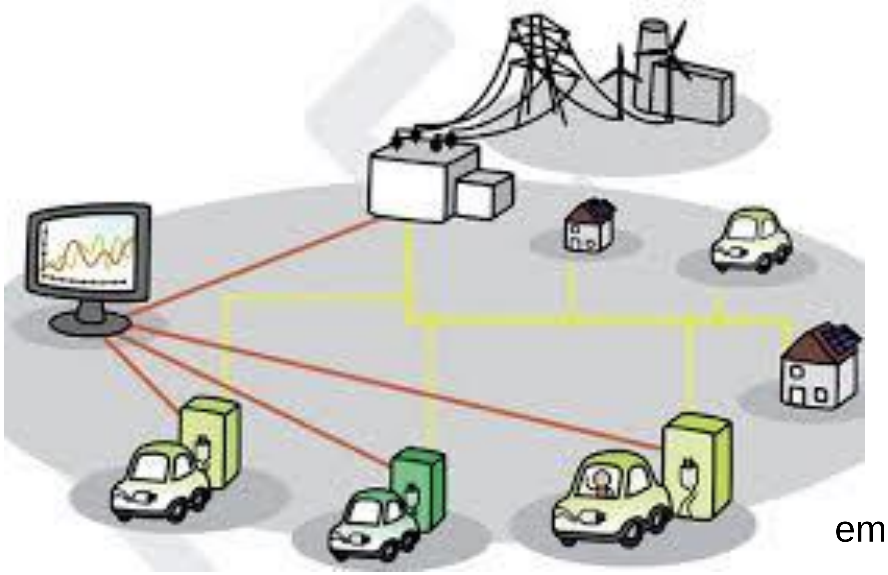
NATIONAL ENERGY TECHNOLOGY LABORATORY



emobil-sw.de

Plug-In Electric Vehicle - Grid Integration

Southeast Distribution Apparatus School
September 21-24, 2015
Auburn, AL

Steve Bossart, Senior Energy Analyst

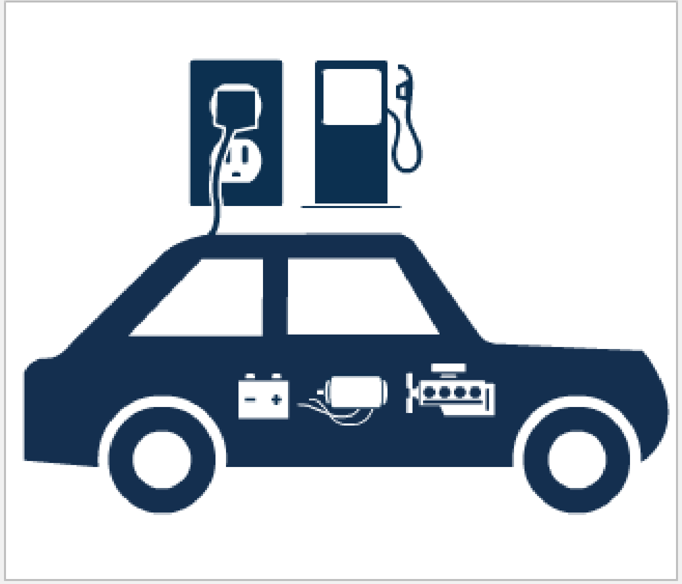
Topics

- **What is an electric vehicle?**
- **What is the market for electric vehicles?**
- **What is in the EV charging infrastructure?**
- **What applications are served by EV and EVSE**
- **What are the main challenges in integrating EV charging on the power grid**
- **What are some results of case studies on EV-grid integration**

Electric Vehicles

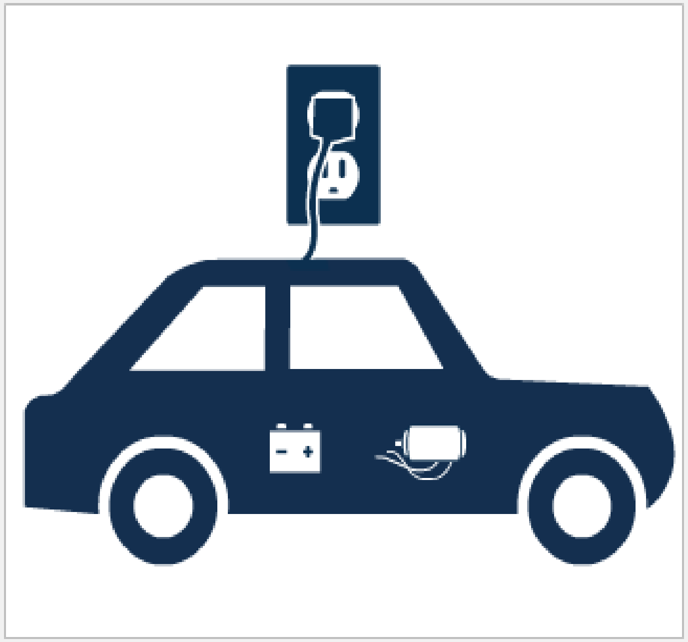
Plug-In Electric Vehicles

Plug-In Hybrid Electric



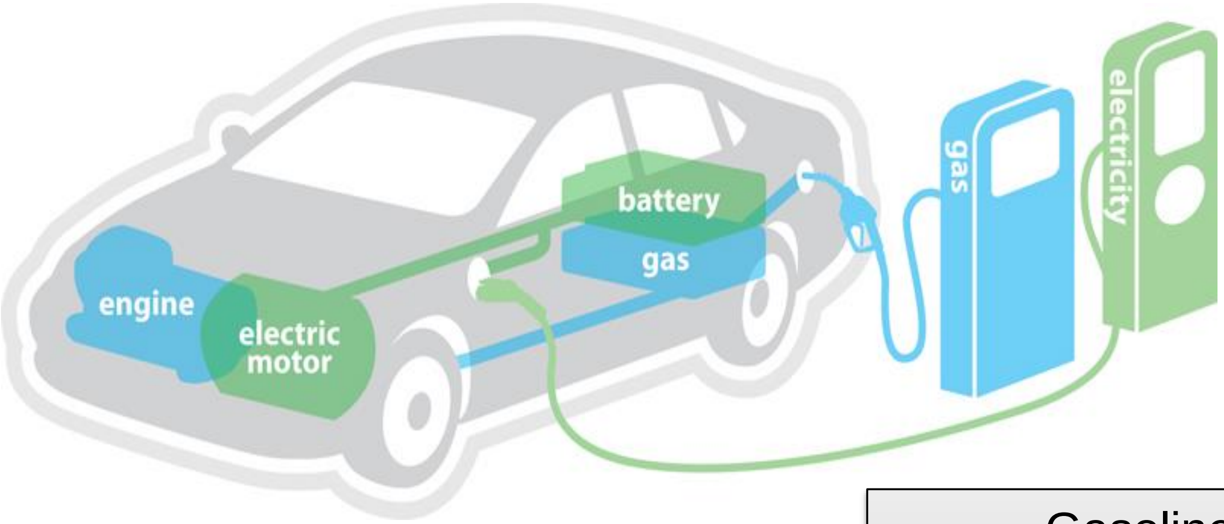
Plug It in or Fill It Up
Plug-in hybrid electric vehicles have an internal combustion engine and electric motor. These vehicles are powered by an alternative fuel or a conventional fuel, such as gasoline, and a battery, which you can plug in to charge.

All Electric



No More Gasoline
All-electric vehicles are plugged in to charge the battery, which stores the electricity that powers the electric motor.

Plug-In Hybrid Electric Vehicle (PHEV)



San Joaquin Valley Plug-In Electric Vehicle Coordinating Council

Mechanism for Driving Wheels

- Parallel (Electric Motor & Engine)
- Series (Electric Motor only)

Gasoline-Electric Usage

- Extended range
  - All electric, then gasoline (Volt)
- Power split
  - Optimize simultaneous electric and gasoline (Prius)

Future DOE Electric Vehicle Goals

Battery cost of $125/kWh by 2022

Currently, about $300-500/kWh

24-85 kWh in today's PEV batteries

200+ mile range for EVs in the 2018 timeframe, comparable to today's cost

Electric Vehicle Market

EV and EVSE Market

- From the first plug-in vehicle sales in 2011 to 2014 about 287,000 vehicles have been sold, with just over 118,000 units in 2014.

- At least 22 different models of plug-in vehicles are available or coming soon to the market.

