NEC 625 requirements and SAE standards, including J1772 connector:
  – 240V single phase up to 100A
  – Current up to 80A (80% of amp breaker)
  – Power up to 19.2 kW
  – 3.3 kW or 6.6 kW

- Charge Times (general approximation)
  – 20 kWh Battery EV 3 hours (at 6.6 kW) to 56 kWh battery in 8.5 hours (at 6.6k kW)
  – PHEV 1.5 to 3.6 hours (at 3.3 kW)

DC Fast Charging (DCFC)

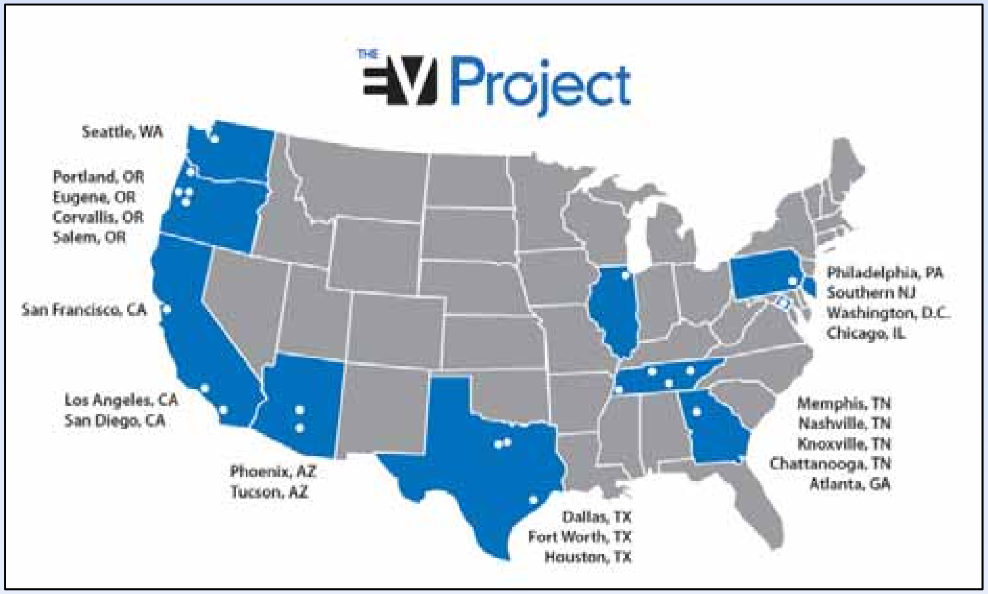
- Expected to be used in an intercity grid pattern or along travel routes between cities in commercial settings
- Off-board charger (high cost, large volume and weight)
- Used for DC energy transfer to vehicle
- Requires charger-to-vehicle communication and control
- Most U.S. fast chargers are using Japanese CHAdeMO protocol connector
- U.S. SAE standard connector not as common (change?)
- Up to 500VDC and 125A. 20 to 60 kW likely
- Charge Times are dependant on battery size
  - 20 kWh BEV is 50% recharge in 15 minutes and 80% recharge in 30 minutes
  - Charge times dependant on charger / battery relative sizing
  - Generally not used for PHEVs and NEVs due to small relative battery sizes

Charging Infrastructure Summary

- **EVSE is a device that allows an electric vehicle to be charged from an off-board electricity source (home outlet, public charging station etc)**
- **AC Level 1**
  - **120V/15-20A outlet typical**
  - **Typically portable**
  - **~1.4 kW, ~16+ hours**
- **AC Level 2**
  - **240V/20-40A outlet typical**
  - **Fixed location**
  - **~3.3 or 6.6 kW, ~4-8 hours**
- **DC Level 2 (DC Fast Charge)**
  - **480V 3phase (industrial power)**
  - **Large, fixed, $$$**
  - **20 to 50kW, ~30 minutes**

EV Project & National Results

EV Project Goal, Locations, Participants, and Reporting



- **50-50 DOE ARRA and ECOtality North America funded**
- **Goal: Build and study mature charging infrastructures and take the lessons learned to support the future streamlined deployment of grid-connected electric drive vehicles**
- **ECOtality is the EV Project lead, with INL, Nissan and Onstar/GM as the prime partners, with more than 40 other partners such as electric utilities and government groups**

EV Project – EVSE Data Parameters Collected per Charge Event

- Data from ECOtality's Blink & other EVSE networks
- 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
- Date/Time Stamp
- Unique ID for Charging Event
- Unique ID Identifying the EVSE
- And other non-dynamic EVSE information (GPS, ID, type, contact info, etc.)

EV Project – Vehicle Data Parameters Collected per Start/Stop Event

- **Data is received via telematics providers from Chevrolet Volts and Nissan Leafs**
- **Odometer**
- **Battery state of charge**
- **Date/Time Stamp**
- **Vehicle ID**
- **Event type (key on / key off)**
- **GPS (longitude and latitude)**
- **Recorded for each key-on and key-off event**

- **Additional data is received monthly from Car2go for the Smart EVs**

EV Project Data Complexity

- The EV Project has 44 Databases (DB)
  - Nissan Leaf & GM/OnStar Volt
  - ECOtality Blink, Aerovironment & EPRI EVSE
  - Admin (look up tables, territories, zips codes, QA parameters, etc.)
    - Each of the above six DBs has three versions (process, stage & production) = 18 DBs
  - Four GIS DBs for the Leafs, Volts, Blink EVSEs, and Base (streets, utility service territory areas, etc.)
  - Above 22 (18 + 4) DBs exist on two systems = 44 DBs
- Hundreds of algorithms and thousands of lines of code required to populate 150 pages of public quarterly reports
- INL must blend multiple data streams, from multiple sources, all on different delivery schedules
- This is not a flat file, spreadsheet experience and this is NOT a simple task

Data Collection, Security and Protection

- **All vehicle, EVSE, and PII raw data is legally protected by NDAs (Non Disclosure Agreements) or CRADAs (Cooperative Research and Development Agreements)**
  - **Limitations on how proprietary and personally identifiable information can be stored and distributed**
  - **Raw data, in both electronic and printed formats, is not shared with DOE in order to avoid exposure to FOIA**
  - **Vehicle and EVSE data collection would not occur unless testing partners trust INL would strictly adhere to NDAs and CRADAs**
  - **Raw data cannot be legally distributed by INL**

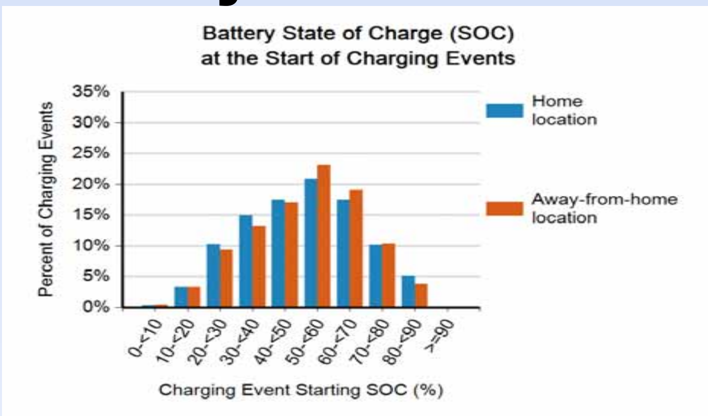
EV Project – National Data

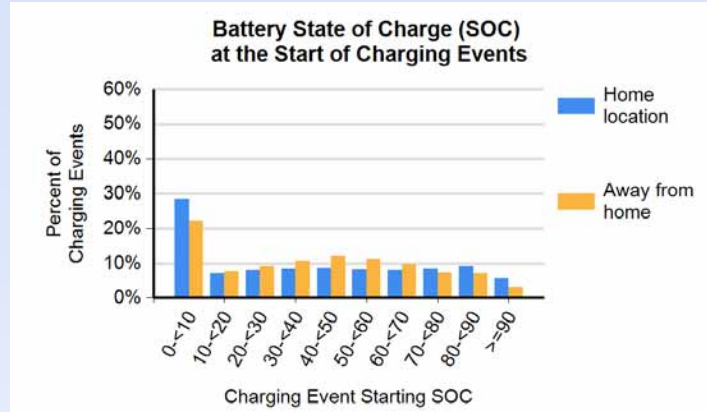
2st quarter 2013 Data Only

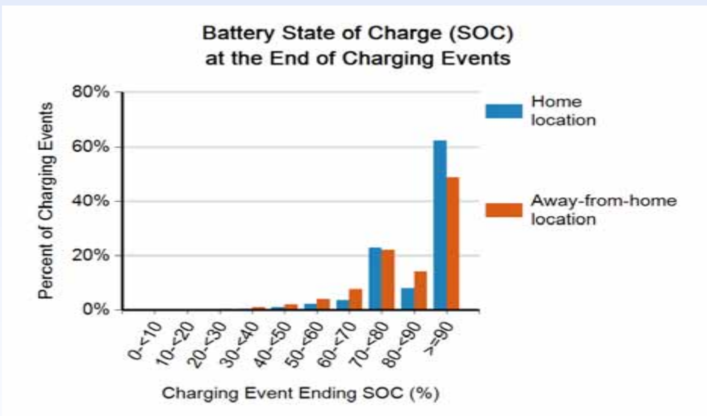
	Leafs	Volts
• Number of vehicles	4,261	1,895
• Number of Trips	1,135,000	676,000
• Distance (million miles)	8.04	5.75
• Average (Ave) trip distance	7.1 mi	8.3 mi
• Ave distance per day	29.5 mi	41.0 mi
• Ave number (#) trips between charging events	3.8	3.3
• Ave distance between charging events	26.7 mi	27.6 mi
• Ave # charging events per day	1.1	1.5

