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Plug-in Electric Vehicle and Infrastructure Analysis

September 2015

Idaho National Laboratory

Prepared for the U.S. Department of Energy's Office of
Energy Efficiency and Renewable Energy

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ABSTRACT

Battelle Energy Alliance, LLC, is the managing and operating contractor for the U.S. Department of Energy's (DOE's) Idaho National Laboratory (INL). INL is the lead laboratory for DOE's Advanced Vehicle Testing Activity. INL's conduct of the Advanced Vehicle Testing Activity resulted in a significant base of knowledge and experience in the area of testing light-duty plug-in electric vehicles and electric charging infrastructure that reduce transportation-related petroleum consumption. Because of this experience, INL was tasked by DOE to develop agreements with companies that were recipients of American Recovery and Reinvestment Act of 2009 Transportation Electrification grants that allowed INL to collect raw data from light-duty vehicles and charging infrastructure developed and deployed as a result of these grants.

INL developed non-disclosure agreements with several companies and their partners, which resulted in INL being able to receive raw data via server-to-server connections from the partner companies. These raw data allowed INL to independently conduct data quality checks, perform analyses, and report publicly to DOE, partners, and stakeholders how drivers used both the new advanced plug-in electric vehicle (PEVs) technologies and the deployed charging infrastructure. The ultimate goal was not deployment of vehicles and charging infrastructure, but rather creation of real-world laboratories of vehicles, charging infrastructure, and drivers that would aid in the design of future electric drive vehicle transportation systems.

The five projects and the goal of each project that INL collected data from were as follows:

1. ChargePoint America – PEV Charging Infrastructure Demonstration
2. Chrysler Ram PEV Pickup – PEV Demonstration
3. General Motors Chevrolet Volt – PEV Demonstration
4. The EV Project – PEV and PEV Charging Infrastructure Demonstration
5. South Coast Air Quality Management District/Electric Power Research Institute/Via Motors – PEV Demonstration.

This document serves to benchmark the performance science involved in execution, analysis, and reporting for the five projects and share lessons learned based on drivers' use of vehicles and recharging decisions made by the drivers. Results are reported describing the use of more than 25,000 vehicles and charging units across the United States.

CONTENT

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TABLES

ACRONYMS

AC	alternating current
ADA	Americans with Disabilities Act
AHJ	authorities having jurisdiction
APS	Arizona Public Service
ARRA	American Recovery and Reinvestment Act
BEV	battery electric vehicle
CARB	California Air Research Board
CCN	Certified Contract Network
CD	charge depleting
CDU	charge dispensing unit
CS	charge sustaining
DBA	Davis-Bacon Act
DC	direct current
DCFC	direct current fast charger
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
EREV	extended-range electric vehicle
ERM	extended-range mode
EV	electric vehicle
EVM	electric vehicle mode
eVMT	electric vehicle miles traveled
EVSE	electric vehicle supply equipment
GHG	greenhouse gas
GM	General Motors
GPU	ground power unit
ICE	internal combustion engine
INL	Idaho National Laboratory
LCFS	low-carbon fuel standard
PEV	plug-in electric vehicle (includes BEVs, EREVs, and PHEVs, but not hybrid electric vehicles)
PGE	Portland General Electric
PG&E	Pacific Gas and Electric
PHEV	plug-in hybrid electric vehicle

SAC	Stakeholder Advisory Committee
SAE	Society of Automotive Engineers
SCAQMD	South Coast Air Quality Management District
SDG&E	San Diego Gas and Electric
SOC	state of change
TOU	time-of-use

1. HOW TO READ THIS REPORT

This report was designed to document and accomplish the following objectives:

- Describe the scope and objectives for five American Recovery and Reinvestment Act of 2009 (ARRA) Transportation Electrification projects
- Describe technologies used in each project
- Document each projects' deployment and data collection rates
- Document how reporting occurred
- Document results
- Summarize results
- Document lessons learned from each project.

In order to read this report in the most expedient and comprehensive manner possible, the report was primarily sectioned into four parts, with the intent of meeting reader and researcher needs. The four primary sections are as follows:

1. Executive Summary (Section 3)
   - Provides the key report takeaway and an overview of all five projects and the outcomes, including the featured highlight write-up: How Americans Charge Their Plug-In Electric Vehicles
2. Key Findings (Section 4)
   - Provides a succinct summary of lessons learned for the projects, in bulleted lists
3. Individual ARRA Project Descriptions (Sections 5 through 10)
   - Provides detailed descriptions of each project; this generally will only to be read by those seeking the most detailed information possible without referencing the many hundreds of reports INL has generated on a per project basis
4. Lessons Learned (Sections 11 and 12)
   - Describes the detailed lessons learned or "take aways" from the projects; this section provides bulleted lists summarizing information found in Section 4 (i.e., the Key Findings section).

Given the vastness of these projects and the magnitude of U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy's investment in each project, the reader should be prepared to first read the Executive Summary and Key Findings section (Section 4). If there is interest in additional information, then the reader should go to the specific lessons learned or project sections.

2. ACKNOWLEDGEMENTS

INL must first and foremost thank DOE for the faith that DOE placed in INL's abilities to complete data accumulation, analysis, and reporting for the largest set of plug-in electric vehicle (PEVs) and charging infrastructure projects ever successfully undertaken.

The five projects and partners involved must also be acknowledged because they agreed to partner with DOE and INL, and set up secure data transfer systems after nondisclosure agreements were signed. Most of the partners had never before shared raw vehicle and charging infrastructure data to this extent. This sharing of raw data via server-to-server connections spoke well of the partners' commitments to see these projects succeed. These data-sharing partners (as follows) are thanked for their individual and group commitments:

- ChargePoint America
  - ChargePoint, Inc.
- Chrysler Ram Plug-In Hybrid Electric Vehicle (PHEV) Pickup
  - Chrysler Group, LLC
- General Motors (GM) Chevrolet Volt
  - General Motors Company
  - OnStar, LLC
- The EV Project's PEV and Charging Infrastructure Demonstration
  - Car Charging Group
  - ECOtality, Inc.
  - General Motors Company / OnStar, LLC
  - Nissan North America, Inc.
  - Car2 Go N.A., LLC
- South Coast Air Quality Management District (SCAQMD) PHEV Demonstration
  - SCAQMD
  - Electric Power Research Institute, Inc. (EPRI)
  - Via Motors, Inc.

While not formally part of the listed five projects, other groups should be acknowledged for their contributions. AeroVironment and the New York State Energy Research and Development Authority contributed charging infrastructure data several times in order to strengthen the charging infrastructure analysis that INL conducted. Both organizations recognized the significance of the analysis being conducted and the importance the results would have for industry. In addition, the states of Oregon and Washington also made various contributions that strengthened INL's analysis.

INL would like to acknowledge and thank DOE staff and the private sector partners for their numerous contributions and long work hours.

3. EXECUTIVE SUMMARY

3.1 Featured Highlight: How Americans Charge Their Plug-In Electric Vehicles

Widespread adoption of PEVs has the potential to significantly reduce the United States transportation petroleum consumption and greenhouse gas (GHG) emissions. However, barriers to adoption remain. One of the most commonly cited barriers is the need for public charging infrastructure that would allow PEV drivers to recharge their vehicles. Questions include: how many and what kind of charging stations are needed and where and how often will PEV drivers choose to charge?

To answer these questions, the DOE launched the following five ARRA projects:

1. The EV Project
2. ChargePoint America Project
3. Chrysler Ram PHEV Pickup – Vehicle Demonstration
4. GM Chevrolet Volt – Vehicle Demonstration
5. SCAQMD/EPRI/Via Motors PHEVs – Vehicle Demonstration.

The EV Project and the ChargePoint America Project, combined, form the largest PEV infrastructure demonstration in the world. Between January 1, 2011, and December 31, 2013, these combined projects installed 17,000 alternating current (AC) Level 2 electric vehicle supply equipment (EVSE) (i.e., 240-volt charging stations) for residential and commercial use and dual-port direct current (DC) fast chargers (DCFCs) in 22 regions across the United States. Over 7,800 privately owned Nissan Leafs™ and Chevrolet Volts and more than 400 Smart ForTwo electric drive vehicles in Car2Go car-sharing fleets were enrolled in The EV Project.

These projects were not just about installing charging infrastructure; the purpose was to study charging infrastructure use and develop lessons learned that can be applied to future deployments of PEVs and charging infrastructure. To accomplish this, INL partnered with the Blink Network, ChargePoint, General Motors (GM) and OnStar, Nissan North America, and Car2Go to collect and analyze data from the electric vehicle charging stations and the PEVs enrolled in these two projects.

Every PEV owner participating in The EV Project had an EVSE installed in their residence. In return, the PEV owners gave written consent for researchers to collect and analyze data from their home charging units and their PEVs. Data also were collected from publicly accessible charging stations installed at a wide variety of venues in and between metropolitan areas around the United States.

Data collected from vehicles and charging infrastructure over the 3-year project period captured use profiles for125 million miles of driving and 6 million charging events, providing the most comprehensive study of PEV and charging usage to-date.

Through partnerships with states, municipalities, electric utilities, local business owners, and numerous other stakeholders, The EV Project and ChargePoint America Project installed charging stations in 22 regions across the United States (Figure 3-1).

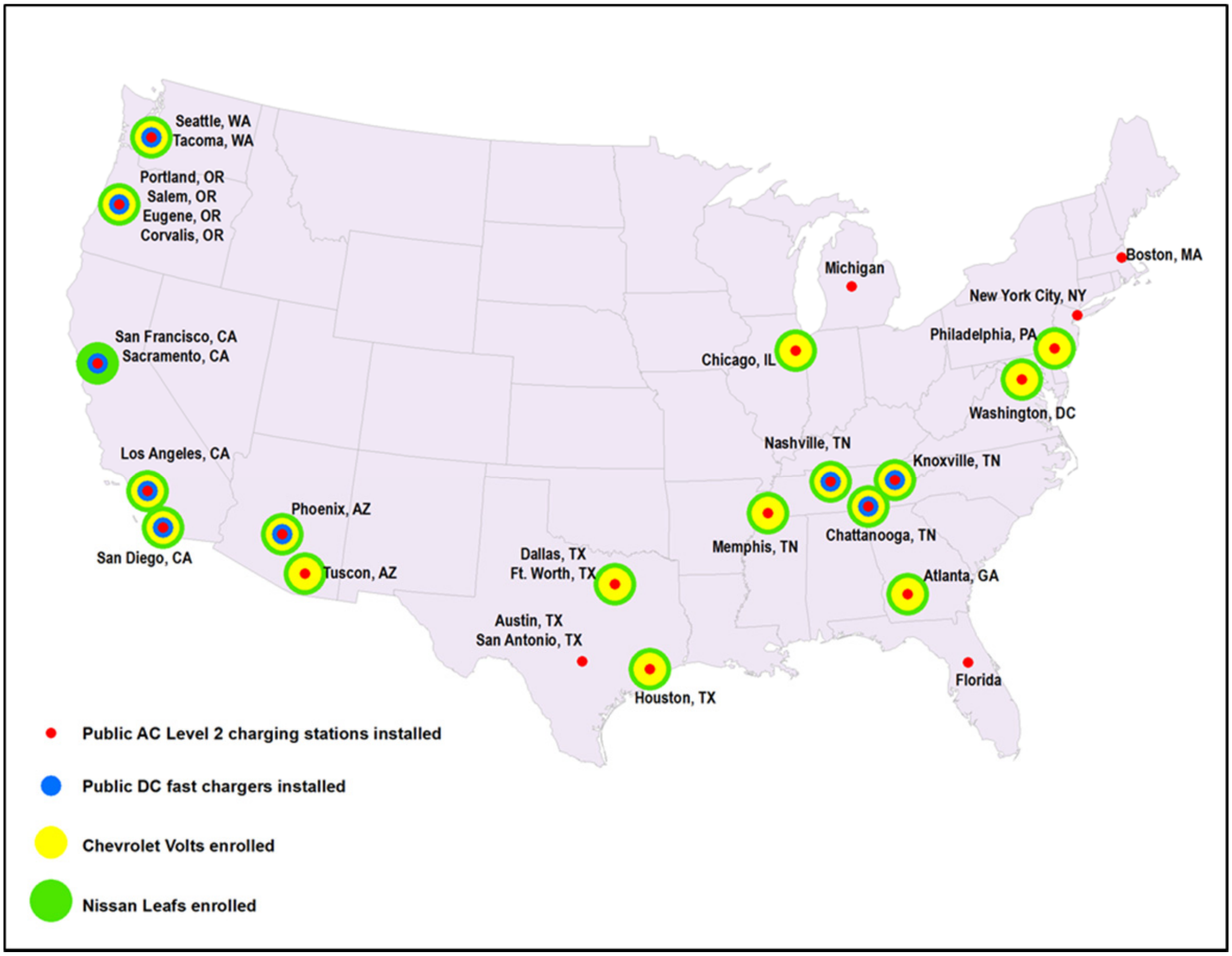


Figure 3-1. Areas where public charging infrastructure was installed and vehicles were enrolled in The EV Project and ChargePoint America Project.

3.1.1 What Have We Learned?

With gas stations seemingly on every block, it would be logical to expect that a similarly ubiquitous network of public charging stations would be needed to refuel, or rather, recharge PEVs. However, charging stations can be installed where gas stations cannot (i.e., at homes, workplaces, and destinations where PEVs spend a long time parked). The projects installed EVSE and DCFC stations (480 V) in a wide variety of locations, including homes, workplaces, stores, restaurants, gas stations, and many other venues, to allow researchers to observe where PEV drivers charge. The primary question about charging infrastructure placement was: would PEV drivers recharge around town at the nearest charging station, following the pattern they followed with the gas-powered cars they grew up with or would they adopt a new refueling paradigm and charge at the few places where they park their cars for the longest periods of time?

The answer is clear: despite installation of extensive public charging infrastructure, in most of the project areas, the vast majority of charging was done at home and work. About half The EV Project participants charged at home almost exclusively. Of those who charged away from home, the vast majority favored three or fewer away-from-home charging locations, with one or more of these locations being at work for some drivers.

This is not to say that public charging stations are not necessary or desirable. Some DCFCS, all of which were accessible to the public, experienced heavy use, which supported both intra and inter-city driving. Also, a relatively small number of public AC Level 2 EVSE sites saw consistently high use. This begs the question: what is it about the small number of highly used charging sites that led to their popularity?

There was some correlation between public charging location characteristics and utilization. Public AC Level 2 EVSE installed in locations where vehicles were typically parked for longer periods of time often were among those used most often. These locations included shopping malls, airports and commuter lots, and downtown parking lots or garages with easy access to a variety of venues. Also, not surprisingly, public charging station utilization was higher in regions with higher PEV sales. However, examples of highly utilized charging sites existed in almost every region and at venues that were not obviously appealing locations for charging. Conversely, many charging sites in seemingly ideal locations did not experience much use.

In the end, it was apparent that exact factors that determine what makes a public charging station popular are predominantly community-specific. More research is needed to pinpoint these local factors. Nevertheless, the projects demonstrated that a ubiquitous charging network is not needed to support PEV driving. Instead, charging infrastructure should be focused at home, workplaces, and in public “hot spots,” where demand for AC Level 2 EVSE or DCFC stations is high.

Naturally, there are exceptions to this rule. There may be reasons for an organization to install public charging stations, even if they are not used (e.g., attract a certain customer demographic, communicate a “green” image, or encourage PEV adoption). Additionally, DCFCs along travel corridors were found to effectively enable long-distance range extension for BEVs. These chargers were not typically used frequently; therefore, their value is hard to quantify from the perspective of the charger host, but when they were used, they provided a vital function to the BEV driver.

Regardless of motivation for installing public charging infrastructure, the project found that public charging stations were more expensive to install than residential and workplace units. Installation costs also varied widely by region and by venue. This further emphasizes the benefit of focusing the bulk of charging infrastructure at home, work, and strategic public charging locations.

The projects shed light on other facets of PEV use. It found that public and workplace charging infrastructure enabled drivers to increase their electric driving range, although most drivers did not charge away from home frequently. It was also discovered that drivers of the Chevrolet Volt (an extended-range electric vehicle [EREV]) tended to charge more frequently and to more fully deplete their vehicle’s battery than drivers of the Nissan Leaf (a BEV). This allowed the overall group of Volts studied to average nearly as many electric vehicle (EV) mode (EVM) miles traveled as the Leafs in the project. Finally, based on observed charging patterns, the project found that there were opportunities to use pricing structures and other policies to manage demand for PEV charging, both in terms of charging station throughput at charging hot spots and electricity demand on the electric grid during peak and off-peak periods.

3.1.2 What Have We Learned About PEV Driving Patterns and Charging Preferences?

By focusing on data collected in 2012 and 2013 from over 4,000 Leafs and 1,800 Volts across the United States, the project provided insights into how PEV early adopters drove and charged their vehicles.

Volt drivers averaged slightly more miles traveled annually than the 2013 national average, while the Leafs studied were driven noticeably less than the national average (see Table 3-1).

Table 3-1. EV Project Leaf and Volt annual miles and annual EV miles traveled during 2012 and 2013.

	Leaf	Volt	National Average[4]
Average annual vehicle miles traveled	9,697	12,238	11,346
Average annual EV miles traveled	9,697	9,112	—

Volt drivers averaged only 6% fewer EV miles per year than Leaf drivers, despite having significantly less battery capacity. There were two reasons for this. First, Volt drivers tended to fully deplete their batteries prior to recharging, whereas Leaf drivers favored recharging when there was still capacity left in their batteries. This is an expected difference between pure BEVs like the Leaf and PHEV vehicles like the EREV Volt, which has a range-extending gasoline engine that allows the vehicle to continue driving after the traction battery is fully depleted. Second, Volt drivers plugged in more often than Leafs. Volts were charged an average of 1.5 times per day on the days the vehicle was driven, whereas Leafs were charged an average of 1.1 times per day on days the vehicle was driven. Much of the difference between Leaf and Volt charging frequency is attributed to the fact that Volts were charged more often during the day at the drivers' residences.

Average driving distance and charging frequency was consistent over time as the number of vehicles reporting data increased, with only slight seasonal variation. Figure 3-2 shows the seasonal variation in average monthly distance traveled for the last 15 months of the project. Charging frequency (not shown) followed the same up-and-down trend.

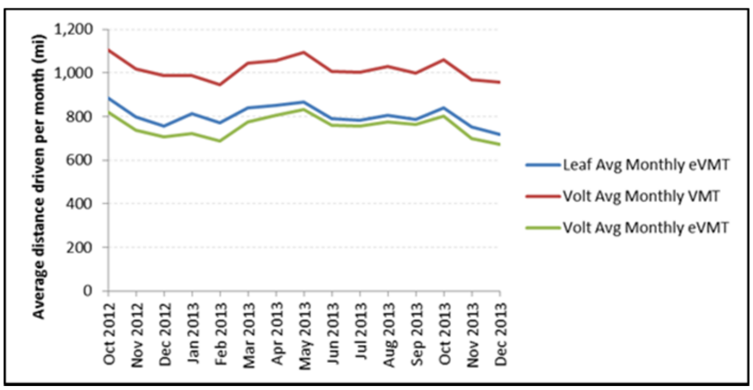


Figure 3-2. Average monthly vehicle miles traveled varied seasonally, but was otherwise consistent over time.

3.1.3 Preference for Charging Frequency and Location

Overall, the Leaf and Volt drivers performed most of their charging at home (Figure 3-3). Nearly all overnight charging was done at home. Daytime charging was split between home and other locations, including work.

Over the weekend, the daytime charging preference for both Leafs and Volts shifted slightly from away-from-home locations to at home. Overnight charging patterns remained the same on weekdays versus weekend days, with both groups of vehicles averaging a charge nearly every night.

[4] Office of Highway Policy Information, Federal Highway Administration, "Highway Statistics 2013-Table VM-1," January, 2015, www.fhwa.dot.gov/policyinformation/statistics/2013/vm1.cfm.

Some drivers spread their charging across many locations, but most drivers in the project who chose to charge away from home had just a few favorite places to charge outside of home (see Figure 3-4).

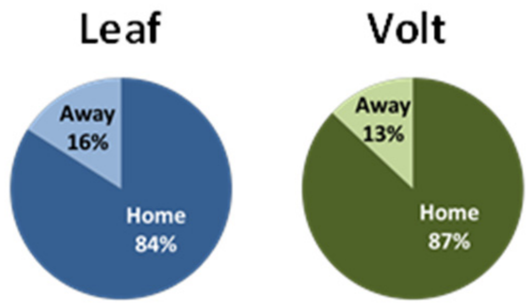


Figure 3-3. Leaf and Volt drivers performed most of their charging at home.

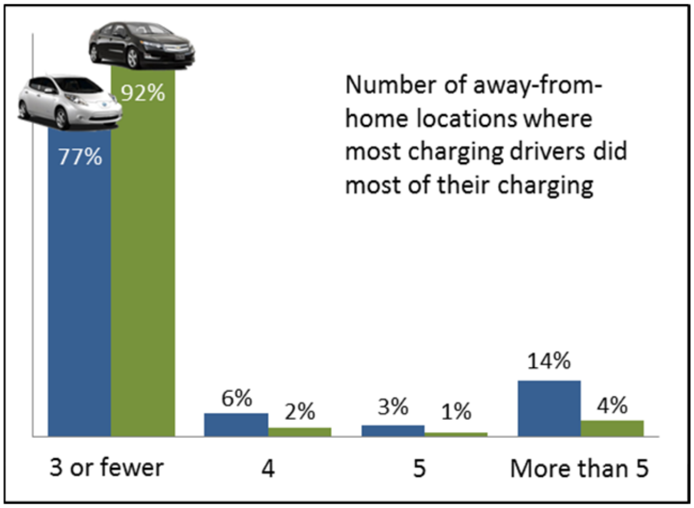


Figure 3-4. In all, 92% of Volt drivers and 77% of Leaf drivers did most of their away-from-home charging at three or fewer locations.

In fact, many drivers performed a vast majority of their away-from-home charging at only one location. On a fleet-wide basis, the charges performed at each vehicle's favorite away-from-home charging location made up 82% of Volt charges and 72% of Leaf charges, with much of this being attributed to workplace charging.

3.1.4 Preference for Charging Equipment

Both the Leaf and the Volt come with AC Level 1 (110 to 120 V) charging cords. They are also compatible with AC Level 2 (208 to 240 V) EVSE that use Society of Automotive Engineers (SAE) J1772-compliant connectors. All Leafs enrolled in the project also were capable of charging using DCFC with CHAdeMO-compliant connectors. All project participants had an AC Level 2 EVSE installed in their homes. When charging away from home, they had the option of using any charging equipment available to them.

For the Volts collectively, about half of the away-from-home charging was done using AC Level 2 EVSE. The other half was AC Level 1 charging using a dedicated charging station or a standard 120-volt outlet.

For Leafs, 8% of away-from-home charging events were performed using DCFCs. The rest were AC Level 1 or AC Level 2 EVSE charging.

Each driver used a different mix of charging equipment types when charging away from home, depending on their preference and what was available. Some Volt drivers chose only AC Level 1 charging (i.e., 110 to 120-V standard home outlet), others chose a mix of AC Level 1 and AC Level 2 EVSE charging, and some only ever used AC Level 2 EVSE. For Leaf drivers charging away from home in areas where DCFCs were installed, some chose to only charge using AC Level 1 or AC Level 2 EVSE; some mixed AC Level 1 EVSE, AC Level 2 EVSE, and DCFC; and a small number of drivers only charged using DCFCs (see Figure 3-5).

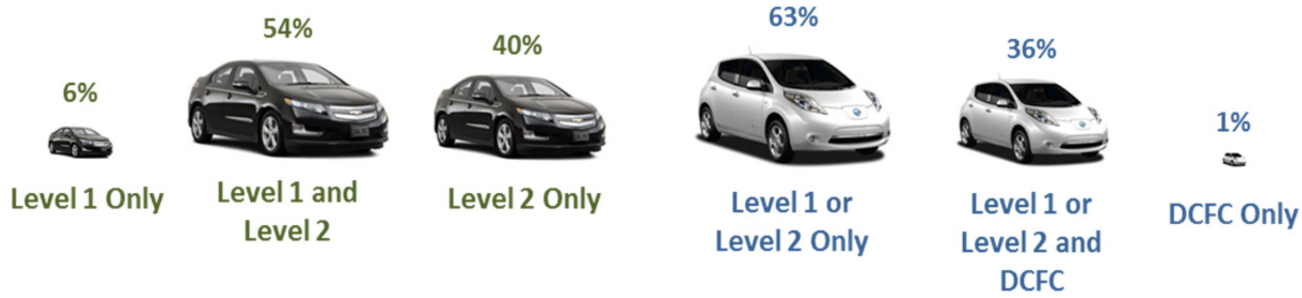


Figure 3-5. Volt and Leaf drivers' away-from-home preferences for charging equipment.

3.1.5 What Have We Learned About Away-From-Home Charging for Range Extension?

PEV drivers who plugged in away from home tended to drive more EV miles (Table 3-2). In fact, drivers who frequently used away-from-home charging stations averaged 72% more daily miles on electricity alone than drivers who never charged away from home.

Table 3-2. Tendency of Leaf and Volt drivers to charge away from home and the daily driving distance associated with these tendencies.

Tendency to Charge Away from Home	Never	Sometimes[5]	Frequently[6]	Most of the Time[7]
Leaf average daily driving distance (mi)	25	31	43	32
Volt average daily driving distance in EVM (mi)	25	29	40	26

However, most drivers did not charge away from home frequently (see Table 3-3); therefore, overall contribution to EV miles traveled was small.

Table 3-3. Frequency of PEV drivers to charge away from home.

Tendency to Charge Away from Home	Never	Sometimes[5]	Frequently[6]	Most of the time[7]
Percent of Leafs	13%	69%	14%	4%
Percent of Volts	5%	81%	13%	1%

[5] Greater than 0 to 30% of all charging events

[6] Greater than 30 to 60% of all charging events

[7] Greater than 60% of all charging events

Overall, 20% of the PEVs studied were responsible for 75% of the away-from-home charging, with much of this away-from-home charging being attributed to workplace charging.

3.1.6 What Have We Learned About Workplace Charging?

A subgroup of project participants was identified that had access to both home and workplace charging. Consistent with conventional wisdom, Leaf and Volt drivers with access to home and work charging performed the vast majority of their charging at those locations (see Figure 3-6).

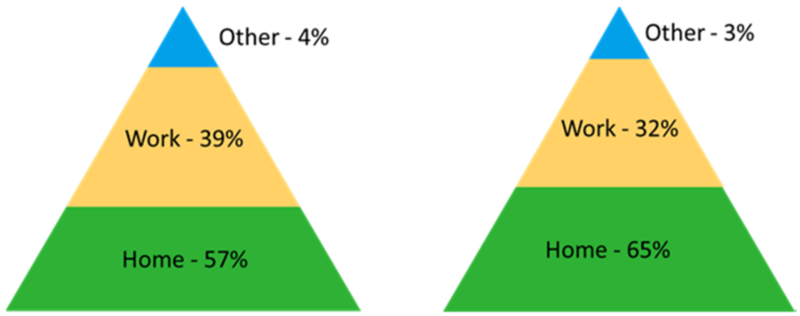


Figure 3-6. Volt (left) and Leaf (right) drivers with access to home and workplace charging performed nearly all of their charging at those locations.

Considering only days when drivers went to work, the effect is even more pronounced. PEV drivers performed 98% of their charging events either at home or work and only 2% at other locations. Charging at work was free for many of these drivers, which may have been one reason why they frequently charged there.

On weekends and other days when they did not go to work, Leaf drivers averaged 8% of their charging events at locations other than home and Volt drivers averaged 11% of their charging away from home. This increased use of public charging on weekends suggests that public charging still plays a role in these drivers' travel routines.

3.1.6.1 Range Extension from Workplace Charging. Workplace charging was found to be an effective range extender, allowing some Leaf owners to drive their Leafs to work even on days when their round-trip commute exceeded the vehicle's range based on home charging alone (see inset).

On days when Leaf drivers had to charge at work in order to complete their daily commute, workplace charging provided an average of 15 miles of range extension that was required to make it home. The entire daily commute on these days, which averaged 73 miles, arguably was enabled by workplace charging.

Volt drivers saw similar electric range-extending benefits from workplace charging. Those with known access to workplace charging garnered an additional 18.5 miles of EV driving, on average, from workplace charging on days when their commute was too far to otherwise complete on electricity alone. On these days, their round-trip commutes averaged 62 miles, with 57 miles of EV range.

> 6% of drivers drove a Leaf to work even though they could not make it back home unless they charged at work.
>
> 8% of Leaf drivers could complete their direct commute without charging at work, but their routine *on most days* required them to drive additional distances, which necessitated charging at work in order to make it home.
>
> 40% of Leaf drivers relied on workplace charging *on at least 1 day a month* to complete their daily commutes.

Leaf and Volt drivers with known access to workplace charging in this study averaged 23% and 26% higher annual EV miles traveled than the overall group of vehicles in the project, respectively (see Figure 3-7).

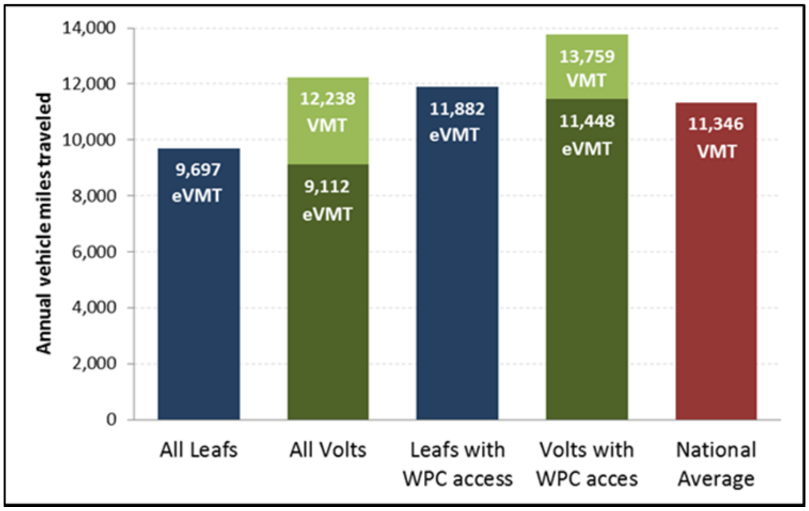


Figure 3-7. Volt and Leaf drivers with access to home and workplace charging drove considerably more annual EV miles than the overall project averages; their annual electric vehicle miles traveled (eVMT) exceeded the national average annual vehicle miles traveled.

3.1.6.2 Workplace Charging as a Substitute for Home Charging. About 30% of drivers only charged at work on most days. This shows that workplace charging could make PEVs viable for people without access to home charging.

3.1.6.3 Management of Workplace Charging. PEV drivers demonstrated that they adjust their charging habits based on conditions (e.g., fees and rules for use). Not surprisingly, drivers were less likely to plug in at work if they had to pay to charge or if they were required to move their vehicle after charging (and the rule was enforced). However, PEV drivers also showed a willingness to use communication tools (e.g., an online message board) to coordinate the use of charging stations with other employees. At the work sites studied, there was also a culture of common courtesy and willingness to follow local practices (e.g., a driver plugging in a neighboring car after unplugging his/her vehicle). In many cases, this self-management by employers led to exceptionally high charging station use and an opportunity for a large number of employees to charge regularly.

3.1.7 What Have We Learned About Public Charging Station Use?

Public AC Level 2 EVSE usage (excluding workplace charging units) was low overall. The median charging frequency per site was 1.4 charges per week, with 75% of the 2,400 public AC Level 2 EVSE sites nationwide averaging four or fewer charging events per week. However, popular public AC Level 2 EVSE sites saw very high usage. Well-designed charging sites at retail stores, especially shopping malls, and parking lots and garages serving multiple venues demonstrated the potential to support from 7 to 11 charges per day.

Of course, charging sites at venues where vehicles are parked for long periods of time (e.g., airports, ride-share parking lots, or parking lots at public transit stations) should not be measured by the number of events per week, but rather by the time vehicles spent connected to charging stations in a day or week. During the two projects, these kinds of sites had vehicles connected for an average of 8.6 hours per charge cord per day. The average time vehicles were plugged in for each individual charge event ranged from 4 to 42 hours, with a median plug-in time of 22.6 hours per event. These types of locations are potential candidates for slower, lower cost AC Level 1 charging equipment.

DCFCs were used much more frequently than most public AC Level 2 EVSE, with a median use frequency of 7.2 events per week, based on averaging each DCFC's use over the course of the entire EV Project. A quarter of the DCFCs averaged over 15 events per week, and one unit averaged 70 events per week. The most highly utilized DCFCs tended to be located close to interstate highway exits. Interestingly, these units were used by local vehicles as much or more than they were used to recharge vehicles traveling on the interstate.

Public charging station usage varied significantly by region, with average utilization rates generally tracking with regional PEV sales. However, highly utilized individual public charging sites were found in most regions, proving that public charging station utilization is dependent on local factors. More research is needed to fully characterize public charging "hot spots" and develop rules of thumb for identifying public charging locations with potential for high utilization.

3.1.7.1 How Did Public Usage Change Over Time? As mentioned, overall usage of public AC Level 2 charging stations was low. However, it slowly increased over the course of the projects, with usage of ChargePoint units increasing at a faster rate than Blink units on average nationwide (see Figure 3-8). The cost to use public AC Level 2 charging stations varied from site to site. Most Blink public AC Level 2 EVSE units charged a fee after September 2012. Many ChargePoint public stations were free through the end of the project, but the exact number is not known**.**

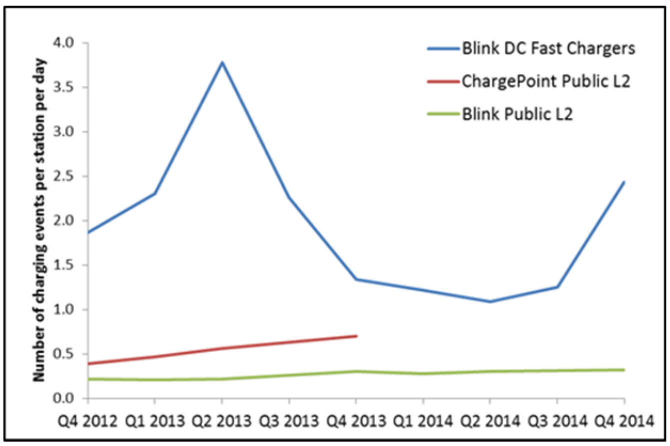


Figure 3-8. Blink DCFC usage fell dramatically in the middle of 2013, coinciding with the onset of fees for use, but increased again in the second half of 2014.

Blink DCFCs were initially free and usage increased quickly. However, usage dropped dramatically when the Blink Network implemented a usage fee in the summer of 2013. Data provided by the Blink Network after the end of project showed that the average Blink DCFC's usage bottomed out in early 2014 and then steadily increased, reaching 2.4 charging events per day by the end of 2014.

Prior to the onset of fees, Blink DCFC sessions lasted an average of 19.5 minutes. When the Blink Network began charging a per-session fee to fast charge, the average time spent charging increased by 20%. Drivers presumably stayed connected longer to get their money's worth.

3.1.8 What Have We Learned About Charging at Home?

3.1.8.1 When Do They Charge? PEV owners have the option of delaying the start of charging electronically, allowing them to plug in their PEV at a convenient time but not starting the consumption of electricity from the grid until later (e.g., when electricity prices are lowest). Project participants could program either their vehicle or their home charging unit to delay charging. Of those who chose to delay their charging using these tools, about half programmed their charging unit and half programmed their vehicle. Some customers chose to program their charging unit, rather than their vehicle, to avoid needing to override the vehicle's charge delay setting when they plug in away from home during the day.

Participants in the project left their vehicles plugged in at home overnight for an average of 12 hours per charge. The vehicles always required less than 5 hours to fully charge at home using the AC Level 2 EVSE units, and usually only took 1 to 3 hours to charge completely. This means that even though most vehicles were plugged in each night by 10:00 pm, overnight charging at home typically could feasibly be delayed until post-midnight when overall demand on the electric grid is the lowest. In fact, many electric utilities offer reduced home electricity prices during off-peak times to incentivize their customers to shift electricity consumption off peak. PEV owners in the project in areas where utilities offer cheaper rates at night showed a willingness to delay charging at home until these off-peak periods. In San Diego, where the cheapest time to charge was between midnight and 5:00 am, most PEV owners programmed their charging to start at midnight or 1:00 a.m. (see Figure 3-9).

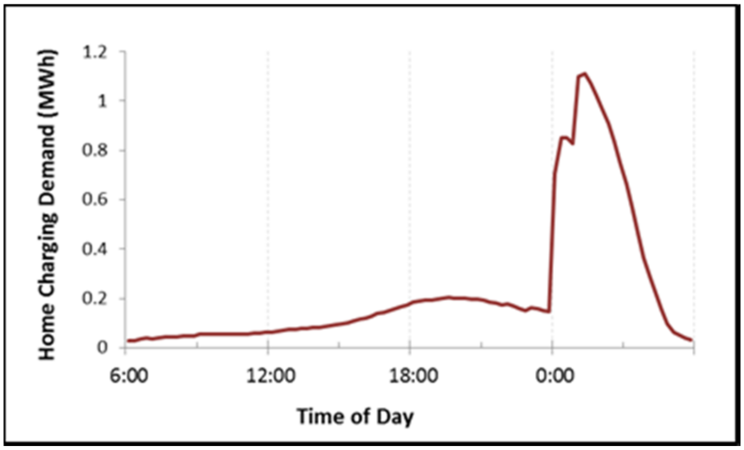


Figure 3-9. The total power drawn over the course of a day by all EV Project vehicles charging at home on a typical weekday in San Diego.

The Volt and Leaf both offer a charge scheduling option that allows the owner to tell the vehicle what time they plan to depart on their next trip. The vehicle chooses what time to start charging, based on how empty the battery is and how much time it calculates it needs to charge. This "depart-by time" scheduling function is helpful for the electric grid, because it essentially randomizes the charge start time from household to household, thus preventing all vehicles from initiating charging at the same time, such as the start of the off-peak period.

3.1.9 What Have We Learned About Charging Station Installation Costs?

Installation costs for residential, workplace, and public charging station was documented for the Blink stations installed in The EV Project. Residential AC Level 2 unit installation cost ranged from a few hundred dollars to over $8,000. The average residential installation cost was $1,354. This average was driven up by expensive installations that required upgraded electrical service, which was often necessary in older homes. Costs varied regionally based on electrician labor wages and permitting fees.

The installation cost of public AC Level 2 charging stations ranged from $600 to $12,660, with an average cost of $3,108. Cost primarily depended on the distance from the facility's electrical panel to the charging station location and varied regionally due to labor costs.

Workplace AC Level 2 charging unit installations averaged $2,223, or 28% less than the average public AC Level 2 unit cost. This difference was attributed to workplaces having more flexibility in choosing the locations of their charging stations and the type of equipment to be installed. However, employers that installed additional charging stations often found the second round of installations to be more expensive because the inexpensive locations had been taken by the initial set of charging stations.

Blink DCFC installation costs in the project ranged from $8,500 to over $50,000, with an average cost of $22,626. This average actually may be artificially low, because installation proposals that exceeded a spending limit were turned down. Many DCFC installations required the addition of electrical service to support the DCFC's 60-kW power rating and requirement for 480-volt, 3-phase power. This significantly increased the installation cost. As with AC Level 2 units, costs varied regionally, depending on permitting requirements and labor costs.

3.1.10 How Have the Findings of These Projects Helped Organizations Promote or Prepare for PEV Adoption?

Project staff had the goal of disseminating as many findings as possible from the projects to help other organizations in their efforts to accelerate PEV adoption. Researchers at INL were specifically assigned to regularly publish reports and present results to key government and industry stakeholders. The following subsections contain some examples of the organizations and efforts that benefitted from the project.

3.1.10.1 National Policy Recommendations. Project researchers provided the National Research Council of the National Academy of Sciences with numerous presentations and reports to help them prepare the recently released report, titled "Overcoming Barriers to Deployment of Plug-in Electric Vehicles." This 204-page report is the result of an intensive 2-year study conducted by the National Research Council for DOE and makes recommendations to the federal government and others on actions to take or avoid to enable adoption of PEVs by the mass market.

3.1.10.2 State Infrastructure Planning Decisions. The California Air Resources Board (CARB), the California Energy Commission, and the California Public Utilities Commission solicited information from project researchers about away-from-home charging observed in The EV Project and ChargePoint America in California to guide their development of sustainable public charging infrastructure for the growing number of PEVs in California. The provided information assisted the California Energy Commission in validating model assumptions used in their statewide PEV infrastructure plan and ultimately fed into the PEV infrastructure assessment that was presented to the Air Resources Board in October 2014.

Analysis of data collected from PEVs and charging stations in Washington was performed for the Washington State Department of Transportation, who incorporated findings of this work into the Washington State Electric Vehicle Action Plan. The plan details the Washington State Department of Transportation's expectations and plans for achieving the Washington governor's goal of 50,000 PEVs on the road in Washington State by 2020.

3.1.10.3 Regional Electric Utility Planning. PEV charging patterns were analyzed and presented to a group of seven Northeast-based electric utilities, referred to as the Regional Electric Vehicle Initiative. The work analyzed diversity patterns and coincidence of PEV charging with utility system loads. The utilities requested this information to guide decisions regarding system planning, rate design, and development of rate/program strategies to mitigate system impacts.

3.1.10.4 Vehicle Regulation. As an independent third party, INL performed analysis of PEV driving data from the project and additional data sets. They presented the results to CARB to support deliberations between CARB and automakers about the redefinition of zero-emission vehicle credits. A revision to this regulatory framework applied to cars sold in California (i.e., the largest market in the United States) would potentially shift billions of research and development dollars at various auto companies. The study was performed on a data set of 158,000,000 miles from 21,000 vehicles operated throughout the United States. Eight models from four automakers (i.e., Ford, GM, Honda, and Toyota) were included.

3.1.10.5 Other Partners and Beneficiaries. Analysis results and findings published over the course of the project have been used by a host of other organizations, including standards development committees, other automakers and electric utilities in the United States and abroad, PEV charging equipment manufacturers, facilities management companies, PEV advocacy groups, and federal and state government agencies to inform PEV and charging infrastructure design and deployment decisions, electricity grid load forecasting, cost/benefit analyses, and a variety of other endeavors.

Numerous organizations were provided with special reports or presentations to aid their research, planning, or policy decisions related to electric vehicles design, promotion, and climate change. These groups include the following:

- Argonne National Laboratory
- Alabama Power
- Arizona Public Service (APS)
- CARB
- California Energy Commission
- Cardiff University, United Kingdom
- Center for Climate and Energy Solutions (formerly the Pew Center on Global Climate Change)
- City of Chattanooga, Tennessee
- City of Knoxville, Tennessee
- Clinton Foundation – Clinton Climate Initiative
- Colorado State University
- Columbia Hospitality
- Commonwealth Edison Company
- Delaware Valley Regional Planning Commission
- Electric Drive Transportation Association
- Energy and Environmental Resources Group, LLC
- Eugene Water & Electric Board
- Harvard University
- International Energy Agency
- Georgia Power
- Green Mountain College
- London Hydro, Inc.
- Los Angeles Department of Water and Power
- Memphis Light Gas and Water
- Middle Tennessee Electric Membership Corporation
- Nashville Electric Service
- National Academy of Sciences Committee on Overcoming Barriers to EV Adoption
- National Renewable Energy Laboratory
- Oak Ridge National Laboratory
- Oncor Electric Delivery
- Pacific Gas and Electric (PG&E)
- PacifiCorp
- PECO Energy Company
- Portland General Electric (PGE)
- Public Utility District No. 1 of Snohomish County
- Puget Sound Energy
- Sacramento Municipal Utility District
- Salem Electric
- Salt River Project
- San Diego Gas and Electric (SDG&E)
- Seattle City Light
- Seattle University
- Southern Company
- Tucson Electric Power
- Union of Concerned Scientists
- University of California - Davis Institute for Transportation Studies
- University of Central Florida
- University of Georgia
- University of Texas Austin
- Vermont Energy Investment Corporation
- Wall Street Journal
- Washington State Department of Transportation

3.2 Introduction

ARRA was an economic package enacted by the 111th United States Congress and signed into law on February 17, 2009. The primary intent of ARRA was to save and create jobs, including in the areas of education, health, infrastructure, renewable energy, and transportation electrification. Within the area of transportation electrification, several PEV and charging infrastructure projects were supported by DOE. In support of some of these projects, INL was tasked by DOE's Vehicle Technologies Office (Office of Energy Efficiency and Renewable Energy) to collect light-duty PEV and charging infrastructure data for several ARRA projects funded by DOE. INL was also tasked by DOE to sign non-disclosure agreements with the funded entities; the resulting raw data provided by the entities allowed for the data security, analysis, and reporting that DOE expected.

Several projects included deployment of EVSE, which safely provide electricity to the PEVs' onboard chargers; deployment of DCFCs, which are chargers located off-board the vehicle that transfer power at higher levels and charge the PEV's battery pack faster; and deployments of PEVs. These projects represent the largest ever deployment and study of charging infrastructure and grid-connected BEVs, EREVs, and PHEVs. Collectively, BEVs, EREVs, and PHEVs are known as PEVs. The projects that collected data, performed analysis, and reported on consisted of the following:

1. ChargePoint America – PEV Charging Infrastructure Demonstration
   - Consisted of 4,647 ChargePoint EVSE
2. Chrysler Ram PHEV Pickup – Vehicle Demonstration
   - Consisted of 111 PEVs
3. GM Chevrolet Volt – Vehicle Demonstration
   - Consisted of 150 EREVs
4. The EV Project – PEV Charging Infrastructure Demonstration
   - Consisted of 8,228 PEVs, EREVs, and BEVs, as well as 12,356 EVSE and DCFC
5. SCAQMD/EPRI/Via Motors PHEVs – Vehicle Demonstration
   - Consisted of 145 PHEV conversions of Chevrolet vans and pickups.

The following sections provide a summary of the high-level results for what was learned across all projects.

3.3 EV Project and ChargePoint America

3.3.1 Building the "Laboratory"

DOE supported the largest-ever demonstration of PEVs and electric charging infrastructure in The EV Project and the ChargePoint Project. Data collection and analysis has provided valuable insights to inform designers of future deployment of PEVs and charging infrastructure. This section provides joint summaries from both projects.

3.3.1.1 The EV Project. The EV Project deployment included the following:

- 12,000+ residential and public AC Level 2 charging units
- 100+ DCFCs
- 8,000+ PEVs.

Formal EV Project data collection and reporting activities ran from January 2011 until December 2013. The primary reporting period was every 3 months, with many custom reports generated for some of the air quality districts in which The EV Project deployed charging infrastructure and for the project partners, including the following:

- Blink
- Nissan
- GM/OnStar
- Car2Go
- The many electric utilities within whose service territories the charging infrastructure was deployed.

3.3.1.2 ChargePoint America. The ChargePoint America Project deployment included 4,600+ residential and public AC Level 2 charging units.

The ChargePoint America Project's data collection and reporting activities ran from May 2011 until December 2013. The primary reporting period was every 3 months, with many custom reports generated for ChargePoint.

3.3.2 EV Project and ChargePoint America Demonstration Objectives

Combined, The EV Project and ChargePoint Project had the following four main objects:

1. Establish a "laboratory" for study (Figure 3-10)
2. Benchmark PEV driving and charging behavior (Figure 3-11)
3. Benchmark infrastructure deployment and usage (Figure 3-12)
4. Understand the impact of PEV charging on the grid (Figure 3-13).

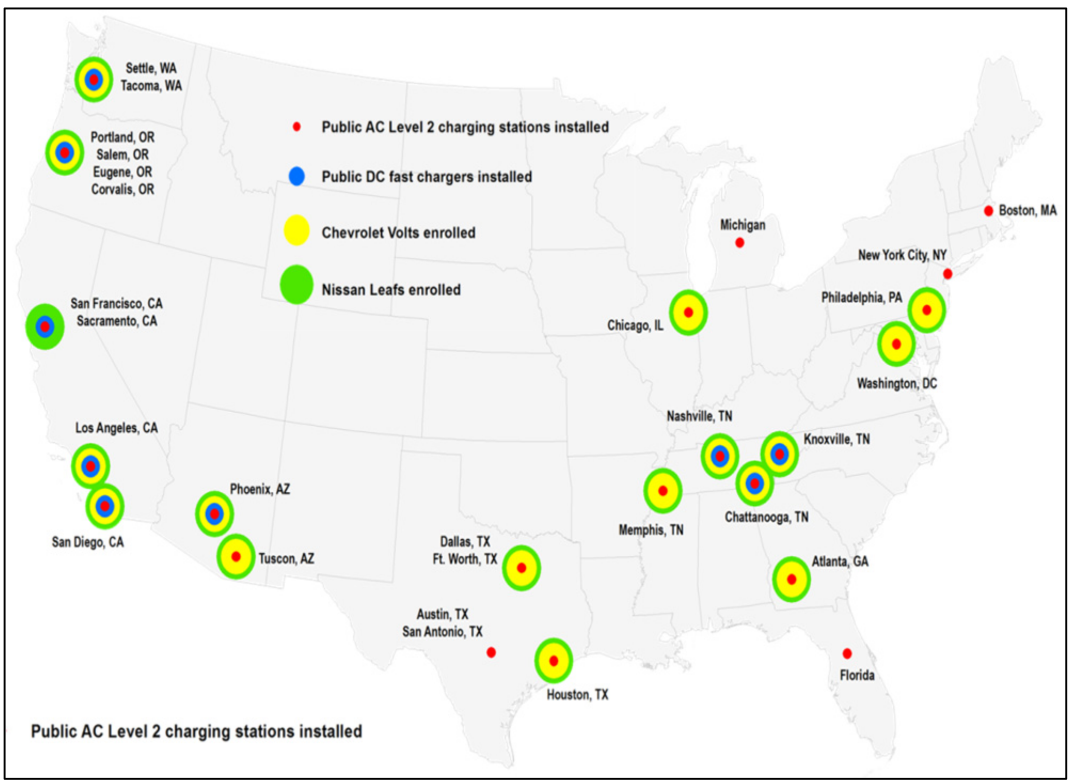


Figure 3-10. Vehicle and charging infrastructure deployment for The EV Project and ChargePoint America Project.

When looking at Figure 3-11, the data represent 3 months of collected data in 15-minute increments. The top blue line is the maximum result during a 15-minute increment during the 3 months. The black line in the middle of the darker gray area is the median and the grey areas above and below the median are the 25% quartiles. The bottom green line is the minimum 15-minute increment during the 3-month reporting period. This type of graphing is true for the connect time and electricity demand profile curves throughout this report.

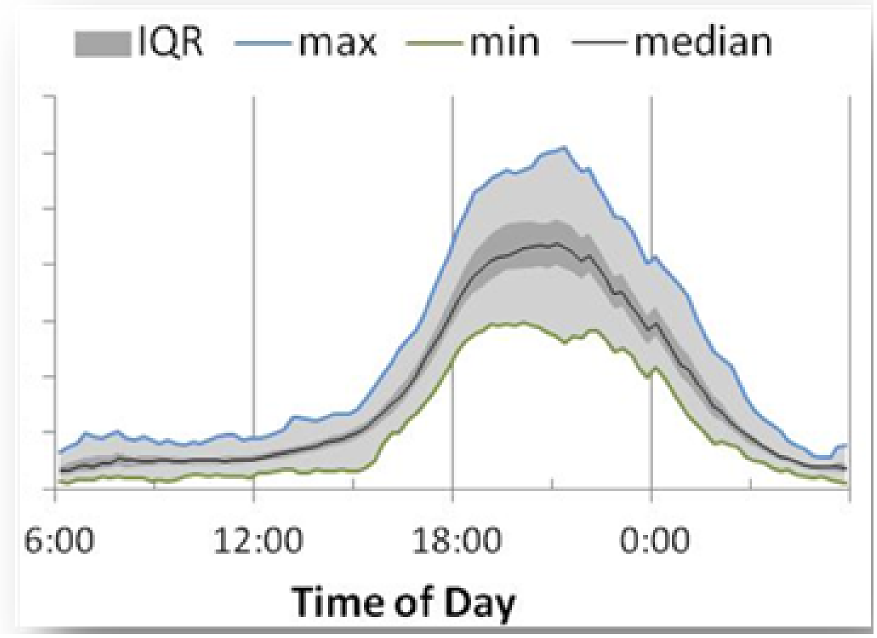


Figure 3-11. Example of demand on the electric utility grid for one reporting quarter in 15-minute increments.

Figure 3-12. Example of an EV Project Nissan Leaf charging at an EV Project DCFC.

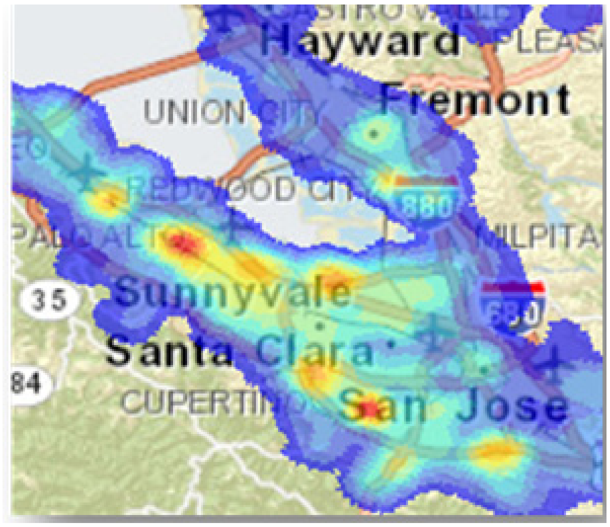


Figure 3-13. Example of charging hot spots (i.e., red\orange) in the greater San Jose area.

While separate subsequent sections are used to document each respective projects' deployments and accomplishments later in this report, The EV Project and ChargePoint America Project are combined in the executive summary because INL researchers found that combining data from the two projects often gave more complete understanding of PEV drivers' decisions, especially in regards to how charging infrastructure was used. Figure 3-10 shows where the PEVs and charging infrastructure for The EV Project and ChargePoint America Project were deployed.

3.3.3 Project Outcomes

One objective of The EV Project and ChargePoint Project was to provide defensible, independent findings for the numerous stakeholders needed to advance the PEV market. These stakeholders included the following:

- Automakers
- Charging equipment manufacturers and service providers
- Electric utilities
- Regulators and policy makers
- Fleet managers
- Start-up companies (i.e., innovators)
- Private consumers
- DOE's Electric Vehicles Everywhere and other research, development, and demonstration activities.

Using data describing124 million miles and 6 million charging events from over 8,000 PEVs and 17,000 charging stations, INL has been able to provide a comprehensive view of PEVs and charging usage to-date; summaries of these results are provided in the following subsections.

3.3.3.1 What Was Learned about Public Charging? Several high-level conclusions can be drawn, including the following:

- Although it has been suggested that there is need for extensive public charging infrastructure, most charging was done at home and work.

- Most drivers who charged away from home using AC Level 2 charging units favored three or fewer locations (including work).
- Most public AC Level 2 charging stations were rarely used, but a small minority were used extensively.
- Instead of having charging stations everywhere, public charging infrastructure needs to be concentrated at high-use charging hot spots.

Data from The EV Project and ChargePoint America Project were also used to characterize the existing hot spots and model charging-choice behavior to understand where new infrastructure deployments should be focused.

3.3.3.2 Can Away-From-Home Charging Support Range Extension? Several high-level conclusions can be drawn, including the following:

- Those drivers that consistently used away-from-home charging infrastructure where able to increase eVMT up to 72%.
- Even if they did not need to charge to make it home, PEV drivers tended to drive more EV miles if they plugged in away from home
- A limited numbers of BEV drivers could drive 2 to 3 times farther than their single-charge range using DCFC along travel corridors.

However, most drivers did not charge away from home very often; therefore, the overall benefit to eVMT was small.

3.3.3.3 Workplace Charging. Several high-level conclusions about workplace charging can be drawn, including the following:

- Workplace charging is highly utilized, sometimes even more so than home charging (Figures 3-14 and 3-15).

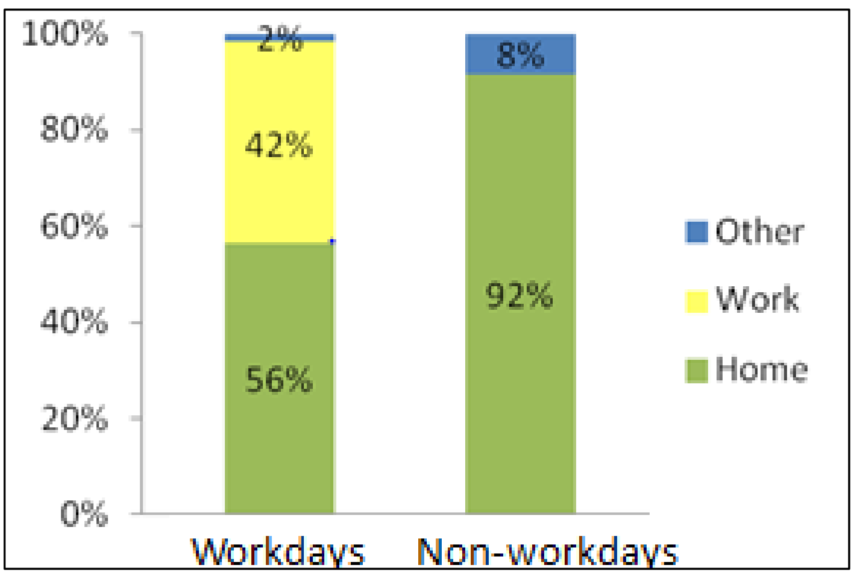


Figure 3-14. Where Nissan Leaf drivers charged their vehicles on workdays and non-workdays. This group of Leafs drivers all had access to workplace charging.

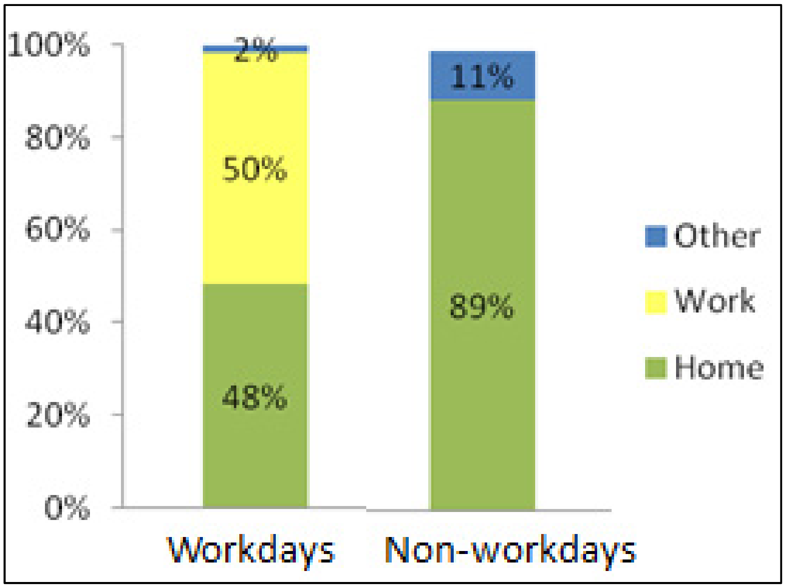


Figure 3-15. Where Chevrolet Volt drivers charged their vehicles on workday and non-workdays. This group of Volt drivers had access to workplace charging.

- Drivers with access to home and workplace charging rarely charged elsewhere.
- Workplace charging is an effective range extender.
- Six percent of drivers drove a Leaf to work, even though they could not make it back home unless they charged at work
- Forty percent of Leaf drivers at least sometimes relied on workplace charging to allow them to drive more miles than they could have driven with home charging alone.
- PEV drivers adjust their charging habits based on conditions (e.g., fees and rules for use).
- Employers offering workplace charging need to consider their goals and select policies accordingly.

3.3.3.4 Grid Impact and Integration. Clustering of PEV owners in residential neighborhoods is happening and will affect local distribution, with some of the following outcomes:

- Uncontrolled PEV charging at peak demand overlaps periods of high system demand in some areas.
- The opportunity is ripe for demand-side management using smart charging.
- Overnight home charging typically took less than 3 hours; however, vehicles were usually connected for more than 10 hours.
- Only about 100 PEVs are needed in a utility service area before the number of PEVs connected to the grid at any given time is consistent and predictable.
- Money talks, meaning that time-of-use (TOU) rates clearly incentivize PEV drivers to start residential charging at night during off-peak periods. Drivers responded to TOU rate price signals.
- Drivers charged less at public charging stations when fees were applied. This is true for both AC Level 2 and DCFC.

Electric utility and facility managers will be able to manage charging demand through pricing. This also helps those drivers who truly need to charge to find an available charging station, because drivers are less likely to recharge in the public domain unless they need to when fees are involved.

3.3.3.5 ***Battery Electric Vehicles and Extended-Range Electric Vehicles.*** The following list provides data for BEVs and EREVs:

- The Volt's average annual vehicle miles traveled (i.e., 12,238 miles) were above the national average of 11,346 miles.
- The Leaf's average annual vehicle miles traveled was 9,697 miles.
- Volt drivers averaged 9,112 miles per year in EVM, only 6% fewer EV miles per year than Leaf drivers, despite having less battery capacity.
- Volt drivers charged more often than Leaf drivers (i.e., Volt 1.5 average charges per day on days driven versus Leaf 1.1 average charges per day on days driven).
- Volt drivers tended to more fully deplete their batteries prior to recharging (Figure 3-16), whereas Leaf drivers tended to recharge with significantly more charge left in their batteries (Figure 3-17).

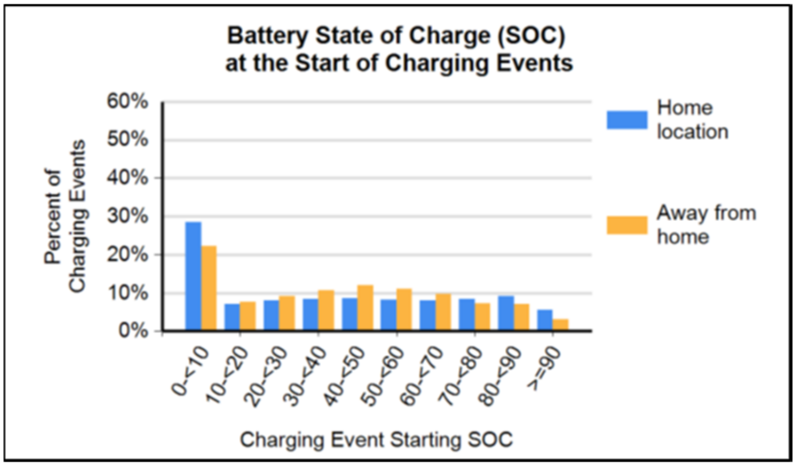


Figure 3-16. Battery state of charge (SOC) at the start of Volt charging events during the second quarter of 2013.

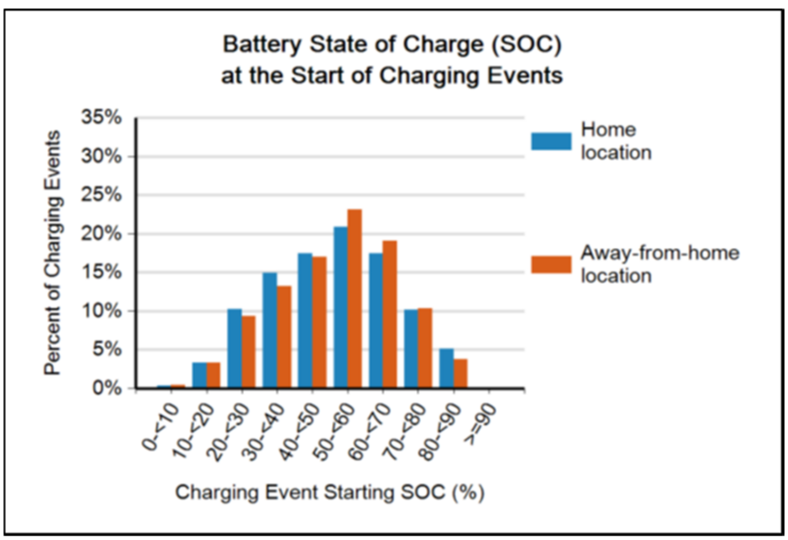


Figure 3-17. Battery SOC at the start of Leaf charging events during the second quarter of 2013.

3.3.3.6 Analyzing Public Charging Venues. Other aspects of location may contribute to an EVSE site's popularity (or lack thereof), including the following:

- A site's geographic proximity to a large business district or an interstate highway.
- The general location of the EVSE site (e.g., the part of town, city, or region where it is located) may also influence its use.
- The demographics of local drivers or commuting drivers to workplaces and local commercial venues also contribute.

Defining the "best" location for installation of EVSE is a complex undertaking. Businesses, government agencies, and other organizations have many reasons for providing EVSE. Their definition of the "best" location for EVSE varies:

- Some entities are concerned with installing EVSE where it will be highly used and provide a return on the investment.
  - This return may come in the form of direct revenue earned by fees for EVSE use.
  - This return may come from indirect return by enticing customers to stay in their businesses longer while they wait for their vehicle to charge or by attracting the PEV driver customer.
- Other organizations have non-financial interests such as supporting GHG or petroleum reductions or furthering other sustainability initiatives.
- Others organizations install EVSE to boost their public brand image.
- Employers provide them as a benefit to attract employees.

3.3.4 Impact of Who Has Benefitted from Information Generated by U.S. Department of Energy Investments?

The EV Project and ChargePoint America project results have been used by a host of organizations to guide decisions in a wide variety of areas related to PEV development and charging infrastructure deployment. Special reports and presentations were requested by and produced for over 70 organizations, including the following:

- Charging station hosts
- Communications, outreach, and standards development organizations
- Electric utilities
- Government agencies and planning organizations
- Manufacturers and service providers
- National laboratories
- Non-government research and planning organizations
- Universities.

3.3.4.1 National Research Council of the National Academy of Sciences released the report, "Overcoming Barriers to Deployment of Plug-in Electric Vehicles."

- This 204-page report is the result of an intensive 2-year study conducted by the National Research Council for DOE and makes recommendations to the federal government and others on actions to take or avoid to enable adoption of PEVs by the mass market
- INL provided a presentation and a series of follow-up reports from The EV Project to this National Research Council report. INL or The EV Project was cited 17 times in the National Research Council report.

3.3.4.2 Impact: State Infrastructure Planning Decisions. CARB, the California Energy Commission, and the California Public Utilities Commission solicited INL for information regarding development of sustainable public charging infrastructure for the growing number of PEVs in California. INL presented analysis results for away-from-home charging observed in PEV charging infrastructure demonstrations. The provided information assisted the California Energy Commission in validating model assumptions used in their statewide PEV infrastructure plan and ultimately fed into the PEV infrastructure assessment presented to CARB in October 2014.

3.3.4.3 Impact: Regional Electric Utility Planning. INL analyzed PEV charging and presented results to a group of seven northeast-based electric utilities, which were called the Regional EV Initiative (www.revi.net).

- The work analyzed diversity patterns and coincidences of PEV charging with utility system loads.
- The utilities requested this information to guide decisions regarding system planning, rate design, and development of rate/program strategies to mitigate system impacts.
- The presentation is available to the general public, accessible on the INL/Advanced Vehicle Testing Activity website at: avt.inl.gov/pdf/EVProj/DiversityPatterns&CoincidenceOfEVChargingWUtilitySystemLoads.pdf.

3.3.4.4 Impact: Vehicle Regulations and Sales. INL performed analysis of PEV driving data from The EV Project and additional data sets as an independent third party and presented results to CARB to support deliberations between CARB and automakers about the redefinition of zero-emission vehicle credits. The results were as follows:

- A revision to regulations on cars sold in California, which is the largest market in the United States, would potentially shift billions of research and development dollars at various auto companies.
- The study was performed by INL on a data set of 158,000,000 miles from 21,000 vehicles operated throughout the United States. It included eight models from five automakers (i.e., Ford, GM, Honda, Nissan, and Toyota) were included.
- INL's analysis and presentation of results was highlighted in an article from a leading auto industry news publication, *Auto News* www.autonews.com/article/20150328/OEM05/303309999/calif-considers-a-plea-for-plug-in-hybrids.

3.3.4.5 Impact: U.S. Department of Energy Leadership. Analysis of workplace charging in The EV Project and ChargePoint America Project led to publication of numerous reports for the EV Everywhere Workplace Charging Challenge. INL researchers were also able to mine data to identify 140 companies offering charging to employees. This list was provided to DOE to aid efforts to recruit employers to join the EV Everywhere Workplace Charging Challenge.

The U.S. president's U.S.-China EV Initiative, launched in 2009, included demonstration projects in paired cities to collect and share data on charging patterns and consumer preferences. The EV Project and ChargePoint America Project provided the means for executing this vision. INL hosted a delegation of Chinese PEV experts for 2 days of discussions that were centered on PEV data collection and analysis.

3.3.4.6 Impact: Independent Technology Assessment. On June 17, 2014, GM issued a press release announcing that Chevrolet Volt owners have surpassed half a billion electric miles. The press release included the following reference to EV Project results:

> "In an independent study conducted between July and December 2013, Volt drivers who participated in the Department of Energy's EV Project managed by Idaho National Labs totaled 1,198,114 vehicle trips of which 974,692, or 81.4%, were completed without the gasoline-powered generator being used."

3.3.4.7 Impact: State Policy and Planning. INL provided the Washington State Department of Transportation with analysis results from data collected from PEVs and charging stations in Washington. The Washington State Department of Transportation incorporated these lessons learned into the Washington State EV Action Plan. The plan details the Washington State Department of Transportation's expectations and plans for achieving the Washington governor's goal of 50,000 PEVs on the road in the state by 2020.

3.3.5 Recommendations for Supporting Market Growth

Based on PEV driver behavior and preference for charging beyond their residences, the following recommendations can be made:

- Continue to promote workplace charging and consider ways to incentivize it
- Identify public AC Level 2 charging hot spots and where PEV drivers tend to park their vehicles at public venues as a guide to future charging infrastructure deployments
- Continue to analyze DCFCs, especially along travel corridors, to determine the cost/benefit of installing charging infrastructure
- Continue work to understand consumer mindset, especially how households with multiple vehicles use all of their vehicles to meet their travel needs.

3.4 U.S. Department of Energy/General Motors Chevrolet Volt Vehicle Demonstration

The DOE and GM demonstration of Chevrolet Volts resulted in placement of 150 Volts in public utility fleets throughout the United States and Canada (Figure 3-18).

The reporting period ranged from the first May to June 2011 report through the final January to March 2014 report. The primary reporting method was quarterly reports, starting with the July to September 2011 period.

The Volts have two operating modes; they are classified as follows:

- EVM operation (i.e., electric vehicle mode)
- ERM operation (i.e., extended range mode).

It should be noted that the results for the 150 Volts were broken down and reported by the EVM and ERM mode, as well as an "all operations" category, which includes both EVM and ERM operations.

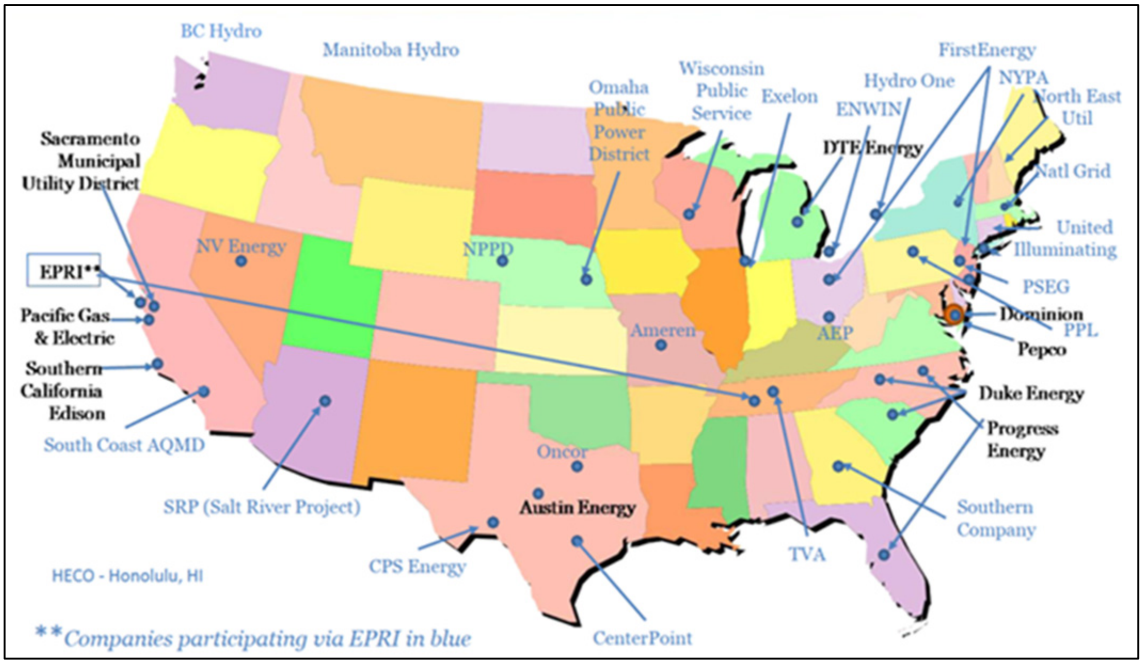


Figure 3-18. Locations of Volt project partners (i.e., black bold font) and the additional 26 utility partners (i.e., light blue font).

3.4.1 U.S. Department of Energy/ General Motors Chevrolet Volt Vehicle Demonstration Results

Over the entire data collection period, which totaled 66,572 days of driving, the fleet's overall average gasoline fuel economy was 67.5 mpg and the overall average AC electric energy consumption was 167 AC Wh/mi.

Over the entire data collection period, the AC electric energy consumption when operating in EVM was 358 AC Wh/mi and no gasoline was used when the Volts were operated in EVM. The fuel economy when operating in ERM was 36.1 mpg and no net electricity from the grid was used. Table 3-4 gives the overall results for the entire demonstration period of May 2011 through March 2014, when the 150 Volts were operated for 3.8 million miles.

Table 3-4. DOE/GM Chevrolet Volt vehicle demonstration results for the entire reporting period of May 2011 through March 2014.

	Combined All Operations	EVM	ERM
Overall mpg	67.5	NA	36.1
Overall AC Wh/mile	167	358	NA
Total distance traveled (miles)	3,837,911	1,787,554	2,050,357
Percent of total distance	100%	46.6%	53.4%

NA – not applicable

It should be noted that the Volts in The EV Project where recharged much more often that the 150 Volts in the electric utility fleets. It should also be noted that The EV Project Volts driven by the general public generally averaged greater than 120 mpg each reporting quarter. Because The EV Project Volts were plugged in more often, they had many more EVM miles, which contributed to the higher mpg for The EV Project Volts. The DOE demonstration Volts, even with their lower EVM miles, still achieved 67.5 mpg, which far exceeds the 54.5 mpg requirement for CAFÉ standards in 2025.

3.5 Chrysler Ram Plug-In Hybrid Electric Vehicle Demonstration

There were two phases for the data collection effort. Chrysler ended up having a first phase of 111 Ram PHEVs deployed in 17 fleets in the United States. The second phase, with a traction battery from a different manufacturer than during the first demonstration phase, saw 22 Ram PHEVs deployed in seven U.S. fleets.

The Ram PHEV was a unique PHEV platform with its 345-hp gasoline engine and two 65-kW electric motors, which provided a total system output of 399 hp. The vehicle had a significant payload and towing capacity, which is a PHEV segment where there have been few choices.

Between the two phases, INL reported performance data from July 2011 through September 2014, with a break between the two phases (Table 3-5). Data were reported for several types of operation modes, including the following:

- All trips combined
- Trips in charge-depleting (CD) mode
- Trips in both CD/charge-sustaining (CS) modes
- Trips in CS mode.

Table 3-5. Fuel and electricity use, number of trips taken, miles driven, vehicles providing data, and data collection ranges for the two demonstration phases.

	Phase 1 All Trips	Phase 1 CD Mode	Phase 1 CD/CS Mode	Phase 1 CS Mode	Phase 2 All Trips	Phase 2 CD Mode	Phase 2 CD/CS Mode	Phase 2 CS Mode
Fuel Economy (mpg)	19	23	21	17	20	25	21	16
DC/Wh/Mile	61	213	68	NA	87	201	67	NA
Total Number of Trips	111,773	42,155	11,855	57,763	19,715	7,317	2,955	9,443
Total Distance (miles)	1,039,138	230,741	244,232	564,843	250,478	57,219	68,544	122,956
Number to Total Rams	111				22			
Data Collection Period	July 2011 to September 2012				November 2013 to September 2014			

The difference in the number of vehicles in each demonstration phase may make comparing the results difficult because ambient temperatures, fleet applications, and locations may have had an impact on gasoline fuel economy and DC Wh per mile. Regardless, this was a first-of-a-kind PHEV in this vehicle class from an original equipment manufacturer and the petroleum fuel efficiency was notable for a vehicle of this payload, towing capacity, and features. Chrysler has stated that the new technologies they demonstrated in this project are and will continue to be introduced into new vehicle products.

3.6 SCAQMD/EPRI/Via Motors Demonstration

During the SCAQMD (South Coast Air Quality Management District)/EPRI/VIA Motors Demonstration Project, VIA deployed a total of 145 VTRUX eREVs (note that Via Motors uses a lower case “e” for EREV) pickup trucks and vans to government and utility fleets throughout the United States.

Information on specific fleets and users was not made available to INL as a part of the data collection effort. EPRI was responsible for instrumentation of data acquisition equipment, data collection, and transmission of data to INL for analysis and reporting.

The primary objective of the SCAQMD/EPRI/VIA demonstration was to gather data and produce reports on the performance of the eREV pickup trucks and vans.

INL analyzed data from the 145 VIA Motors vans and pickups that were collected from December 2014 through June 2015. The data were not received at INL until shortly before this report was written, which only allowed for a brief analysis period. A summary report will be published (http://avt.inl.gov/), which will detail the fuel efficiencies and usage of the pickups and vans.

Over the data collection period, the data benchmarked more than 56,000 VIA van miles and 13,000 VIA pickup miles. Over these miles, the vans had an overall gasoline fuel economy of 16.5 mpg and electrical energy consumption of 126 DC Wh/mile, while the pickups had overall fuel economy of 18.4 mpg and electrical energy consumption of 72 DC Wh/mile. It is important to remember when considering these results that due to issues with data logging and collection, these results represent only a subset of the total driving performed by vehicle users. Additional metrics will be analyzed to further understand vehicle performance and driver behavior.

4. SUMMARY OF KEY LESSONS LEARNED FINDINGS

These key findings are based on the lessons learned results from the ARRA research projects described in this report. Note that these findings should not be considered representative of how every PEV and EVSE is used in the United States. However, collectively, the projects and the results represent the largest instrumented sample and resulting performance science of PEVs and EVSE that ever provided data for analysis. The analysis results can be used to guide decisions about where to install future PEV charging infrastructure. Therefore, these key findings are likely the best basis for making decisions about how, where, and when future charging infrastructure should be deployed.

The key findings are provided by subject area and mostly result from The EV Project work. However, some key findings are based on a combination of ARRA projects.

4.1 Summary EV Project Lessons Learned

4.1.1 EV Project Direct Current Fast Chargers

What were the Cost Drivers for the DCFC Installations

The cost drivers for DCFC installations were as follows:

- Hardware design
- Functionality (the more functionality added, the higher the hardware costs):
  - If more than one port or cord set is added
  - If a large screen is added for advertising
- High power rating
- Two parking places dedicated for EV charging
- Materials
- Administration
- Ground surface conditions
- Electrical service upgrade
- Surface material under which electrical wiring/conduit was installed
- Distance from the electrical power source to the DCFC ground power unit (GPU) if a two-unit design was used
- Distance from the GPU to the charge dispensing unit (CDU)
- Permit and engineering drawings.

DCFC installation costs for The EV Project were as follows:

- Average cost $23,662
- Median cost $22,626
- Minimum $8,500
- Maximum $50,820.

What Location Factors Did Highly Utilized DCFCs Have in Common

- The most highly utilized DCFCs in The EV Project were located in the metropolitan areas of Seattle and San Francisco.
- The metropolitan areas of San Francisco and Seattle represent two of the top five U.S. sales markets for the Nissan Leaf.
- The top 10% of the most highly utilized DCFCs in The EV Project averaged 40 fast charges per week.
- The most utilized DCFC stations were located along major commuter routes within the major metropolitan areas.
- Many of the highly utilized DCFCs were located near or associated with high-tech employers.

- Regarding the location of the most highly utilized DCFCs in The EV Project, there is a greater likelihood that a DCFC will be highly utilized if its location exhibits all of the following location-based characteristics:
  - Within a half mile of a major commuter route
  - On or near the campus of a company with a highly compensated workforce, where it can function as both workplace and publicly accessible recharging resource
  - It is in a welcoming location (i.e., not too closely associated with the host).

What is the Impact of Utility Demand Charges on a DCFC Host

- Demand charges associated with the 50 to 60-kW high-power charging of a DCFC can have a significant impact on a business' monthly electric utility bill.
- The business owner will need to choose whether to power the DCFC on the original business service electrical supply or provide separate service to the DCFC.
- Detailed analysis of potential costs and electric utility rate schedule options to determine the optimal rate schedule for a DCFC site is important and should be conducted in consultation with the electric utility.
- Some electric utilities provide rate schedules for commercial customers without imposing demand charges. When demand charges are imposed by utilities, they can cause monthly utility bill to increase by as much as four times.
- DCFC site hosts may be compensated for the energy used in DCFC charging by access or use fees imposed on PEV drivers in those states that allow energy billing; however, demand charges are typically uncompensated and can be significant.
- The host's monthly DCFC demand charge is based on the single highest power required by the DCFC during the month, regardless of the number of charge events in the month. A higher number of PEV charges in a month can reduce the average demand charge cost per PEV charge.