- There are more than 10,700 electric vehicle charging stations throughout the nation – about 85% of charging stations are public

- States with tax credits and other incentives adopt PEV at higher rate

ORNL 2014 Vehicle Market Report

Plug-In Electric Vehicle Sales 2011-2014

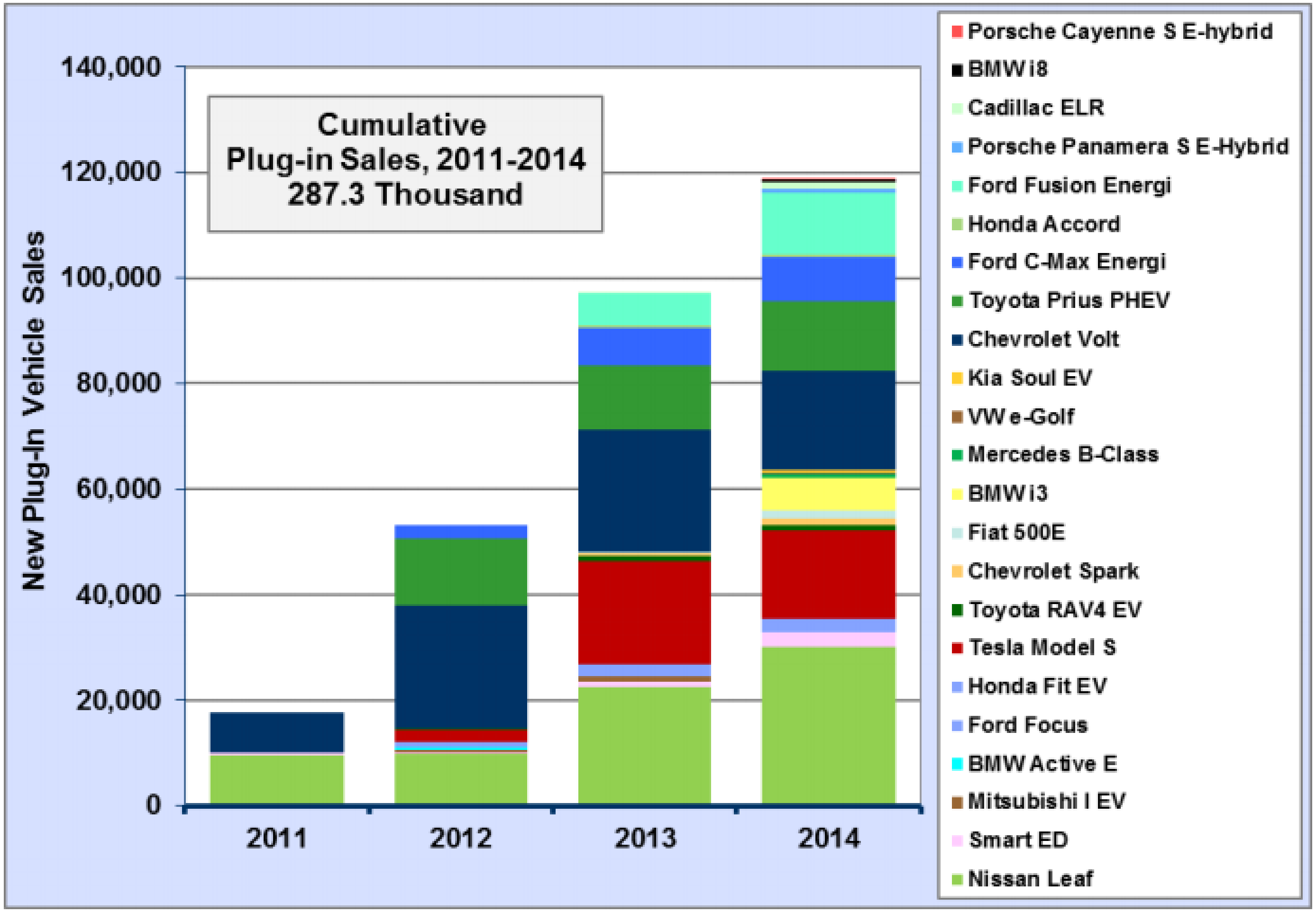


FIGURE 95. Plug-In Vehicle Sales, 2011-2014

ORNL 2014 Vehicle Market Report

Plug-In Electric Vehicle Forecast

Navigant Research projects growth in annual PEV sales of 860,000 to 1,200,000 by 2024

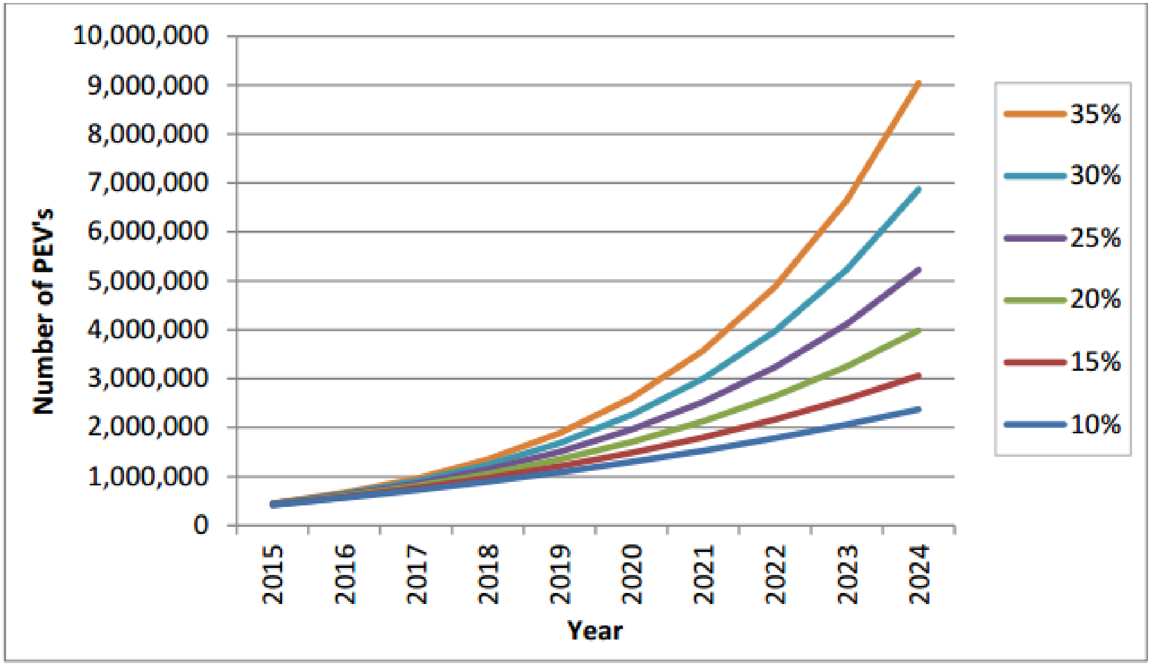


Figure 2. PEV Sales

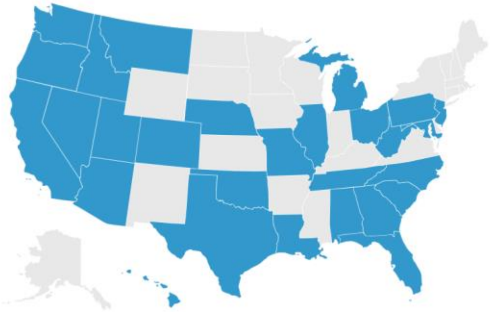
Electric Vehicle Transportation Center, University of Central Florida

Predictions from other sources suggest a 20% growth rate which would result in about 600,000 PEV sales per year and a total of 3.2 million PEV by 2023

Approximately 1% of all vehicles in US will be PEV by 2023

Financial Incentives

- **Qualified Plug-In Electric Drive Motor Vehicle Tax Credit**
  - At least five kwh of battery capacity
  - Gross vehicle weight up to 14,000 lbs
  - Tax credit ranges from $2,500 to $7,500 depending on battery capacity and gross vehicle weight
  - Credit will be phased out after a minimum of 200,000 plug-in electric vehicles have been sold by that manufacturer
  - Tax credit applies to vehicles acquired after Dec 31, 2009
- **27 states have financial incentives for electric vehicles**



Plug-In America

Electric Vehicle Charging Infrastructure

Overview of Electric Vehicle Charging

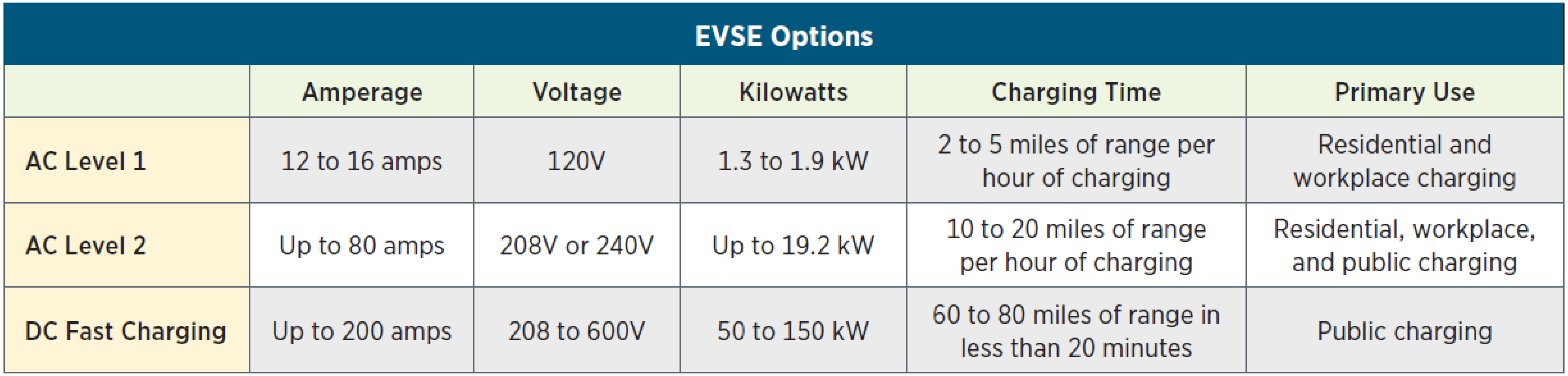
- Power Levels
  - Level I – 120V, 12 Amps
  - Level II – 240V, 30 Amps
  - Fast Charging – 480V, Greater than 100Amps, DC