*** Note that per day data is only for days a vehicle is driven**

EV Project – Leaf & Volt Charging

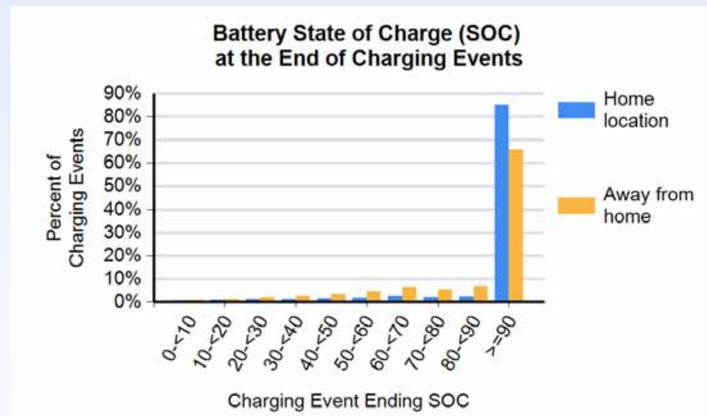


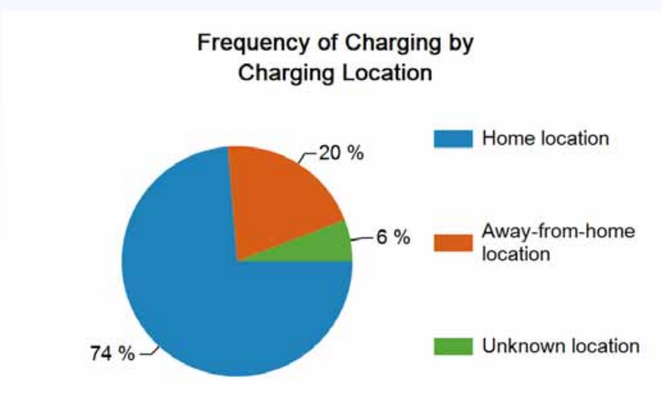


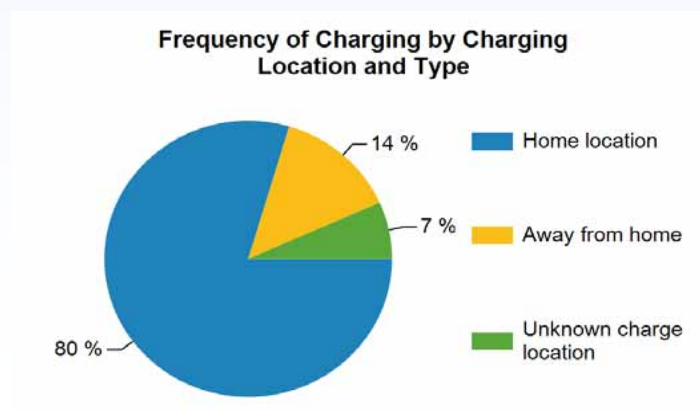


Leafs

Volts



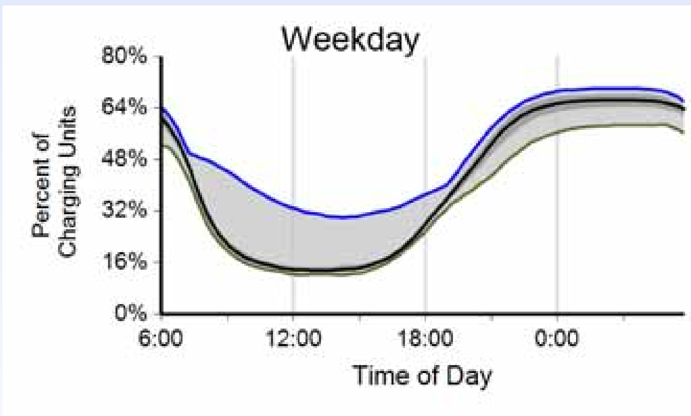




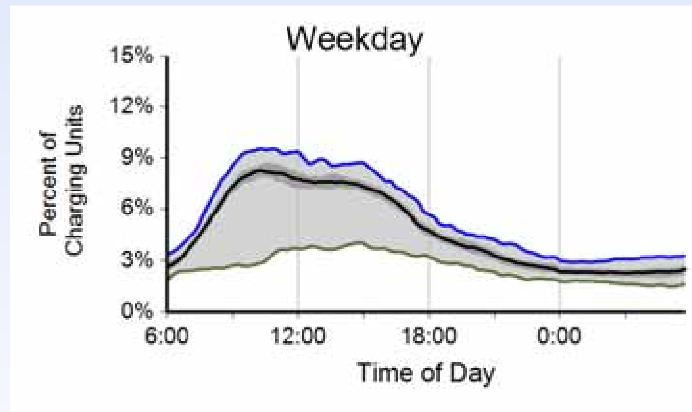
EV Project – EVSE Infra. Summary Report

- **National Residential and Public Level 2 Weekday EVSE 2nd Quarter 2013**
- **Residential and public connect time and energy use are fairly opposite profiles. Note different scales**

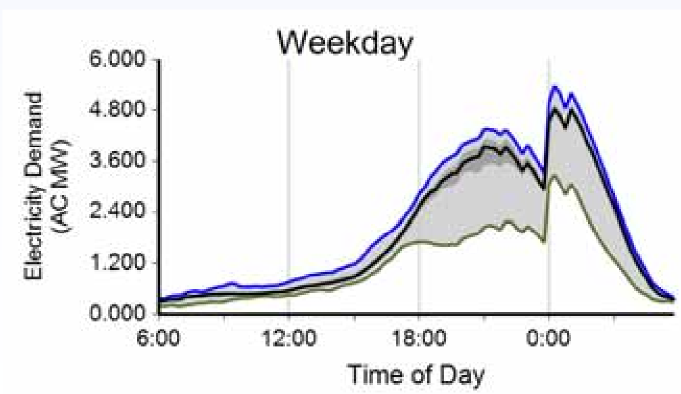
National Residential Connect Time



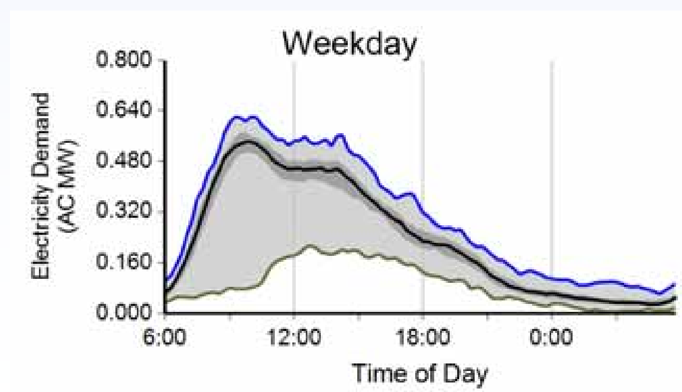
National Public Connect Time



National Residential Demand



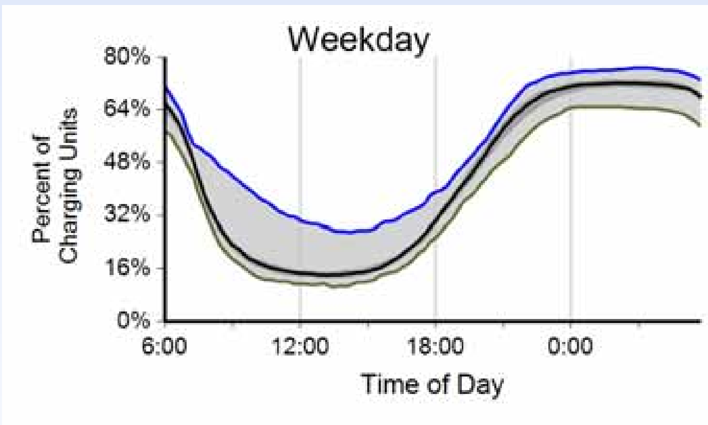
National Public Demand



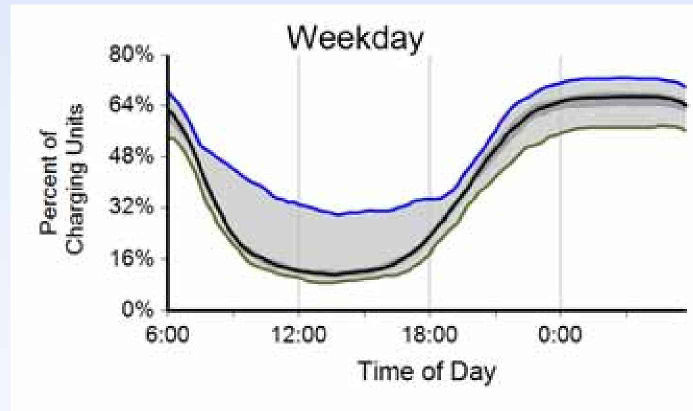
EV Project – EVSE Infra. Summary Report

- **Residential Level 2 Weekday EVSE 2nd Quarter 2013**
- **San Diego and San Francisco, with residential L2 TOU rates, are similar to national and other regional EVSE connect profiles**