DCFC – Demand Charge Reduction

- Demand charges are levied by the utility, typically for commercial properties, for peak power used during a billing cycle, regardless of the amount of energy drawn at this power rate.
- Demand charges can add significantly to the utility bill for an EVSE host and can make EVSE hosting cost prohibitive.
- In order to determine the best method for reducing demand charge, the first step is to verify the following parameters for a given location:
  - What is the expected peak demand of the site owner in a billing period? Over how much of the 15-minute interval does the peak demand span?
  - What is the average site demand?
  - What is the utility rate structure? Is there a yearly maximum average power demand charge in addition to the billing cycle maximum average power demand charge?
  - What is the demand charge tolerance?
- Once the above parameters are specified, the next step is to choose from the possible methods for reducing the demand charge. The six methods that have been identified are:
  - Never allow the overall site power demand to exceed a specified value.
  - Attempt to ensure the average power over the interval is less than or equal to a specified value.
  - Attempt to recoup the demand charge cost through structured pricing for EVSE charging.
  - Add an energy storage system that buffers the EVSE unit from high-power demands during charging.
  - Aggregate demand among multiple EVSE installations into one demand charge

calculation, taking advantage of the diversity that may exist in individual unit usage.
  - Provide demand response capability to the utility to either offset or circumvent demand charges.

4.1.2 EV Project Electric Vehicle Supply Equipment

What Were the "Best Practices" Identified for Residential Charger Installations

- Although at the outset of The EV Project the local permitting authority having jurisdiction (AHJ) typically did not have a permit designation for installation of residential EVSE, many were quick to implement a unique permit for EVSE and introduced simple online or self-inspection processes.
- Installation of separate, metered electric service for PEV charging, as implemented in some EV Project electric utility service areas, eliminated the need to upgrade the homeowner's electric service panel.
- EV Project personnel met with the local AHJ in many of the project study markets prior to installation of the first EVSE in order to educate them about The EV Project and gain their support. This helped speed up permit application reviews and maintain the project's installation schedule.
- The primary features of an "ideal" residential installation include the following:
  - Utilization of plug-in EVSE rather than requiring the EVSE to be hard-wired to its power source. This allowed installation of the circuit to be completed independent of the actual EVSE installation and presence of the PEV, providing more flexibility for contractors and home owners in scheduling installations.
  - An electric service panel with at least two open spaces (to allow installation of a double-pole breaker) and at least 200 amps of total service capacity.
  - Clear wall AND floor space around the EVSE installation location.
  - An electrical distribution panel nearby (within 8 ft) the EVSE installation location.

How Do Residential AC Level 2 Charging Installation Costs Vary by Geographic Location

- During The EV Project, the average (mean) cost for installation of a residential AC Level 2 charging unit (including permit fees and service upgrades, but excluding charger cost) was $1,354.
- The median installation cost was $1,200.
- The Los Angeles market had the highest average installation cost at $1,828, while Atlanta had the lowest at $775
- Permit fees can have a significant impact on overall costs. Average permit costs varied from $49 to $206 across The EV Project markets and from 3.9% to 14.5% of overall installation costs.
- On average, EV Project participants paid $250 toward installation of their Blink home charging unit.
- Because residential EVSE installations were only at single family residences, variation in installation costs was driven by the following:
  - Materials
  - Service panel upgrade needed
  - Breaker for dedicated 40-ampere circuit
  - Wiring length
  - Conduit length
  - Labor.
- ARRA funding for The EV Project required compliance with the Davis-Bacon Act (DBA). Prevailing electrician labor wages under DBA varied from over $55 per hour to under $12 per hour.

- Administrative effort complied with DBA over the 2-plus years of the residential portion of The EV Project, including supplementary weekly payroll documentation.
- Labor cost variation reflected prevailing market wages.
- Older homes typically required an upgrade to their electrical service panels in order to accommodate the AC Level 2 charging unit's dedicated 40-amp circuit. This was not only a significant cost driver, but likely affected the PEV driver's decision about whether to participate in The EV Project.

How Do PEV Owners Respond to Residential TOU Rates While Charging EV Project Vehicles

- TOU programs do influence PEV driver charging patterns.
- 57% of survey respondents changed their utility rate subscription as a result of obtaining a PEV.
- A shift in charging demand to the TOU period is very obvious in the demand curve for PG&E. This shift causes a demand spike at or shortly after the beginning of the TOU period.
- Two factors that influence the level of awareness and, ultimately, TOU program enrollment are the perceived value of the incentive and the program's outreach and education efforts.
- Southern California Edison defines its TOU tiered domestic rate as follows:
  - On-peak: 12 to 6 p.m. weekdays
  - Off-peak: All other hours.
- PG&E defines summer weekday times on Electric Schedule E-9 as follows:
  - On-peak: 2 to 9 p.m.
  - Partial-peak: 7 a.m. to 2 p.m. and 9 p.m. to 12 a.m.
  - Off-peak: All other times.
- PGE defines summer weekday times as:
  - On-peak: 3 to 8 p.m.
  - Mid-peak: 6 a.m. to 3 p.m. and 8 to 10 p.m.
  - Off-Peak: 10 p.m. to 6 a.m.

Residential Charging Behavior in Response to Utility Experimental Rates in San Diego

- The EV Project and the SDG&E experimental rate study confirmed that price incentives can substantially influence PEV driver residential charging behavior.
- The SDG&E rate study showed that the greater the differential electrical price between the utility's non-desired charge time and its desired charge time, the greater the behavioral change in driver residential charging.
- The cost of installation of a second electric utility meter, required by many utilities for their special PEV charging rates, may exclude many drivers from participating.
- Participation in electric utility incentive programs requires the considered design of electric rate structures and the enabling technology to set charge start times by the residential EVSE or the PEV. It may also require the EVSE or PEV to communicate billing information to the utility for subtractive billing.

When EV Project Participants Program their PEV Charge, Do They Program Their Vehicle, Their EVSE Unit, or Both

- Introduction of large-scale production of PEVs led to entry of many EVSE providers into the market. Some have selected to provide basic units, which provide power to the vehicle with no services other than the required safety features. Others provide smart units, such as the Blink units deployed in The EV Project, which contain many extra features, including the ability to program the charge start and stop times. Knowing which type of unit the customer prefers is important for car manufacturers and EVSE suppliers in deciding which features to provide with their products.
- Most EV Project participants in the PGE and PG&E service territories program their PEV

and/or EVSE unit to schedule charging at home.

- About half the participants prefer to program only their vehicle.
- One quarter prefer to program only their EVSE.
- Over two-thirds of survey respondents in the PGE and PG&E service territories have selected TOU rates (either whole-house or PEV rate plans), which provide an incentive for them to schedule their home charging times during off-peak hours.
- Whether they program the PEV or the EVSE unit appears to be a matter of consumer choice; it is not difficult to do in either case.
- It is understandable why participants in areas without TOU rates do not program (although some do anyway).
- Of survey respondents, 28% are on a basic rate plan, despite the fact that their electric utility offers TOU rates.

What Residential Clustering Effects have been Experienced in the San Diego Region

- The San Diego region contains several examples of residential neighbors charging PEVs simultaneously.
- Two neighbors simultaneously charging PEVs have shown a power demand nine times that of the typical San Diego residential power demand.
- Two neighbors charging their PEVs at super-off peak times can increase energy consumption by nearly five times that of those without PEVs.
- Charging PEVs at other times of the day, in addition to typical super off-peak times, can nearly double the daily energy demand by two neighbors.
- Currently, the utility impact of residential PEV charging is low because overall PEV adoption is still in its infancy. However, some transformer replacements have already been linked to cluster PEV charging.
- A question frequently asked in relation to adoption of PEVs is "What is the impact of PEV charging on the electrical grid?" This question can be directed at the big picture of total utility system load; however, focus is on impact to the local electrical distribution system and, in particular, the local residential electrical transformer. Higher than originally anticipated loads on this transformer can lead to damage, local power outages, and higher costs to the electric utility for replacement equipment.

What Residential Clustering Effects Have Been Seen by The EV Project, and Specifically, in the PG&E Service Territory

- The effects of clustering on neighborhood transformers using EV Project charging data include the following:
  - Higher peaks
  - Longer operation at higher power
  - Periods of high power demand during times when residential transformers are traditionally expected to have only low loads
  - The electric utility rate structures for TOU might be contributing to the impact on the local transformer by creating a new peak in demand at the beginning of the off-peak period.
  - Clustering effects may result in service outages and the need to upgrade transformers.
  - Damage to the transformer may be caused by exceeding the transformer's load rating or by depriving it of its normal cool-down period.
  - Electric utilities will need to be involved with PEV adoption, both for the overall system load profile and for impacts to the local neighborhood distribution transformer.

What is the Controllable Electrical Demand from Residential EVSE in the San Diego Region

- The aggregated EV Project's residential EVSE charging demand in San Diego exceeded 100 kW from 4 p.m.to 4 a.m. during the third quarter of 2013.

- This aggregated demand during the third quarter of 2013 was sufficient for bidding into controllable demand response activities in the San Diego region.
- The positive adoption of PEVs in the San Diego region increased the probability of enlisting sufficient PEV owners in demand response activities. However, the numbers of residential EVSE must grow by a factor of 18 to make direct control at all hours of the day minimally worthwhile.
- The incentive programs promoted by SDG&E, coupled with easily programmable EVSE, are highly effective in moving residential charging to off-peak hours.
- For the foreseeable future, direct utility control of residential EVSE is not beneficial, whereas indirect control through rate incentives is beneficial.

4.1.3 EV Project Public Electric Vehicle Supply Equipment

How do Publicly Accessible Charging Infrastructure Installation Costs Vary by Geographic Location

- Similar to residential EVSE and DCFC installation costs, AC Level 2 EVSE installed in California were the most expensive installations.
- Costs for installation of these units were an important part of The EV Project infrastructure study because these costs had an impact on host participation.
- Of the nearly 4,000 AC Level 2 EVSE units installed for public use, installation cost data for analysis is available for 2,479 units (approximately 60%).
- The overall average was $3,108 per unit installed, with installation costs varying from less than $600 per unit to over $12,000.
- The five most expensive geographic markets had per unit installation costs over $4,000 ($4,004 to $4,588).
- The five least expensive geographic markets had per unit installation costs under $2,600 ($2,088 to $2,609).
- The 40 most expensive installations in the Atlanta market (i.e., 26% of total installations with cost data in Atlanta) had an average cost of $7,175 per unit installed. This is well over twice the average installation cost of $3,108.
- These stations were installed away from the front of the building in conspicuous parking spaces that were not in direct competition with shoppers seeking the shortest path to and from the store.
- Long electrical runs from the electric service panel (typically at the back of the store) to a location well into the parking lot at the front of the store made these installations much more expensive than typical installations in other markets.
- Although the number of installations was small, publicly accessible installations in Washington D.C. were also of interest. These EVSE installations represented the least expensive installations, in large part, because they used wall mounted EVSE.
- Some charging site hosts supplemented the installation allowance provided by The EV Project to make their EVSE installations a more visible part of their business. While these decisions on EVSE installation met the host's objectives, they also led to higher-than-average installation costs (80% of them were wall-mounted installations).
- As with residential installation costs, California's costs for labor and permitting of publicly accessible EVSE installations made them among the most expensive sites by geographic region

EV Public Charging – Time Versus Energy

- Through The EV Project, charging infrastructure at commercial locations has been deployed in various cities across the country. To stimulate use of this charging infrastructure and familiarize EV owners with its operation, access to the infrastructure was initially provided at no cost.

- While free access to commercial charging infrastructure provides an effective means of initializing infrastructure use, it does not support a "viral" expansion of charging infrastructure.
- Widespread deployment of charging infrastructure at commercial locations must be subsidized or it must generate sufficient income to provide a return on the investment made by the infrastructure owner.
- The quantity of charging infrastructure necessary to support widespread adoption of PEVs must be supported by private investment, anticipating a return.
- The EV community currently employs the following three means to assess fees when an EV owner accesses commercial charging infrastructure:
  - By time connected to the unit for charge
  - By energy used measured in kWh
  - By means of a subscription, wherein all in-network charging is included in a monthly fee.

What is the Impact of Utility Demand Charges on an AC Level 2 EVSE Host

- Some electric utilities in The EV Project market areas impose demand charges on the highest power delivered to a customer in a month.
- Simultaneously charging multiple AC Level 2 EVSE can create significant increases in power demand.
- These demand charges can have a significant impact on monthly electric utility costs, especially for small businesses.
- The increased charging rate allowed by many newer PEVs will exacerbate this impact.
- A separately metered EVSE charging service may enable AC Level 2 charging site hosts to avoid most of these impacts.

How Well Did Non-Residential EVSE Installations Match the Planned Areas in San Diego

- In the early stages of PEV delivery to local markets, the options were as follows:
  - Plan locations related to key attraction sites where PEV parking is anticipated
  - Solicit retail and public charging hosts for random placement
  - Ask early adopters where they want public infrastructure
  - Identify sites near known high-traffic areas.
- The San Diego planning process developed 3,333 target areas for deployment.
- The EV Project installed 530 non-residential EVSE in 160 locations in the San Diego region.
- 98% of the installed EVSE units are within target areas.
- 98% of installed sites are within target areas.
- More than 1,135 target areas (i.e., 34%) were served by the 160 deployed EVSE sites.

How Does Utilization of Non-Residential EVSE Compare Between those Installed in Oregon in Planned Versus Unplanned Locations

- The options available at that time for determining where chargers should be placed were as follows:
  - Plan locations related to key attraction sites where PEV parking is anticipated
  - Solicit retail and public charging hosts for random placement
  - Ask early adopters where they want public infrastructure
  - Identify sites near known high-traffic areas.
- To evaluate the effectiveness of the planning process used by The EV Project, the following two relevant questions were asked:
  - How well did final installation sites fit with planned locations?
  - How does utilization of non-residential AC Level 2 EVSE vary between those areas where it was planned versus areas where it was not planned?

- A significant planning effort for non-residential AC Level 2 EVSE placement was undertaken using the EV Micro-Climate® process in the greater Portland area during 2010.
- Fully 74% of The EV Project's available EVSE were placed in the predicted high utilization zones.
- Overall, EVSE placed in the predicted high utilization zones experienced 87% greater charge events per week than those outside these zones.
- The EVSE placed in predicted high utilization zones had average vehicle connect time periods 4.4 times longer than those outside these zones.
- The charging site host venue is an important factor in EVSE utilization, both within and outside the high utilization zones.
- The EV Micro-Climate® planning process utilized in the greater Portland area was highly successful in predicting high non-residential EVSE utilization.

EVSE Signage

- Signage has two primary purposes:
  - Way finding: assisting PEV drivers in locating charging stations is the way-finding purpose
  - Regulatory: signage determines who may park in the designated location and allowed uses of that charging facility.
- Way-finding and regulatory signage are highly recommended for all EV parking stalls.
- While cost of the sign is added to the cost of the installation, this can be reduced if a combination sign is used.
- Marking pavement with the symbol is a matter of preference, but is not required. Indeed, it will increase periodic maintenance following significant use and weathering. However, it will have the effect of reducing the incidence of internal combustion engine (ICE) vehicles parking in PEV charging locations
- Placement of the sign during installation of the station will not add significant cost or time delay to the project, and cost of the sign is minimal compared to the benefit.

The EV Micro-Climate® Planning Process

The following objectives were identified for the EV Micro-Climate® planning process:

- Create a local Blink presence in the market area
- Establish Blink leadership in the market area
- Establish relationships with the key stakeholders in the community
- Create a synergistic focus for stakeholders already interested/involved in EV promotion
- Establish a common ground for nomenclature and discussion
- Identify specific areas that require local action in deployment of EVSE
- Create a plan for placement of EVSE
- Communicate regularly with stakeholders, area government, and potential hosts
- Message potential hosts about the benefits they may accrue with placement of an EVSE.

4.1.4 EV Project Gasoline and CO2 Savings, Carbon Credits, and Greenhouse Gases

EV Project Gasoline and CO_2 Savings Extrapolated Nationally

- The amount of petroleum that was avoided by Leaf and Volt drivers in The EV Project on an annual basis was analyzed.
- Petroleum savings were extrapolated to the national fleet of light-duty vehicles, on a percentage replacement basis.

- The 7,812 Volts and Leafs accumulated as much as 75 million eVMT on an annual basis.
- On a per EV Project PEV basis, each PEV avoided the use of 299 gallons of gasoline and 5,980 pounds of CO_2 annually.
- The 7,812 PEVs saved 2.2 million gallons of gasoline and 44 million lb of CO_2 annually.
- The best citable number of short wheel base, light-duty vehicles in the United States that could to be replaced by PEVs is 183 million.
- National potential gasoline and CO_2 savings are calculated based on the percentage of vehicles replaced.
- As a reference, Electric Transportation Applications states that as of August 2015, 357,768 PEVs have been sold in the United States since 2010.

National Potential PEV Gasoline and CO_2 Savings When PEVs are Used

Percentage of U.S. Light-Duty Vehicles Replaced by PEVs	Number of PEVs (millions)	Annual Gallons of Gasoline Avoided (millions)	Annual CO_2 Avoided at 20 lb CO_2 per Gallon Avoided (billions)
0.20%	0.37	109	2.2
1%	1.8	547	11
5%	9.2	2,734	55
10%	18.3	5,469	109
50%	91.6	27,345	547

As can be seen in the above table, PEVs have the potential to significantly reduce national gasoline use and creation of CO_2. It was demonstrated by The EV Project PEV drivers that they can achieve the high levels of eVMT required to achieve these benefits. If just 10% of the PEV market replacement occurred, there would be 18.3 million PEVs on the road in the United States and these PEVs would avoid use of 5.5 billion gallons of gasoline and generation of 109 billion pounds of CO_2.

How Many of California's Low-Carbon Fuel Standard (LCFS) Credits were Generated by Use of Charging Infrastructure Deployed During The EV Project

- In January 2007, Governor Schwarzenegger issued an Executive Order to enact LCFS credits in the State of California. This standard calls for reduction in the carbon intensity of California's transportation fuels, including tailpipe emissions and all other associated emissions from production, distribution, and use of transport fuels within the state. CARB established regulations for meeting the target of reducing carbon intensity by at least 10% by 2020.
- LCFS includes emissions trading as a means for the State of California to meet its overall emissions objective. Credits are earned for emissions reduction and these credits can be sold to entities that need credits in order to comply with the regulations.
- Although generation of LCFS credits was not a named objective of The EV Project, it is another means of generating revenue for PEV service providers.
- As a PEV service provider dispensing electricity as a transportation fuel in California, charging infrastructure deployed in The EV Project was eligible for generating LCFS credits.
- The EV Project dispensed over nine gigawatt hours of energy that were eligible for LCFS credits.
- The measure of LCFS credits is megatons of CO_2 averted. The EV Project generated over 5,500 credits (i.e., megatons).

GHG Avoidance and Cost Reduction

- All U.S. residents would likely see a reduction in fuel and life-cycle ownership costs driving a PEV as opposed to a comparable ICE vehicle.

- For a large majority of U.S. residents (approximately 87%), driving a PEV as opposed to a comparable ICE vehicle will result in reductions in emissions.
- A small minority would see their GHG emissions rise, depending on the state where they reside. However, as the push to adopt cleaner electricity sources across the country continues, the emissions reduction numbers will continue to become more and more favorable.
- The grid transition may raise the price of electricity, but the volatility of oil prices and the specter of future constrained oil supplies mean that the price of gasoline is also likely to rise, affirming the fuel cost benefit for the foreseeable future.

4.1.5 EV Project Participants

Who Were Participants in The EV Project

- Demographics of innovators and early adopters of EVs were speculated by many, but little has actually been published; therefore, demographics information was solicited from EV Project participants in a survey.
- Overall, 63% of primary PEV drivers are male; however, this percentage reaches nearer 70% in Texas, Washington D.C., and Chicago.
- Oregon presents the highest percentage of female drivers at 34%.
- The mean age for all regions was 50.9 years, but distribution varies by region.
- The average household income was $148,811.
- Almost 50% of households had an average income above $150,000.
- There was little difference between types of vehicle purchased or leased based on income.
- Leaf drivers were more likely than Volt drivers to have graduate degrees (46% versus 38%).

How Did EV Project Participants Feel About Their EVs

- The EV Project participants were very cooperative and enthusiastic about their participation in the project and very supportive in providing feedback and information. The information and attitudes of these participants concerning their experience with their PEVs were solicited using a survey in June 2013. At that time, some had up to 3 years of experience with their PEVs.
- In June 2013, EV Project survey respondents were very satisfied with their PEVs and 96% would replace their current PEV with another PEV.
- The EV Project survey respondents had an average of 2.6 vehicles in their household and 70% reported the PEV as their primary vehicle.
- The number one reason EV Project survey respondents selected the PEV was that PEVs are energy efficient and cheaper in the long run than ICE vehicles.
- 94% of survey respondents reported they drove their PEVs the same or more miles per day than when they first acquired it.

How Did EV Project Participants Feel about Charging Their EVs at Home

- In June 2013, 72% of EV Project survey respondents were very satisfied with their home charging experience.
- 21% of survey respondents relied totally on home charging for all charging needs.
- Volt owners relied more on home charging than Leaf owners, who reported more use of away-from-home charging.
- 74% of survey respondents reported that they plugged in their PEV every time they park at home. Others plugged in as they determined necessary to support their driving needs.
- 40% of survey respondents reported they would not have or were unsure in June 2013 whether they would have purchased an AC Level 2 EVSE for home charging if it had not been provided by The EV Project.

- 61% of survey respondents reported that The EV Project incentive was very important or important in their decision to obtain a PEV.

How Did EV Project Participants Feel About Charging Their EV Away From Home

- In June 2013, 41% of survey respondents who used their PEVs for work reported having the availability of charging at their workplace.
- For those who had workplace charging available, nearly twice as many reported AC Level 2 being available, as well as AC Level 1.
- 36% of survey respondents reported that workplace charging was very important or essential to meeting their PEV driving needs.
- 69% of survey respondents reported that they very rarely or never used publicly accessible charging.
- 34% of survey respondents suggested that expanding the availability of public charging would result in greater use.

4.1.6 EV Project Vehicle Use

How Many Electric Miles did Nissan Leafs and Chevrolet Volts in The EV Project Travel

- BEVs, such as the Nissan Leaf, are powered exclusively by electricity. The maximum driving range between refueling (in this case recharging) of a BEV is limited by the energy storage capacity of the vehicle's battery.
- EREVs, such as the Chevrolet Volt, can also be powered exclusively by electricity; however, they have smaller batteries and, therefore, shorter EVM range than BEVs. EREVs provide range extension using an ICE.
- The electric ranges of BEVs and EREVs are quantified by auto manufacturers and third parties such as the U.S. Environmental Protection Agency (EPA).
- The owners' driving and charging behavior determines how much distance is actually traveled using electric power.
- Between October 2012 and December 2013, Nissan Leaf drivers in The EV Project averaged 808 eVMT per month.
- Chevrolet Volt drivers in The EV Project Volt averaged 759 eVMT per month and 1,020 total vehicle miles traveled per month.
- The distributions of eVMT per month for Leafs and Volts overlap significantly, indicating that many Volts drove the same or more electric miles than Leafs, despite a large difference in electric range.
- Change in eVMT from month to month over the 15-month study period was similar for Leafs and Volts, suggesting that seasonal effects influence drivers of both vehicles in the same way.

What Kind of Charging Infrastructure Did Nissan Leaf Drivers in The EV Project Use and When Did They Use It

- A sample of 4,038 Nissan Leaf drivers who participated in The EV Project performed 867,293 charges at AC Level 1, AC Level 2, and DCFC units over a 15-month period.
- Leaf drivers relied on home charging for the bulk of their charging. Of all charging events, 84% were performed at drivers' home locations. Over 80% of those home charges were performed overnight and about 20% of home charges were performed between trips during the day.
- The remaining 16% of charging events were performed away from home. The vast majority of these were daytime AC Level 1 or AC Level 2 charges.
- Overall, usage of DCFCs by drivers of vehicles in this study, all having access to a AC Level 2 charging unit at home and some having workplace charging access, was low. DCFC (all away from home) represented only about 1% of all charging events and charging energy consumed. Ignoring charges by vehicles that never charged away from home, DCFC were

used for 6% of all away-from-home charging events. However, some drivers used DCFC more than others and may have relied on DCFC to meet their need for driving range.

- Not everyone used away-from-home charging infrastructure equally. In fact, three quarters of the away-from-home charging was performed by 20% of the vehicles. A significant portion of vehicles (i.e., 13%) were never charged away from home.
- Half of the away-from-home charging was performed by a group of vehicles who averaged 1.5 charging events per days driven. Drivers of these vehicles supplemented near-daily home charging with frequent away-from-home charging. This allowed these vehicles to average 43 miles per day driven, a 72% increase over vehicles that were never charged away from home.
- Although all vehicles in this study had access to home charging, some vehicles rarely charged at home. Instead, they relied on frequent away-from-home charging during the day. This demonstrates the viability of publicly accessible and/or workplace charging infrastructure for drivers of EVs without access to home charging.

What Kind of Charging Infrastructure Did Chevrolet Volt Drivers in The EV Project Use and When Did They Use It

- A sample of 1,867 Chevrolet Volt drivers participating in The EV Project performed 87% of their charging events at home and 13% away from home over a 15-month study period.
- Although the majority (59%) of all charging events was performed at home overnight, 28% of all events were performed at home during the day. Only 12% of charging events were performed away from home during the day. The fact that 70% of daytime charging was performed at home is significant, because typically daytime "opportunity" charging has been thought of as away-from-home charging.
- All vehicles in this study had access to AC Level 2 (240-V) charging at home; therefore, it is not surprising that nearly all home charging was conducted using AC Level 2 charging equipment. Away-from-home charging was split evenly between AC Level 2 charging units and AC Level 1 (120-V) charging units or standard 120-volt outlets.
- Not everyone used away-from-home charging infrastructure equally. In fact, three quarters of the away-from-home charging was performed by 20% of the vehicles. A small portion of vehicles (i.e., 5%) were never charged away from home.
- Drivers who performed 30 to 60% of their charging events away from home tended to supplement daily home charging with regular away-from-home charging. Altogether, these drivers averaged 2.0 charges per day. Frequent charging allowed them to average 40.3 miles driven in EVM per day, which is a 60% increase in daily EV miles over the group of vehicles that never charged away from home.
- Drivers who charged away from home for more than 60% of their charging events tended to supplement frequent away-from-home charging with home charging. Their away-from-home charging frequency was the same as the home charging frequency of the group of drivers that never charged away from home.
- All away-from-home charging frequency groups averaged 74 to 80% of their distance driven in EVM. Overall average charging frequency increased as average daily distance driven increased, suggesting that drivers changed their charging behavior in order to extend EVM operation.

How Much were Chevrolet Volts in The EV Project Driven in EVM

- A sample of 1,154 Chevrolet Volt drivers participating in The EV Project drove 73% of their total miles in EVM over an 8-month study period.
- 70% of vehicles drove more than 70% of their total miles in EVM, while 131 vehicles (11%) drove more than 95% of their miles in EVM.
- Volt drivers who drove farther per day also tended to consume more charging energy, either through more frequent charging, longer charge sessions, or both.

- The average amount of energy delivered per charging event varied widely from vehicle to vehicle, even among vehicles whose batteries were typically fully depleted prior to charging.
- Drivers with a high percentage of miles in EVM averaged fewer trips of shorter length between charging events. They also tended to charge more frequently for shorter durations.

4.1.7 EV Project Workplace Charging

What Were the Cost Drivers for Workplace Charging Installations

- The average cost for installation of EVSE at workplace locations was $2,223.
- The average installation cost for workplace charging EVSE was 75% of the average cost to install publicly accessible EVSE (i.e., $2,979).
- 27% of workplace EVSE installed were wall-mount units, while 17% of publicly accessible EVSE units were wall-mount units.
- Greater flexibility in location of workplace installations provided installation cost savings opportunities not typically available to EVSE installed for public use.
- Imposing a fee to charge at work will likely reduce charging station use. If fees are too high and/or employee commuting distances are low, charging equipment may be seldom used.
- Providing PEV-owning employees with tools for self-managing charging can be an effective way of maximizing charging station use and accommodating a lot of vehicles, even if charging is free.
- An enforced policy requiring drivers to move their vehicles from parking spaces designated for charging is a deterrent to workplace charging. Employees may be disinclined to risk a reprimand or fine if they are unable to interrupt their work day to unplug and move their vehicles at the required time.
- Corporate culture may affect employee workplace charging behavior. For example, if a company executive owns a PEV, lower-ranking employees may be reluctant to use a charging station the executive uses. Likewise, employees with a particular status or background may feel entitled to occupy a charging station for as long as they want, without regard to other employees' desire to charge. Naturally, these cases could occur at any work site, but may be more likely and will have a more significant effect at smaller work sites.
- Future expansion of workplace charging infrastructure represents a significant installation cost concern for employers, because these expansions will frequently require additional electrical service capacity.

Where Did Nissan Leaf Drivers in The EV Project Charge When They Had the Opportunity to Charge at Work

- A group of 707 Nissan Leafs from The EV Project, whose drivers had the opportunity to charge at work, performed 65% of their charging events at home, 32% at work, and 3% at other locations over the period between January 1, 2012, and December 31, 2013. The proportion of charging energy consumed by location during this time period was similar.
- During this study period, this group charged their vehicles away from home more than twice as much as the overall group of Nissan Leaf drivers enrolled in The EV Project.
- This study's Leaf drivers (with workplace charging) performed 91% of their away-from-home charging events at work and 9% at non-workplace away-from-home locations.
- On days when this study's Leaf drivers went to work, they performed 98% of their charging events either at home or work and only 2% at other locations.
- On days when this study's Leaf drivers did not go to work, they performed 92% of their charging events at home and 8% at other locations.

Charging and Driving Behavior of Nissan Leaf Drivers in The EV Project with Access to Workplace Charging

- A sample of 622 Nissan Leaf drivers participating in The EV Project with access to workplace charging charged at work on 53,351 vehicle days between March 2011 and December 2013.

- On nearly a quarter of those days, drivers drove far enough that they could not have completed their daily driving without workplace charging, even if they fully charged at home.
- On about half the days, drivers fully charged at home and "topped off" at work. On about a quarter of the days, drivers only charged at work, even though they had access to home charging.
- While 14% of vehicles needed workplace charging to complete their daily commutes most of the time, 43% of vehicles needed it some of the time (i.e., on at least 5% of commuting days). This shows that workplace charging is valuable as a range extender for drivers who live far from work and for drivers who sometimes need additional driving range beyond their typical commute.
- On days when drivers charged at work, they drove an average of 15% farther than days when they did not charge at work. This demonstrates that workplace charging provides a significant benefit for increasing eVMT.
- In fact, on days when drivers needed workplace charging, they drove 15 more miles, on average, than they would have been able to drive without workplace charging. The average commute on those days was 73 miles.

Where Did Chevrolet Volt Drivers in The EV Project Charge When They Had the Opportunity to Charge at Work

- A group of 96 Chevrolet Volts from The EV Project, whose drivers had the opportunity to charge at work, performed 57% of their charging events at home, 39% at work, and 4% at other locations over the period between January 1, 2013, and December 31, 2013. The proportion of charging energy consumed by location was similar.
- During this study period, this group charged their vehicles away from home more than twice as much as the overall group of Chevrolet Volt drivers enrolled in The EV Project.
- This study's Volt drivers (with workplace charging) performed 92% of their away-from-home charging events at work and 8% at non-workplace away-from-home locations.
- On days when this study's Volt drivers went to work, they performed 98% of their charging events either at home or work and only 2% at other locations.
- On days when this study's Volt drivers did not go to work, they performed 89% of their charging events at home and 11% at other locations.

Accessibility at Public EV Charging Locations

- One purpose of The EV Project was to identify potential barriers to widespread adoption of PEVs and deployment of EVSE to support them
- This process identified topics of national interest in the early deployment of PEV charging stations in order to facilitate discussion and resolution. One of these topics was The EV Project's approach to compliance with the U.S. Americans with Disabilities Act (ADA) – 28 CFR Part 36.
- Federal accessibility standards do not specifically address EV charging stations. Nevertheless, incorporate ADA accessibility requirements in the design of commercial charging station equipment and installation plans is required.
- In general, design requirements provided by the 2010 ADA Standards for Accessible Design can be accommodated in design and installation of publicly available EVSE. In some cases, strict interpretation of these design requirements may increase project costs disproportionally or create such facility design issues that compliance is not feasible. Public policy and direction is favoring the expansion of EV charging infrastructure and strict interpretation may impede its development. Consideration for this situation is already provided in the ADA Standards related to "disproportionality" and "maximum extent

feasible."

- For the purpose of The EV Project and early market deployment of commercial EVSE, it was found that reasonable efforts to incorporate accessibility requirements during installation of commercial DCFC stations can be accomplished.

4.2 Lessons Learned from Combined Projects

4.2.1 Categorizing Electric Vehicle Supply Equipment Venues: Describing Publicly Accessible Charging Station Locations

- Many stakeholders in the PEV industry are interested in how non-residential EVSE units are used at various types of locations. The EV Project, ChargePoint America Project, and West Coast Electric Highway Project provided the opportunity to collect data from Blink, ChargePoint, and AeroVironment brand charging stations installed around the United States.
- In order to analyze EVSE usage by location, it was necessary to create a system for categorizing EVSE sites by location type or venue. A two-level classification system was selected, where EVSE sites were assigned a primary venue and a sub-venue.
- The primary venue is a coarse classification that broadly defines the site location and provides a general perspective on why a PEV driver would be parking at that location. Primary venue categories were chosen to be compatible with other PEV charging infrastructure demonstrations.
- A sub-venue subdivides the primary venue category to provide an additional level of detail.
- Information provided about EVSE sites by The EV Project, ChargePoint America, and AeroVironment, as well as publicly available information, were used to classify EVSE sites into venue categories. The publicly available information sources that were used included Google Earth, Google Maps, Google Street View, PlugShare, ReCarGo, and various ESRI geographic layers. Geospatial data were visually inspected and cross-referenced with project data to classify each EVSE site.

4.2.2 Analyzing Public Charging Venues: Where are Publicly Accessible Charging Stations Located and How Have They Been Used

- Many of the AC Level 2 charging stations discussed in this paper were located at retail locations and parking lots/garages.
- DCFCs were not broadly distributed across venue categories; they only existed at eight types of venues. Most of the venues showed similar use ranges. This indicates that the venue may not be drawing customers to DCFCs.
- The workplace venue was the most utilized venue for AC Level 2 EVSE. People are likely to use AC Level 2 charging infrastructure for longer periods of time while they are working.
- All DCFC venues had a median average of 4 to 7 charge events per week per site. All AC Level 2 EVSE had a median average of 9 to 38 charge events per week per site. DCFCs only require approximately 30 minutes to charge a vehicle; therefore, it's expected that they would have a higher number of daily charging events.
- EVSE sites were not evenly distributed across venues. If a venue contained a small number of EVSE sites, there may not have been enough data to accurately describe potential usage.
- Data presented in this paper were collected at the beginning of EV adoption across the United States. Also, charging infrastructure was being deployed throughout the data collection effort. Because the number of vehicles increased as the number of available EVSE increased, this paper demonstrates the potential for each venue, but it may not accurately describe a mature market.

4.2.3 Workplace Charging Case Study: Charging Station Utilization at a Work Site with Alternating Current Level 1, Alternating Current Level 2, and Direct Current Fast Charger Units

- Use of numerous workplace charging stations from May to August 2013 at Facebook's office campus in Menlo Park, California was studied. Charging stations at this facility included AC Level 1, AC Level 2, and DCFC. The AC Level 2 charging units were the most heavily utilized, accounting for 83% of charging events, with 11% of charging events being performed using the DCFC. Drivers opted for AC Level 1 charging only 6% of the time.
- AC Level 2 charging units were used heavily during the work day, averaging 8.7 hours connected per cord per work day. Drivers tended to stay connected to AC Level 2 cords for around 4 hours or for around 9 hours, which is either half a work day or an entire work day. Most of the time, vehicles fully charged their batteries in less than 5 hours.
- AC Level 1 outlets were used infrequently and typically remained connected to vehicles for 8 or more hours per charging event. Because of the slower charge rate, many charging events required 5 to 10 hours to fully charge the vehicles' batteries. However, a significant number of charging events required only 2 to 3 hours to reach full charge because the vehicles being charged had small battery packs.
- Drivers overwhelmingly preferred AC Level 2 charging over AC Level 1 charging. Data were collected from 10 charging units at this work site that were capable of both AC Level 1 and AC Level 2 charging. When drivers arrived at these units and both AC Level 1 and AC Level 2 options were available, they chose to use the AC Level 2 cord 98% of time. With only a few exceptions, the AC Level 1 outlet was only used if the AC Level 2 cord was already connected to another vehicle.
- Facebook followed a few simple guidelines for encouraging employees to self-manage EVSE usage. First, charging units were installed to allow access from multiple parking spaces. Drivers were encouraged to plug in neighboring vehicles after their vehicle completed charging. Second, employees were provided with an online message board – in this case, a Facebook page that allowed them to coordinate charging station usage. Data from the EVSE suggest that drivers leveraged these resources to minimize the time EVSE were not in use. Thirty-seven percent of the time when one charging event ended and the next began at the same AC Level 2 EVSE during the same work day, less than 30 seconds elapsed between the two charging events. Sixty percent of the time, less than 3 minutes elapsed between consecutive charging events.
- The DCFC was typically used between 2 and 6 times per work day for 24 minutes or less per charging event. Eleven percent of the time when a DCFC event ended and another event began on the same work day, a vehicle had been connected to the second DCFC prior to the end of the first vehicle's charging event.

4.2.4 Direct Current Fast Charger Usage in the Pacific Northwest

- The West Coast Electric Highway Project established a network of DCFCs in the states of Oregon and Washington. In addition, The EV Project installed a dozen DCFCs in metropolitan areas throughout the region. Data from these two networks were analyzed to determine how often DCFCs were used between September 1, 2012, and December 31, 2013. The most highly used DCFCs were located in the Seattle, Washington, metropolitan area. Other highly used DCFCs were found in Portland and Salem, Oregon and along Interstate 5 (I-5) north from Salem to Vancouver, British Columbia. Usage generally decreased as distance from I-5 increased.
- When Nissan Leafs in The EV Project based in Washington and Oregon used DCFCs located inside Seattle and Portland, they tended to use them during round-trip outings of less

than 75 miles. This is less than the range of the Leaf on a single charge.

- Leaf drivers used DCFCs located outside city boundaries to support longer travel, often driving 150 miles or more before returning home. For these drivers, the West Coast Electric Highway successfully enabled significant range extension.

4.3 Miscellaneous Observations

4.3.1 Top 10 EV Cities and American Recovery and Reinvestment Act Charging Infrastructure Deployments

- ChargePoint released what they have calculated as the 10 cities in the United States with the highest number of EVs.
- While details about how this was calculated are not known and it can only be assumed that PEVs are included, it is interesting to note the correlation (perhaps not causation) between these 10 cities and the two charging infrastructure deployments that were conducted via DOE's ARRA activities.
- Combined charging infrastructure was deployed in seven of the top 10 cities, with The EV Project deploying infrastructure in six of the 10 and the ChargePoint America Project in four of the 10.
- When looking at the four metropolitan areas with the most PEVs combined, the projects are in all four.

4.3.2 Comparing Chevrolet Volt Performance by Driver Groups

- Driver behavior can have a large impact on the full capability of PEV technology and driver recharging behavior can reduce petroleum consumption.
- When comparing the operation of privately owned Chevrolet Volts in The EV Project to commercially owned Volts in the General Motors Chevrolet Volt Demonstration, the single largest difference was the amount of electric miles driven. The privately owned Volts averaged 79% more miles driven in EVM than commercial Volts. The result is that more gasoline was used by commercial drivers because their vehicles were operated more in ERM, during which the gasoline ICE must operate.
- Based on AC Wh/mile, commercial vehicles were likely driven more aggressively, with AC Wh/mile about 9% higher. However, this difference could have been influenced by the private drivers' desire to maximize all electric miles by minimizing the use of auxiliary loads, impacts from different climates, or commercial drivers being more focused on "getting their job done."
- General public owners charged their Volts more often, with about 35% more charge events on the days the Volts were driven.
- The commercial Volts were driven for longer trips than the general public drove their Volts. These longer trips, especially ones beyond 40 miles (which are beyond the Volt's EVM range of approximately 40 miles per full charge) would clearly necessitate use of ERM operations and use of gasoline for propulsion.

4.3.3 Comparing EV Project Chevrolet Volt Use and Nissan Leaf Use

- Driver behavior influenced things like charge times, SOC at the beginning and end of charges, and miles driven per charge and day driven. Driver behavior can have large impacts when using technologies that can significantly reduce petroleum use while still providing functionality similar to a comparative ICE vehicle.
- The Volts were driven about 28% more miles per day than the Leafs on days they were driven.

- The average trip distance for Volt drivers was 17% longer than Leaf drivers.
- Leaf drivers took 15% more trips than Volt drivers per charge event.
- Miles driven per charge event were nearly the same, with Volt drivers driving 3% more miles per charge event.
- Volt drivers charged their vehicles 36% more often than Leaf drivers on days the vehicles were driven.
- Volt drivers charged at home 80% of the time compared to Leaf drivers charging 74% of the time.
- Conversely, Leaf drivers charged 20% at home versus Volt drivers charging 14% at home.

4.3.4 ChargePoint America and EV Project Results

- Residential EVSE "time connected" and "drawing power" profiles are fairly similar.
- For public EVSE use in both projects, the ChargePoint public EVSE and PEVs were connected more often, with ChargePoint public AC Level 2 units having a vehicle connected 14% of the time compared to The EV Project's 8% of the time.
- The percentage of time power was being drawn was 4% for ChargePoint and 2% for The EV Project. However, this ignores The EV Project's public DCFC connect time of 5% and power draw of 5%.
- Weekday residential profiles are fairly similar and both display similar power transfer characteristics at midnight, when TOU rates influence the drivers to set midnight start times for charging.
- Charge events at residential EVSE in The EV Project saw connection times of about 30 minutes less than residential EVSE in the ChargePoint Project; they also drew power for a slightly shorter period of time. However, The EV Project's residential chargers drew slightly more energy per charge event.
- Based on the percentage of public EVSE with a vehicle connected in The EV Project and in the ChargePoint Project, it appears that the ChargePoint public EVSE consistently had a higher percentage of time with a vehicle connected on weekdays. Weekend connect percentages were much flatter; however, ChargePoint public EVSE had more vehicles connected. It should be noted that The EV Project was requiring a fee at nearly all EVSE while ChargePoint EVSE use is believed to be have been free at 70% of the EVSE.
- Public demand profiles for both EVSE projects were similar, with power transfer peaking before noon on weekdays. However, based on the April to June 2013 reporting quarter, the ChargePoint demand was about twice as high as The EV Project, even though The EV Project had about 25% more EVSE reporting use. Again, the fees charged for public charging in The EV Project versus ChargePoint's mostly free charging were a likely influence.
- Even though drivers charging at public EVSE in The EV Project were connected for about 30 minutes less than public EVSE in the ChargePoint Project, they actually drew power for a slightly longer period of time. The longer draw times resulted in slightly more energy used during the average public charge event. The EV Project public EVSE saw an average of 8.7 kWh used weekdays and 8.4 kWh on the weekends. The energy transfer amounts for the ChargePoint public EVSE were 7.86 kWh on weekdays and 7.56 on weekends.
- While there were some slight differences in use patterns, public and residential AC Level 2 EVSE were used in similar ways, with similar amounts of energy being transferred per charge event. No other categories of EVSE were compared because their characterizations varied too much.

5. INDIVIDUAL AMERICAN RECOVERY AND REINVESTMENT ACT PROJECTS

The purpose of ARRA included the following:

- To preserve and create jobs and promote economic recovery
- To assist those most impacted by the recession
- To provide investments needed to increase economic efficiency by spurring technological advances in science and health
- To invest in transportation, environmental protection, and other infrastructure that will provide long-term economic benefits
- To stabilize state and local government budgets in order to minimize and avoid reductions in essential services and counterproductive state and local tax increases.

Within the area of Transportation Electrification, several electric drive vehicle and charging infrastructure projects were supported by DOE. In support of some of these projects, INL was tasked by DOE's Vehicle Technologies Office to collect light-duty PEV and charging infrastructure data for several ARRA projects. INL was also tasked by DOE to sign non-disclosure agreements with the funded entities; the resulting data provided by the entities allowed for the data security, analysis, and reporting that INL conducted.

Several projects included deployment of EVSE, which safely provide electricity to the PEVs' onboard chargers; deployment of DCFCs, which are chargers located off-board the vehicle that transfer power at high levels to properly equipped PEVs; and the deployments of PEVs. These projects represent the largest ever deployment and study of charging infrastructure and grid-connected BEVs, EREVs, and PHEVs. Collectively, the BEVs, EREVS, and PHEVs are known as PEVs. The projects that INL collected data for, performed analysis, and reported on consisted of the following:

1. ChargePoint America – PEV Charging Infrastructure Demonstration
   - Consisted of 4,647 of ChargePoint EVSE
2. Chrysler Ram PHEV Pickup – Vehicle Demonstration
   - Consisted of 111 PEVs
3. GM Chevrolet Volt – Vehicle Demonstration
   - Consisted of 150 EREVs
4. The EV Project – PEV Charging Infrastructure Demonstration
   - Consisted of 8,228 PEVs, EREVs, and BEVs, as well as 12,356 EVSE and DCFC
5. SCAQMD/EPRI/Via Motors PHEVs – Vehicle Demonstration.
   - Consisted of PHEV conversions of Chevrolet vans and pickups.

The five projects varied in the equipment deployed; therefore, the data collected were not universal. For the ChargePoint America Project, the equipment deployed and charge data generated were limited to EVSE.

The Chrysler Ram Pickup and Chevrolet Volt Projects included PHEVs and EREVs, respectively, and the only data collected came from the vehicles. However, both were able to provide charging data to INL. For the Chrysler Ram PHEV, several charging-related data parameters were collected.

For The EV Project, data streams came from BEVs, EREVs, EVSE, and DCFC.

The subsequent sections of this report discuss:

- Data collection methods
- How data were sent to INL
- Details of equipment
- Periods of data collection for each project
- Analysis and results
- Lessons learned.

It should be noted that INL was not tasked with verifying the number or sustainability of jobs created. This report is limited to information INL was able to generate based on data collected and analyzed from each of the five projects.

6. CHARGEPOINT AMERICA PROJECT

6.1 ChargePoint America Project Scope and Objectives

The ChargePoint America Project was led by ChargePoint with ARRA funding support from DOE. The project deployed 4,647 residential and commercial charging stations in nine U.S. regions. The data collection phase of the project ran from May 1, 2011, through December 31, 2013, and captured over 1.5 million charge events. Quarterly reporting started during the January to March 2012 time period. It should be noted that the only way INL was able to count the number of EVSE deployed was by reporting the number of EVSE reporting data. INL was not tasked with field inspections.

ChargePoint, which was originally known as Coulomb Technology, was tasked by DOE to deploy EVSE in the following metropolitan areas of the United States:

- Boston area (Massachusetts and Rhode Island
- D.C. Area (District of Colombia, Maryland, and Virginia)
- Florida
- Los Angeles area
- Michigan
- New York area(Connecticut, New Jersey, and New York)
- Sacramento/San Francisco Area
- Texas
- Washington State.

The primary objective of the ChargePoint Project was creation of jobs and development of a PEV charging network, which would facilitate analysis and study of where future EVSE should be installed.

6.2 ChargePoint America Electric Vehicle Supply Equipment Types

Three types of EVSE were deployed in the ChargePoint Project and can be described as follows:

- A single AC Level 2 port or cord and connector set in a single EVSE. These units can differ in design, depending on the application, which can be residential (Figure 6-1) or public (Figures 6-2 and 6-3). Public EVSE tended to be of a more rigid design, given the environment the EVSE was subjected to.
- Another AC Level 2 EVSE design also included a 110-V National Electrical Manufacturers Association-style receptacle (AC Level 1) in addition to the AC Level 2 SAE 1772-style connector. With the exception of a few special studies, energy use and charge events were not reported for the 110-V service. ChargePoint requested that only the AC Level 2 events be reported, which was what they were tasked to report on by DOE.
- The third EVSE design used a two-cord/connector set, with both being AC Level 2 (208 to 240 V). There was no 110-V receptacle. Each one of the two SAE J1772connectors were considered as two distinct units for reporting purposes, given that each connector was capable of charging a PEV simultaneously. Note that the two connectors shared a single pedestal (Figure 6-4) and were designed to the SAE J1772 standard.

Figure 6-1. ChargePoint residential EVSE.

Figure 6-2. ChargePoint public EVSE.

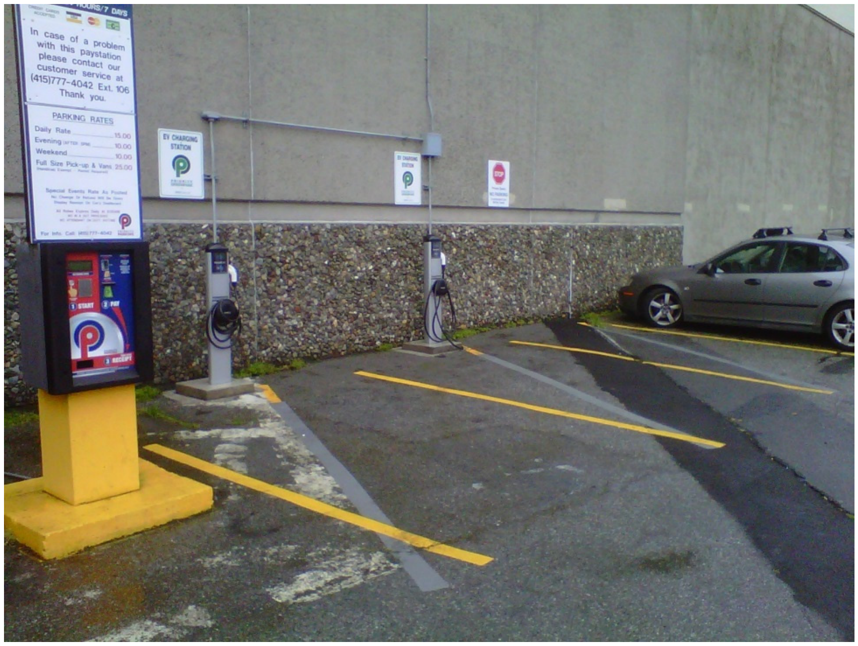


Figure 6-3. ChargePoint EVSE installation in the San Francisco area.

Figure 6-4. Dual-port ChargePoint EVSE.

6.3 ChargePoint America Electric Vehicle Supply Equipment Deployment and Data Collection Rate

The rate of the ChargePoint America Project's EVSE deployment can be seen in Figure 6-5. A total of 4,647 EVSE SAE J1772 cord and connector sets were deployed and reported on throughout the United States (Figure 6-6). However, not every cord and connector reported a charge event or energy transfer during each reporting period. Multiple reasons exist for a connector to not report a charge event from one quarter to the next. For instance, the unit may have been vandalized, it may have been run over by a vehicle, or it simply may not have been used. One of the goals of the EVSE-focused projects was to understand where EVSE should be deployed and if people will use them. Of course, this is also highly dependent on how many PEVs are located in the area and the types of venues the EVSE are installed at. This will be discussed in further detail in subsequent sections.

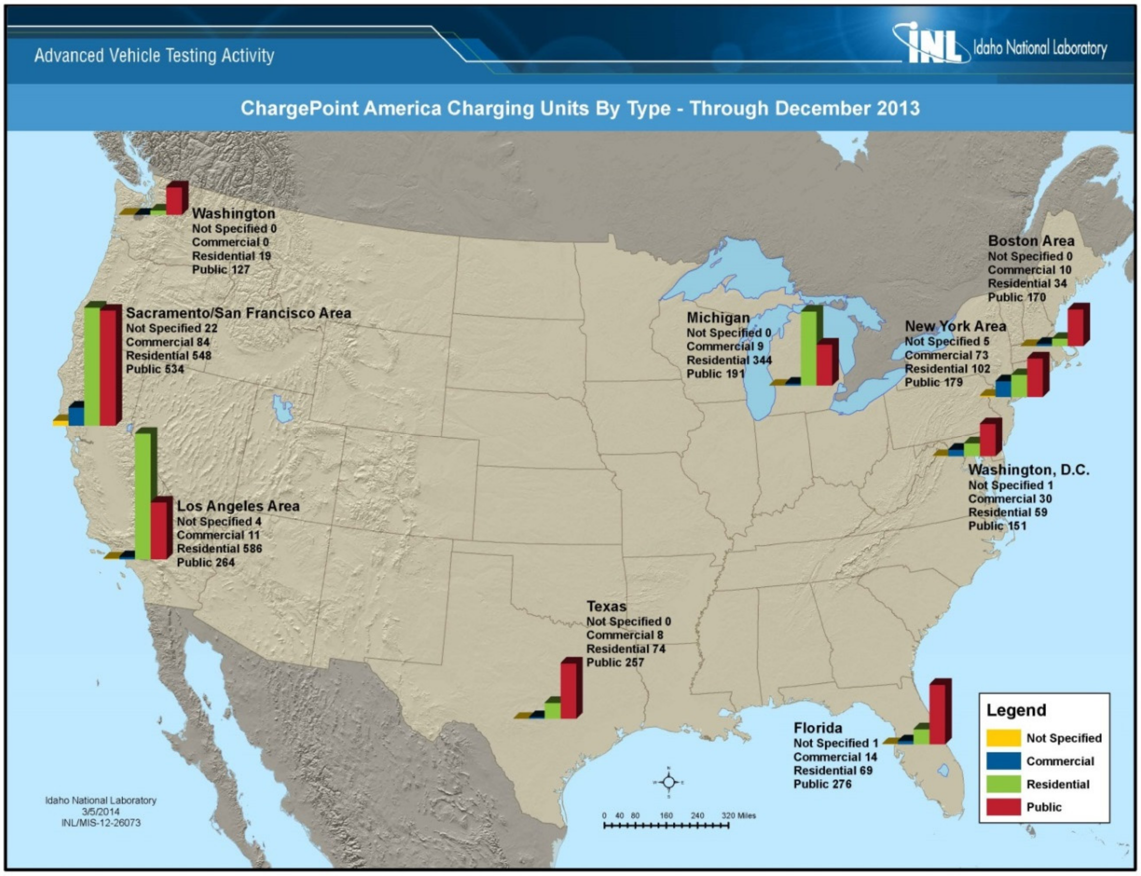


Figure 6-5. Locations and total number of EVSE reporting data as of the end of the ChargePoint Project, which was December 2013.

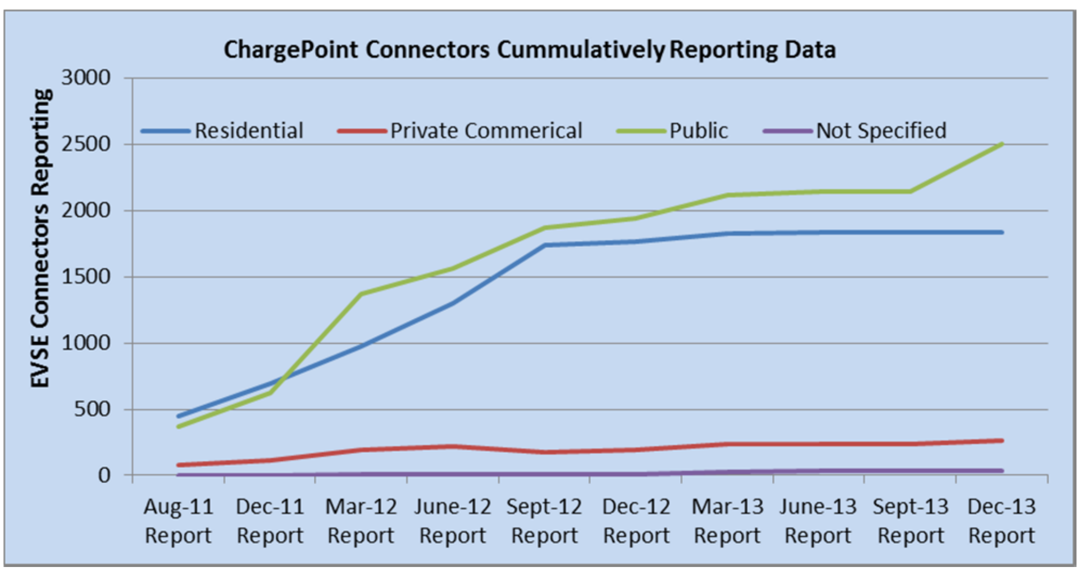


Figure 6-6. By reporting period, the graph displays the cumulative number of ChargePoint connectors that have reported a charge event and energy transfer. Note that the Private Commercial (i.e., red line) line dipped from June 2012 to September 2012 due to venue reclassifications.

The number of connectors reporting data each quarter does not match the deployment seen in Figure 6-5. As can be seen in Figure 6-7, not every cord and connector reported a charge event and energy transfer for each reporting period.

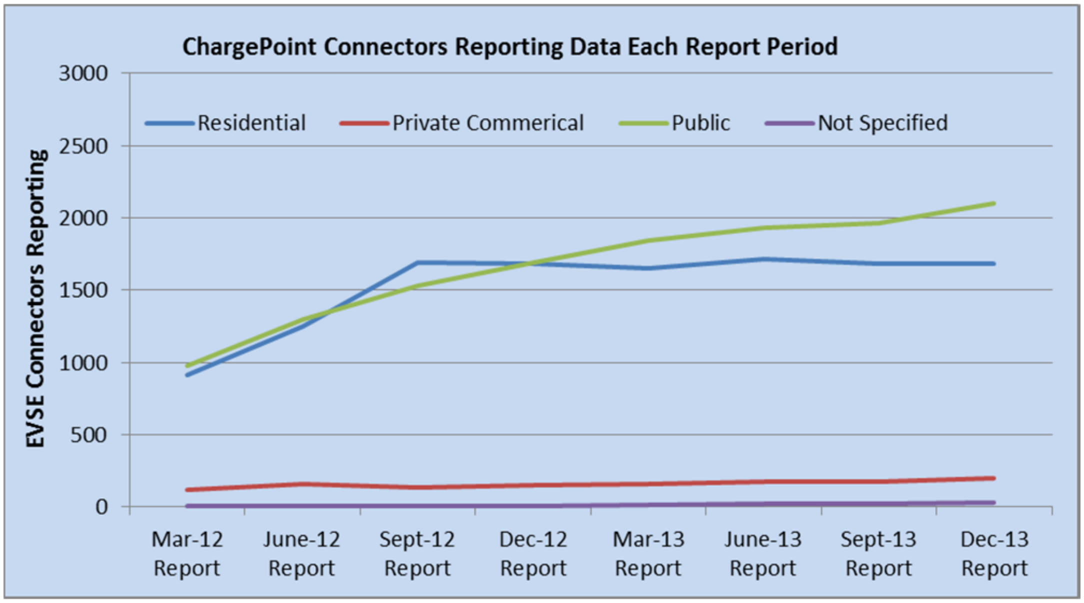


Figure 6-7. By reporting period, the graph displays the number of ChargePoint America connectors that reported a charge event and an energy transfer.

6.4 ChargePoint America Reporting

The primary reporting method was via quarterly reports, which documented both cumulative data collected to-date for each region and the project totals. The statistics reported on included the following:

- EVSE deployment by the following location categories:
  - Residential
  - Private non-residential or private commercial (i.e., generally, limited access locations such as commercial fleets)
  - Publicly accessible
  - Not specified
  - Total EVSE
- Number of charging events performed
- Electricity consumed (AC MWh)
- National map of deployment locations.

As the project and reporting progressed, the reports grew in complexity (i.e., by the October to December 2013 final report, the quarterly report and grown to 17 pages). All of the reports can be found on INL's web pages for the ChargePoint America Project at: http://avt.inel.gov/chargepoint.shtml. After cumulative data provided on page 1, the remaining pages presented the following information by EVSE type (as noted above):

- Number of charging units (connectors)
- Number of charging events

- Electricity consumed (AC MWh)
- Percent of time with a vehicle connected
- Percent of time with a vehicle drawing power
- Time of day vehicles were connected and time of day they drew power in 15-minute increments, both for weekends and weekdays during each 90-day reporting period; these data were graphed by median, maximum and minimum results, and the inner-quartile ranges.

The ChargePoint America Project reports included all EVSE in the project that reported results by each EVSE type (based on locations) and results for various regions. The amount of information in each quarterly report was driven by the amount of EVSE deployed. Therefore, earlier quarterly reports had less content than subsequent reports.

6.5 ChargePoint America Project Results

6.5.1 ChargePoint America Project Duration Results

Charge event frequency for each reporting period was highest for residential EVSE, averaging about 80 events per EVSE per 3-month period (Figure 6-8), which would equate to slightly less than one per day. Private commercial and public EVSE were initially used between 20 and 40 times per reporting period; however, usage grew to between 55 and 65 charge events during the final reporting period.

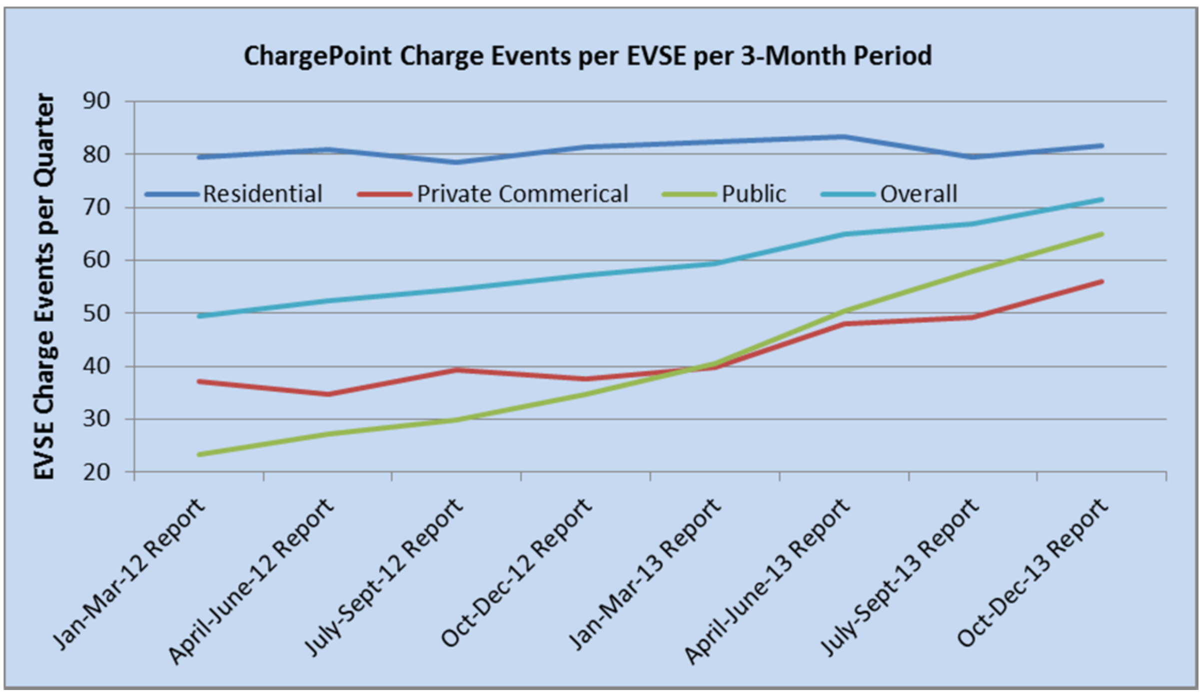


Figure 6-8. Average number of charge events reported per reporting quarter for each EVSE connector in the ChargePoint America Project.

The energy transferred per charging event for the private commercial EVSE centered around 8.5 kWh per charge event (Figure 6-9), suggesting that while not used as frequently as residential EVSE, the private commercial EVSE may have been used to charge larger battery packs or these vehicles were more fully depleted when they visited the private commercial EVSE. The residential EVSE's charge energy ranged from 6.5 to 7.5 kWh during the reporting period. Public EVSE charge energy initially averaged about 7 kWh per charge event, rising to more than 8 kWh during the last two reporting periods.

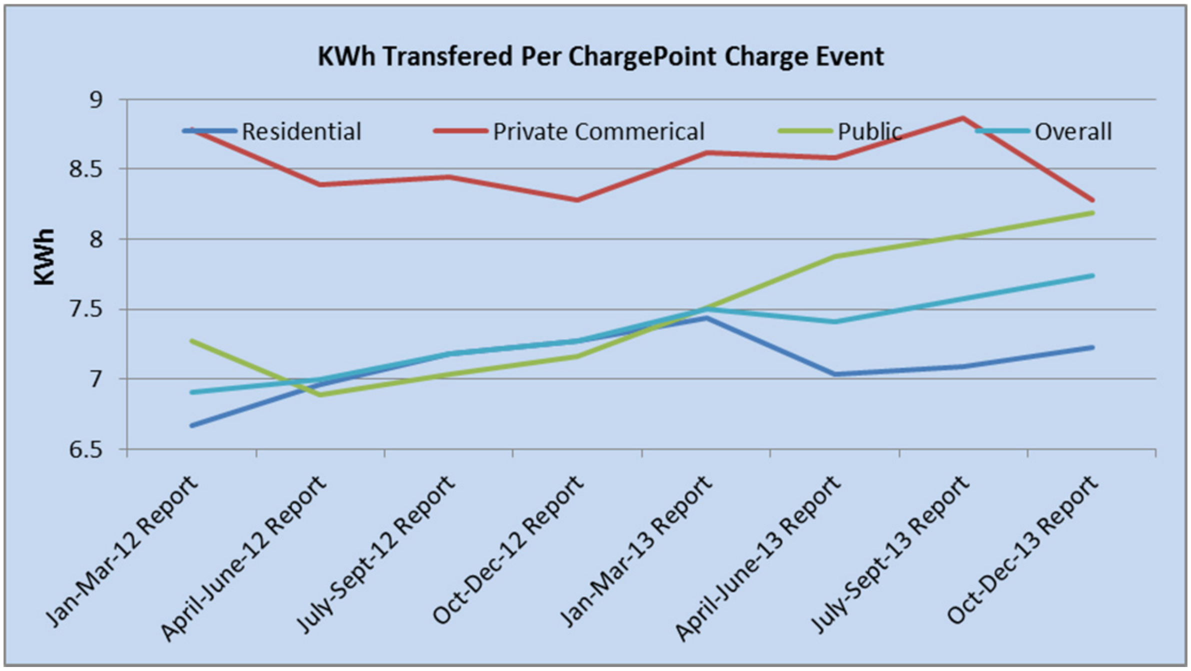


Figure 6-9. Average energy (kWh) used for each charge event per ChargePoint America Project EVSE and reporting period.

As seen in Figure 6-10, the first reporting quarter appears to have the longest connection times between the vehicles and EVSE. This may have been driven by several factors; for example, drivers overcoming any initial range anxiety fears, because they may have wanted to ensure maximum battery capacities. After the first reporting period, connection times ranged from 45 to 48% for residential EVSE, 22 to 28% for the private commercial EVSE, and 7 to 14% for public EVSE.

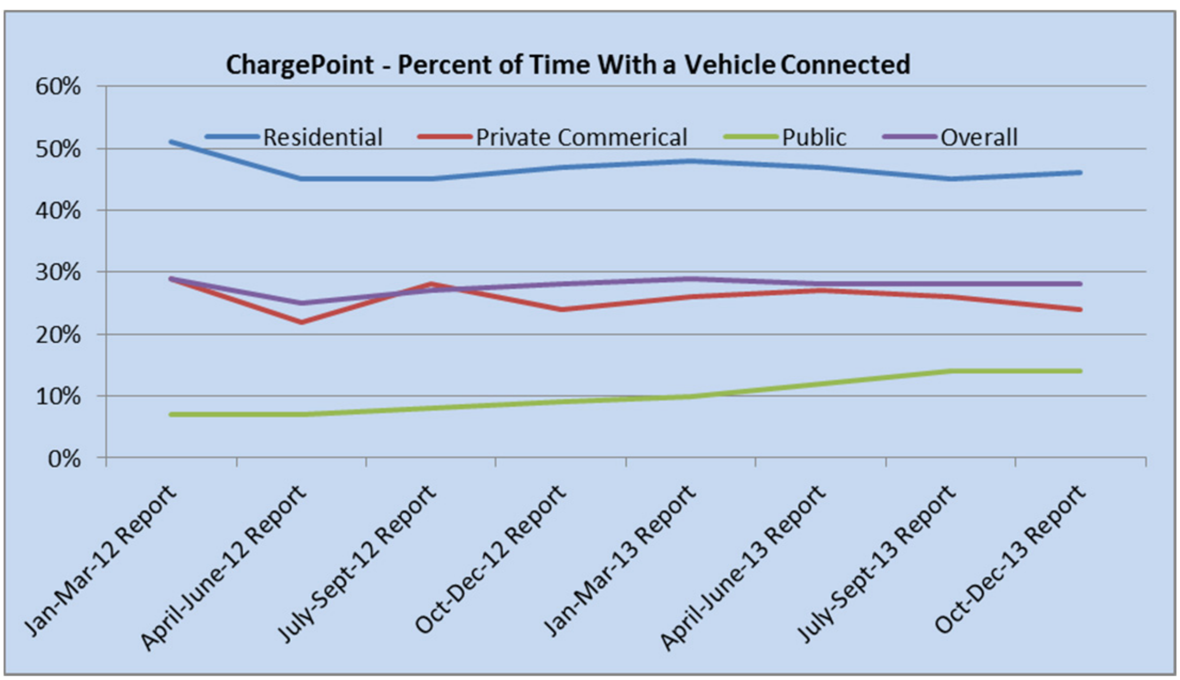


Figure 6-10. Average percentage of time the ChargePoint America EVSE had a vehicle connected for each reporting period.

Similar to the percentage of time a vehicle is connected, Figure 6-11 documents a much higher percentage of time when a vehicle was drawing power during the first reporting period. After the first reporting period, power draw times ranged from 8 to 9% for residential EVSE, 4 to 6% for private commercial EVSE, and 2 to 7% for public EVSE.

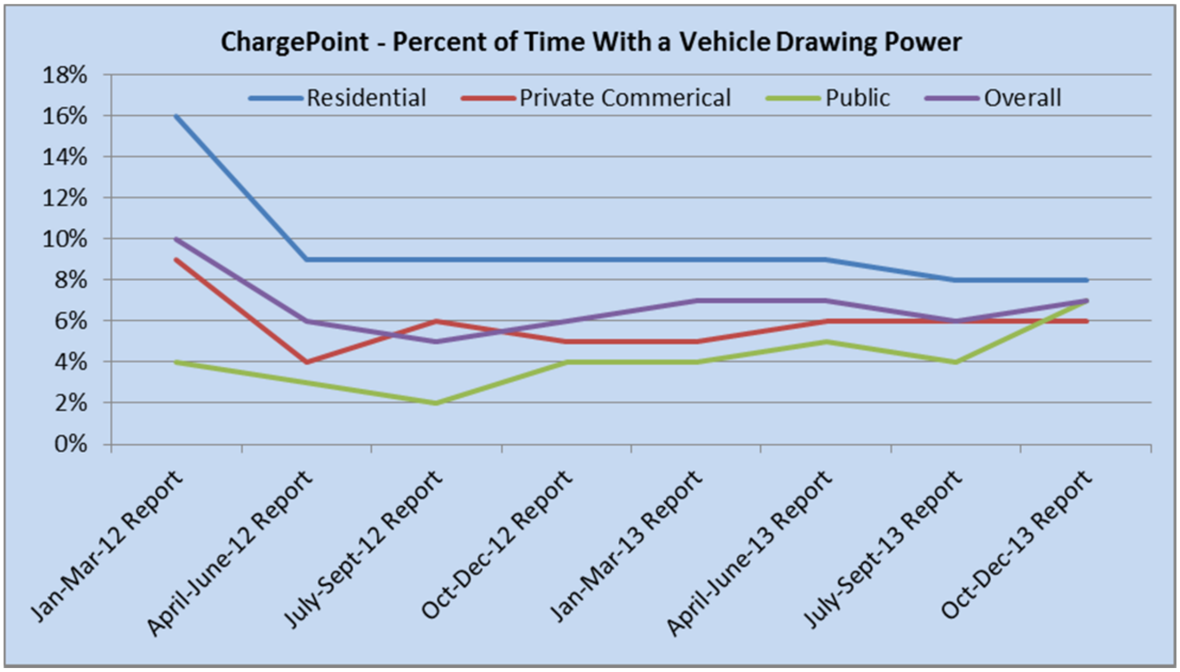


Figure 6-11. Percent of time a vehicle was drawing power from the ChargePoint America EVSE, with the average by EVSE type each reporting period.

Total energy used during all charging events for the duration of the data collection activity was 13,399 AC MWh. This equates to 7.3 kWh per charge event and 2,883 total kWh per EVSE during the data collection activity.

The ChargePoint America Project scope did not include a vehicle data collection component to it; therefore, the project does not allow a discussion of how much eVMT was enabled. However, ChargePoint America data have provided significant value to INL's classification of venues where EVSE were sited, travel patterns, and other analysis. These results are discussed toward the end of this report, where they are combined with results for other data collection activities.

6.5.2 October to December 2013 Results

In order to provide additional information about how PEV drivers used ChargePoint America EVSE, results from the October to December 2013 reporting period are discussed in more detail.

As can be seen in Figure 6-12, public EVSE reported the most data, representing 52% of all ChargePoint America EVSE reporting data. However, residential EVSE were used the most times, with 836 more charge events than public EVSE (Figure 6-13). Figure 6-14 shows that public EVSE actually delivered the most energy to PEVs, with 51% of all electricity consumed. Along with the relatively short amount of time public EVSE had a vehicle attached when compared to residential EVSE, it can be assumed that public charging occurred when power was highly needed by drivers for charging their PEVs and that drivers left their vehicle connected to EVSE overnight at residences, regardless of the SOC level. Of course, given that residences are where people park their PEVs overnight while sleeping, the long residential connection times are expected. Private commercial EVSE mostly supported commercial fleet vehicles.

Figure 6-15 highlights the difference between the percentage of time with a vehicle connected to EVSE versus the percentage of time a vehicle is drawing power for the respective EVSE reporting categories.

Figure 6-16 documents the percentage of EVSE with a vehicle connected and Figure 6-17 is the EVSE electricity demand for all EVSE in the project during the reporting period. However, more important curves that indicate how drivers used EVSE can be found when looking at the data for a single EVSE type. For instance, Figures 6-18 and 6-19 show the connect times and demand curve at residential EVSE, which varied significantly from the other sites.

EVSE at residential sites clearly had signicantly different connect and demand curves compared to private commercial and public EVSE. Residential EVSE (Figure 6-18) with a vehicle connected on weekdays, as represented by the median line, show how vehicles were starting to be disconnected at 6 a.m. as drivers head to work, school, etc., with the lowest percentage connected around 2 or 3 p.m. As drivers returned to their residences, starting around 4 p.m., more and more vehicles were connected. From about 6 p.m to 10 or 11 p.m., the slope of the vehicles being connected was steepest, with the most PEVs connected to the EVSE during the post midnight hours.

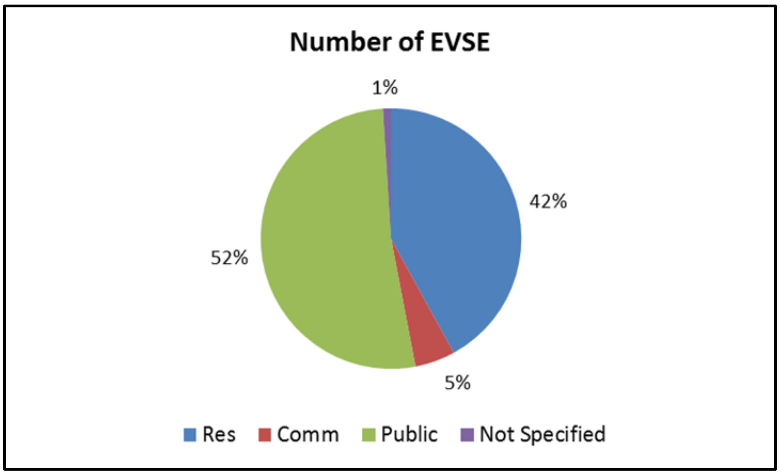


Figure 6-12. Percentage of EVSE reporting data during the October to December 2013 reporting period by EVSE type.

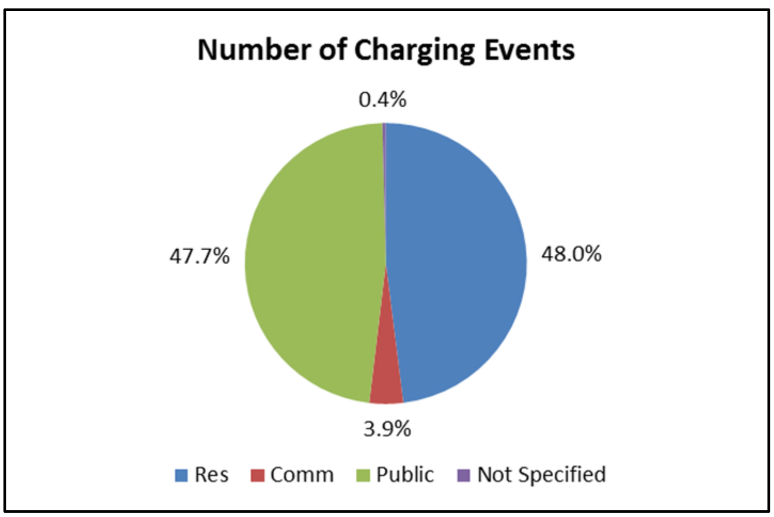


Figure 6-13. Percentage of charging events during the October to December 2013 reporting period.

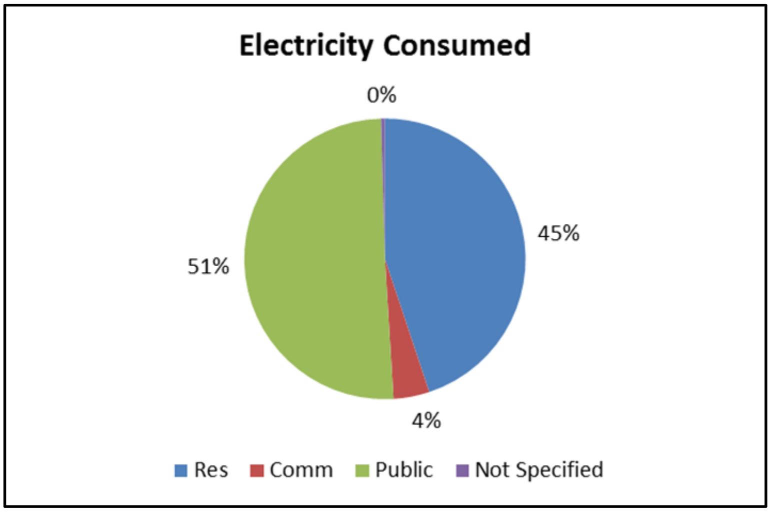


Figure 6-14. Percentage of electricity consumed during the October to December 2013 reporting period.

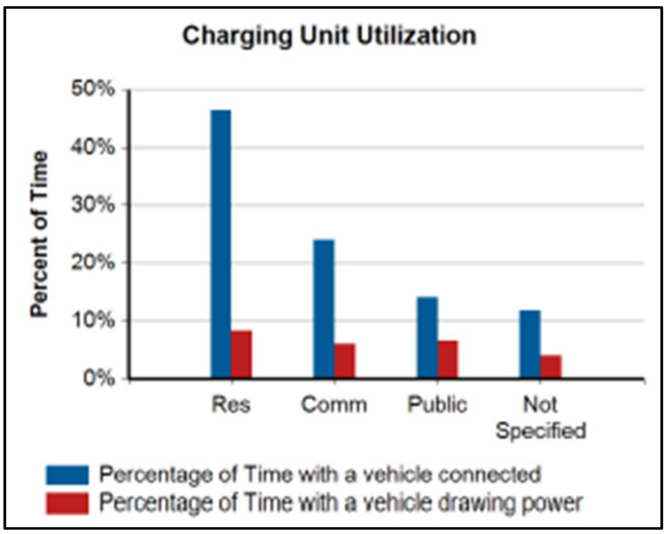


Figure 6-15. Percentage of time EVSE had a vehicle connected and drawing power.

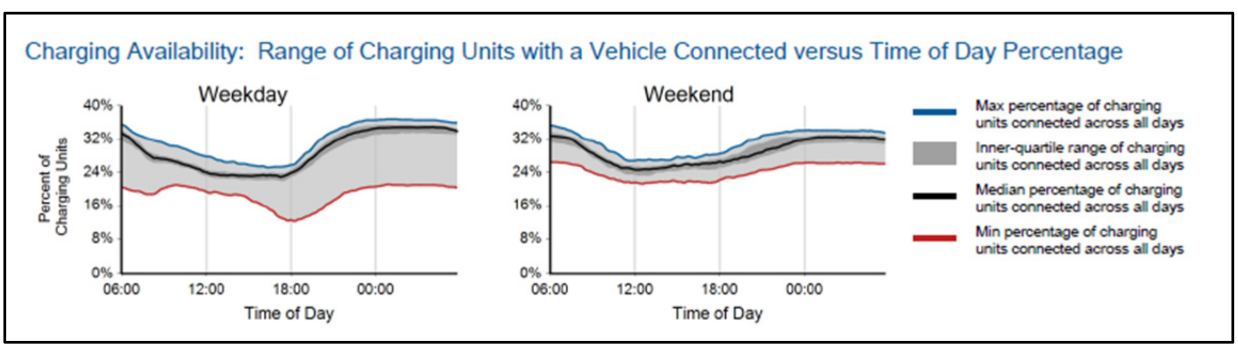


Figure 6-16. The two graphs show, by time of day, the percentage of all EVSE with a vehicle connected to it during the reporting period. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

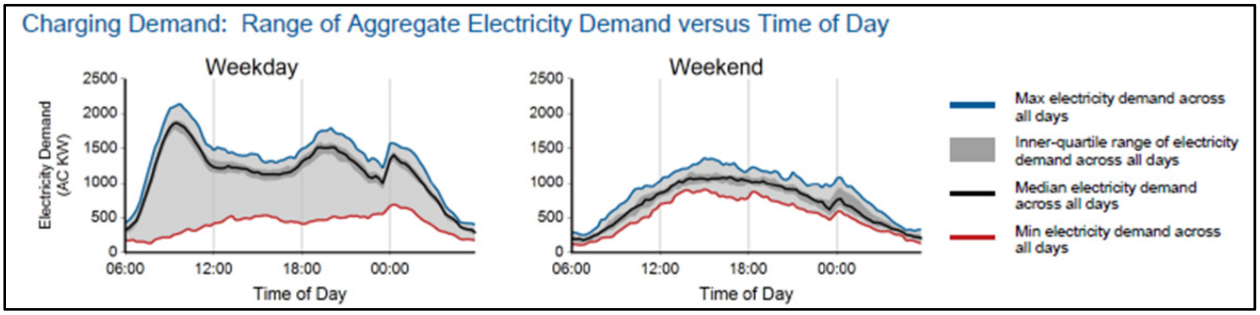


Figure 6-17. The two graphs show the electricity demand at all EVSE by time of day during the reporting period. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

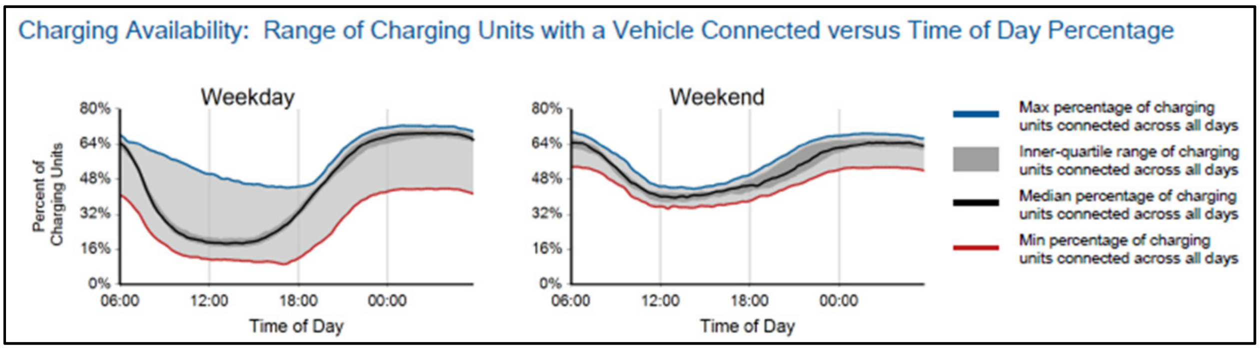


Figure 6-18. The two graphs show, by time of day, the percentage of residential EVSE with a vehicle connected to it during the reporting period. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

Looking at the residential median demand curve for weekdays (Figure 6-19), power demand was as expected given the residential connected curves (Figure 6-18), with demand increasing significantly from about 4 p.m. on. The first peak occurred around 9 p.m. and started to decrease until a little before midnight. At midnight, it peaked again, suggesting that at least some of the EVSE were sited in electric utility territories that offer TOU rates that start at midnight and drivers were aware of this and set their vehicles or EVSE to take advantage of the reduced TOU rates. Demand increased significantly during evening hours when many utilities experienced peak demand. However, given high connectivity after midnight, there were opportunities to shift demand later in the night as seen with the TOU ranges in this project and The EV Project.