Level II
is
Most Popular

- Time to Charge (for 100 mile range battery)
  - Level I – 20 hours
  - Level II – 4 to 8 hours
  - Fast Charging – 20 minutes

- Standard Connector
  - New connector called J1772, developed by Society of Automotive Engineers
  - All major car companies have agreed to use
  - Includes safety features to protect drivers and general public

SemaConnect



EVSE Options					
	Amperage	**Voltage**	**Kilowatts**	**Charging Time**	**Primary Use**
AC Level 1	12 to 16 amps	120V	1.3 to 1.9 kW	2 to 5 miles of range per hour of charging	Residential and workplace charging
AC Level 2	Up to 80 amps	208V or 240V	Up to 19.2 kW	10 to 20 miles of range per hour of charging	Residential, workplace, and public charging
DC Fast Charging	Up to 200 amps	208 to 600V	50 to 150 kW	60 to 80 miles of range in less than 20 minutes	Public charging

NREL

Figure 9. Residential Charger Installed by Progress Energy

Level 1

Figure 6. Example of a 240-Volt Commercial Charging Station Installed by IPL

Level 2

Level 3
DC Fast Charging

Electric Vehicles Charger Installation Costs

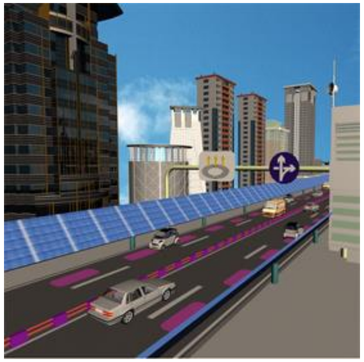
- **Level 1 – Little to no additional cost**
- **Level 2 - $600-$3,600; permits and licensed electrician**
- **Level 3 - $50,000-$100,000; public charging**
  - ADA compliance, underground wiring, distance to distribution transformer

Renewable and energy storage integration with EVSE

- **Photovoltaic solar panels and/or wind power combined with energy storage at EVSE stations**
- **Grid power combined with energy storage at EVSE stations**

Next Generation EV Charger

- Standards can be difficult due to matching different chargers with different vehicles
- Debate on intelligence in charger versus vehicle
- Debate on voltage conversion in charger versus vehicle
- Desire to reduce cost, improve communications, and enable real-time pricing
- Research underway on wireless power transfer technologies including electrified roadways

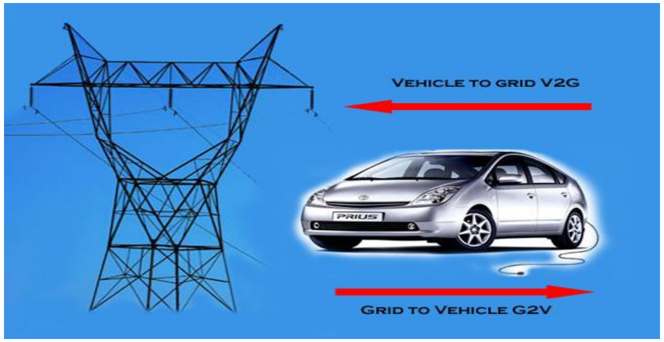


- Data management challenge to control EV charging due to number and types of EVs, EVSEs, and pricing structures, and power flow

Electric Vehicle Applications

Electric Vehicle Applications

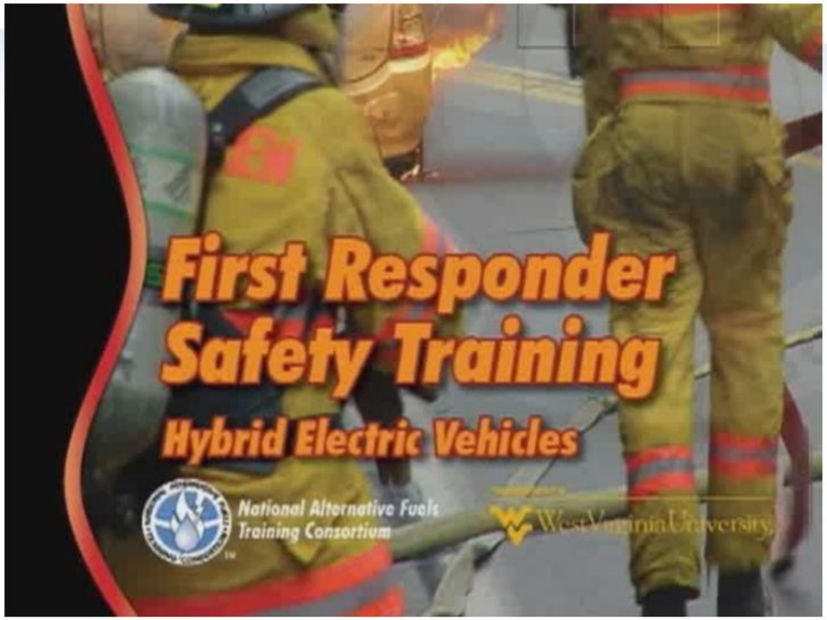
- **Grid to vehicle G2V (i.e., charging vehicle battery)**
  - – Smart charging (i.e., price, state of charge, transportation)



- **Vehicle to grid V2G (i.e., discharging vehicle battery)**
  - – Ancillary services (e.g., frequency regulation, spinning reserve)
  - – Backup generation at home & businesses
  - – Mobile power and lighting for emergency response
  - – Reducing peak demand

Electric Vehicles in Emergency Situations

- **Emergency services**
  - Mobile
  - Temporary power
  - Temporary lighting
- **Emergency response for electric vehicle accident**



ARRA Funding
EERE Vehicles Program

Secondary Use for EV Batteries

- **Community energy storage**

  Detroit Edison SGDP

- **Yellowstone National Park is using recycled battery packs from hybrid cars to store solar power for its Lamar Buffalo Ranch**

Electric Vehicle-Grid Integration Challenges

Challenges of Electric Vehicles

- **Limited Range**
  - Large battery weight/size
- **Long charge times**
- **High initial cost**
- **Battery life**
- **Consumer acceptance**

Range Anxiety

Battery Swapping vs. Fast Charging

Source: http://pneumaticaddict.wordpress.com/2009/03/10/hybridcarscom-mercedes-rejects-electric-car-battery-swapping/

Challenges of Electric Vehicle Charging

- **Cul-de-sac factor**
- **Transformer overload**
- **Mobility of load**
- **Billing**
- **Gas tax recovery**
- **Carbon credits**
- **Helpdesk support**
- **Data security and privacy**
- **Installation model**
- **Messaging and education**

Reference: Public Utilities Fortnightly, June 2011, Top 10 EV Challenges

Charging Ahead: The Last Mile (Deloitte)

- **More than 70 entities, including utilities, retail businesses, electric vehicle equipment suppliers, state and local government agencies, and trade associations**
- **In general, utilities will not need to expand G&T capacity in the next ten years to meet electric demand of EVs at current projected adoption rate**
- **Possible near-term impacts of clustering EVs on low-capacity local distribution transformers (e.g., 25 kVA)**
- **About half of utilities are not notified when a ratepayer purchases an EV**
- **One concern is that some street-level transformers are designed to cool at night; EV charging at night could shorten transformer life and/or cause a local outage**

Electric Vehicle Charging

- **PNNL - Up to 84% of vehicles could convert to PHEV without additional electric infrastructure**
- **NREL – large-scale deployment of PEVs will have limited, if any, negative impacts on the electric power generation requirement**
- **EPRI – if PEVs replaced half of all vehicles by 2050, they would require only at 8% increase in electricity generation**

Case Studies

Case Studies

Six Smart Grid Investment Grants

Pecan Street SGDP

AEP Ohio SGDP

CCET SGDP

SCE SGDP

Commercial & Residential EVSE Level 2 R&D Projects

Case Study – EV Charging in Six SGIG Projects

- **Impact of EV Charging on:**
  - Utility operations
  - Consumer behavior
    - 700 residential chargers & 270 public charging stations

Smart Grid Investment Grants

Burbank Water and Power (BWP)

Duke Energy (Duke)

Indianapolis Power and Light (IPL)

Madison Gas and Electric (MGE)

Progress Energy (Progress, now part of Duke Energy)

Sacramento Municipal Utility District (SMUD)