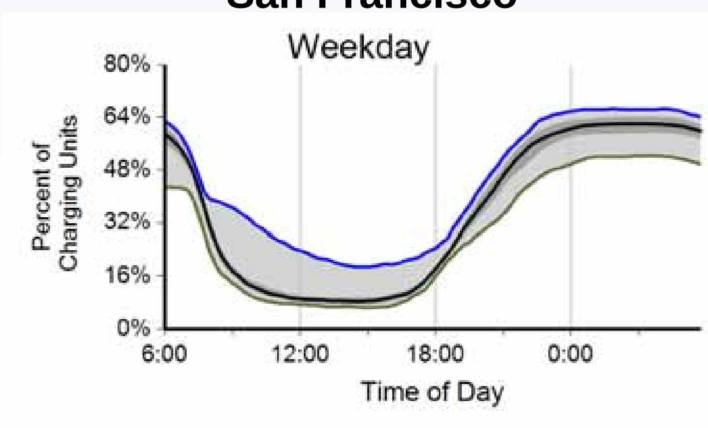
San Diego



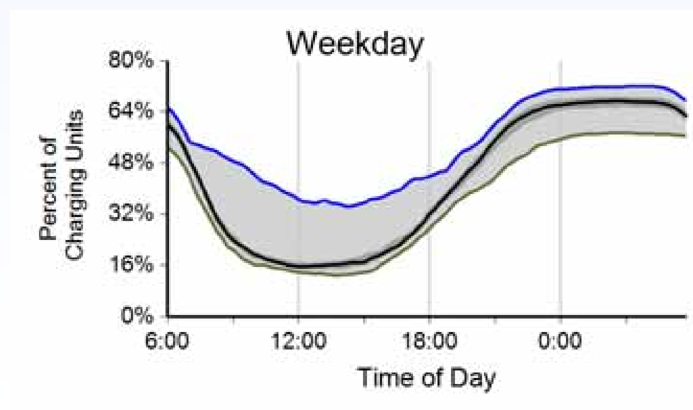
Los Angeles



San Francisco



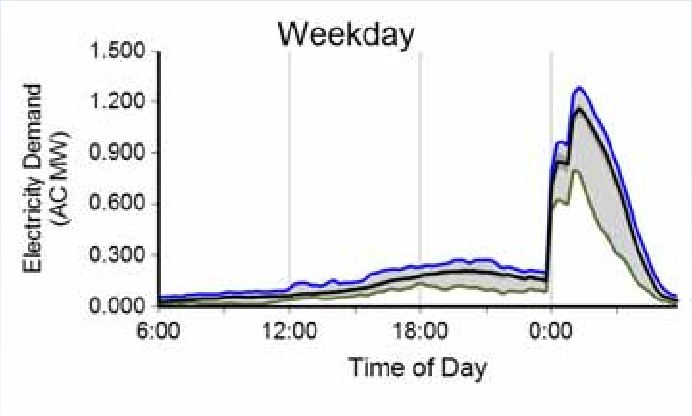
Washington State



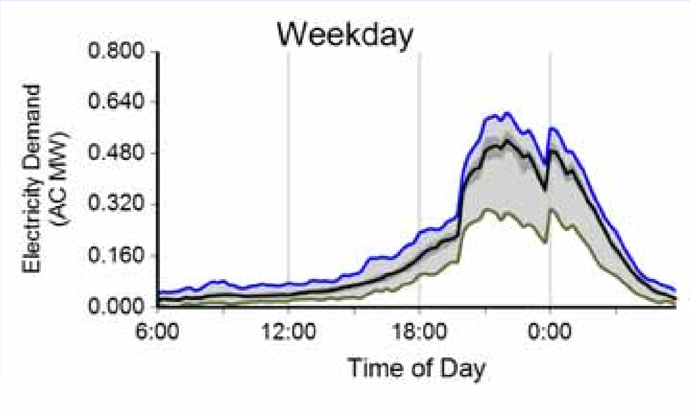
EV Project – EVSE Infra. Summary Report

- **Residential Level 2 Weekday EVSE 2nd Quarter 2013**
- **TOU kWh rates in San Diego and San Francisco clearly impact when vehicle charging start times are set**