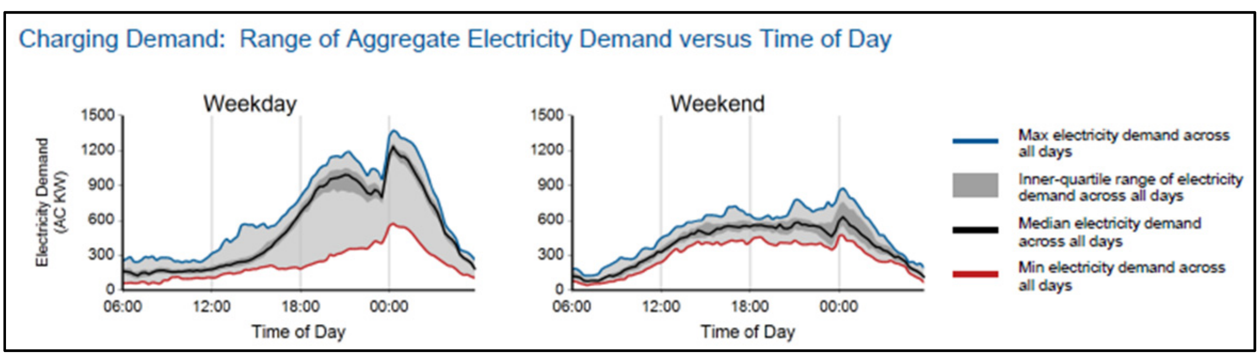


Figure 6-19. The two graphs show the electricity demand at residential EVSE by time of day during the reporting period. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

Private commercial EVSE connect times were extremely flat (median line) on weekends (Figure 6-20), suggesting fleet vehicles were connected to about 23% of the EVSE. During the weekday, connect times (Figure 6-20) bumped up, starting around 7 a.m. and returned to the approximate 23% rate after 6 p.m. This suggests that either vehicles that used these EVSE may have been vehicles driven to work and charged there or general public visitors charged at the private commercial EVSE during the day (although this was probably not as likely as the first scenario).

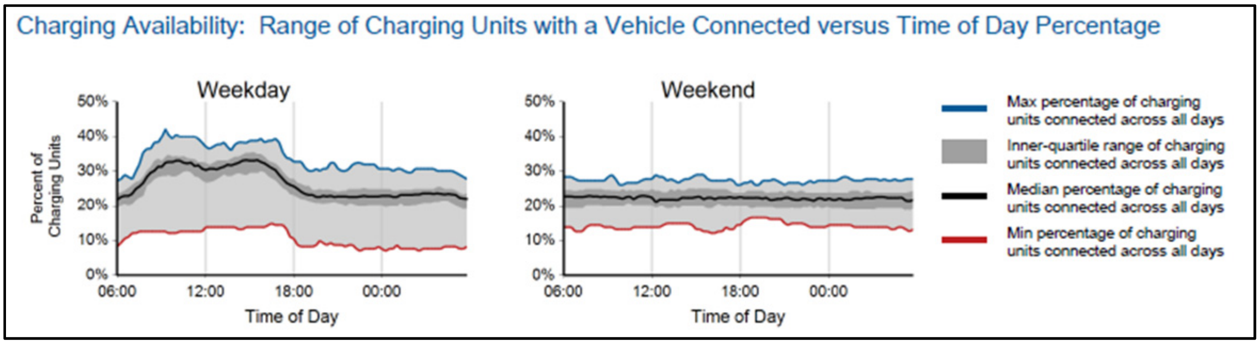


Figure 6-20. The two graphs show, by time of day, the percent of private commercial EVSE with a vehicle connected to it during the reporting period. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

While a significant rise in demand on weekdays at the private commercial EVSE (Figure 6-21) appears dramatic (and it is considering how much it rises from near zero at 6 p.m.), it should be viewed in context of the graph scale. The peak demand on any one day (i.e., blue line) appears to have maxed out at about 170 kW, which is still fairly low for the 174 private commercial EVSE providing data.

The weekday connect curve (Figure 6-22) for public EVSE suggests that workers may have used EVSE to support driving of PEVs to work because the curves were so different for the weekdays and weekends, with weekdays being more representative of traditional work days for the demographics of many PEV drivers. Some errand running or shopping may have been connected with the daytime rise in weekday connect times.

The public EVSE demand curve (Figure 6-23) followed the connect curve for public EVSE (Figure 6-22), which would be expected. Given the demand profile, this suggests that peak demand would be around 9 a.m., which is not an atypical time to arrive at work. Of course, this may also have resulted from PEV drivers having arrived at other locations with public EVSE and plugging in, such as at shopping malls, health clubs, libraries, or city centers.

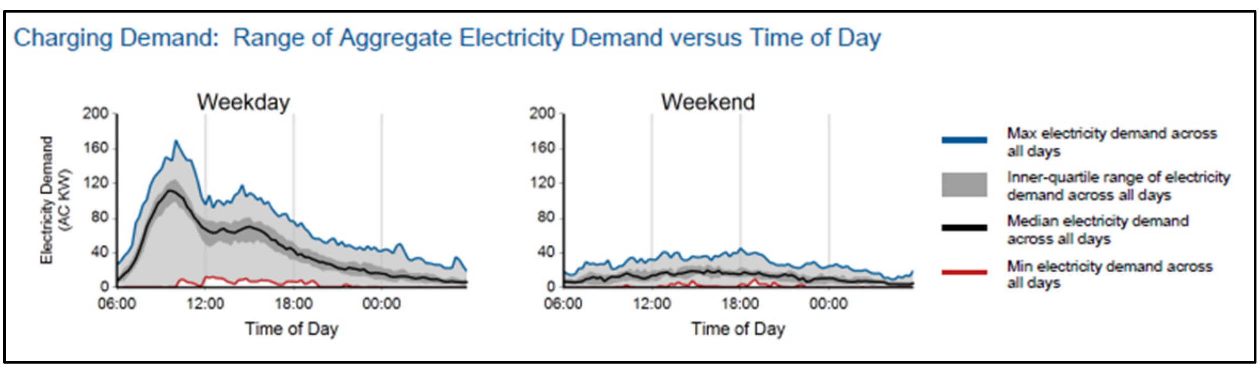


Figure 6-21. The two graphs show electricity demand at private commercial EVSE by time of day during the reporting period. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

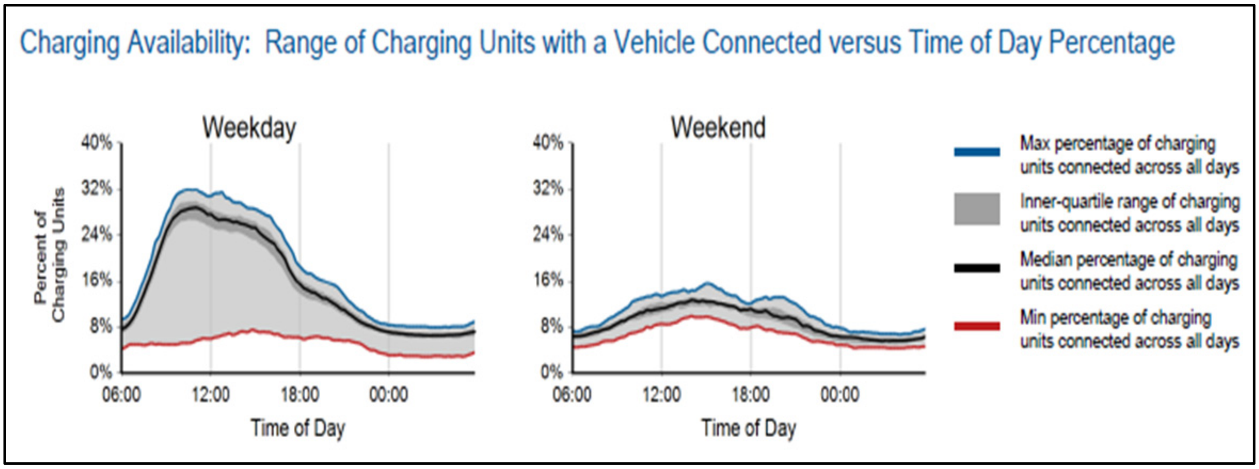


Figure 6-22. The two graphs show, by time of day, the percent of public EVSE with a vehicle connected during the reporting period. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

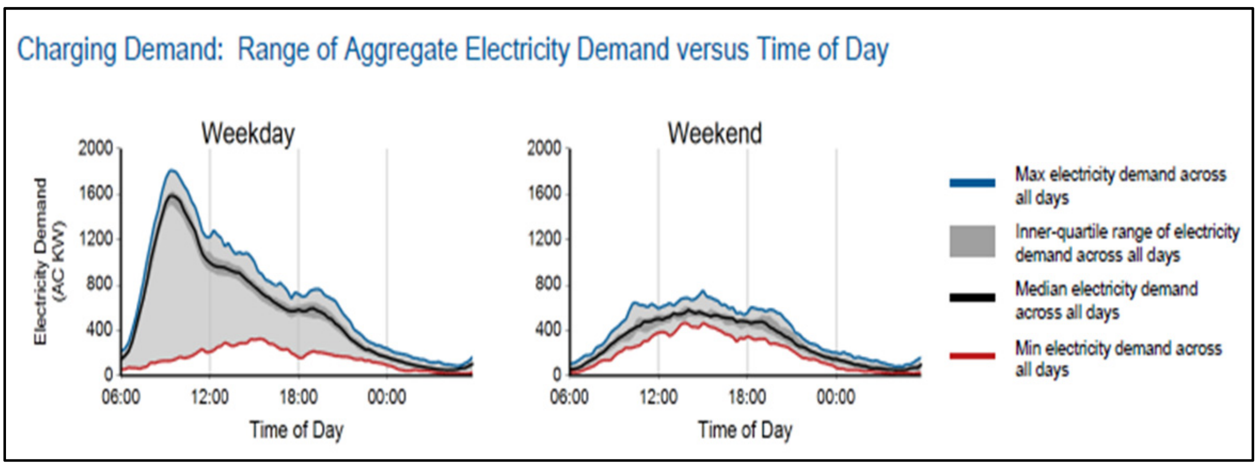


Figure 6-23. The two graphs show electricity demand at public EVSE by the time of day during the reporting period. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

Figures 6-24 and 6-25 document the length of time vehicles were connected to residential and public EVSE. Residential EVSE had a significant number of charge events with a vehicle connected for a long period of time (greater than 20 hours), while public EVSE mostly experienced much shorter connection times. The distributions of length of time a vehicle drew power were fairly similar, with almost all charging events less than 6 hours. Given that most PEVs charge at 3.3 or 6.6-kW rates, one would assume the battery packs would have been completely charged within this period of time. However, it is possible that the PEVs that charged may have included Tesla BEVs, which could have had a battery pack as large as 85 kWh. Observing the amounts of energy transferred per charge event (Figures 6-26 and 6-27), it would be reasonable to suggest that these vehicles were either Leaf or Volt drivers who drove their vehicles to very low SOCs or some of the vehicles were Tesla or other BEVs with large battery packs, which would also explain the long periods of time that some vehicles were drawing power from the EVSE.

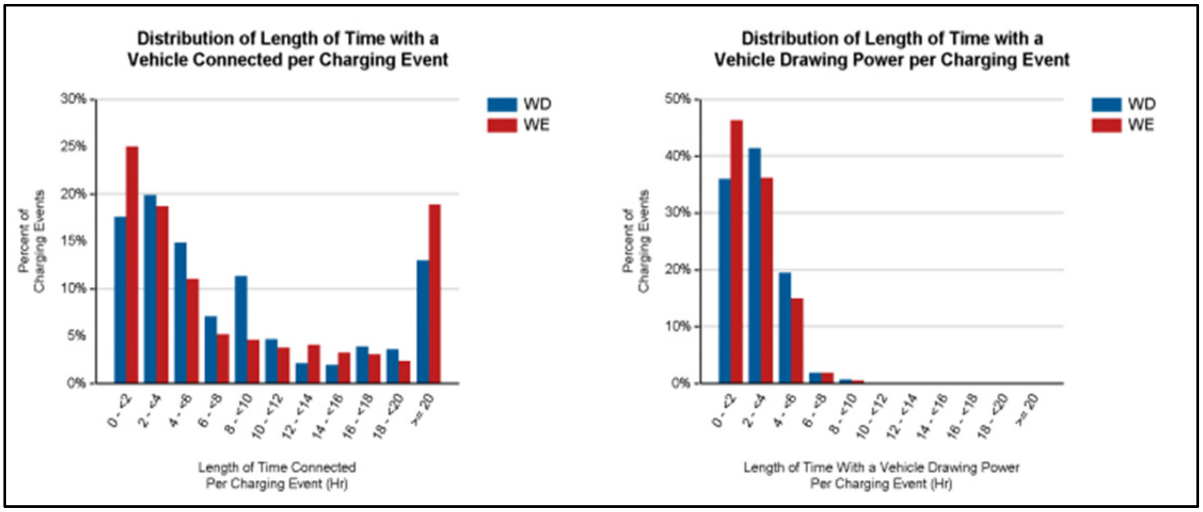


Figure 6-24. Residential EVSE length of time a vehicle was connected and drawing power.

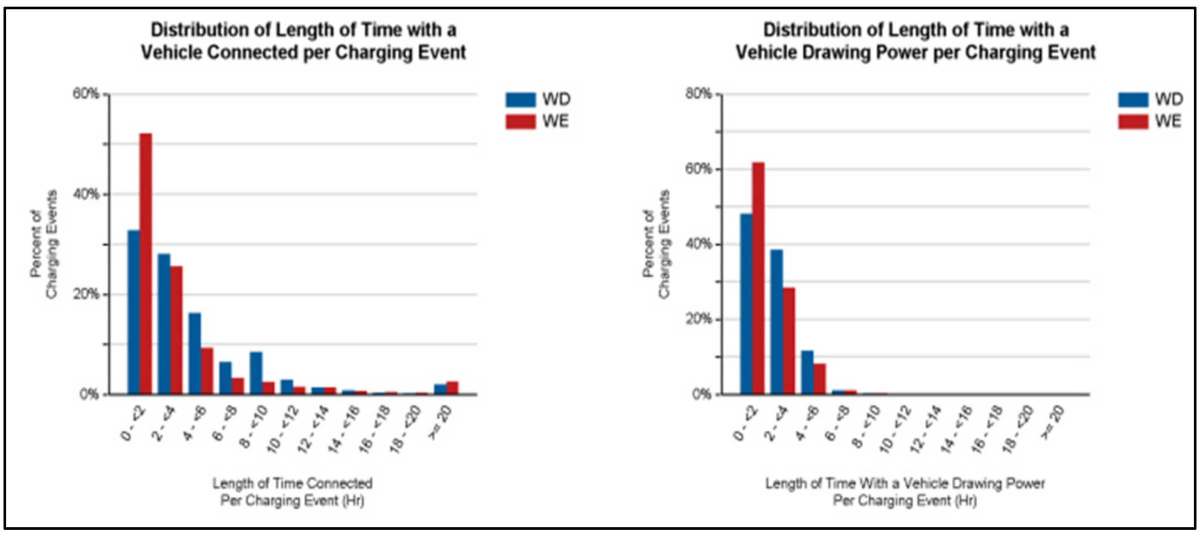


Figure 6-25. Public EVSE length of time a vehicle was connected and drawing power.

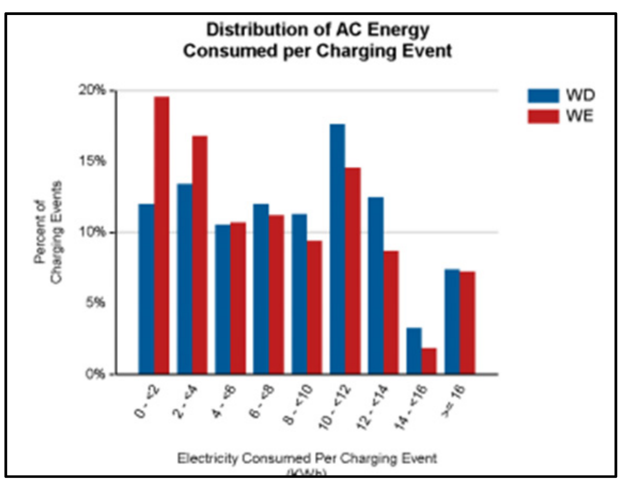


Figure 6-26. Energy transferred per charge event at residential EVSE.

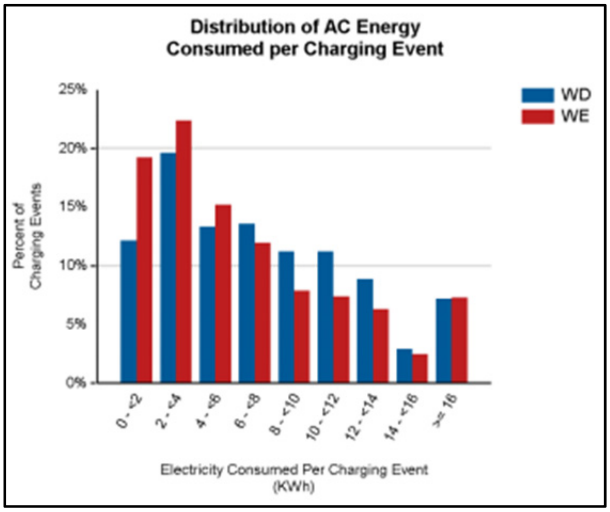


Figure 6-27. Energy transferred per charge event at public EVSE.

6.6 ChargePoint America Project Summary

INL's reporting of EVSE use that was part of the ChargePoint America Project occurred from May 2011 through December 2013. During the approximate 2.5 years of data collection, 4,647 EVSE were used for 1,823,470 charge events or about 400 charge events per EVSE.

ChargePoint America Project EVSE data were combined with EVSE data from Blink's ARRA EV Project and AeroVironment's deployment of EVSE data. This larger set of EVSE use patterns enabled a more valuable analysis about the best sites for EVSE placement in order to maximize use of future EVSE. This required a significant effort to characterize a single set of definitions and venues for more than 5,600 public EVSE. The results of this work and the popularity (as measured by high and low use rates) of the public EVSE is discussed in another section of this report.

The specifics of the revenue model were not known; therefore, any impact that the imposition of costs may have had on EVSE usage was unknown. However, it is believed that about 70% of the public EVSE in the ChargePoint America Project were free to drivers needing a charge and EVSE hosts were the ones that decided if a revenue model would be used.

7. U.S. DEPARTMENT OF ENERGY/GENERAL MOTORS CHEVROLET VOLT DEMONSTRATION

7.1 U.S. Department of Energy/General Motors Volt Demonstration Scope and Objectives

General Motors deployed a total of 150 EREV Volts (Figure 7-1). The project goal was to evaluate the use of advanced EREV technology by commercial fleet drivers and how they utilized charging infrastructure in order to take maximum advantage of the technology to reduce petroleum consumption. The DOE/GM Chevrolet Volt Demonstration Project was one of five ARRA projects that INL collected data for, with the first reporting period being May to June 2011. The electric utility fleet partners included the following:

- Austin Energy
- DTE Energy
- Dominion Energy
- Duke Energy
- PG&E
- Pepco
- Southern California Edison
- Sacramento Municipal Utility District
- EPRI.

Figure 7-1. Chevy Volt.

In addition to the partner organization fleets listed above, an additional 26 electric utilities (Figure 7-2) also participated in the project as they received vehicles through EPRI's participation. Each participant fleet received at least one Chevy Volt for use in their commercial fleets. OnStar was also a partner in this project because OnStar provided the Volt operations and charging data to INL. In addition to the public reports, INL generated many reports internal to OnStar, GM, and their fleet partners.

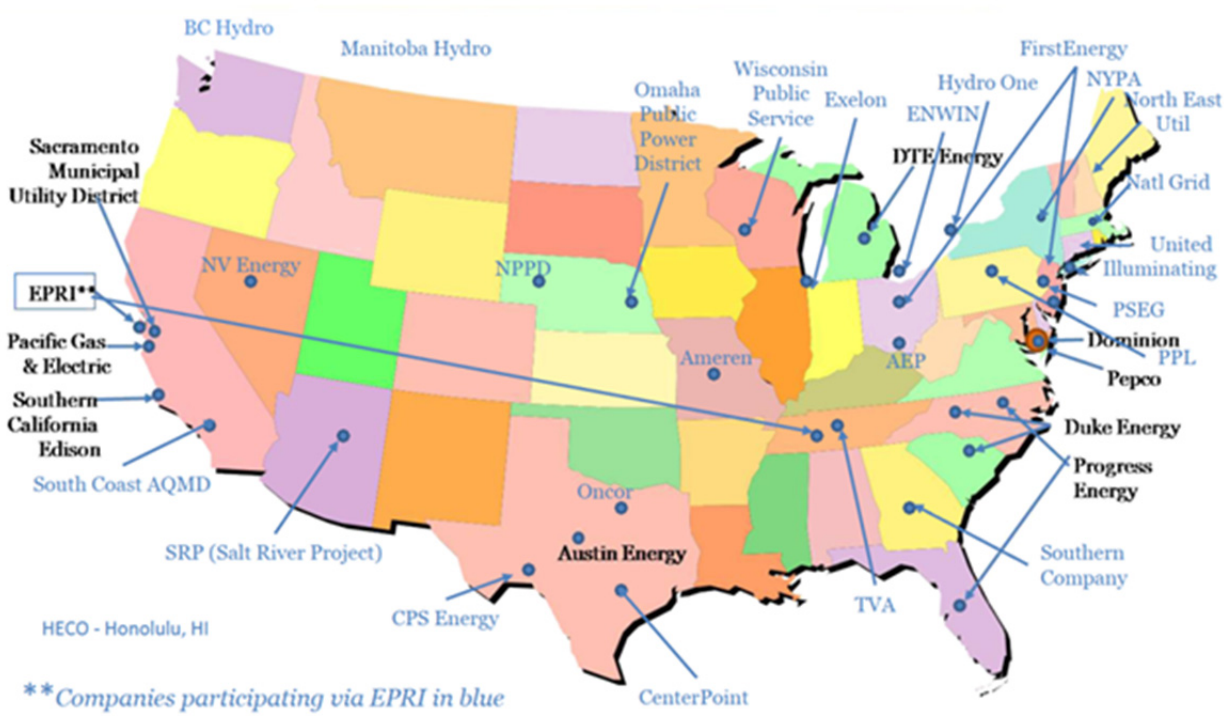


Figure 7-2. Locations of the Chevy Volt Project partners (black bold font) and the addional 26 utility partners (light blue font).

7.2 U.S. Department of Energy/General Motors Volt Demonstration Electric Vehicle Supply Equipment Types

This project did not have an EVSE deployment or EVSE data collection activity associated with it. The only way the Volt could be charged was from AC Level 2 (208 to 240 V) EVSE or AC Level 1 (110 to 120 V) EVSE (i.e., standard household or commercial receptacles). It should be noted that OnStar did provide vehicle-collected charging data to INL.

7.3 U.S. Department of Energy/General Motors Volt Features

The 2011 Chevrolet Volt is a compact class-sized vehicle with four sitting positions. The electric motor is liquid cooled, with maximum power (torque) of 111 kW (370 Nm). The generator is also liquid cooled, with maximum power of 55 kW (200 Nm) and maximum generator speed of 6,000 rpm. The traction battery is of a lithium-ion design, manufactured by LG Chem, with a rated pack energy of 16 kWh. The Volt's gasoline engine has a displacement of 1.4 liters and an output of 63 kW. A complete list of the Volt's specifications can be found at http://avt.inel.gov/pdf/EREV/fact2011chevroletvolt.pdf. The testing report found at this link is not a project of the DOE/Volt demonstration being discussed in this report.

The Volt is an all-electric-capable PHEV, also referred to as an EREV. As its name suggests, it is capable of operating as a pure EV while in CD mode (i.e., energy in the traction battery pack), regardless of the driver's power demand. When operating in this mode, the Volt is essentially operating as a pure BEV. In this BEV operating mode, the Volt is also referred to as being in EVM. All of its accessories, including the climate control system, are capable of operating without running the ICE in non-extreme temperature environments. Because there is always an exception to every statement, there are environmental situations where the ICE will start to supply climate comfort. Depending on the vehicle's features and settings, the gasoline ICE engine will start at a point below 30°F in order to heat the cabin and defroster.

To operate the vehicle in EVM, the Volt's 16-kWh battery pack must be charged from the electric grid. As the vehicle is driven and its battery pack is depleted below a certain SOC, it transitions to ERM. When in ERM, the ICE cycles on and off to drive an onboard generator, which charges the battery and provides electricity for other vehicle systems. In ERM, the Volt can be thought of as operating like a traditional hybrid EV.

7.4 U.S. Department of Energy/General Motors Volt Demonstration Deployment and Data Collection Rate

INL started receiving driving and charging data from OnStar for 66 Chevrolet Volts during the May to June 2011 reporting period. With the exception of the first report, which only covered 2 months, each of the 12 quarterly reports was of 3-month durations. This project ended with the final data set received by INL for the January to March 2014 quarter. A total of 150 Volts reported data to INL by the end of the project; however, the maximum number of Volts reporting data for any reporting period was 146 vehicles (Figure 7-3). It was typical that not all vehicles reported data each month for various reasons (such as partners deciding to withdraw from a project or vehicles being involved in collisions). This is a very common experience for a project of this type and magnitude.

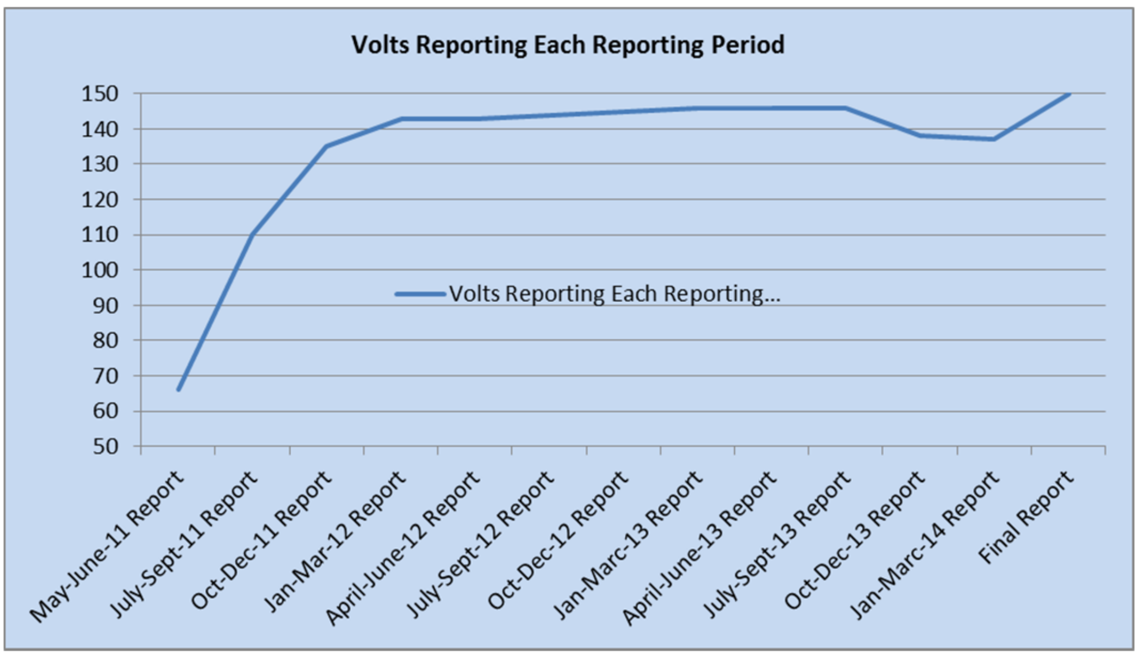


Figure 7-3. Number of Volts reporting data to INL during each reporting period.

The miles accumulated for each reporting period can be seen in Figure 7-4. The amount of EVM miles driven stayed fairly close to the ERM miles driven per reporting period. It may be worth reminding readers that the 150 Volts were in commercial fleets and it appears the drivers either may not have been as enthusiastic about maximizing eVMT as the public drivers in The EV Project or they simply had work missions that did not allow as many eVMT due to their inability to charge during the work day or their driving missions may simply have been significantly longer than the battery pack capacity.

As INL has found with many field demonstrations, including this project, past month's data are sometimes backfilled when another period of data arrives. Instead of potentially having several different copies of the same quarterly report, a conscious decision was made to not rerun past reports and to wait for the summary report to use all backfilled data. The differences in total miles were low and the differences in actual results, such as watt-hours per mile, and trip distance results were near non-existent.

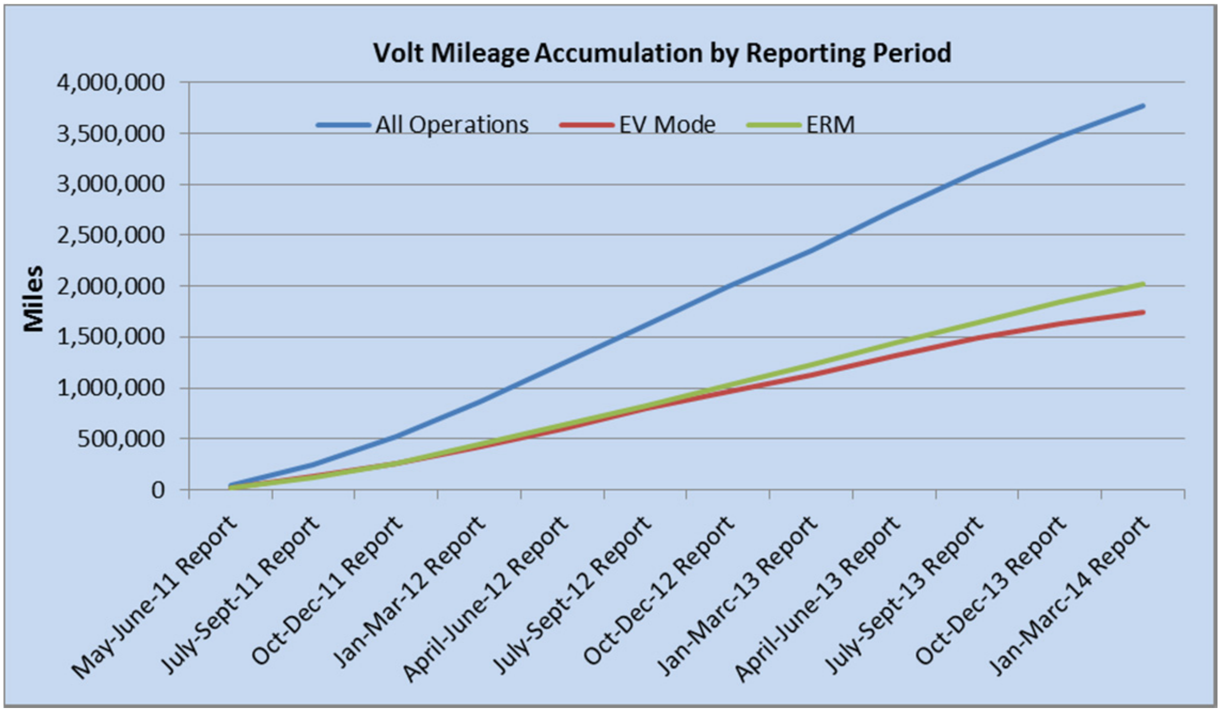


Figure 7-4. Volt Demonstration Project mileage accumulation by report period and operating mode. Note that All Operations contains the sum of EVM and ERM modes.

Volt data were collected via the OnStar telematics system and were transferred from OnStar servers to INL servers.

7.5 U.S. Department of Energy/General Motors Volt Demonstration Reporting

The primary public reporting method was via 12 quarterly reports and the final report, which documented data collection results for all fleets during each respective reporting period. The reports included the following parameters. Note that vehicle performance is reported in the categories of All Operation (combined EVM and ERM), EVM Operation, and ERM Operation. The parameters in the three main categories of operations are as follows:

- All Operation
  - Overall gasoline fuel economy (mpg)
  - Overall AC electrical energy consumption (AC Wh/mi)
  - Average trip distance
  - Total distance traveled (miles)
  - Average ambient temperature (degrees F)
- EVM Operation
  - Gasoline fuel economy (mpg)
  - AC electrical energy consumption (AC Wh/mi)
  - Distance traveled (miles)

- Percent of total distance traveled
- Average driving style efficiency (distance weighted)

- ERM Operation
  - Gasoline fuel economy (mpg)
  - AC electrical energy consumption (AC Wh/mi)
  - Distance traveled (miles)
  - Percent of total distance traveled
  - Average driving style efficiency (distance weighted).

Additional information provided documented differences between operational modes and how drivers operated the Volts. Both tables and graphs were used to highlight the results. The parameters include the following:

- The following parameters were given for city and highway driving:
  - Percent of miles in EV operation (%)
  - Percent number of trips
  - Average trip distance (miles)
  - Average driving style efficiency (distance weighted)
- Graphed data included the following:
  - Percent distance driven for each driving style efficiency
  - Fuel economy and electric consumption by operating mode
  - Percent distance traveled by operating mode (EVM/ERM)
  - Percent distance traveled by route type (city/highway)
  - Distribution of average ambient temperatures
  - Time of day when driving
  - Time of day when charging
  - Battery SOC at end of charging prior to driving
  - Battery SOC at end of drive prior to plugging in.
- The final set of parameters documents charging information and includes the following:
  - Average number of charging events per vehicle month
  - Average number of charging events per vehicle day
  - Average distance between charging events (miles)
  - Average number of trips between charging events
  - Average time charging per charging event (hour)
  - Average energy per charging event (AC kWh)
  - Average charging energy per vehicle month (AC kWh)
  - Total charging energy (AC kWh).

7.6 U.S. Department of Energy/General Motors Volt Demonstration Results

Over the entire data collection period (total of 66,572 days of driving), the 150 Volt fleet average fuel economy was 67.5 mpg and overall AC electrical energy consumption was 167 AC Wh/mile. Over the entire data collection period, the AC electrical energy consumption, when operating in EVM, was 358 AC

Wh/mile. The gasoline fuel economy when operating in ERM was 36.1 mpg. The fleet summary metrics are shown in Figure 7-5.

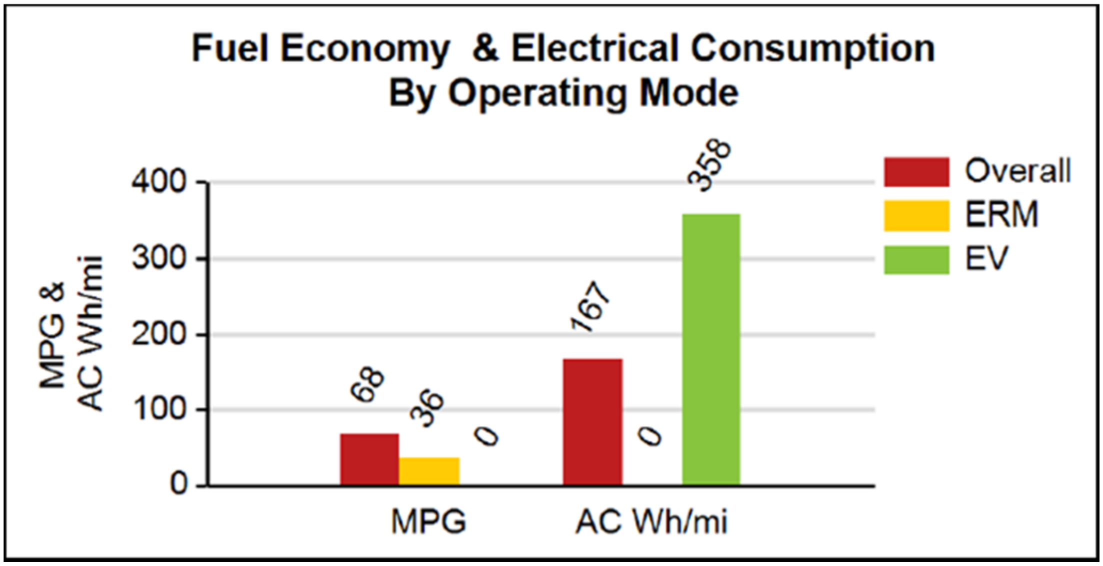


Figure 7-5. Overall fleet fuel economy and electrical energy consumption.

In order to better understand how the fleet of vehicles were operated given the two operating modes (i.e., EVM and ERM), a histogram was created to help visualize the distribution of distance traveled in each operating mode for a given total trip distance. Figure 7-6 shows the percentage of total distance traveled for both EVM and ERM across various trip distances for the entire fleet of 150 Volts during the entire data collection period. The majority of miles driven in EVM were primarily of trip distances less than 50 miles, with the largest percentage of total distance traveled during trips of 10 to 20 miles in duration. Miles driven in ERM are more evenly distributed across all trip distances. The largest percentage of total distance traveled in ERM occurred for trip distances greater than or equal to 100 miles.

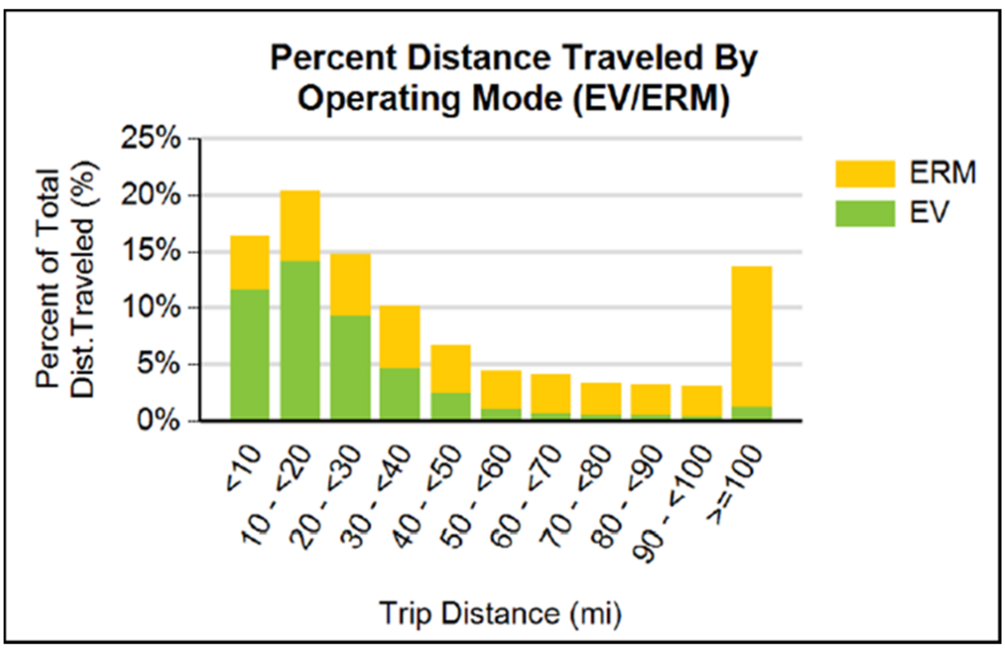


Figure 7-6. Percent distance traveled in each operating mode.

During real-world, on-road operation of the 150 Chevrolet Volts, the vehicles were used for a wide variety of purposes, across a wide range of driving routes and geographical areas. As previously mentioned, these routes were characterized into two categories: (1) city routes and (2) highway routes. This was done in order to better understand and visualize vehicle utilization. Predominately, the city driving routes had lower average vehicle speed with multiple stops per mile, whereas the highway driving routes had a higher average vehicle speed with minimal stops per mile. Figure 7-7 shows the percentage of total distance traveled for both city driving and highway driving for the entire fleet of 150 Volts for the entire data collection period. The majority of the city route trip distances were less than 30 miles. In contrast, the highway trips were more evenly distributed across trip distances, except for trip distances greater than 100 miles and less than 10 miles. Those equal to or greater than 100 miles were significantly the largest percentage of total distance traveled for highway driving routes.

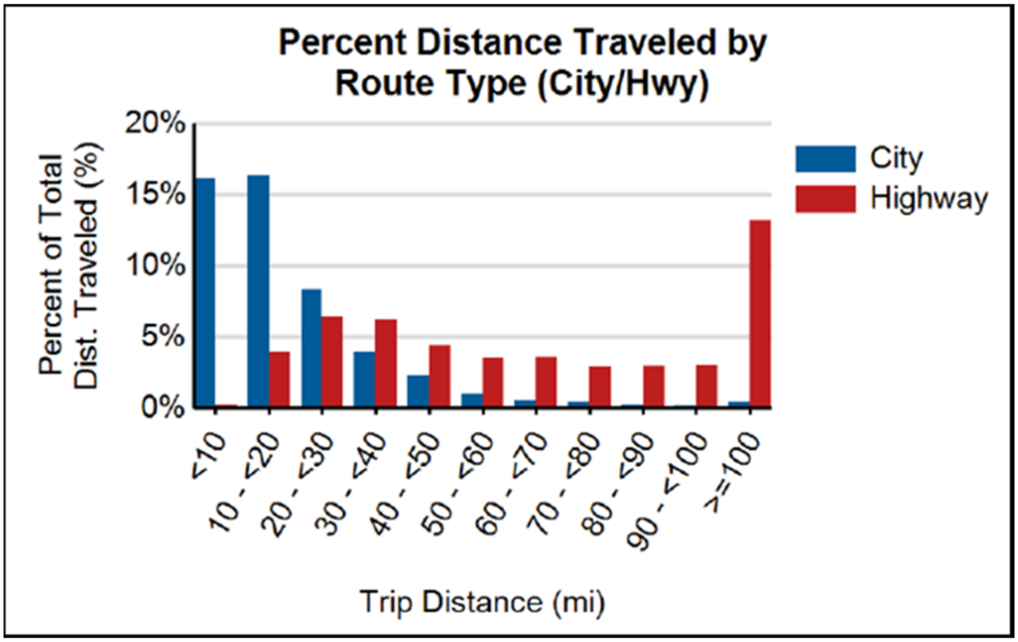


Figure 7-7. Percent distance traveled for city or highway routes.

During driving, the Volt calculated driving style efficiency based on many parameters (e.g., acceleration, vehicle speed, accessory utilization, and other factors). This driving style efficiency impacted electrical energy consumption and fuel economy of the vehicle. The higher the driving style efficiency, the better the fuel economy and electrical energy consumption. In order to understand and characterize the fleets' driving style efficiency in both EVM and ERM, a histogram was created. Figure 7-8 shows the percentage of total distance traveled versus driving style efficiency for both EVM and ERM, for the entire fleet of 150 Volts, for the entire data collection period. The average driving style efficiency for the EVM and ERM were 78% and 77%, respectively. The distribution for EVM operation had a slightly wider spread than for ERM. Also, the mode (i.e., most frequent occurrence) for EVM operation occurred between 90 and 100% driving style efficiency, whereas the mode for ERM operation occurs between 80 and 90% driving style efficiency.

For grid-connected vehicles, like the Volt, it is important to understand the driving patterns and charging patterns. For the fleet of 150 Volts, the time of day when driving and charging occurred was analyzed and are shown in Figures 7-9 and 7-10, respectively.

Figure 7-11 shows the SOC of the battery pack at the end of driving prior to plugging in. Nearly half of these drive events ended with a battery SOC less than 10%, which indicates there was little to no energy remaining in the battery pack. Figure 7-12 shows the SOC of the battery pack at the end of charging prior to driving. Over 80% of these charge events ended with a full battery pack (i.e., greater than or equal to 90% SOC), which indicates that the vehicle would have had the opportunity to maximize eVMT because energy stored in the battery pack was near maximized.

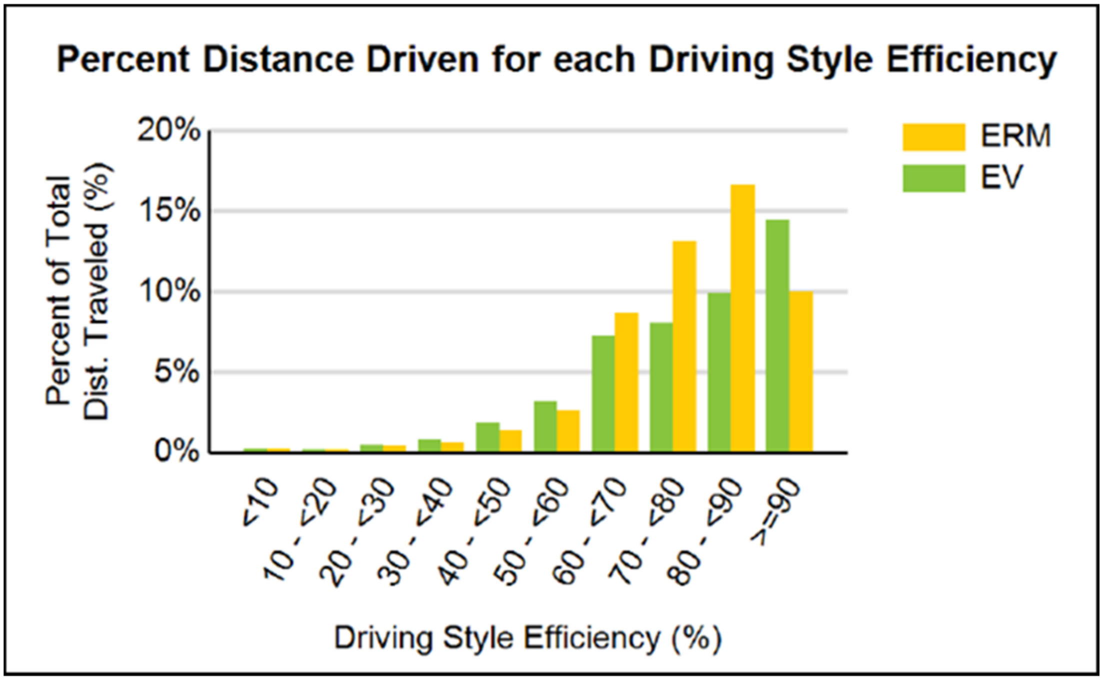


Figure 7-8. Percent distance traveled for each driving style efficiency.

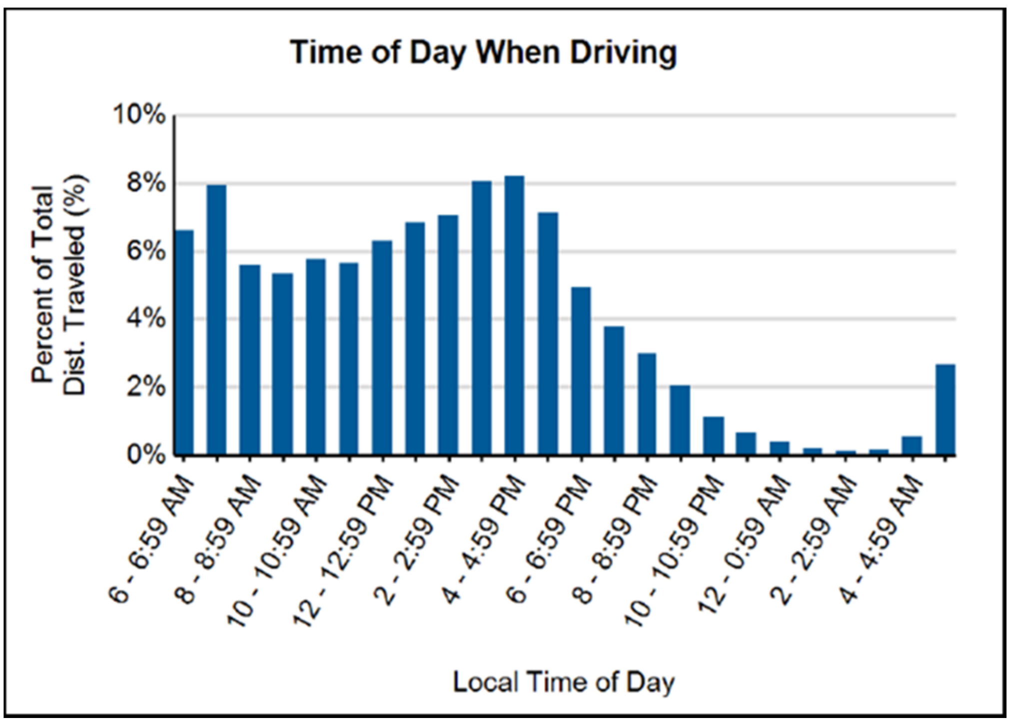


Figure 7-9. Percent distance traveled versus time of day when driving.

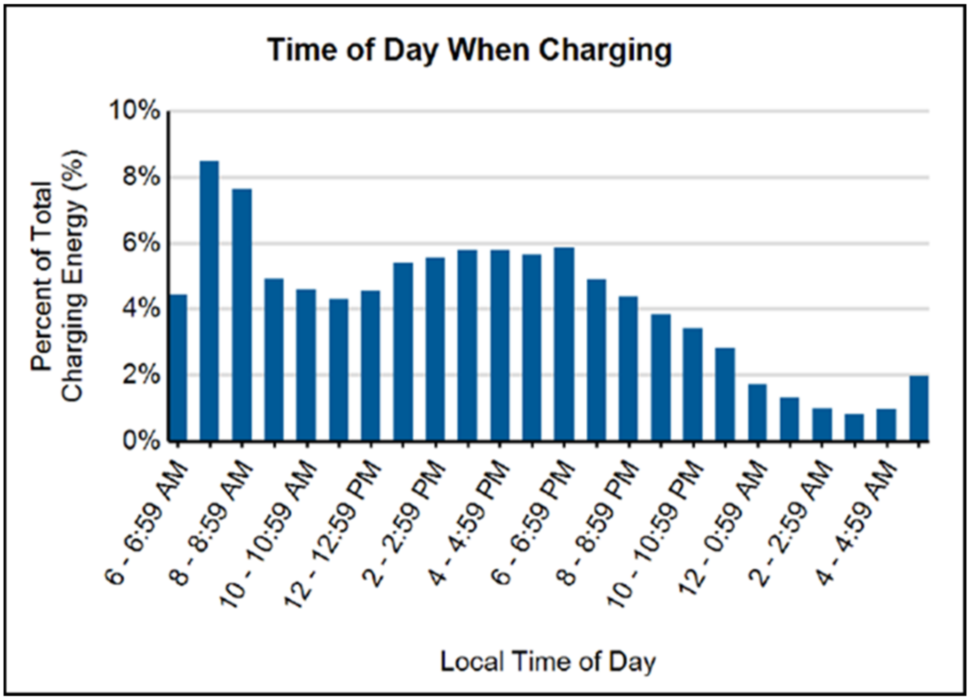


Figure7-10. Percent of electrical energy delivered versus time of day when charging.

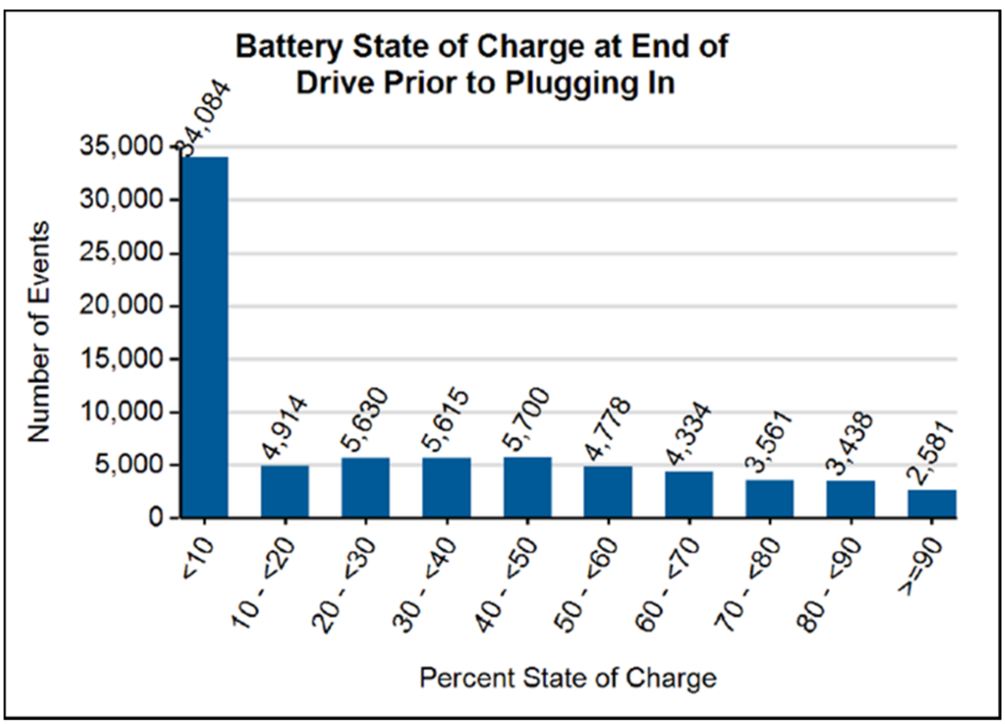


Figure 7-11. Distribution of battery SOC at the end of driving prior to plugging in.

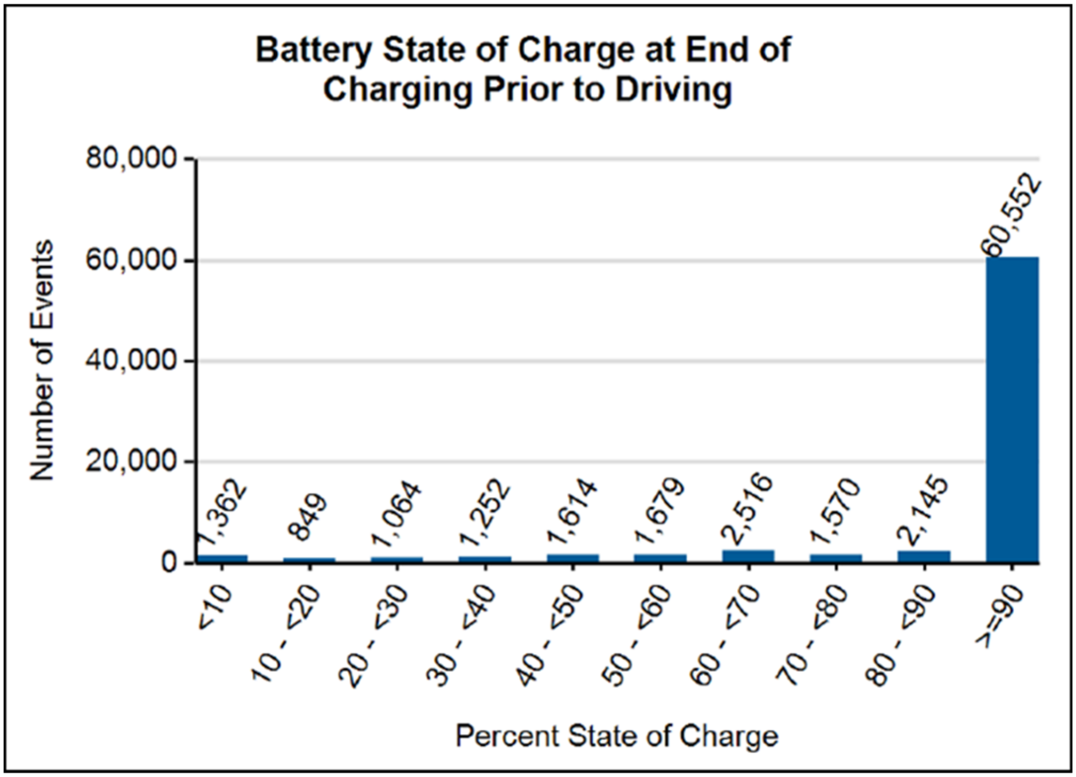


Figure 7-12. Distribution of battery SOC at the end of charging prior to driving.

Throughout the data collection period, additional analysis was conducted to determine other metrics (e.g., percentage of total driving distance in EVM and ERM and fleet average driving distance between charge events). Figure 7-13 shows the correlation between fleet average driving distance between charge events and percentage of total distance traveled in EVM over the duration of the entire data collection period. Near the beginning of the data collection period for the 150 Volts, the fleet average driving distance between charge events was less than 40 miles and the percent of total distance traveled in EVM was greater than 50%. As the demonstration progressed, driving and charging use of the vehicle changed. By the end of the data collection period, the fleet average driving distance between charge events was greater than 50 miles and the percent of total distance traveled in EVM was less than 40%. This shows a correlation between the percentage of total distance traveled in EVM and the driving distance between charge events. Decreasing the fleet average driving distance between charge events can increase the percent of total distance traveled in EVM, which inherently improves fleet petroleum displacement by driving more electric miles.

The data collection period for the fleet of 150 Volts nearly covers 3 years. This enabled analysis of the impact of seasonal ambient temperature variation on vehicle fuel economy and electrical energy consumption. Figure 7-14 shows the quarterly average ambient temperature impact, as averaged on a per vehicle basis, on electrical energy consumption (AC Wh/mi) when driving in EVM and fuel economy (mpg) when driving in ERM. At colder fleet average ambient temperatures (i.e., less than 60°F), a measurable trend shows an increase in electrical energy consumption while driving in EVM and a decrease in fuel economy when driving in ERM. For moderate temperatures (i.e., between 60 and 80°F), there appears to be little to no impact of ambient temperature change on fuel economy or electrical energy consumption.

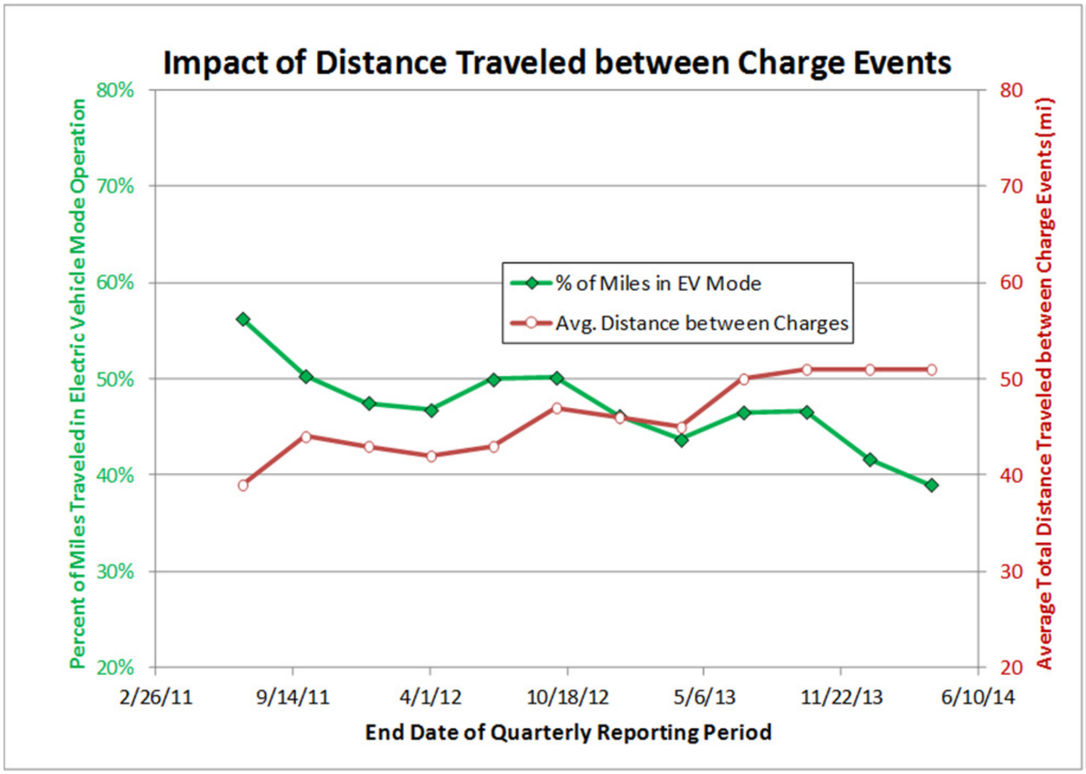


Figure 7-13. Impact of average distance driven between charge events on percent of total miles driven in EVM.

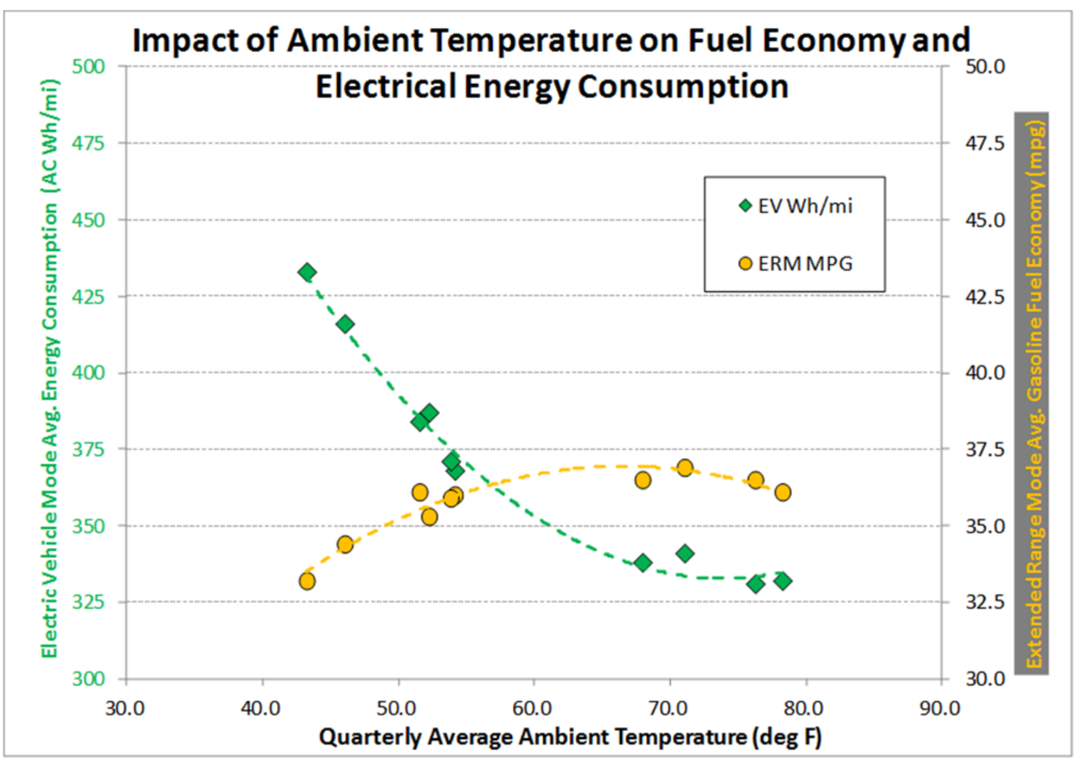


Figure 7-14. Impact of quarterly average ambient temperature on fuel economy in ERM and electrical energy consumption in EVM.

7.7 U.S. Department of Energy/General Motors Volt Demonstration Summary

INL analyzed data from 150 Chevrolet Volts that were collected from May 2011 through March 2014 as part of the ARRA-funded DOE/GM Volt Demonstration Project. Quarterly reports were published at http://avt.inel.gov/gmvehicledemo.shtml, which detailed the vehicle's operational characteristics, fuel economy, electrical energy consumption, driving and charging utilization, driving style efficiency, and ambient temperature profiles. Over the period of data collection, the fleet of 150 Chevrolet Volts accumulated 3.84 million miles over a total of 66,572 days of driving. Over the entire data collection period, the fleet average gasoline fuel economy was 67.5 mpg and overall AC electrical energy consumption was 167 AC Wh/mile. Additional metrics were analyzed to characterize and visualize their impact on fuel economy and electrical energy consumption. These additional metrics include ambient temperature, driving style efficiency, EVM and ERM operation, battery pack SOC utilization, route type, and distance driven between charge events. For an example of the reports generated, see http://avt.inel.gov/gmvehicledemo.shtml, which contains the final fact sheets with the above parameters detailed for the complete project.

Results for the 150 Volts in the vehicle demonstration varied somewhat from the results for the 2,023 Volts in The EV Project. This is discussed in Section 9.

8. CHRYSER RAM PLUG-IN HYRBRID ELECTRIC VEHICLE DEMONSTRATION

8.1 Chrysler Ram Plug-In Hybrid Electric Vehicle Demonstration Scope and Objectives

The first phase of the Chrysler Ram PHEV Demonstration Project required Chrysler to deploy the Rams (Figure 8-1) in a total of 18 fleets in the United States (Figure 8-2). This first phase resulted in 19 quarterly and monthly reports, and one summary report that documented deployment, vehicle performance, and vehicle use from July 2011 through September 2012. A total of 111 Rams provided data to INL during the first demonstration phase. The organizations that operated the Rams in their various fleets during Phase 1 included the following:

- Argonne National Laboratory
- Central Hudson Gas and Electric
- Center Point Energy
- City of Auburn Hills, Michigan
- City and County of San Francisco
- City of Yuma, Arizona
- Chrysler Headquarters
- Colorado Tri-State Generation and Transmission Association
- DTE Energy
- Duke Energy
- EPRI – two locations
- INL
- Massachusetts Bay Transportation Authority
- National Grid
- Nevada Energy – two locations
- New York City Police Department
- Sacramento Municipal Utility District.

Chrysler made the decision to switch battery manufacturers during the second phase of the demonstration and the first monthly report of this phase was generated in November 2013. Phase 2 resulted in 11 monthly reports and one summary report that documented the deployment, vehicle performance, and vehicle use through September 2014. A total of 22 Rams provided data to INL during Phase 2 demonstration. The fleets that operated the Rams were during Phase 2 were as follows:

- Center Point Energy
- Colorado Tri-State Generation and Transmission Association
- DTE Energy
- Duke Energy
- EPRI National Grid

- Sacramento Municipal Utility District.

It should be noted that during both data collection phases, INL also generated many reports internal to Chrysler and their fleet partners. The primary objective of the Chrysler Ram PHEV Demonstration Project included demonstration of PHEV pickup trucks in diverse fleets to understand customer usage.

Figure 8-1. Chrysler Ram PHEV Demonstration Project vehicle.

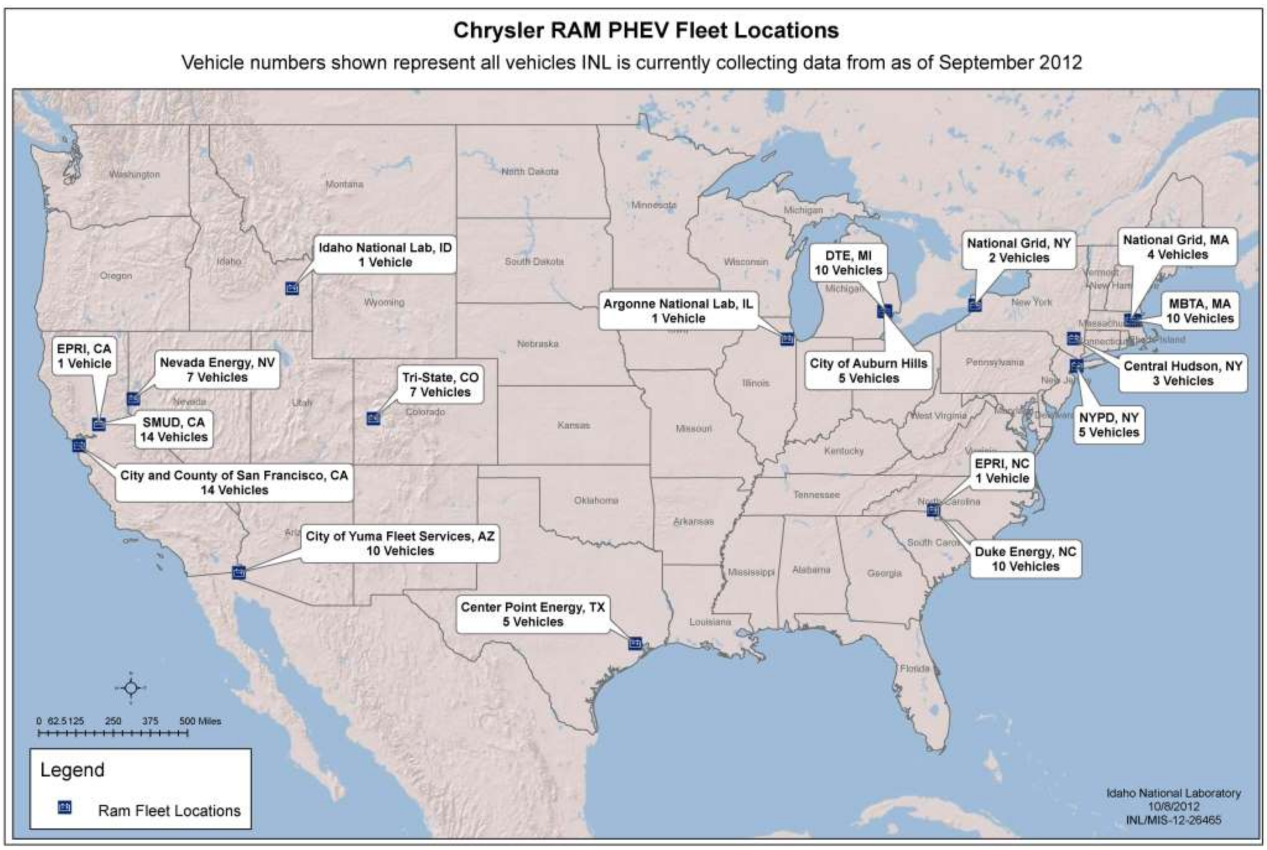


Figure 8-2. Locations of Ram PHEV Demonstration Project fleets during the first demonstration phase.

8.2 Chrysler Ram Plug-In Hybrid Electric Vehicle Demonstration Electric Vehicle Supply Equipment Types

EVSE deployment and data collection were not part of this project, because this project was a vehicle-focused demonstration. However, based on the parameter that identified the voltage going into the Ram's onboard charger, AC Level 1 (110 to 120 V) and AC Level 2 (208 to 240 V) charging events could be segregated and reported on, including energy flows at both levels.

8.3 Chrysler Ram Plug-In Hybrid Electric Vehicle Demonstration Features

The Ram was a blended-mode PHEV, with a two-mode hybrid transmission and two 65-kW electric motors. It also had a 5.7-liter, 345-hp gasoline engine. The Phase 1 battery pack was a 12.9-kWh, liquid-cooled Li-ion battery that could be charged at AC Level 1 or AC Level 2 at a rate up to 6.6 kW via a SAE J1772 connector. The specific capacity of the battery during the Phase 2 deployment is not known.

8.4 Chrysler Ram Plug-In Hybrid Electric Vehicle Demonstration Deployment and Data Collection Rate

8.4.1 Phase 1 Chrysler Ram Deployment and Data Collection Rate

For Phase 1 activities, INL started receiving driving and charging data from Chrysler for 10 Ram PHEVs during the June 2011 reporting period. Both quarterly and monthly reports are available for this project at: http://avt.inl.gov/chryslerram.shtml. A report for June 2012 is not available because the number of miles was very low due to Chrysler updating the vehicle during this month. This phase of the Ram PHEV Project ended with a final data set being received by INL for September 2012. A total of 111 Rams reported data to INL; however, the maximum number during any reporting period was 107 vehicles (Figure 8-3). Not all of the Ram PHEVs reported data each month for various reasons (e.g., partners deciding to withdraw from a project or vehicles being involved in collisions). This is a very common experience for a project of this type.

Data acquisition and downloading was performed via a data logger with a cellular modem. The number of parameters collected and provided to INL was very rich, numbering several dozen.

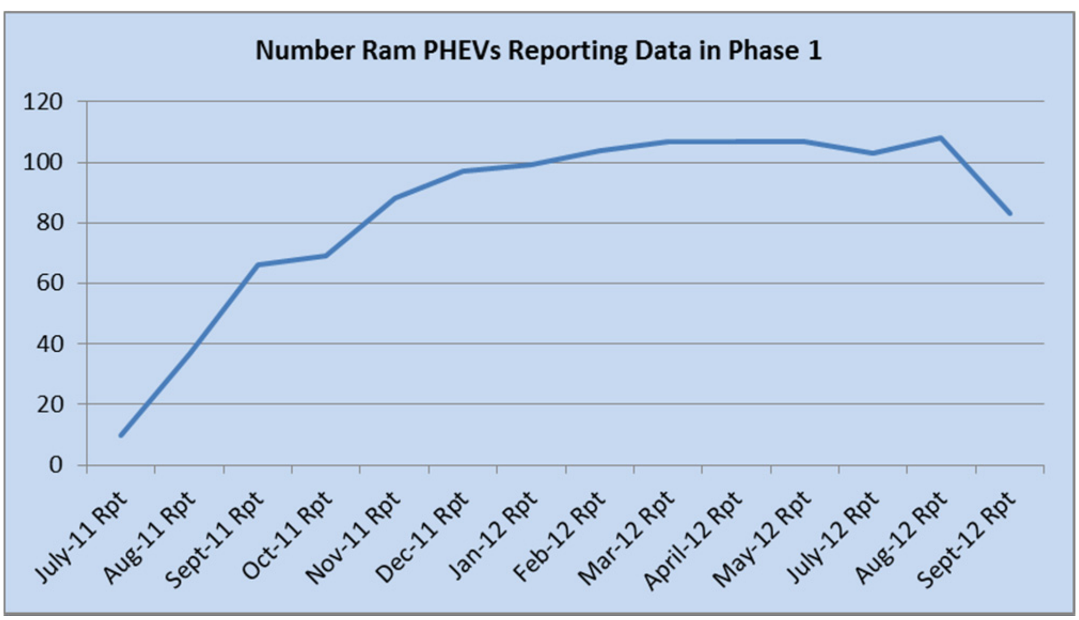


Figure 8-3. Number of Ram PHEVs that reported data to INL during Phase 1.

The miles accumulated per each reporting period can be seen in Figure 8-4. The Ram PHEV operates in several modes and data were reported by each mode and as overall summaries. The modes are as follows, noting that at nominal 0% SOC, there is still some energy in the traction battery with which the vehicle functions as a hybrid:

- Trips in CD mode
  - During these trips, there is energy in the Ram's PHEV traction battery pack and it was being depleted during the entire trip, but it never reaches nominal 0% SOC.
- Trips in both CD/CS mode
  - During these trips, there is energy in the Ram's PHEV traction battery pack at the beginning of the trip, but the Ram's PHEV traction battery pack reaches nominal 0% SOC before the trip was completed. In order to recharge the PHEV traction battery pack, the vehicle had to be connected to the electric grid or some sources of distributed energy.
- Trips in CS mode
  - During these trips, there was no energy (nominal 0% SOC) in the Ram's PHEV traction battery pack at the start of the trip. In order to recharge the PHEV traction battery pack, the vehicle had to be connected to the electric grid or some source of distributed energy.

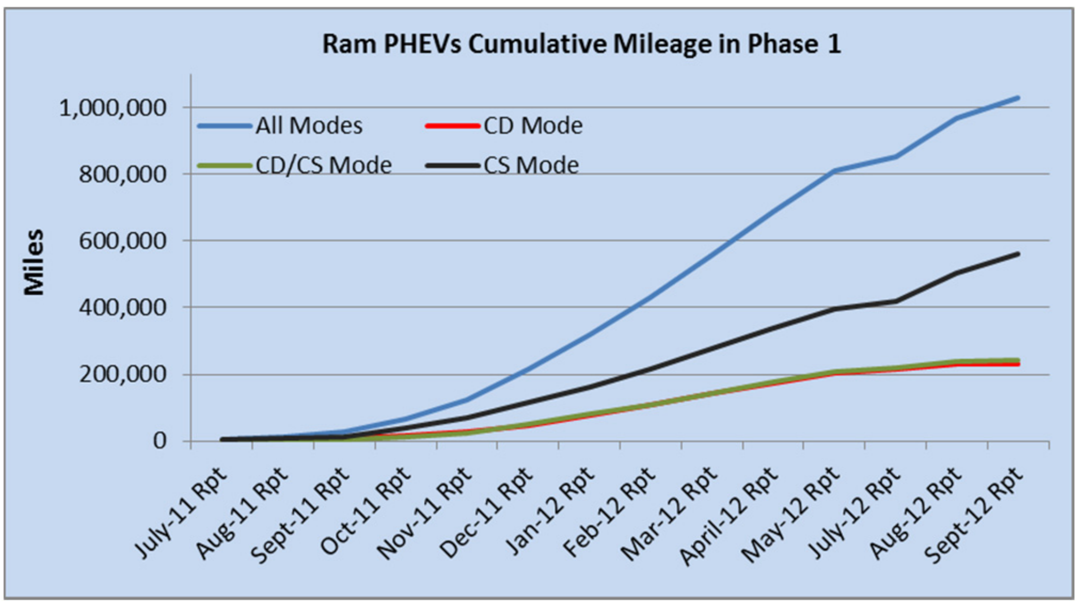


Figure 8-4. Ram PHEV Demonstration Project mileage accumulation by reporting period. Note that "All Modes" was the summary of CD, CD/CS, and CS modes.

The Ram reports also included results for all-trips-combined, which combines and reports the CD, CD/CS, and CS mode data as a summary. Partial- or all-electric advanced vehicle technologies such as the Ram PHEV can be extremely efficient compared to gasoline fueled vehicles. However, they must be charged and charged frequently to maximize the value of their electric propulsion systems. Otherwise, the technologies can appear to not provide any petroleum reduction benefits. Therefore, INL published the results in the different trip modes (i.e., the CD, mixed CD/CS, and CS trip categories) in order to document the petroleum reduction benefits of partial or all-electric drive technologies when drivers charge the vehicles.

In Figure 8-4, it should be noted that the CD and CD/CS lines mostly overlap until the very last months. This is not an indication of correlation. The number of CD trip miles was only 26% of the total miles driven; however, this is not a reflection on the technology. It may be worth reminding readers that the 111 Ram PHEVs in Phase 1were placed in commercial fleets and it appears that the drivers may not have been as enthusiastic as possible about maximizing eVMT, that they simply had work missions that did not allow as many eVMT due to their inability to charge during the work day, or that their driving missions may simply have been significantly longer than the battery pack's capacity.

INL found that with many field demonstrations, including the Ram PHEV Demonstration Project, past months data are sometimes backfilled when another period of data arrives. Instead of potentially having several different copies of the same month's report, a conscious decision was made to not rerun past reports and to wait for the summary report. The differences in total miles if one sums the individual reports and compares it to the summary report were low and the differences in actual results (such as the Wh per mile and trip distance results) were near non-existent.

8.4.2 Phase 2 Chrysler Ram Deployment and Data Collection Rate

As part of the Phase 2 activities, INL started receiving driving and charging data from Chrysler for 11 Ram PHEVs during the November 2013 reporting period. Both quarterly and monthly reports are available for this project at: http://avt.inl.gov/chryslerram.shtml. The final phase of the Ram PHEV project ended with a final data set received at INL for September 2014. A total of 22 Rams reported data to INL (Figure 8-5). It is typical that not all vehicles report data each month for various reasons (e.g., partners deciding to withdraw from a project or vehicles being involved in collisions). This is a very common experience for a project of this type.

As in Phase 1, data acquisition and downloading were performed via a data logger with a cellular modem. The number of parameter collected and provided to INL was very rich, again numbering several dozen.

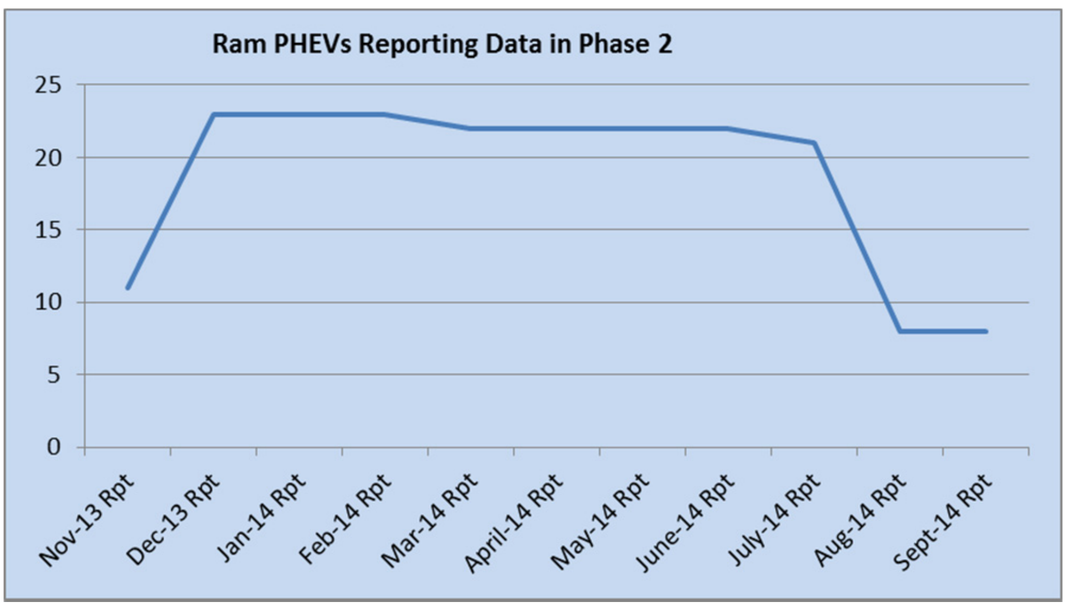


Figure 8-5. Number of Ram PHEVs reporting data to INL during each reporting period.