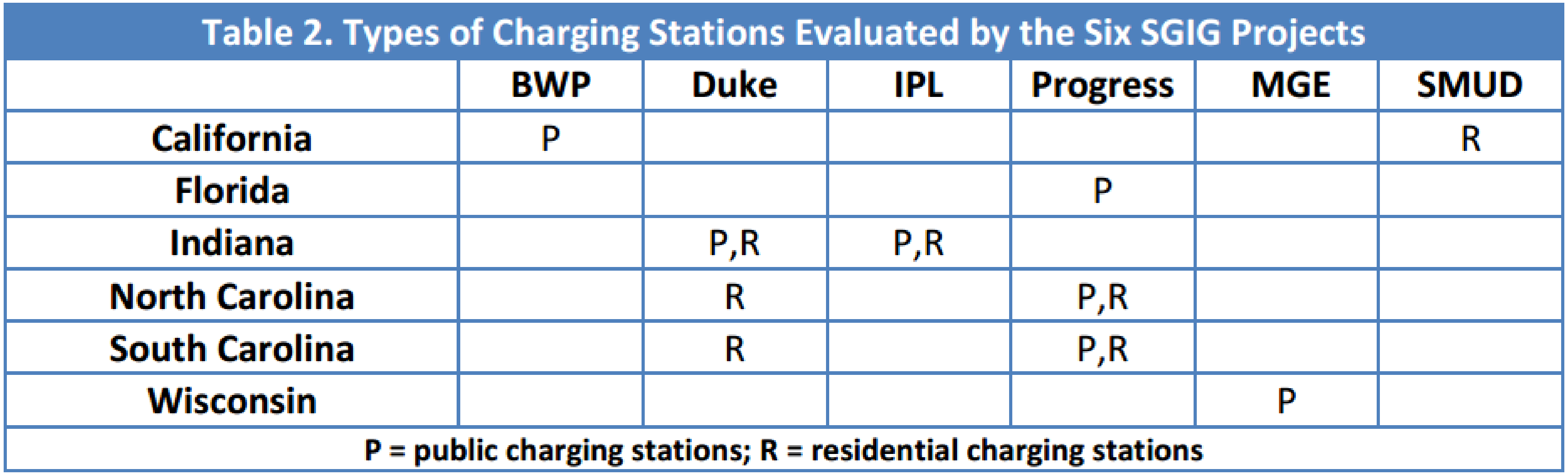


Table 2. Types of Charging Stations Evaluated by the Six SGIG Projects

	BWP	Duke	IPL	Progress	MGE	SMUD
California	P					R
Florida				P		
Indiana		P,R	P,R			
North Carolina		R		P,R		
South Carolina		R		P,R		
Wisconsin					P	

P = public charging stations; R = residential charging stations

Four projects – residential charging units
Five projects – public charging stations

EV Charging in Six SGIGs

Objectives were to evaluate:

- **Technical performance of charging systems**
- **Grid impacts of charging during peak periods**
- **Need for distribution system upgrades and capacity additions**

Figure 9. Residential Charger Installed by Progress Energy

Figure 3. Example of AC Level 2 Public Charging Station Installed by MGE

Key Questions

- How long will existing infrastructure be sufficient?
- What type of capacity upgrades are needed?
- When will consumers want to charge electric vehicles?
- What incentives and prices will motivate consumers to charge during off-peak periods?

Evaluation factors

- Equipment performance and interoperability
- Back-office support
- Customer acceptance and outreach
- Business models (e.g., third-party)
- Pricing options (e.g., time-based rates, cost per hour, cost per kwh, and no-cost charging)

Major Findings – Charging Behavior

Charging Behaviors

- **In-home charging was overnight and time-based rates were successful in encouraging off-peak charging**
- **Public charging station usage was low, but occurred during business hours and overlapped with peak**
  - Frequently used free public stations
- **IPL found 76% of electricity used for charging occurred during off-peak periods**
- **Duke observed different patterns of charging**
  - 84% at public retail locations was <2 hours
  - Only 45% at office and municipal locations was >2 hours

Charging Behavior

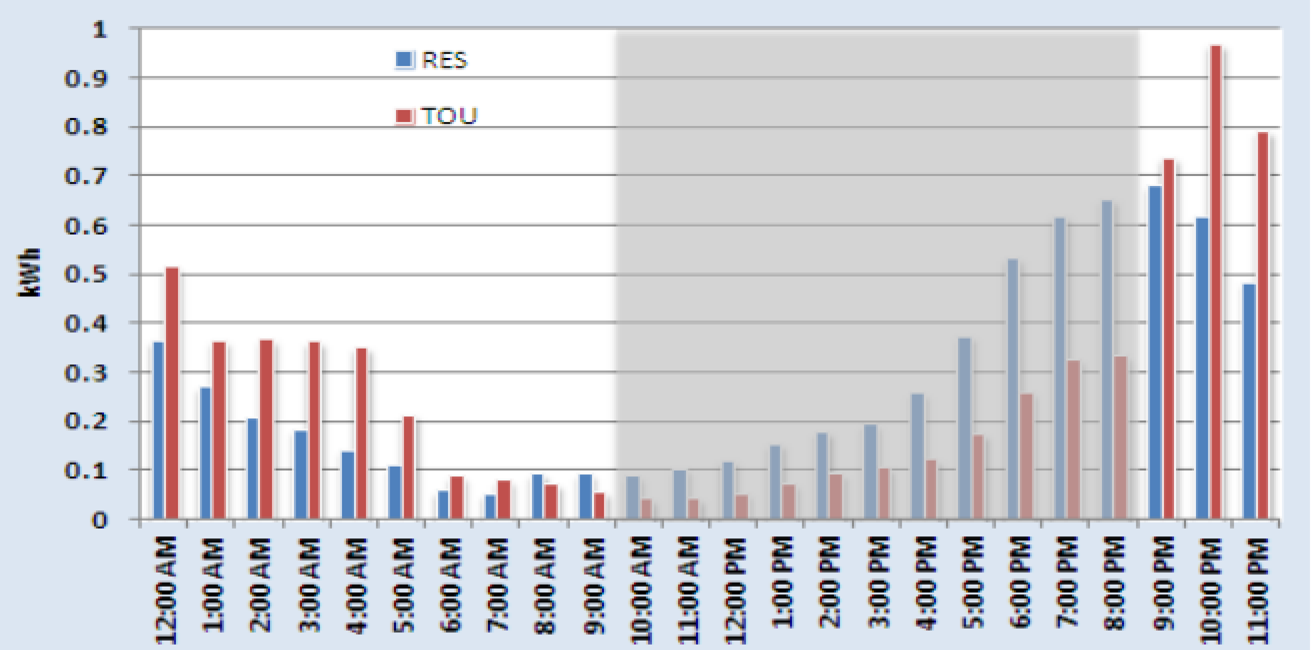


Figure 11. Charging Patterns with (TOU) and without (RES) Whole House Time-of-Use Rate during Summer Weekdays at Progress Energy (Peak period is in gray)

Major Findings - Grid Impacts

- **Duration of charging and power requirement varied by vehicle model; charger type; and state of battery**
- **Average power demand was 3-6 kW (i.e., small AC unit)**
- **Power demand can be as high as 19 kW which is more than most large, single family homes**
- **PHEV battery size ranges from 7-17 kwh, while PEV battery size ranges from 20-50 kwh**
- **Progress Energy reported average daily charging sessions of 7.1 kwh**
  - Would add 2,500 kwh per year to a customer's bill
  - Average residence consumes 10,908 kwh annually (EIA)
  - Equates to 24 miles per day assuming 3.3 mi/kwh

Major Findings – Technology & Cost

- **Faster chargers may require more expertise to install**
  - Potential need for service upgrades
- **Public charging station installation costs were high**
  - Coordination with equipment vendors, installers and host organization to address construction, safety, and code requirements
- **Low usage at public charging stations will result in longer payback period without substantial growth in usage**
- **BWP indicated that growth in usage of 25% per year has payback period of 7 years for public charging stations**
- **Some residential interoperability problems in communications between smart meter and charging stations**

Lessons Learned

Planning and Management

- Conduct small field trials to justify broader deployment
- Plan for sufficient resources to support customers
- Develop detailed process maps to streamline activities

Market Development

- Consider varying needs of different market segments
- Evaluate use cases to determine charging patterns

Implementation

- Locate chargers for customer convenience, not necessarily for utility convenience

Common Technical and Market Needs

- Improve reliability of communications
- Improve ease of integration between smart meters and EV chargers
- Better coordination with equipment vendors
- Reduce cost for equipment and maintenance for public charging stations
- Make affordable Level 2 EV chargers available to residential customers
- Develop pricing strategies for public EV chargers to encourage their use
- Don’t exacerbate peak demands (see next slide)
- Enable profitable business models

Don’t exacerbate peak demand

- **Need integration of EV chargers with time-based rates to encourage off-peak charging**
- **AMI metering allows utilities to analyze charging behavior**
- **Track homes and public charging stations with Level 2 and 3 EV chargers**
- **Use smart grid technologies to monitor possible overload situations**