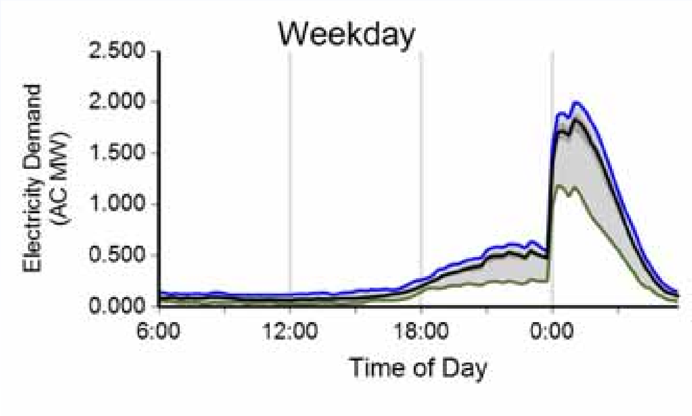
San Diego



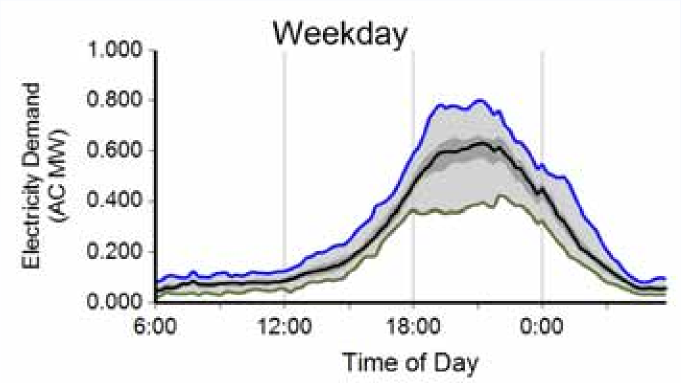
Los Angeles



San Francisco

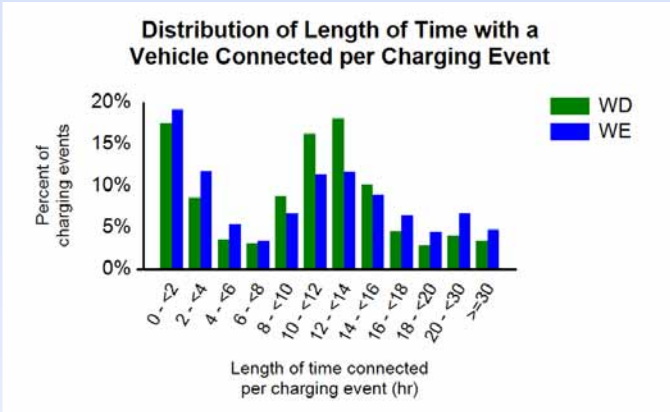


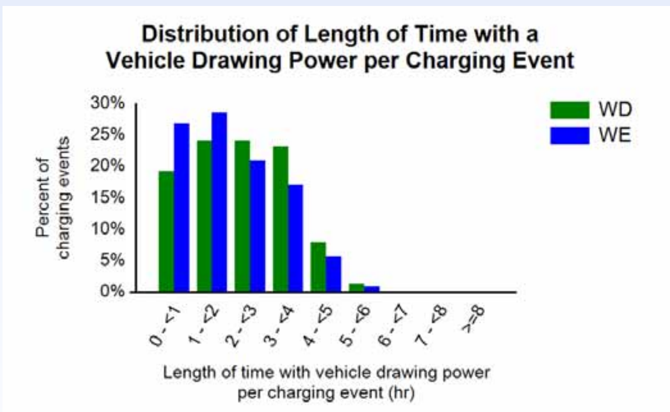
Washington State

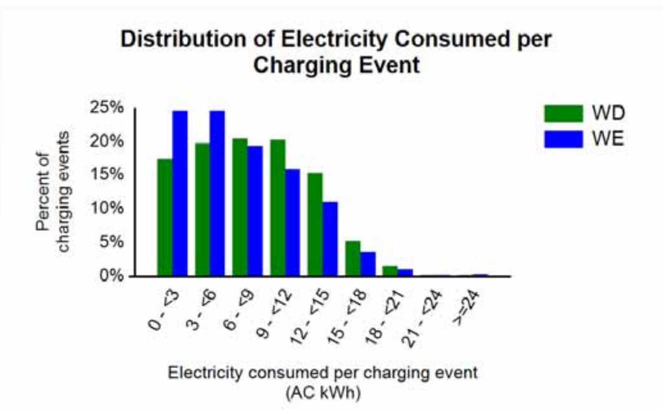


EV Project – EVSE Connect & Power

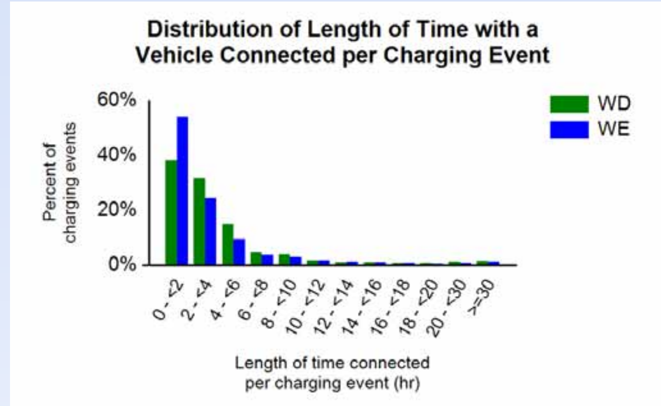
Residential

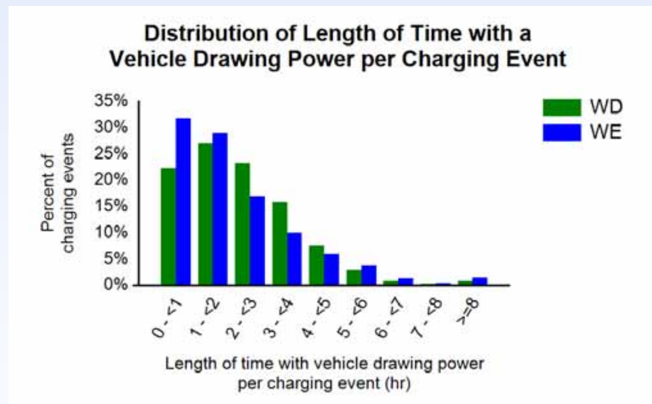


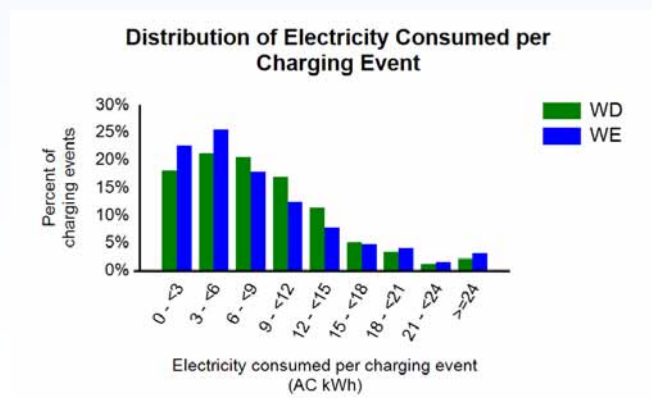




Non Residential Public

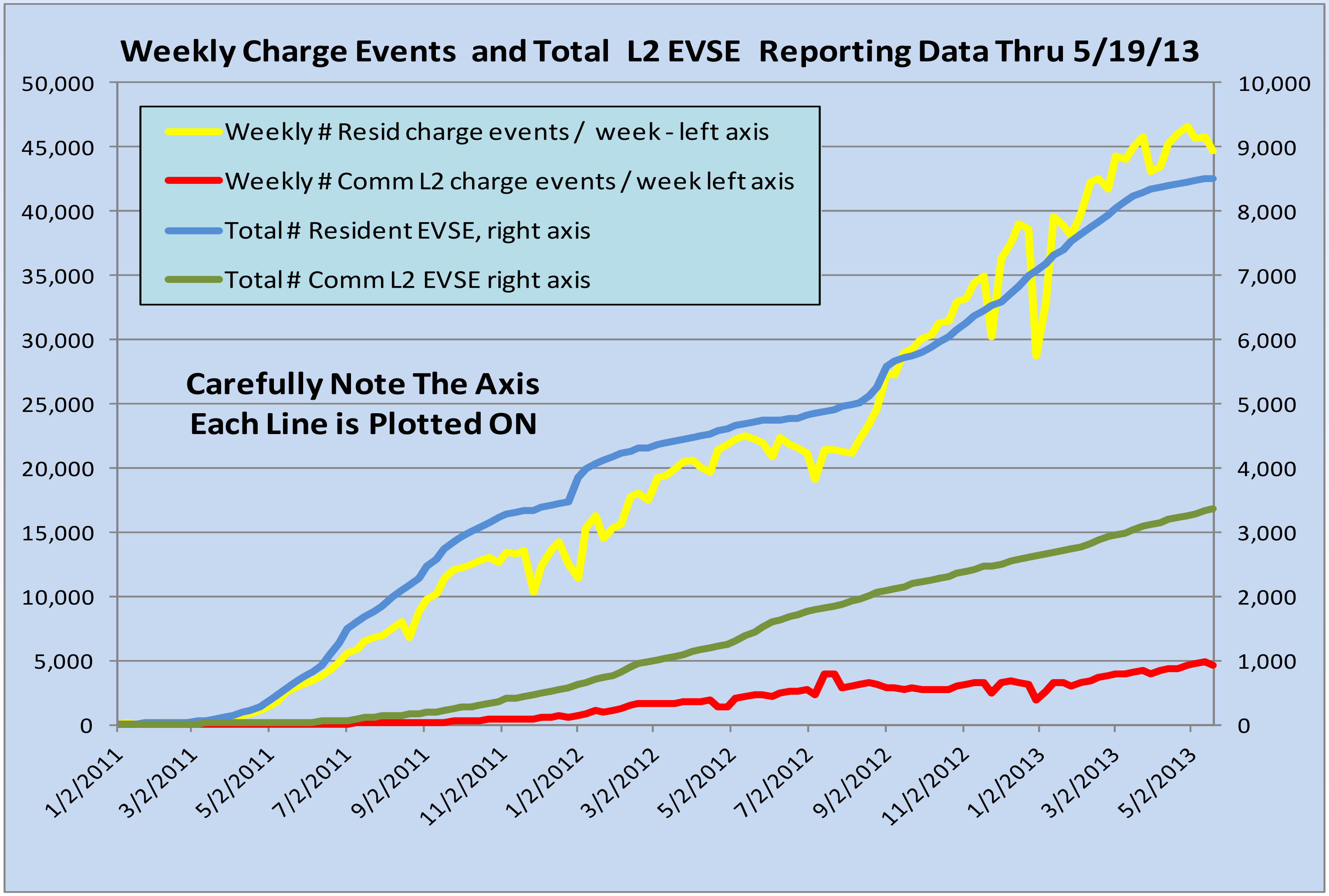






EV Project Weekly Charge Events 5/19/13

- **Note 5.4 to 1 weekly Residential EVSE use rate versus weekly Commercial EVSE use rate (last 5 weeks)**

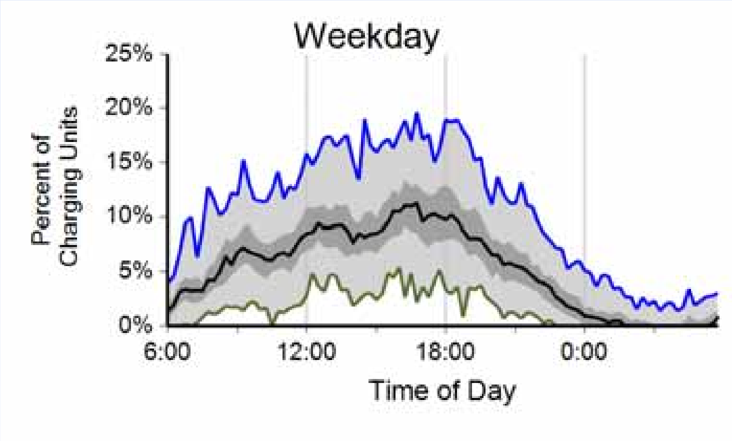


EV Project EVSE and DCFC – Usage, Deployment, Costs, and Some Lessons Learned

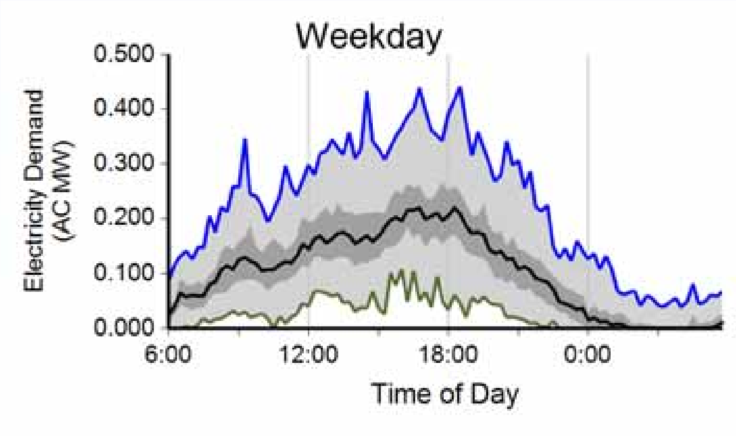
EVSE DCFC Use

- **DC Fast Chargers Weekday 2st Quarter 2013**
- **87 DCFC, 27,000 charge events and 223 AC MWh**

Weekday Connected Profile



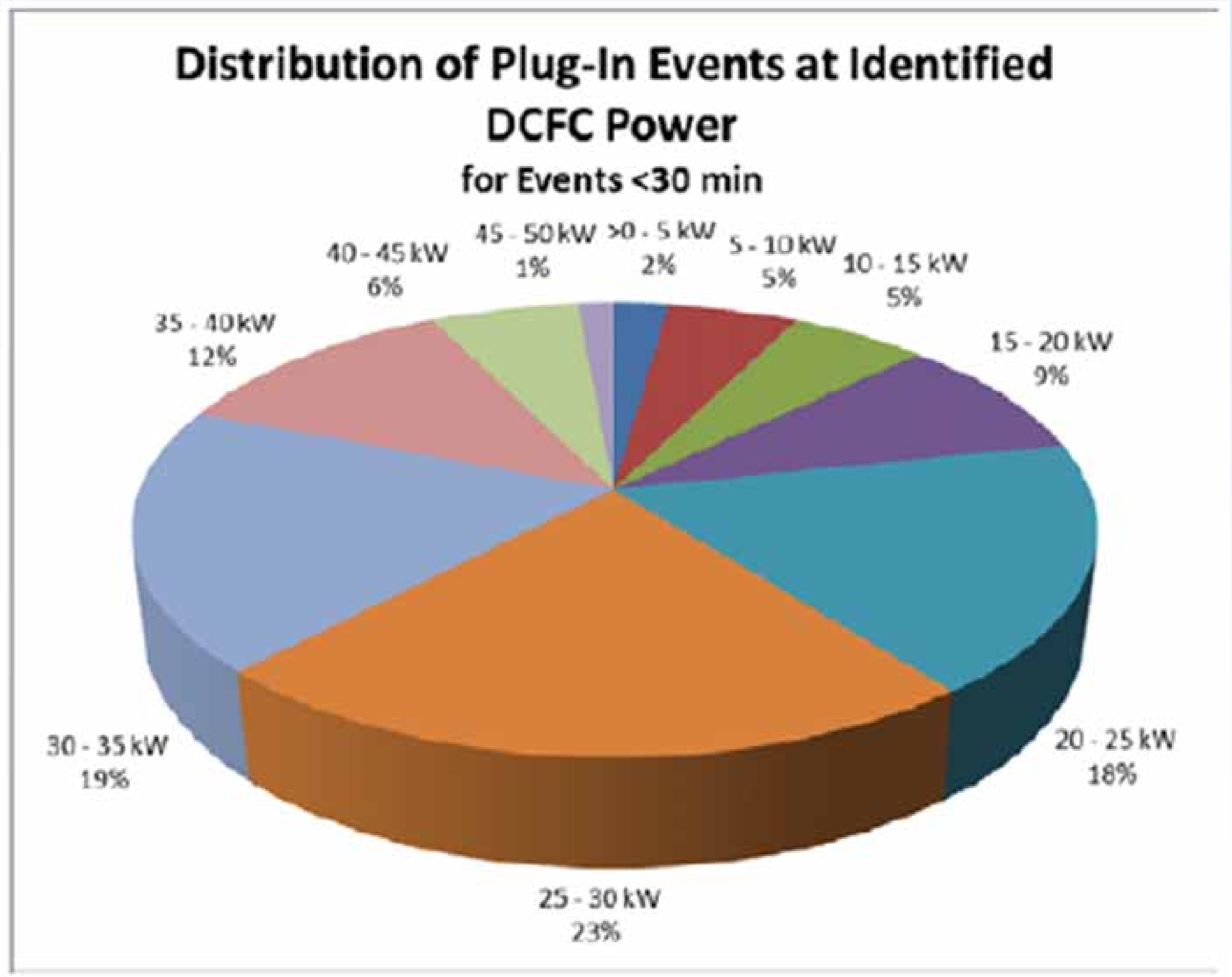
Weekday Demand Profile



- **EV Project Leafs 25% charge events and 24% energy used**
- **Unknowns are Non EV Project vehicles**
- **3.8 average charge events per day per DCFC**
- **19.5 minutes average time connected**
- **19.5 minutes average time drawing energy**
- **8.3 kWh average energy consumed per charge**