The miles accumulated for each reporting period can be seen in Figure 8-6. The Ram PHEV operates in several modes and data are reported by each mode and in overall summaries. The modes are as follows, noting that at nominal 0% SOC, there is still some energy in the battery with which the vehicle functions as a hybrid, though the grid energy stored during charging is nominally depleted:

- Trips in CD mode

- During these trips, there is energy in the Ram's PHEV traction battery pack and it is being depleted during the entire trip, but it never reaches nominal 0% SOC.

- Trips in both CD/CS mode
  - During these trips, there is energy in the Ram's PHEV traction battery pack at the beginning of the trip, but the Ram's PHEV traction battery pack reaches nominal 0% SOC before the trip is completed. In order to recharge the PHEV traction battery pack, the vehicle must be connected to the electric grid or some sources of distributed energy.
- Trips in CS mode
  - During these trips, there is no energy (nominal 0% SOC) in the Ram's PHEV traction battery pack at the start of the trip. In order to recharge the PHEV traction battery pack, the vehicle must be connected to the electric grid or some sources of distributed energy.

The Ram reports also include results for all-trips-combined, which combines and reports the CD, CD/CS, and CS mode data as a summary.

The number of CD trip miles was 24% of the total miles driven. However, if the CD portion of miles driven during the CD/CS trips is included, the total distance driven in CD mode rises to 33%. Remember that the 22 Ram PHEVs were operated in most of the same commercial fleets in Phase 1 and it appears that the drivers may not have been as enthusiastic as possible about maximizing electric miles, that they simply had work missions that did not allow as many electric miles due to their inability to charge during the work day, or that their driving missions may simply have been significantly longer than the battery pack's capacity.

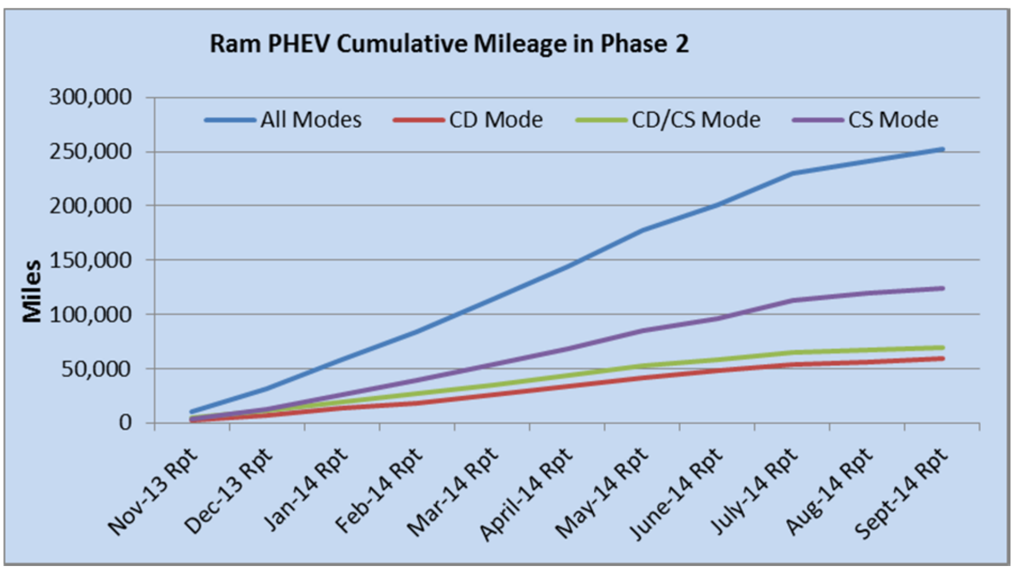


Figure 8-6. Ram PHEV Demonstration Project mileage accumulation by reporting period. Note that "All Modes" is the sum of the CD, CD/CS, and CS modes.

8.5 Chrysler Ram Plug-In Hybrid Electric Vehicle Demonstration Reporting

8.5.1 Phase 1 Chrysler Ram Plug-In Hybrid Electric Vehicle Demonstration Reporting

The primary reporting method was via 19 monthly and quarterly reports and a final summary fact sheet, which documented data collection analysis and results for each respective reporting period. The reports included the following parameters. Vehicle performance was reported in the categories of all trips, CD trips, mixed CD/CS trips, and CS trips. The parameters in the four main categories of operations are listed as follows. Note that these reported results are summaries for both city and highway operations.

- All Trips Combined
  - Overall gasoline fuel economy (mpg)
  - Overall AC electrical energy consumption (AC Wh/mile)
  - Overall DC electrical energy consumption (DC Wh/mile)
  - Overall DC electrical energy captured from regenerative braking (DC Wh/mile)
  - Total number of trips
  - Total distance traveled (miles)
- Trips in CD Mode
  - Gasoline fuel economy (mpg)
  - DC electrical energy consumption (DC Wh/mile)
  - Number of trips
  - Percent of trips city/highway
  - Distance traveled (mile)
  - Percent of total distance traveled
- Trips in both CD/CS Modes
  - Gasoline fuel economy (mpg)
  - DC electrical energy consumption (DC Wh/mile)
  - Number of trips
  - Percent of trips city/highway
  - Distance traveled CD/CS (miles)
  - Percent of total distance traveled CD/CS
- Trips in CS Mode
  - Gasoline fuel economy (mpg)
  - Number of trips
  - Percent of trips city/highway
  - Distance traveled (mile)
  - Percent of total distance traveled.

Additional information was provided that further breaks down Ram performance and was used for CD, CD/CS, and CS trips. This information was provided both for the city and highway portions of the three trip categories. The reported parameters in this section of the fact sheet were as follows:

- Trips in CD Mode
  - Gasoline fuel economy (mpg)
  - DC electrical energy consumption (DC Wh/mile)
  - Percent of miles with ICE off
  - Average trip aggressiveness
  - Average trip distance (miles)
- Trips in CD/CS Mode

- Gasoline fuel economy (mpg)
- DC electrical energy consumption (DC Wh/mile)
- Percent of miles with ICE off
- Average trip aggressiveness
- Average trip distance (miles)

- Trips in CS Mode
  - Gasoline fuel economy (mpg)
  - Percent of miles with ICE off
  - Average trip aggressiveness
  - Average trip distance (miles).

An additional section documented the charging activities and driving behaviors between charge events. The reported parameters included the following:

- Plug-in charging
  - Average number of charging events per vehicle per month when driven
  - Average number of charging events per vehicle per day when driven
  - Average distance driven between charging events (miles)
  - Average number of trips between charging events
  - Average time charging per charging event (hours)
  - Average energy per charging event (AC kWh)
  - Average charging energy per vehicle per month (AC kWh)
  - Total number of charging events
  - Number of charging events at AC Level 1 and AC Level 2
  - Total charging energy consumed (AC kWh)
  - Charging energy consumed at AC Level 1 and AC Level 2 (AC kWh)
  - Percent of total charging energy from AC Level 1 and AC Level 2
  - Average time to charge (in hours) from 20 to 100% SOC at AC Level 1 and AC Level 2.

In addition to the above reported parameters, the fact sheets also documented the number of vehicles and number of vehicle days driven that the data represent, as well as the reporting period. Several graphs were used to bin results and provide comparative graphical results:

- Graphed data included the following:
  - Gasoline fuel economy by trip type
  - Distance traveled by trip type
  - Percent of drive time by operating mode
  - Effect of driving aggressiveness on fuel economy
  - Trip fuel economy distribution by trip type
  - Time of day when driving
  - Time of day when charging
  - Time of day when plugging in.

8.5.2 Phase 2 Chrysler Ram Plug-In Hybrid Electric Vehicle Demonstration Reporting

The primary reporting method for Phase 2 was via 11 monthly fact sheets and the final summary fact sheet, which included the same parameters as the Phase 1 fact sheets (see Section 8.5.1). The only difference was some enhanced graphics, but the content was identical.

8.6 Chrysler Ram Plug-In Hybrid Electric Vehicle Demonstration Results

In an effort to best capture the petroleum reduction benefits of partial electric propulsion, the results were reported by each operating mode and the following two categories: (1) city routes and (2) highway routes. This was done in order to better understand and visualize vehicle utilization. Predominately, the city driving routes were a lower average vehicle speed with multiple stops per mile, whereas the highway driving routes had a higher average speed with minimal stops per mile.

8.6.1 Phase 1 Chrysler Ram Plug-In Hybrid Electric Vehicle Demonstration Results

Over the entire data collection period and a total of 18,620 days of driving, the fleet average fuel economy was 19 mpg and the overall AC electric energy consumption was 90 AC Wh/mile and 61 DC Wh/mile. Over the entire data collection period, electric energy consumption, when operating in CD mode, was 213 DC Wh/mile and fuel economy was 23 mpg. Fuel economy when operating in CD/CS mode was 21 mpg and electric energy consumption was 68 DC Wh/mile. Fuel economy when operating in CS mode was 17 mpg.

The majority of the 1,039,138 miles driven during Phase 1 were in CS mode (Figure 8-7), which resulted in 52% of the trips being started (Figure 8-8) with no available grid energy in the PHEV battery pack. In each operating mode, the vast majority of trips were city routes (Figure 8-9).

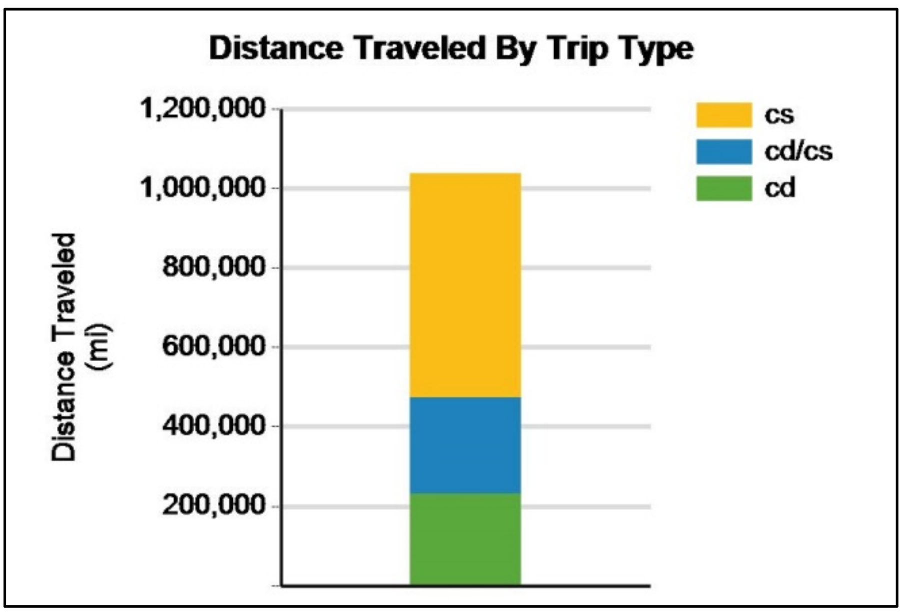


Figure 8-7. Distances driven by operating mode for the Ram PHEVs in Phase 1.

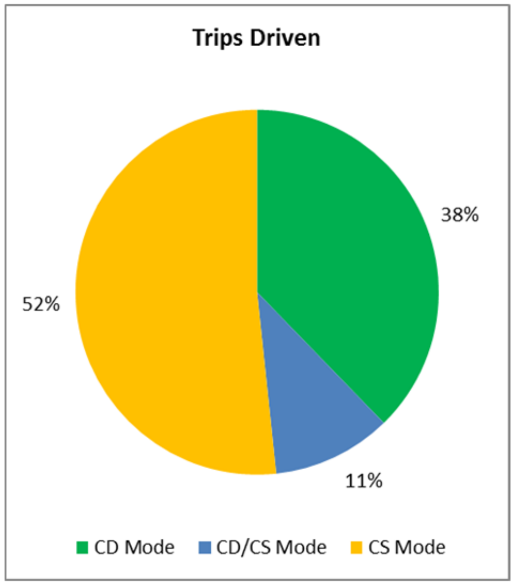


Figure 8-8. Trips driven by operating mode for the Ram PHEV in Phase 1.

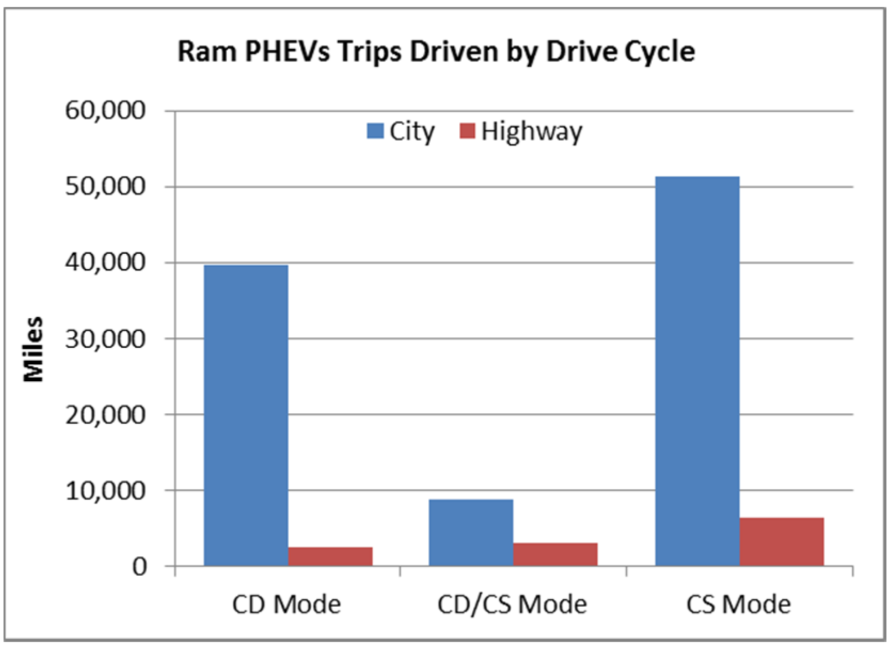


Figure 8-9. Ram PHEV city and highway trips driven.

The Rams achieved the highest gasoline fuel economy during highway cycles while in CD mode (Figure 8-10), which would be expected for trips driven with energy in the battery pack the entire trip.

The highest use of electricity per mile occurred during city driving while in CD mode (Figure 8-11). At first glance, it would be expected that the highest mpg results occur during the same type of driving, when the most electricity per mile was being used; however, the energy required to repeatedly accelerate a heavy vehicle like the Ram during city driving had a greater influence on mpg results than the higher use of electric propulsion. In addition, aggressive driving will also have an influence on energy use. As seen in Figure 8-12, during CD mode and city driving operations, the highest aggressiveness was measured, which impacted mpg results. Aggressiveness was a measure (8-12) of how much energy was required for acceleration during a trip (Figure 8-13).

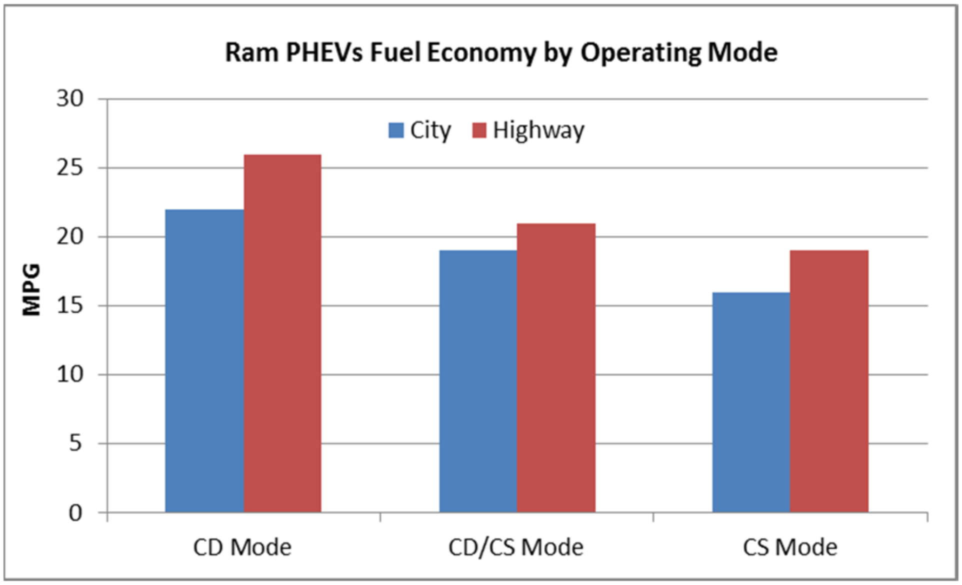


Figure 8-10. Gasoline fuel economy by operating mode and drive cycle.

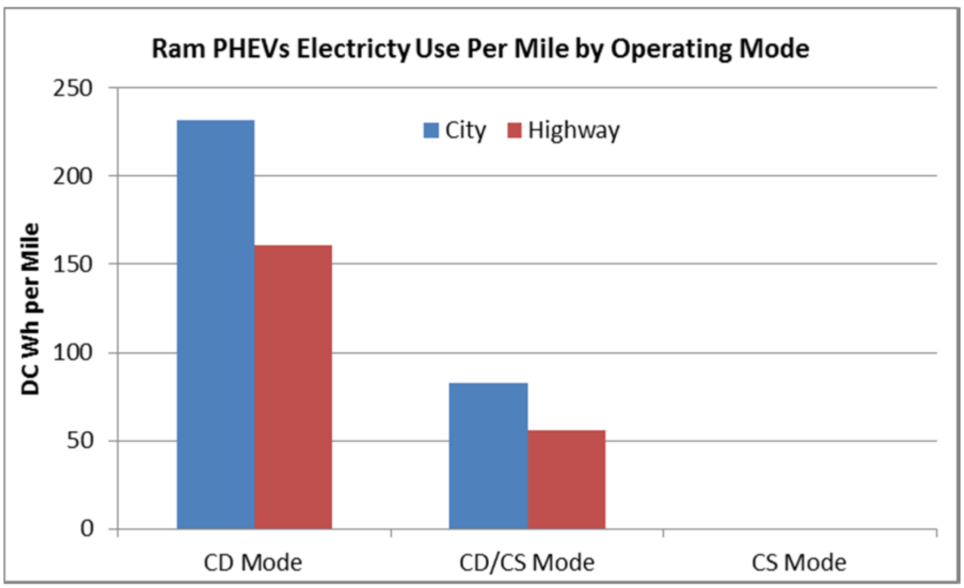


Figure 8-11. Electricity use by operating mode and drive cycle.

$$Aggressiveness = PKE \times 10, where\ PKE = \frac{\sum (V_f^2 - V_i^2)}{X}\ for V_f > V_i\ over\ the\ trip$$

$$and\ X\ is\ trip\ distance\ in\ m\ and\ V_f\ and\ V_i\ are\ vehicle\ speed\ in\ m/s$$

Figure 8-12. Calculations used to determine the aggressiveness of trips.

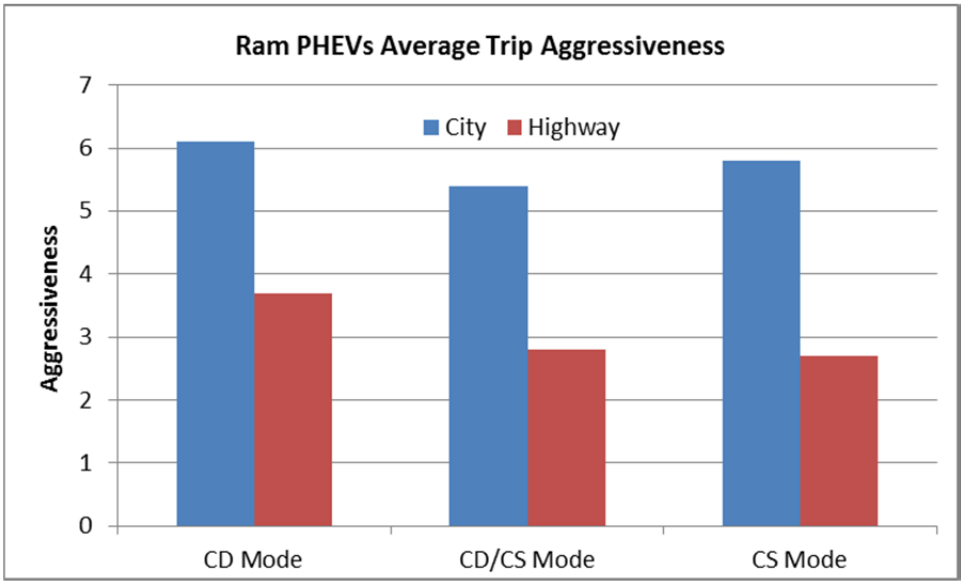


Figure 8-13. Average trip aggressiveness by operating mode and drive cycle.

As can be seen in Figure 8-14, the least driving aggressiveness can result in approximately twice as high average mpg results.

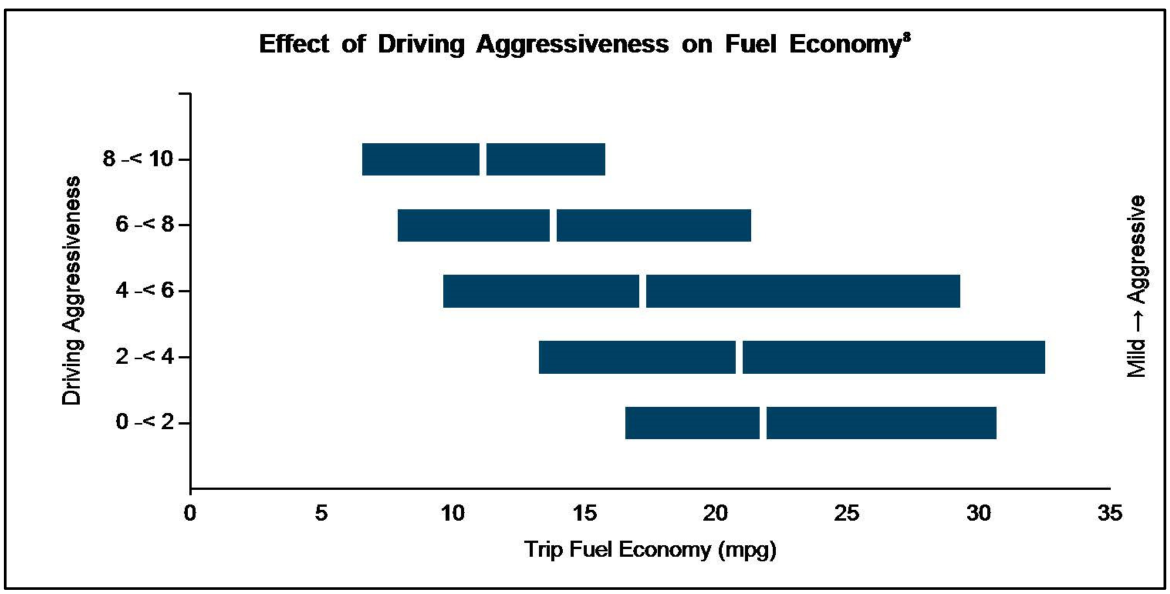


Figure 8-14. Driving aggressiveness impacts on petroleum use.

Another factor that can impact petroleum use is trip distances driven. As seen in Figure 8-15, shorter trip distances could allow for more proportional use of the electric propulsion if the battery pack is fully charged at the beginning of each trip, though very short trips may reflect more heavily on cold-start fuel consumption.

For grid-connected vehicles, it is important to understand driving patterns and charging patterns. For the fleet of Ram PHEVs, the time of day when driving and charging occurred was analyzed and are shown in Figures 8-16 and 8-17, respectively. Driving primarily occurred during the daytime, with a moderate increase between 6:00 and 8:00 a.m. and 3:00 and 5:00 p.m. local time. Charging primarily occurred during the daytime.

The time of day when plugging in (Figure 8-18) is closely followed by the time of day when charging.

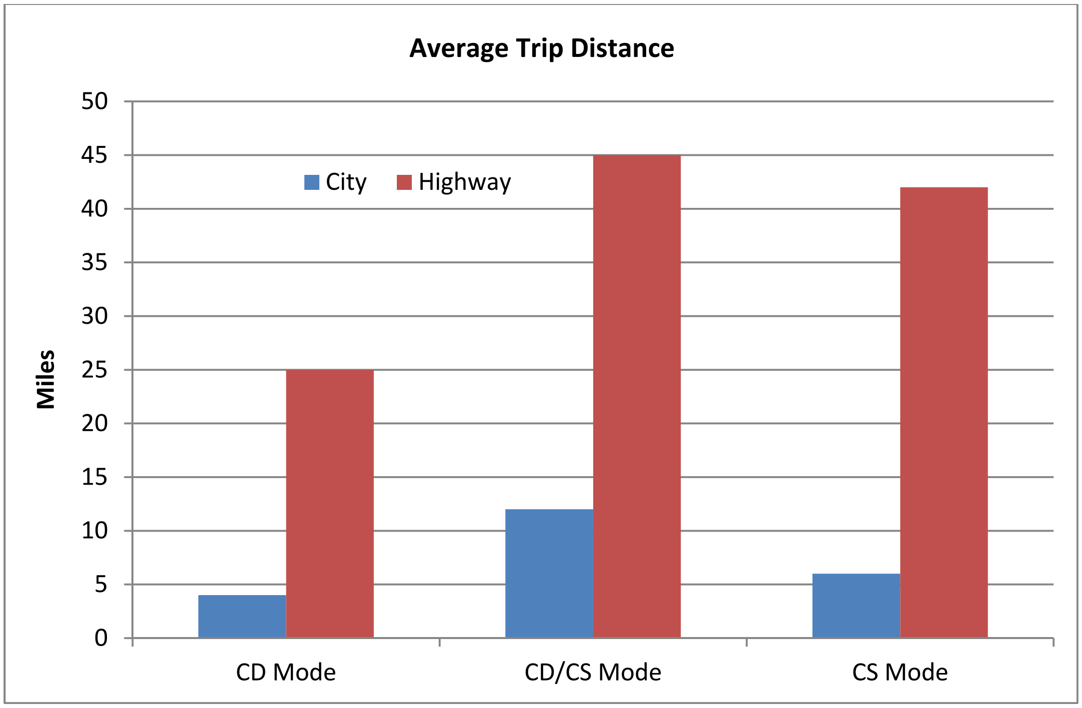


Figure 8-15. Average trip distances by operating mode and drive cycle.

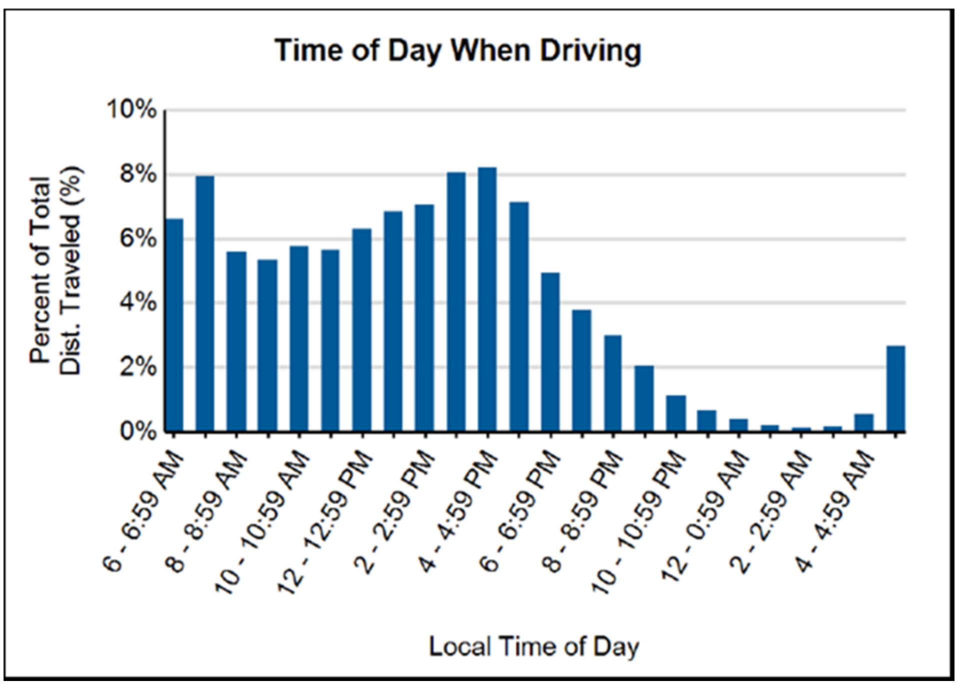


Figure 8-16. Time of day when Ram PHEVs were driven.

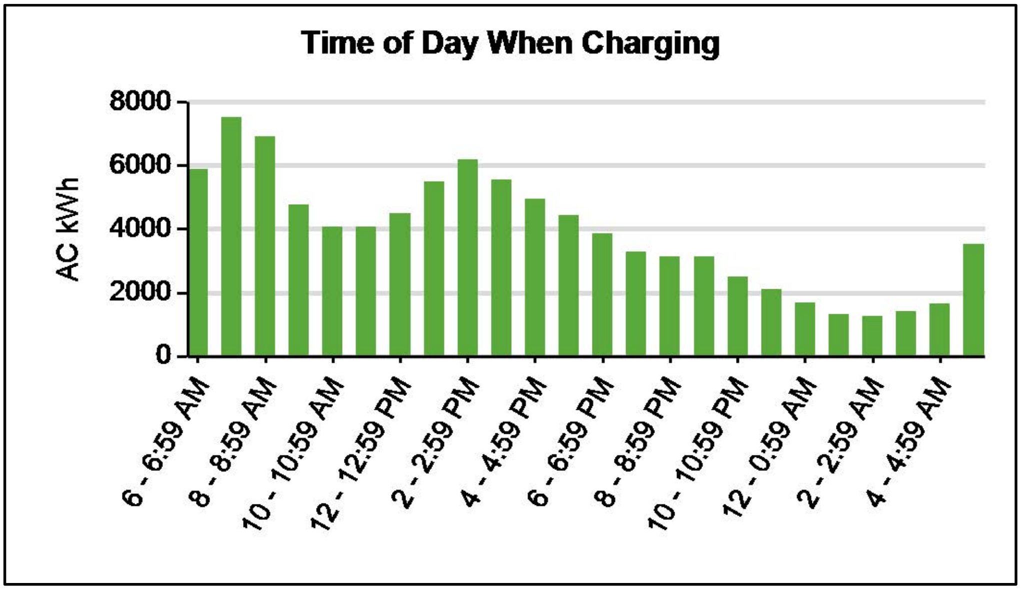


Figure 8-17. Time of day when Ram PHEVs were charged.

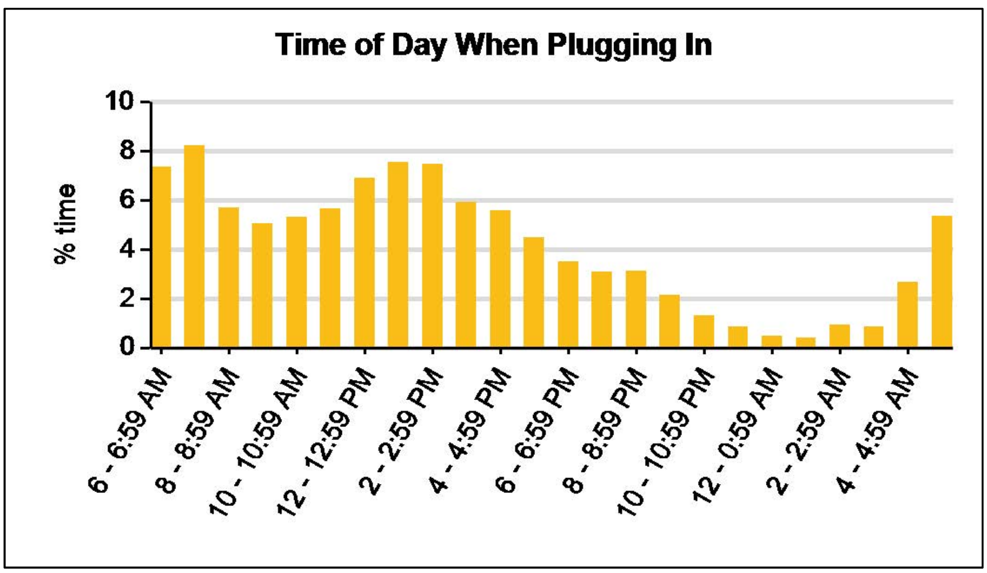


Figure 8-18. Time of day when Ram PHEVs were plugged in for charging.

Because of the design of the Ram's PHEV control system, the gasoline engine will shut off at times, including when the vehicle is stopped and sometimes when driving (Figure 8-19). Figure 8-20 highlights the percentage of miles driven by operating mode and drive cycle when the gasoline engine was stopped. The significance of Figures 8-19 and 8-20 is that the PHEV control system stopped the gasoline engine up to 37% of the time and 15% of all miles driven in CD mode during city driving. Of course, stopping the engine results in periods of no fuel use and greater reductions in petroleum consumption. An additional Ram PHEV feature included shutting down four of the eight cylinders as power demands warranted.

Looking at plug-in charging statistics (Table 8-1), several observations can be drawn about why more electric miles were not achieved by fleet operators. Less than one charge event occurred per day, the average distance between charging events was high at 70.6 miles, and 7.6 trips were taken between charge events. Given that this equates to an average of 9.3 miles per trip, it appears that there may have been many opportunities to at least charge at AC Level 1. This of course depends on the mission of the vehicles and if a grid connection is nearby.

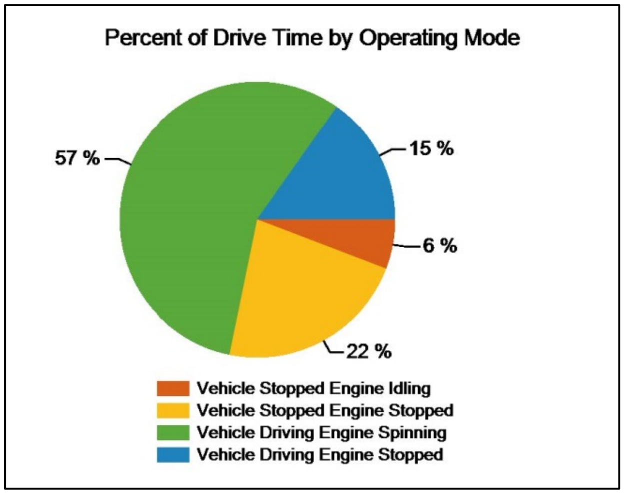


Figure 8-19. Percent of drive time when the Ram's gasoline engine was either stopped, spinning, or idling.

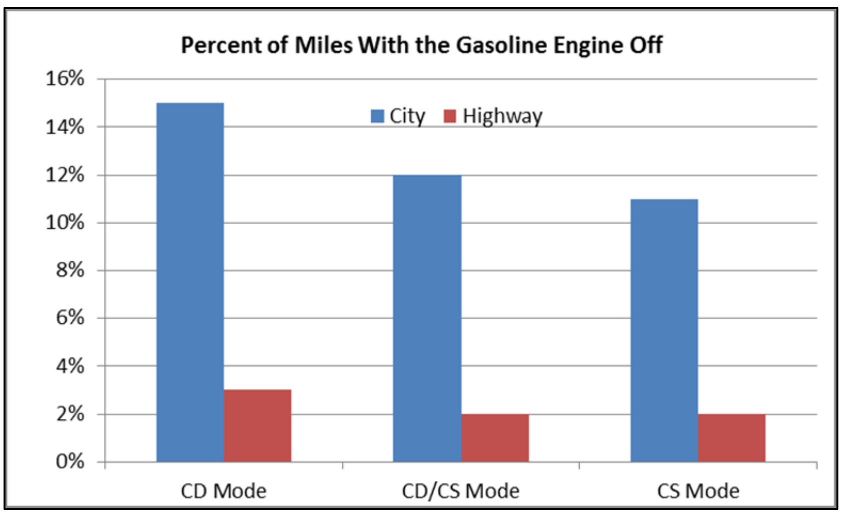


Figure 8-20. Percent of miles by operating mode and drive cycle when the Ram's gasoline engine was stopped.

Table 8-1. Plug-in charging statistics for Ram PHEVs during Phase 1.

Plug-In Charging	
Average number of charging events per vehicle per month when driven	11.27
Average number of charging events per vehicle per day when driven	0.79
Average distance driven between charging events (miles)	70.6
Average number of trips between charging events	7.6
Average time charging per charging event (hours)	2.38
Average energy per charging event (AC kWh)	6.35
Average charging energy per vehicle per month (AC kWh)	71.55
Total number of charging events	14,712

Plug-In Charging		
Number of charging events at AC Level 1/AC Level 2	3,556	11,073
Total charging energy consumed (AC kWh)		93,374
Charging energy consumed at AC Level 1/AC Level 2 (AC kWh)	22,220	71,144
Percent of total charging energy from AC Level 1/AC Level 2	24%	76%
Average time to charge from 20 to 100% SOC AC Level 1/AC Level 2 (hours)	12.62	2.87

8.6.2 Phase 2 Chrysler Ram Plug-In Hybrid Electric Vehicle Demonstration Results

Over the entire data collection period and a total 4,050 individual vehicle days of driving, the fleet average fuel economy was 20 mpg and the overall electric energy consumption was 87 AC Wh/mile and 65 DC Wh/mile. Over the entire data collection period, energy consumption when operating in CD mode was 201 DC Wh/mile and the fuel economy was 25 mpg. The fuel economy when operating in CD/CS mode was 21 mpg and electric energy consumption was 67 DC Wh/mile. The fuel economy when operating in CS mode was 18 mpg.

The majority of the 250,478 miles driven during Phase 2 was in CS mode (Figure 8-21), which results from 48% of the trips being started (Figure 8-22) with no grid energy in the traction battery pack. In each operating mode, the vast majority of trips taken were city routes (Figure 8-23).

The Rams achieved highest mpg results during highway cycles while in CD mode (Figure 8-24), which would be expected for trips driven with energy in the battery pack the entire trip. The highest use of electricity per mile occurred during city driving while in CD mode (Figure 8-25).

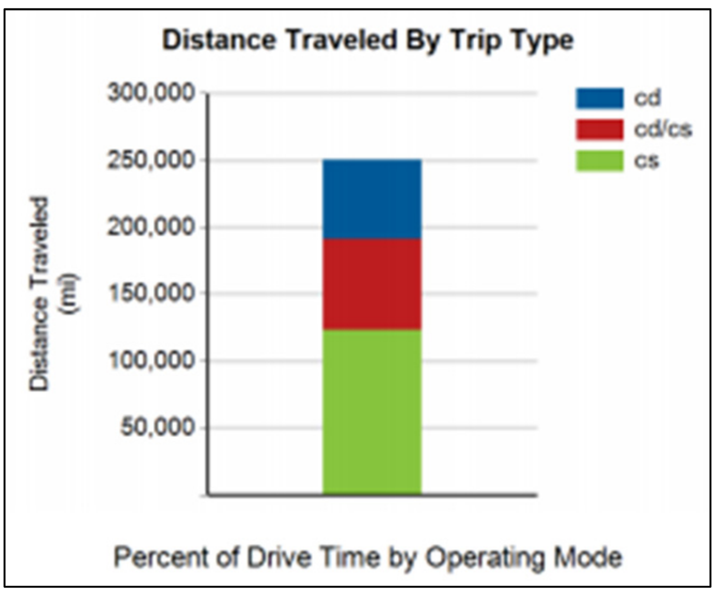


Figure 8-21. Distances driven by operating mode for Ram PHEVs in Phase 2.

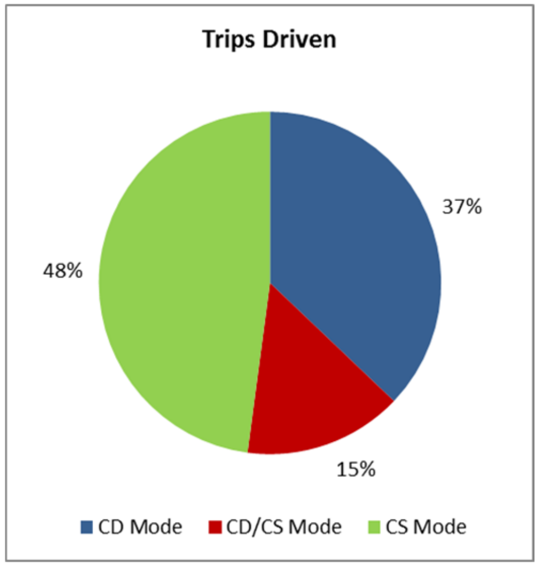


Figure 8-22. Trips driven by operating mode for the Ram PHEV in Phase 2.

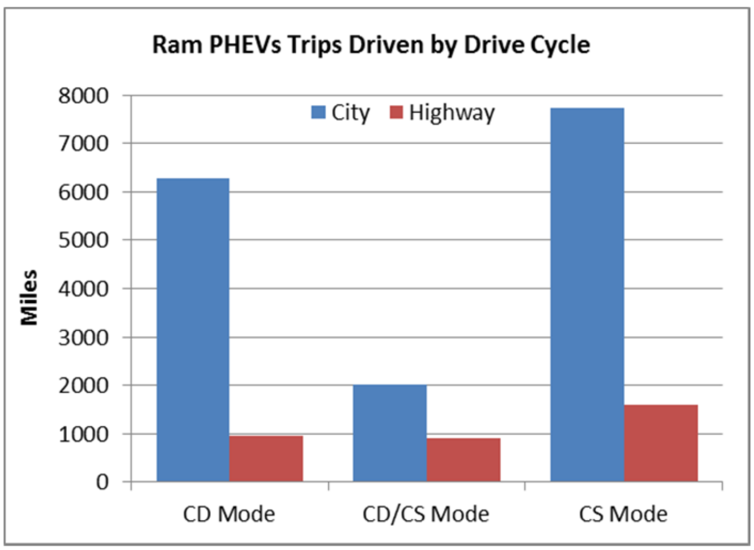


Figure 8-23. Ram PHEV city and highway trips driven.

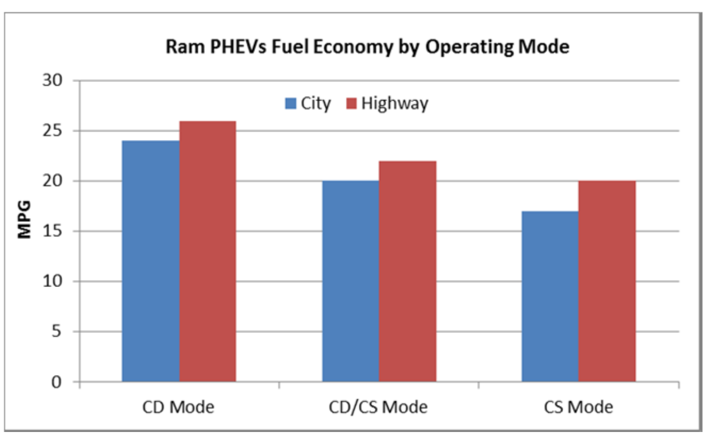


Figure 8-24. Gasoline fuel economy by operating mode and drive cycle.

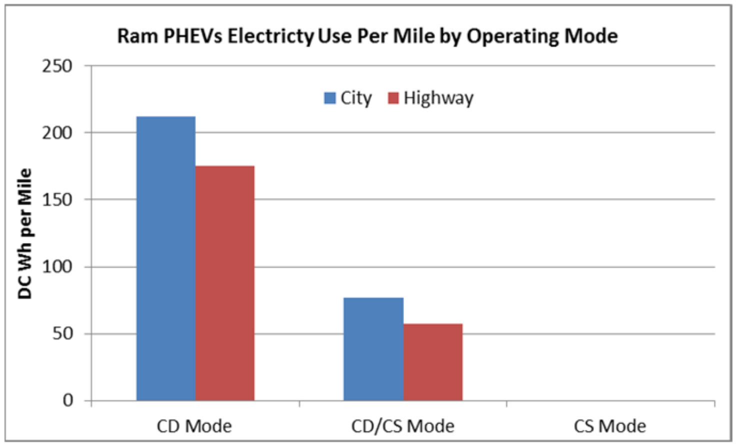


Figure 8-25. Electricity use by operating mode and drive cycle.

At first glance, it would be expected that the highest mpg results would occur during the same type of driving when the most electricity per mile was being used; however, the type of energy required to repeatedly accelerate a higher weight vehicle, like the Ram during city driving, had a greater influence on mpg results than the higher use of electric propulsion. In addition, aggressive driving will have an influence on energy use. As seen in Figure 8-26, during CD mode and city driving operations, the highest aggressiveness was measured, which impacted mpg results. Aggressiveness is a measure of how much energy was required for accelerations during a trip (Figure 8-27). As can be seen in Figure 8-28, less aggressiveness can result in approximately twice as high mpg results.

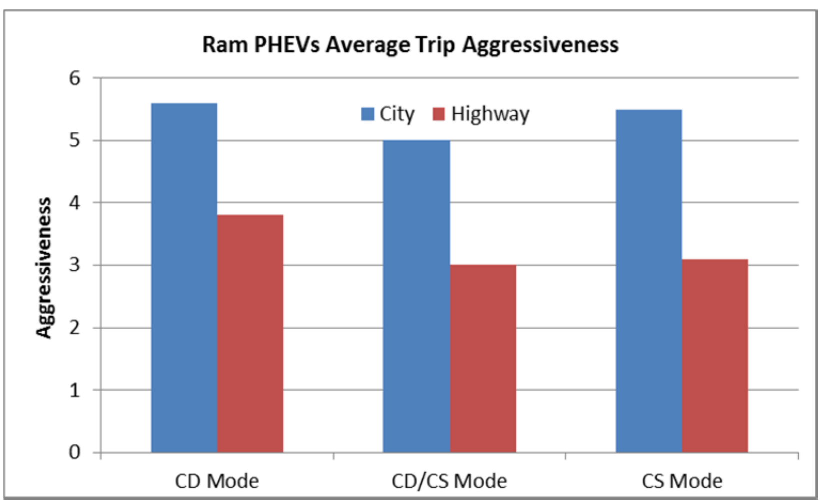


Figure 8-26. Average trip aggressiveness by operating mode and drive cycle.

$$Aggressiveness = PKE \times 10, \text{ where } PKE = \frac{\sum (V_f^2 - V_i^2)}{X} \text{ for } V_f > V_i \text{ over the trip}$$

$$\text{and } X \text{ is trip distance in m and } V_f \text{ and } V_i \text{ are vehicle speed in m/s}$$

Figure 8-27. Calculations used to determine a trip's aggressiveness.

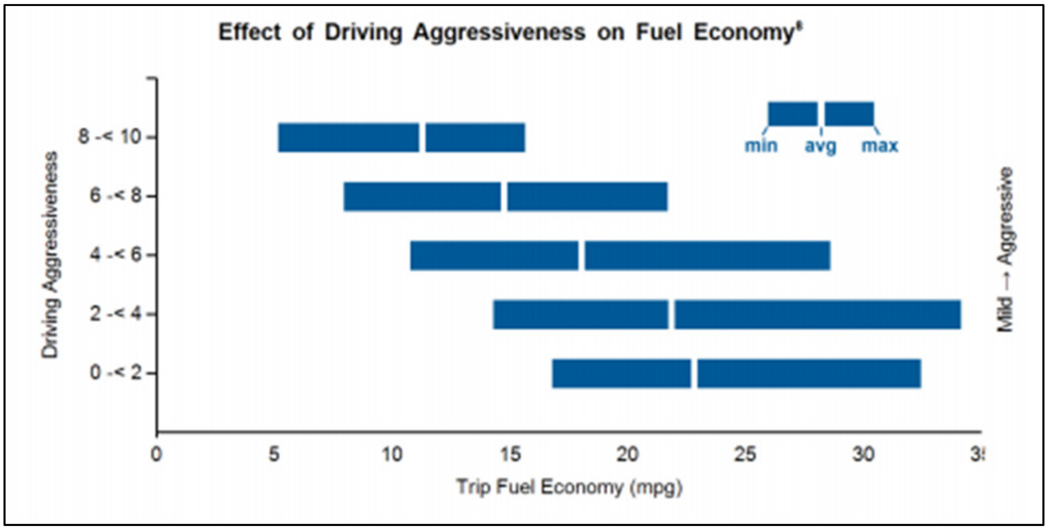


Figure 8-28. Impacts of driving aggressiveness on petroleum use.

Another factor that can impact petroleum use is trip distances driven. As seen in Figure 8-29, shorter trip distances would allow for more proportional use of electric propulsion if the battery pack is fully charged at the beginning of each trip.

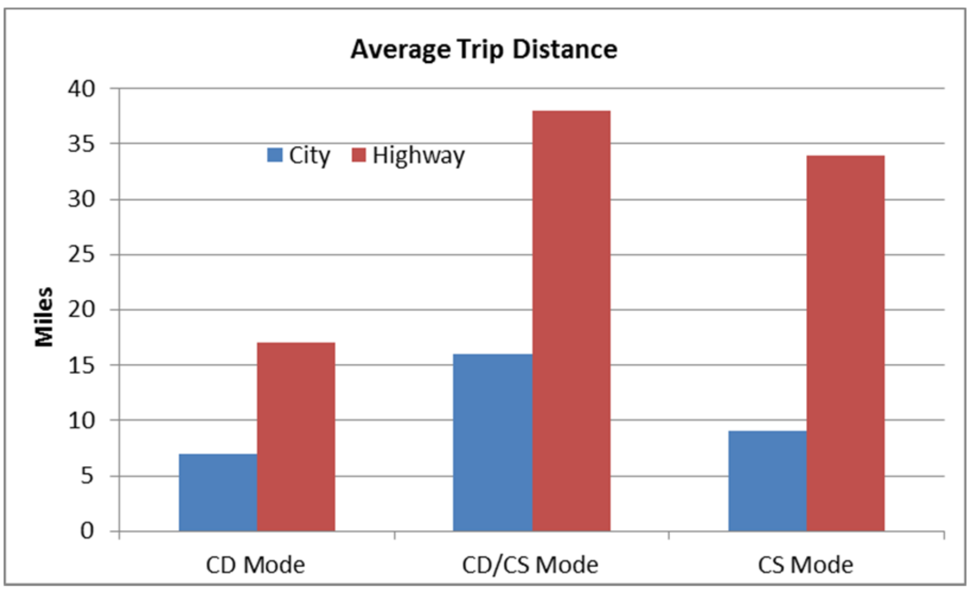


Figure 8-29. Average trip distances by operating mode and drive cycle.

For grid-connected vehicles, it is important to understand driving patterns and charging patterns. For the fleet of Ram PHEVs, the time of day when driving and charging occurred was analyzed and is shown in Figures 8-30 and 8-31, respectively. Driving primarily occurred during the daytime, with much less driving from late night to early morning. Charging primarily occurred during the daytime, with the highest group of charging occurring between 6:00 and 9:00 a.m. The time of day when plugging in (Figure R-32) was closely followed by the time of day when charging occurs and the highest grouping of when the Rams were plugged in occurred between 5:00 and 8:00 a.m., with the second highest point at mid-day.

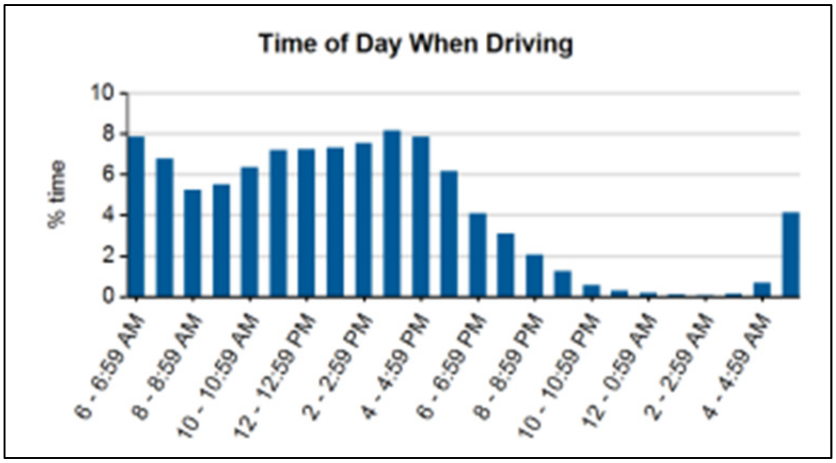


Figure 8-30. Time of day when Ram PHEVs were driven.

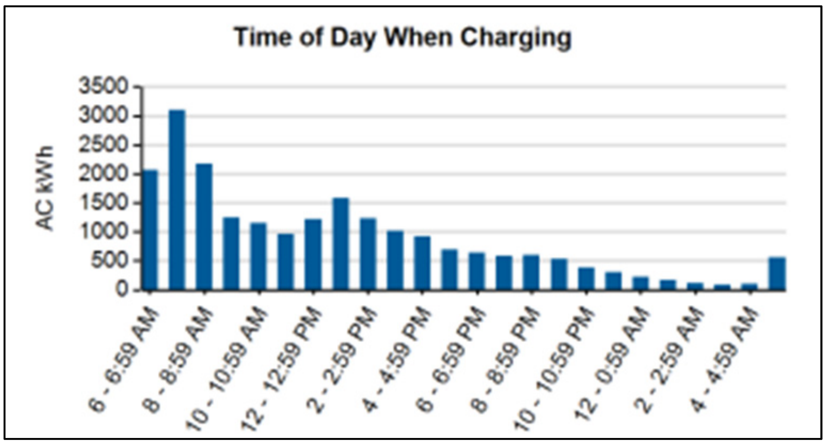


Figure 8-31. Time of day when Ram PHEVs were charged.

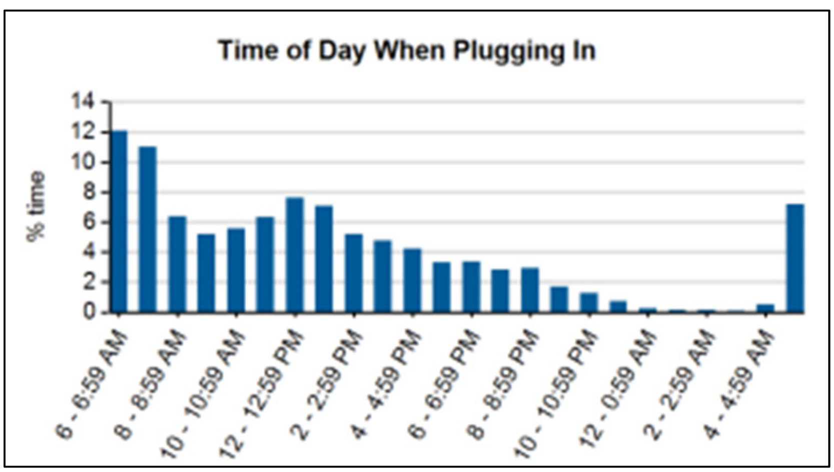


Figure 8-32. Time of day when Ram PHEVs were plugged in for charging.

Because of the design of the Ram's PHEV control system, the gasoline engine shut off at times, including when the vehicle was stopped and when driving (Figure 8-33).

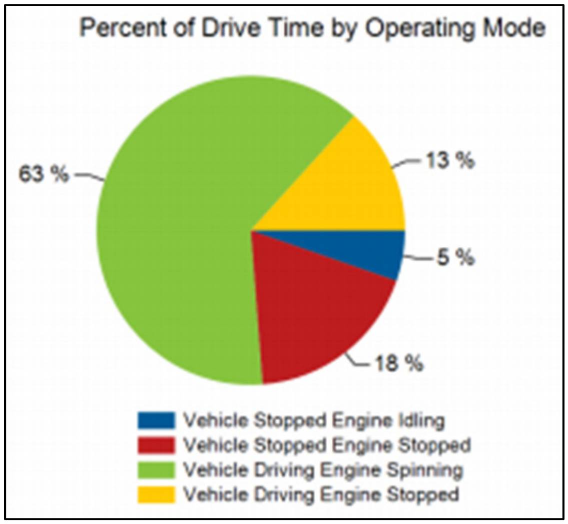


Figure 8-33. Percent of drive time when the Ram's gasoline engine was either stopped, spinning, or idling.

Figure 8-34 highlights the percentage of miles driven by operating mode and drive cycle when the gasoline engine was stopped. Figures 8-33 and 8-34 show that the PHEV control system stopped the gasoline engine up to 21% of the drive time and 12% (Figure 8-34 city driving and CD mode) of all miles driven. Of course, stopping the engine results in no fuel being used and a greater reduction in petroleum use. An additional Ram PHEV feature was shutting down four of the eight cylinders as power demands warranted.

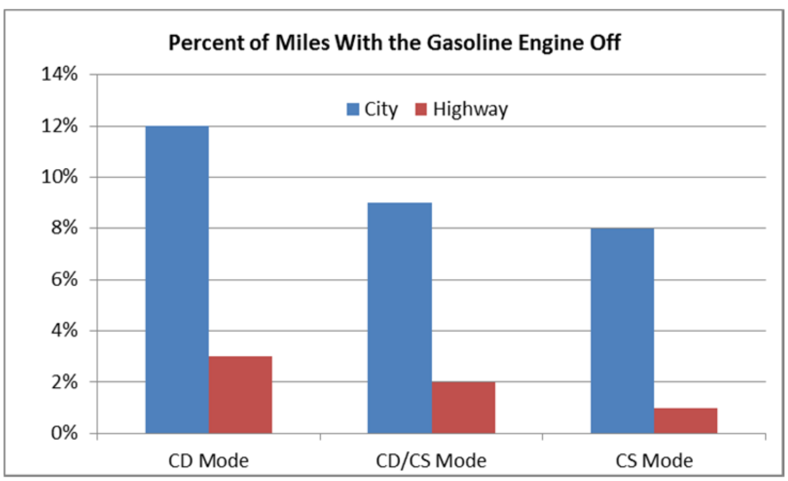


Figure 8-34. Percent of miles by operating mode and drive cycle when the Ram's gasoline engine was stopped.

Looking at plug-in charging statistics (Table 8-2), several observations can be drawn as to why more electric miles were not achieved by fleet operators. There was less than one charge event per day, the average distance between charging events was high at 58.8 miles, and 4.6 trips were taken between charge events. Given that this equates to an average of 12.8 miles per trip, it appears that there may have been many opportunities to at least charge at AC Level 1. This of course depends on the mission of the vehicles and if a grid connection was nearby.

Table 8-2. Plug-in charging statistics for Ram PHEVs during Phase 2.

Plug-In Charging	AC Level 1 (When Applicable)	AC Level 2 (When Applicable)
Average number of charging events per vehicle per month when driven		21.32
Average number of charging events per vehicle per day when driven		1.05
Average distance driven between charging events (miles)		58.76
Average number of trips between charging events		4.62
Average time charging per charging event (hours)		1.56
Average energy per charging event (AC kWh)		5.08
Average charging energy per vehicle per month (AC kWh)		108.35
Total number of charging events		4,263
Number of charging events at AC Level 1/AC Level 2	794	3,383
Total charging energy consumed (AC kWh)		21,670
Charging energy consumed at AC Level 1/AC Level 2 (AC kWh)	3,246	18,418
Percent of total charging energy from AC Level 1/AC Level 2	15%	85%
Average time to charge from 20 to 100% SOC (hours) AC Level 1/ AC Level 2	11.51	2.23

8.7 Chrysler Ram Plug-In Hybrid Electric Vehicle Demonstration Summary

8.7.1 Phase 1 Chrysler Ram Demonstration Summary

INL analyzed data from 111 Chrysler Ram PHEVs during the Phase 1 project from July 2011 through September 2012 as part of the ARRA Chrysler Ram PHEV Demonstration Project. Quarterly reports were published to http://avt.inel.gov/chryslerram.shtml, which detailed vehicle operational characteristics, fuel economy, electrical energy consumption, driving and charging utilization, driving style efficiency, and ambient temperature profiles. Over the period of data collection, the fleet of 111 Chrysler Rams accumulated a total of 1.04 million miles over a total of 18,620 days of driving. Over the entire data collection period, the fleet's average fuel economy was 19 mpg and the overall AC electrical energy consumption was 90 AC Wh/mile and 61 DC Wh/mile. Additional metrics were analyzed to characterize and visualize their impact on fuel economy and electrical energy consumption. These additional metrics included ambient temperature, driving style efficiency, EVM and ERM operation, battery pack SOC utilization, route type, and distance driven between charge events.

Results for Phase 1 Chrysler Ram PHEVs varied somewhat from the Phase 2 Ram PHEVs; this will be discussed in Section 8.7.3.

8.7.2 Phase 2 Chrysler Ram Demonstration Summary

INL analyzed data from 22 Chrysler Ram PHEVs during Phase 2 of the project from November 2011 through September 2014 as part of the ARRA Chrysler Ram PHEV Demonstration Project. Quarterly reports were published to http://avt.inel.gov/chryslerram.shtml, which detailed vehicle operational characteristics, fuel economy, electrical energy consumption, driving and charging utilization, driving style efficiency, and ambient temperature profiles. Over the period of data collection, the fleet of 22 Chrysler Rams accumulated a total of 250,000 miles over 4,050 total days of driving. During the entire data collection period, the fleet average fuel economy was 20 mpg and overall electrical energy consumption was 87 AC Wh/mile and 65 DC Wh/mile. Additional metrics were analyzed to characterize and visualize their impact on fuel economy and electrical energy consumption. These additional metrics include ambient temperature, driving style efficiency, EVM and ERM operation, battery pack SOC utilization, route type, and distance driven between charge events.

Results for the 22 Phase 2 Chrysler Ram PHEVs varied somewhat from the 111 Phase 1 Ram PHEVs; this will be discussed in Section 8.7.3.

8.7.3 Phases 1 and 2 Combined Chrysler Ram Plug-In Hybrid Electric Vehicle Demonstration Results

The number of vehicles in each phase was significantly different, which suggests that ambient temperatures and terrain were likely much different. In addition, drivers as a total fleet group may have been different. In addition, it is not known if the vehicles were modified in any way beyond changing the traction battery pack manufacturer. What can be noted is the change in relative vehicle driver behavior in terms of increasing the frequency of charge events and the higher percentage of charge events being performed at AC Level 2 versus AC Level 1.

As seen in Figure 8-35, during Phase 2, the amount of average charges events per vehicle month almost tripled (i.e., from 11 to 31) when comparing Phase 2 to Phase 1 and, as would be expected, the average number of miles driven per charge event decreased from 71 to 59 miles during Phase 2. Again, as would be expected, the average AC energy used during charging increased from Phase 1 to 2, from 71.6 to 108.4 AC kWh per month.

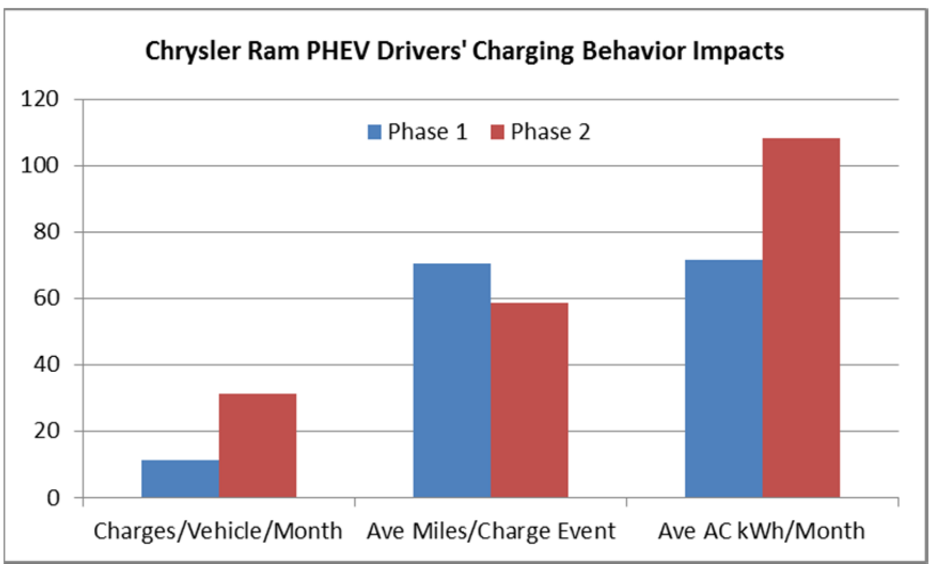


Figure 8-35. Average number of charging events per vehicle per month when driven (Charges/Vehicle/Month), average distance driven between charging events in miles (Ave Miles/Charge Event), and average charging energy per vehicle per month AC kWh (Ave AC kWh/Month) for Phases 1 and 2.

As seen in Figure 8-36, the average number of trips per charging event went from 7.6 in Phase 1to 4.6 in Phase 2, which also indicates a higher frequency of charging. However, the average time in hours per charge event went down 34% from Phase 1 to Phase 2. The average AC kWh energy per charge event also went down, but only by 20%. This proportionally lower decrease in energy per charge event is likely the result of greater use of AC Level 2 EVSE over AC Level 1 EVSE (Figure 8-37).

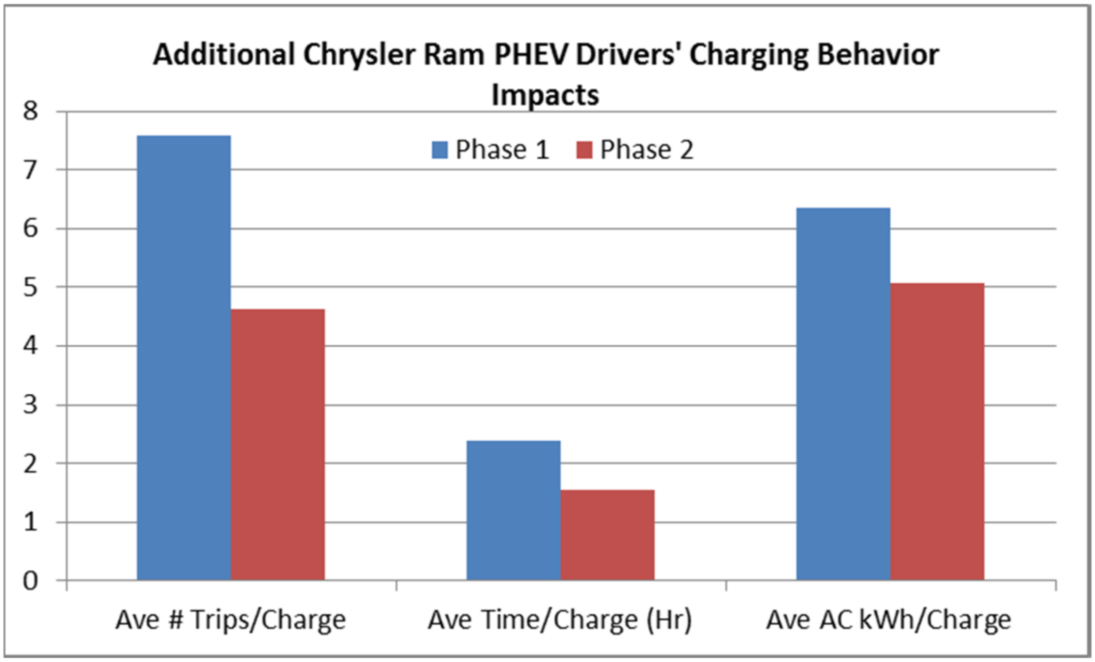


Figure 8-36. Average number of trips between charging events (Ave # Trips/Charge), average time charging per charge event in hours (Ave Time/Charge (Hr)), and average energy per charging event in AC kWh (Ave AC kWh/Charge) for Phases 1 and 2.

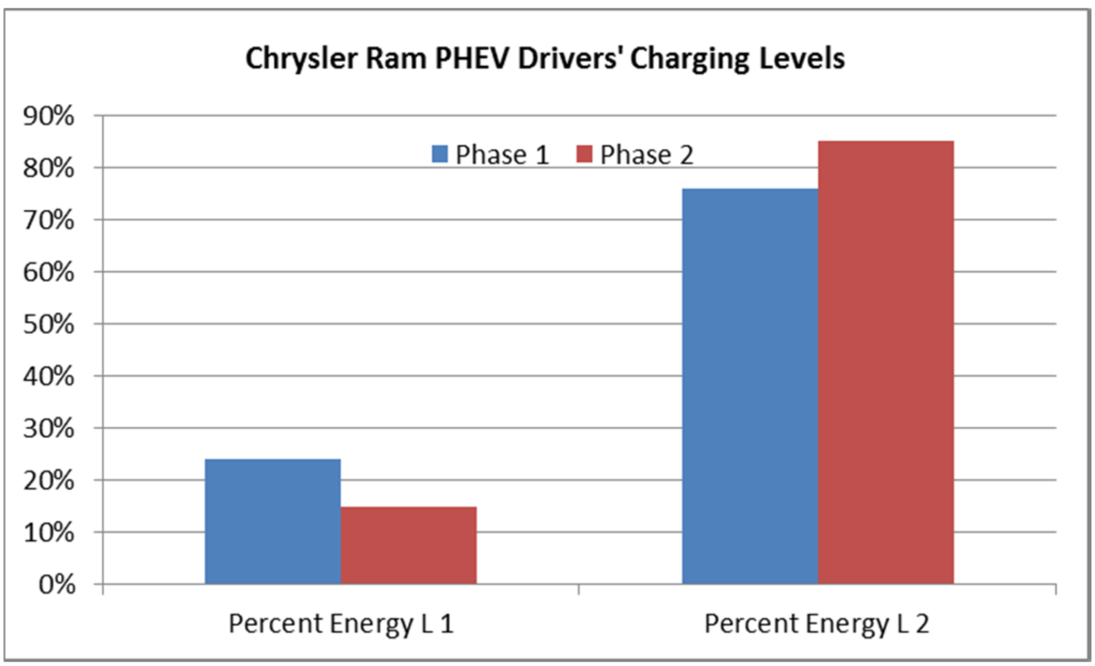


Figure 8-37. Percent of charge events that occurred at AC Levels 1 and 2 during the Phases 1 and 2.

9. THE EV PROJECT

9.1 The EV Project Scope and Objectives

The EV Project was the largest and most complex of several ARRA projects from which INL collected data because it included data streams from several partners and it was the largest ever deployment of charging infrastructure and PEVs as a research project, with the first reporting period from January to March 2011. INL was able to count the number of EVSE and PEV deployed by reporting the number of PEVs and EVSE reporting data. INL was not tasked with field inspections.

The Nissan Leaf sales rollout plan defined the initial five regions of The EV Project, anticipating these five regions to be the locations of early adopters of PEVs. The initial scope of The EV Project as agreed to by DOE was as follows:

- Deploy 4,700 Nissan Leaf BEVs, Blink EVSE, and DCFC in the following five regions:
  - Phoenix and Tucson, Arizona
  - San Diego, California
  - Portland, Eugene, Corvallis, and Salem, Oregon
  - Chattanooga, Knoxville, and Nashville, Tennessee
  - Seattle, Washington
- Establish a mature charging infrastructures to support deployment of the Nissan Leafs
- Identify and resolve barriers to infrastructure deployment
- Develop an infrastructure utilization database
- Evaluate infrastructure effectiveness
- Develop models for future infrastructure deployment
- Develop an infrastructure deployment model to support deployment of the first 5 million PEVs.

The general uptake of the Leafs was slower than initially expected when the project was first designed. In order to increase the number of vehicles in The EV Project, additional models and project areas were included. A timeline of events can be found in Table 9-1. In should be noted that ECOtality held the initial EV Project contract; however, during the fall of 2013, Blink (including The EV Project) was purchased by the Car Charging Group. Car Charging continued to provide data to INL, as did GM/OnStar, Nissan, and Car2Go, after INL signed new non-disclosure agreements with each organization. The official end of The EV Project data collection period was the end of December 2013.

Table 9-1. Timeline of significant events in The EV Project.

Date	Event
October 2009	Contract signed. Nissan Leaf markets included the following: • Phoenix/Tucson, Arizona • San Diego, California • Portland, Eugene, Corvallis, and Salem, Oregon • Seattle, Washington • Knoxville, Chattanooga, and Nashville, Tennessee.

Date	Event
Spring 2010	Chevrolet Volts were added. Markets added included the following: • Los Angeles, California (both Leaf and Volt) • Washington D.C. (Volt only) • Dallas and Houston, Texas (Volt only).
Late 2010/Early 2011	San Francisco, California was added (Leafs only).
December 2010	Residential deployment begins with just a handful of participants. The first 20 or 30 units installed were Clipper Creek non-networked units and they were replaced in February 2011 with Blink residential "smart" EVSE.
April 2010	First AC Level 2 EVSE units were deployed in commercial locations.
Autumn 2011	First AC Level 2 DCFC were deployed in Tennessee at Cracker Barrel restaurants.
August 2012	Chicago, Illinois; Philadelphia, Pennsylvania; and Atlanta, Georgia added (Leafs and Volts).Volts allowed in EV Project markets that previously only included Leafs, except in San Francisco, which remained the only market exclusive to one vehicle (i.e., Leafs).
Fall 2013	Car Charging Group bought the Blink assets.
December 31, 2013	EV Project data collection ended.

After project areas were added, The EV Project included 16 regions in nine states and the District of Columbia:

- Phoenix, Arizona metropolitan area
- Tucson, Arizona metropolitan area
- Los Angeles, California metropolitan area
- San Diego, California metropolitan area
- San Francisco, California metropolitan area
- Washington, D.C. metropolitan area
- Oregon State
- Chattanooga, Tennessee metropolitan area
- Knoxville, Tennessee metropolitan area
- Memphis, Tennessee metropolitan area
- Nashville, Tennessee metropolitan area
- Dallas/Fort Worth, Texas metropolitan area
- Houston, Texas metropolitan area
- Washington State
- Chicago, Illinois metropolitan area
- Atlanta, Georgia metropolitan area
- Philadelphia, Pennsylvania metropolitan area.

The primary research objective of The EV Project was development of a PEV charging network that would facilitate analysis and study of where future EVSE should be installed. Creation of a living laboratory that would identify various business models would enable deployment of the next 5 million PEVs by using lessons learned to facilitate efficient mass deployment of charging infrastructure and PEVs. This would also include identifying driver's preferences for charging at home, work, and public sites, as well as they best public venues for installing EVSE. In addition, drivers would identify the type of charging they prefer: AC Level 2 EVSE or DCFC.

9.2 EV Project Electric Vehicle Supply Equipment Types

Two types of EVSE were deployed in The EV Project and they are described as follows:

- A single AC Level 2 "port" or cord and connector set in a single EVSE with a SAE J1772-compliant connector. These units differed in design and they included residential installations that hung on a wall (Figures 9-1 and 9-2), public with a pedestal design (Figure 9-3), or public wall mounted (Figures 9-4 and 9-5).
- The second design is a DCFC. It is technically classified as a DC AC Level 2 unit, with the ability to fast charge a fast-charge capable PEV. It uses the CHAdeMO fast charging protocol. Two connectors shared a single fast charger internal to the unit (Figure 9-6).

Figure 9-1. EV Project residential EVSE hung on a residential garage wall.

Figure 9-2. EV Project residential EVSE hung on the side of a house.

Figure 9-3. EV Project public EVSE in the Seattle, Washington area.

Figure 9-4. EV Project commerical EVSE installation in the Oak Ridge, Tennessee area.

Figure 9-5. EV Project EVSE at the parking lot of a fuel station in San Diego, California.

Figure 9-6. EV Project DCFC installation in the Phoenix, Arizona area. The DCFC is charging a Nissan Leaf.

9.3 EV Project Deployment and Data Collection Rate

The EV Project was unique in that it was the only ARRA project that involved multiple data streams being received by INL for a single project. In addition to the Blink EVSE and DCFC data, INL also received data from OnStar/GM, Nissan via their CARWINGS telematics provider, and Car2Go (a subsidiary of Daimler). Sections 9.3.1 and 9.3.2 discuss the deployment and data collection rates for AC Level 2 EVSE, DCFC, and PEVs.

9.3.1 EV Project Electric Vehicle Supply Equipment and Direct Current Fast Charger Deployment and Data Collection Rate

The overall locations and totals for the EVSE and DCFC deployments in The EV Project can be seen in Figure 9-7. A total of 12,356 Blink EVSE and DCFC were deployed and whose use was reported by INL.

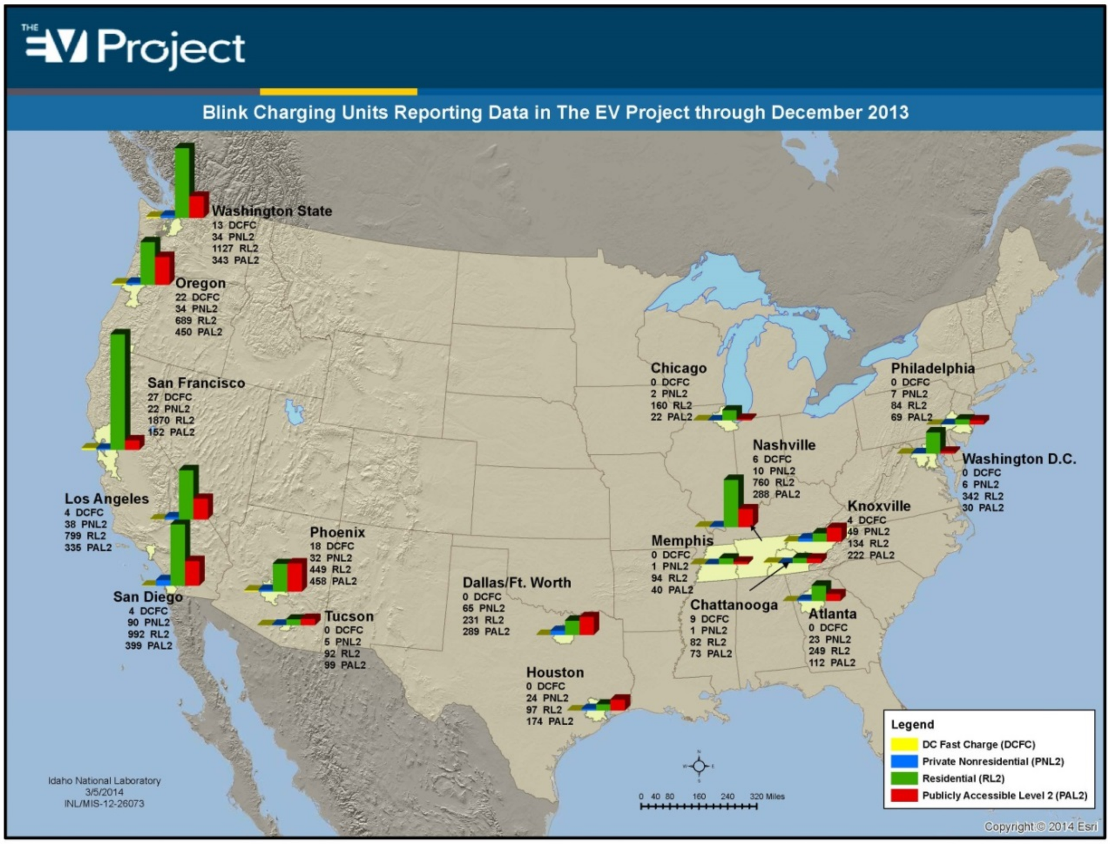


Figure 9-7. Locations and total number of EVSE reporting data through the end of The EV Project, which was December 2013. The map includes the installations by EVSE type.

Not every EVSE or DCFC reported a charge event for each reporting period. There are multiple reasons for EVSE or DCFC to not report a charge event from one quarter to the next. For instance, the unit may have been vandalized, it may have been run over by a vehicle, or it simply may not have been used because of something like a construction barrier being placed in front of it (Figure 9-8). Another factor in the number of EVSE and DCFC reported was the number of EVSE installed at a single location. Generally, when two or more EVSE were installed at the same public site, the EVSE closest to the entrance of a store, transportation center, or elevator would have the highest number of charge events.

While a total of 12,256 individual EVSE and DCFC units (Figure 9-9) reported data over the life of the project, the highest number of units reporting data during any one reporting period was approximately 9,200 units (Figure 9-10); this number comes from the quarterly reports. Certain criteria had to be met in order for an EVSE to appear in the report. For instance, for a residential EVSE to be included in the report it had to have had a charge event and the PEV that was matched to that individual residential EVSE also had to have reported data during that reporting period.

Figure 9-8. A temporary construction barrier was placed in front of a Blink AC Level 2 EVSE and a Blink DCFC. Prior to access being blocked, this DCFC unit was among the most highly used units in the EV Project.

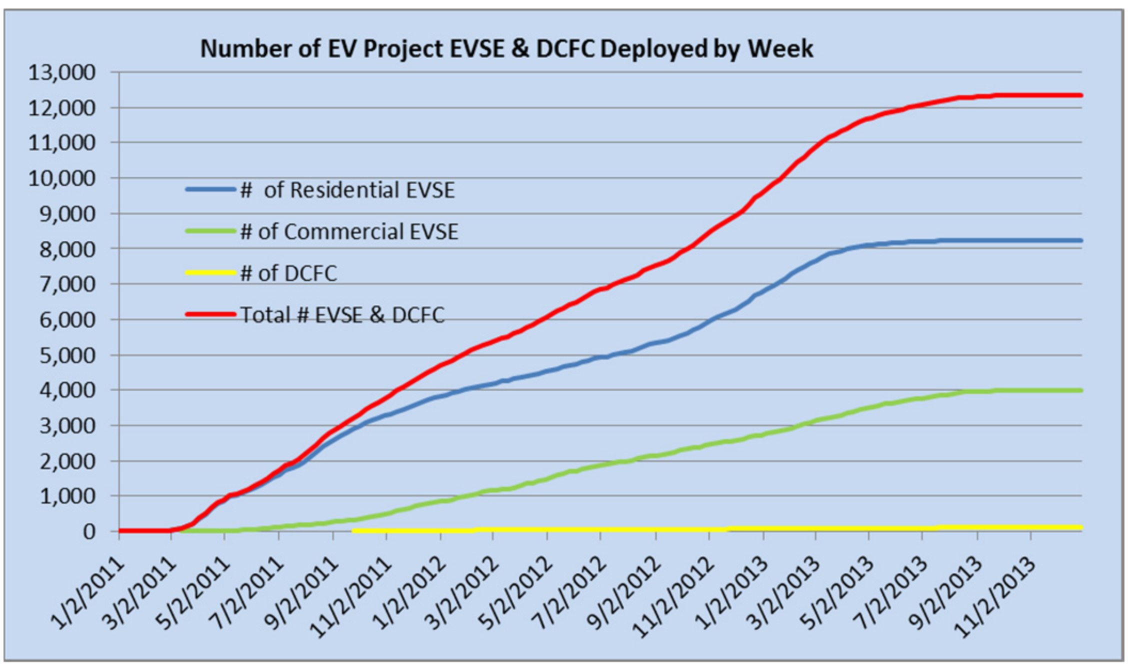


Figure 9-9. The number of EV Project residential EVSE, commercial EVSE (which includes both public and private non-residential EVSE), and DCFC cumulatively reporting charge event data to INL by project week.