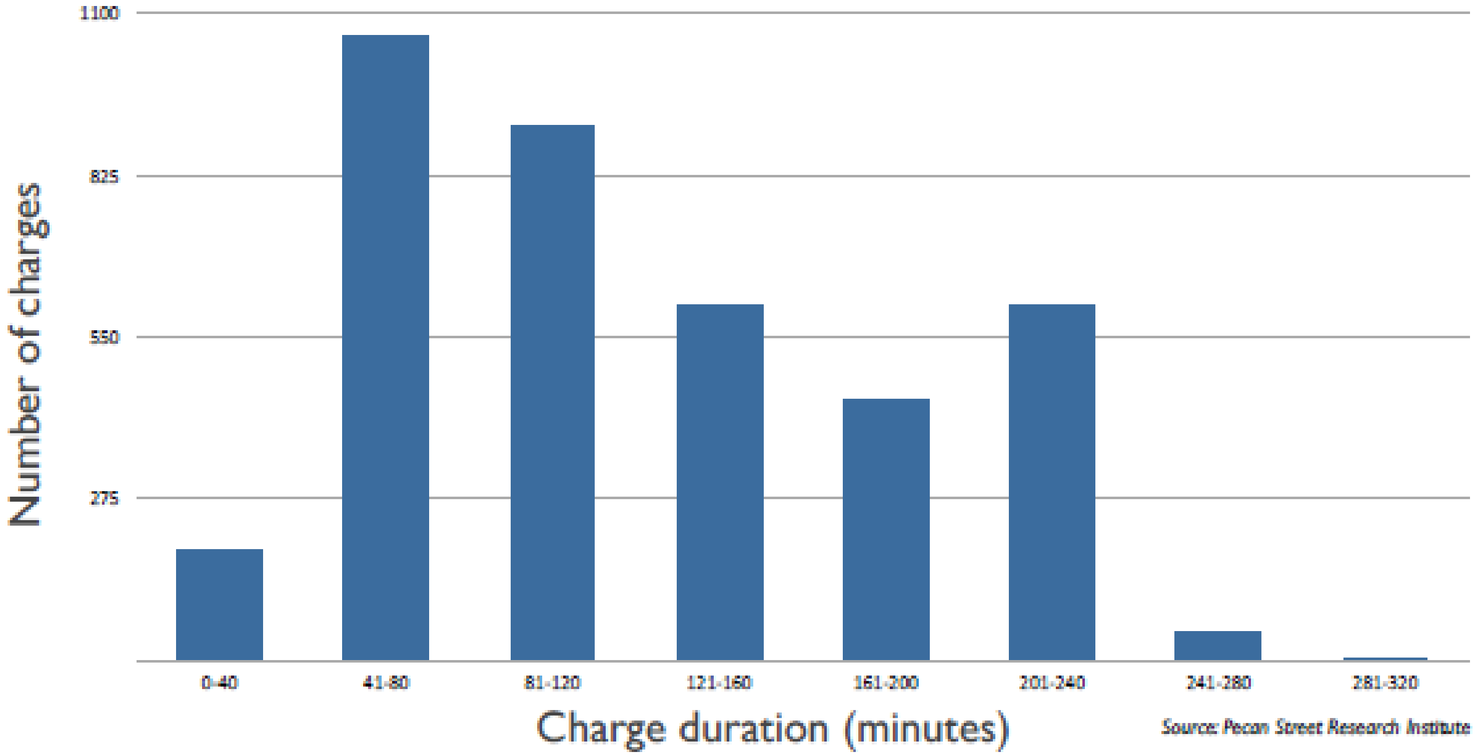
Case Study – Pecan Street SGDP

- **Mueller community in Austin, Texas**
- **Pecan Street incentivized purchase/lease of 69 EVs with Level 2 charging with almost all homes having rooftop PV**

  - What is the charging behavior pattern in neighborhoods with EV clustering?
  - How does rooftop PV impact residential peak load and distribution system?

Electric vehicle charge duration in minutes, from June 1, 2012 to January 15, 2013