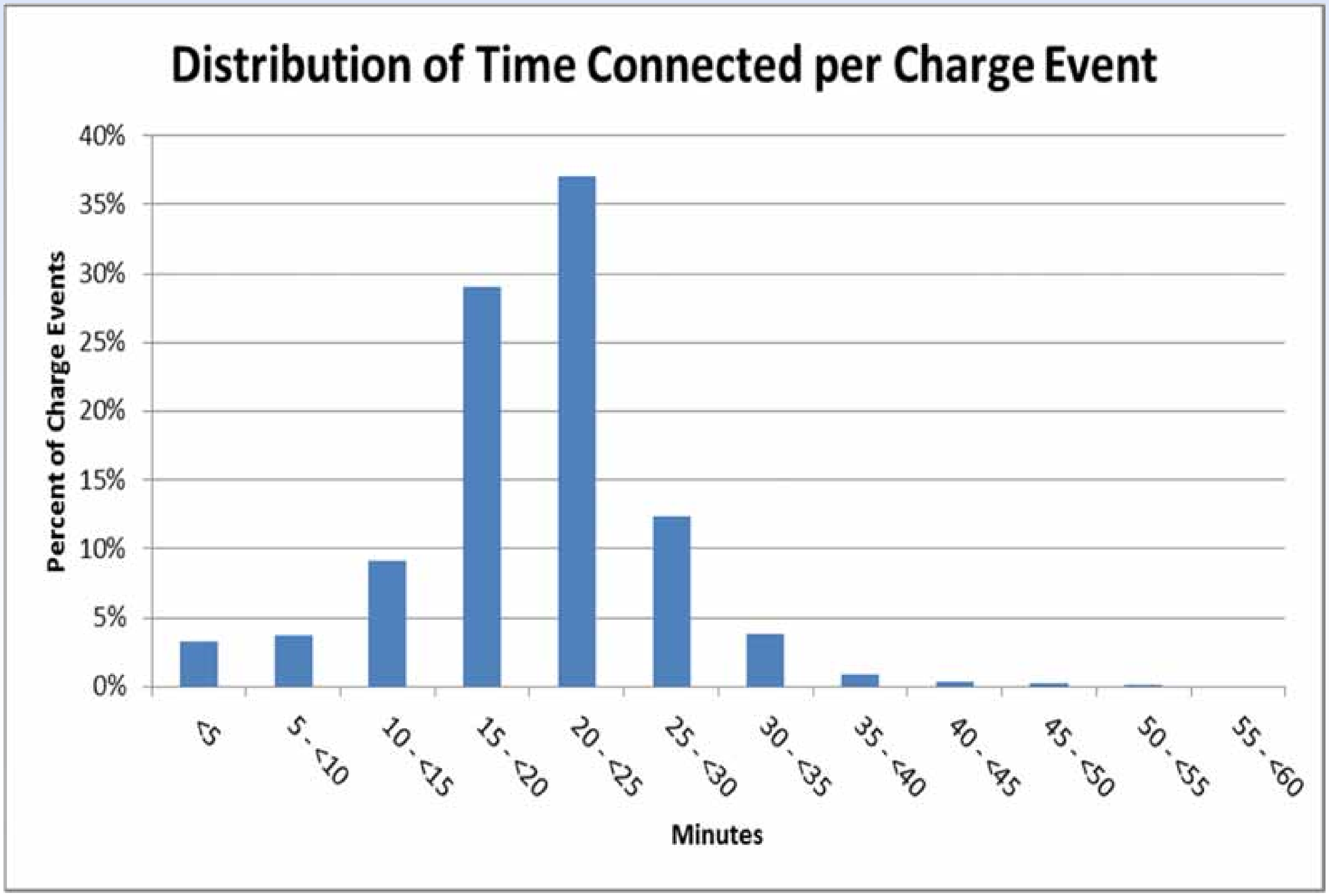
EV Project – DCFC Power Levels

- DC Fast Chargers Weekday 1st Quarter 2013
- 72 DCFC, 13,500 charge events and 102 AC MWh



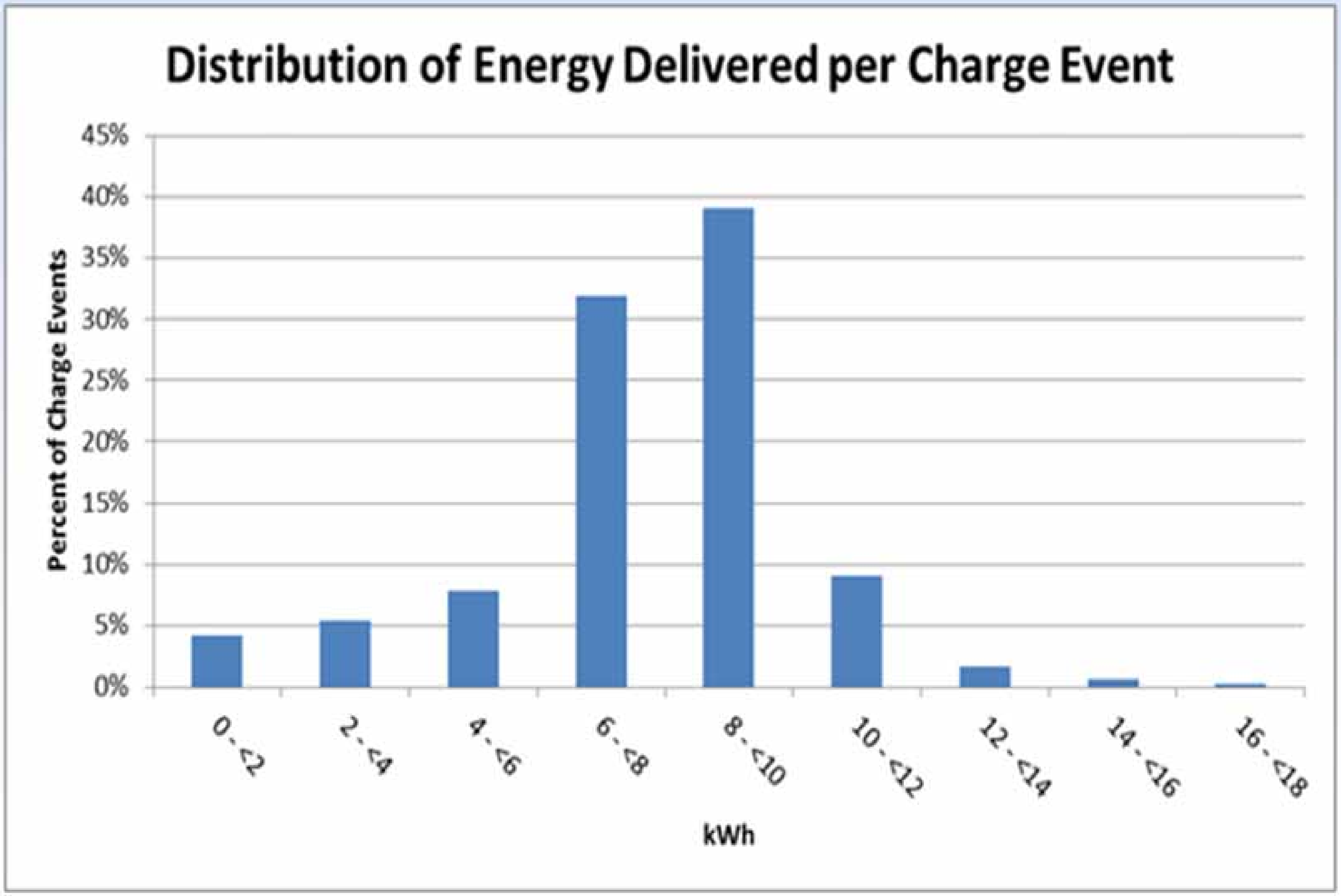
EV Project – DCFC Connect Time

- **Distribution of time vehicle connected per DCFC charge event for all regions. No charge events have occurred where connect time is greater than 60 minutes**