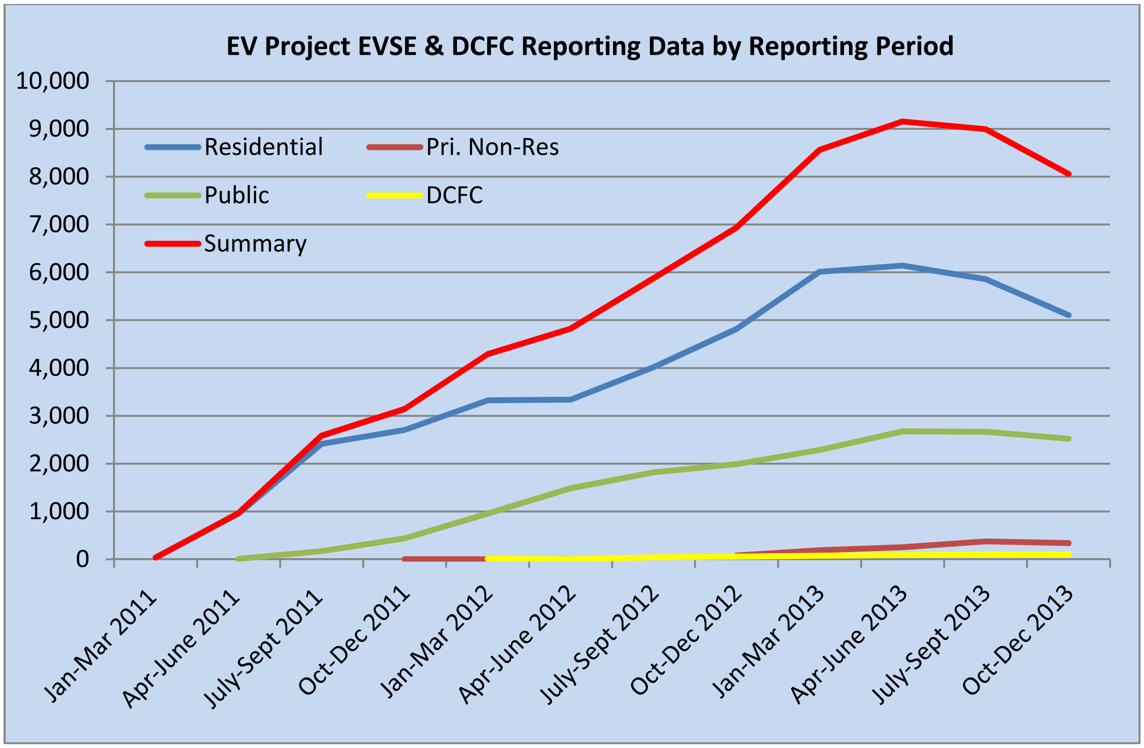


Figure 9-10. The number of EV Project residential EVSE, public EVSE, private access non-residential EVSE (i.e., Pri. Non-Res), and DCFC reporting charge event data to INL during each reporting period.

9.3.2 EV Project Plug-In Electric Vehicle Deployment and Data Collection Rate

The overall number of Nissan Leafs, Chevrolet Volts, and Smart Electric Drives (all PEVs) that participated in The EV Project in each of the project areas can be seen in Figure 9-11. A total of 8,228 PEVs (Figure 9-12) were enrolled and reported data during the duration of the project. The very first PEVs were deployed in late 2010 and actual reporting started during the first quarter of 2011 (i.e., January to March). Quarterly reporting was the norm throughout the duration of the project and the last quarterly report covered the fourth quarter (i.e., October to December) of 2013.

Not every PEV participated in The EV Project during all reporting quarters for several reasons, including the following:

- PEVs started to provide data as people bought them and not all PEVs were bought in the first reporting quarter
- Sometimes PEVs were involved in traffic accidents
- People moved out of The EV Project regions
- PEVs may not have been driven
- Participants did sometimes choose to drop out of The EV Project.

While a total of 8,228 individual PEVs (Figure 9-12) reported data over the life of the project, the highest number reporting during any one reporting period was approximately 6,519 PEVs (Figure 9-13), with this number coming from the quarterly reports. Certain criteria had to be met in order for a PEV to appear in the report. For instance, for a PEV to be included in the report, the residential EVSE it was paired with must also have reported a charge event at that residence during that reporting period.

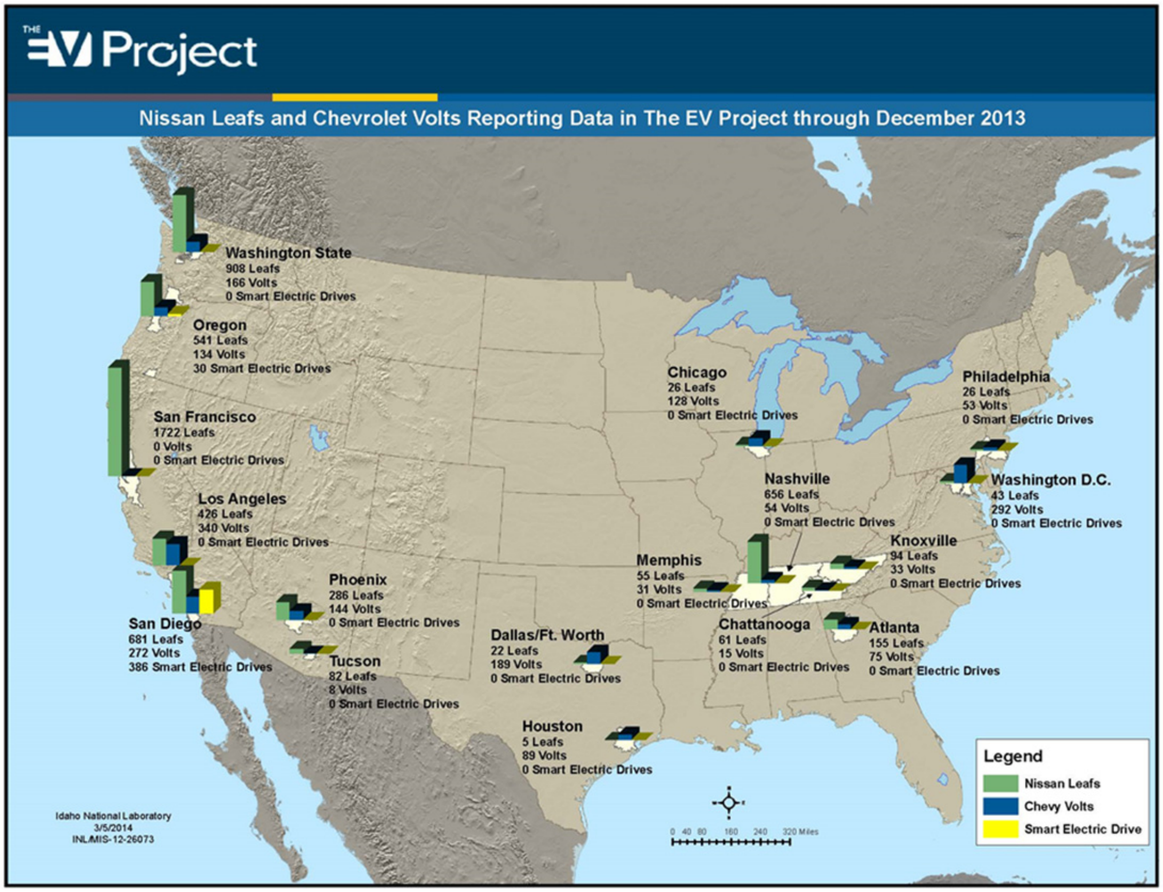


Figure 9-11. Locations and total number of PEVs reporting data in The EV Project through the end of The EV Project, which was December 2013. The map includes PEVs by vehicle model.

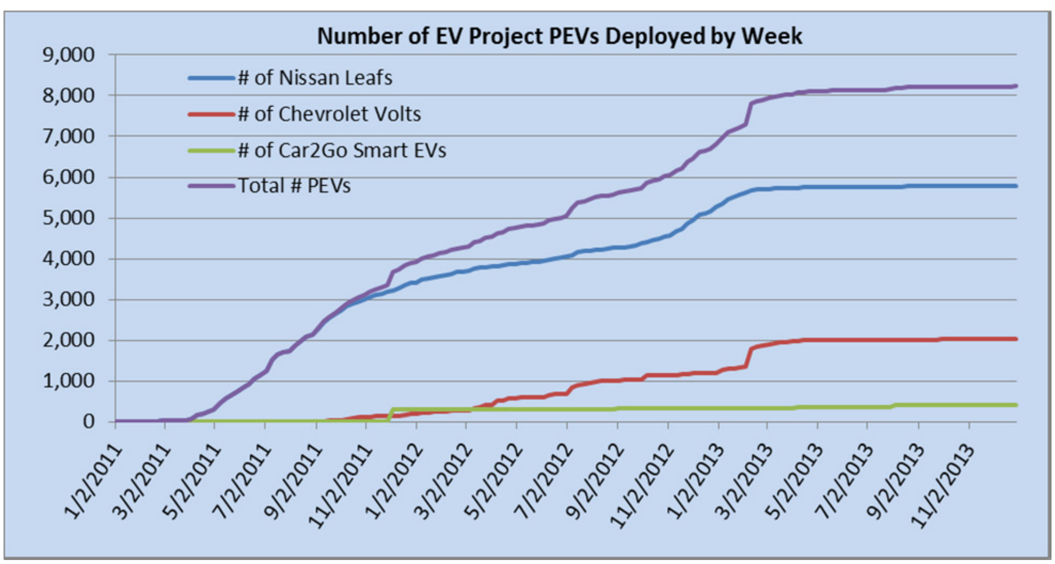


Figure 9-12. Cumulative number (#) of PEVs that were deployed and reported data to INL during the duration of The EV Project.

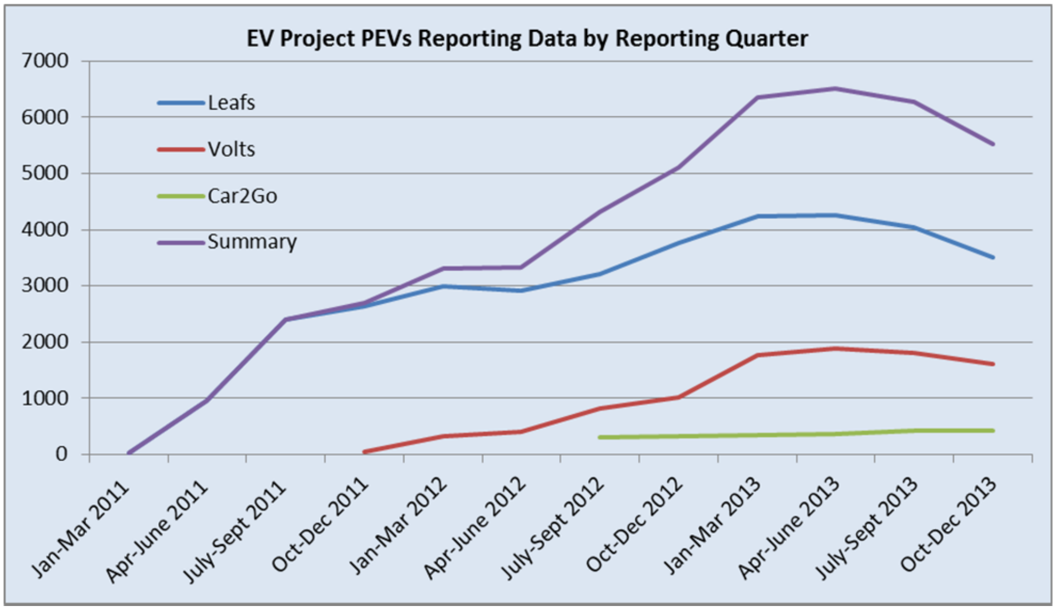


Figure 9-13. Number of PEVs reporting data and included in The EV Project's quarterly reports.

9.4 EV Project Reporting

The primary reporting method for The EV Project was via quarterly reports, which documented both cumulative data collection to-date for each region and nationally. However, unlike other ARRA projects that INL performed analysis and generated reports on, The EV Project had multiple data sources, or data streams, that allowed for combining data streams in order to develop much more reporting detail. For instance, by matching a PEV with a residential EVSE, driver preferences for charging events and locations could be identified by residential versus public charging venues. This included AC Level 2 public charge events versus charge events at DCFC public locations. While a small percentage of EV Project report readers, who were very familiar with The EV Project reports, could glean results, trends, and relationships in how PEV drivers operated and charged their vehicles, most readers preferred some summarization of the results. For this reason, lessons learned white papers were developed as The EV Project progressed. The content of the quarterly reports grew as more PEVs were introduced and the level of detail increased in the individual reports, especially the quarterly infrastructure reports.

Eventually, the quarterly reports were expanded to include regional results, results by EVSE location type (i.e., residential; public; private non-residential, which basically means fleet or work locations; and DCFC, which were always publicly sited), and time-of-day charging availability and demand quartile figures. As The EV Project grew in size, in terms of the number of EVSE and PEVs deployed and producing data and the number of regions increased, the quarterly infrastructure report grew from 2 pages initially to 122 pages of results in each of the last two quarterly reports.

At the end of The EV Project, the quarterly reports had evolved into five standard reports and two different maps. These seven different and unique reports were as follows for the last reporting period:

- Observations from The EV Project: October to December 2013
- Overview Report: Project To-date through December 2013
- Nissan Leaf Vehicle Summary Report: October to December 2013 (pdf) (data)
- Chevrolet Volt Vehicle Summary Report: October to December 2013 (pdf) (data)
- EV Charging Infrastructure Summary Report: October to December 2013 (pdf) (data)

- Blink Charging Units Map – Project To-date through December 2013
- Nissan Leafs and Chevrolet Volts Map – Project To-date through December 2013.

Based on requests by EV Project report readers, reporting for the last six quarters included results in pdf format and the data that populated the pdf results were generated and posted on The EV Project web pages for downloading. Reports having these data included the Nissan Leaf reports, Chevrolet Volt reports, and the EV charging infrastructure summary reports.

The parameters reported in each quarterly report are discussed in Sections 9.4.1 through 9.4.4. The lessons learned reports were unique and are included later in this report.

9.4.1 EV Project Electric Vehicle Supply Equipment and Direct Current Fast Charger Reporting

The primary infrastructure use reporting method was via the EV charging infrastructure summary reports, which documented national and regional results for the following types of siting locations:

- EVSE deployment for the following location categories:
  - Residential AC Level 2
  - Private non-residential AC Level 2, which were installed in limited access locations such as commercial fleet motor pools
  - Publicly accessible AC Level 2
  - Publicly accessible DCFC
  - Total results for all four categories.

All reports can be found on INL's web pages for The EV Project at: http://avt.inl.gov/evproject.shtml. The parameters reported on in the infrastructure reports included the following:

- Number of charging units (connectors)
- Number of charging events
- Electricity consumed (AC MWh)
- Percent of time with a vehicle connected
- Percent of time with a vehicle drawing power
- Time of day vehicles are connected and time of day drawing power in 15-minute increments, both for weekends and weekdays for each 90-day reporting period, graphed by median, maximum, and minimum results and upper and lower quartiles
- The fraction of charging events performed by Leafs, Volts, or unknown vehicles
- The number of charging events performed on weekdays, weekends, and overall.

The data stream from the Blink charging infrastructure was the main source of data that was used to populate the infrastructure reports.

9.4.2 EV Project Nissan Leaf Reporting

The primary Nissan Leaf reporting method was via the Nissan Leaf vehicle summary reports, which documented national and regional results for the following types of vehicle use characteristics:

- Number of PEVs being reported on
- Number of trips
- Total distance traveled (miles)

- Average trip distance (miles)
- Average distance traveled per day when the vehicle was driven (miles)
- Average number of trips between charging events
- Average distance traveled between charging events (miles)
- Average number of charging events per day when the vehicle was driven
- Frequency of charging by charging location
- Number of charging events and the percent of all charging events by the following:
  - Home charging location
  - Away-from-home charging locations
  - Unknown charging locations
- Battery SOC at the start of charging events
- Battery SOC at the end of charging events.

The above information was presented based on data from the Leaf data stream (i.e., Nissan/ CarWings). The Leaf was the only EV Project vehicle model capable of being charged at AC Level 1, AC Level 2, and DCFC. Therefore, it was the only EV Project PEV that used the DCFC infrastructure. AC Level 1 charge levels were basically charges while connected to a 110-volt National Electrical Manufacturers Association receptacle and the receptacles were not equipped with a power meter. However, AC Level 1 charge events and AC Level 2 charge events at EVSE not part of The EV Project could be derived from the absence of a corresponding EV Project AC Level 2 or DCFC record when the vehicles SOC increased between key off and key on events.

9.4.3 EV Project Chevrolet Volts Reporting

The primary Chevrolet Volt reporting method was via the Chevrolet Volt vehicle summary reports, which documented national and regional results for the following types of vehicle use characteristics. In addition to each report identifying whether it covered all or specific regions and the number of vehicles reported on, the design of the Volt's powertrain required additional reporting categories, which included the range-extending gasoline ICE.

- Vehicle usage was reported for each of the following operating modes:
  - EVM operation
  - ERM operation
  - All operation.

The individual parameters presented in each of the three categories were as follows:

1. Vehicle Usage
   - Overall gasoline fuel economy (mpg)
   - Overall electrical energy consumption (AC Wh/mile)
   - Number of trips
   - Total distance traveled (miles)
   - Average trip distance (miles)
   - Average distance traveled per day when the vehicle was driven (miles)
   - Average number of trips between charging events
   - Average distance traveled between charging events (miles)

- Average number of charging events per day when the vehicle was driven

2. EVM Operation
   - AC electrical energy consumption (AC Wh/mile)
   - Distance traveled (miles)
   - Percent of total distance traveled

3. ERM Operation
   - Gasoline fuel economy (mpg)
   - Distance traveled (miles)
   - Percent of total distance traveled.

Other parameters reported on in the Volt reports included the following:

- Number of charging events and the percent of all charging events by
  - Home charging location
  - Away-from-home charging location
  - Unknown charging location
- Percent distance traveled by operating mode (EVM or ERM)
- Frequency of charging by charging location and type
- Battery SOC at the start of charging events
- Battery SOC at the end of charging events.

The above information was presented based on data from the Volt data stream (i.e., OnStar/GM). The Volt was capable of being charged at AC Level 1 and AC Level 2. AC Level 1 charge levels were charges while connected to a 110-volt National Electrical Manufacturers Association receptacle and the receptacles were not equipped with a power meter. However, AC Level 1 charge events and AC Level 2 charge events at EVSE not part of the EV Project could be derived from the absence of a corresponding EV Project AC Level 2 when the vehicles SOC increased between key off and key on events.

9.4.4 EV Project Car2Go Smart Electric Drive Reporting

A stand-alone report was not produced for the Car2Go Smart Electric Drives (Figure 9-14) due to the limited data set INL received for these vehicles. Data received were limited to the individual vehicle miles driven and a unique vehicle identifier. Their access to and use of Blink charging infrastructure was identified by a single fleet account at Blink, not by individual vehicles. However, this allowed identification of when Car2Go Smart Electric Drive vehicles charged at private non-residential AC Level 2 EVSE and publicly accessible AC Level 2 EVSE in Portland and San Diego, which were the only two areas of The EV Project where the Car2Go data were provided. (See pages 5 and 7 of the October to December 2013 EV Project Electric Vehicle Charging Infrastructure Summary Report at: http://avt.inel.gov/pdf/EVProj/EVProjectInfrastructureQ42013.pdf).

9.5 EV Project Results

EV Project results are summarized in the following subsections of this report using results from the quarterly reports. Following the quarterly results sections, infrastructure use for calendar year 2013 is also described. Because some of The EV Project partners provided additional parameters during the duration of The EV Project, the reports became more information rich as the project progressed. This change in parameters did not allow a single final report to be run to the same level of detail as the 2013 report. However, three final reports for calendar years 2011, 2012, and 2013 were developed and published. The additional information generated and reported via the lessons learned white papers are also reported in Section 11 of this document.

Figure 9-14. Smart Electric Drive Vehicles in the Car2Go fleet parked at an EV Project charging site, with multiple AC Level 2 EVSE, in San Diego.

9.5.1 EV Project Charging Infrastructure Quarterly Reporting Results

Finding a single parameter to document what constitutes the best location for siting EVSE and DCFC, or the best EVSE or DCFC power level, or the best type of venue for a charging site is something many ask when contemplating installing EVSE or DCFC. It is not possible to universally define what constitutes the "best" location. To the PEV driver who rarely uses public charging infrastructure, the one time a year he or she needs to charge their PEV in order to make it home, that EVSE or DCFC they find is the "best" one. Conversely, some PEV drivers use both residential and public charging infrastructure to extend the number of electric miles they can drive every day, which may suggest the charging infrastructure near their place of employment or entertainment is "best."

Figure 9-15 documents that the most frequently used charging infrastructure, as measured by the number of units reporting data by reporting quarter, are located at residences. Based on the EVSE that reported use each quarter from the April through June 2012 quarter to the end of The EV Project, it can be stated that residential EVSE were used about 2.3 times more often than public AC Level 2 EVSE, which was the second most frequently used EVSE. However, it must be noted that non-EV Project PEVs also used public EVSE; therefore, EV Project preferences for home charging would, at times, be significantly greater than 2.3 times. The April through June 2012 quarter through the end of The EV Project was used because the April to June 2012 quarter was the first reporting quarter with more than 1,000 public EVSE deployed.

If the average number of individual charge events per reporting quarter for the April through June 2012 quarter to the end of the project was used to determine the best sites for EVSE, residential EVSE were used 8.0 times more frequently (Figure 9-16) than public AC Level 2 EVSE. Comparing residential

EVSE use rates to all other types of charging infrastructure, the residential units are used 7.9 times more often (Figure 9-17). It should be noted that the averages are not weighted averages.

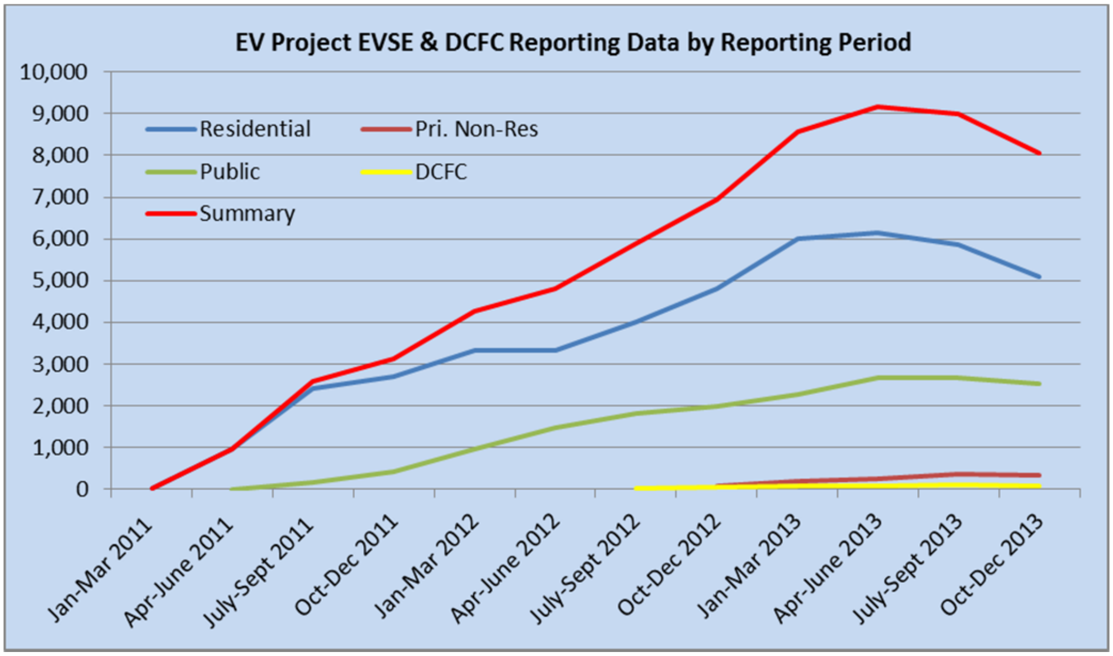


Figure 9-15. Overall number of EVSE and DCFC reporting use data by EV Project reporting quarter. Pri NonRes L2 = private access non-residential AC Level 2 EVSE.

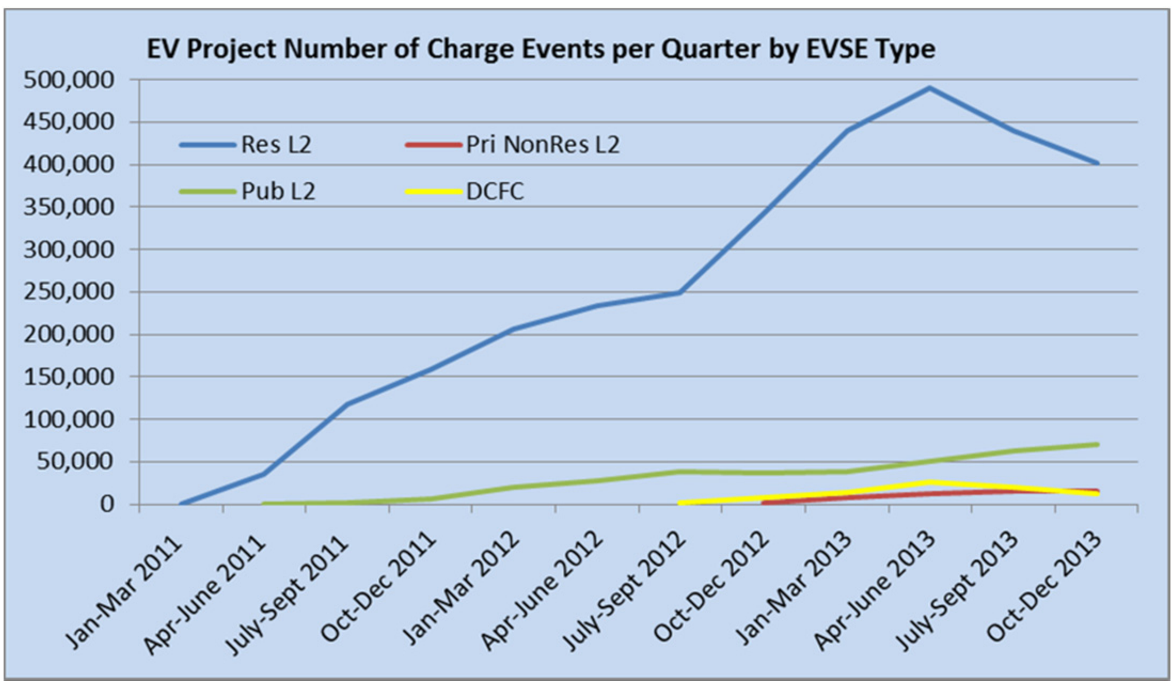


Figure 9-16. Overall number of EVSE and DCFC charge events by EV Project reporting quarter. Res L2 = residential AC Level 2 EVSE, Pub L2 = public access AC Level 2.

For the second quarter 2012 through the end of the project, if the average total energy transferred each reporting period is used to measure the most frequently preferred site for recharging PEVs, residential EVSE transferred 85% of all the energy compared to the other EVSE and DCFC options (Figure 9-18).

While not necessarily a measure of a driver's preference for where they prefer to recharge their PEVs, charging duration can be seen in Figure 9-19. Drivers clearly leave their vehicles "plugged in" most often at residential locations. This is at least partically a function of overnight charging when the drivers are sleeping.

Figure 9-20 highlights the percentage of time a vehicle is drawing power, or actually recharging, at the various types of charging locations. During 2013, 8.3% of the time, the EVSE at private non-residential sites were providing power to vehicles, while the percentage at residences was 8% of the time. Public AC Level 2 EVSE were used to transfer energy to PEVs 2.3% of the time and DCFC transferred energy 3.3% of the time.

As can be seen in Figure 9-21, the actual hours per day that a vehicle was connected to charging infrastructure varied significantly by EVSE type. The residential AC Level 2 EVSE had a vehicle connected to them an average of 11.3 hours per day; the private non-residential AC Level 2 EVSE averaged 8.4 hours per day; the public AC Level 2 EVSE averaged 5.5 hours per day; and the DCFC averaged 0.35 hours per day.

The bulk of the hours a PEV was connected to a residential EVSE was during the evening and overnight hours. The private non-residential EVSE were connected to a vehicle about the length of a typical workday (i.e., about 8 hours per day). However, these connection times may have included multiple vehicles per day. The 5.5 hours per day that public EVSE had vehicles connected mostly occurred during the workday, predominately on weekdays. This may be tied to a combination of parking for shorter shopping trips and workers using public parking to charge their vehicles during the workday.

Some EVSE installed at workplaces were available for use the by the general public; therefore, they were classified as public EVSE. Finally, the brief 20.9 minutes a day DCFC had vehicles connected and the even slightly shorter period of time the DCFC provided power to a vehicle would strongly support the theory that drivers arrived at DCFC, charged their PEV, and then immediately departed. It should be noted that the averages described here are not weighted averages.

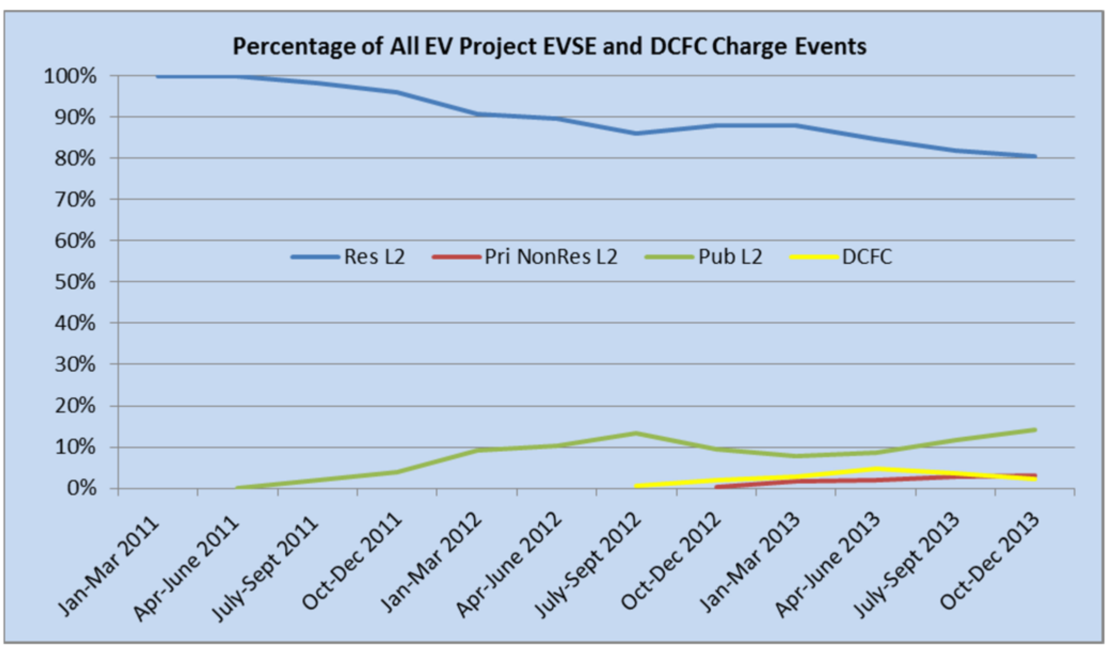


Figure 9-17. Overall percentage of all EVSE and DCFC charge events by EV Project reporting quarter.

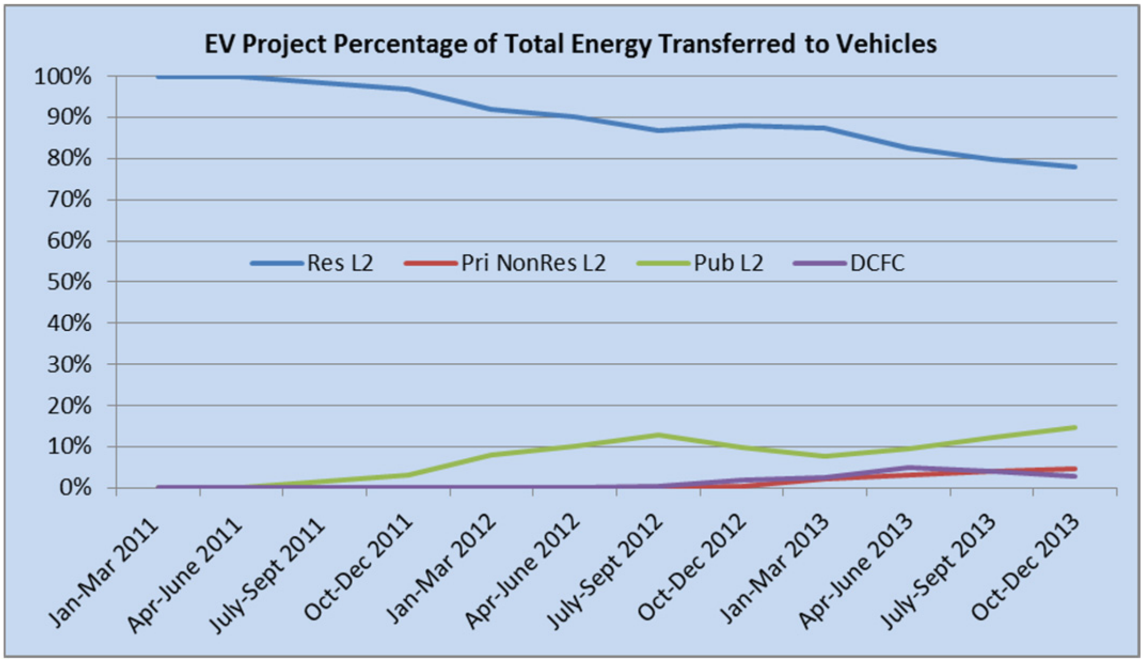


Figure 9-18. Percentage of energy transferred to vehicles reported per period for each EVSE during each EV Project reporting quarter.

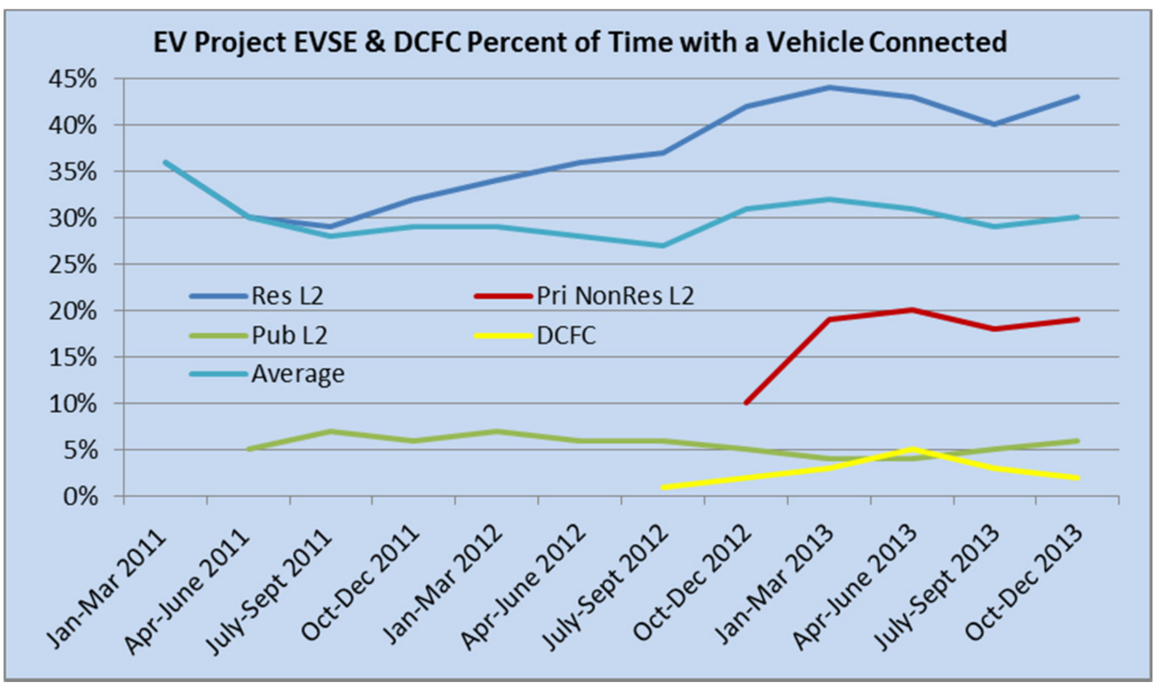


Figure 9-19. Percentage of energy transferred to vehicles reported per period for each EVSE during each EV Project reporting quarter.

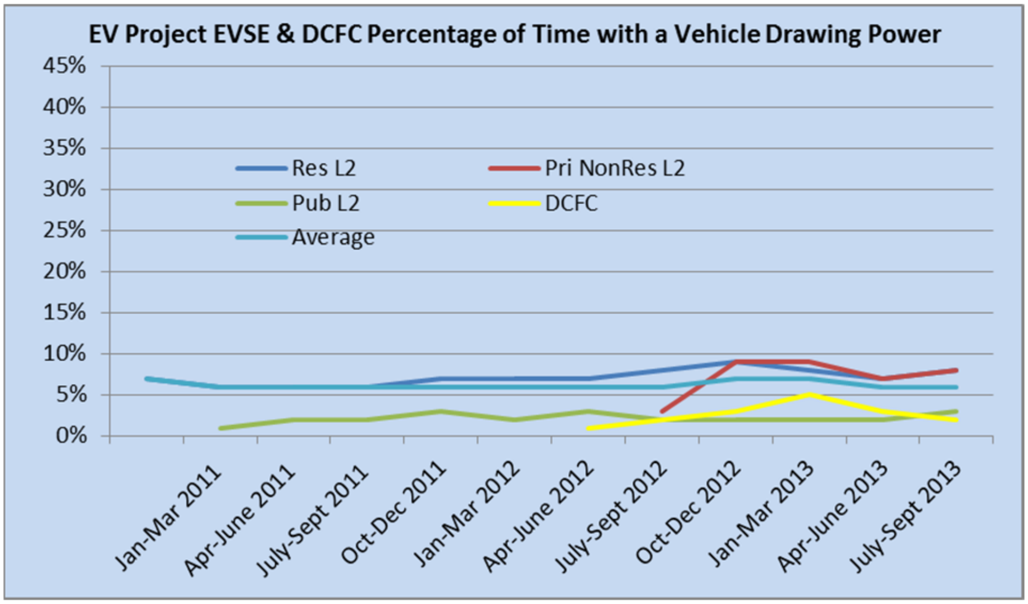


Figure 9-20. Percentage of time for individual charging units with a vehicle drawing power from an EVSE during each EV Project reporting quarter.

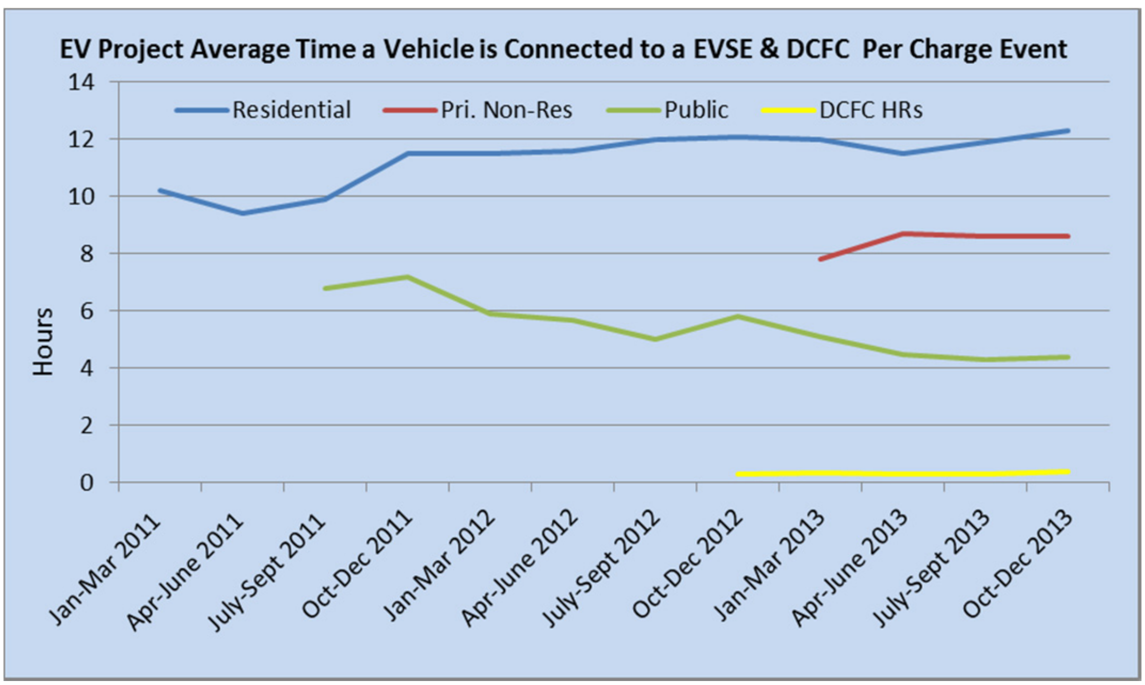


Figure 9-21. The length of time in hours per EVSE with a vehicle connected to an EVSE or DCFC during each EV Project reporting quarter.

Figure 9-22 documents the average time an EVSE and DCFC provided power to a PEV. While the scale used may imply some large differences, the actual average time drawing power was not that large for the AC Level 2 EVSE units. The private non-residential EVSE had a power draw for an average of 3.55 hours, 2.22 hours for a residential EVSE, and 2.18 hours for public EVSE. DCFC had a power draw for charging of 0.35 hours (20.8 minutes). It should be noted that these averages are not weighted averages.

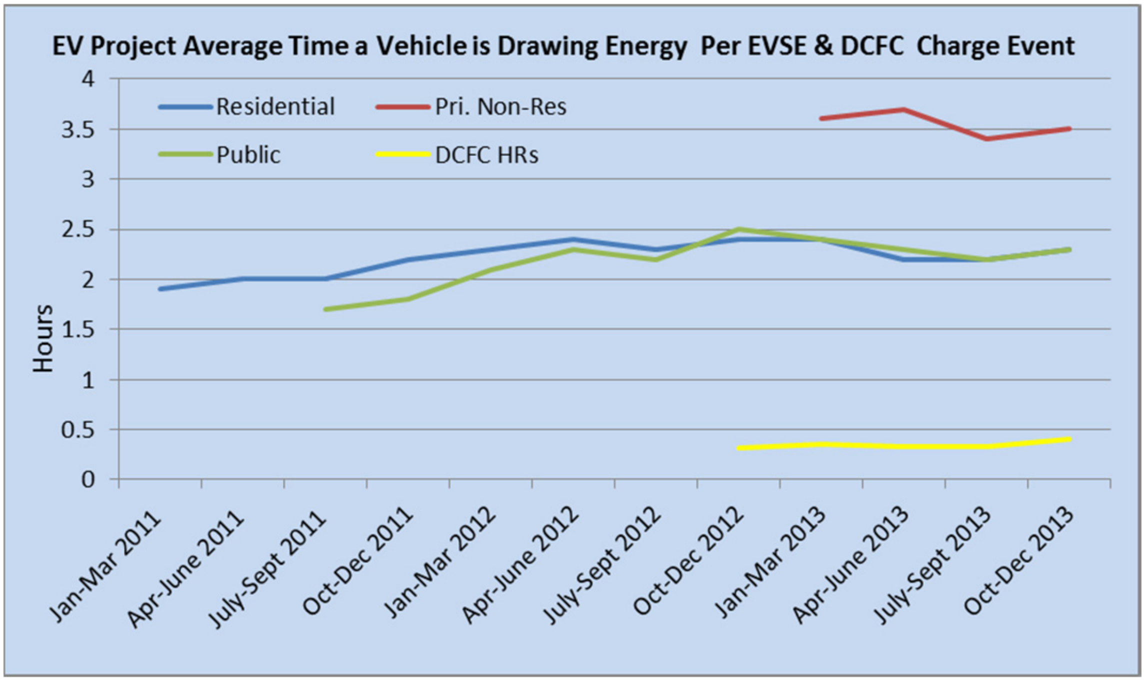


Figure 9-22. The length of time per EVSE, in hours, with a vehicle pulling power from an EVSE or DCFC unit during each EV Project reporting quarter.

Figure 9-23 shows a tighter spread in the amount of AC kWh energy transferred by the charging infrastructure during each charge event. The private non-residential EVSE averaged 11.6 AC kWh of energy per charge event; this was the highest average. A very high percentage of unidentified vehicles used the EVSE infrastructure at the private non-residential sites; there may have been larger non-project vehicles such as Smith Electric or some other brand of electric trucks with much larger battery packs using the infrastructure. The residential EVSE averaged 7.77 AC kWh per charge event, while the public EVSE averaged 7.73 AC kWh per charge event. It is unknown if this closeness was due to drivers driving round trips to and from work and charging at public EVSE while working, with the return drive home likely being the same distance that was followed by charging at the residences when arriving home. Or drivers may simply have become accustomed to recharging their PEVs at the same level SOC regardless of where they charged. It should be noted that the residential EVSE, public EVSE, and DCFC all had noticeable upward slopes in the average amount of energy transferred per charge event during the duration of The EV Project. It should be noted that these averages are not weighted averages.

The AC Level 2 EVSE all experienced fairly constant rates of charge events per day per EVSE (Figure 9-24). Residential EVSE had the highest daily use of AC Level 2 EVSE, averaging about 0.80 charge events per day. The private non-residential AC Level 2 EVSE had the second highest use of AC Level 2 EVSE at 0.55 charge events per day per unit. The public EVSE had the fewest at 0.25 charge events per day per unit. It should be emphasized that these results are on a per individual EVSE basis, not on a site basis. The importance here is that a residential location would only have one EVSE per PEV in The EV Project. However, a public site often had numerous AC Level 2 EVSE at each site (Figures 9-25 through 9-27) and the total group of EVSE at a site may be used frequently; however, some individual EVSE at a public site may have had very low usage rates. DCFC were considerably more popular than AC Level 2 public EVSE on a per-unit basis. The sharp decline in DCFC use during the second reporting quarter of 2013 coincided with the introduction of Blink Network DCFC usage fees.

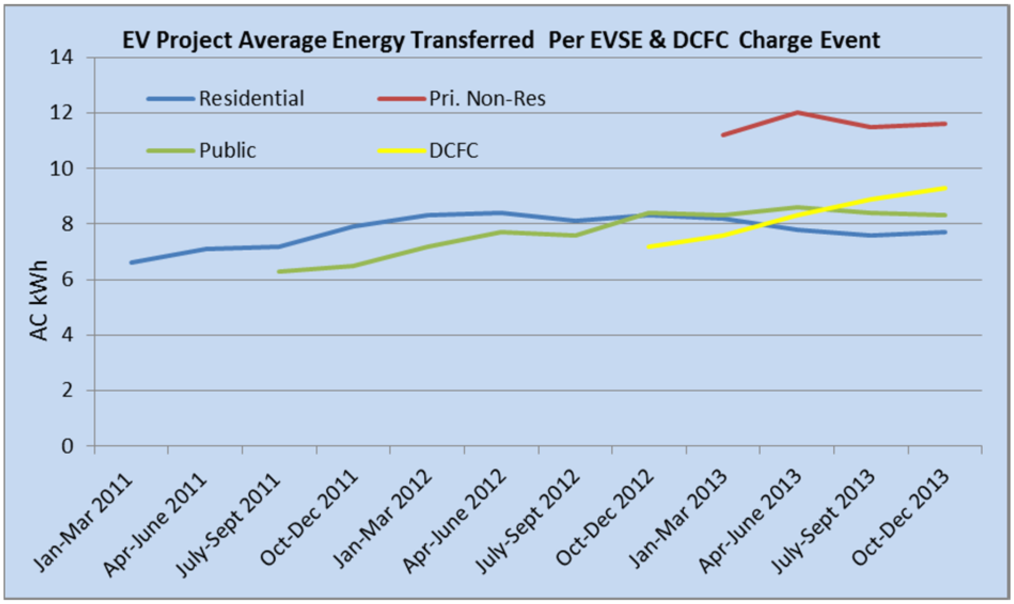


Figure 9-23. The average energy transferred per charge event in AC kWh during each EV Project reporting quarter.

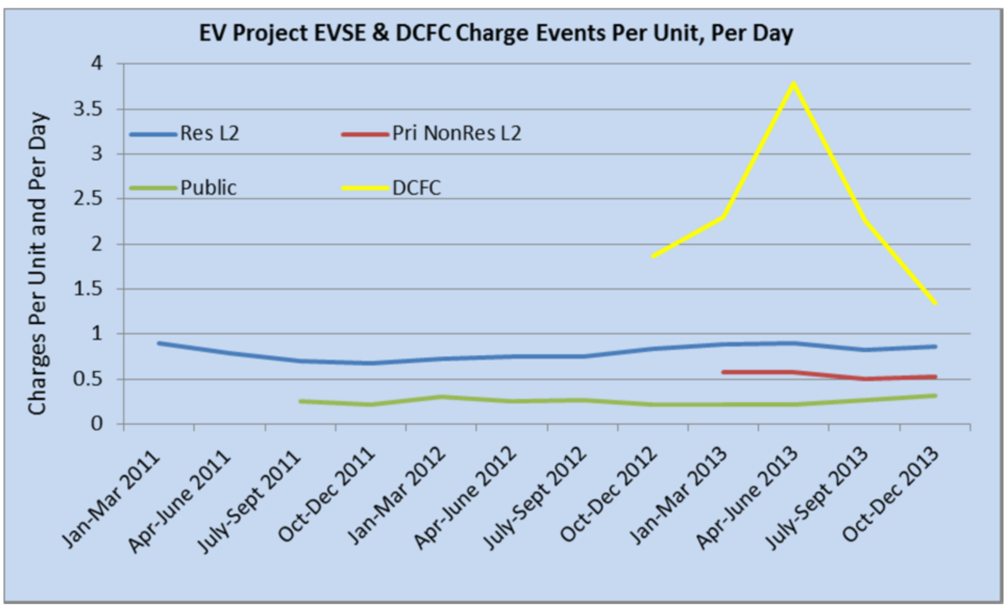


Figure 9-24. The length of time, in hours, with a vehicle connected to an EVSE or DCFC during each EV Project reporting quarter.

Figure 9-25. Multiple EV Project AC Level 2 EVSE installed at a department store parking lot.

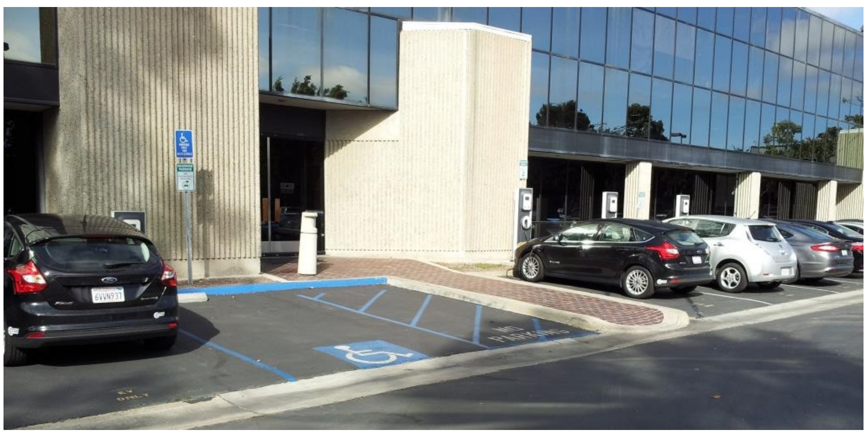


Figure 9-26. Multiple EV Project AC Level 2 EVSE installed at an office building parking lot.

Figure 9-27. Multiple EV Project AC Level 2 EVSE installed at an office building parking lot.

9.5.2 EV Project Nissan Leaf Quarterly Reporting Results

A total of 5,789 unique Nissan Leafs provided operational data to INL during the duration of The EV Project. However, based on results for the quarterly reports, at no time during the project duration were all 5,789 Leafs providing data at the same time. The peak reporting quarter for the Leafs was during the second quarter of 2013, when data were received for 4,261 Leafs (Figure 9-28). The number of Leafs reporting data during any one quarter was given by several factors, including the following (which was discussed earlier):

- Vehicles were damaged in accidents
- Owners moved outside The EV Project areas
- Owners sold their Leafs to new owners outside The EV Project areas
- Owners did not agree to continue providing data beyond the original 2-year period
- New Leafs were purchased and added to the project throughout the duration of The EV Project.

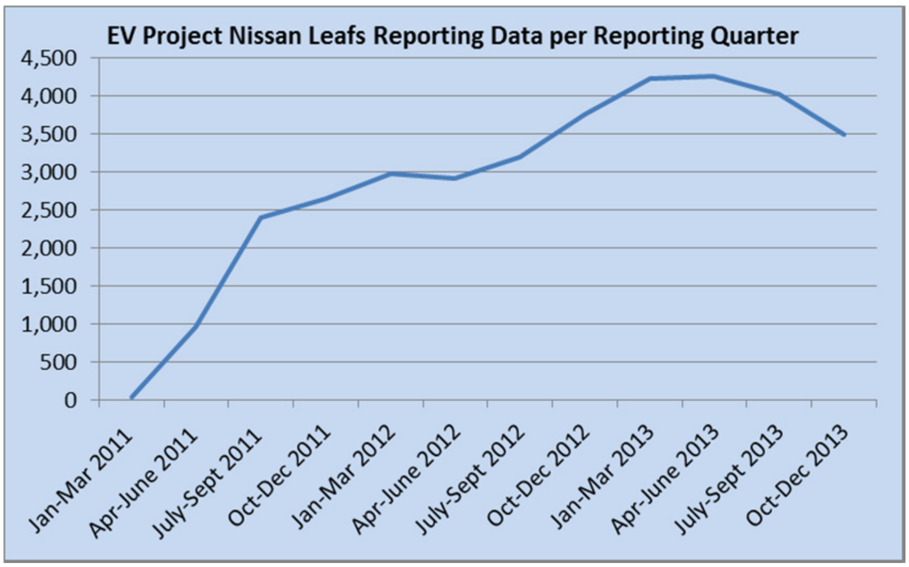


Figure 9-28. Number of Nissan Leafs providing data to INL during The EV Project, by reporting quarter.

Of all regions where the Leafs were participants for The EV Project, the San Francisco area clearly represented the highest number of Leafs providing data for every reporting quarter (Figure 9-29). During the second quarter of 2013, a total of 1,311 Leafs in San Francisco reported data. This was almost twice as many as the next highest provider of Leaf data, which was Washington State's total of 658 Leafs during the same reporting quarter. Throughout the project, San Francisco's contribution to reporting Leaf driver behaviors averaged about 30% (Figure 9-30).

As would be expected, the number of trips reported by Nissan Leafs during each reporting quarter and the number of total trips taken (Figure 9-31) mirrors the number of Leafs (Figure 9-29) in each region in The EV Project. Similarly, the number of total miles driven per reporting quarter (Figure 9-32) also has similar curves to the number of Leafs and total trips taken.

Note that for Figures 9-29 through 9-39, quarterly results are only discussed for the fourth quarter of 2011 through the fourth quarter of 2013 reports, when the number of Leafs reporting data was highest.

The average trip distance over the duration of The EV Project hovered above and below 7 miles (Figure 9-33). Because of the scale of the graph, the regional variations look significant, but the variations by region were mostly plus or minus 1 mile per trip. What drove the variations of average trip distances could be a function of many things, including population densities, drivers in different regions choosing to live and work in different types of areas (suburbia versus inner city), the densities of shopping locations, and likely the availability of affordable housing.

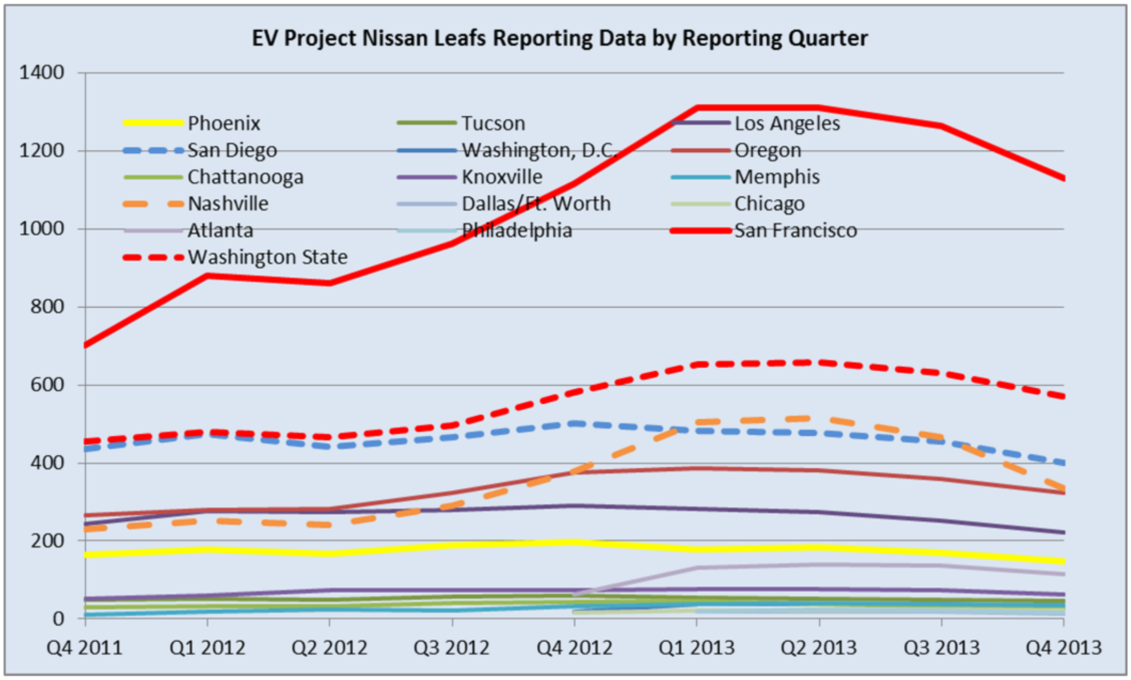


Figure 9-29. Number of Leafs reporting operational data during each reporting quarter throughout The EV Project.

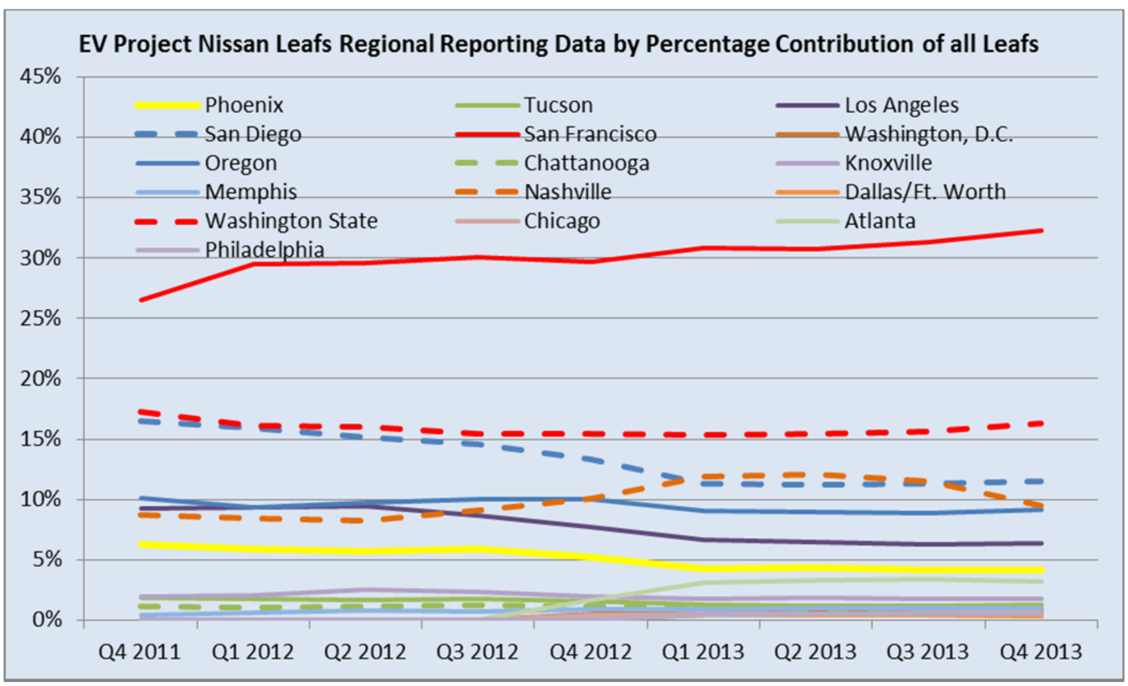


Figure 9-30. The percentage of Leafs reporting data by each reporting period compared to the total number of Leafs reporting data each reporting period during The EV Project.

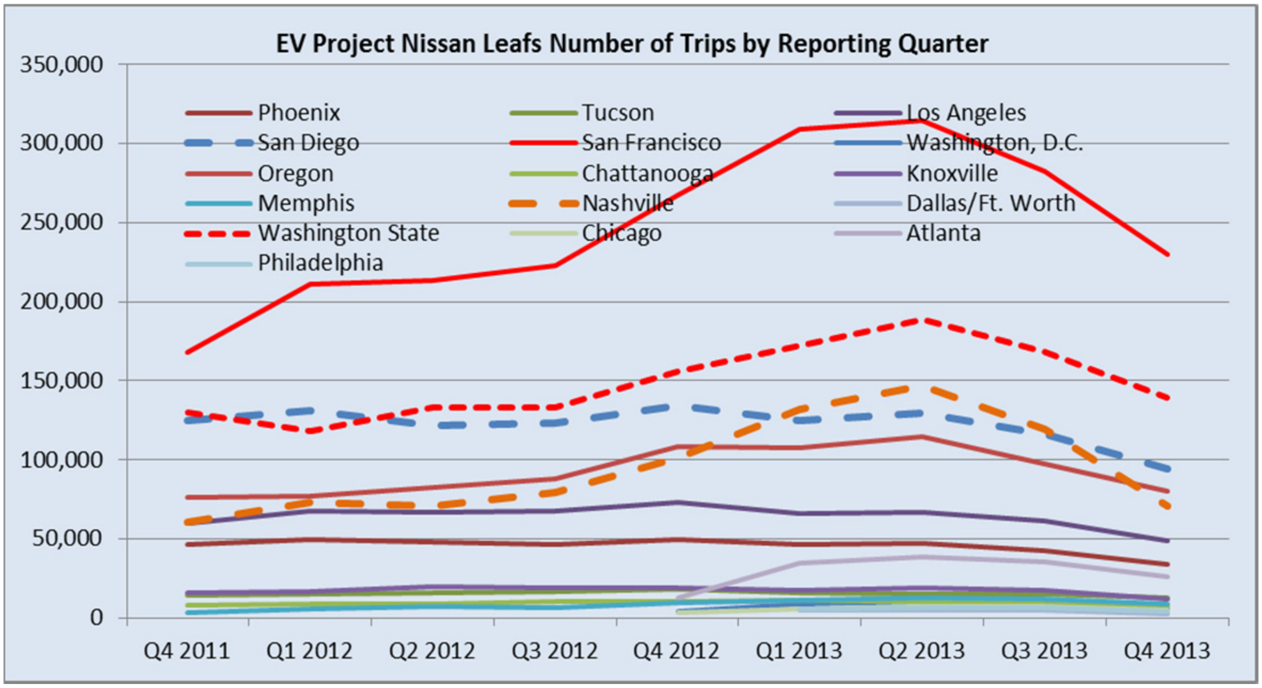


Figure 9-31. Number of Nissan Leaf trips by reporting quarter for The EV Project.

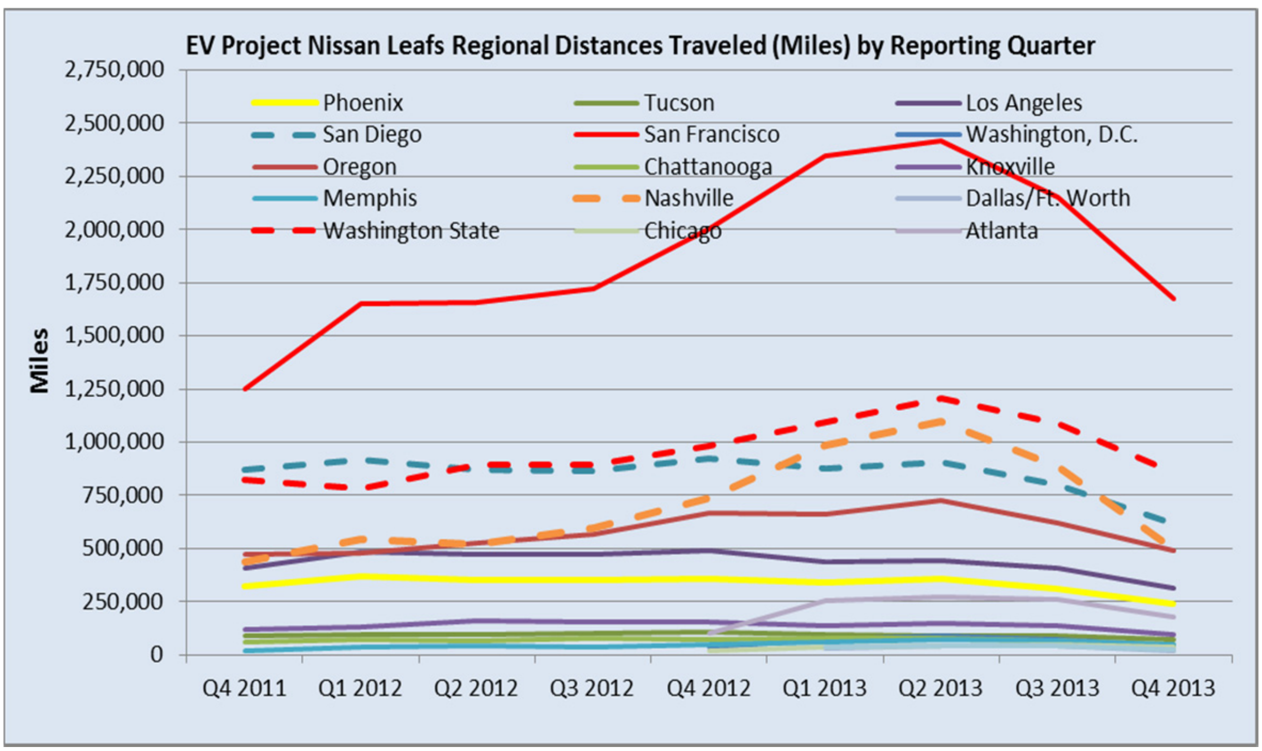


Figure 9-32. Number of miles reported as being driven by the Nissan Leafs per each EV Project reporting quarter.

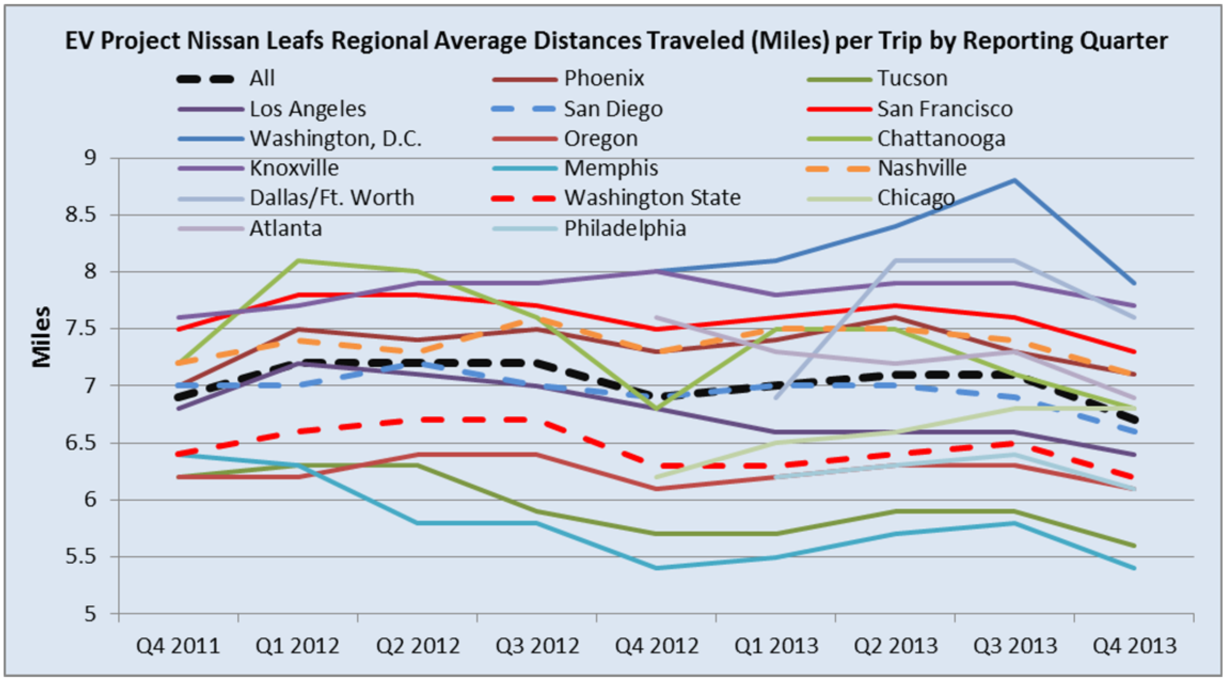


Figure 9-33. Nissan Leaf drivers' trip distance profiles by each region for all of The EV Project reporting quarters.

The miles driven per day, on days the Leafs were driven, averaged on a non-weighted basis about 29 miles per day. Looking at the "All" data in Figure 9-34, the earliest quarterly reports showed an average daily distance of slightly more than 30 miles per day and the last few report quarters had average distances of 29 miles or less per day driven. While 1 mile per day is not a large variation, the overall downward slope of the curves is apparent in all of the regions. Some might argue that the earliest Leaf drivers were early adopters who tended to be "hyper-milers," while the more "mainstream" drivers tended to enter the program later in the duration of the project. This argument will be left to the reader to resolve, because INL does not have the data needed to definitively answer this question. As discussed before, the variables that influenced regional average distances per trip likely also influenced the average miles driven per day. Average miles driven per day do not include the days when the vehicles were not driven at all.

As seen in Figure 9-35, the non-weighted average number of trips between driving events was 3.8 for the life of The EV Project. Tucson and Memphis had the most trips between charging events.

The amount of charging infrastructure installed and reporting use data (Figure 9-36) did not appear to influence the number of trips between charging events. This would suggest that the richness of charging infrastructure may not play as large a role in PEV use as would be assumed. Going back to Figure 9-33, Tucson and Memphis had some of the lowest miles driven per day, while Knoxville and Washington D.C. had some of the highest miles driven per day, yet Knoxville had the most EVSE installed and Washington D.C. about the least. Likely, the demographics of home versus work locations and the distances from schools, shopping, and errand locations from home and work locations had large influences on how Leafs were used and how many miles were driven and trips were taken per charge event.

As seen in Figure 9-37, there was an overall decrease in the distance traveled per charge event for the Nissan Leafs reporting data both nationally and in most of the regions during the nine reporting quarters. This is likely due to the decrease in miles driven per reporting quarter and increasing deployment of public EVSE, which translated to more charging opportunities.

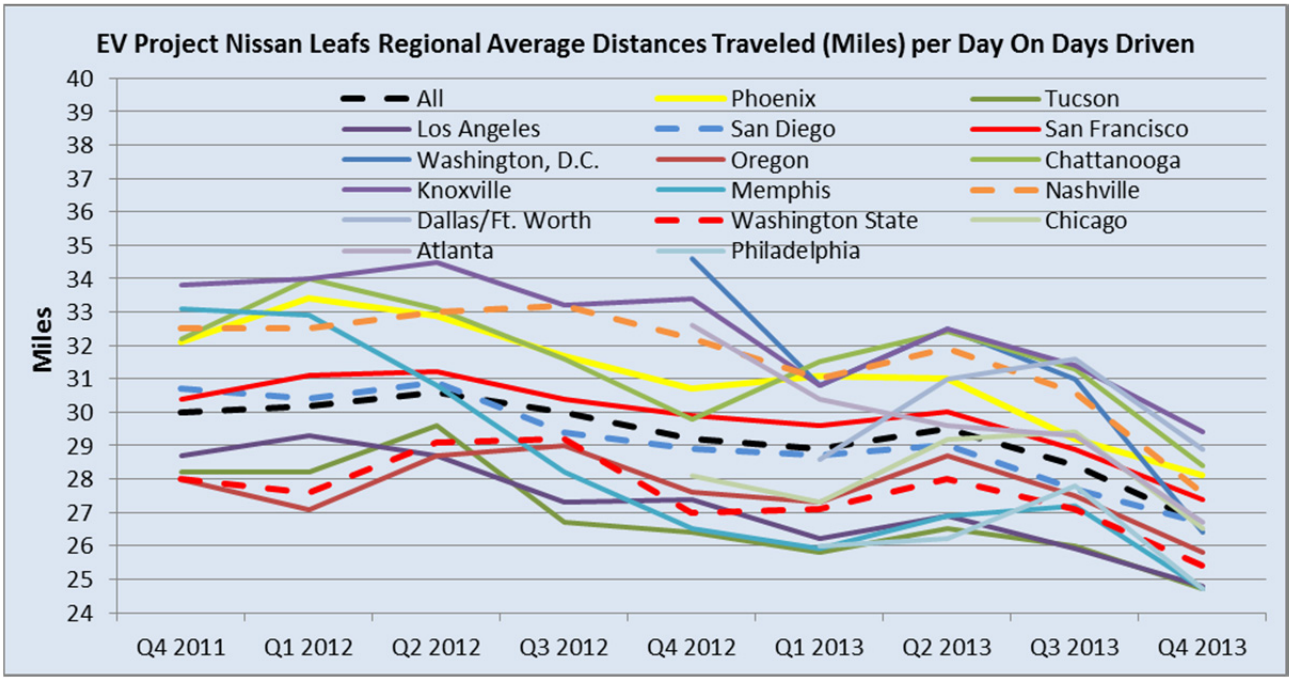


Figure 9-34. Average distances (miles) the Nissan Leafs were driven each day that they were driven by reporting period.

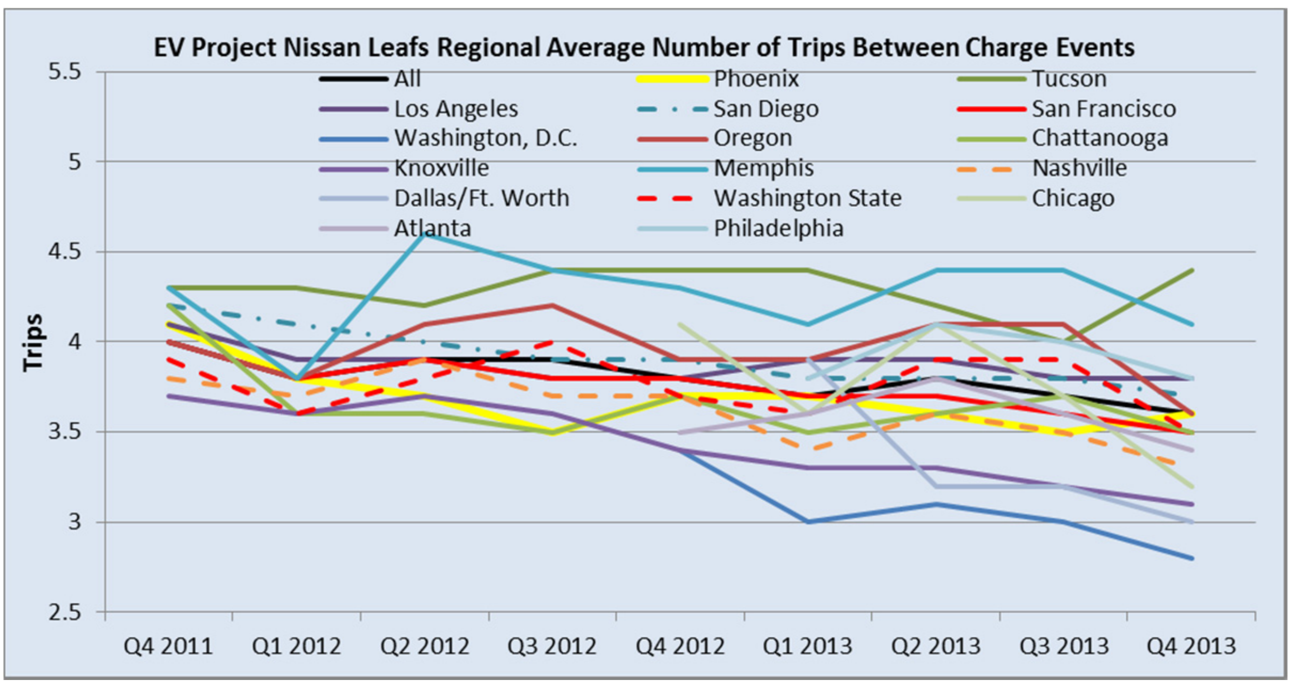


Figure 9-35. Average number of trips between charge events that were driven by Nissan Leaf owners in The EV Project, by reporting period and region.

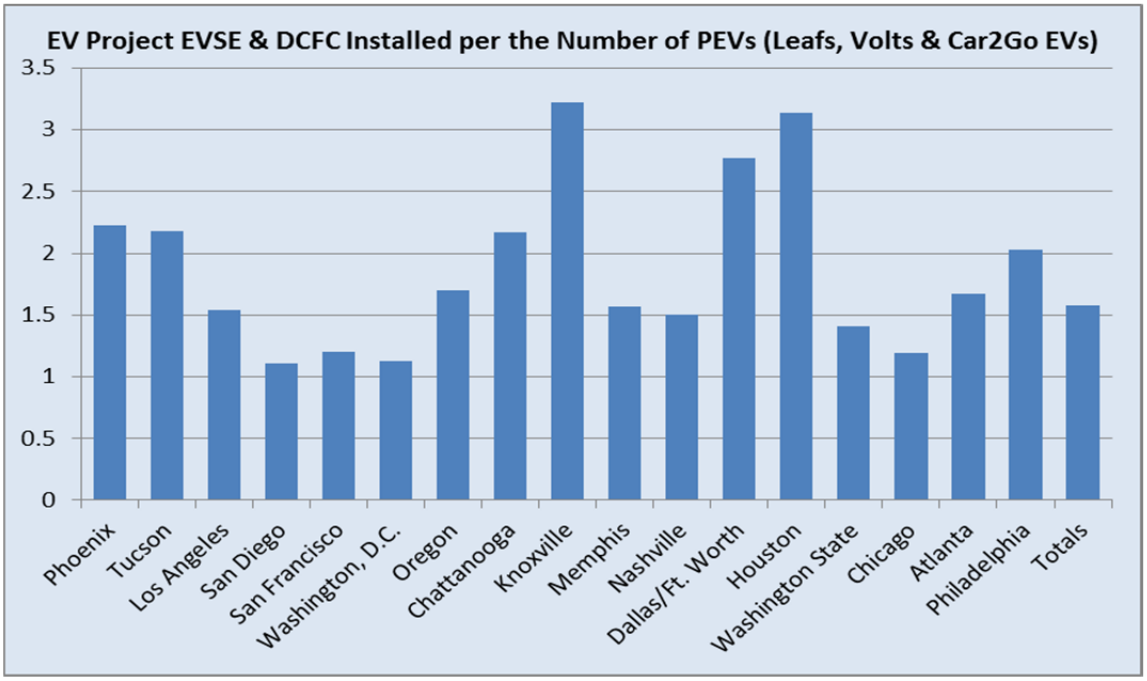


Figure 9-36. Number of EV Project installed EVSE and DCFC reporting data throughout the duration of the project per PEV (includes Nissan Leafs, Chevrolet Volts, and Car2Go EVs) reporting data throughout the duration of the project.

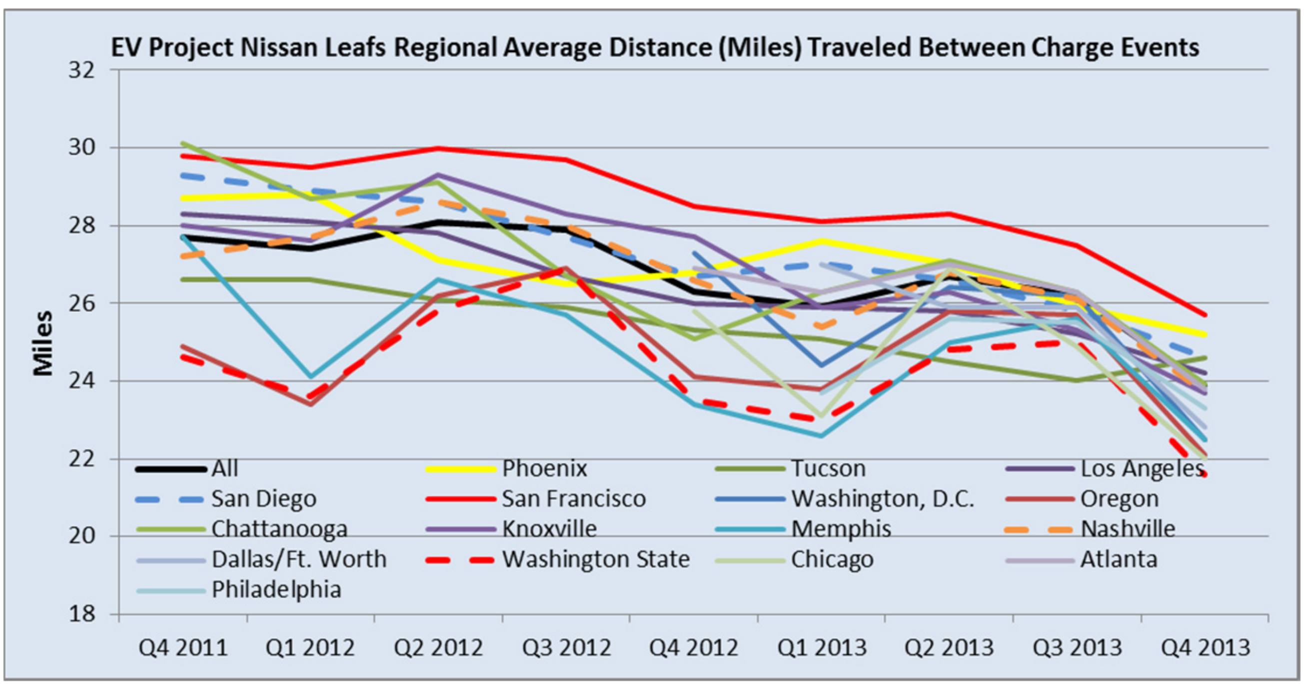


Figure 9-37. Average regional distance, in miles, EV Project Nissan Leafs were driven between charging events.