Source: Pecan Street, February 2015

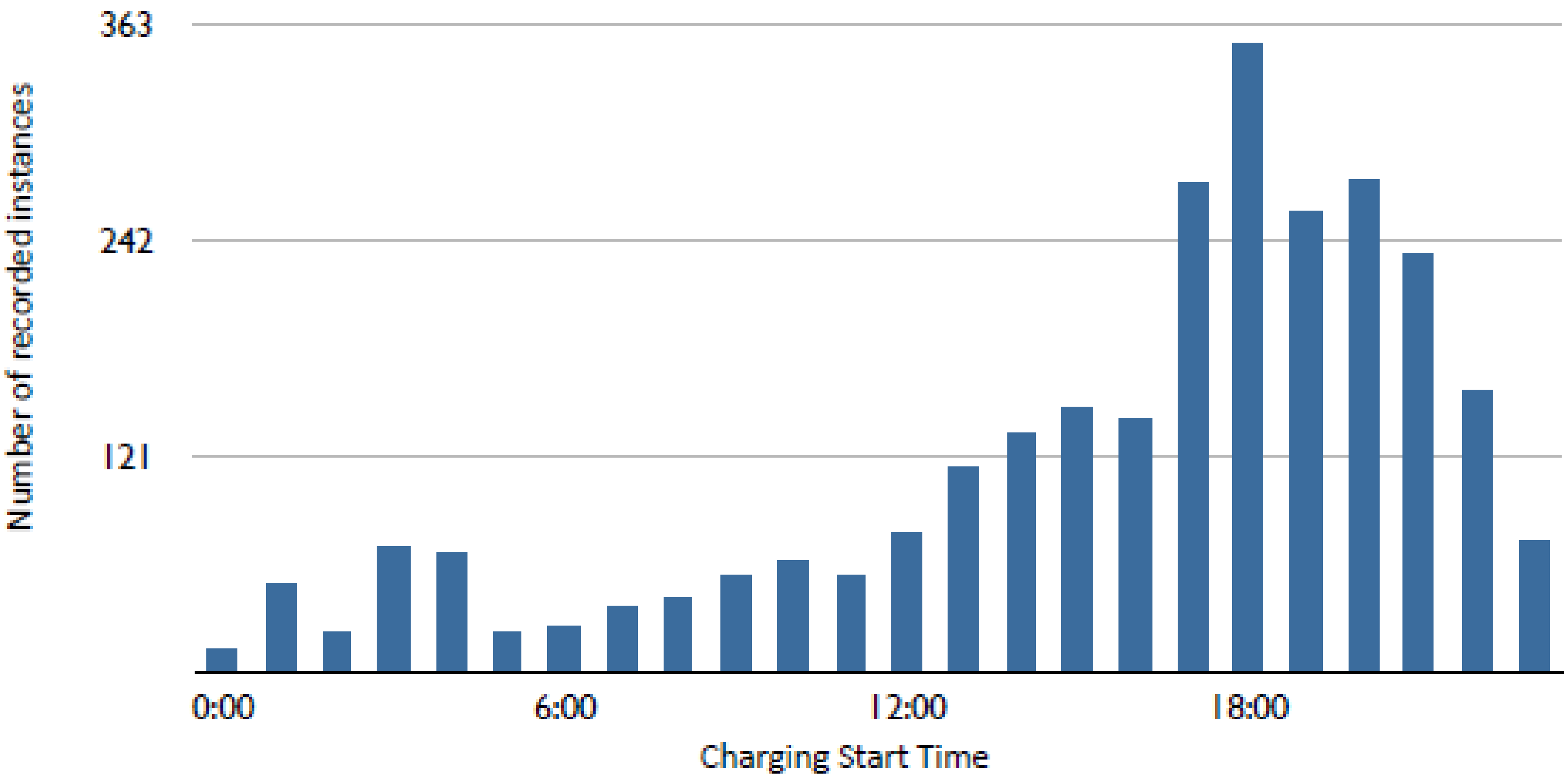


Source: Pecan Street Research Institute

EV charging duration mostly between 40-120 minutes

Electric vehicle charging start times from June 1, 2012 to January 15, 2013

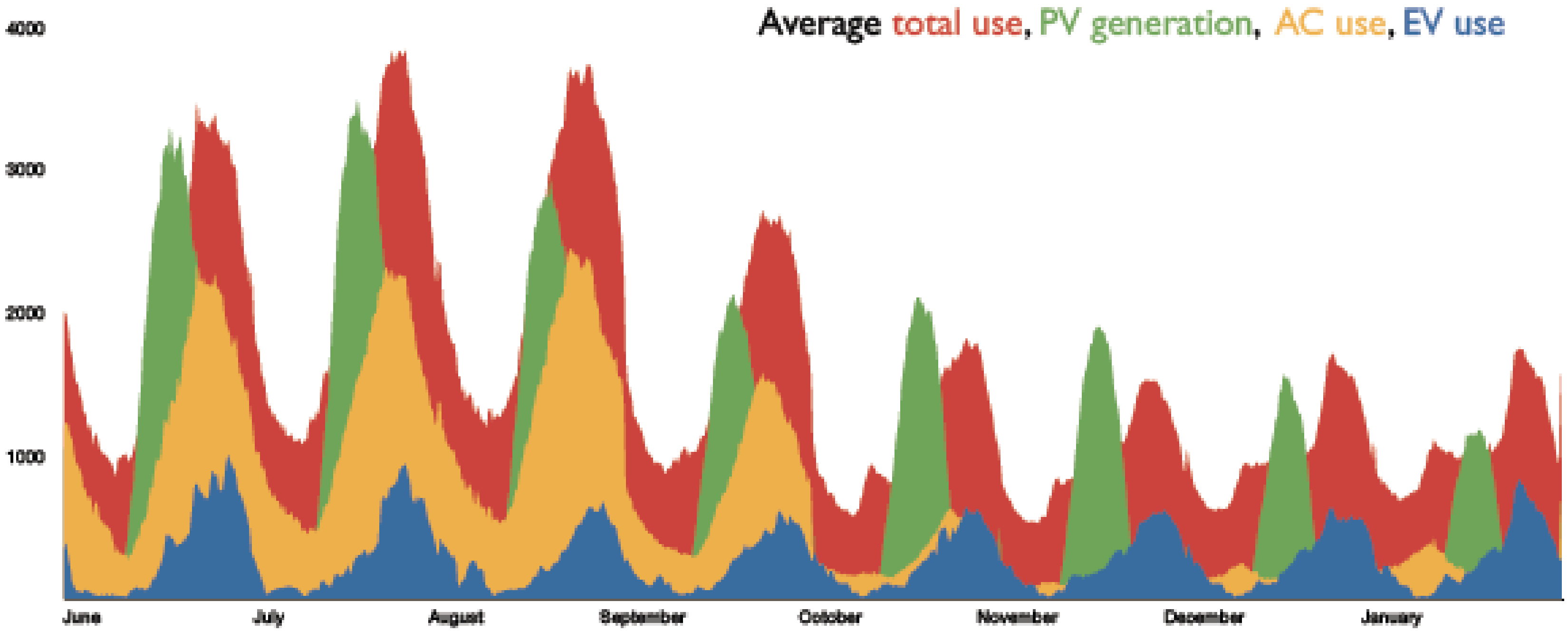
Source: Pecan Street, February 2015



Most EV charging started when workers arrived back at home

Average energy use over time (in watts)

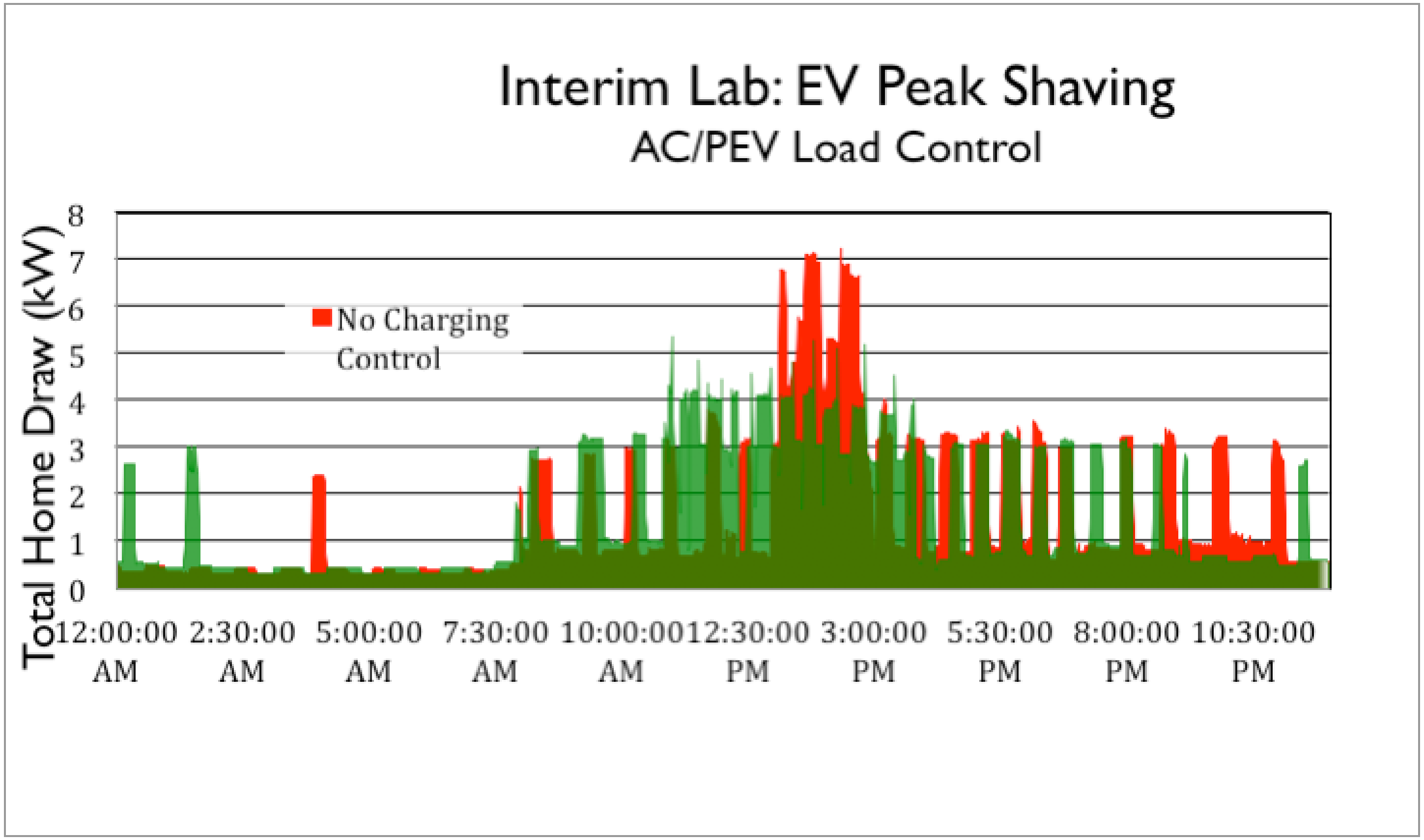
Source: Pecan Street, February 2015



Demonstration was in Austin, Texas; other areas of the country will have different trends for total energy usage, PV generation, AC/heating usage, and EV usage

Comparison of residential demand with and without load control

Source: Pecan Street, February 2015



🟦	With Charging Control ; AC and PEV charging control <2.3 kW total – charging to start; 2.3 to 5.8 kW – charging to continue; > 5.8 kW – disable charging
🟥	No Charging Control; AC and PEV charging at Level 2 (3.3 kW)

Case Study – Fast Response Frequency Regulation Using Fleet Electric Vehicles

Center for the Commercialization of Electric Technologies SGDP

- In 2013, ERCOT started a new pilot program for FRRS
- EV batteries are ideal for FRRS (G2V and V2G)
- EV fleet at Frito-Lay in Fort Worth, TX used in demonstration
- 11 EVs used for deliveries primarily at night; charged during day when load is high and need for FRRS is high
- Built custom power meter to monitor individual EV circuits and developed an aggregation control system
- Aggregated EVs responded to ERCOT signal or >0.09 Hz deviation
- Aggregated EVs could provide at least 100 kW of FRRS
- FRRS services bid into market in one-hour intervals
- Frito-Lay compensated for providing energy capacity to grid
- First time demonstration of using aggregated EVs for grid management