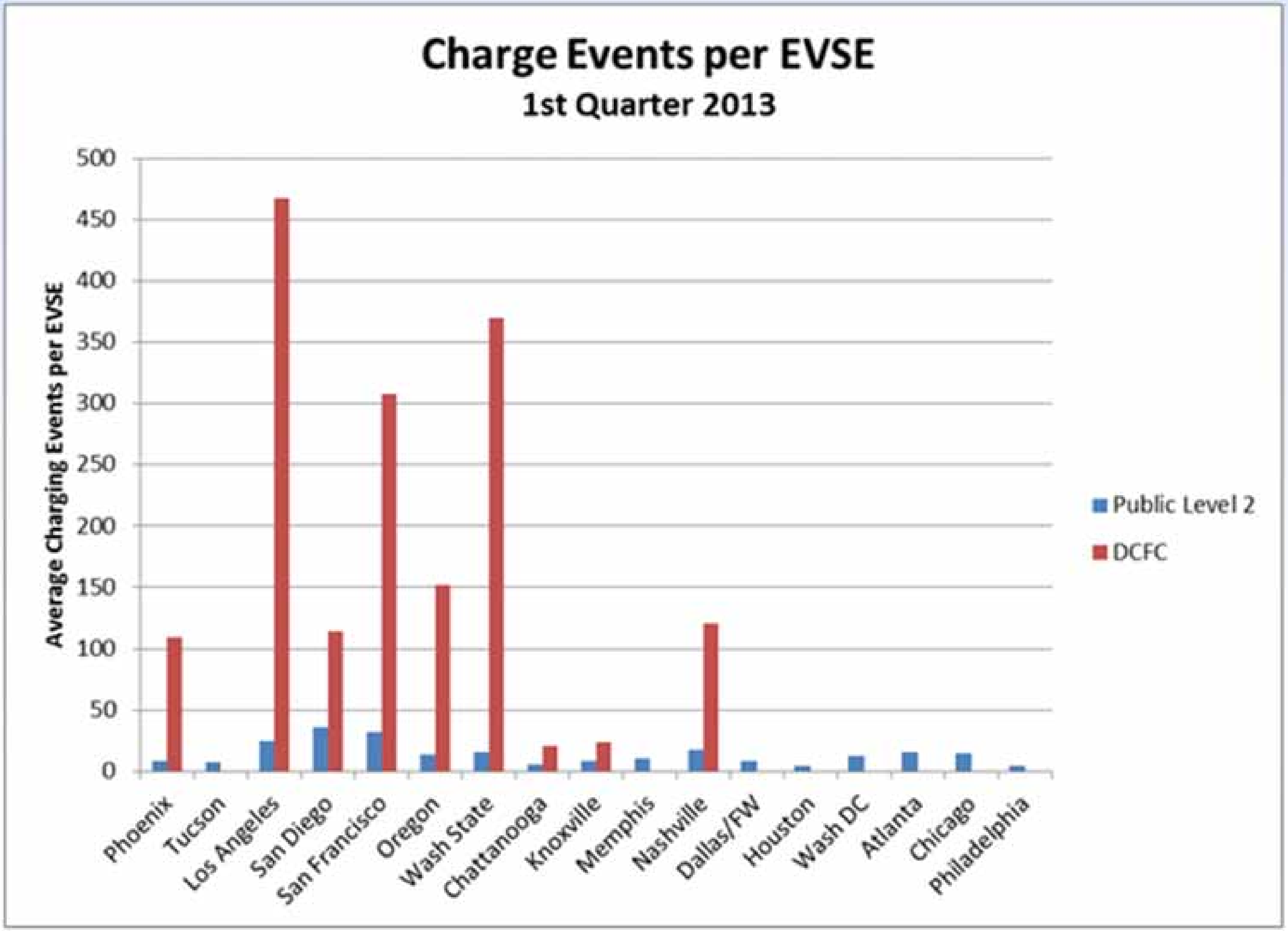
EV Project – DCFC Energy Delivered

- **Distribution of energy delivered per DCFC event time for all regions. No charge event delivered more than 18 kWh**



EV Project – DCFC Versus Level 2 Public

- **Number of charge events per publicly accessible Level 2 EVSE versus per DCFC in the 1st Quarter 2013**
- **Nationally, 17 events per public L2 and 188 per DCFC this quarter**



DCFC Installation Costs / Issues

- Current installations range from $8,500 to $48,000 (99 units)
- Average installation cost to date is about $21,000
- Host has obvious commitment for the parking and ground space - not included in above costs
- Above does not include any costs that electric utility may have incurred in evaluating or upgrading service

- These are the preliminary costs to date. When all 200 DC Fast Chargers are installed, installation costs may be different
  - All the best (lower-cost) sites are installed first, so final costs may be higher
  - Lessons learned may help lower future costs and site selections, so final costs may be lower

DCFC Installation Costs

- **Total installation costs (99 units)**
- **Includes everything EV Project has funded per DCFC installation except DCFC charging unit**

Number per Region	National - 99	AZ - 17	WA - 12	CA - 37	OR - 15	TN - 16
Minimum	$8,440	$8,440	$18,368	$10,538	$12,868	$14,419
Mean	$20,848	$15,948	$24,001	$21,449	$19,584	$23,271
Maximum	$47,708	$33,990	$33,246	$47,708	$26,766	$31,414

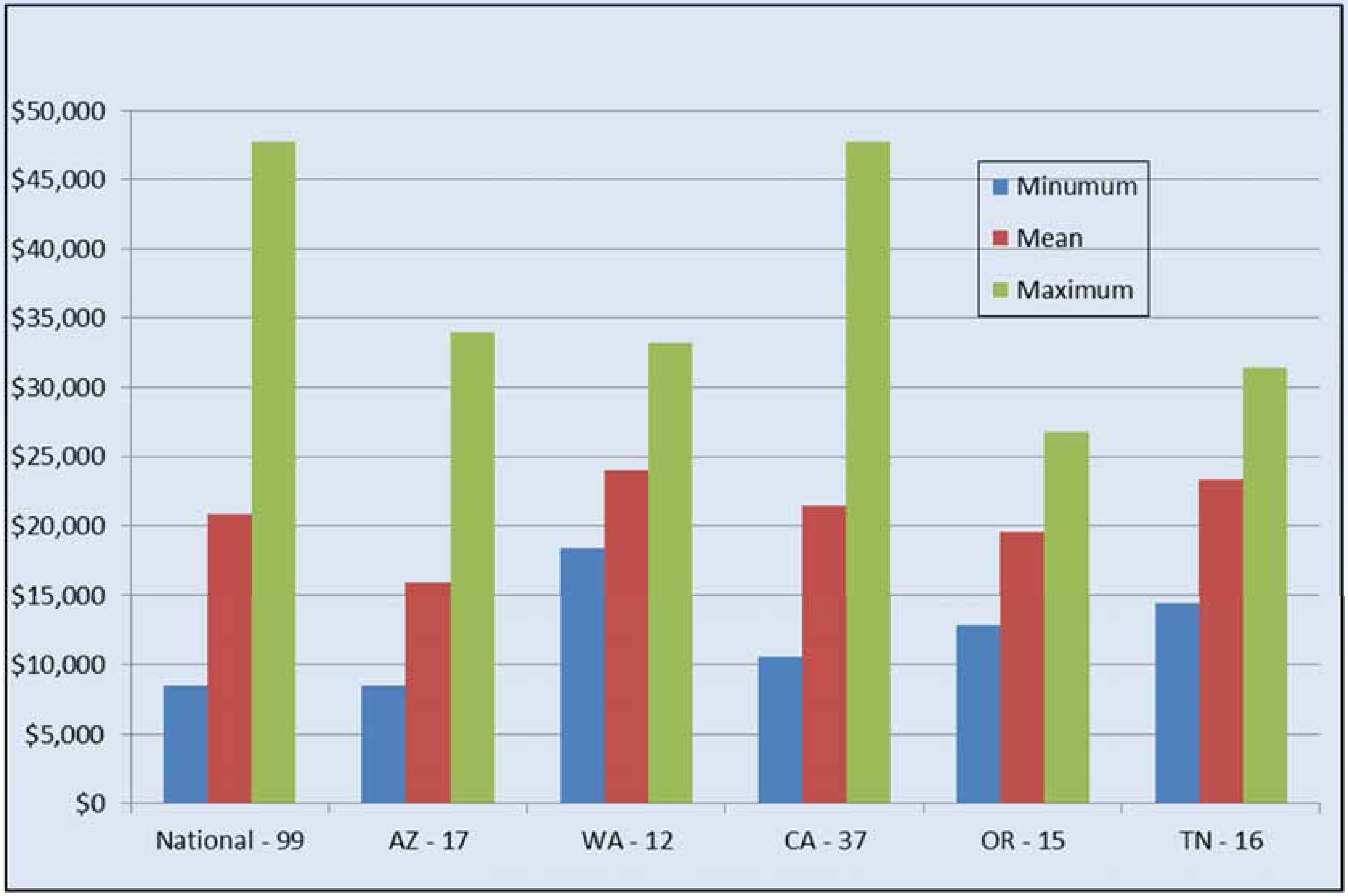
DCFC Individual Installation Costs

- **Total installation costs (99 units)**
- **Does not include DCFC hardware**

Mean - $20,848
Mode - $20,188

DCFC Individual Installation Costs

- **Total installation costs (99 units)**
- **Does not include DCFC hardware**



DCFC Installation Costs / Issues

- Items of concern associated with DCFC installations that drive costs
  - Power upgrades needed for site
  - Impact on local transformer
  - Ground surface material and cost to “put back” (e.g. concrete, asphalt, landscaping)
  - Other underground services that may affect method of trenching power to DCFC
  - Gatekeeper or decision-maker for the property is not always apparent
  - Magnitude of operating costs and revenue opportunities are still largely unknown
  - Time associated with permissions
    - Permits, load studies, and pre-, post-, and interim inspections

DCFC Lessons Learned

- Demand and energy costs are significant for some utilities
  - 25¢/kWh
  - $25/kW
- Some utilities offer commercial rates without demand charges
- Others incorporate 20 kW to 50 kW demand thresholds
- Nissan Leaf is demand charge free in some electric utility service territories

No Demand Charges - Nissan Leaf	
CA	Pacific Gas & Electric
	City of Palo Alto
	Alameda Municipal Power
	Silicon Valley Power
AZ	Tucson Electric Power
OR	Eugene Water & Electric Board
	Lane Electric Co-op
TN	Middle Tennessee Electric
	Duck River Electric
	Harriman Utility Board
	Athens Utility Board
	Cookeville Electric Department
	Cleveland Utilities
	Nashville Electric Service
	EPB Chattanooga
	Lenoir City Utility Board
	Volunteer Electric Cooperative
	Murfreesboro Electric
	Sequachee Valley Electric Cooperative
	Knoxville Utility Board
	Maryville
	Fort Loudoun Electric
	Memphis Light Gas and Water Division

DCFC Commercial Lessons Learned

- **Especially in California, DC fast charge demand charges are significant in many utility service territories**

Utility Demand Charges - Nissan Leaf		Cost/mo.
CA	Glendale Water and Power	$ 16.00
	Hercules Municipal Utility:	$ 377.00
	Los Angeles Department of Water and Power	$ 700.00
	Burbank Water and Power	$ 1,052.00
	San Diego Gas and Electric	$ 1,061.00
	Southern California Edison	$ 1,460.00
AZ	TRICO Electric Cooperative	$ 180.00
	The Salt River Project	$ 210.50
	Arizona Public Service	$ 483.75
OR	Pacificorp	$ 213.00
WA	Seattle City Light	$ 61.00

L2 and DCFC Commercial Lessons Learned

- **ADA significantly drives cost**
  - **Accessible charger**
  - **Van accessible parking**
  - **Accessible electric and passage routes to facility**
- **Permit fees and delays can be significant**
  - **Load studies**
  - **Zoning reviews**