9.5.3 EV Project Chevrolet Volt Quarterly Reporting Results

A total of 2,023 Chevrolet Volts provided operational data to INL during the The EV Project. However, based on the results for the quarterly reports, at no time during the project duration were all 2,023 Volts providing data simutaneously. The peak reporting quarter for the Volts was during the second quarter of 2013, when data were received for 1,895 Volts (Figure 9-38). The number of Volts reporting data during any one quarter was driven by several factors, including the following:

- Vehicles that were damaged in accidents
- Owners moved outside EV Project areas
- Owners sold their Volts to new owners outside The EV Project areas
- Owners did not agree to continue providing data beyound the original 2-year period
- New Volts were purchased and added to the project at different times.

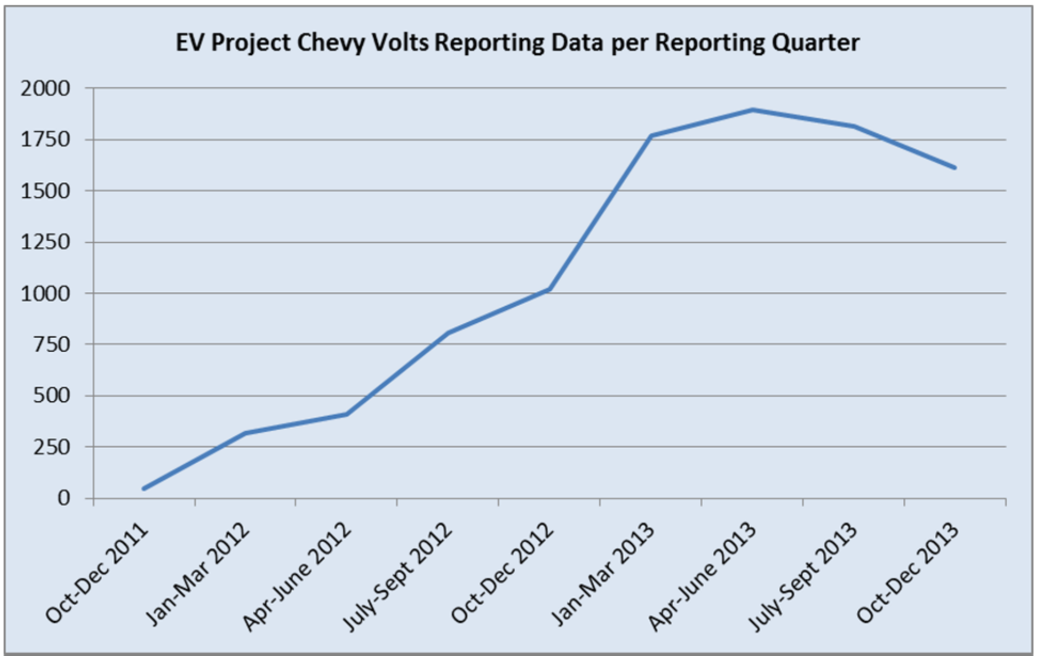


Figure 9-38. Number of Chevrolet Volts providing data to INL during The EV Project by reporting quarter.

Of all regions in The EV Project where Volts were participants, the Los Angeles area represented the highest number of Volts providing data toward the end of The EV Project (Figure 9-39). During the second quarter of 2013, a total of 320 Volts in Los Angeles reported data. This was 20% higher than the next highest provider of Volt data, which was the Washington D.C. area's total of 266 Volts during the same reporting quarter. During the second quarter of 2013, all reporting regions had their maximum number of Volts reporting data to INL via OnStar. Los Angeles, Washington D.C., and San Diego had the most Volts providing data (Figure 9-40).

As would be expected, the number of trips reported for the Volts during each reporting quarter (Figure 9-41) and the number of total miles driven per reporting quarter (Figure 9-42) have similar curves to the number of Volts reporting data.

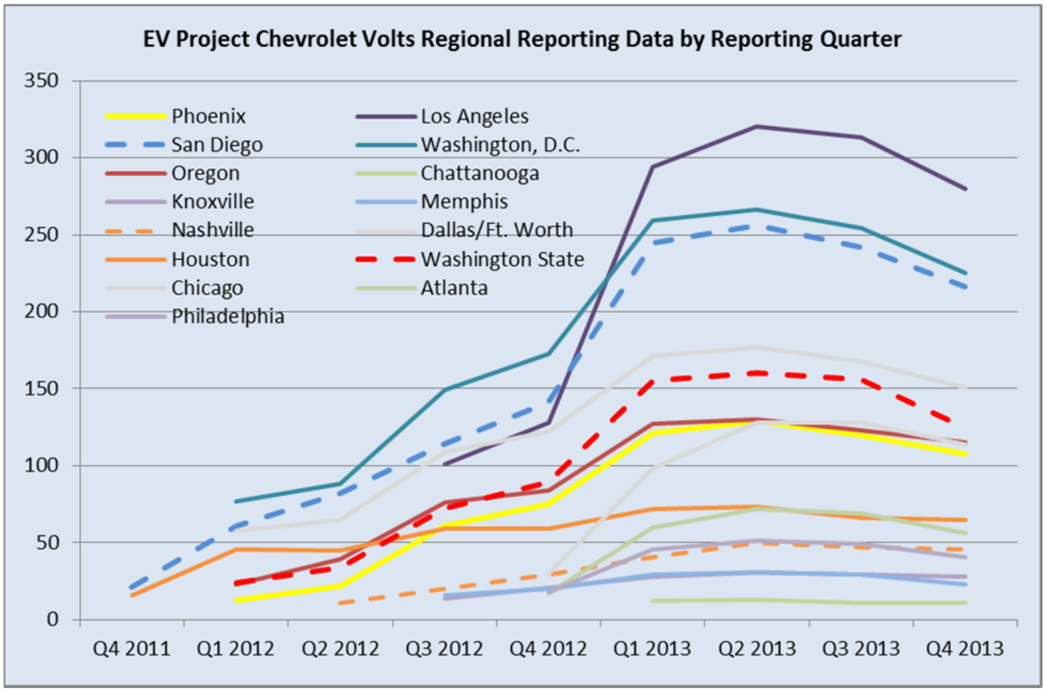


Figure 9-39. Number of Volts reporting operational data during each reporting quarter throughout The EV Project.

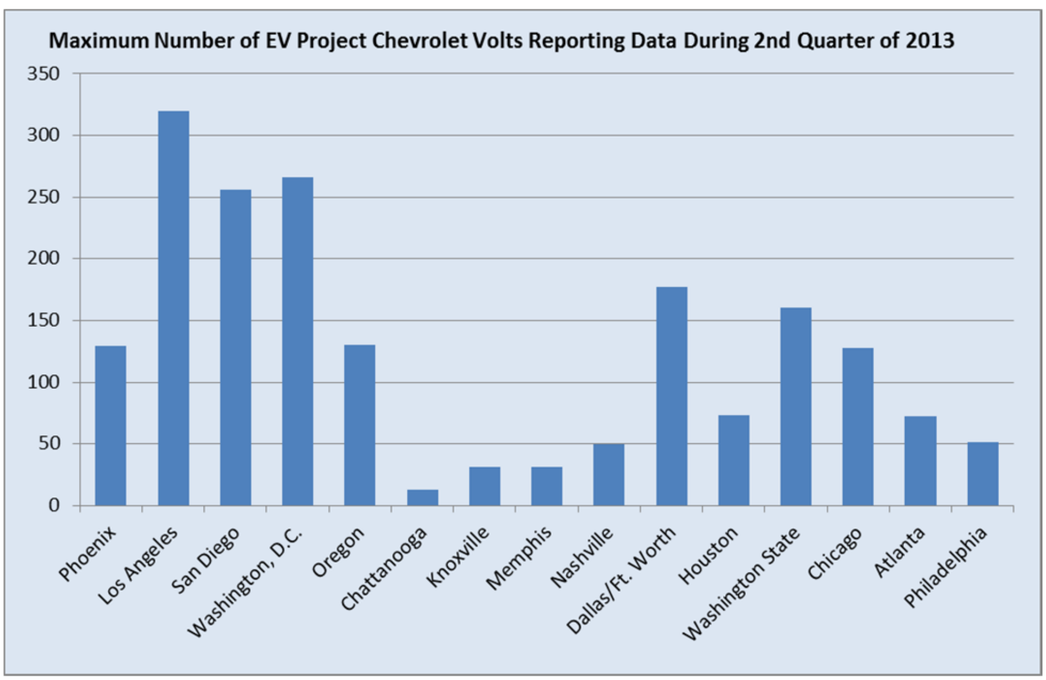


Figure 9-40. Number of Chevrolet Volts reporting data for all EV Project regions during the second reporting quarter of 2013, which was the quarter with the maximum number of Volts reporting data.

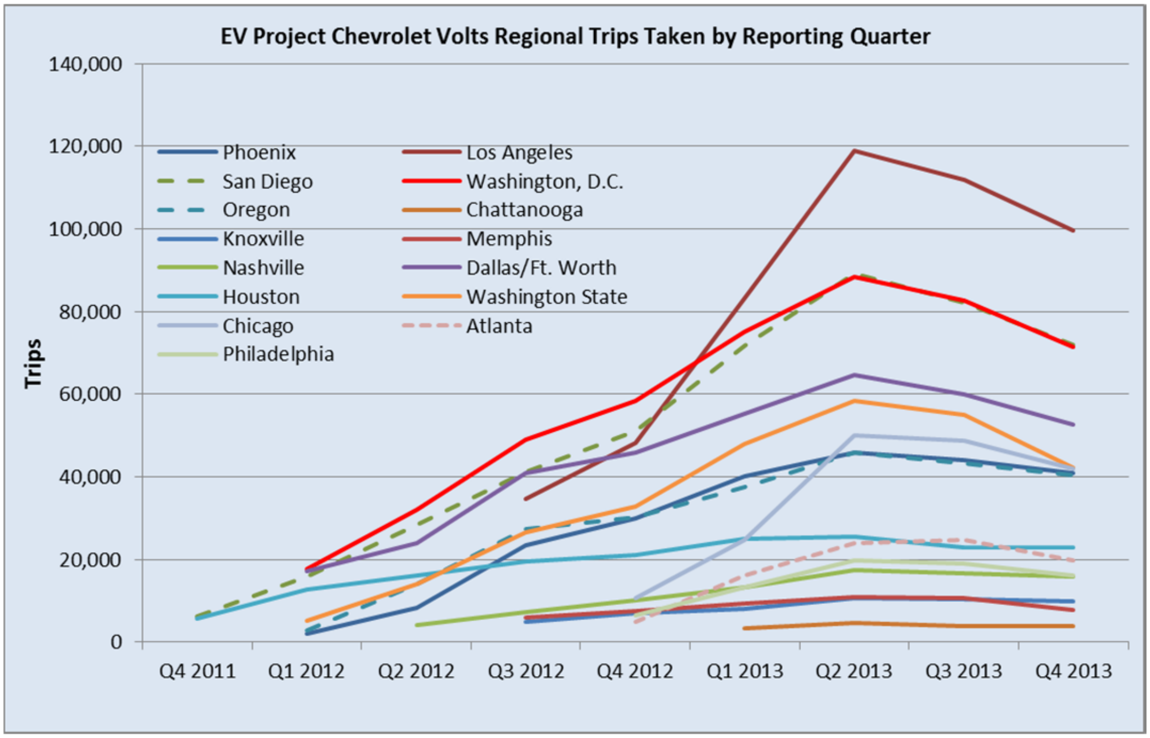


Figure 9-41. Number of Chevrolet Volts trips by reporting quarter for The EV Project.

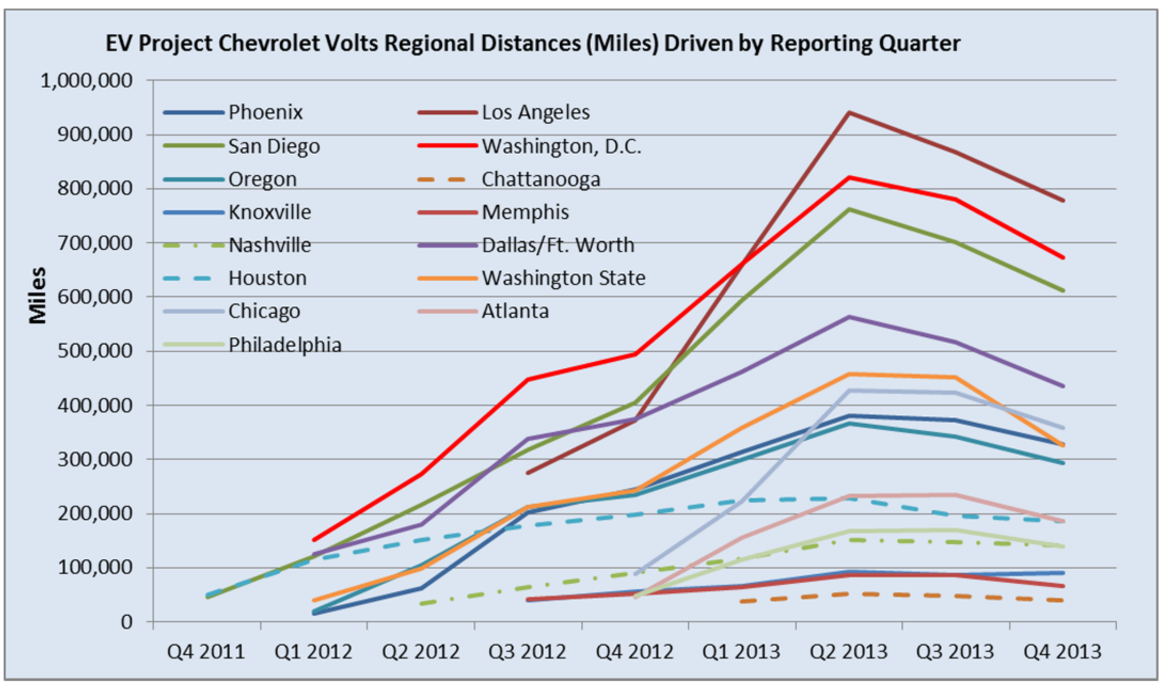


Figure 9-42. Number of miles reported as being driven by Chevrolet Volts per each EV Project reporting quarter.

The average Volt trip distance over the duration of The EV Project was generally slightly above 8 miles (Figure 9-43). Because of the scale of the graph, the regional variations look significant; however, variations by region were mostly plus or minus approximately 1 mile per trip. The exception to this is

Chattanooga, which averaged slightly over 11 miles driven per trip. It should be noted that the Chattanooga sample of Volts during The EV Project was never greater than 13 per reporting period. What drove variations in average trip distances could be a function of many things, including population densities, the different choices of drivers in different regions about where to live and work (suburbia versus inner city), the densities of shopping locations, and availability of affordable housing.

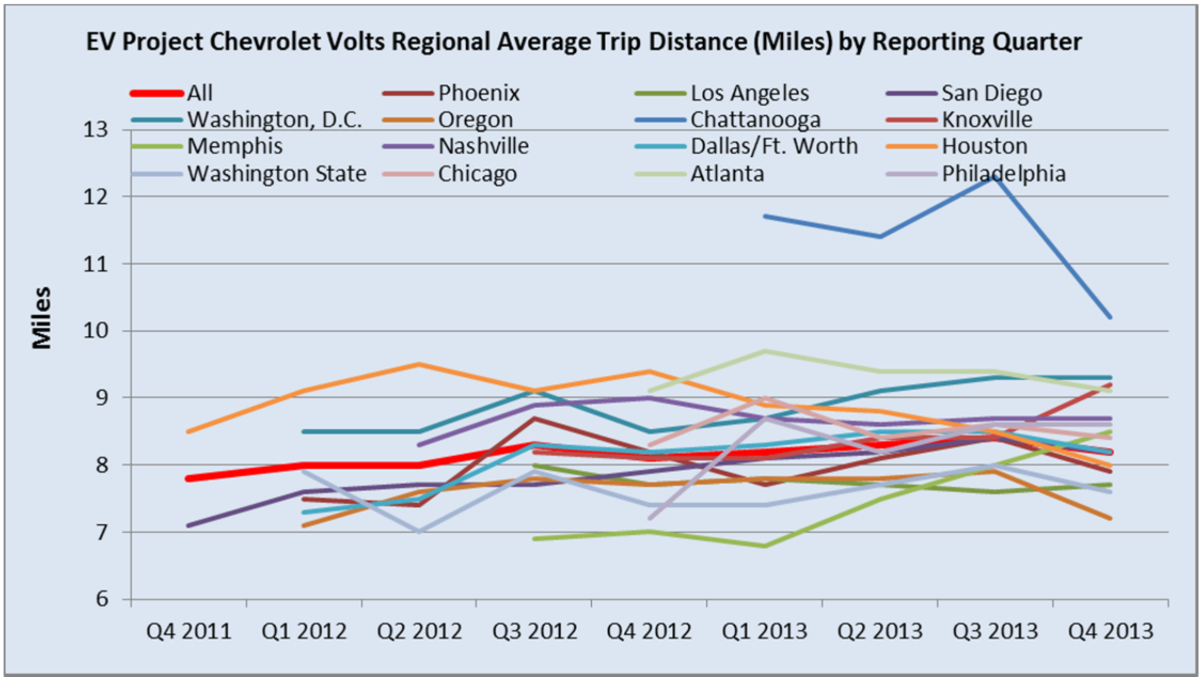


Figure 9-43. Average trip distance profiles for Chevrolet Volt drivers by each region for all EV Project reporting quarters.

The Volt miles driven per day, just for days the Volts were driven, averaged on a non-weighted basis about 40 miles per day. The outlier again appears to be Chattanooga, with its very small sample of vehicles, where Volts drivers averaged slightly more than 50 miles per day. Looking at the “All” data in Figure 9-44, the earliest quarterly reports showed an average daily distance of slightly less than 40 miles per day and the last few quarters had average distances of slightly more than 40 miles per day. This might suggest that the earliest Volt drivers in The EV Project were not early-adopters who tended to be “hyper-milers.” The variables that influenced regional average distances per trip likely also influenced the average miles driven per day. Average miles driven per day do not include the days when the vehicles were not driven at all. As seen in Figure 9-45, the non-weighted average number of Volt trips between driving events was 3.3 for the life of The EV Project. Los Angeles had the most trips between charging events.

On an unweighted basis, The EV Project Volts were driven, on average, slightly more than 27 miles per charge event (Figure 9-46). Chattanooga had the highest average miles per charging event at 40 miles per charge. The States of Oregon and Washington had the least miles driven per charge event, both at slightly more than 24 miles. These distances can be the result of several influences, including how much charging infrastructure exists, normal driving distances, and how near to work and shopping locations is one’s home. Nationally, the Volts in The EV Project were charged 1.46 times per day on the days they were driven. The States of Oregon and Washington had charge rates on the days they were driven of 1.54 and 1.6, respectfully. Chattanooga and Los Angeles both averaged 1.3 charge events per day on days driven. It should be noted again that the sample size of EV Project Volts reporting data in Chattanooga was very small.

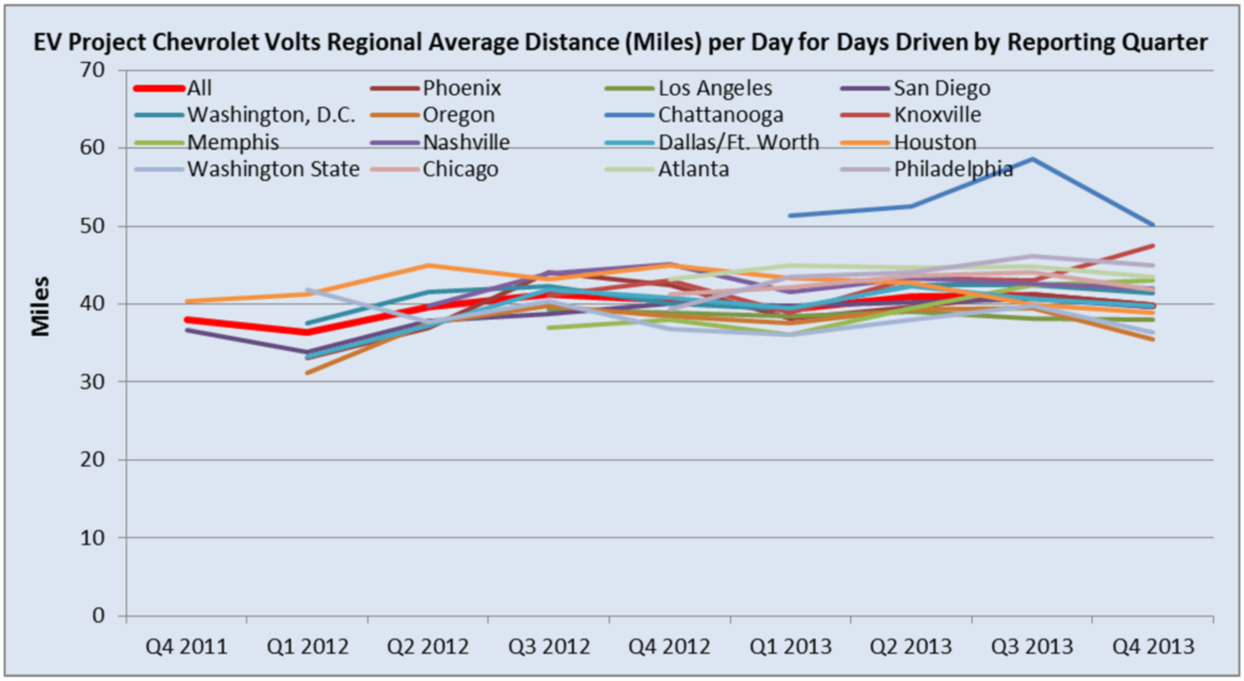


Figure 9-44. Average distances (miles) the Volts were driven each day that they were driven by reporting period.

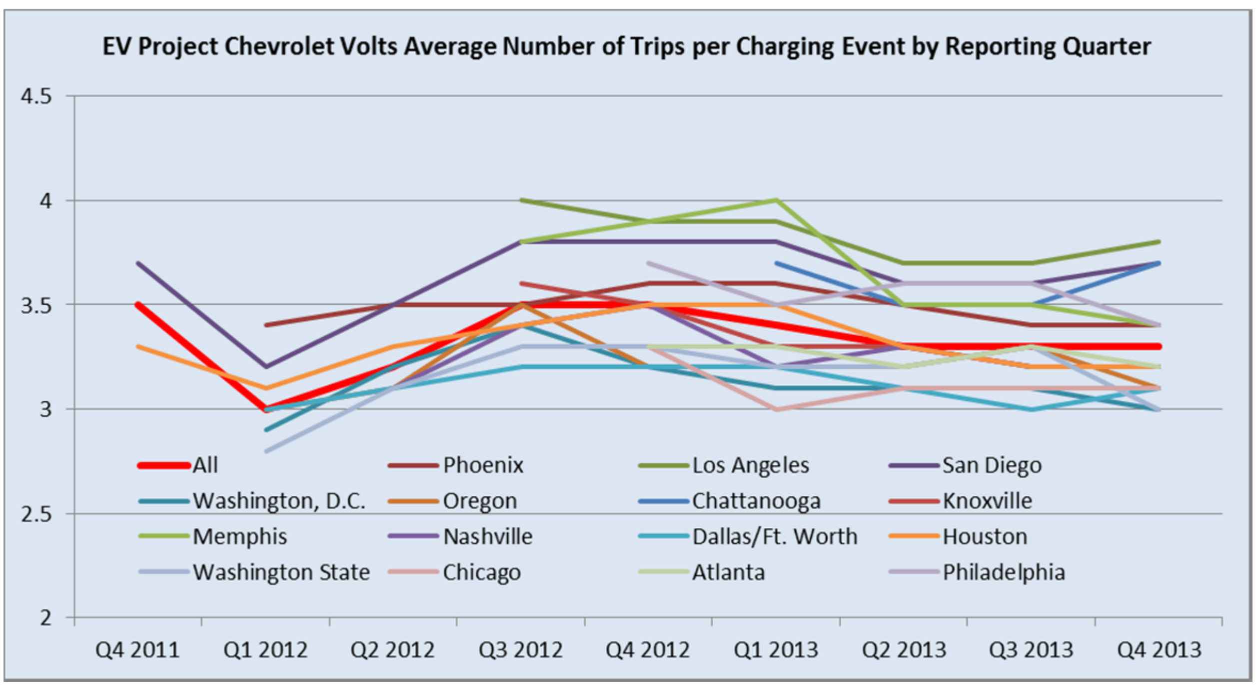


Figure 9-45. Average number of trips between charge events by Volt owners in The EV Project by reporting period and region.

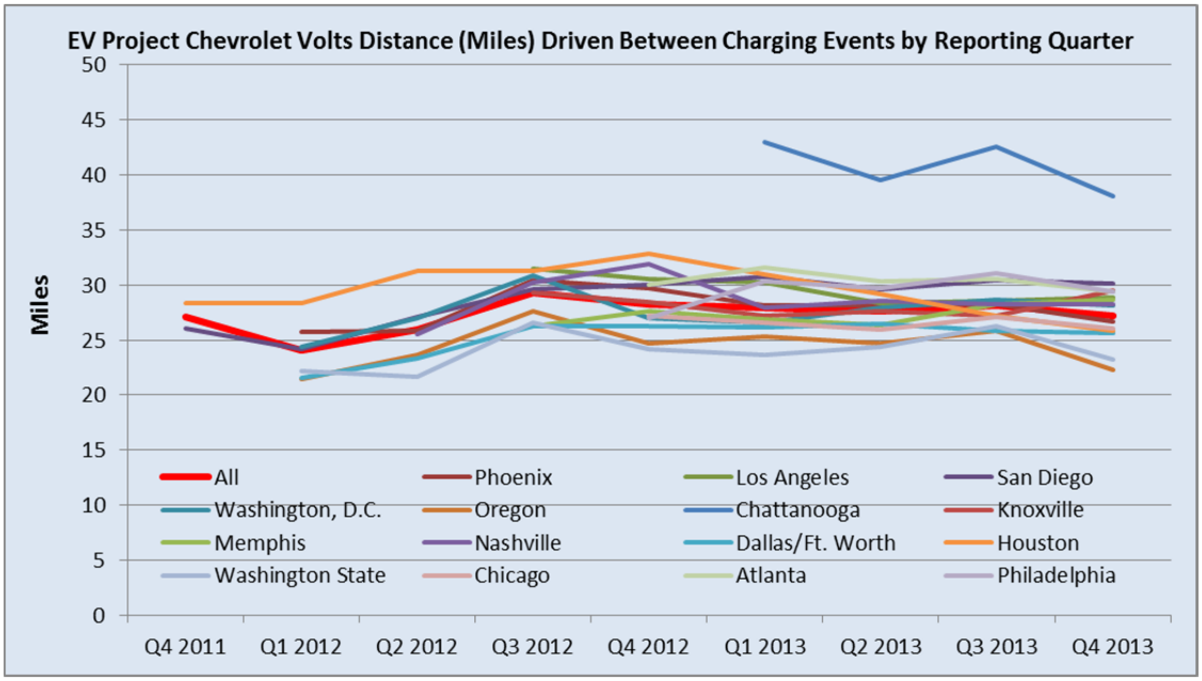


Figure 9-46. Distance, in miles, The EV Project Volts traveled between charge events.

It should be noted that about 11% of all EV Project Volt charge events were at unknown locations. These events included a change in the Volts SOC between key off and key on events, but there was no known EV Project EVSE nearby. Examples have also included charging a Volt at a known residence during the week, but the vehicle is charged via 110-V at a weekend cabin with no EVSE. Also, charging in the bowels of a parking garage would result in no cellular signal during the charge event; therefore, the charge location was unknown.

Nationally, 73% of all miles driven by EV Project Volt drivers were in electric mode (Figure 9-47). The small number of Volts in Chattanooga had the lowest percentage of all electric miles at 56%. When not driving in electric mode, the Volt operates in ERM, meaning it operates as a regular hybrid electric vehicle.

9.5.4 January through December 2013 EV Project Results

Charging infrastructure use within The EV Project was reported via the quarterly reports published from January 2011 through December 2013. Individual reports can be found on the quarterly and annual reports website (http://avt.inel.gov/evproject.shtml#ReportsAndMaps). Three annual reports can also be found on the same site for 2011, 2012 and 2013. Ideally, a single final report would have been run; however, as The EV Project progressed, some of the data fidelity improved and some venue definitions changed. A decision was made to generate three separate annual reports instead of "dumbing down" the 2013 final report. In order to discuss a year's worth of EV Project infrastructure use, the results for 2013 are shown in the following pages. When looking at Figure 9-48, it is clear that the highest number of infrastructure reporting data, the highest number of charge events, and the most energy was transferred from the grid to the vehicles during the 2013 reporting period. This suggests that the 2013 report is the richest set of results to discuss in order to highlight infrastructure utilization.

As previously mentioned, two types of charging infrastructure were deployed: AC Level 2 EVSE and DCFC. However, charging infrastructure use is reported in the following four categories:

- Residential AC Level 2 EVSE

- Private non-residential AC Level 2 EVSE (i.e., commercial fleets)
- Publicly accessible AC Level 2 EVSE
- Publicly accessible DCFC.

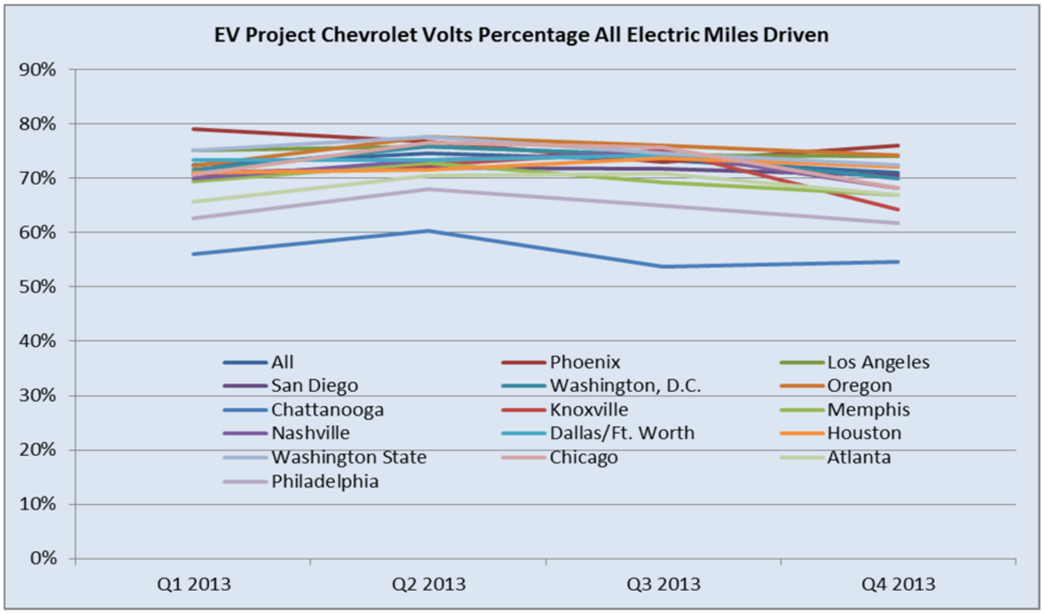


Figure 9-47. Percentage of EV Project Volts driven in all electric mode.

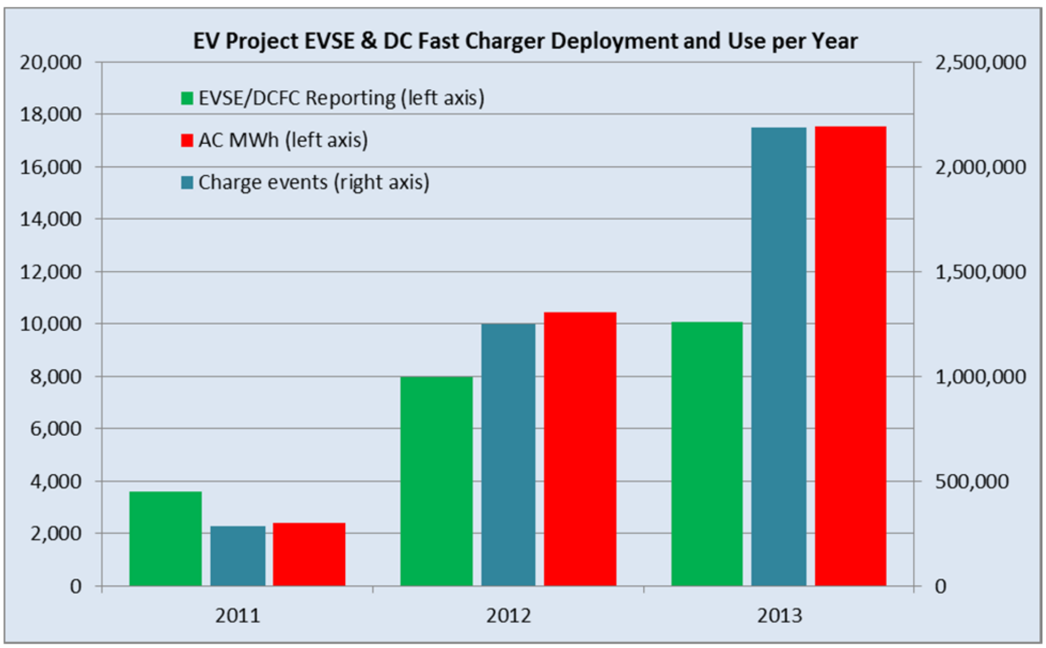


Figure 9-48. EV Project charging infrastructure reporting, energy used, and charge events annually by calendar year.

9.5.4.1 Entire EV Project Charge Infrastructure Use. As can be seen in Figure 9-49, residential EVSE represented the largest reporting venue at 64%. Residential EVSE were used a significant number of times to charge PEVs, with 1.86 million charge events out of the total 2.19 million charge events during 2013 (Figure 9-50). Figure 9-51 documents that residential EVSE also delivered the most energy to PEVs, with 83% of all energy being used. DCFCs had PEVs connected for only a short percentage of the time (Figure 9-52), but transferred energy to PEVs nearly the entire time connected. Residential EVSE had a PEV connected 41% of the time, but it was transferring energy only 8% of the time. Public EVSE had a PEV connected 4% of the time and they were transferring energy 2% of the time. It can be assumed that public charging occurred when power was needed for charging PEVs when fees for public charging were in place and drivers left their vehicle connected at residences regardless of SOC level. Of course, given that residences are where people park their PEVs overnight while sleeping, long residential connection times are expected.

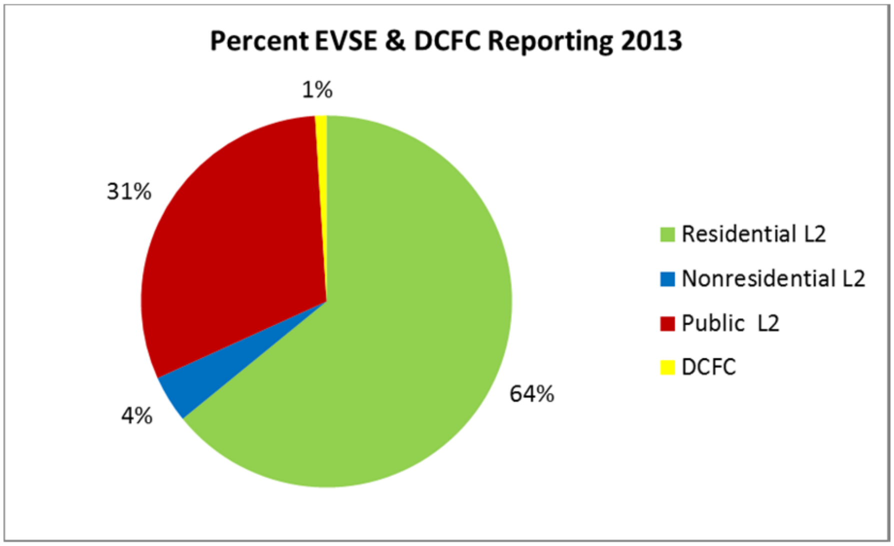


Figure 9-49. Percentage of EV Project EVSE and DCFCs reporting data during 2013.

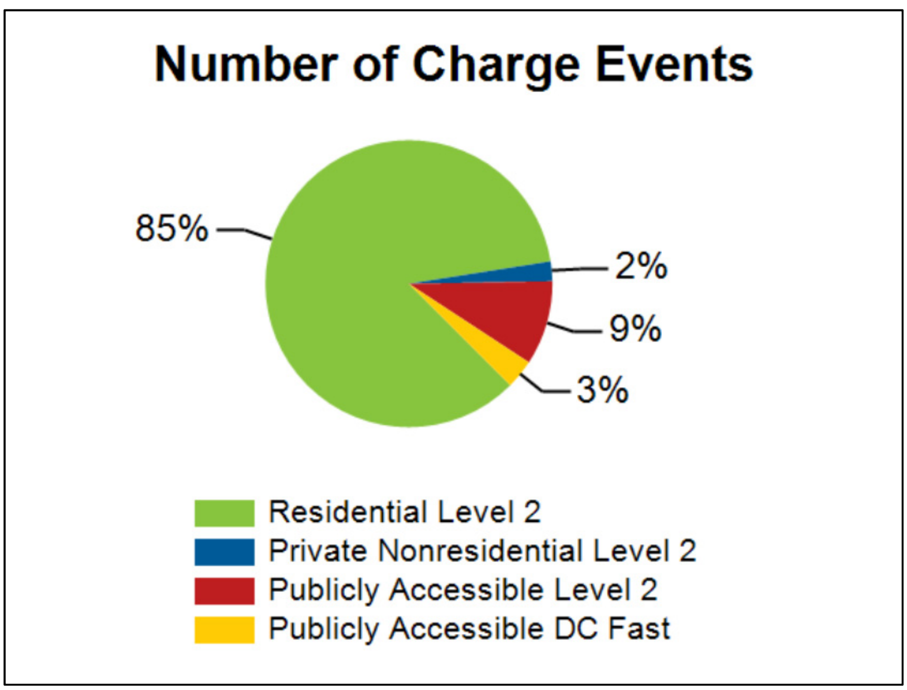


Figure 9-50. Percentage of EV Project charging events reported during 2013.

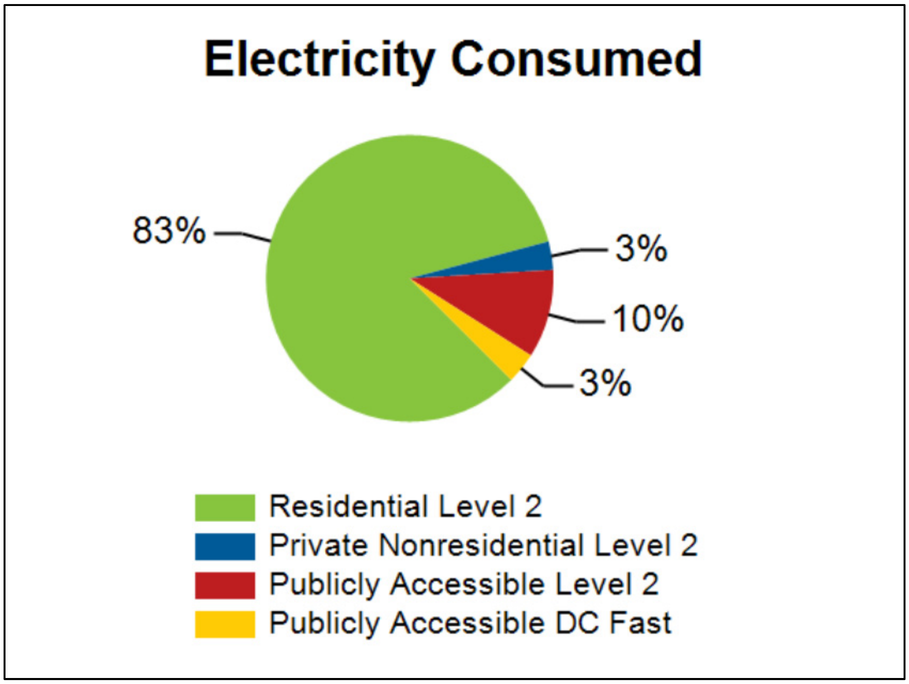


Figure 9-51. Percentage of EV Project electricity consumed during 2013.

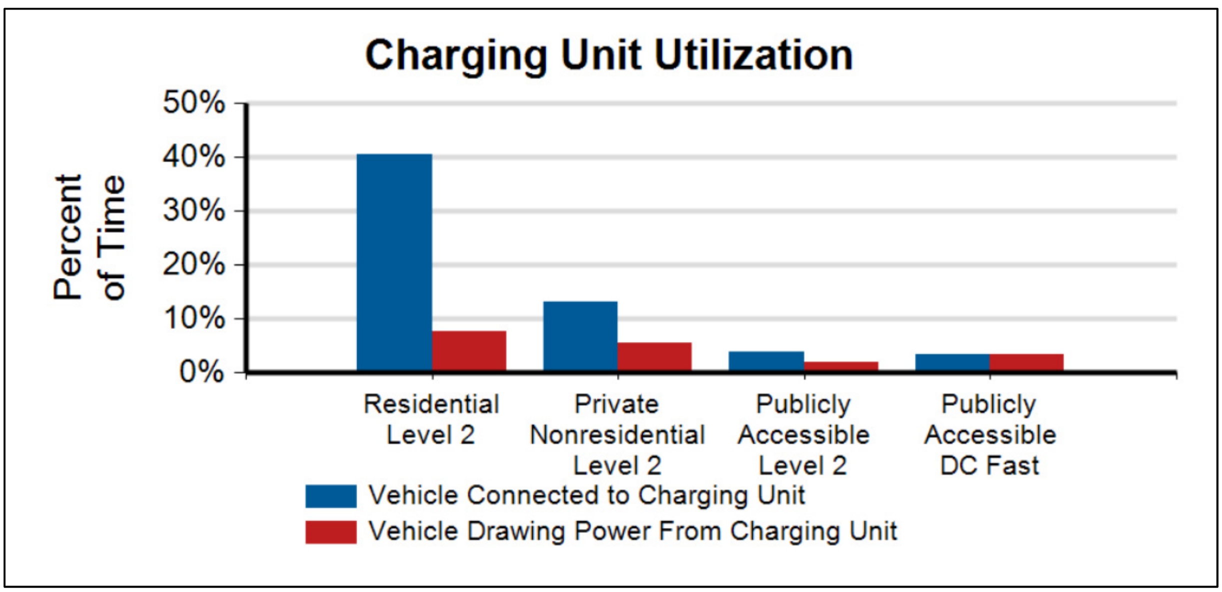


Figure 9-52. Percentage of time EV Project EVSE had a vehicle connected and drawing power during 2013.

Figure 9-53 documents the percentage of EVSE and DCFC with a vehicle connected and Figure 9-54 is the EVSE electricity demand for all EVSE and DCFC in the project during the reporting period. However, the more important curves, which better indicate how drivers use EVSE, can be found when looking at the individual EVSE type categories. For instance, Figures 9-55 and 9-56 show the connection times and demand curve at residential EVSE, which vary significantly from other venues.

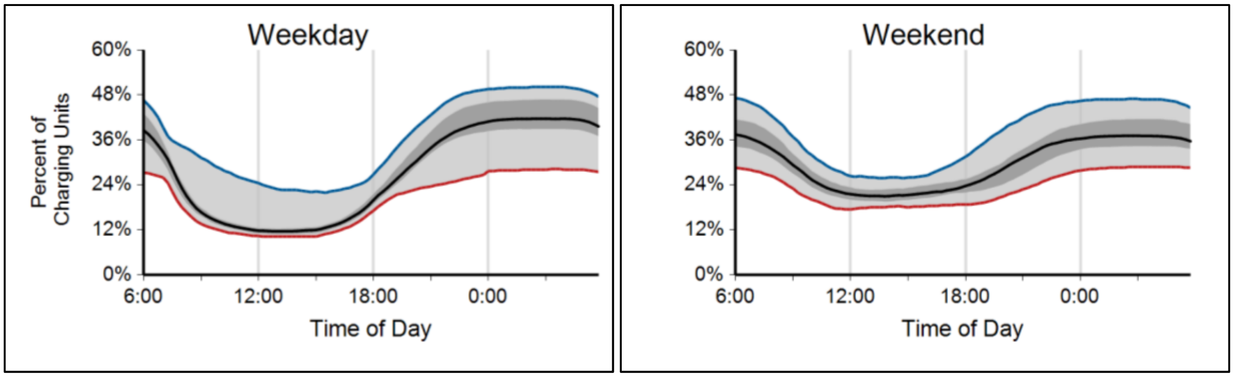


Figure 9-53. The two graphs show, by time of day, the percent of all EV Project EVSE and DCFC with a vehicle connected to it during 2013. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

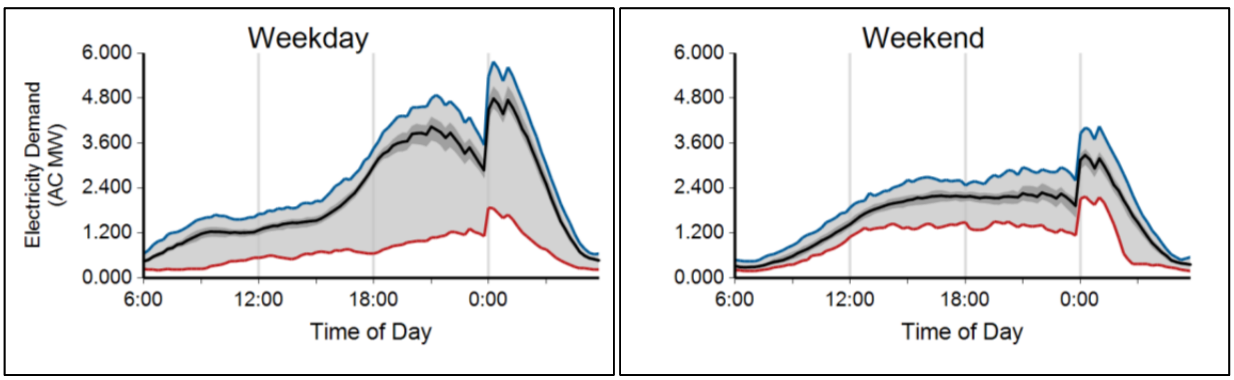


Figure 9-54. The two graphs show, by time of day, The EV Project electricity demand in AC MWh at all of the EVSE and DCFC during 2013. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

9.5.4.2 Residential Alternating Current Level 2 Electric Vehicle Supply Equipment.

EVSE sited at residential sites clearly had signicantly different connect and demand curves compared to private commercial and public EVSE and DCFC. The weekday EVSE in Figure 9-55, with a vehicle connected, as represented by the median line, show how vehicles were starting to be disconned at 6 a.m. as drivers head to work, school, and other responsibilities, with the lowest percentage connected during the early afternoon hours. As drivers return to their residences, starting about 4 p.m., more and more drivers were connected. From about 6 p.m to 10 or 11 p.m., the slope of the vehicles being connected was steepest, with the highest number of PEVs connected after midnight.

Looking at the residential median demand curve for weekdays (Figure 9-56), it was as expected given the residential connected weekday curve, with demand increasing significantly from about 4 p.m. on. The first peak occurs about 9 p.m., after which demand falls until midnight. At midnight, it dramatically peaked again, demonstrating that at least some of the EVSE were sited in electric utility territories that offer TOU rates that started at midnight. Demand was increasing significantly during evening hours when many utilities experience peak demand. However, given the high connectivity post-midnight, there were opportunities to shift demand later in the evening, as we were seeing with the TOU electricity price ranges.

The positive impact that TOU rates can have on peak demand is discussed in detail in Section 11 in a lessons learned white paper, but a brief discussion is warranted here. Although the percentage of vehicles connected is higher, the connection time curve in the San Diego area (Figure 9-57) is similar to the connection curve nationally for residential EVSE (Figure 9-56). Figure 9-58 shows the similar disconnecting starting about 6 a.m., similar early afternoon low percentage of PEVs connected, the steep slope of PEVs being reconnected starting about 5 p.m. What makes San Diego worth discussing is the demand profile seen in Figure 9-58.

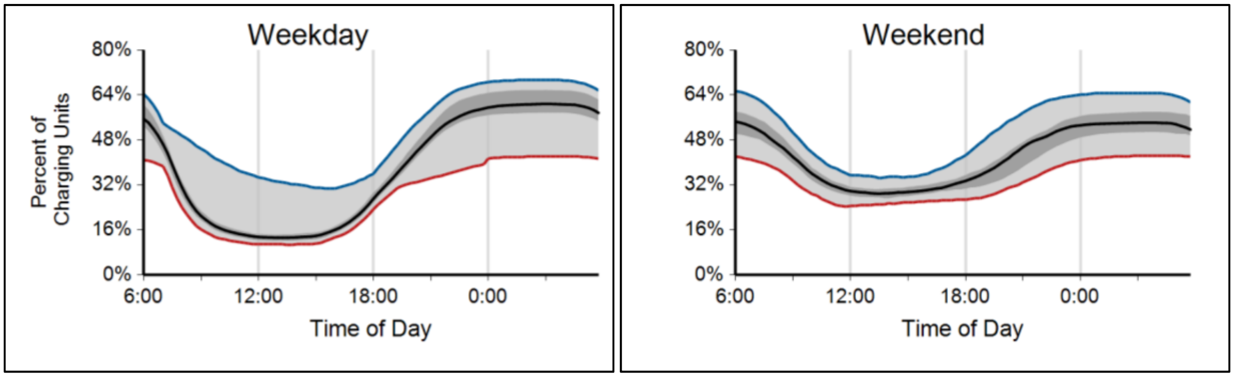


Figure 9-55. The two graphs show, by time of day, the percent of all residential EV Project EVSE with a vehicle connected to it during 2013. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

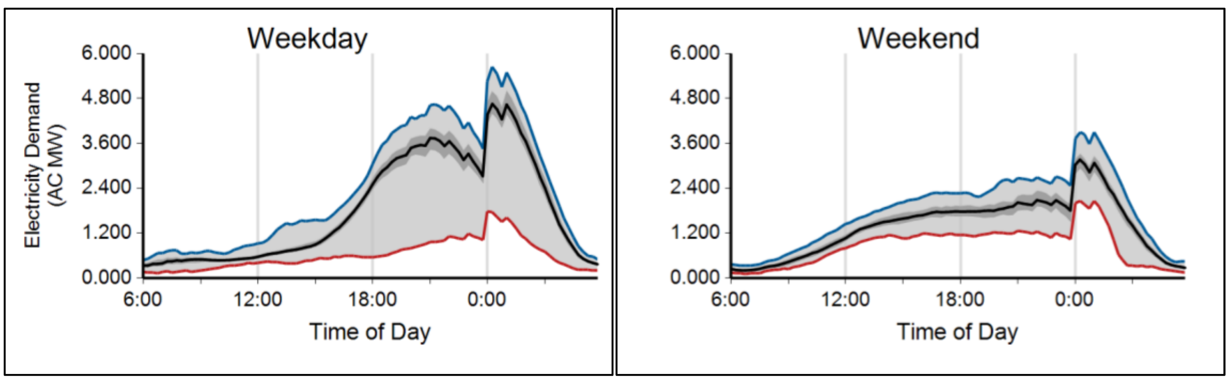


Figure 9-56. The two graphs show, by time of day, the electricity demand in AC MWh at all residential EV Project EVSE during 2013. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

SDG&E is solely responsible for providing electricity for all customers within the San Diego region of The EV Project. SDG&E offered its customers an experimental TOU rate from charging PEVs. The electricity rates in kWh and rate periods are as follows:

- 5 a.m. to noon $0.22
- Noon to 6 p.m. $0.49
- 6 p.m. to midnight $0.22
- Midnight to 5 a.m. $0.16.

From Figure 58, it was obvious that the TOU rates successfully encourage PEV drivers to start charging at midnight.

Residential EVSE on weekdays had a PEV connected 39% of the time, provided power 8% of the time, and had 0.85 charge events per day. On weekdays, the connection time was 11.9 hours and energy transfer time was 2.4 hours, which resulted in 8.2 kW transferred. The shorter energy transfer times compared to the longer connect times suggest there was much opportunity for shifting energy transfer times to avoid peak demand times when the grid was stressed, which was essentially what occurred in San Diego.

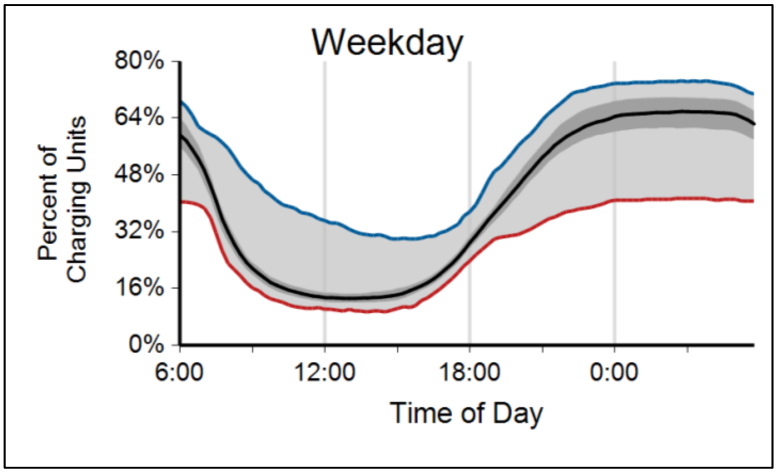


Figure 9-57. The weekday time-connected curve for residential EV Project EVSE in the San Diego area during 2013. The median percentage is the black line.

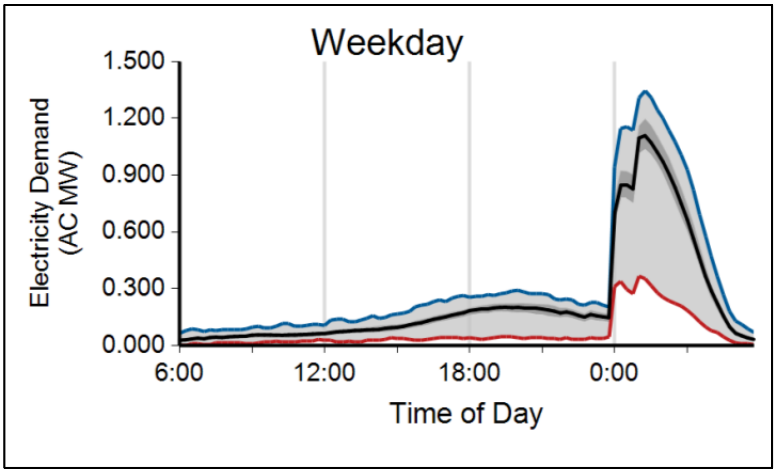


Figure 9-58. The weekday electricity demand in AC MWh at residential EV Project EVSE in the San Diego area by time of day during 2013. The median percentage is the black line.

Figures 9-59 and 9-60 document the lengths of time vehicles were connected to and drawing power from residential EVSE. Residential EVSE included a significant amount of time with vehicles connected for long periods of time (i.e., greater than 10 hours). The distribution of the length of time a vehicle was drawing power was significantly shorter, with almost all charging events being less than 6 hours. Given that most PEVs charge at 3.3 or 6.6-kW rates, one would assume that the battery packs would be completely charged within this period of time. However, it is possible that PEVs being charged may have included Tesla BEVs, which have a large battery pack. Tesla vehicles were not part of The EV Project. However, it was known that non-EV Project vehicles sometimes utilized The EV Project charging infrastructure. The amounts of energy transferred per charge event (Figure 9-61) suggests that either Leaf drivers drove their vehicles to very low SOCs or some of the vehicles using The EV Project network of EVSE were likely Tesla BEVs.

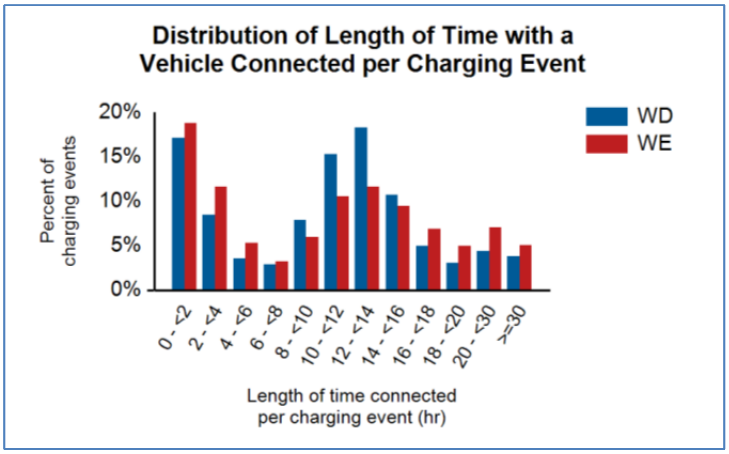


Figure 9-59. The length of time a PEV was connected when using EV Project residential EVSE.

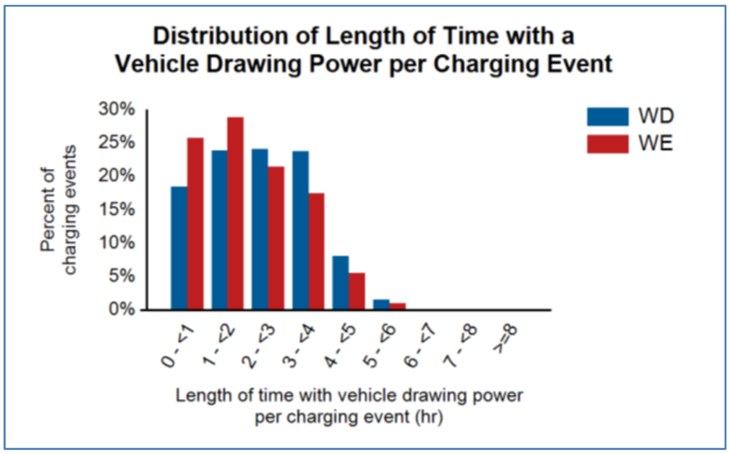


Figure 9-60. The length of time a PEV was drawing power when using EV Project residential EVSE.

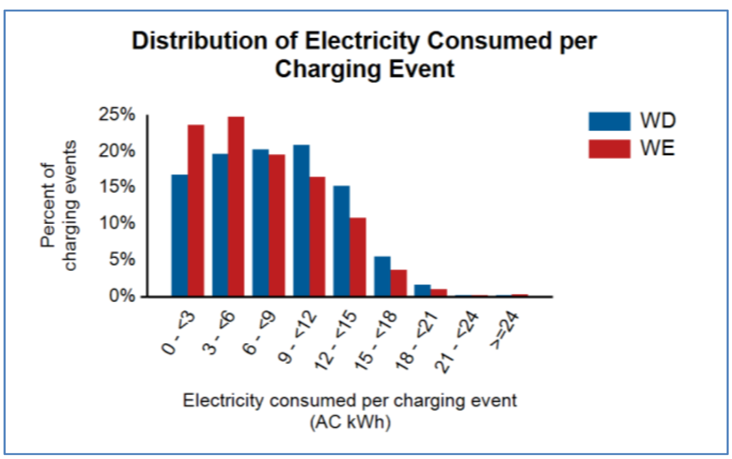


Figure 9-61. The energy consumed per charging event when using EV Project residential EVSE.

9.5.4.3 Private Non-Residential Alternating Current Level 2 Electric Vehicle Supply Equipment. The private non-residential EVSE connection times were fairly flat (median black line) on weekends (Figure 9-62), suggesting fleet vehicles were connected to about 11% of the EVSE. During the weekday, a similar 11% rate from 10 p.m. to 6 a.m. was observed. During the weekdays (Figure 9-62), it appears either customers or employees were using the EVSE as PEVs that were driven to work and charged there.

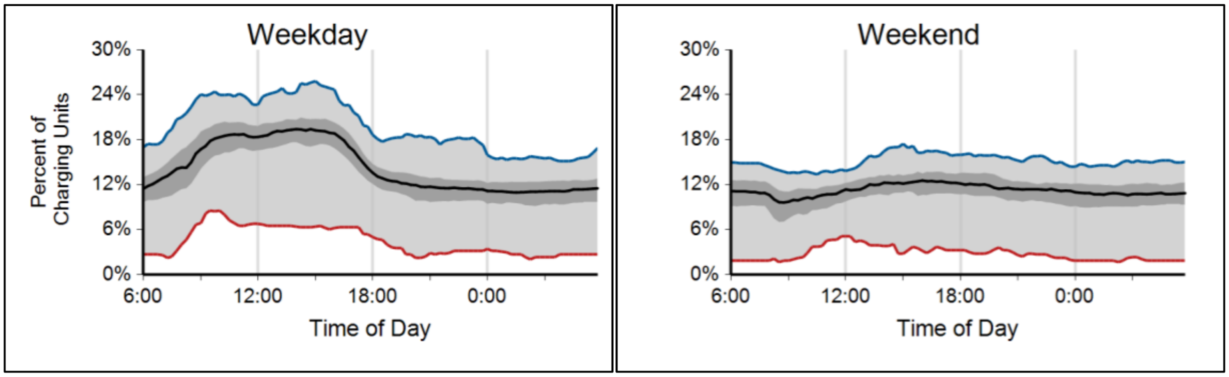


Figure 9-62. The two graphs show, by time of day, the percentage of private non-residential EV Project EVSE with a vehicle connected to it during 2013. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

While the significant rise in demand on weekdays (Figure 9-63) at the private non-residential EV Project EVSE appears dramatic, and it is considering how much it rises from about 25 kW at 6 a.m. to about 130 kW about 9 a.m., it should be viewed in the context of the graph scale. The peak demand on any one day (blue line) appears to max out at about 240 kW, which is still fairly low for the 415 private non-residential EVSE providing data. There is also a rise during the weekends (Figure 9-63), but again, consider the scale.

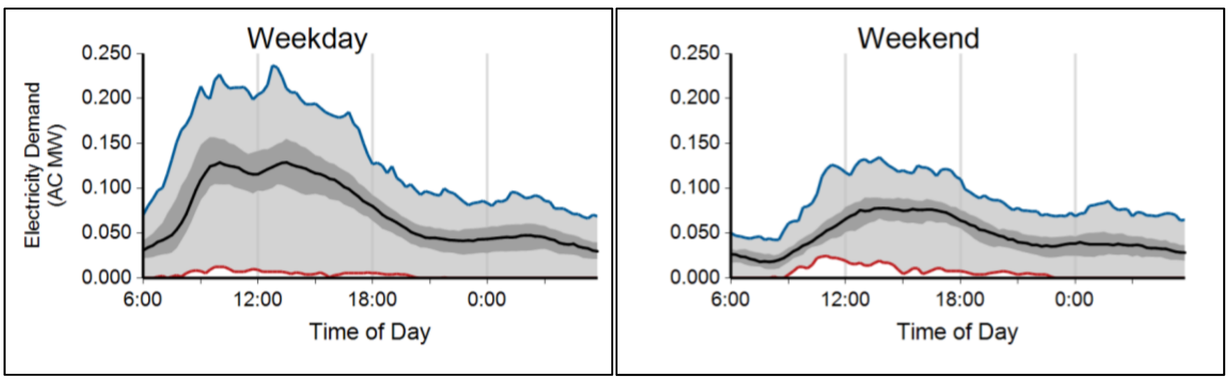


Figure 9-63. The two graphs show, by time of day, the electricity demand at private non-residential EV Project EVSE during 2013. The median percentage is the black line. Note that one is for weekdays and the other is weekends; the scale is AC MWh.

Private non-residential EVSE on weekdays had a PEV connected 14% of the time, provided power 6% of the time, and had 0.5 charge events per day. On weekdays, the connection time was 8.0 hours and energy transfer time was 3.3 hours, which resulted in 11.1 kW transferred. Private non-residential EVSE on weekends had a PEV connected 11% of the time, provided power 4% of the time, and had 0.24 charge events per day. On weekends, the connection time was 7.8 hours and energy transfer time was 4.0 hours, which resulted in 13.6 kW transferred.

Figures 9-64 and 9-65 document the length of time vehicles were connected to and drawing power from private non-residential EVSE. Private non-residential EVSE included a significant amount of time with a vehicle connected for long periods of time (i.e., greater than 20 hours), which was likely weekends. The distribution of the length of time a vehicle was drawing power was significantly shorter, with almost all charging events being less than 8 hours. Given that most PEVs charge at 3.3 or 6.6-kW rates, one would assume that the battery packs would be completely charged within this period of time. However, it is possible that the PEVs being charged may include Tesla PEVs or electric trucks, both of which have a large battery pack. Teslas and electric trucks were not part of The EV Project. It was know that non-EV Project vehicles sometimes utilized The EV Project charging infrastructure. It was known that the Car sharing fleet (i.e., Car2Go EVs), which were part of The EV Project, were responsible for 45% of the charge events and 61% of the energy transferred. The amounts of energy transferred per charge event (Figure 9-66) suggest that either PEV drivers drove their vehicles to very low SOCs or some of the vehicles utilizing The EV Project network of EVSE were likely non-EV Project PEVs with large batteries.

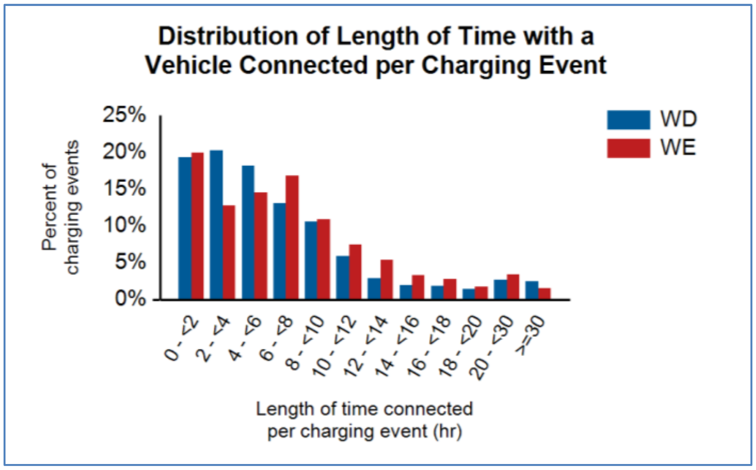


Figure 9-64. The length of time a PEV was connected when using EV Project private non-residential EVSE.

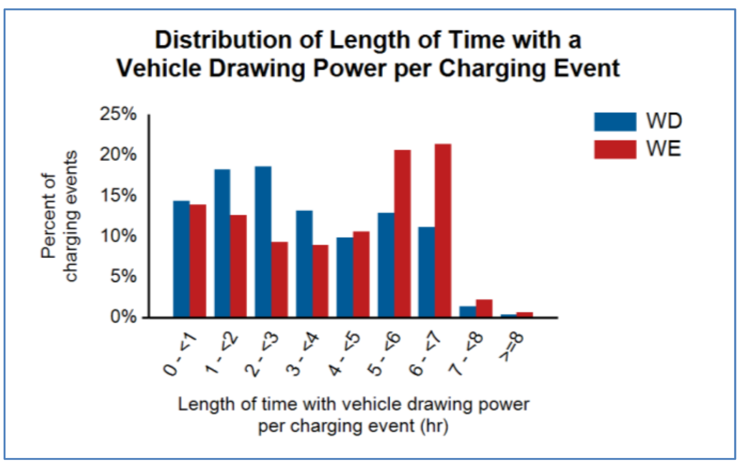


Figure 9-65. The length of time a PEV was drawing power when using EV Project private non-residential EVSE.

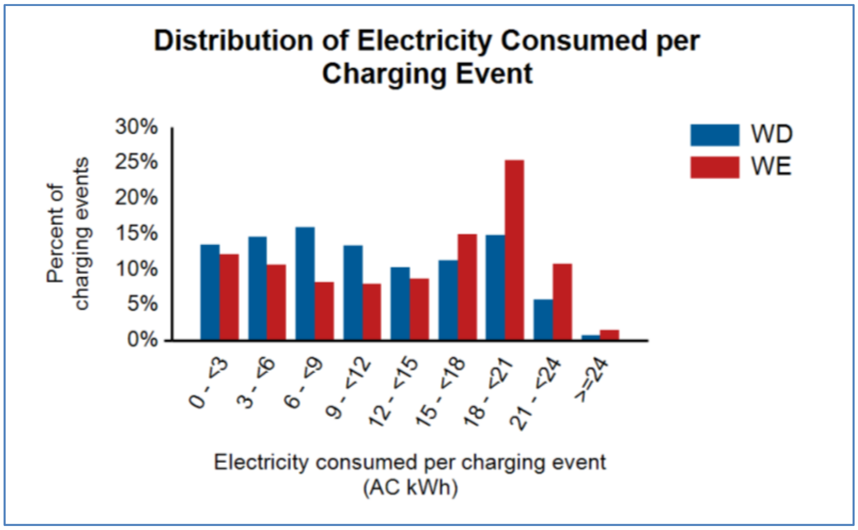


Figure 9-66. The energy consumed per charging event when using EV Project private non-residential EVSE.

9.5.4.4 Publicly Accessible Alternating Current Level 2 Electric Vehicle Supply Equipment. The weekday connect curve (Figure 9-67) for public EVSE suggests that workers may be using EVSE to support driving their PEVs to work because the curves are so different for weekdays and weekends, given that weekdays are more traditional work days for the demographics of many PEV drivers. However, some errand running or shopping may be connected with the daytime rise in weekday connect times.

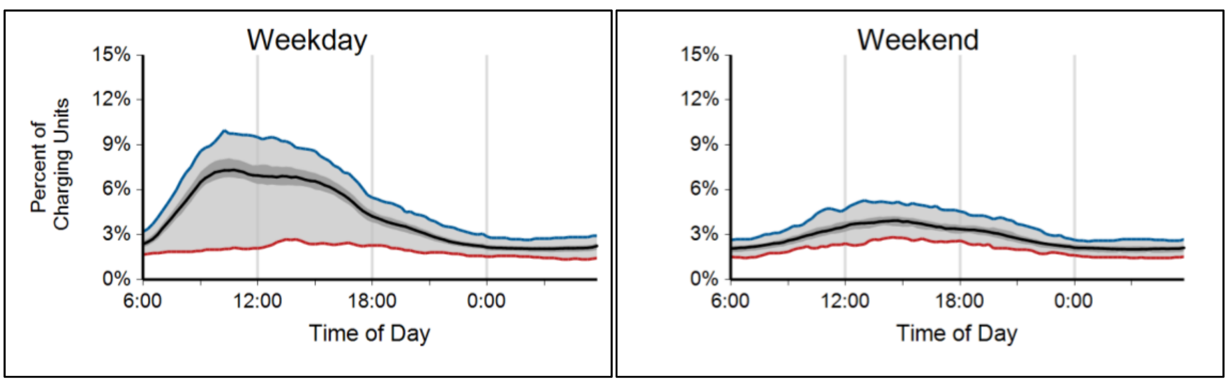


Figure 9-67. The two graphs show, by time of day, the percent of public EV Project EVSE with a vehicle connected to it during 2013. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

The public EVSE demand curve (Figure 9-68) follows the time-connect curve for public EVSE (Figure 9-68) as would be expected. Given the demand profile, this suggests peak demand will be around 9 a.m. weekdays, which is a typical time to arrive at work.

During 2013, public EVSE on weekdays have a PEV connected 4% of the time, provide energy 2% of the time, and have 0.24 charge events per day. On weekdays, the connection time was 4.5 hours and energy transfer time was 2.3 hours, which resulted in 8.5 kW transferred. Also during 2013, public EVSE on weekends have a PEV connected 3% of the time, provide power 1% of the time, and have 0.14 charge events per day. On weekends, the connection time was 3.6 hours and energy transfer time was 2.1 hours, which resulted in 8.0 kW transferred.

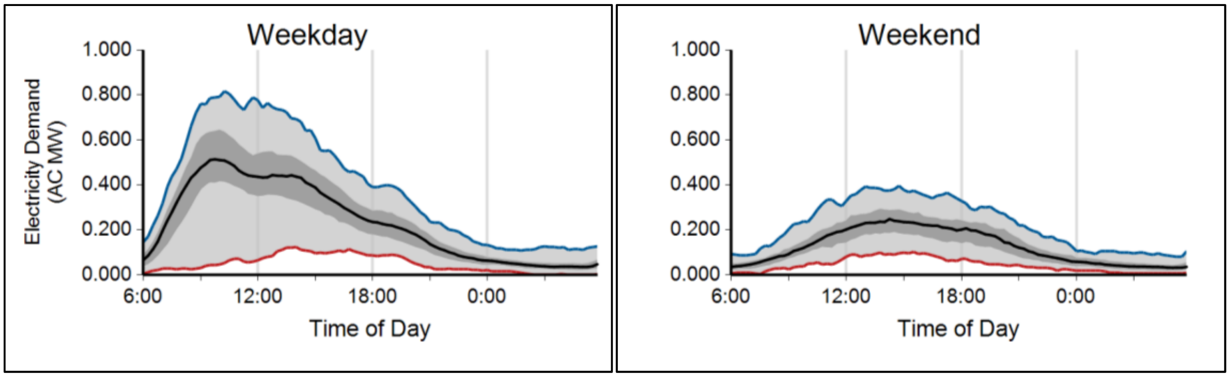


Figure 9-68. The two graphs show, by time of day, the electricity demand at public EVSE for The EV Project during 2013. The median percentage is the black line. Note that one is for weekdays and the other is weekends; the scale is AC MWh.

Figures 9-69 and 9-70 document the length of time vehicles are connected to and drawing power from the public EVSE. Public EVSE include a much shorter amount of time with a vehicle connected than do the two other types of AC Level 2 EVSE. The distribution of the length of time a vehicle is drawing power is significantly shorter, with almost all charging events being less than 6 hours. Given that most PEVs charge at 3.3 or 6.6-kW rates, one would assume that the battery packs would be completely charged within this period of time. Given that there were a few long duration charge events, it is possible that the PEVs being charged may include PEVs with large battery packs that were not part of The EV Project. It was known that a significant number of non-EV Project PEVs utilized The EV Project charging infrastructure. It was known that the Car sharing fleet (Car2Go electrice vehicles), Leafs, and Volts were only reponsible for 24% of public charge events and energy transferred during 2013. This is a reversal from 2011, when the same EV Project PEVs where responsible for 57% of all public EVSE charge events and energy transferred. During 2012, the same PEVs represented 64% of charge events and 68% of energy transferred. The 2013 results were likely driven by the significant increase in number of PEVs being purchased in the United States, especially in The EV Project areas. Again, observing the amounts of energy transferred per charge event (Figure 9-71), it can be suggested that either Leaf drivers drove their vehicles to very low SOCs or some of the vehicles using The EV Project network of EVSE were likely non-EV Project PEVs with large batteries.

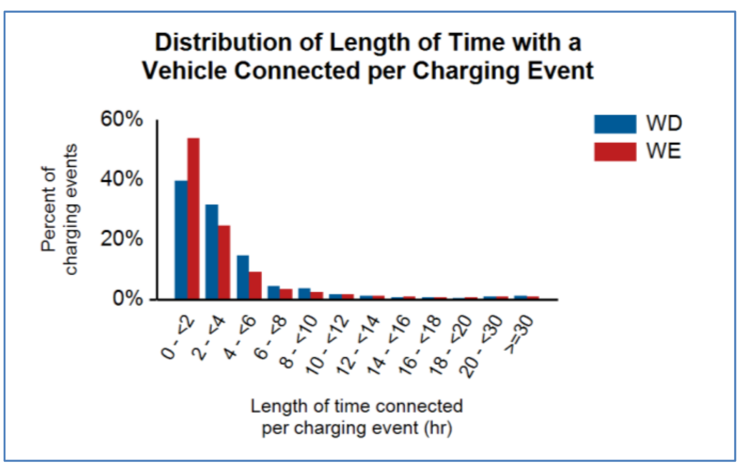


Figure 9-69. Length of time a PEV was connected when using EV Project public EVSE.

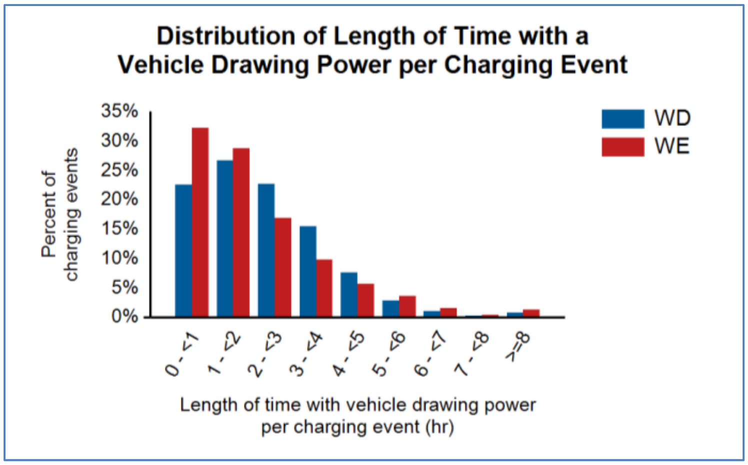


Figure 9-70. Length of time a PEV was drawing power when using EV Project public EVSE.

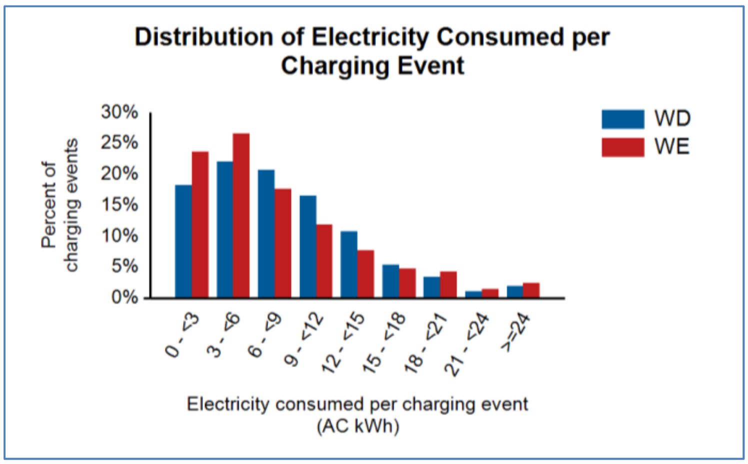
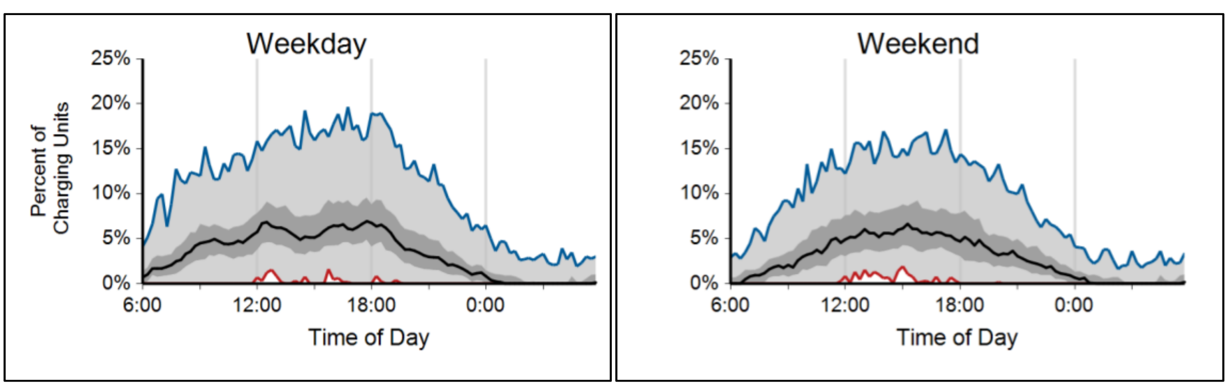


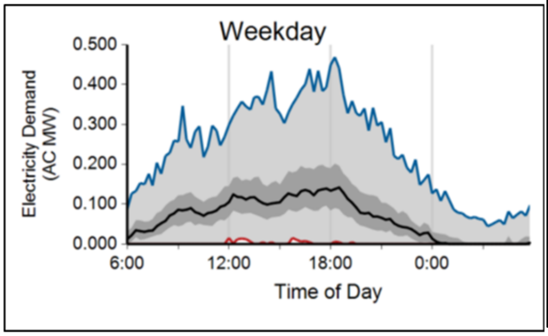
Figure 9-71. Energy consumed per charging event when using EV Project public EVSE.

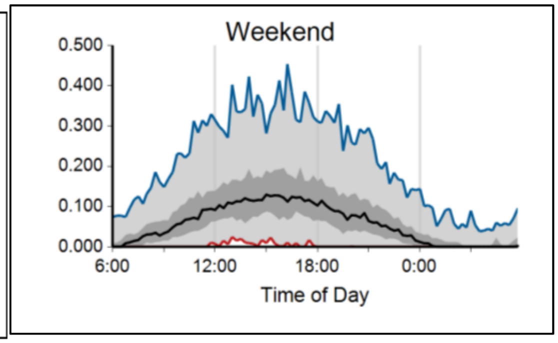
9.5.4.5 Publicly Accessible Direct Current Fast Chargers. The weekday time-connected curves (Figure 9-72) for DCFCs for The EV Project are very similar, with peak use about even on weekdays and weekends. Opposite the high daytime relative connection times for AC Level 2 EVSE, DCFC have a very low percentage of PEVs connected at night.