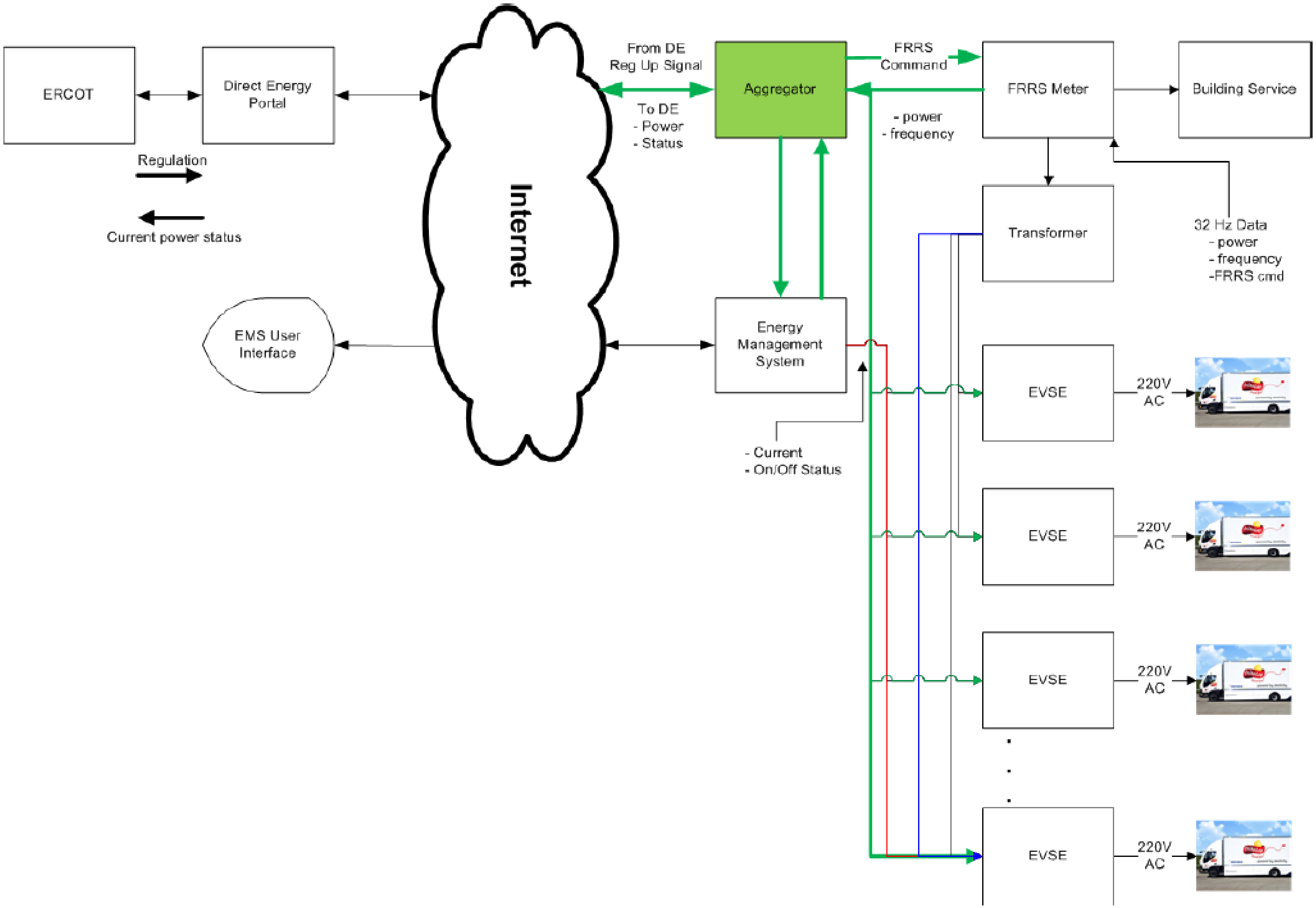


Figure 203. Architecture for Delivering FRRS from the Frito-Lay Facility

Case Study – AEP Ohio

- 10 EVs (9 Chevy Volts, 1 CODA)
- 36 EVSE (13 L1 at 1.4 kW; 23 L2 at 3.3-6.6 kW)
- 16 drivers from AEP Ohio

<u>Conclusions</u>

- Initial adoption of EVs did not have significant impact on transformer loading
- Demonstrated correlation between price and charging behavior when price differences are significant
- Participants indicated preference for electric vehicle on their next vehicle purchase
- Thorough analysis for placement of public chargers; usage depends on location
- Level 1 charging may be sufficient at home and workplace as parking duration is long enough for full charge

Case Study - Southern California Edison UC-Irvine SGDP

Workplace Electric Vehicle Chargers and Solar PV Structure

Source: Southern California Edison, 2014

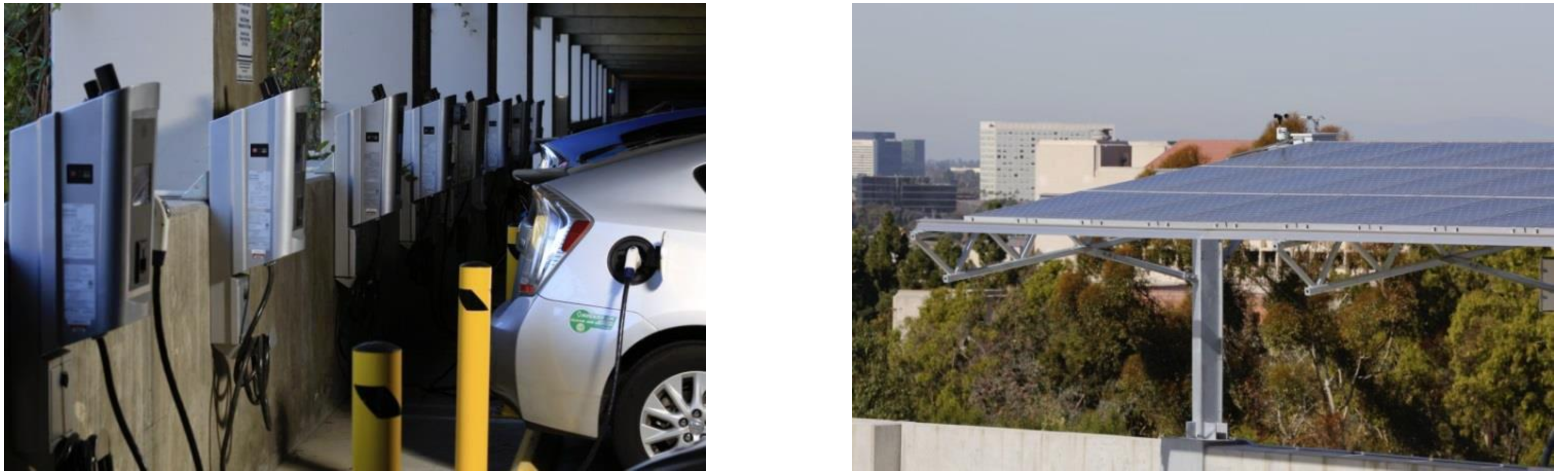
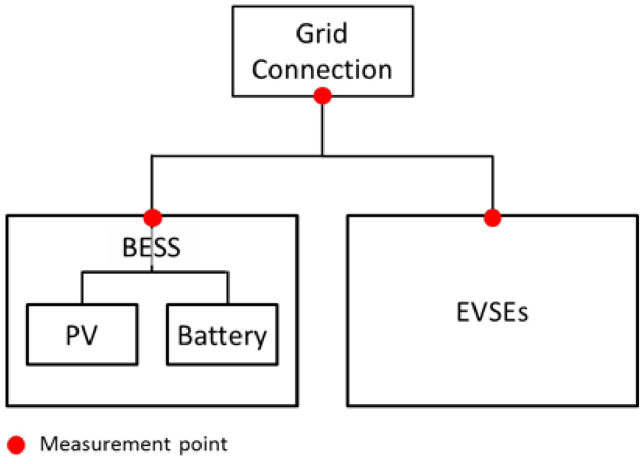


Figure 64: Solar Car Shade System Overview

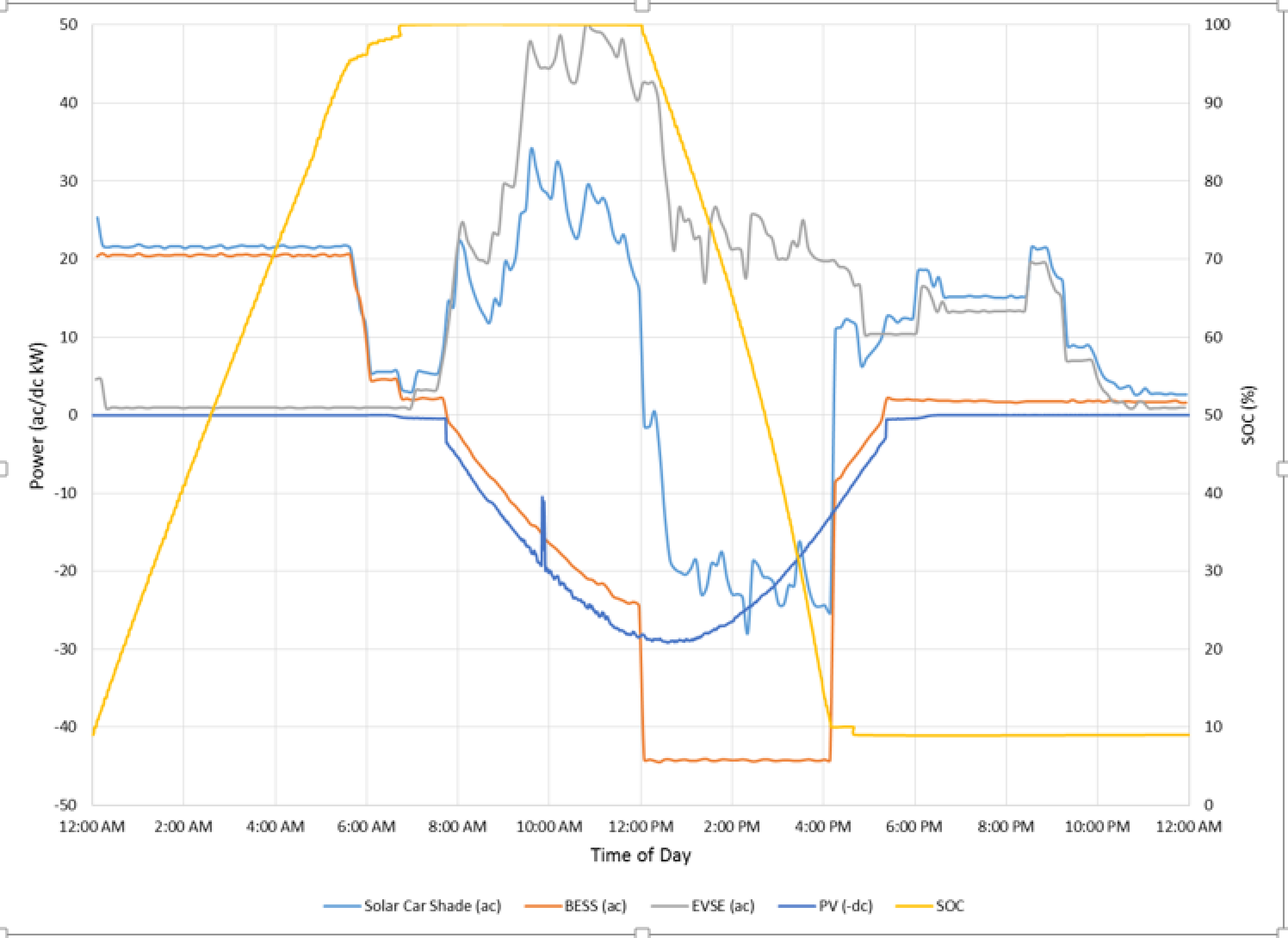


48kW solar PV array
20 parking spaces with 6.6 kW EVSE at UCI
BESS sized for 100 kW and 100 kWh