Commercial Level 2 Permits Cost

- **Commercial permits range $14 to $821**

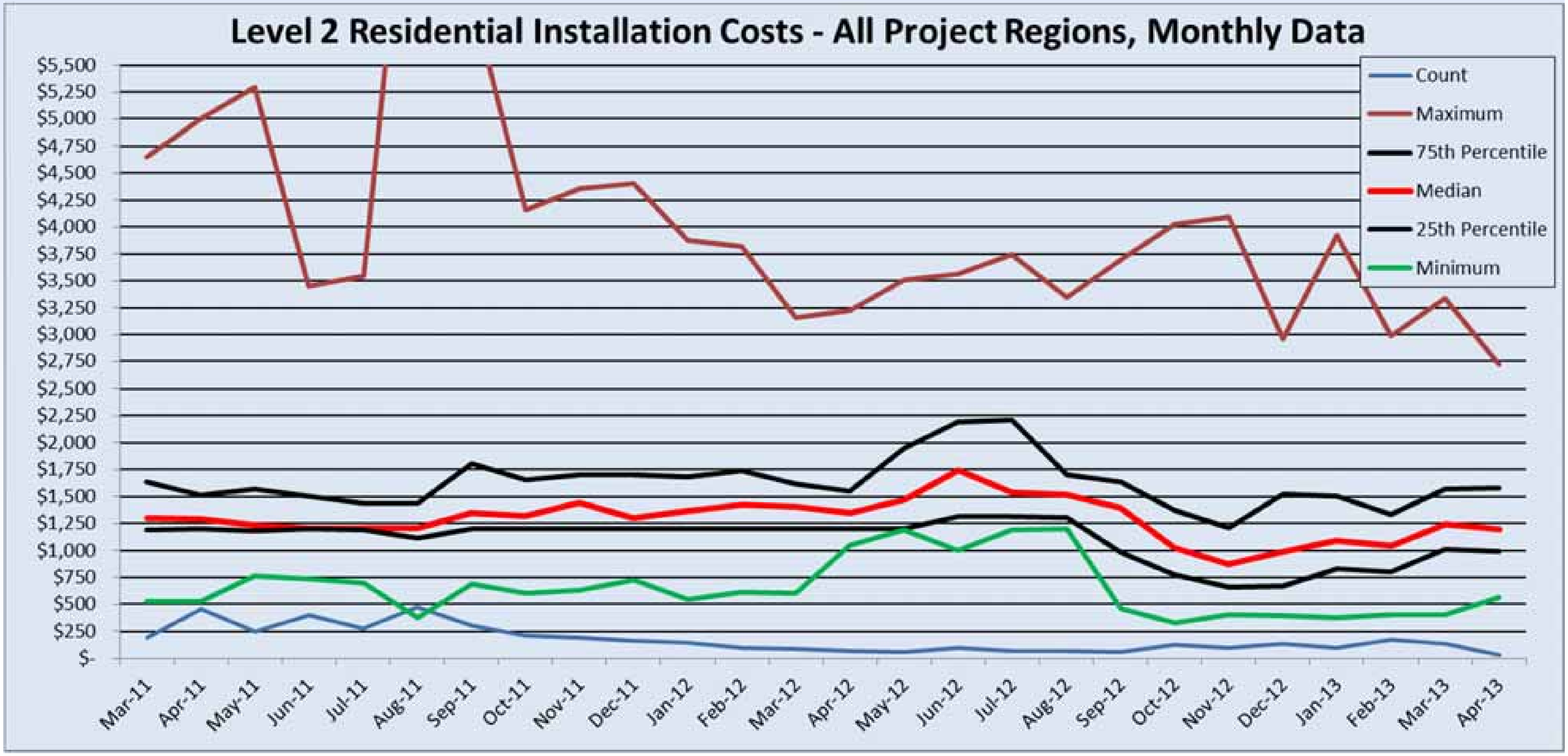
Region	Count of Permits	Average Permit Fee	Minimum Permit Fee	Maximum Permit Fee
Arizona	72	$228	$35	$542
Los Angeles	17	$195	$67	$650
San Diego	17	$361	$44	$821
Texas	47	$150	$37	$775
Tennessee	159	$71	$19	$216
Oregon	102	$112	$14	$291
Washington	33	$189	$57	$590

Commerical Level 2 Installation Costs

- **Nationally, commercially sited Level 2 EVSE average between $3,500 and $4,500 for the installation cost**
  - **Does not include hardware or permitting costs**
- **There is much variability by region and by installation**
  - **Multiple Level 2 units at one location drive down the per EVSE average installation cost**
  - **Tennessee and Arizona have average installation costs of $2,000 to $2,500**
- **Costs are significantly driven by poor sitting requests**
  - **Example: mayor may want EVSE by front door of city hall, but electric service is located at back of building**
- **These numbers are preliminary**

Residential Level 2 EVSE Installation Costs

- Max - $8,429
- Mean $1,414
- Min $250
- Medium $1,265
- Count 4,466
- Total installation costs, does not include EVSE hardware



Residential Level 2 EVSE Installation Costs

- **Regional results for 4,466 units**
- **Permit versus other install costs. No EVSE costs**

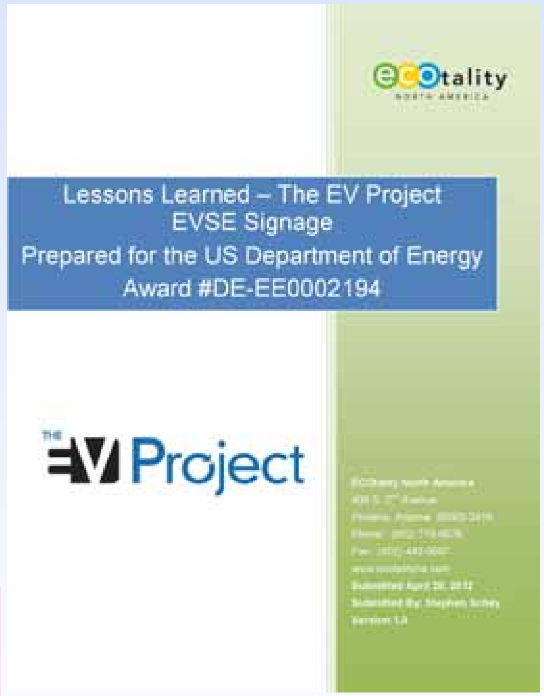
Residential Level 2 EVSE Installation Costs

- **Regional results for 4,466 units**
- **Permit versus other install costs. No EVSE costs**

Signage Example

Ignoring Signage – See Ticket on Windshield

- Sing to the left is one of two Federal Highway Administration interim approved symbol


ecotality
NORTH AMERICA

Lessons Learned – The EV Project
EVSE Signage
Prepared for the US Department of Energy
Award #DE-EE0002194

THE EV Project

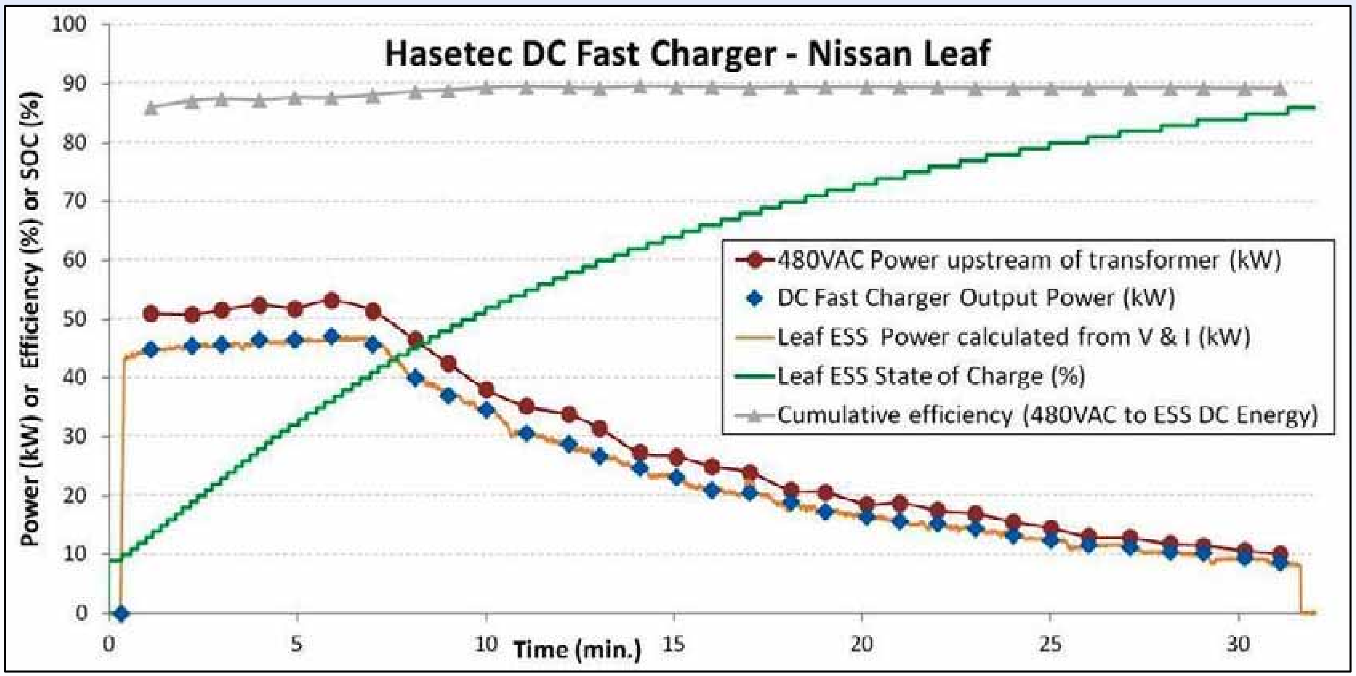
- http://www.theevproject.com/downloads/documents/Signage%20Initial%20Issue%204-20-2012.pdf