Figures 9-72. The two graphs show, by time of day, the percent of DCFC for The EV Project with a vehicle connected to it during 2013. The median percentage is the black line. Note that one is for weekdays and the other is weekends.

The DCFC energy transfer demand curves (Figure 9-73) follow the time-connect curve closely for DCFC, as would be expected given that the connection and energy transfer duration times are identical. On weekdays, the connection and energy transfers both were 20.8 minutes during which 8.4 kWh was transferred on average. On weekends, the connection and energy transfer times were slightly shorter, both at 20.4 minutes, which resulted in a slightly higher 8.6 kWh transferred. Intuitively, during a slightly shorter period of time, one would anticipate less energy being transferred. One explanation may be the battery's SOC. The lower the SOC at the start of a charge event, the more power that can be accepted by the pack in a short period of time, which translates into more energy transferred.





Figures 9-73. The two graphs show, by time of day, electricity demand at DCFC for The EV Project during 2013. The median percentage is the black line. Note that one is for weekdays and the other is weekends; the scale is AC MWh.

During 2013, DCFC on weekdays have a PEV connected 3% of the time, provide power 3% of the time, and have 2.4 charge events per day. Also during 2013, DCFC on weekends have a PEV connected 3% of the time, provide power 3% of the time, and have 2.13 charge events per day. Figures 9-74 and 9-75 document the length of time vehicles are connected to and drawing power (Figure 9-76) from DCFC. DCFC include a much shorter amount of time with a vehicle connected than do AC Level 2 EVSE. The distribution of the length of time a vehicle is drawing power is also significantly shorter, with almost all charging events being less than 45 minutes. The Nissan Leafs are the only EV Project PEV model that can use DCFC. The profiles for time connected and drawing power are identical. It is known that a significant number of non-EV Project PEVs utilized The EV Project DCFC, because Leafs only constituted 25% of the charge events and 24% of the energy transferred.

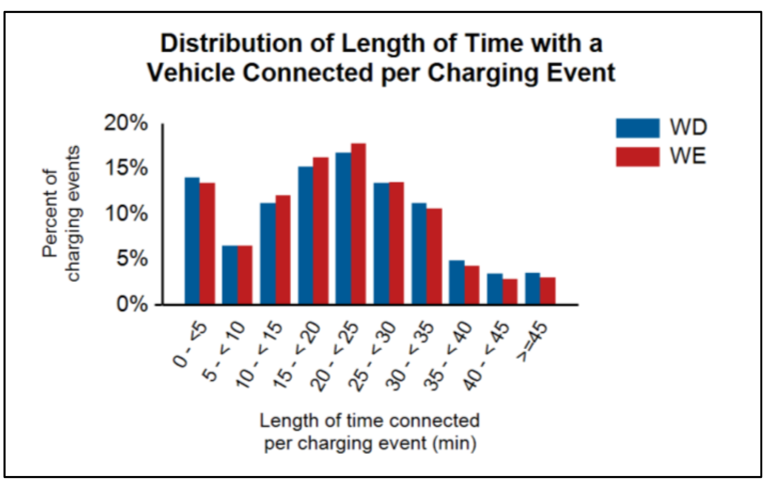


Figure 9-74. Length of time a PEV was connected when using EV Project public DCFC. Note that the scale used for time is in minutes, compared to hours used in similar figures describing AC Level 2 EVSE use.

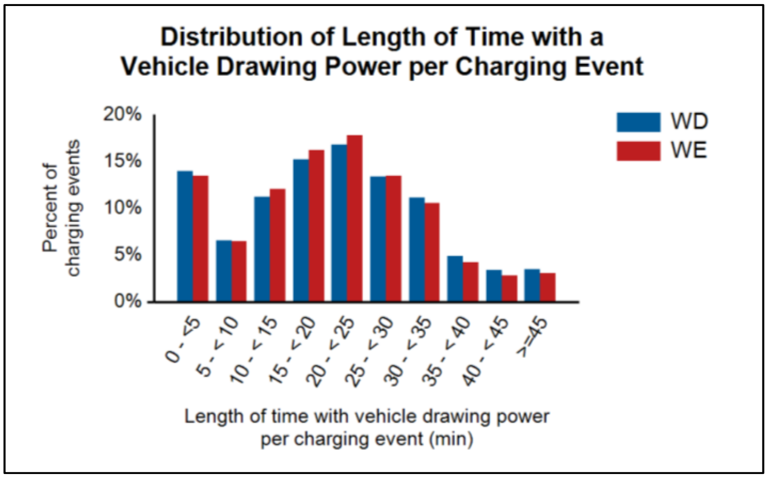


Figure 9-75. Length of time a PEV was drawing power when using EV Project public DCFC. Note that the scale used for time is in minutes.

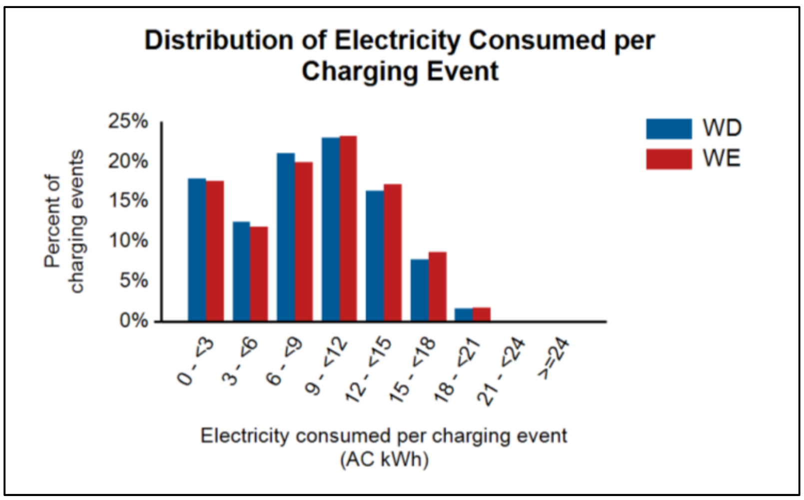


Figure 9-76. Energy consumed per charging event when using EV Project DCFC.

During 2012, the Leafs were responsible for 46% of the charge events and 49% of energy transferred at DCFC. The average amount of energy transferred, 8.5 kWh, suggests that the DCFC where often used to extend trip distances rather than fully recharging the PEVs from a very low SOC. Depending on conditions, the 8.5 kWh would likely extend the range about 25 to 30 miles for a Leaf.

9.6 EV Project Summary

INL's reporting of results for EV Project PEVs and EVSE ranged from January 1, 2011, to the end of December 31, 2013. Quarterly reports were produced for each quarter, starting with the January to March 2011 quarter.

During the 3 years of data collection, the 12,356 EVSE were used for 4,173,933 charge events or about 338 charge events per EVSE. The EV Project EVSE data were sometimes combined with Blink and AeroVironment EVSE data to enable more valuable analysis about the best sites for siting public EVSE in order to maximize utilization of EVSE. This required a significant effort to characterize, to a single set of definitions, the venues for more than 7,000 public AC Level 2 EVSE. For examples of EV Project reports generated, see the following links:

- EV Project Overview Report (January 2011 to December 2013, 1 page) http://avt.inel.gov/pdf/EVProj/EVProjectOverviewQ42013.pdf.
- Observations from The EV Project in the Fourth Quarter of 2013 (5 pages) http://avt.inel.gov/pdf/EVProj/EVProjectSummaryReportQ42013FINAL.pdf.
- EV Project EV Charging Infrastructure Summary Report (January through December 2013, 124 pages) http://avt.inel.gov/pdf/EVProj/EVProject%20Infrastructure%20ReportJan13Dec13.pdf.
- EV Project Nissan Leaf Vehicle Summary Report (October to December 2013, 17 pages) http://avt.inel.gov/pdf/EVProj/EVProjectNissanLeafQ42013.pdf.
- EV Project Chevrolet Volt Vehicle Summary Report (October to December 2013, 16 pages) http://avt.inel.gov/pdf/EVProj/EVProjectChevroletVoltQ42013.pdf.

Many lessons learned white papers, maps, presentations, reports, and planning documents are available for viewing and can be found on The EV Project's overall website: http://avt.inel.gov/evproject.shtml#ReportsAndMaps.

10. SCAQMD/EPRI/VIA MOTORS DEMONSTRATION

10.1 SCAQMD/EPRI/VIA Motors Demonstration Scope and Objectives

The SCAQMD (South Coast Air Quality Management District)/EPRI/VIA Motors Demonstration Project was an ARRA project during which VIA deployed a total of 145 VTRUX eREV pickup trucks and vans (Figure 10-1) to government and utility fleets throughout the United States. EPRI was responsible for instrumentation of data acquisition equipment, data collection, and transmission of data to INL for analysis and reporting.

The primary objective of the SCAQMD/EPRI/VIA demonstration was to gather data and produce reports on the performance of the eREV pickup trucks and vans in commercial fleet applications and the related petroleum reduction capabilities.

Figure 10-1. VIA Motors eREV VTRUX Van.

10.2 SCAQMD/EPRI/VIA Motors Demonstration Electric Vehicle Supply Equipment Types

This project did not have an EVSE deployment or data collection activity. However, data were collected by the vehicles during charging events. The VIA Motors vehicles can be charged using standard SAE J1772 AC Level 2 (208 to 240 V) EVSE or AC Level 1 (110 to 120 V) EVSE (i.e., commercial receptacles or standard household).

10.3 SCAQMD/EPRI/VIA Motors Demonstration Features

The VIA Motors vans and pickups are eREV conversions of production Chevrolet Express vans and Silverado pickup trucks. Both models share the same eREV architecture and almost identical components. Traction power comes from a 23-kWh lithium-ion battery and is delivered to the wheels by a 190-kW electric motor. To extend the range of the battery, a gas-fueled ICE is used to drive an electric generator to provide electric energy to the onboard battery. The pickup trucks use a 4.3L V6 Generation V Chevrolet engine, which drives a 115-kW electric generator. The vans use a 4.8L V8 Generation IV Chevrolet engine to drive a 100-kW generator.

VIA Motors eREVs operate as PEVs while in CD mode. This mode of operation is referred to as EVM. When the battery is fully depleted, the ICE starts and drives the onboard generator to provide electric energy to the batteries, which extends the range of the vehicle. Operation in this mode is referred to as ERM operation. During ERM operations, the SOC of the batteries does not change beyond the increase and decrease in SOC normally experienced by hybrid electric vehicles, meaning the vehicles operate similar to a traditional hybrid electric vehicle during ERM operations. During ERM, no electricity from the electric grid is used for traction power and all external energy used to move the vehicle comes from gasoline. At no time does the gasoline engine directly connect to the wheels.

Driving the vehicle in EVM requires the traction batteries be at least partially charged at the start of each trip. This is normally accomplished by plugging the vehicle into the electric grid, similar to other PHEVs or BEVs. The VIA vehicles can also be put into an operating mode, which uses the onboard ICE engine and generator to charge the traction batteries on the fly. In this mode, the combination of the ICE engine and generator produce more electric energy than is required to drive the vehicle; the surplus of electrical energy gets stored in the onboard traction battery pack.

When a VIA vehicle is not being driven, it can be used as a mobile electricity generator, allowing the use of corded tools and other electric-powered equipment. Users can get power from 120 or 240-V outlets that are able to provide up to 50 A of current. In this mode, the battery pack supplies power until it is depleted, at which point the ICE will turn on and generate electricity.

10.4 SQACMD/EPRI/VIA Motors Demonstration Deployment and Data Collection Rate

Data collection from the VIA Motors vehicles began in December 2014 and continued through June 2015. During July 2015, INL received data from EPRI for the entire data collection period. During the first month of data collection, data were collected from 37 VIA Motors vans and during the last month of data collection, data were received from 119 pickups and vans. VIA made the first pickup deliveries to fleets during April and the received data reflects this. The number of pickups and vans that provided data during each month can be seen in Figure 10-2. The total number of distinct vehicles for which data was received throughout the demonstration was 145, which was made up of 97 pickups and 48 vans. This is higher than the maximum number in any month because not every vehicle provided data for every month in the study period.

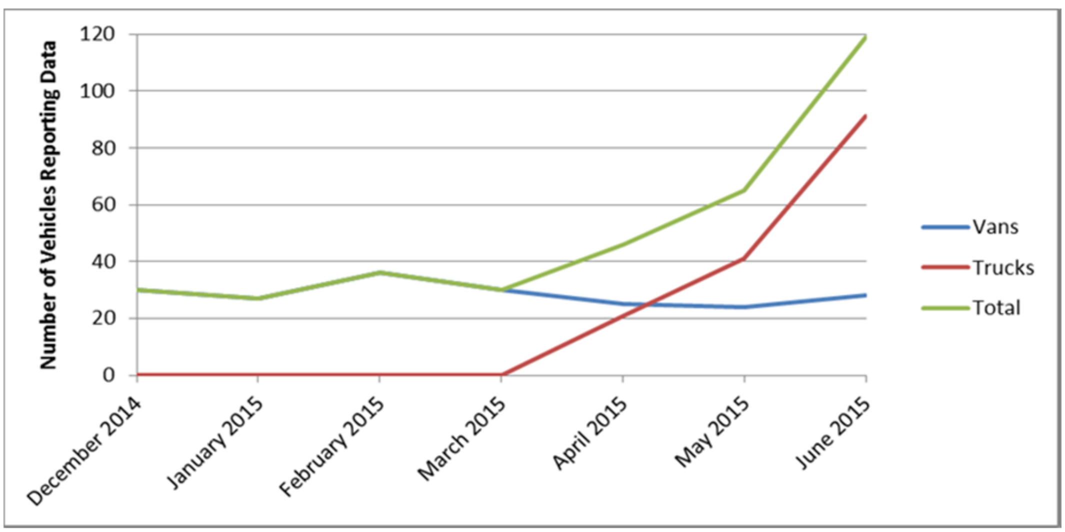


Figure 10-2. Number of VIA Motors vehicles reporting data to INL during each month.

The accumulation of miles driven by the vehicles in the demonstration can be seen in Figure 10-3. The total driving distance captured in the available data was approximately 56,000 miles for VIA vans and 13,000 miles for VIA pickups. For the vans and pickups, driving in EVM made up 20% and 15% of the total driving distance, respectively.

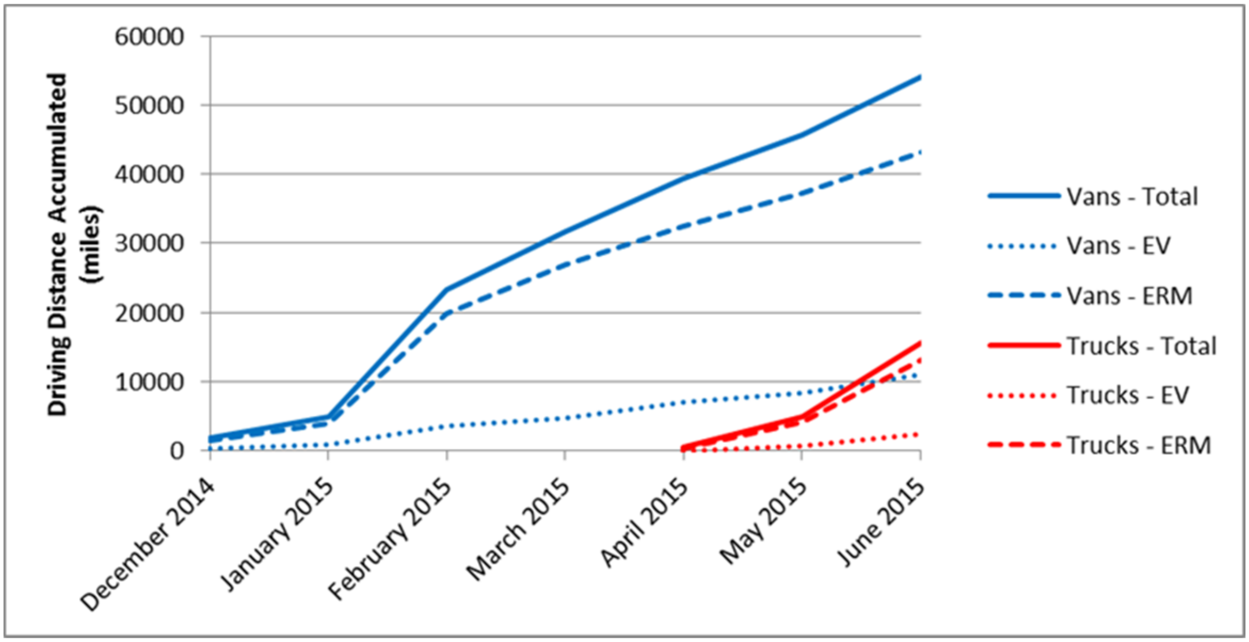


Figure 10-3. VIA Motors eREV vans and pickup trucks total miles driven, ERM miles driven, and EV miles driven by reporting month.

VIA motors data were collected using an EPRI-designed custom data logger and telematics system. The telematics system in the vehicles transferred data to EPRI servers, where the data were processed and transferred to INL servers. Another section in this report discusses how this was accomplished for all of the projects in this report.

10.5 SCAQMD/EPRI/VIA Motors Demonstration Reporting

The results of the VIA vehicle demonstration will be reported in fact sheets detailing the performance of all VIA vans and pickups. One fact sheet will be produced for the vans and one will be produced for the pickups, each providing results for the entire data collection period. Because of the timing of data availability and the writing of this report, these fact sheets have not yet been produced. However, the initial results are included in this report.

Note that the vehicle driving performance is reported in the categories of All Operation, EVM operation, and ERM operation. The parameters in the three main categories of operations are as follows:

- All Operation
  - Overall gasoline fuel economy (mpg)
  - Overall DC electrical energy consumption (DC Wh/mi)
  - Total distance traveled (miles)
  - Average ambient temperature (degrees F)
- EVM Operation
  - DC electrical energy consumption (DC Wh/mi)
  - Distance traveled (miles)
  - Percent of total distance driven
- ERM Operation
  - Gasoline fuel economy (mpg)

- DC electrical energy consumption (DC Wh/mi)
- Distance traveled (miles)
- Percent of total distance driven.

Additional information will be provided to understand differences in operational modes and how the vehicles are being used by consumers, including vehicle charging behavior and usage of export power.

10.6 SCAQMD/EPRI/VIA Motors Demonstration Results

Throughout the 7-month data collection period, nearly 70,000 miles of driving data were collected for the VIA Motors pickups and vans. Overall summary metrics for the collected data can be seen in Table 10-1. Over 75% of the logged miles were driven by the vans, which is to be expected because the pickups entered the project later. Overall, the vans achieved a gasoline fuel economy of 16.5 mpg and used 126 DC Wh/mile of electrical energy, while the pickups were generally more efficient, achieving 18.4 mpg and using 72 DC Wh/mile of electricity. In EVM operations, the electrical energy consumption of the vans and pickups was 640 DC Wh/mile and 523 DC Wh/mile, respectively. In ERM operation, the vans achieved gasoline fuel economy of 13.2 mpg and the pickups 15.6 mpg; both put a very small amount of energy back into the battery pack.

Table 10-1. Summary of VIA Motors vehicle performance in each driving operation mode.

Operating Mode	Overall Operation		EVM Operation		ERM Operation	
Vehicle Type	Vans	Pickups	Vans	Pickups	Vans	Pickups
Total Distance Driven (miles)	54,170	15,579	11,053	2,363	43,117	13,216
Fuel Economy (mpg)	16.5	18.4	—	—	13.2	15.6
Electric Energy Use (DC Wh/mile)	126	72	640	523	-5	-8

To better understand how the vehicles were used, histograms were made to show the total distance driven for different trip distances and the breakdown between EVM and ERM driving within those trips. These plots are shown in Figure 10-4 and Figure 10-5. For both pickups and vans, the largest percentage of miles were driven during trips of less than 10 miles and the majority of EV driving was done on trips of 40 miles or less.

To determine the effects of ambient temperature on energy use during driving, energy use was split into bins based on ambient temperature. The average EV energy use and ERM fuel economy was then calculated for each bin and plotted for vans and pickups in Figures 10-6 and 10-7, respectively. For the vans, ERM driving is most efficient when the ambient temperature is between 10 and 15°C (50 and 59°F), and EVM driving is most efficient between 15 and 30°C (59 and 86°F).

For the pickups, EV driving was most efficient between 10 and 15°C, while ERM driving was most efficient around 25 to 30°C (77 to 86°F). In general, vehicle operations tend to get less efficient at more extreme temperatures due to the addition of heating and air conditioning loads. These trends are seen for both the pickups and vans, with the exception of cold weather driving for pickups, because data collection began after the cold winter months had passed.

Data were also collected during charging and use of the export power function. INL received charging data from 44 vans and 79 pickup trucks representing approximately 10,350 kWh of DC energy charged into the vehicles' traction batteries.

Export power data were received for 52 pickup trucks and 17 vans, during which 62.9 kWh of battery energy and 1.6 gallons of gasoline were consumed. Not all of the charging and export power usage is represented in the collected data. For this reason, further analysis must be performed to determine meaningful, accurate metrics regarding these operating modes. These results will be reported in the demonstration fact sheets.

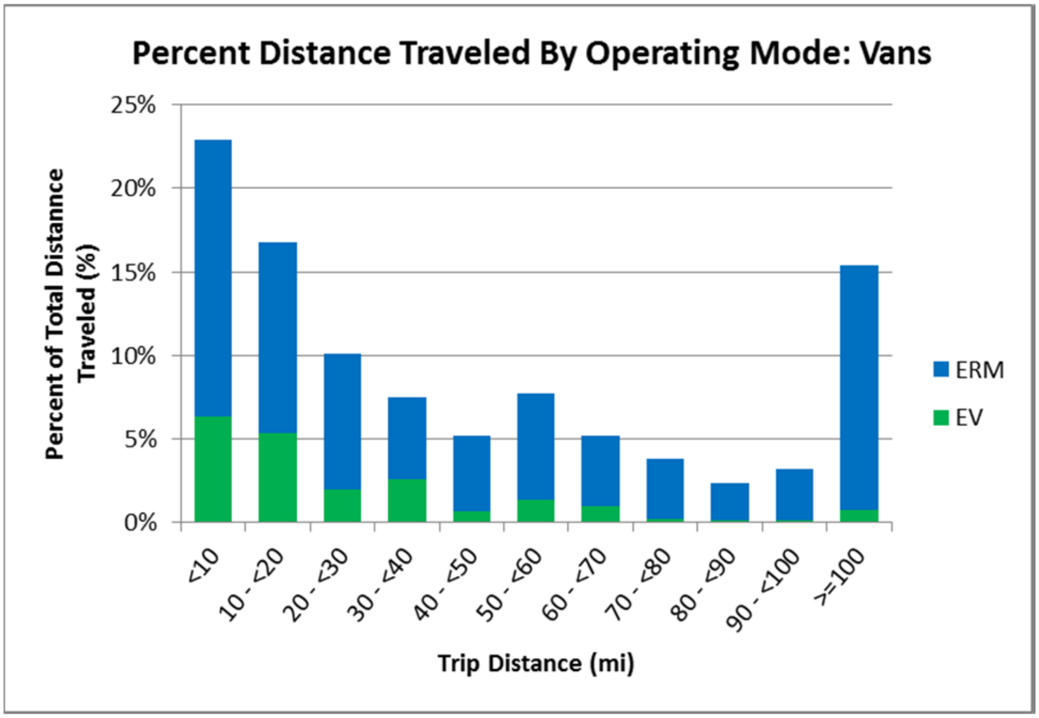


Figure 10-4. Percentage of distance traveled by operating mode for VIA Motors vans.

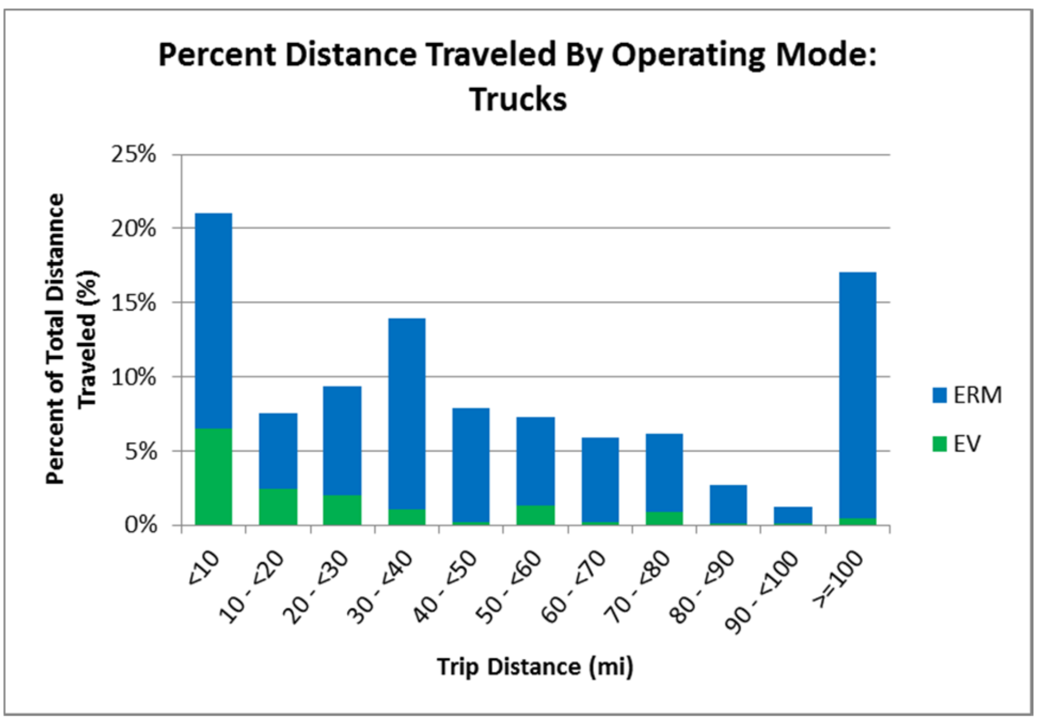


Figure 10-5. Percentage of distance traveled by operating mode for VIA Motors pickup trucks.

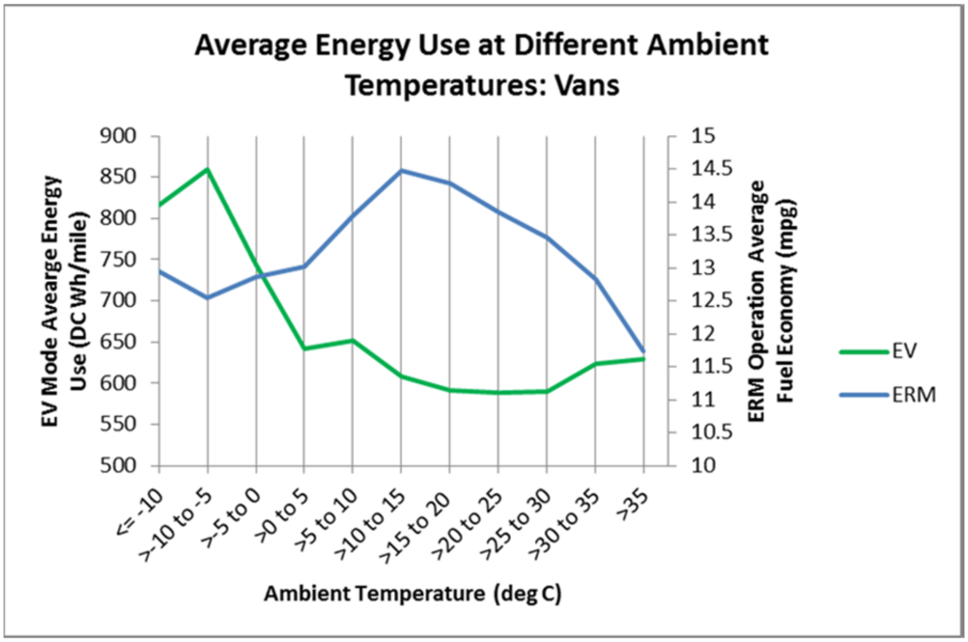


Figure 10-6. Average EV energy use and ERM fuel economy of VIA vans during driving at different ambient temperatures. The green EV line scale is the left axis and the blue ERM scale is the right axis.

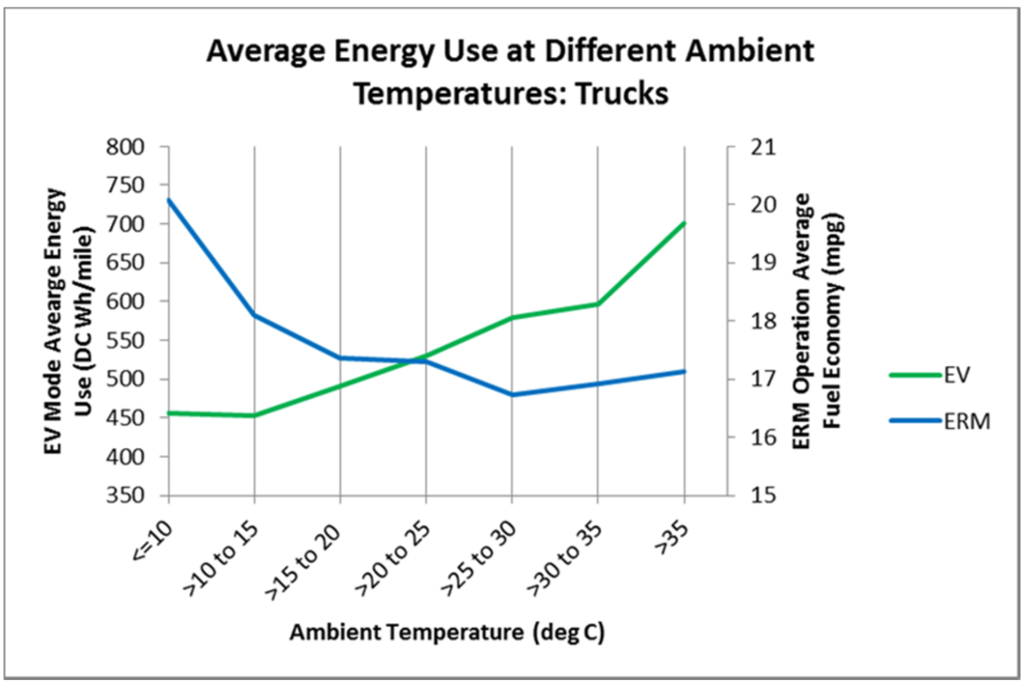


Figure 10-7. Average EV energy use and ERM fuel economy of VIA pickups during driving at different ambient temperatures. The green EV line scale is the left axis and the blue ERM scale is the right axis.

10.7 SCAQMD/EPRI/VIA Motors Demonstration Summary

INL analyzed data from 145 VIA Motors vans and pickups that were collected from December 2014 through June 2015 as part of the ARRA-funded SCAQMD/EPRI/VIA Motors Demonstration Project. A summary report will be published (http://avt.inl.gov/), which will detail the performance and usage of vehicles in commercial and government fleets across the United States. Over the data collection period, the data benchmarks more than 56,000 VIA van miles and over 13,000 VIA pickup miles. Over these miles, the vans had overall gasoline fuel economy of 16.5 mpg and electrical energy consumption of 126 DC Wh/mile, while the pickups had overall fuel economy of 18.4 mpg and electrical energy consumption of 72 DC Wh/mile.

11. EV PROJECT LESSONS LEARNED

Many lessons learned papers were published based on the large amount of data made available from both the charging infrastructure and the vehicles in The EV Project. In addition, several lessons learned papers were published after combining data from The EV Project and other projects, including non-ARRA projects. These lessons learned papers with combined data are noted and reported separately from The EV Project's lessons learned papers.

Many of the lessons learned in this section were written early on during execution of The EV Project. The assumptions and statements made at the time of creation were accurate at the time. However, some things (e.g., gasoline prices and electricity prices) have changed, but the methods used to calculate benefits and develop lessons learned are still valid. The lessons learned have been reviewed and, where possible, have been updated. The majority of the lessons learned papers reproduced in this document were developed during 2014 and 2015.

EV Project participants were generally very cooperative and enthusiastic about participation in the study and very supportive in providing feedback and information. The demographics of these innovators and early adopters of PEVs were speculated by many; therefore, the lessons learned papers include the results of a limited number of participant surveys.

Some lessons learned papers cross multiple charging infrastructure technologies and issues and they are available in the following report subsections.

11.1 EV Project Direct Current Fast Chargers

11.1.1 What Were the Cost Drivers for the Direct Current Fast Charging Installations?

11.1.1.1 Introduction. To evaluate the cost drivers for DCFC installations in The EV Project, some of the features of the installed hardware and site conditions must be understood.

The following four significant characteristics of the Blink dual-port DCFC affected installation costs:

1. Separate GPU and CDU
2. Availability in both 208-volt and 480-volt models
3. Dual port configuration
4. 60-kW power rating.

The EV Project DCFCs were designed with all power electronics in a single industrial-style cabinet (i.e., GPU) and all user interface equipment in a separate stylized cabinet, including a large video display. Separating the GPU from the CDU (Figure 11-1) provided two advantages for installation of the Blink DCFC. One, it enabled production of a common CDU and two different GPUs: one at 208 V (which could more easily be installed in a commercial facility with more commonly found 208-V service) and the other at 480 V. Offering two GPUs enabled the most appropriate equipment to be directly installed without requiring a separate transformer. Two, the separate units also enhanced safety, because the high-voltage GPU could be installed away from vehicle traffic, with a lesser likelihood of impact damage.

The dual-port configuration of the CDU (Figure 11-2) allows two EVs to be parked at the DCFC and connected at the same time. The Blink DCFC sequencing technology initiates charging for the first connected vehicle and automatically shifts charging to the second vehicle upon completion of the first vehicle's charge. The dual-port configuration had little significant effect on electrical installation cost, because no additional field-installed conduit or wire was required to implement this feature.

Figure 11-1. GPU (left) and CDU (right) for Blink DCFC.

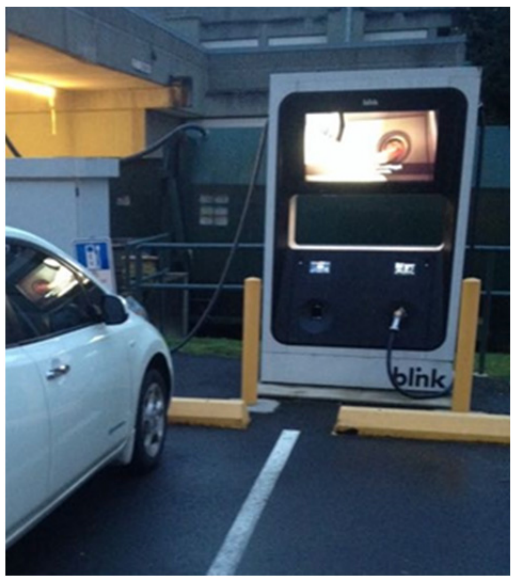


Figure 11-2. Dual-port Blink DCFC (photo courtesy of Plugshare.com).

However, the dual-port arrangement impacted siting because two adjacent parking spaces were required to provide user access to both charge ports.

Finally, the 60-kW charge power capability of the Blink unit affected installation costs because it often required a new electrical service to be provided by the local electric utility. The magnitude of this cost increase depended on existing electrical services (both available power and space for additional circuit breakers) at the host site and costs from the electric utility to install a new metered electrical service. It is likely the cost impact of a new service for supporting a 60-kW charger would be the same as it would be for a 50, 40, or 20-kW unit. However, it is more likely that the host electrical service will have 20 kW of additional power capability available than it will have 60 kW available.

All other installation cost drivers (e.g., distance from power source and installation site surface features such as concrete, asphalt, grass, etc.), local labor costs, and cost to add new service to the charging site were not affected by the hardware design and can be assumed as cost drivers for all DCFC installations.

11.1.1.2 Data Analyzed. This evaluation reviews not only the costs and site conditions associated with the 111 DCFC deployed during The EV Project, but also includes estimates obtained for another 50+

DCFC sites that were planned, but were not installed. These estimates were performed by experienced EV Project electrical contractors, validated by EV Project field services personnel, and accepted by the electrical contractor for a fixed cost installation. Therefore, they are assumed to be valid data points to be included in this assessment of installation cost drivers.

The total cost of installations cited in this report included only the costs paid to the electrical contractors to install Blink DCFCs. This cost typically would have included permit costs, engineering drawings (usually required), contractor's installation and administration labor, subcontracted construction labor or equipment (e.g., concrete, asphalt, trenching, boring, etc.), and materials other than the DCFC itself, which was provided by The EV Project. Installation costs did not include the cost of any AC Level 2 EVSE units that may have been simultaneously installed at the same site.

11.1.1.3 Analyses Performed. The first analysis performed quantified and characterized the costs for installation of DCFCs in The EV Project.

Examination of the DCFC installation costs gathered in The EV Project found the following:

- Average cost $23,662
- Median cost $22,626
- Minimum $8,500
- Maximum $50,820.

Further, statistical analysis of the costs (Figure 11-3) revealed that the average and median costs were not a good measure of what one could expect for the cost of DCFC installation. The standard deviation from the mean of $8,965 was nearly 40% of the average installation cost (i.e., $23,662), indicating there was a wide distribution of installation costs.

Further investigation of installation costs at or near the average finds that nearly 50% of them were Tennessee installations at Cracker Barrel restaurants. These 12 installations all followed the same pattern of a new service from a single electrical utility with the GPU installed near a pole-mounted utility transformer in the parking lot, resulting in costs that varied very little (within $720 [i.e., 3%] of the mean).

Removing the effect of the Cracker Barrel installations, the distribution of typical costs followed a pattern similar to that for the Arizona market, which is shown in Figure 11-4.

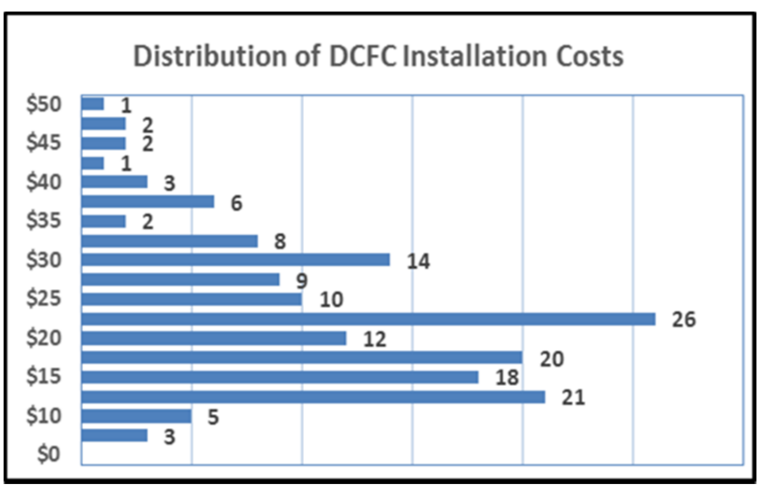


Figure 11-3. Number of EV Project DCFC sites by installation cost, shown in thousands of dollars.

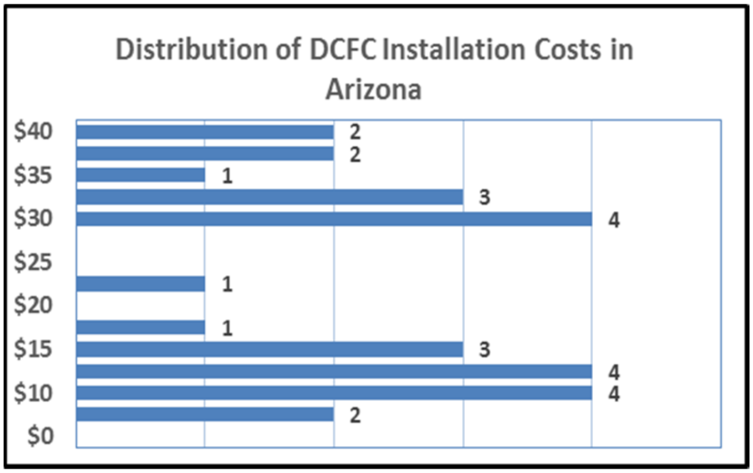


Figure 11-4. Number of EV Project DCFC sites by installation cost, shown in thousands of dollars.

11.1.1.4 Discussion of Results

Impact of Blink DCFC Hardware Features (Dual-Port, and Separate Power and Dispensing Units) on Installation Costs—There are some unique costs for installing the Blink DCFC unit, with its separate power and CDUs, dual-port connector design, and include the following:

- Two parking places dedicated for EV charging
- Two pads on which units are set
- Marginal increase in wiring/conduit due to the possibility of two trenches (one for GPU and one for CDU), but overall length of trenches is the same as a more typical single-unit, single-dispenser DCFC
- 60-kW power required for the DCFC.

Separating the unit into two parts also increased costs associated with two ground surface-mounted structures. The GPU base measures 3 ft x 4½ ft, while the CDU occupies a 2-ft x 5-ft space. The large size of the CDU was an intentional design decision because it made the DCFC more prominent for use as an advertising medium and easier to see; therefore, making it safer and easier to find. Depending on the installation location, a concrete surface or pre-cast pad was used for mounting the DCFC.

Because the CDU required two parking spaces, restriping of these parking spaces was typically required, increasing installation costs. Existence of two voltage-rated models provided installation cost savings because it eliminated the need for a separate transformer for installation.

Primary Installation Cost Drivers—The following are the significant DCFC installation cost drivers observed in The EV Project that are not specific to the Blink dual-port DCFC. Their impact on installation costs would be applicable for any installation of a DCFC unit rated at 20 kW or more:

1. Materials
2. Administration
3. Ground surface conditions
4. Electrical service upgrade.

Materials: The materials used in DCFC installations can be separated into the following three groups:

1. Standard installation materials, which would be in nearly every installation, but whose quantities may vary. Examples of standard installation materials include conduit, conductors, emergency shut-off switch, circuit breaker, fasteners, etc.

2. Installation surface replacement materials, which would depend entirely on where the DCFC was sited relative to the power source and work needed to restore the surface(s) impacted by installation of the unit and its associated electrical wiring (e.g. concrete, asphalt, gravel, etc.).
3. New electrical service materials, which include switch gear with meter section, conduit, and wire.

Administration: Administrative costs that were specifically associated with total DCFC installation costs include permit application processing, permit fees, engineering drawings, and, where required by the permitting authority, load studies. Just as the materials were affected by the specific installation site, so too were administration costs.

Permit fees varied greatly depending on permitting jurisdiction, extent of construction, whether installation was stand alone or part of another construction project, and whether it was for a new service or just an addition to the existing host electrical system.

The costs for preparing engineered drawings were another significant administrative cost. These varied, but generally represented from $1,000 to $3,000 or 5 to 10% of the total installation cost.

Ground Surface Conditions: It is self-evident that the DCFC site surface impacted by installation of conduit, concrete mounting pads, parking spaces, striping, etc. would vary depending on the surface the DCFC was installed on. Installation of underground electrical conduit was done either by trenching or boring (Figure11- 5). The basis for this decision depended on the site owners' preference regarding the appearance of after work restoration. The decision was also impacted by underground (e.g. water, gas, or electrical services) or aboveground (e.g., planters) features that may have made trenching impractical.

Figure 11-5. Examples of trenching for DCFC electrical conduit and wiring.

Electrical Service Upgrades: Many of the DCFC installations required new electrical service to be added to the host's site. The cost of these installations was significantly higher than those that did not require new service. The total cost increased due to the fees charged by the local electric utility to extend the service from the grid to the host site and the additional electrical switch gear and new meter required to manage this new electrical service.

Costs paid to the electric utility for service extension to the site varied due to circumstances associated with the surrounding grid and the electric utility's willingness to absorb some of these costs. Some of the utilities in The EV Project acted as partners and absorbed some or all of the costs to get the power to the charging site host's property.

Electrical service extension costs also varied depending on the electric utility's policies for aboveground or underground service. Overhead service is typically less expensive and quicker than trenching for an underground service extension. Electrical service extension costs for The EV Project's DCFCs varied from $3,500 to $9,500.

Addition of this service not only increased installation costs due to electric utility line extension costs and electrical switch gear needed, but also extended the time required to install the DCFC by many weeks.

Characteristics of Least Expensive Installations—Very simply put, the least expensive installations had sufficient electrical power at the site to accommodate the Blink dual-port DCFC. The very lowest cost installations had sufficient power and a simple installation with either short underground conduit runs (i.e., hand-shoveled) or surface-mounted conduit. Figure 11-6 shows one of three installations that cost less than $9,000. In addition to sufficient existing power at the site, this installation used surface-mounted electrical conduit.

Figure 11-6. Example of one of the least expensive installations.

Characteristics of Most Expensive Installations—As with the least expensive, the primary characteristic of the more expensive installations can be simply identified as those that had a new service installed to accommodate the DCFC. In some cases, the increased cost for new service was compounded by long underground conduits and surface conditions that were expensive to restore (e.g., concrete or asphalt).

Other Costs and Considerations—Time: Most of the "costs" discussed in this paper are monetary costs. However, another consideration for the DCFC site hosts is the amount of time this installation process takes, which can be divided into three installation conditions: (1) contractors installing equipment, (2) contractors waiting to start, and (3) contractors waiting to finish**.**

When things went smoothly and construction started and finished on consecutive days (no waiting for inspections or materials after installation started), the installation took from 30 to 60 days from the agreement to proceed. However, in many circumstances, there were delays in administration and materials. When a new service was required, the duration of the installation from start to finish often exceeded 90 days.

Electrical Contractors: Installation contractors were selected for participation in The EV Project based on their interest, qualifications, and ability to meet DOE-mandated DBA requirements. When The EV Project began in late 2009, the economic conditions of the construction trade were significantly affected by the recession. During this time, contractors were very willing to accept the additional administrative requirements of working under DBA and other administrative requirements of a federally funded project. Three years later, when the majority of the DCFC installations were underway, the economy had improved and the contracting requirements of this federally funded project became an impediment to securing contractors capable of providing timely installations and competitive estimates.

Electric Utilities and Municipalities: As previously discussed, the costs associated with permits, inspections, and new service increased costs, not only in monetary terms, but in time. Both the electric utility and municipal partners in deployment of EV infrastructure had a significant impact on the time cost of the installation project. These time costs were often many weeks waiting for permit approval, plan approval, or service extension work to be scheduled. The EV Project cooperated with local municipalities and electric utilities by providing these two important partners in the project with advanced notification of installations in an effort to minimize the impact of time and, in some cases, cost.

11.1.1.5 Conclusions. The primary cost driver for DCFCs installed or scheduled to be installed in The EV Project was the requirement for new electric service. This cost had the greatest impact on overall installation costs.

Other significant cost drivers were as follows:

- Surface material under which electrical wiring/conduit was installed
- Distance from the electrical power source to the DCFC GPU
- Distance from the GPU to the CDU
- Permit and engineering drawings.

In some instances, cost drivers were either reduced or eliminated through support and cost share by electric utilities and local government.

Electric utilities have a significant impact on the cost of what is required to add new service. Meanwhile local governments can (and did) provide support by waiving permit fees or expediting the permit process.

11.1.1.6 List of Blink DCFCs Deployed during The EV Project

Table 11-1. Name of host and street address for dual-port DCFCs deployed in The EV Project.

1. Cracker Barrel 29 East Ridge 1460 North Mack Smith Road East Ridge, TN 37412 **2. Cracker Barrel 21 Cleveland** 1650 Clingan Ridge Drive NW Cleveland, TN 37312 **3. Cracker Barrel 9 Athens (Sweetwater)** 110 Burkett L. Witt Blvd Athens, TN 37303	**55. Harvard Market** 1401 Broadway Seattle, WA 98122 **56. Tahoma Market (I-5 Exit 137)** 6006 Pacific Highway East I-5 Exit 137 Fife, WA 98424 **57. Fred Meyer - #683 Grand Central** 2500 Columbia House Blvd

4. Cracker Barrel 15 Cookeville 1295 S Walnut Avenue Cookeville, TN 38501 **5. Cracker Barrel 79 Crossville** 23 Executive Drive Crossville, TN 38555 **6. Cracker Barrel 75 Farragut (W. Knoxville)** 716 N Campbell Station Road Exit 373 Farragut, TN 37934 **7. Cracker Barrel 6 Harriman** 1839 South Roane Street Harriman, TN 37748 **8. Cracker Barrel 565 Kimball** 550 Kimball Crossing Drive Kimball, TN 37347 **9. Cracker Barrel 3 Manchester** 103 Paradise Street Exit 110 Manchester, TN 37355 **10. Cracker Barrel 90 Murfreesboro** 138 Chaffin Place Murfreesboro, TN 37129 **11. Cracker Barrel 23 Nashville** 3454 Percy Priest Drive Nashville, TN 37214 **12. Riverview Toyota** 2020 W Riverview Auto Drive Mesa, AZ 85201 **13. Bell Ford** 2401 W. Bell Road Phoenix, AZ 85032 **14. Fred Meyer - #663 Sandy** 16625 SE 362nd Ave Sandy, OR 97055 **15. Walmart #2927** 23500 NE Sandy Blvd Wood Village, OR 97060 **16. Fred Meyer - #661 Sunset** 22075 NW Imbrie Drive Hillsboro, OR 97124 **17. Nissan of Santa Rosa** 1275 Santa Rosa Ave. Santa Rosa, CA 95404 **18. Linear City Development LLC - Mateo Street** 662 Mateo Street Los Angeles, CA 90021 **19. Hillsboro Civic Center**	Vancouver, WA 98661 **58. Fred Meyer - #460 Salmon Creek** 800 NE Tenney Rd Vancouver, WA 98685 **59. Fred Meyer - #391 Totem Lake** 12221 120th Ave NE Kirkland, WA 98034 **60. Fred Meyer - #090 East Salem** 3740 Market NE Salem, OR 97301 **61. Fred Meyer - #375 Tigard** 11565 SW Pacific Highway Tigard, OR 97223 **62. Fred Meyer - #179 Lake City Way** 13000 Lake City Way NE Seattle, WA 98125 **63. Fred Meyer - #600 Hollywood** 3030 NE Weidler St Portland, OR 97232 **64. CBRE - Britannia Point Grand** 280 E Grand Ave South San Francisco, CA 94080 **65. Cracker Barrel 2 Lebanon** 635 South Cumberland Lebanon, TN 37088 **66. CBRE-Britannia Oyster Point** 1110 Veterans Parking Garage South San Francisco, CA 94080 **67. United Markets San Anselmo** 100 Red Hill Rd. San Anselmo, CA 94960 **68. 1935 Waterman Ave -San Bernardino- LA/CA** 1935 S. Waterman Ave, San Bernardino San Bernardino, CA 92408 **69. Fry's Store #612 Phoenix** 4707 E. Shea Blvd. Phoenix, AZ 85028 **70. Nissan of the Eastside** 11815 NE 8th Ave Bellevue, WA 98005 **71. Fred Meyer - #393 Tualatin** 19200 SW Martinazzi Tualatin, OR 97062 **72. MAPCO - Hillsboro Road - Franklin TN** 1100 Hillsboro Road Franklin, TN 37064 **73. United Markets San Rafael**

150 E Main Street
Hillsboro, OR 97123

20. South Lake Union Discovery Center - DCFC

101 Westlake Ave N
Seattle, WA 98109

21. Elmer's

255 N Arney Rd # 255
Woodburn, OR 97071

22. Intuit - Menlo Park Campus

180 Jefferson Drive
Menlo Park, CA 94025

23. Wash Wizard

1845 E. University Drive
Tempe, AZ 85281

24. Trillium North

20425 North 7th Street
Phoenix, AZ 85024

25. Silver Spring Networks

585 Broadway Street
Redwood City, CA 94063

26. MJ - Santa Ysabel

30250 Julian Rd
Highway 78 and 79
Santa Ysabel, CA 92070

27. Good Earth Market/Route Zero

720 Center Blvd.
Fairfax, CA 94930

28. Chateau Montelena Winery

1429 Tubbs Lane
Calistoga, CA 94515

29. Intuit - Mountain View Campus, Building 4

2500 Garcia Ave.
Mountain View, CA 94043

30. Burgerville #41 92nd and Powell

3504 SE 92nd
Portland, OR 97266

31. Spirent Communications

1325 Borregas Avenue
Sunnyvale, CA 94089

32. Shell Station 35408 - 24805 N Lake Pleasant Pkwy

24805 N Lake Pleasant Pkwy
Peoria, AZ 85383

33. Clackamas Town Center - Barnes and Noble Parking

11900 SE 82nd Ave
Happy Valley, OR 97086

34. Facebook - Building 12

515 Third St.
San Rafael, CA 94901

74. 450 South Street Parking Garage

450 South Street
San Francisco, CA 94158

75. EAI, Inc.

1337 E. Washington
Phoenix, AZ 85034

76. Santa Clara City Library DCFC

2635 Homestead Drive
Santa Clara, CA 95051

77. Fred Meyer - #023 Bellevue

2041 148TH NE
Bellevue, WA 98007

78. Ohlone College - Newark Campus

39399 Cherry Street
Newark, CA 94560

79. Edgewood Plaza

2050 Channing Way
Palo Alto, CA 94303

80. Fry's Store #64 Gilbert

714 S. Val Vista
Gilbert, AZ 85296

81. 19 Duncan St

19 Duncan St
Clayton, GA 30525

82. Walgreens Store #7677

1502 Lake Tapps Pkwy SE
Auburn, WA 98092

83. Walgreens Store #7480

1701 Auburn Way S
Auburn, WA 98002

84. Walgreens Store #7700

34008 Hoyt Rd SW
Federal Way, WA 98023

85. Walgreens Store #7594

1416 Harvey Rd
Auburn, WA 98002

86. DCFC - SDSU Lot G

5500 Campanile Dr
San Diego, CA 92182

87. City of Hayward - 805 B St

805 B Street
Hayward, CA 94541

88. Haselwood Family YMCA Silverdale

Haselwood YMCA
3909 NW Randall Way
Silverdale, WA 98383

1601 Willow Rd. Menlo Park, CA 94025 **35. Bellevue College** 3000 Landerholm Circle SE Bellevue, WA 98007 **36. Wilsonville Town Center** 8255 SW Wilsonville Road Wilsonville, OR 97070 **37. Camelback Toyota - South Side of Dealership** 1550 E. Camelback Road Phoenix, AZ 85014 **38. BP #1101 Bell Road** 1101 Bell Road Antioch, TN 37013 **39. Shari's Restaurant and Pies - Keizer** 4998 River Rd. N Keizer, OR 97303 **40. North Bay Nissan** 1250 Auto Center Drive Petaluma, CA 94952 **41. Sunset Development - Bishop Ranch** 2430 Camino Ramon San Ramon, CA 94583 **42. SEARS - Store #1078** 6515 E Southern Ave MESA, AZ 85206 **43. SEARS - Store #1798** 7780 W Arrowhead Towne Ctr GLENDALE, AZ 85308 **44. SEARS - Store #1768** 4604 E CACTUS RD PHOENIX, AZ 85032 **45. SEARS - Store #1115 (Hamilton Place Mall)** 2100 Hamilton Place Blvd Chattanooga, TN 37421 **46. Concord Hilton** 1970 Diamond Blvd. Concord, CA 94520 **47. Chevron Discovery Market** 2128 E. Florence Blvd Casa Grande, AZ 85122 **48. Best Western Escondido** 1700 Seven Oaks Road Escondido, CA 92026 **49. Applied Materials - Building 12** 3225 Oakmead Village Drive Santa Clara, CA 95051	**89. Roth's Silverton** 918 N 1st Street Silverton, OR 97381 **90. Alexandria Real Estate - Owens St Parking Garage** 1670 Owens Street San Francisco, CA 94158 **91. Simpson Strong Tie DCFC** 5956 West Las Positas Boulevard Pleasanton, CA 94588 **92. Santa Clara Convention Center** 5001 Great America Parkway Santa Clara, CA 95054 **93. Walgreens Store #12168** 3929 Kitsap Way Bremerton, WA 98312 **94. Dalton Utilities - College Drive** 890 College Drive Dalton, GA 30722 **95. Blink Network (2nd Avenue)** 430 S. 2nd Avenue Phoenix, AZ 85003 **96. City of Chula Vista - Towne Center Parking Structure** 340 F Street Chula Vista, CA 91910 **97. Mira Mesa – AT&T Building** 8248 Mira Mesa Blvd San Diego, CA 92126 **98. Plaza Escuela, West Parking Lot, 2nd Floor** 1500 Botelho Drive Walnut Creek, CA 94596 **99. Stanford Shopping Center** 600 Stanford Shopping Center Palo Alto, CA 94304 **100. IdleAir at Carneys Point, NJ - Flying J #688 - I-295 Exit 2C** 326 Slapes Corner Carneys Point, NJ 08069 **101. IBEW 48 - Union Hall** 15937 NE Airport Way Portland, OR 97230 **102. Serramonte Center** 3 Serramonte Center Daly City, CA 94015 **103. Equity Office - 101 Metro** 101 Metro Drive San Jose, CA 95110

50. Ohlone College - Fremont Campus - Hyman Hall 43600 Mission Blvd Fremont, CA 94539 **51. Shari's Restaurant and Pies - Sherwood** 16280 SW Langer Dr Sherwood, OR 97140 **52. Toyota of El Cajon** 965 Arnele Ave El Cajon, CA 92020 **53. City of Azusa - San Gabriel and W. 6th** San Gabriel and W. 6th Azusa, CA 91702 **54. SEARS - Store #1169** 3111 W Chandler Blvd Chandler, AZ 85226	**104. Walgreens Store #4372 San Jose** 780 East Santa Clara Street San Jose, CA 95112 **105. Walgreens Store #2612 Santa Clara** 200 N Winchester Blvd Santa Clara, CA 95050 **106. Shell Station #70 - 1509 E. Buckeye** 1509 E. Buckeye Phoenix, AZ 85034 **107. Thousand Oaks Transportation Center - DCFC** 265 S Rancho Rd Public Works Department Thousand Oaks, CA 91320

11.1.2 What Location Factors Did Highly Utilized Direct Current Fast Chargers Have in Common

11.1.2.1 Introduction. The EV Project deployed over 100 DCFCs using the CHAdeMO charging standard [1]. This option for fast charge capability was included on all Nissan Leaf vehicles that participated in The EV Project.

The EV Project's plan for deployment of DCFCs included some located within metropolitan areas of The EV Project and some located on transportation corridors between metropolitan areas. The latter were intended to enable Leaf drivers to extend their travel range and move between metropolitan areas. This was most extensively done in Tennessee, where there are distinct population centers separated by miles of highway, passing primarily through rural areas.

The distribution, by state, of DCFCs deployed in The EV Project is shown in Figure 11-7. DCFCs were deployed in the California markets of The EV Project as follows: 30 in San Francisco and 5 each in Los Angeles and San Diego.

11.1.2.2 Key Conclusions

- The most highly utilized DCFCs in The EV Project were located in the metropolitan areas of Seattle and San Francisco.
- The metropolitan areas of San Francisco and Seattle represent two of the top five U.S. sales markets for the Nissan Leaf.
- The top 10% of the most highly utilized DCFCs in The EV Project averaged 40 fast charges per week.
- The most utilized DCFC stations were located along major commuter routes within the major metropolitan areas.
- Many of the highly utilized DCFCs were located near or associated with high-tech employers.

11.1.2.3 Data Analyzed. Data analyzed for this paper included DCFC use data collected by the Blink network and transmitted to the Advanced Vehicle Testing Activity at INL. INL's data experts then qualified and aggregated data for reporting. DCFC utilization data includes all charging operations, not just those from vehicles that were part of The EV Project.

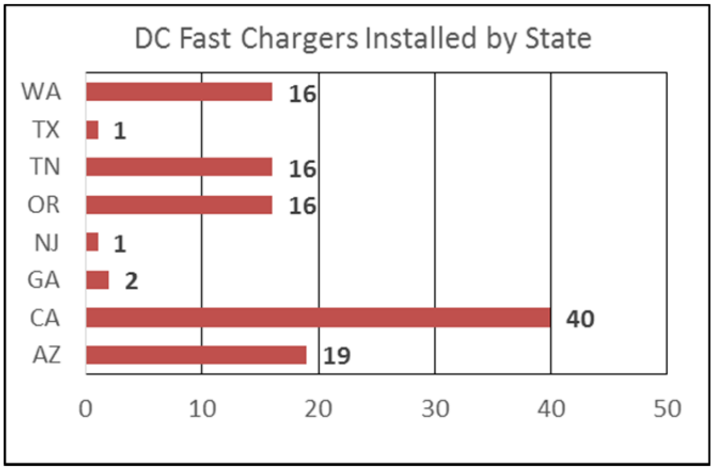


Figure 11-7. Deployment of DCFCs by state.

This report analyzed DCFC utilization over the final 6 months of 2013, including charge events and energy dispensed per DCFC. During this period, over 30,000 charge events and 275,000 kWh of electrical energy were delivered from The EV Project's DCFCs.

In order to determine what effect location had on DCFC use, the most utilized stations were mapped and their locations examined for distance to local attractions, large employers, and transportation routes.

11.1.2.4 Analyses Performed. The top 20 most utilized DCFC stations in The EV Project are listed in Table 11-2. The top 12 most utilized DCFCs in The EV Project were located in the Seattle (seven DCFC) and San Francisco (five DCFC) markets. Based on the average number of charge events per week, the Blink DCFC at Evernote in Redwood City, California was used most frequently at 66.5 charge events per week over the last 6 months of 2013.

Because DCFCs in Seattle and San Francisco represent the top 12 sites and 70% of the top 20 most utilized stations, analysis focused on location-based factors that contributed to the high utilization of these DCFCs. Figure 11-12 shows all DCFC stations in San Francisco and Seattle that had an average of more than three charge events per week. This figure also shows significant variation in DCFC utilization within these two markets. San Francisco DCFC utilization ranged from 66.5 to only 4.3 charge events per week. While the metropolitan Seattle area had utilization ranging from 58.85 to 3.77 charge events per week.

Figures 11-8 and 11-9 (also included in larger format as Figures 11-13 and 11-14) show the geographic relationship between DCFCs in the San Francisco and Seattle markets. The figures represent DCFC use with the height of the bars.

Analysis of these highly utilized locations was performed using annual average daily traffic and the location of the DCFC station relative to the nearest major transportation route. Figure 11-10 shows an example of this for the most frequently used DCFC, which was at Evernote in Redwood City, California. The Evernote site is near a major junction of the Bayshore Freeway (US-101) and is associated with the highly compensated workforce of a high-tech employer.

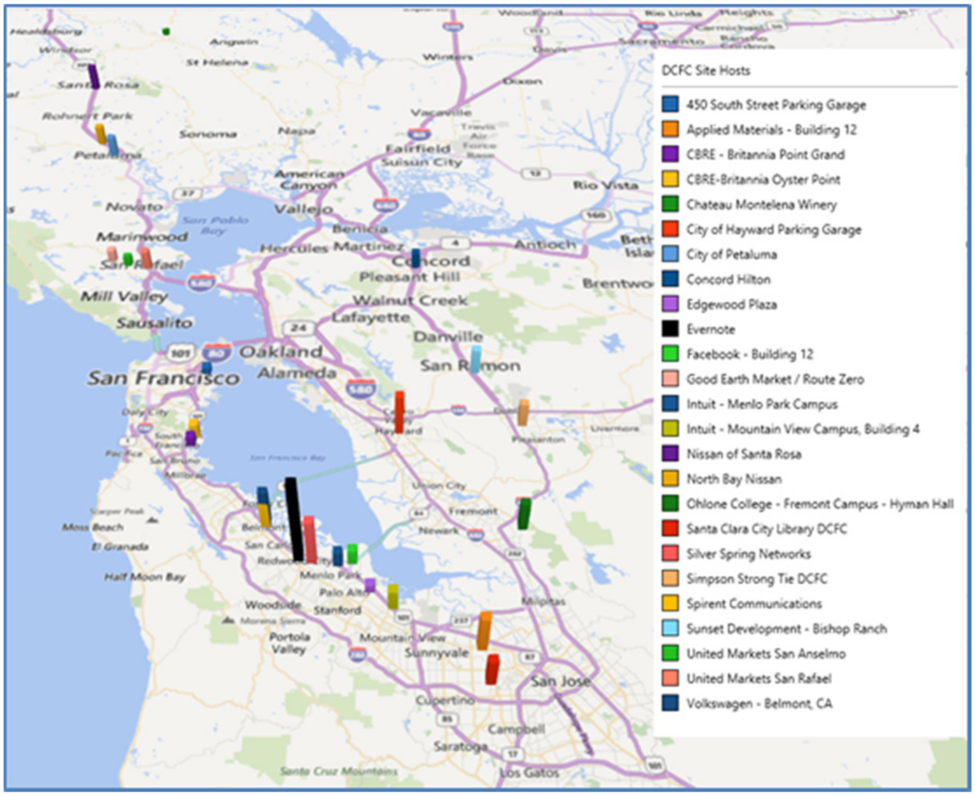


Figure 11-8. DCFC use in San Francisco market.

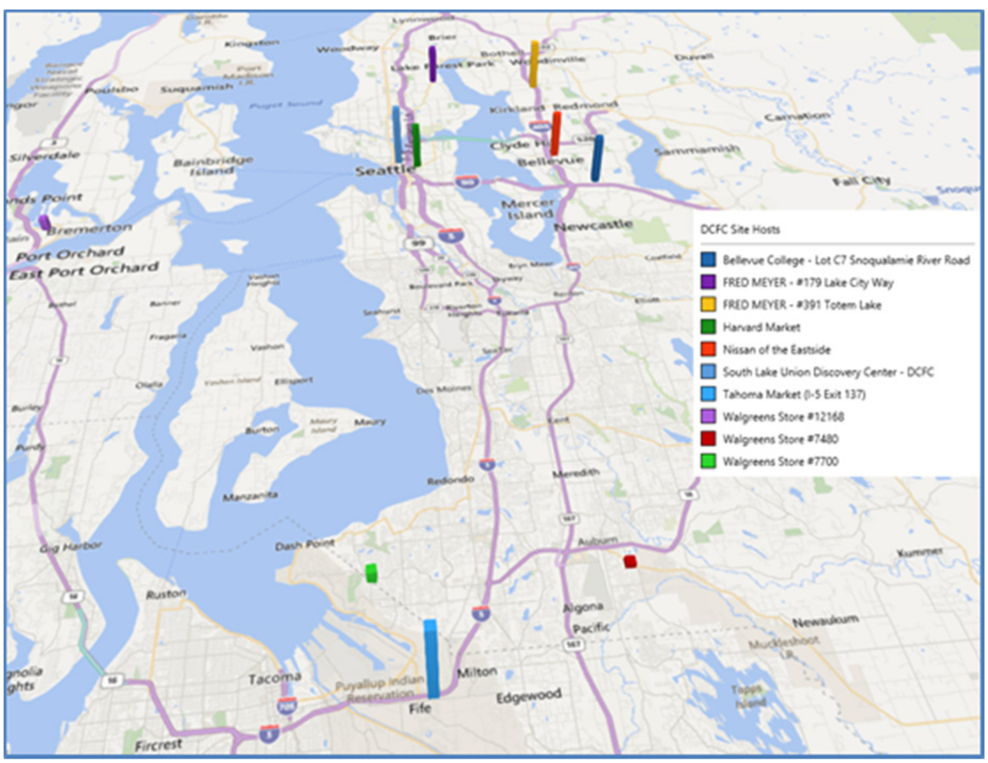


Figure 11-9. DCFC use in Seattle market.

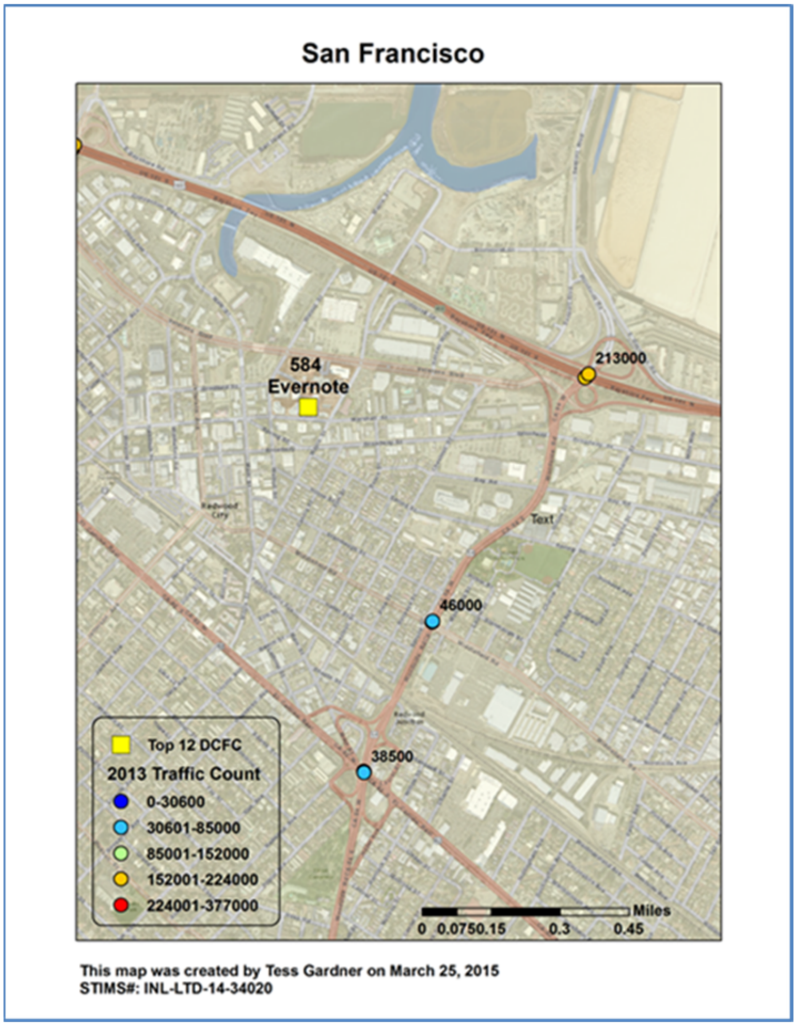


Figure 11-10. Geographic information system map of DCFC and annual average daily traffic for 2013.

11.1.2.5 Discussion of Results. In addition to being the first (i.e., San Francisco) and fourth (i.e., Seattle) largest markets for sales of the Nissan Leaf in 2013, three location-based characteristics are associated with the highest utilized DCFCs in these markets:

- Close proximity to popular commuter routes
- Close proximity to or direct association with a highly compensated workforce
- DCFC located in an obviously publicly accessible venue.

Near Busy Transportation Routes—The proximity to popular commuter routes appears to have the greatest influence on DCFC popularity, because it was a feature that was common amongst most of the high-use stations. Table 11-3 lists the top 12 DCFCs and the average daily traffic that was within half a mile of the DCFC station. Nine of the 12 stations are located near very significant transportation routes. The majority of these transportation routes are located within the urban areas they serve. The exception is the second most frequently used station at Tahoma Market in Fife, Washington. This station is more accurately described as being outside the urban Seattle area and more likely acts as a range extending or connecting station between metropolitan areas. It is located adjacent to Junction 137 on highly travelled Interstate 5 (as seen in Figure11-11).

Typically, DCFCs located adjacent to highways between metropolitan areas were not used as often as those located adjacent to commuter routes within a metropolitan area.

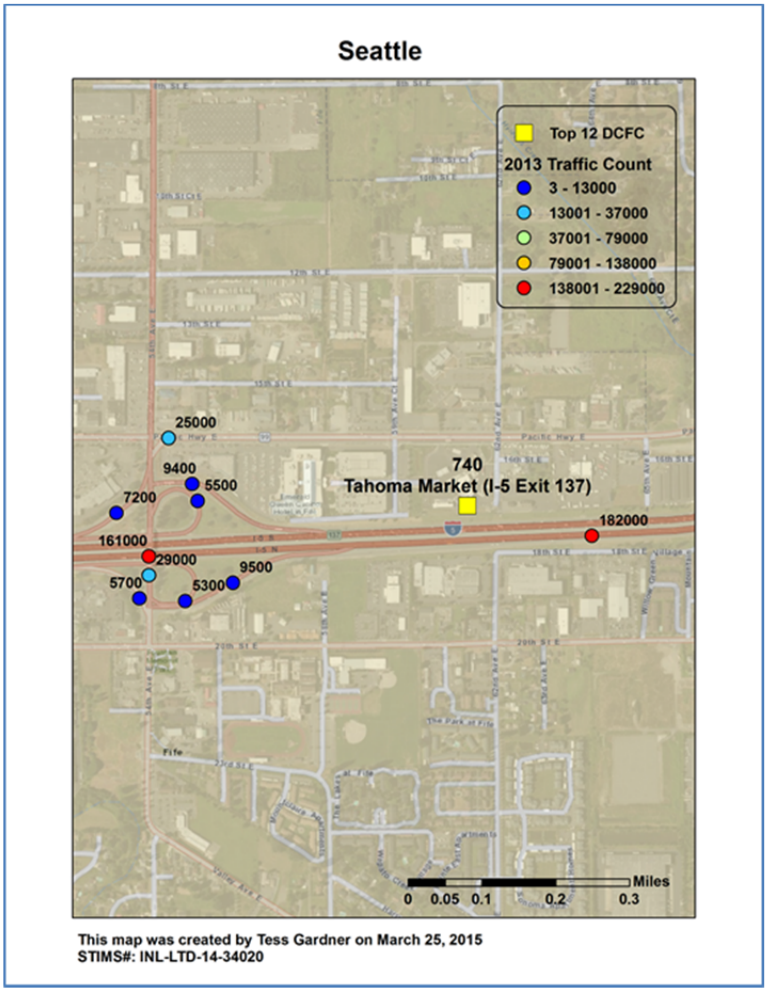


Figure 11-11. Geographic information system map of DCFCs and annual average daily traffic for 2013.

Near Employers with Highly Compensated Workforce—Another factor that appears to influence utilization is the location of the DCFC near the campus of high-tech businesses, which typically have a highly compensated workforce. This is likely due to the matching demographics between employees of high-tech businesses and EV purchasers as highlighted in a paper published by Experian Automotive in April 2014 [2]. In addition to being used as a workplace charger, these DCFCs also benefit from a very local population of EV drivers accessing the stations for public use.

However, installations on high-tech campuses near commuter routes are not a guarantee of high utilization (as can be seen in the map showing DCFC locations in Table 11-4). Facebook, Intuit, and Spirent Technologies are all high-tech companies with a highly compensated workforce and DCFC stations similarly located adjacent to the same Bayshore Freeway as the Evernote DCFC. Utilization of these stations was not as high as it was for others along the Bayshore Freeway. One factor that likely kept these stations from being used as much as the others along the Bayshore Freeway was the existence of a free DCFC at a Nissan Technology Center that is located within a 10 minute walk (per comments on Plugshare.com) from Spirent Technologies.

Easily Accessible Location—Finally, simple and easy access to the DCFC station was an important factor for frequent utilization. Among the highest used sites are those that were clearly accessible to the public. Two-thirds of the top 20 most utilized sites were found in public parking garages and parking lots at public venues like shopping centers and community colleges.

Although Facebook's DCFC is available to the public, it is inside a large employee parking lot (as seen in bird's eye view shown in Figure 11-15) and may be perceived as less welcoming to passing EV drivers.

11.1.2.6 Conclusions. The first observation that must be made about highly utilized DCFCs in The EV Project is that they are located in two very successful markets for the Nissan Leaf. Without a significant population of "fast-chargeable" PEVs, high utilization cannot be achieved.

Regarding the location of the most highly utilized DCFCs in The EV Project, there is a greater likelihood that a DCFC will be highly utilized if its location exhibits all of the following location-based characteristics:

- Within a half mile of a major commuter route
- On or near the campus of a company with a highly compensated workforce, where it can function as both workplace and publicly accessible
- It is in a welcoming location (i.e., not too closely associated with the host).

11.1.2.7 References

1. CHAdeMO Association http://www.chademo.com/wp/.
2. Experian Automotive, "Consumers purchasing an electric vehicle are younger and more affluent than those buying a hybrid," April 22, 2014 https://www.experianplc.com/media/news/2014/experian-automotive-consumers-purchasing-an-electric-vehicle-are-younger-and-more-affluent/.

11.1.2.8 Tables

Most Utilized Direct Current Fast Chargers by Charge Events per Week

Table 11-2. Report from data supplied by Blink network from July 1 through December 31, 2013 (source: Advance Vehicle Testing Activity at INL).

Charge Events per Week	Host	Street Address	City	State	ZIP	EV Project Market
66.50	Evernote	305 Walnut St.	Redwood City	CA	94063	San Francisco
58.85	Tahoma Market (I-5 Exit 137)	6006 Pacific Highway East	Fife	WA	98424	Seattle
43.90	South Lake Union Discovery Center - DCFC	101 Westlake Ave N	Seattle	WA	98109	Seattle
37.93	FRED MEYER - #391 Totem Lake	12221 120th Ave NE	Kirkland	WA	98034	Seattle
36.48	Silver Spring Networks	585 Broadway Street	Redwood City	CA	94063	San Francisco
35.19	Bellevue College - Lot C7 Snoqualamie River Road	3036 Snoqualamie River Road	Bellevue	WA	98005	Seattle
34.58	Nissan of the Eastside	11815 NE 8th Ave	Bellevue	WA	98005	Seattle
33.21	Harvard Market	1401 Broadway	Seattle	WA	98122	Seattle
31.16	City of Hayward Parking Garage	777 B Street	Hayward	CA	94541	San Francisco
30.32	Volkswagen - Belmont CA	500 Clipper Drive	Belmont	CA	94002	San Francisco
29.94	Applied Materials - Building 12	3225 Oakmead Village Drive	Santa Clara	CA	95051	San Francisco
28.68	FRED MEYER - #179 Lake City Way	13000 Lake City Way NE	Seattle	WA	98125	Seattle
26.90	FRED MEYER - #661 Sunset	22075 NW Imbrie Drive	Hillsboro	OR	97124	Oregon
25.15	Clackamas Town Center	11900 SE 82nd Ave	Happy Valley	OR	97086	Oregon
23.36	South Coast Air Quality Management District	21865 Copley Dr	Diamond Bar	CA	91765	Los Angeles
22.90	FRED MEYER - #375 Tigard	11565 SW Pacific Highway	Tigard	OR	97223	Oregon
22.52	FRED MEYER - #090 East Salem	3740 Market NE	Salem	OR	97301	Oregon
22.45	Ohlone College - Fremont Campus - Hyman Hall	43600 Mission Blvd	Fremont	CA	94539	San Francisco
21.57	Santa Clara City Library DCFC	2635 Homestead Drive	Santa Clara	CA	95051	San Francisco
20.81	Linear City Development LLC - Mateo Street	662 Mateo Street	Los Angeles	CA	90021	Los Angeles

Annual Average Daily Traffic near the Most Utilized Direct Current Fast Chargers

Table 11-3. Report from data supplied by Blink network from July 1 through December 31, 2013 (source: Advance Vehicle Testing Activity at INL).

Charge Events per Week	Host	Street Address	City	State	Nearest AADT
66.50	Evernote	305 Walnut St.	Redwood City	CA	213,000
58.85	Tahoma Market (I-5 Exit 137)	6006 Pacific Highway East	Fife	WA	182,000
43.90	South Lake Union Discovery Center - DCFC	101 Westlake Ave N	Seattle	WA	206,000
37.93	FRED MEYER - #391 Totem Lake	12221 120th Ave NE	Kirkland	WA	129,000
36.48	Silver Spring Networks	585 Broadway Street	Redwood City	CA	213,000
35.19	Bellevue College - Lot C7 Snoqualamie River Road	3036 Snoqualamie River Road	Bellevue	WA	16,000
34.58	Nissan of the Eastside	11815 NE 8th Ave	Bellevue	WA	164,000
33.21	Harvard Market	1401 Broadway	Seattle	WA	206,000
31.16	City of Hayward Parking Garage	777 B Street	Hayward	CA	37,000
30.32	Volkswagen - Belmont CA	500 Clipper Drive	Belmont	CA	229,000
29.94	Applied Materials - Building 12	3225 Oakmead Village Drive	Santa Clara	CA	191,000
28.68	FRED MEYER - #179 Lake City Way	13000 Lake City Way NE	Seattle	WA	34,000

Utilization of Direct Current Fast Chargers in the San Francisco and Seattle Market Areas

Table 11-4. Report from data supplied by Blink network from July 1 through December 31, 2013 (source: Advance Vehicle Testing Activity at INL).