<u>Field Experiments</u>

- Minimize peak period impact of EV charging
- Cap demand of charging from power grid
- BESS load shifting

Figure 65: BESS Weekday Power Profile (October 28, 2014)



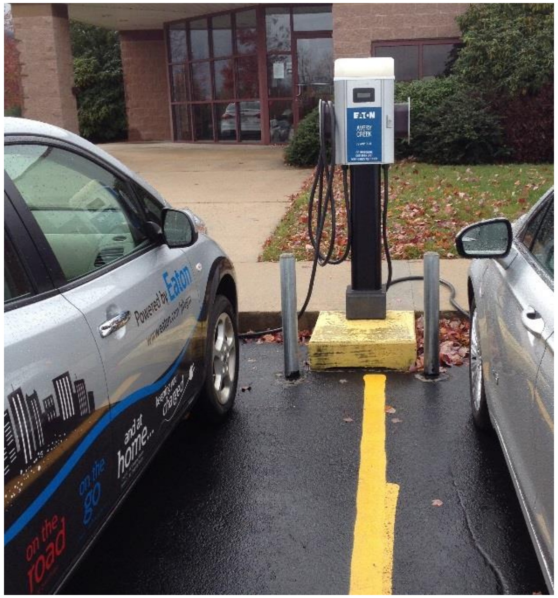
Case Study
Reducing Cost of L2 Electric Vehicle Chargers

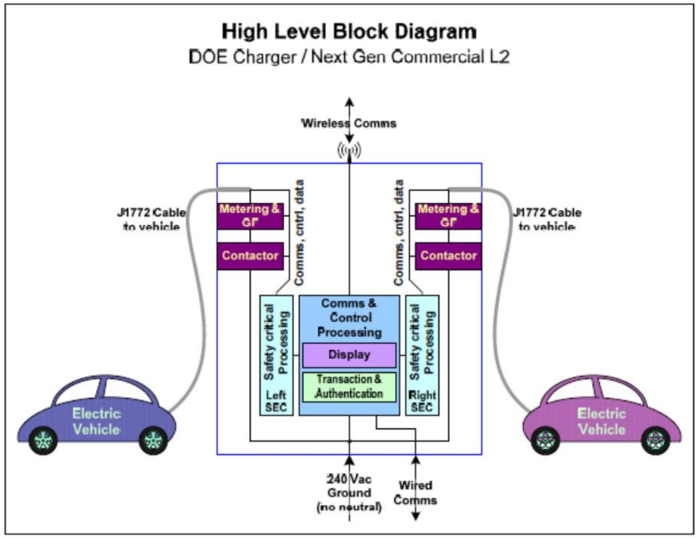
Commercial

Residential

Eaton

- **Team included Eaton, Duke Energy and Toyota**
- **Program goal achievements:**
  - Integrated smart grid functionality for two-way communication including 5 protocols, utility level signaling for demand response, and revenue grade metering
  - Reduced cost of ownership by 50%
  - Successfully integrated developed technology into existing EVSE product line and is applying the Supply Equipment Controller (SEC) to a new breaker design
  - Passed independent testing including both functionality and cyber security testing
  - Advanced HMI for consumer messaging

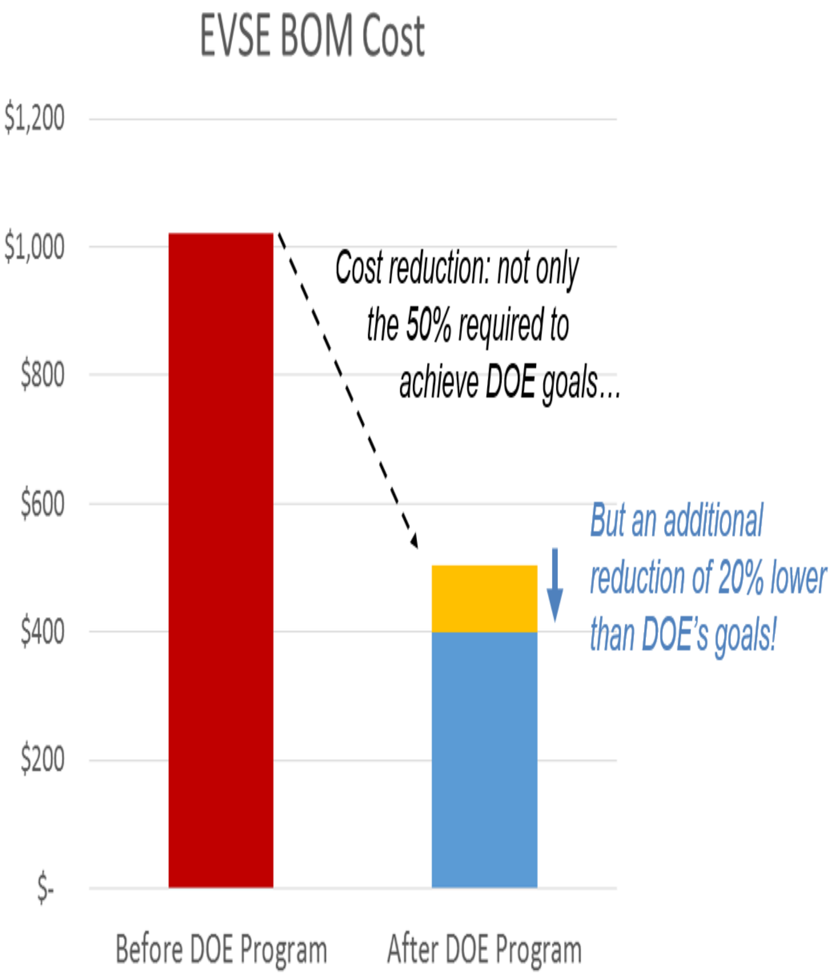




GE Global Research

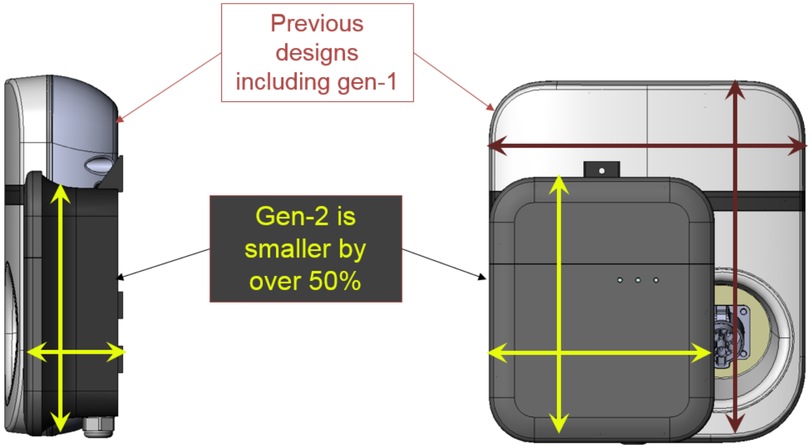
- **Program goal achievements:**
  - Cost reduction by 46% of total installed cost for a commercial charging station installation
  - Bi-directional communications were enabled using a cellular network
  - While a revenue grade meter was not installed inside the EVSE, the EVSE had the measurement precision required to participate in a demand response program
  - By adding a single board computer with its enhanced networking capabilities inside the EVSE, a broad range of communication interfaces can now be supported
  - Firmware and Server software modifications were completed to allow EV charging load control.

Delta
L2 Residential EVSE



Cost reduction: not only the 50% required to achieve DOE goals…

But an additional reduction of 20% lower than DOE's goals!



Previous designs including gen-1

Gen-2 is smaller by over 50%

Delta
L2 Residential EVSE

- Over 50% cost reduction achieved to meet DOE's aggressive goals
- Revenue Grade metering as required by DOE
- Extended scope to include 24 working units in a workplace-charging field installation
- All in a compact working prototype with UL approval

The Gen-2 EVSE Prototype incorporates multiple communication protocols and capabilities

- Zigbee communication with SEP 1.1 link to AMI
- Wifi version for workplace charging / smart home
- Demand Response
- Charging Profiles
- Logging of Historic Data

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