Ignoring Signage – See Ticket on Windshield

Other Testing Activities

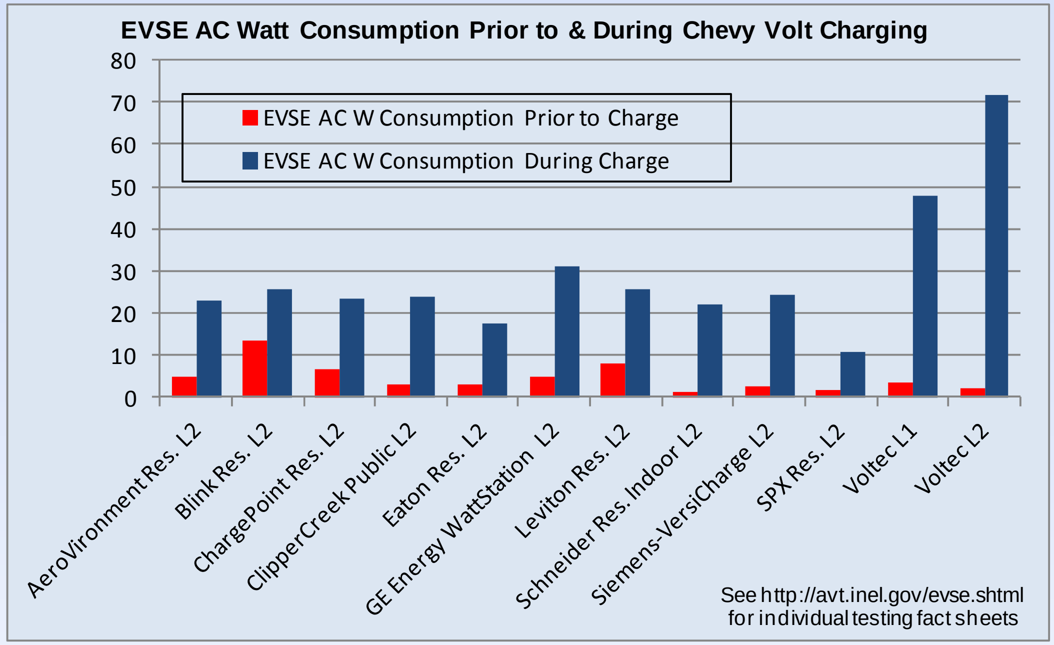
Hasetec DC Fast Charging Nissan Leaf

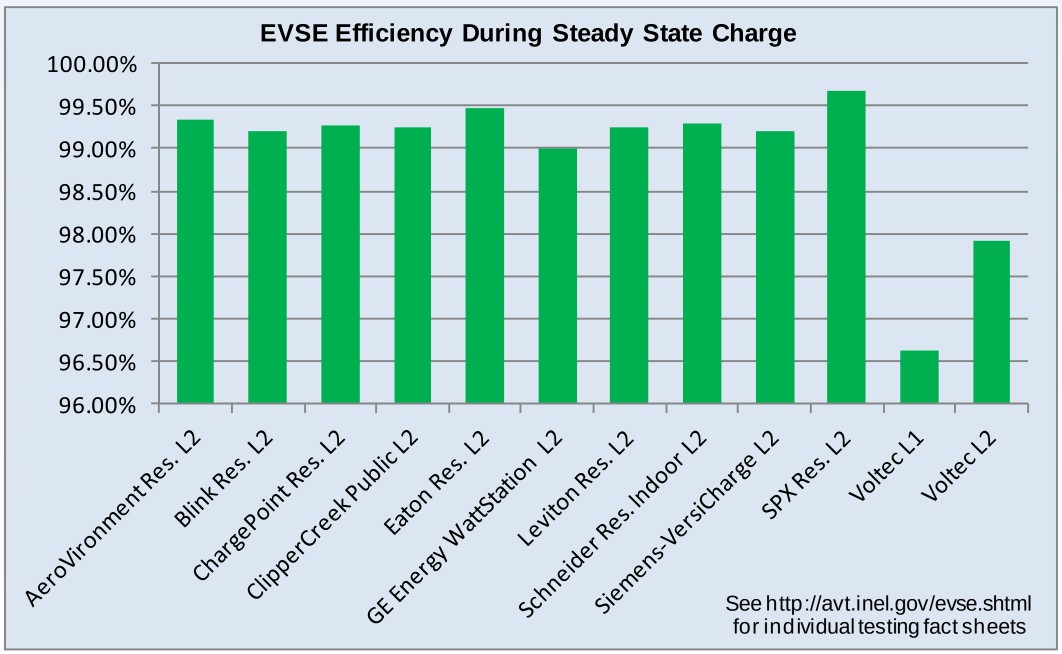
- 53.1 AC kW peak grid power
- 47.1 DC kW peak charge power to Leaf energy storage system (ESS)
- 15.0 Grid AC kWh and 13.3 DC kWh delivered to Leaf ESS
- 88.7% Overall charge efficiency (480VAC to ESS DC)



EVSE Testing

- AC energy consumption at rest and during Volt Charging benchmarked
- Steady state charge efficiency benchmarked





- Most EVSE consume 13 W or less at rest
- Watt use tied to features
- Most EVSE under 30 W during charge
- Most EVSE 99+% efficient during steady state charge of a Volt

INL Wireless Charging Bench Testing

Grid Power 480 & 240 VAC

Hioki Power Meter 3390

Chroma AC Load

Chroma DC Load

Fiberglass Unistrut Secondary Coil Support

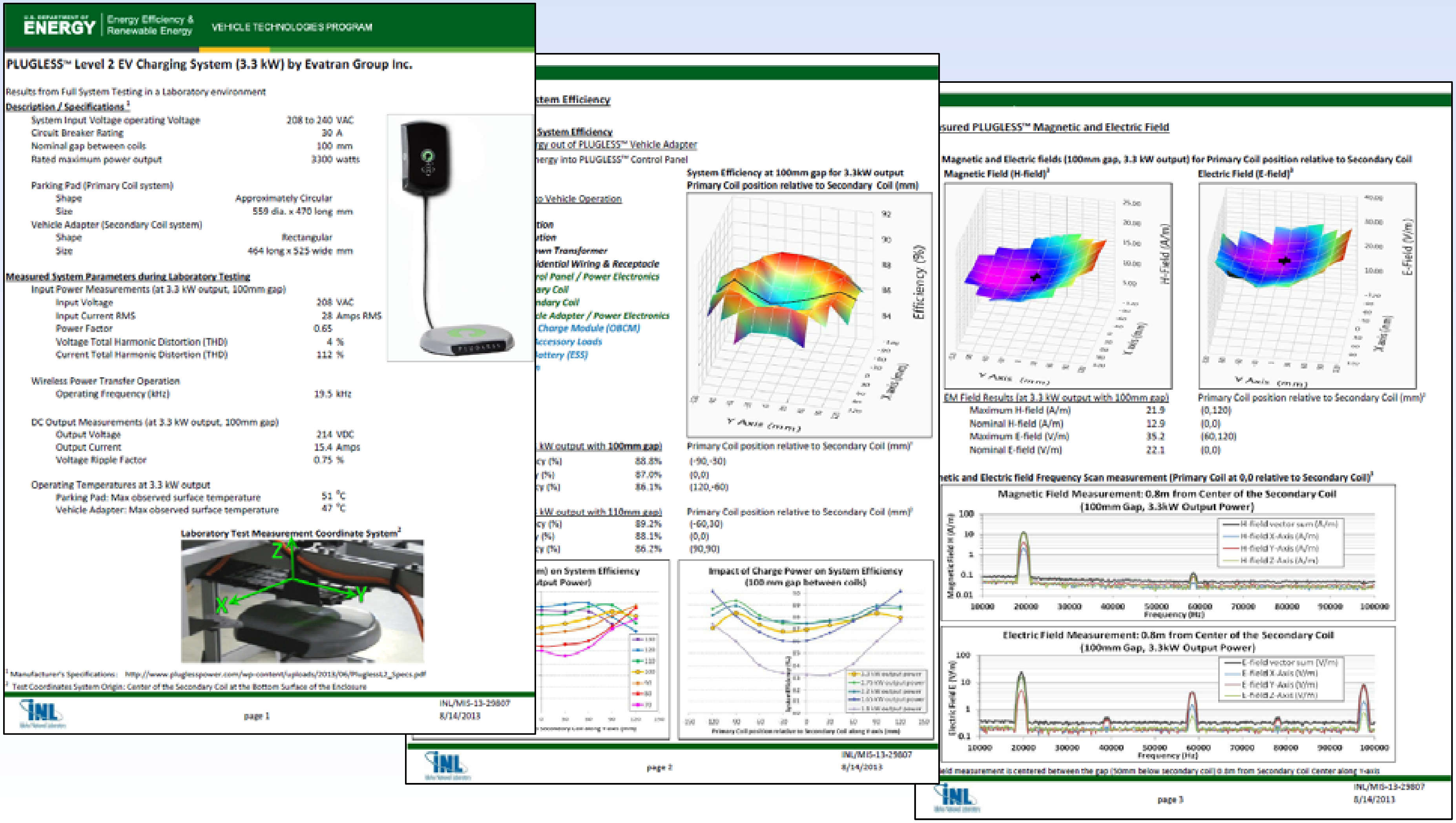
Narda EM Field Meter (EHP-200)

Polycarbonate Primary Coil Support

Multi-Axis Positioning System

Custom LabVIEW Host and Data Acquisition

INL's Wireless Power Transfer Test Results



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

Additional Infrastructure Work

- Initiated I-5 corridor DCFC study
- Six Leaf DCFC and L2 charging study on battery life
  - Two vehicles driven on road and L2 charged
  - Two driven identical routes DCFC charged
  - One L2 and one DCFC in battery lab
  - At 20k miles each Leaf similar minimal capacity fade

- INL conducted with NFPA and US DOT, traction battery fire first responder suppression burns. See avt.inl.gov
- INL initiated ~400 New York EVSE data collection with NYSERDA, NYPA, Port Authority of NY/NJ, and Energetics
- 30 EVSE and 10 vehicle conductive interoperability testing with SAE scheduled for January
- INL receiving data from six NYC Nissan Leaf taxis, six Level 2 EVSE, three DCFCs, and Taxi & Limo Commission
- If I only had another 30 minutes I could have 100 slides….

Acknowledgement

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

More Information & Sources

- **INL Fact Sheets and Presentations**
  - **http://avt.inl.gov**
- **Twenty EV Project lessons learned papers**
  - **http://avt.inl.govhttp://www.theevproject.com/documents.php**

Questions? & Things We Have Not Tested



Claris Cane road tests the fruits of his labor – the Super Trolley.