Host Name	Address	City	Stat	ZIP	Charge Events per Week
Evernote	305 Walnut St.	Redwood City	CA	94063	66.50
Tahoma Market (I-5 Exit 137)	6006 Pacific Highway East	Fife	WA	98424	58.85
South Lake Union Discovery Center - DCFC	101 Westlake Ave N	Seattle	WA	98109	43.90
FRED MEYER - #391 Totem Lake	12221 120th Ave NE	Kirkland	WA	98034	37.93
Silver Spring Networks	585 Broadway Street	Redwood City	CA	94063	36.48
Bellevue College - Lot C7 Snoqualamie River Road	3036 Snoqualamie River Road	Bellevue	WA	98005	35.19
Nissan of the Eastside	11815 NE 8th Ave	Bellevue	WA	98005	34.58
Harvard Market	1401 Broadway	Seattle	WA	98122	33.21
City of Hayward Parking Garage	777 B Street	Hayward	CA	94541	31.16
Volkswagen - Belmont, CA	500 Clipper Drive	Belmont	CA	94002	30.32
Applied Materials - Building 12	3225 Oakmead Village Drive	Santa Clara	CA	95051	29.94
FRED MEYER - #179 Lake City Way	13000 Lake City Way NE	Seattle	WA	98125	28.68
Ohlone College - Fremont Campus - Hyman Hall	43600 Mission Blvd	Fremont	CA	94539	22.45
Santa Clara City Library DCFC	2635 Homestead Drive	Santa Clara	CA	95051	21.57
Spirent Communications	1325 Borregas Avenue	Sunnyvale	CA	94089	20.66
Nissan of Santa Rosa	1275 Santa Rosa Ave.	Santa Rosa	CA	95404	19.71
Sunset Development - Bishop Ranch	2430 Camino Ramon	San Ramon	CA	94583	19.21
Simpson Strong Tie DCFC	5956 West Las Positas Boulevard	Pleasanton	CA	94588	18.39
City of Petaluma	210 Lakeville Street	Petaluma	CA	94952	15.98
Intuit - Mountain View Campus, Building 4	2500 Garcia Ave.	Mountain View	CA	94043	15.41
North Bay Nissan	1250 Auto Center Drive	Petaluma	CA	94952	15.18
United Markets San Rafael	515 Third St.	San Rafael	CA	94901	14.54
Concord Hilton	1970 Diamond Blvd.	Concord	CA	94520	12.86
Intuit - Menlo Park Campus	180 Jefferson Drive	Menlo Park	CA	94025	12.40
Facebook - Building 12	1601 Willow Rd.	Menlo Park	CA	94025	11.49
CBRE-Britannia Oyster Point	1110 Veterans Parking Garage	South San Francisco	CA	94080	10.69
Good Earth Market / Route Zero	720 Center Blvd.	Fairfax	CA	94930	9.21
Walgreens Store #7700	34008 HOYT RD SW	FEDERAL WAY	WA	98023	9.12
Walgreens Store #12168	3929 KITSAP WAY	BREMERTON	WA	98312	8.79
United Markets San Anselmo	100 Red Hill Rd.	San Anselmo	CA	94960	7.76
CBRE - Britannia Point Grand	280 E Grand Ave	South San Francisco	CA	94080	7.53
Edgewood Plaza	2050 Channing Way	Palo Alto	CA	94303	6.20
450 South Street Parking Garage	450 South Street	San Francisco	CA	94158	5.57
Chateau Montelena Winery	1429 Tubbs Lane	Calistoga	CA	94515	4.30
Walgreens Store #7480	1701 AUBURN WAY S	AUBURN	WA	98002	3.77

11.1.2.9 Figures

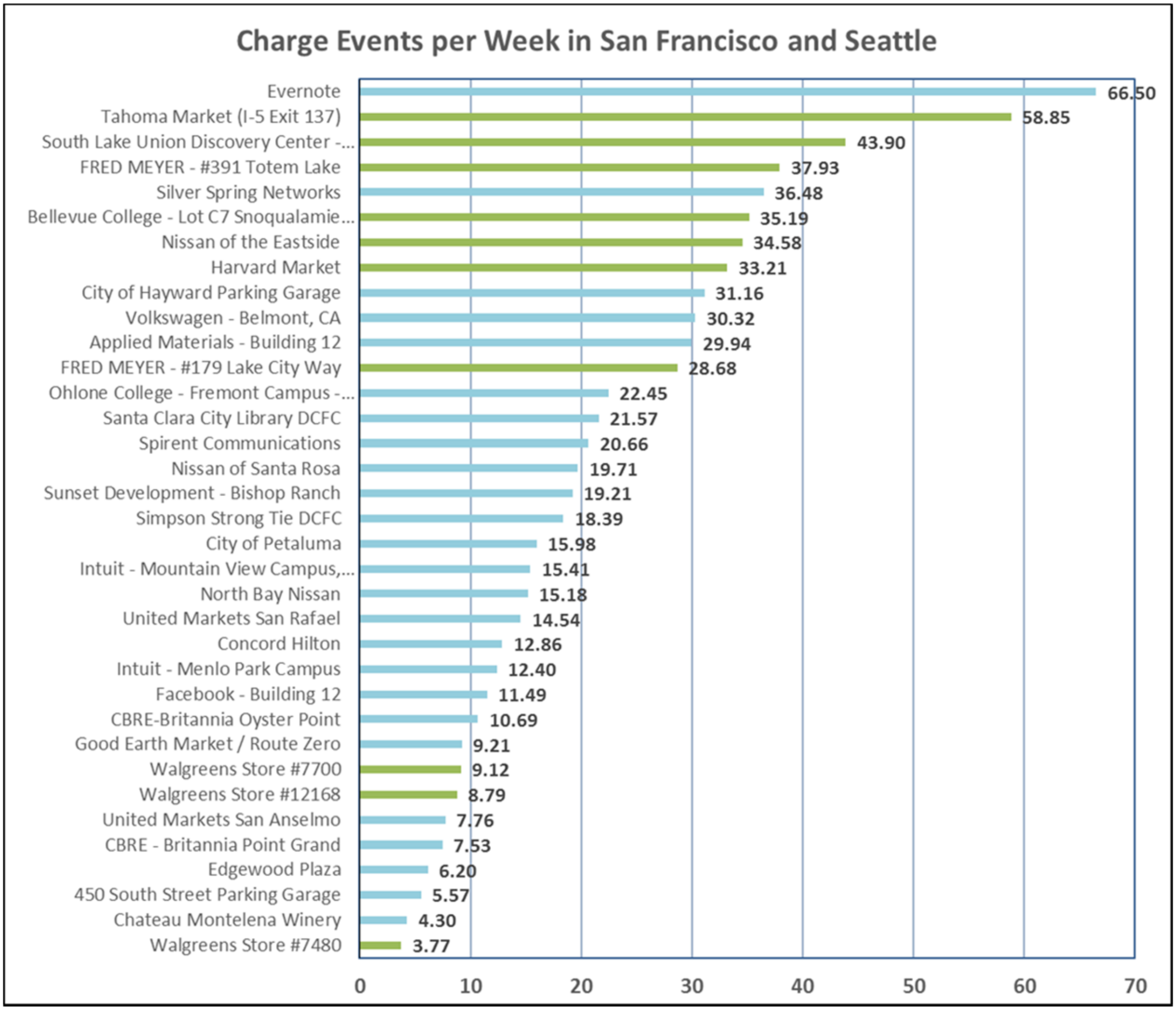


Figure 11-12. Report from data supplied by Blink network from July 1 through December 31, 2013 (source – Advance Vehicle Testing Activity at INL).

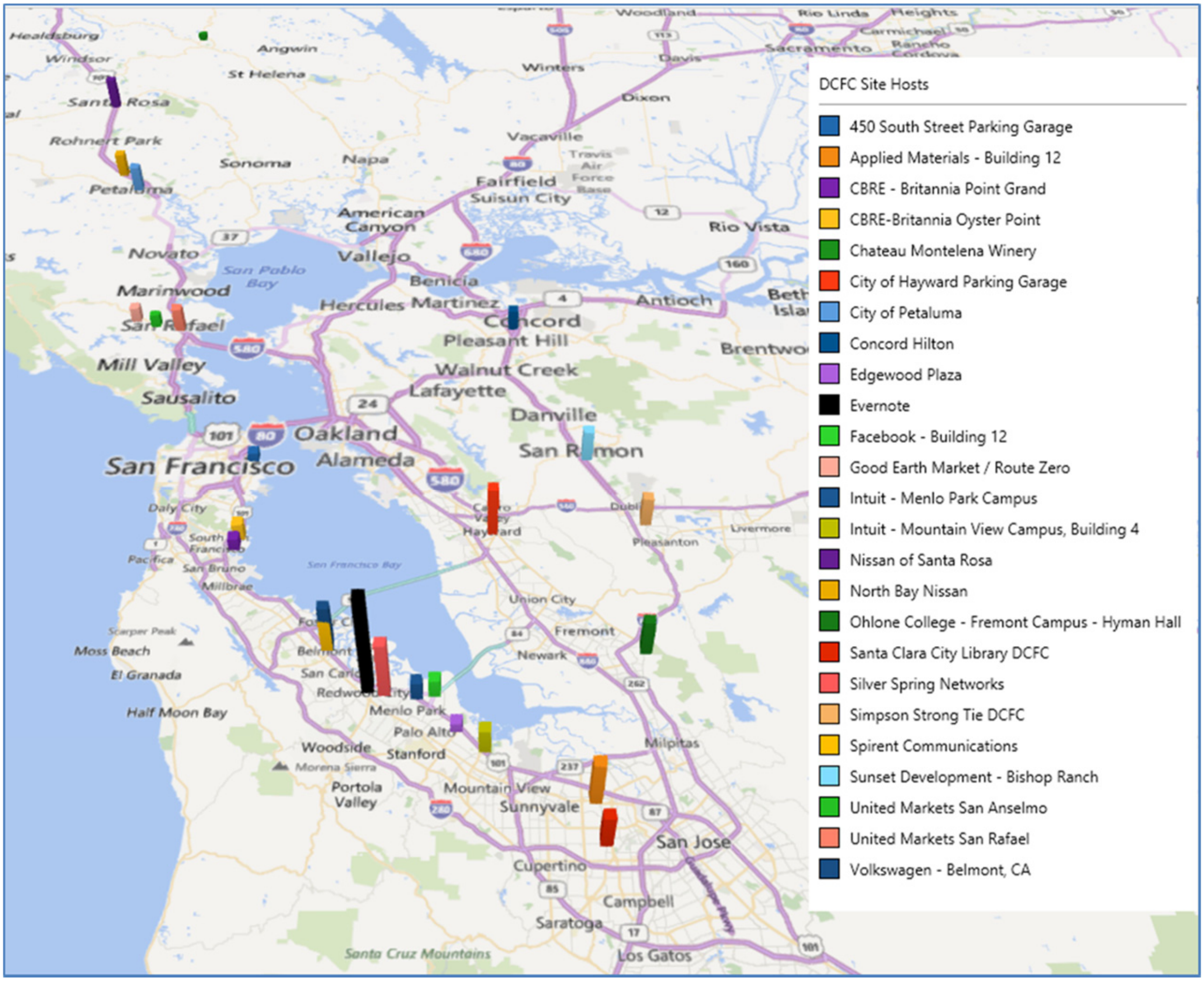


Figure 11-13. Report from data supplied by Blink network from July 1 through December 31, 2013 (source – Advance Vehicle Testing Activity at INL).

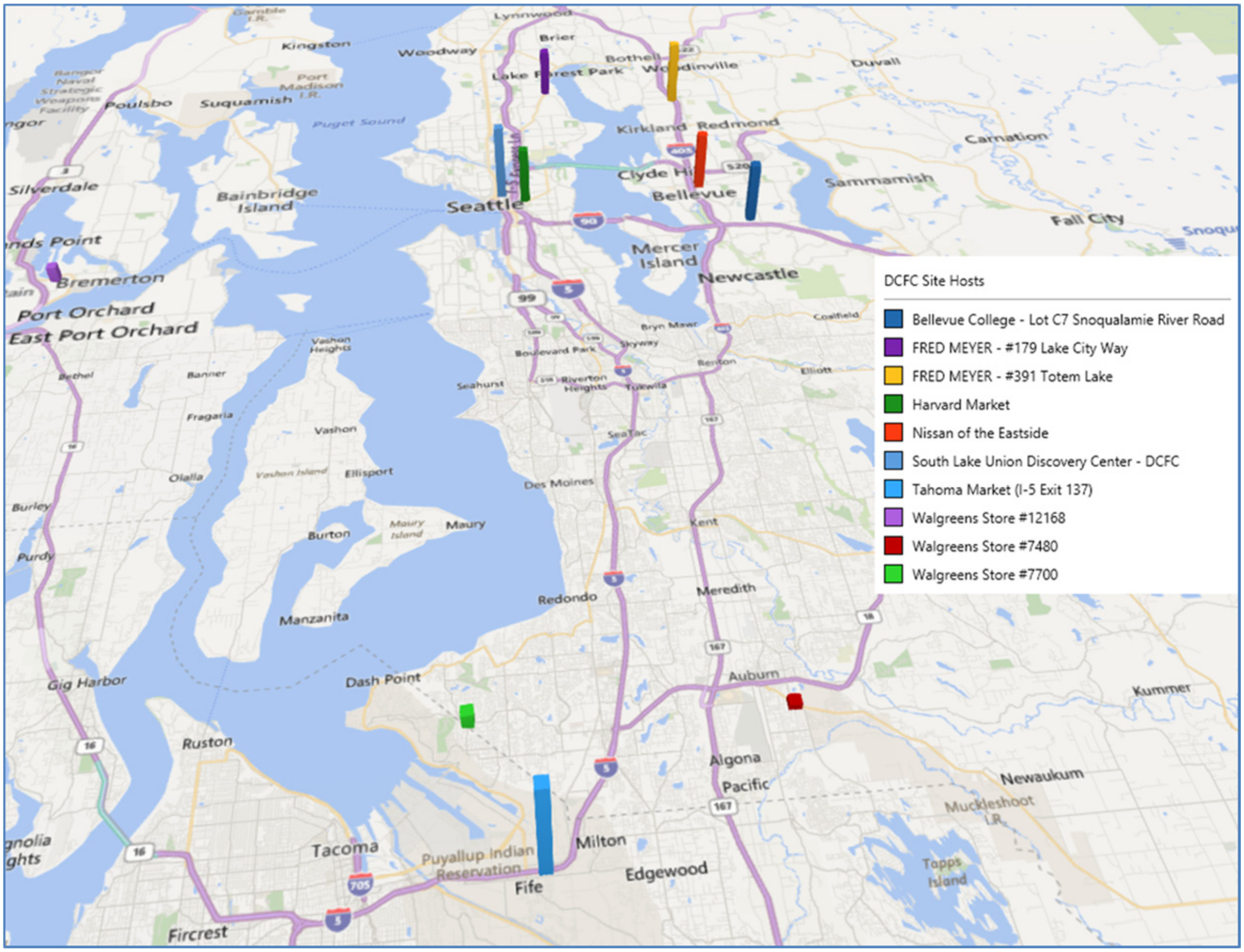


Figure 11-14. Report from data supplied by Blink network from July 1 through December 31, 2013 (source – Advance Vehicle Testing Activity at INL).

Figure 11-15. Google Earth view of Facebook campus at 12 Hacker Way, Menlo Park, California. DCFC located at circle marker on left side of photo.

11.1.3 What is the Impact of Utility Demand Charges on a Direct Current Fast Charger Host?

11.1.3.1 Introduction. The PEV EVSE delivered by The EV Project included both AC Level 2 and DCFC units. Over 100 of these dual-port Blink DCFCs were deployed by The EV Project. These DCFCs were installed in workplaces and in publicly accessible locations near traffic hubs, retail centers, parking lots, restaurants, and similar locations.

The Blink DCFC is capable of charging at power up to 60 kW. Its dual-port design sequences the charge from one port to the other, delivering power to only one of two vehicles connected at a time. The actual power delivered through a port is determined by the PEV's onboard battery management system. Both the power and total energy used to recharge a PEV can represent a significant cost for the charging site host.

Many electric utilities impose fees for power demand as part of their commercial rate structure. The demand charge incurred by a customer is related to the peak power used during a monthly billing cycle. This is in contrast to the cumulative total energy usage that is the more familiar utility charge seen for most residential services. A demand charge is typically assessed for the highest average power over any 15-minute interval during the monthly billing cycle.

One objective of The EV Project was to identify and elucidate the motivations and barriers to potential DCFC site hosts. Application of electric utility demand charges is one such potential barrier.

This subject was introduced in the paper: *DC Fast Charge - Demand Charge Reduction* [3], where it discussed demand charge impact in general terms in order to focus on potential mitigation actions. This paper identifies specific cases in order to quantify the impact of demand charges on EV Project DCFC hosts.

11.1.3.2 Key Conclusions

- Demand charges associated with 50 to 60-kW high power charging of a DCFC can have a significant impact on a business' monthly electric utility bill.
- The business owner will need to choose whether to power the DCFC on the original business service electrical supply or provide separate service to the DCFC.
- Detailed analysis of potential costs and the electric utility rate schedule options to determine the optimal rate schedule for a DCFC site is important and should be conducted in consultation with the electric utility.
- Some electric utilities provide rate schedules for commercial customers without imposing demand charges. When demand charges are imposed by utilities, they can cause a monthly utility bill to increase by as much as four times.
- DCFC site hosts may be compensated for energy used in DCFC charging through access or use fees imposed on PEV drivers in those states that allow energy billing, but demand charges are typically uncompensated and can be significant.
- The host's monthly DCFC demand charge is based on the single highest power required by the DCFC during the month, regardless of the number of charge events in the month. A higher number of PEV charges in a month reduces the average demand charge cost per PEV charge.

11.1.3.3 Background. The EV Project recommended that all DCFC charging site hosts should contact their local electric utility for guidance in selecting the optimum arrangement for providing power to their DCFC. Essentially two options were available: (1) either the DCFC was powered from the existing service to the facility or (2) new service was provided through a separate electric meter. Selection of the best option required consideration of the nature of the business, the proximity of the site's electrical service to the location of the installed DCFC, existing facility power demands, capability of the existing service to add new loads, local permitting requirements, and special rates that may be applied by the local utility.

Fleet and workplace hosts typically absorb the electrical power and energy costs required to recharge PEVs as part of their business expenses. Hosts for publicly accessible DCFCs in The EV Project were compensated for energy used through use fees paid by the PEV driver. Some of the hosts elected to provide DCFC service at no cost to the PEV driver. In this case, the host was responsible for all costs for charging, including compensating Blink for their network services.

Electric utilities provide rate schedules for commercial customers that are usually based on their history of energy and power. Appendix A provides information on the following two electric utilities involved with The EV Project:

- APS – provides service to most of the metropolitan Phoenix area and other parts of the state. Among its schedules, it provides rate schedules for small commercial (i.e., 21 to 100 kW), medium commercial (i.e., 101 to 400 kW), large commercial (i.e., 401 kW+), and extra-large commercial (i.e., 3 MW).

- PGE – provides rate schedules for small non-residential (i.e., 0 to 30 kW), medium and large non-residential (i.e., 31 to 200 kW) and large non-residential (i.e., 31 to 200 kW).

These two electric utility rate structures are used in this paper for comparative analysis.

11.1.3.4 Data Analyzed. This paper selected the Phoenix metropolitan region served by APS, where demand charges are imposed on all but the extra small commercial customers. PGE was selected because it does not impose demand charges on certain customers. The effects of DCFC charging on monthly utility bills related to demand charges were then identified.

Three months of charge data were selected for analysis, including June, July, and August 2013. The EV Project deployment of DCFC was stable over this time period and PEV drivers were well aware of the location of these DCFC. The fee structure for DCFC access had been in place for approximately 1 year, was stable, and, therefore, had little effect on utilization.

OpenEI (http://en.openei.org/wiki/OpenEI:About) provides analyses on renewable energy and energy efficiency and provides load profiles [4] for various sized businesses in each of the major regions of the United States. Those load profiles are used for further analysis in Phoenix and Portland.

This paper uses typical host usage load profiles combined with actual DCFC charge data collected by The EV Project to measure the impact of demand charges. Using the APS and PGE rate schedules, the cost impact of each is identified.

11.1.3.5 Direct Current Fast Charge Load Analysis. DCFC delivers power at a rate controlled by the PEV's onboard battery management system. Some of the vehicle factors that determine the maximum charge rate (and the greatest power demand) include battery conditions such as state of charge, temperature, age, and condition. The Leaf was the only PEV in The EV Project capable of charging at a DCFC and its highest maximum charge power was limited by the battery management system to 50 kW. In addition, the charge was typically terminated at approximately 80% battery state of charge.

Figure 11-16 shows the energy delivered per charge time for Phoenix DCFC charge data over the 3-month period identified above.

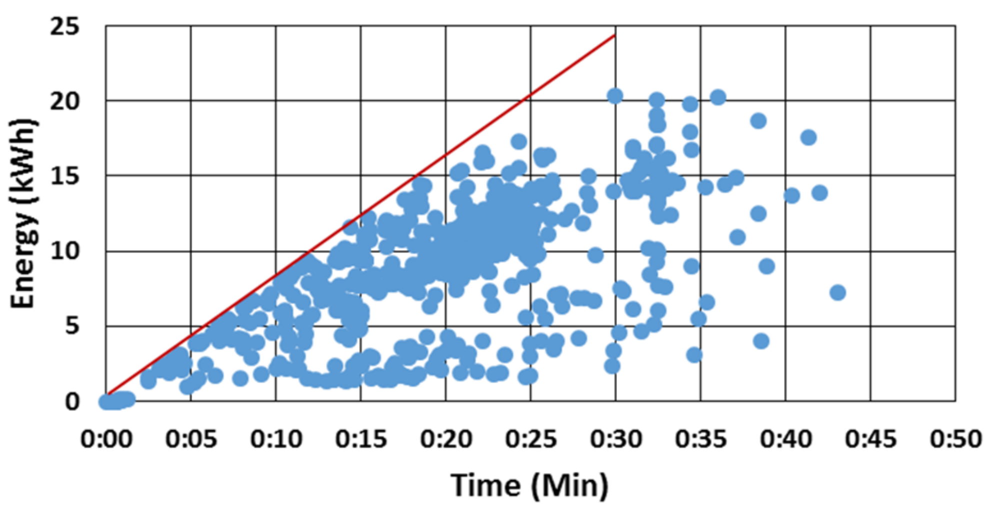


Figure 11-16. DCFC charge energy versus time.

The maximum slope in Figure 1 identified by the red line illustrates the maximum charge power of approximately 49 kW. For APS, the peak demand was determined as the average power (kW) demand over a 15-minute period. For charges longer than 15 minutes, the peak demand used for the monthly billing cycle was the maximum power demand of 49 kW. If the charge duration was less than 15 minutes, the peak demand used for the monthly billing is shown in Figure 11-17.

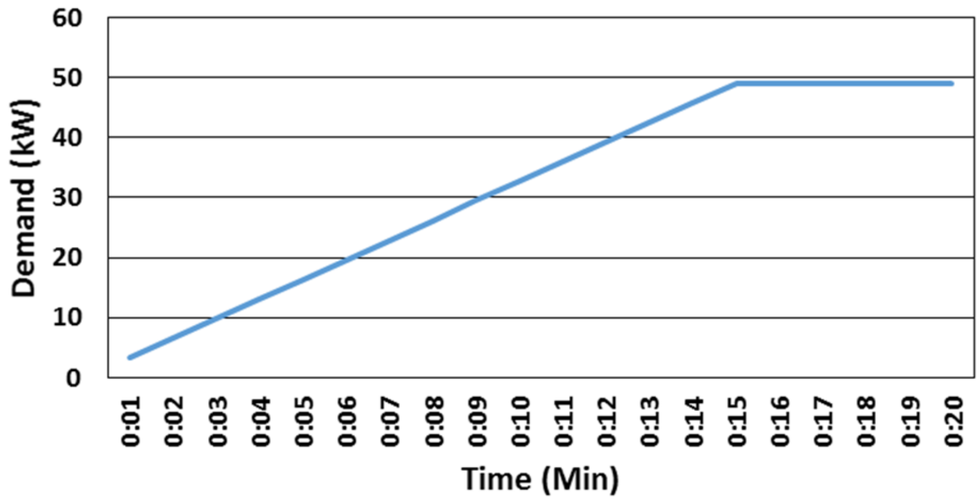


Figure 11-17. APS DCFC peak demand versus charge time.

The median DCFC connect time in Phoenix was 20 minutes, which results in the maximum demand of 49 kW. The median energy delivered during this typical charge is 9.1 kWh. Because this charge could occur at any time of the day (as was the case identified in the charge data), the worst case scenario for analysis would occur if the DCFC charge is coincident with the business peak demand. Average usage of all DCFC deployed in the Phoenix area over the 3-month period is 18 charges per month. Review of the Portland data revealed that average usage was 78 charges per month. Based on these data, analyses were conducted for 1, 20, and 100 charges per month.

11.1.3.6 Customer Load Profile Analysis

Small Office Evaluation – Phoenix Small Office Analysis—The small office average load profile in the Phoenix area as provided by OpenEI for June through August is shown in Figure 11-18. The business peak power demand was 17.5 kW. The energy consumed was 289 kWh for this work day. Assuming 21 work days per month, the monthly energy consumed is 6,069 kWh.

If this business owner elected to install a DCFC, they would need to decide whether to add the DCFC to the existing service or to separately meter the DCFC. A separately metered service may allow the DCFC to operate under one of the other rate schedules and keep the business at the existing rate.

When the DCFC was added to the existing service, a new peak demand of 66.5 kW would be reached if the DCFC charged a vehicle at 49 kW (Figure 11-19) coincident with the business peak. This coincidence is highly likely because the DCFC will be available all afternoon when PEV drivers are likely to desire charge. It is unlikely that the existing service would be able to absorb this added power demand. Thus, new service would be required; therefore, the business owner’s decision is whether to put all loads under the new service or to power only DCFC under the new service.

One Service: Prior to addition of DCFC, the business’ monthly electric utility statement under APS rate schedule E-32 XS would have been $800. The monthly bill (for energy and power) after the addition is shown in Table 11-5.

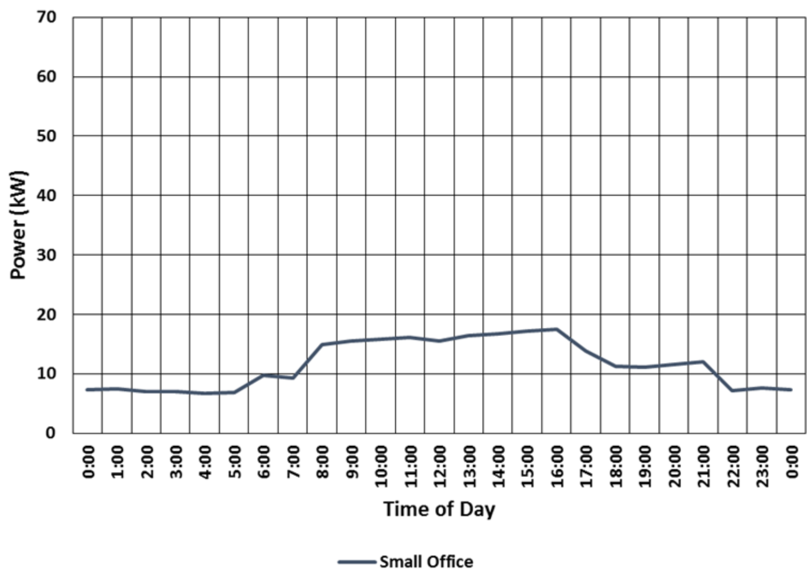


Figure 11-18. Phoenix small office profile.

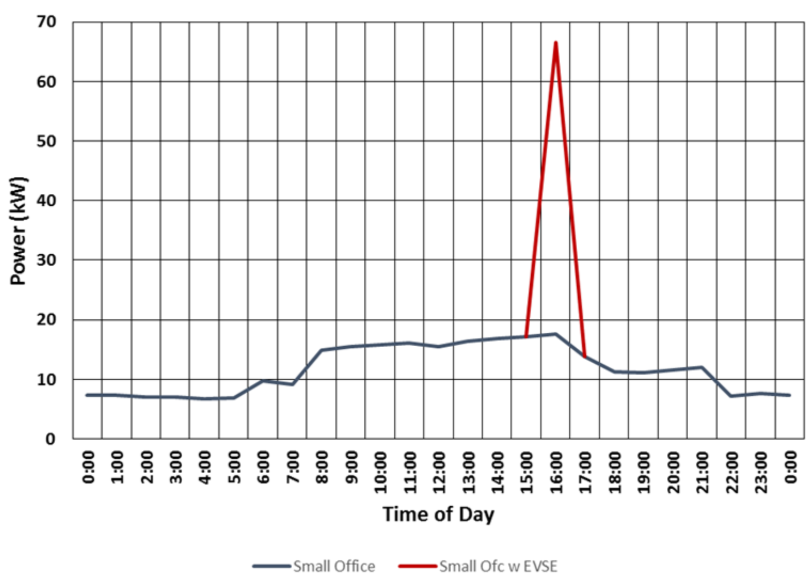


Figure 11-19. Phoenix small office with DCFC charging.

Table 11-5. Monthly costs for DCFC and small office.

DCFC Uses	DCFC kW $	DCFC kWh $	Business kW $	Business kWh $	Total Monthly
1	$482	$0.57	$172	$388	$1,042
20	$482	$11.39	$172	$388	$1,053
100	$482	$56.94	$172	$388	$1,098

Because the demand charge for DCFC was a one-time charge for the peak demand, it did not change over the month. The business energy cost decreased because costs were lower under the E-32 S schedule than under the original E-32 XS schedule.

New Service for Direct Current Fast Charge – Direct Current Fast Charge Schedule E-32 S: The new service included only the DCFC; therefore, the business could be retained on the original service. Table 11-6 identifies the costs associated with the new service, which would be on rate schedule E-32 S plus the business on the original service under E-32 XS.

Table 11-6. Monthly costs for new DCFC service.

DCFC Uses	DCFC kW $	DCFC kWh $	Business kWh $	Total Monthly
1	$482	$0.94	$800	$1,283
20	$482	$18.81	$800	$1,300
100	$482	$65.10	$800	$1,347

The DCFC energy charge is higher in this case because energy used is charged at a higher rate as part of the first 200 kWh. However, as seen when comparing these tables, the business would have benefited from using the E-32 S rate instead of E-32 XS.

New Service for Direct Current Fast Charge – Direct Current Fast Charge and Business E-32 S: Selecting new service for the DCFC and changing the rate to E-32 S for the business results in the monthly costs shown in Table 11-7.

Table 11-7. Monthly costs for DCFC and business separately metered on Schedule E-32 S.

DCFC Uses	DCFC kW $	DCFC kWh $	Business kW $	Business kWh $	Total Monthly
1	$482	$0.94	$172	$388	$1,043
20	$482	$18.81	$172	$388	$1,061
100	$482	$65.10	$172	$388	$1,107

It makes little difference then whether the business selects to individually meter the DCFC or provides power to it from one service if both are on rate schedule E-32 S. In both cases, the utility demand charge affects not only the DCFC but the business costs as well. However, if the business was originally on this schedule, the demand charge for the DCFC increases the monthly cost by 86%.

Small Office Evaluation – Portland Small Office Analysis—The small office average load profile in the Portland area as provided by OpenEI for June through August is shown in Figure 11-20. The business peak demand was 11.4 kW. The energy consumed was 179 kWh for this work day. Assuming 21 work days per month, the monthly energy consumed was 3,764 kWh. DCFC charging at the business peak is also displayed in Figure 11-20.

Under Schedule 32, the business' monthly energy cost was $411. When the DCFC was added to the existing service, a new peak demand of 65.1 kW would be reached when the DCFC charged a vehicle at 49 kW (similar to Figure 11-19). Again, it is unlikely that the existing service would be able to absorb this added power demand. As before, the business owner's decision is whether to put all loads under the new service or to power only the DCFC under the new service.

One Service: The new peak would require Schedule 38 or 83. Both are TOU rates. Under Schedule 38, on-peak is weekdays from 7 a.m. to 8 p.m. All other times are off-peak. Energy consumed by the business on-peak is 2,549 kWh, with 1,210 kWh at off-peak. Using the PGE summer rate schedule, Schedule 38 costs for this business and DCFC charging are shown in Table 11-8.

Schedule 83 includes a demand charge. Costs for this business and DCFC charging are shown in Table 11-9.

Schedule 38 is less costly if both the business and DCFC charging are on one service meter.

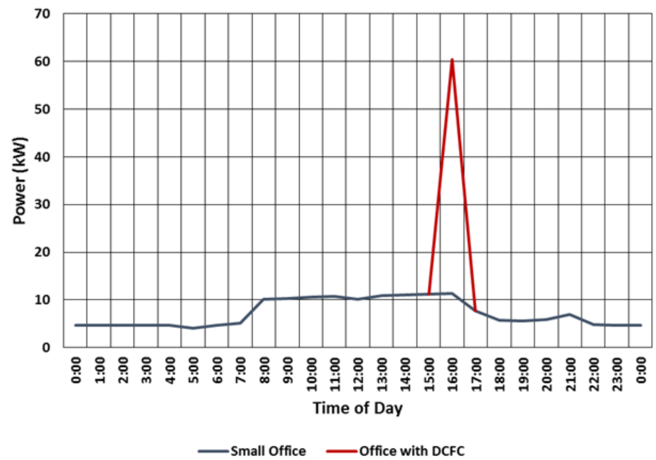


Figure 11-20. Portland small office profile.

Table 11-8. Small business with DCFC charging Schedule 38.

DCFC Uses	DCFC kW $	DCFC kWh $	Business kW $	Business kWh $	Total Monthly
1	$0	$1.22	$0	$491	$493
20	$0	$24.38	$0	$491	$516
100	$0	$121.90	$0	$491	$613

Table 11-9. Small business with DCFC charging Schedule 83.

DCFC Uses	DCFC kW $	DCFC kWh $	Business kW $	Business kWh $	Total Monthly
1	$248	$0.67	$66	$258	$572
20	$248	$13.38	$66	$258	$585
100	$248	$66.89	$66	$258	$638

New Service for Direct Current Fast Charging: These options are identified on the PGE Schedule 32. However, the DCFC charge would exceed the kW limit of this schedule and Schedule 38 or 83 would apply. Because there is no demand charge, Schedule 38 is selected and the only added cost is the energy consumed by the DCFC. The monthly utility statement with the business separately metered on Schedule 32 and DCFC separately metered under Schedule 38 is identified in Table 11-10.

Table 11-10. Monthly costs for Portland small business with separate DCFC service and with different rate schedules.

DCFC Uses	DCFC kW $	DCFC kWh $	Business kW $	Business kWh $	Total Monthly
1	$0	$1.22	$0	$411	$412
20	$0	$24.38	$0	$411	$435
100	$0	$121.90	$0	$411	$533

This would be the least costly alternative for this small business.

While the business energy charge and the DCFC charge is similar between Phoenix and Portland, the demand charges imposed by APS result in a monthly bill that is more than two times higher.

Full-Service Restaurant Analysis – Phoenix Full Service Restaurant Analysis—The full-service restaurant average load profile in the Phoenix area as provided by OpenEI for June through August is shown in Figure 11-21; it also includes the DCFC charging event previously identified. The peak power demand increased from 72 to 121 kW. Because this is a restaurant, the daily load profile is assumed for all days of the week.

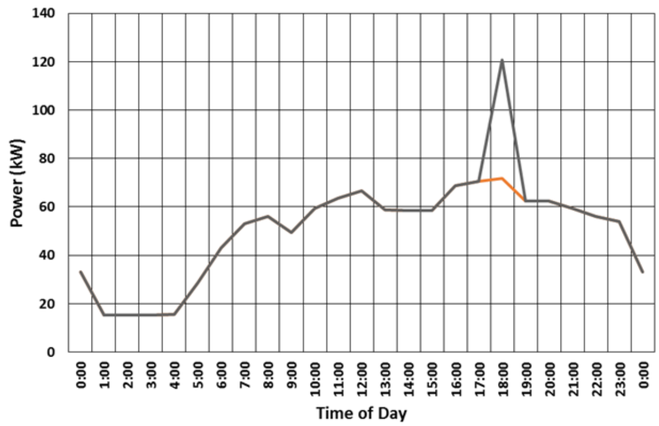


Figure 11-21. Phoenix full-service restaurant with DCFC profile.

This customer typically would have been assigned rate schedule E-32 S. Because the new peak was above 100 kW, the business was placed in the new schedule E-32 M. The business owner then needed to evaluate whether the DCFC should be placed on a separate meter under schedule E-32 S or the original service upgraded to service both the business and the DCFC charging.

One Service: With both the business and DCFC charging on the same meter on Schedule E-32 M, monthly costs are shown in Table 11-11.

Table 11-11. Phoenix full-service restaurant with DCFC E-32 M.

DCFC Uses	DCFC kW $	DCFC kWh $	Business kW $	Business kWh $	Total Monthly
1	$401	$0.55	$734	$2,250	$3,386
20	$401	$11.09	$734	$2,250	$3,396
100	$401	$55.43	$734	$2,250	$3,441

New Service for Direct Current Fast Charging: Providing new service for DCFC allows both the business and DCFC to be on Schedule E-32 S, but on separate meters. Costs for this arrangement are shown in Table 11-12.

Table 11-12. Phoenix full-service restaurant on E-32 S.

DCFC Uses	DCFC kW $	DCFC kWh $	Business kW $	Business kWh $	Total Monthly
1	$482	$0.94	$705	$2,312	$3,500
20	$482	$18.81	$705	$2,312	$3,518
100	$482	$65.10	$705	$2,312	$3,564

Because there is little difference between the two options, the business owner will likely base the choice on other factors, such as installation costs involved with routing power to the DCFC. The demand charge on the DCFC adds approximately 15% to the utility bill.

While both Schedule E-32 S and E-32 M have TOU alternatives, most of the restaurant demand and DCFC charging is on-peak and there is little opportunity to shift any loads to off-peak. Therefore, these rates are not evaluated here.

Full-Service Restaurant Analysis – Portland Full Service Restaurant Analysis—The full-service restaurant average load profile in the Portland area as provided by OpenEI for June through August is shown in Figure 11-22; it also includes DCFC charging events previously identified. The peak power demand increased from 50 to 99 kW.

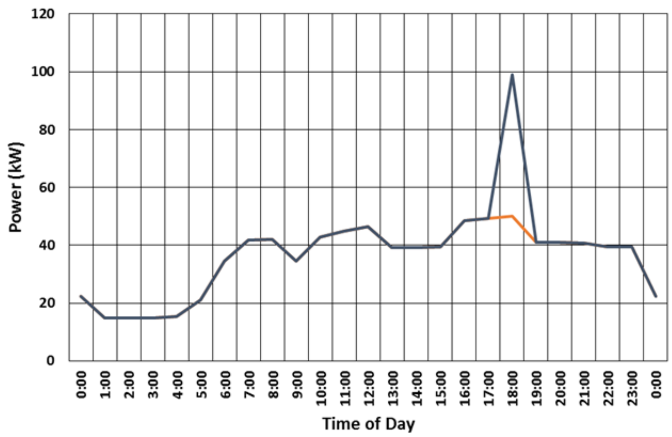


Figure 11-22. Portland full-service restaurant with DCFC charging.

Rate Schedules 38 TOU and 83 may apply to the business and DCFC charging. Because the original business demand exceeded 30 kW, Schedule 32 does not apply.

One Service – Schedule 38 Time of Use: For Schedule 38 TOU, on-peak is defined as 7 a.m. to 8 p.m. Monday through Friday and off-peak is all other times. Using the PGE summer rate schedule and assuming that all DCFC charging occurs on-peak, the total monthly utility cost for this business is shown in Table 11-13.

Table 11-13. Portland restaurant with DCFC charging Schedule 38 TOU.

DCFC Uses	DCFC kW $	DCFC kWh $	Business kW $	Business kWh $	Total Monthly
1	$0	$1.22	$0	$3,439	$3,440
20	$0	$24.38	$0	$3,439	$3,463
100	$0	$121.90	$0	$3,439	$3,561

One Service – Schedule 83: Schedule 83 contains on-peak times from 6 a.m. to 10 p.m. Monday through Friday and off-peak at all other times. It also imposes demand charges. Assuming all DCFC charging occurs on-peak, the total monthly utility cost under this schedule is shown in Table 11-14.

Table 11-14. Portland restaurant with DCFC charging Schedule 83.

DCFC Uses	DCFC kW $	DCFC kWh $	Business kW $	Business kWh $	Total Monthly
1	$277	$0.67	$286	$1,848	$2,412
20	$277	$13.38	$286	$1,848	$2,424
100	$277	$66.89	$286	$1,848	$2,478

In this case, the utility rate schedule imposes demand charges but reduces energy costs, resulting in lower monthly costs with the DCFC charges. The contribution of demand charges for DCFC adds $277 to the monthly bill.

New Service for Direct Current Fast Charging: Based on the costs shown Tables 11-13 and 11-14, the business owner would likely have elected Schedule 83 for the business before adding the DCFC, even though it imposed demand charges. However, the DCFC added under new service could be added under Schedule 38 with no demand charge. The resulting monthly cost is shown in Table 11-5.

Table 11-15. Portland restaurant with separate service.

DCFC Uses	DCFC kW $	DCFC kWh $	Business kW $	Business kWh $	Total Monthly
1	$0	$1.22	$286	$1,848	$2,135
20	$0	$24.38	$286	$1,848	$2,158
100	$0	$121.90	$286	$1,848	$2,256

In this case, the addition of DCFC had no impact on the business demand costs.

The Phoenix restaurant consumes more energy and requires higher power than the Portland restaurant during these summer months. The demand charges in Phoenix of $1,135 compare to the demand charges in Portland of $286.

11.1.3.7 Separately Metered Service. Cost for installation of separately metered service is the customer's responsibility. This cost is dependent on site conditions and varies with each installation. Each utility assesses the basic costs for providing service through a meter, which is typically $25 to $30 per month. The separately metered service includes this monthly service cost. The previous analyses do not include these costs because they do not significantly impact the monthly service cost.

In most cases, installation practice for The EV Project provided DCFC charging through new electrical service, because sufficient electrical capacity to add the DCFC load to an existing service was rarely available. In most cases, this was also advantageous in maintaining the lowest monthly cost. Prior consultation with the electric utility was used to identify the best choice for the DCFC host.

As noted above, PGE requires that when PEV charging is separately metered, "… Such service must be metered with a network meter as defined in Rule B (30) for the purpose of load research, and to collect and analyze data to characterize EV use in diverse geographic dynamics and evaluate the effectiveness of the charging station infrastructure" [7]. The cost of this networked meter is the responsibility of the DCFC host.

11.1.3.8 Demand Cost per Plug-in Electric Vehicle. As seen in the tables above, the demand charge is a single monthly charge to the business regardless of the number of PEVs charging. Thus, the cost per charge is reduced if more PEVs are charged. For example, the demand cost for DCFC charging shown in Table 8 in Phoenix is $482. If one PEV is charged in the month, the cost per charge is $482. If 20 PEVs are charged in the month, the cost per is $24. If 100 PEVs are charged in the month, the cost per charge is $4.82.

Some revenue sharing plans provide compensation to the host at rates higher than the energy cost to assist in offsetting the demand charge. While significant, the demand charge is easier to absorb with higher DCFC utilization. Higher utilization will also mean more opportunities to attract customer traffic for the business.

11.1.3.9 Observations. Power demanded by DCFC has a more significant impact on electric utility costs for smaller commercial businesses than for larger ones. Each electric utility defines commercial businesses and their rate schedules based on its own needs and as regulated by the local Public Utility Commission or municipal rules. These rate schedules vary widely among utilities and each business needs to evaluate its options. Consultation with the electric utility is essential when adding PEV charging to an existing business; this is especially true when considering the high demand of a DCFC. Separately metered service for the DCFC may allow the customer to avoid demand charges in some cases.

DCFC access fees charged to PEV drivers during The EV Project were based on energy costs. This revenue sharing plan partially compensated the DCFC host for the cost of energy consumed for charging. However, any demand charges were not reimbursed by these fees and may be a significant impact to the host.

11.1.3.10 References

3. http://avt.inl.gov/pdf/EVProj/DCFastCharge-DemandChargeReductionV1.0.pdf [accessed March 14, 2015].

4. Open EI load profiles, http://en.openei.org/datasets/files/961/pub/.

5. APS Business Electric Rate Schedules, http://www.aps.com/en/ourcompany/ratesregulationsresources/serviceplaninformation/Pages/business-sheets.aspx.

6. PGE Rate Schedules, https://www.portlandgeneral.com/our_company/corporate_info/regulatory_documents/tariff/rate_schedules.aspx.

7. ibid.

11.1.3.11 Electric Utility Overview

Arizona Public Service—APS rate schedules are provided in Reference [5]. While all contain basic service charges and fees, the charges of interest are for energy and power demand. Summer and winter rates are provided. Summer rates are of interest in this analysis. Schedules E-32 XS, E-32TOU XS, E-32 S, and E-32TOU S offer rates for bundled and unbundled service. Bundled service is used in this analysis.

Several schedules offer TOU options. Time periods are on-peak weekday from 11 a.m. to 9 p.m. and off-peak time periods are all remaining hours.

Monthly maximum demand is based on the highest average kW supplied during the 15-minute period during either the on-peak or off-peak hours of the billing period, as determined from readings of the company's meter.

APS has no special distinction related to businesses charging PEVs.

Table A-1 shows basic differences between rate schedules for energy usage and demand.

Table 11-16. APS rate schedules for commercial customers.

Schedule	Max kW	Energy	Demand
E-32 XS	20	$0.14258/kwh first 5,000 kWh plus $0.08148 for additional kWh	NA
E-32TOU XS	20	$0.17033/kWh for the first 5,000 kWh On-Peak plus $0.08564/kWh for all additional On-peak plus $0.12686/kWh for the first 5,000 kWh off-peak plus $0.04755 per kWh for all additional Off-peak kWh.	NA
E-32 S	100	$0.10337 per kWh for first 200 kWh plus $0.06257 for additional kWh	$9.828 per kW for the first 100 kW plus $5.214 for all additional kW

Schedule	Max kW	Energy	Demand
E-32TOU S	100	$0.07367 /kWh during On-Peak plus $0.05873/kWh Off-Peak	$14.303/kW for the first 100 kW on-peak plus $9.713/kW for all additional On-Peak kW plus $5.484/kW for the first 100kW Off-Peak plus $3,054 for all additional kW off-peak
E-32 M	400	$0.09884/kWh for the first 200 kWh plus $0.06091/kWh for all additional kWh	$10.235 for the first 100 kW plus $5.385 per kW for all additional kW

Portland General Electric—PGE rate schedules are provided in Reference [6].

Schedule 32 applies to small (i.e., less than 30-kW service) non-residential customers. It provides the two energy charge options involving either standard service or TOU. A PEV TOU option applies for those businesses that wish to charge EVs. They may do so with the existing service of either standard service or TOU. If the customer chooses to separately meter the PEV charging, it will be billed under the TOU option. All costs associated with the second meter are the customer's responsibility. Basic, transmission, and related services and distribution charges will apply to the second meter and the initial meter.

The PGE TOU rates are set at on-peak, off-peak, and mid-peak and are set as the following for the summer months:

On-peak 3:00 p.m. to 8:00 p.m. Monday through Friday

Mid-peak 6:00 a.m. to 3:00 p.m. and 8:00 p.m. to 10:00 p.m. Monday through Friday; 6:00 a.m. to 10:00 p.m. Saturday

Off-peak is set at 10:00 p.m. to 6:00 a.m. all days; 6:00 a.m. to 10:00 p.m. Sunday and holidays.

Schedule 38 applies to large (i.e., less than 200-kW service) non-residential customers with no monthly demand exceeding 200 kW more than once in the preceding 13 months. It provides for one standard rate that includes energy charges for on-peak and off-peak periods. On-peak is weekday 7 a.m. to 8 p.m. Off-peak is all other times. This rate also includes the EV time-of-day option that may be billed directly under the basic schedule or as a separately metered service billed under the TOU option.

The separately metered PEV circuit is required to meet special conditions that allow for load research and to collect and analyze data to characterize PEV use.

Schedule 83 applies to large (i.e., less than 200-kW service) non-residential customers with no monthly demand exceeding 200 kW more than six times in the preceding 13 months and not more than 4,000 kW more than once. EVSE charging may occur under this service or through a separately metered option on Schedules 32 or 38.

Table A-2 summarizes these rate schedules.

Table 11-17. PGE rate schedules for commercial customers.

Schedule	Max kW	Energy	Demand
Schedule 32 Standard Service	30	$0.10914/kwh first 5,000 kWh plus $0.08228 for additional kWh	NA

Schedule	Max kW	Energy	Demand
Schedule 32 TOU	30	$0.15615/kWh on-peak, $0.10914/kWh mid-peak, $0.08357 off-peak for first 5000 kWh. Reduced by $0.02686 above 5000 kWh.	NA
Schedule 38 TOU	200	$0.13396 per kWh on peak, $0.12396 per kWh off-peak	NA
Schedule 83	200	$0.07351 per kWh on peak, $0.05851 per kWh off-peak	$2.83/kW for first 30 kW and $2.73/kW for over 30 kW plus $2.92/kW for on-peak kW

11.1.4 Direct Current Fast Charge - Demand Charge Reduction

Author's note: This lessons learned white paper section was originally written while The EV Project was still active and it has been left in the original present tense.

11.1.4.1 Introduction. The first objective of The EV Project is to collect usage data from deployed EVSE to understand the charging behavior and habits of users. The second objective is to elucidate the motivations and hindrances to EVSE ownership. To achieve this second objective, it is important to consider the various factors that a prospective EVSE owner will weigh when deciding to purchase and install an EVSE unit.

One such factor that arises with EVSE ownership is application of "demand charges." These are charges levied by the utility, typically for commercial properties, for peak power used during a billing cycle, regardless of the amount of energy drawn at this power rate. These demand charges can add significantly to the utility bill for an EVSE host and can make EVSE hosting cost prohibitive. While demand charges can be incurred for sites with several AC Level 2 EVSE installed on one meter and methods for demand charge reduction apply to both EVSE types, demand charge costs for DCFC hosts are likely to be more significant because of the much higher power draw by a single DCFC. Thus, the methods for demand charge reduction are more likely to be applied in the DCFC case; therefore, this white paper will focus on DCFCs.

This section identifies issues associated with electric utility demand charges for power drawn by DCFC units and discusses opportunities for demand charge avoidance.

The following sections discuss the issue of demand charges more explicitly and outline the various methods for demand charge reduction. Subsequently, there is a section on a case study in which the methods are applied to a specific hypothetical EVSE installation. It should be noted that the specific electric utility rates are from 2012.

11.1.4.2 Background. The demand charge incurred by a customer is related to the peak power used during a billing cycle. In contrast to total energy usage which is a more familiar utility charge, a demand charge is incurred for a one-time occurrence of an elevated power level and is not a cumulative-type charge. Demand charge rates are specified in $/kW and are usually incurred when the peak power used during a billing cycle rises above a specified threshold, but are sometimes incurred for any power level above zero. Certain utilities even levy a yearly peak power demand charge. Demand charges are the method by which utilities disincentivize power use during high demand periods and high peak demands.

For most U.S. utilities, the peak power for a given billing cycle is determined by calculating the average power in consecutive 15-minute intervals (from start to finish of the billing cycle) and extracting the highest average from the entire cycle of intervals. Some utilities will impose a demand charge for every kW of usage; others will impose no demand charge until a specified power threshold is surpassed. In some of the latter cases, the demand charge is calculated by subtracting the demand charge threshold power level from the highest average power from the set of intervals, and then multiplying the remainder by the demand charge rate. In other cases where a threshold exists, any incursion over the threshold will result in a demand charge for the entire average power level, not just the amount above the threshold. Because power is averaged over the interval, it is possible for power demand during an interval to exceed the threshold and still incur no demand charge, as long as the average power over the interval is below the threshold.

Demand charges can become quite significant, and can, in fact, dominate a utility bill in certain circumstances. A generic example of the effect of demand charges on a utility bill is shown in Table 11-18, where the bills for a varying number of charged PEVs are shown, along with the cost per vehicle charged. In this example, the basic meter charge is $200 (regardless of the power and energy drawn by the EVSE); the demand charge is $10/kW, a typical commercial value; and the energy charge is $0.11/kWh, also a typical commercial value. Each PEV that is charged is assumed to use the full 60 kW available from the Blink DCFC for 20 minutes, for a total energy usage of 20 kWh per vehicle. A further assumption is that there is no other load on this particular meter. Implicit in this assumption is it means a new utility service is installed for the EVSE and additional costs associated with a new service for the EVSE are ignored.

Table 11-18. Demand charge scenarios.

Scenario	Number of Vehicles Charged/ Month	Meter Charge	Demand Charge	Energy Charge	Monthly Total	Cost per Vehicle
1	0	$200	$0	$0	$200	NA
2	1	$200	$600	$2.20	$802.20	$802.20
3	10	$200	$600	$22	$822	$82.20
4	100	$200	$600	$220	$1,020	$10.20
5	250	$200	$600	$550	$1,350	$5.40
6	500	$200	$600	$1,100	$1,900	$3.80

As shown in Table 11-18, the demand charge remains constant regardless of the number of vehicles charged and it becomes proportionally less of the bill as the number of vehicles charged increases. Furthermore, as the number of vehicles charged increases, the overall cost per vehicle falls dramatically. If a sufficiently large number of vehicles use the EVSE to charge, the demand charge becomes less of a concern. However, because the number of vehicle customers cannot be estimated with any precision and site owners may be unwilling to incur large demand charges, strategies to reduce or eliminate these charges must be developed. The number of PEVs and the number of EVSE users will be low at first, but are expected to grow gradually. The demand charges incurred from hypothetical DCFC installations in EV Project areas can also be examined. For this analysis, a particular duty cycle will be assumed. The duty cycle involves three vehicles charging from 30 to 90% and seven vehicles charging from 30 to 60% per day, all at the maximum rate of 60 kW. The vehicles will all be assumed to be Nissan LEAFs, each with a useable energy storage system capacity of approximately 20 kWh. Thus, the three vehicles will each receive 12 kWh and the seven vehicles will receive 6 kWh for a total of 18 kWh per day. The DCFC will again be assumed to be the only load on the meter.

Some The EV Project utility partners do not impose any demand charges for power and energy demand of a DCFC installation, including the following:

- Tucson Electric Power

- Alameda Municipal Power
- Silicon Valley Power
- PG&E
- City of Palo Alto Utilities.

Three utilities within The EV Project (in 2012) with the highest demand charge rates are all in California (these are given as the highest possible demand charge; demand charges may be lower at other times of the year and/or at other times of the day):

1. Los Angeles Department of Water and Power: $9.00 per kW (high-peak demand charge) plus $5.00 per kW (facilities charge) for a total of $14.00 per kW
2. Southern California Edison: $17.05 per kW (summer demand charge) plus $12.18 per kW (facilities charge) for a total of $29.20 per kW
3. Burbank Water and Power: $9.86 per kW (billing demand charge) plus $11.18 per kW (special demand charge) for a total of $21.04 per kW.

Demand charges for a representative sample of utilities in The EV Project are presented in Appendix B. Note that Tennessee utilities (in 2012) only impose demand charges above 50 kW; therefore, if the DCFC was the only appliance on the circuit and the maximum AC power was 50 kW, there would be no demand charge.

Using the base and energy rates from Section 11.1.4.9 for the high demand charge utilities, along with the demand charge rates, the monthly (i.e., 30.4 days) bill for DCFC installation with the assumed duty cycle could reach the following:

- Los Angeles Department of Water and Power: $28.00 (base) + $25.60 (energy) + $840 (demand) for a total of $893.60. The demand charge would be 94% of the total monthly bill.
- Southern California Edison: $134.17 (base) + $12.13 (energy) + $1,752 (demand) for a total of $1,898.30. The demand charge would be 92% of the total monthly bill.
- Burbank Water and Power: $15.99 (base) + $62.22 (energy) + $1,052 (demand) for a total of $1,130.21. The demand charge would be 93% of the total monthly bill.

It is clear from these examples that devising solutions to the demand charge problem associated with DCFC PEVs is imperative in order to prevent hindrance to growth of this industry. The purpose of this white paper is to discuss the various options available for reducing or eliminating demand charge for EVSE installations. It is unlikely that one method will be optimal for each specific location; therefore, all options should be considered on a case-by-case basis.

11.1.4.3 Demand Charge Reduction Options. In order to determine the method for reducing demand charge, the first step is to determine the following parameters for a given location:

1. What is the expected peak demand of the site owner in a billing period? Over how much of the 15-minute interval does the peak demand span?
2. What is the average site demand?
3. What is the utility rate structure? Is there a yearly maximum average power demand charge in addition to the billing cycle maximum average power demand charge?
4. What is the demand charge tolerance?

Once these parameters are specified, the next step is to choose from the possible methods for reducing demand charge. The six methods that have been identified are as follows:

1. Never allow overall site power demand to exceed a specified value.
2. Attempt to ensure average power over the interval is less than or equal to a specified value.
3. Attempt to recoup demand charge cost through structured pricing for EVSE charging.
4. Add an energy storage system that buffers the EVSE unit from high power demands during charging.
5. Aggregate demand among multiple EVSE installations into one demand charge calculation, taking advantage of the diversity that may exist in individual unit usage.
6. Provide demand response capability to the utility to either offset or circumvent demand charges.

The first option is more conservative in that demand charges will be less likely to be incurred. The second option allows more flexibility, higher EVSE power levels, and is useful when the expected site peak demand (without the EVSE contribution) is much larger than the average site demand. Ensuring that the average site power does not exceed the specified value can be accomplished in two ways: (1) using a combination of historical data for peak and average power, the EVSE power is de-rated, and (2) using only the historical average demand data, allow full EVSE power but only for a portion of the 15-minute interval. The third option can ensure that the EVSE owner is compensated for the demand charges incurred, but the cost per charge may become prohibitive for the average vehicle owner or DCFC host. These three options are discussed in more detail in the following subsections.

The fourth option can provide certainty that the demand charges are minimized, but only up to a certain number of vehicles and the complexity and cost of the overall system will necessarily increase. The fifth and sixth options offer demand charge reduction opportunities, but they both involve substantial negotiations with the electric utility. The fifth option would require the utility to allow the EVSE network operator to aggregate all of the deployed EVSE into one demand. The sixth option, which is known as interruptible service and is offered already by some utilities, would require an agreement between the operator and utility on the value of the network providing demand response capabilities. The complexities of these last three methods warrant separate discussions in future white papers and are not discussed further in this paper.

11.1.4.4 Demand Charge Reduction Method 1: Peak Site Demand-Dictated Approach. The first method for demand charge reduction (or elimination) is to ensure the peak output of the EVSE never exceeds the value that is the difference between the demand charge tolerance and the expected peak demand of the site owner. This is depicted in Figure 11-23, where the blue line is the billable power over the interval (the sum of the site power demand and EVSE power demand), the red line is the demand charge tolerance (T), the orange line is the EVSE power demand (X), and the green line is the site peak power demand (P) without the EVSE contribution. Even though the expected peak demand without the EVSE contribution may not extend over the entire interval, in order to ensure the total demand never exceeds the threshold, the peak expected demand is assumed to last the entire interval.

To capture this strategy in a formula, the following variables are assigned:

- Let D be the threshold above which there is a demand charge (in kW); D is known from the published utility rate structure
- Let P be the expected peak site demand without the EVSE over the 15-minute interval (in kW)
- Let X be the peak power of the EVSE over the 15-minute interval (in kW)
- Let T be the demand charge tolerance (in kW, is zero when total demand charge avoidance is desired); T will be a function of the demand charge rate structure and demand charge threshold D.

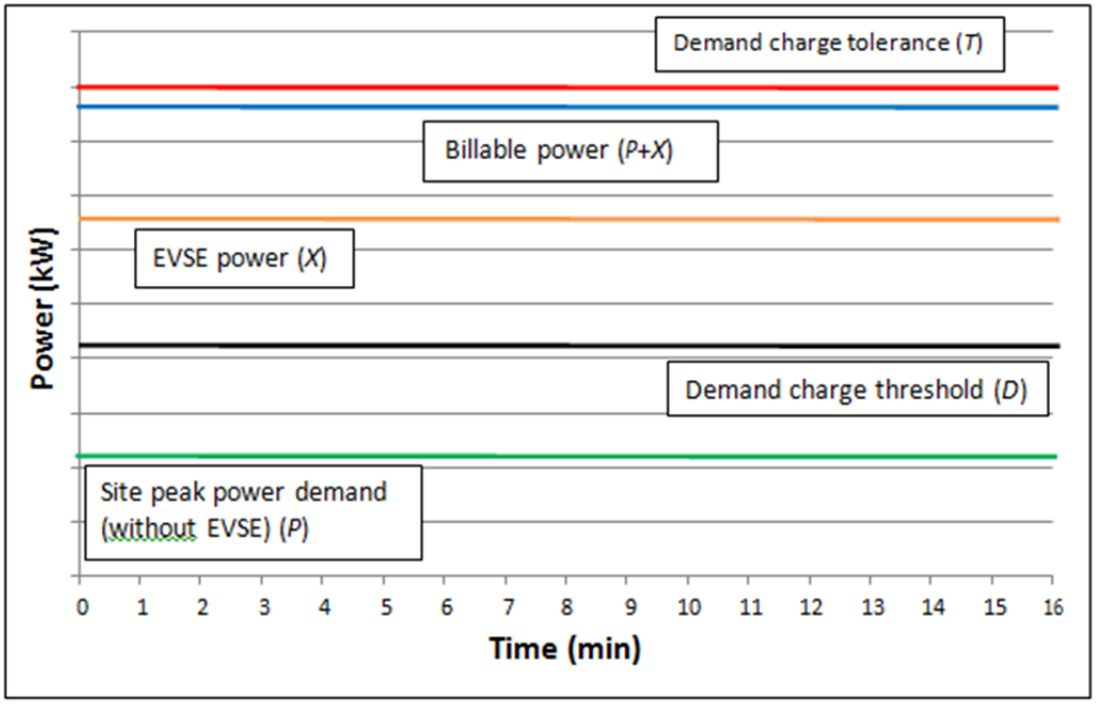


Figure 11-23. Billable power never exceeds the demand charge tolerance.

The equation that governs the relationship is

$$P + X \leq T \tag{1}$$

or billable power is less than or equal to the demand charge tolerance. The variable T is defined by the customer's preference and published utility rate structure. The expected peak site demand can be obtained from historical usage data and so the peak power allowable for the EVSE (X) to obtain a desired demand charge can be calculated from Equation (1). The DCFC can be electrically limited at the time of installation.

11.1.4.5 Demand Charge Reduction Methods 2a and 2b: Exceeding the Demand Charge Tolerance Approach. Methods 2a and 2b for demand charge reduction (or elimination) involves allowing the sum of the peak site demand and EVSE power to exceed the value of the demand charge tolerance, but only for a short period of time. The power sum for the rest of the 15-minute interval must be sufficiently low that the average power demand over the interval does not exceed the demand charge tolerance.

Method 2a—Method 2a is depicted in Figure 11-24 for when the site peak power demand duration is well defined. A crucial aspect of this method is that reliable historical data on the site peak demand duration must exist and the average site power value must be relatively stable for the time outside of the peak site demand. If the peak demand timeframe is unknown or if the average site power has a large standard deviation, Method 2a cannot be used with any confidence that the demand charge will be reduced or eliminated. This method is complicated by the fact that even if the peak demand timeframe is known, the 15-minute interval begins at an unknown time. Therefore, the 15-minute interval with the highest peak and average site demand should be used in order to conservatively determine the highest allowable EVSE power.

For Method 2a, two more variables must be assigned:

- Let Y be the average site power demand

- Let t be the amount of time over which the site peak power demand (P) occurs (in minutes; is less than or equal to 15 minutes).

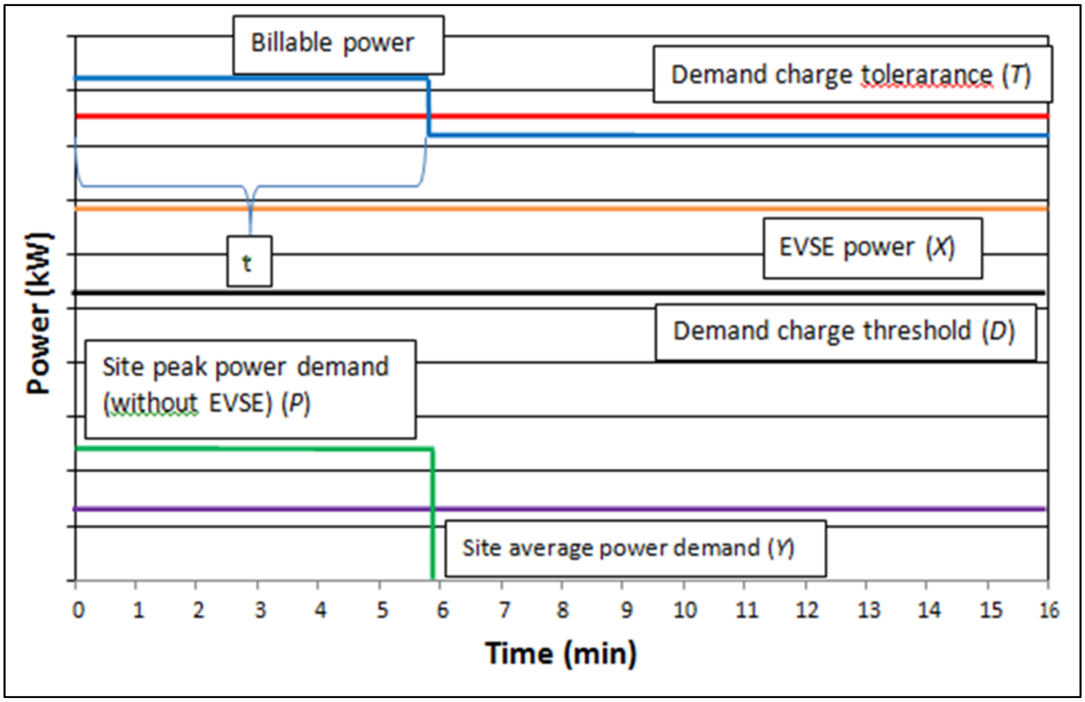


Figure 11-24. Billable power exceeds the demand charge threshold for duration 't' due to site peak power demand.

The formula relating these variables for this strategy is

$$\frac{(P+X)t+(Y+X)(15-t)}{15} \leq T \qquad (2)$$

As before, the variable T is defined by the customer's preference and published utility rate structure. The expected peak site demand (P) and average site power (Y) are obtained from historical usage data, as well as the peak site demand period (*t*). The peak power allowable for the EVSE (X) to obtain a desired demand charge can be calculated from Equation (2). The DCFC can again be electrically limited at the time of installation.

Method 2b—It should be noted that experience to-date indicates that nearly all commercial sites that are subject to utility demand charges already have a load management system in place that controls site loads to maintain a consistent average site power demand that is below the host's demand charge tolerance. Method 2b is then implemented, where the duration of the EVSE charge is controlled to allow for full EVSE power, but only for a shortened duration such that the average power demand over the interval does not exceed the demand charge tolerance (Figure 11-25). Equation (2) is therefore modified:

$$\frac{15Y+Xt}{15} \leq T \qquad (3)$$

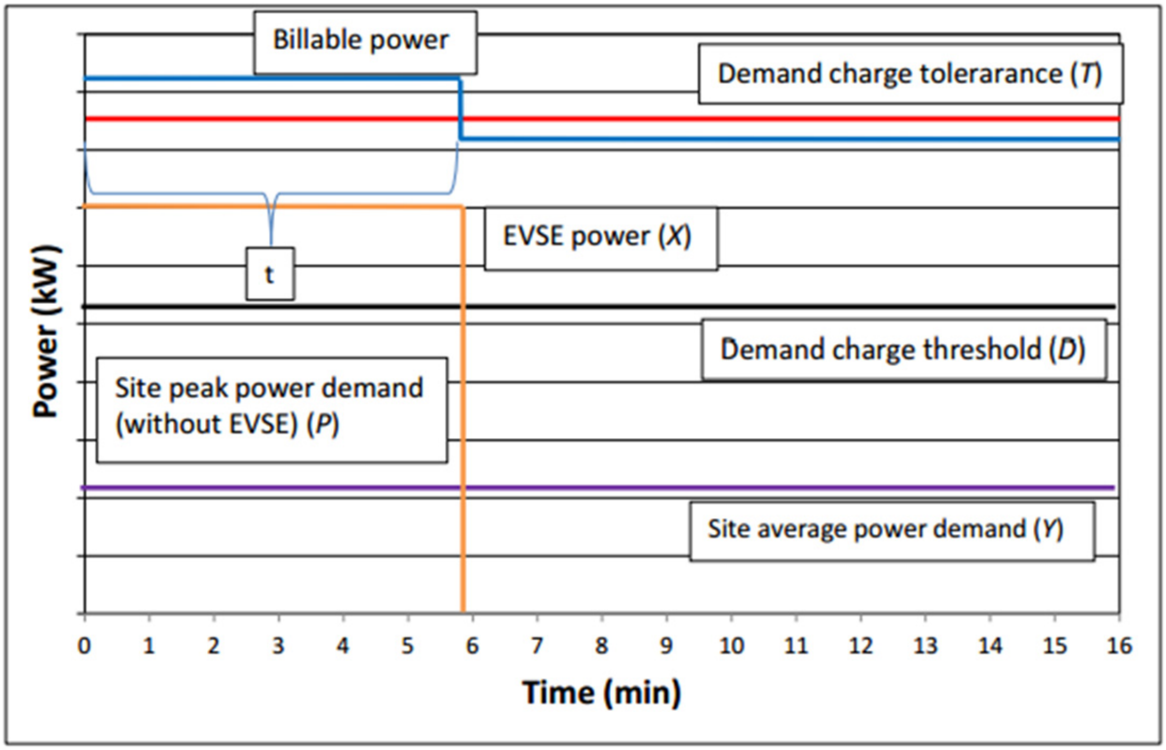


Figure 11-25. Duration of the EVSE charge is controlled to allow for full EVSE power, but only for a shortened duration.

Limiting the EVSE charge to a portion of the 15-minute interval may be a viable method until the number of vehicles increases to the point that demand charges are amortized over a large number of charges per month. This strategy may also be advantageous in that the user can be notified that the charge is done for the 15-minute interval and can perhaps be given the choice to disconnect. However, depending on site data, energy provided to the PEV may be lower with Method 2b, creating PEV owner dissatisfaction.

11.1.4.6 Demand Charge Reduction Method 3: Selective User Charge Rates

Approach. The third method for reducing or eliminating demand charge for EVSE usage is for the user to be allowed to select different charge rates (e.g., "premium," "regular," and "economy") with cost differences for each rate. For example, the premium rate for DCFC might be the maximum allowable power of the unit (60 kW), while other rates can be any combination that is deemed commercially beneficial. The advantage of this method is that any power schedule that is the EVSE owner's preference can be used. The disadvantages include potentially pricing EVSE usage out of range of the average user and uncertainty because the number of users selecting each tier will affect the amount that must be assessed for each vehicle. Also, this approach may cause legal problems because charging at different power levels may contravene the legal requirement that only utilities can legally sell power. It is important to note that even though a user may select a given charge power rate, the battery management system of the battery on board the vehicle will ultimately control flow of electricity to the battery and may not allow the power rate chosen. The strategy in the battery management system will take several factors into account, including temperature and SOC, and also potentially battery characteristics such as total Ah throughput.

11.1.4.7 Case Study.

This section outlines case studies for demand charge reduction using the three methods outlined above for the DCFC case. Unlike the previous examples, this case study considers a DCFC installation that will be additional to a building service, not a stand-alone service.

One of the building meters at Blink headquarters was instrumented with measurement equipment that captured power and energy usage data at a sampling frequency of once per minute. The data were captured over a 3-day period from 8:35 a.m., August 8, 2011 to 7:47 a.m., August 11, 2011. The resultant data were then analyzed and the 15-minute interval with the highest average power was determined. The peak site demand of 16.6 kW was the highest from the 3-day collection period. Data from this interval are presented in Table 11-19.

Table 11-19. Blink site demand data for 15-minute interval.

Statistic	Value
Peak Site Demand	16.6 kW
Time at Peak	2 minutes
Average Site Demand	14.6 kW
Site Demand Standard Deviation	4.2 kW

The local utility is APS and commercial rates for an extra small location are used for this case study:

- Energy usage rate: $0.10403 per kWh for the first 200 kWh; $0.06083 per kWh for all additional energy
- Demand charge rate: $9.675 per kW for the first 100 kW; $5.146 per kW for all additional energy.

While the interval with the highest average and peak demand is considered for the demand charge, the energy charge is calculated using the entire 3-day period data. The electrical energy consumed over the 3-day period was 512.02 kWh. Extrapolating this demand over a month (i.e., 30.4 days) of energy usage and using the energy use rate from above, results in an energy charge of $489.65. The demand charge tolerance for the DCFC is assumed to be equal to the cost for the energy portion of the site bill (i.e., T is assumed to be $489.65 divided by the demand charge rate of $9.675/kW or 50.6 kW).

The case study will include the same duty cycle from Section 11.1.4.2 for charging of PEVs. The costs for Methods 1, 2a, and 2b will be the same because the charging energy is constant and the demand charge threshold is set. The only difference will be the charge times associated with each method. Method 3 will be considered separately. The total bill not is determined, only the additional costs associated with DCFC operation will be calculated.

Demand Charge Reductions Using Methods1, 2a and 2b—The total monthly bill for these three methods would be: $20.43 (base) + $41.93 (energy) + $489.56 (demand) for a total bill of $551.92. The demand charge would be 89% of the total bill. The cost per vehicle is $1.82 if all charges are considered equal. If value of the charge from 30 to 60% is considered to be one-half of the 30 to 90% charge, the costs per vehicle would be $2.79 (i.e., 30 to 90%) and $1.40 (i.e., 30 to 60%).

The demand charge reduction for Method 1 is determined by using Equation (1) and the maximum allowable DCFC charge would be 34.0 kW. The amount of energy that could be provided during any single 15-minute charge period would be 8.5 kWh. Thus, all seven of the vehicles charging from 30 to 60% could be fully charged within the 15-minute interval, while the three vehicles charging from 30 to 90% would require nearly 22 minutes each.

The demand charge reduction for Method 2a is determined using Equation (2) and the maximum allowable DCFC charge would be 35.7 kW. The amount of energy that could be provided during any single 15-minute charge period would be 8.9 kWh. All seven of the vehicles charging from 30 to 60% could be fully charged within the 15-minute interval, while the three vehicles charging from 30 to 90% would require over 20 minutes each.

The demand charge reduction for Method 2b is determined using Equation (3) and the DCFC can charge a vehicle at its full 60-kW capacity for 9 minutes. After the 9 minutes elapse, the DCFC power output would have to drop to zero in order to prevent the demand charge threshold from being exceeded; the charge could resume at the start of the next interval. The amount of energy that could be provided during any single 15-minute interval would be 9.0 kWh. All seven of the vehicles charging from 30 to 60% could be fully charged within the 15-minute interval, while the three vehicles charging from 30 to 90% would require 18 minutes each.

The EVSE site host could be more confident that demand charges would not be larger than the specified value by using Method 1 and Method 2b over Method 2a. Method 2a appears to be inferior because a priori knowledge of peak power values and durations will be difficult to obtain. Method 2b is likely superior of the three methods because it allows for the highest energy transfer at the maximum DCFC charge rate; Method 1 could pay a penalty in customer satisfaction because of the lower charge power. However, Method 2b could also result in customer dissatisfaction because the charge will terminate and cannot begin again until the next 15-minute interval begins.

Demand Charge Reduction Using Method 3—For Method 3, it is assumed that the three tiers, “premium,” “regular,” and “economy,” are available to the customer. The power levels for the three tiers are assumed to be 60 kW, 40 kW, and 20 kW, respectively. The charging component of the demand charges associated with the three tiers are $580.50, $387.00, and $193.50. Adding the base and charging energy costs ($20.43 [base] + $41.93 [energy]) from duty cycle charging results in total costs of charging for the three tiers to be $642.86, $449.36, and $255.86, respectively. The required costs for different combinations of charge rates are presented in Table 11-20. The demand charge will always be associated with the maximum tier for a given billing cycle (e.g., if there are any vehicles charged at the “premium” rate, the $642.86 charge will apply as shown in the last entry in the table). The prices will follow the relative differences in power of the tiers for this analysis, although it is not necessarily required. This assumption means that the “premium” charge rate costs three times that of the “economy” rate. The duty cycle of 10 cars charging per day is used again for each scenario and has been made so that a comparison with the results from Methods 1, 2a, and 2b can be made. However, the demand charge tolerance, which was held constant for the other methods, is not fixed in Method 3, and this makes direct comparison difficult.

Table 11-20. Method 3 scenarios and costs per vehicle.

Scenario	Premium	Regular	Economy	Required Cost Per Premium Vehicle	Required Cost Per Regular Vehicle	Required Cost Per Economy Vehicle
1	304	0	0	$2.11	—	—
2	0	304	0	—	$1.48	—
3	0	0	304	—	—	$0.84
4	104	100	100	$3.15	$2.10	$1.05
5	204	50	50	$2.53	$1.69	$0.84
6	50	204	60	$3.17	$2.11	$1.06
7	50	50	204	$4.25	$2.83	$1.42
9	1	0	303	$6.30	—	$2.10

It is apparent that the fewer premium selections for a given number of overall cars to be charged, the higher cost that must be assigned to both the premium and regular vehicle prices in order to amortize the demand charge.

It should also be noted that using the three tier power levels, the time required to charge from 30 to 60% at each tier is 6 minutes (premium), 9 minutes (regular), and 18 minutes (economy), and from 30 to 90%, the charging time at each tier is 12 minutes (premium), 18 minutes (regular), and 36 minutes (economy).

11.1.4.8 Conclusion. Several conclusions can be reached through analysis of the three methods presented for reducing demand charges and the case study. First, for two out of the three methods, it is imperative that reliable historical energy use data are available for any prospective DCFC site. If the site's demand data without the DCFC contribution are not entirely reliable, a margin of error should be maintained to prevent inadvertent exceeding of a demand charge threshold that could vastly increase the cost of operation. Each site must be vetted thoroughly for appropriateness for DCFC deployment, including the obvious permitting and installation costs and complexities, but also from the standpoint of site demand data reliability and uniformity: If the data are unavailable or demand varies widely, the site may not be a suitable for a DCFC unit. This decision must be made on a case-by-case basis and will largely depend on tolerance of the DCFC host to large and varying demand charges.

The various methods represent different approaches and philosophies to demand charge reduction. The peak demand-dictated approach of Method 1 is very conservative, especially if the assumed peak demand is conservatively chosen with a margin of error. The maximum demand charge can be made to be very predictable. However, the user may be forced to accept a lower charge rate and this may result in dissatisfaction with the DCFC experience.

The exceeding the demand charge tolerance approach of Method 2a is less conservative and will allow for higher charge rates. This will increase user satisfaction, but the host may incur larger demand charges as a result. The reliability and invariability of the site demand are is even more important for this method. Method 2b is likely to be no less conservative than Method 1 (whereas Method 1 relies on the historical site peak demand, Method 2b relies on the historical site average demand) and the full power of the DCFC is available; however, because charge time must be truncated within the 15-minute interval, customer dissatisfaction may result from having to wait for the next interval to occur, with potentially prolonged periods with a connected vehicle and no charging.

If the pricing scheme of Method 3 is used, the objective is to compensate the host for demand charges, rather than attempting to reduce the incurrence of demand charges. In this case, the site demand data are largely irrelevant, but reliable data on user tier preferences and on user numbers are crucial to the pricing scheme settings in order to maintain satisfaction of the DCFC host. The larger the number of users, the lower the price can be per charge for the customers. Furthermore, the more users that choose the higher-priced charge rate, the lower the price can be for all tiers.

It should be noted once again that the three methods described in detail in this paper are not the only ways that demand charges can be reduced. Further study will be conducted and white papers will be released to devise additional methods that may provide more flexibility, options, and cost-reduction certainty for the DCFC host. In particular, an approach in which the DCFC is paired with a ground energy storage system that could accept power during periods of low demand (and during periods of low TOU rates to reduce energy charges) and release power during periods of high demand to reduce the peak demand value should be investigated fully. Alternatively, the EVSE network operator could negotiate with the local utility, whereby instead of a demand charge being incurred for each DCFC unit, the demand can be aggregated into a single demand charge to help lower the overall cost and remove burden from EVSE hosts. Finally, the EVSE network operator could agree to classify the EVSE units as interruptible service units; therefore, the utility could direct the EVSE to stop charging whenever warranted by excessive overall grid demand. In this case, demand charges would still be incurred, but the charges would be offset by compensation for interruptible service provision.

On a broader scale, some comments on demand charges themselves are warranted. The basic rationale for demand charges is that they will reduce peak power demands by financially impacting behavior regarding the use of electrical power. This assumption is based on the premise that utilities should reduce peak demand, which will reduce the need for additional generation facilities by using existing plants more efficiently and will also reduce the need for the inherently inefficient usage of spinning reserve plants. This premise remains appropriate in the absence of smart grid technologies and distributed energy storage. However, utilities may be able to substitute these two paradigm-shifting additions in the electricity sector for new generation capacity because the additions allow for much more utility control over the electricity demand. Eliminating demand charges, at least in certain circumstances, in exchange for more utility control, may be in the public interest for a number of reasons, including the advancement of PEVs. PEVs offer the possibility of distributed energy storage, interruptible service provision, in addition to additional revenue from increased electricity demand that can be shifted to off-peak times. Imposing burdensome demand charges may stunt the nascent introduction of PEVs by limiting the attractiveness of DCFC deployment; this may be against the interest of utilities as well. While demand charge reduction using the methods outlined in this document for the current rate structures should be undertaken, the issue and indeed the concept of demand charges should be revisited in the context of PEVs and DCFCs to determine what steps can be taken to address the needs of all stakeholders.

11.1.4.9 Utility Rates. Because of the size and number of pages of utility rates, they are not included in this report. However, they can be found at http://avt.inel.gov/pdf/EVProj/DCFastCharge-DemandChargeReductionV1.0.pdf.

11.1.4.10 Utility Demand Charges

Author's note: data were current in 2012.

Washington

1. Seattle City Light: $61.00

California

1. Burbank Water and Power: $1,052.00
2. Glendale Water and Power: $16.00 (July through October); $11.00 (November through June)
3. Los Angeles Department of Water and Power: $250 + $450 = $700 (June through September high peak); $250 + $162.50 = $412.50 (June through September low peak); and $250 + $212.50 = $462.50 (October through May)
4. Southern California Edison: $1,460.00
5. PG&E: None
6. City of Palo Alto Utilities: None
7. SDG&E : $678.50 (non-coincident);$382.50 (Maximum on-peak, summer) and $237.50 (maximum on-peak winter)
8. Alameda Municipal Power: None
9. Hercules Municipal Utility: $377.00(summer) and $93.00 (winter)
10. Silicon Valley Power: None

Arizona

1. Salt River Project: $210.50 (summer) and $123.00 (winter)
2. Tucson Electric Power: None
3. TRICO Electric Cooperative: $180.00

4. APS: $483.75 (secondary) and $448.00 (primary)

Oregon

1. PacifiCorp: $213.00 (secondary) and $216.00 (primary)
2. PGE: Schedule 38: none; Schedule 83: $71.40 + $41.60 = $113.00 (facilities) + $41.00 (transmission and related services charges) + $88.00 (distribution charge) = $242.00
3. Eugene Water and Electric Board: Primary: No charge for first 300 kW; secondary: $306.50
4. Lane Electric Co-Op: None (cut-off at 50 kW exactly)

Tennessee

1. Middle Tennessee Electric: None (cut-off at 50 kW exactly)
2. Duck River Electric Membership: None (cut-off at 50 kW exactly)
3. Harriman Utility Board: None (cut-off at 50 kW exactly)
4. Athens Utility Board: None (cut-off at 50 kW exactly)
5. Cookeville Electric Department: None (cut-off at 50 kW exactly)
6. Cleveland Utilities: None (cut-off at 50 kW exactly).

11.2 EV Project Residential Electric Vehicle Supply Equipment

11.2.1 What were the "Best Practices" Identified for Residential Charger Installations?

11.2.1.1 Introduction. In most communities, installation of electrical equipment such as EVSE in a residence requires a permit to be issued by the AHJ. At the outset of The EV Project, most AHJs did not have a process for installation of EVSE, because PEV deployment was just getting started across the United States. Because The EV Project was being conducted in their jurisdiction, these AHJs needed to develop a process. The resulting permitting processes proved to be one of the most varied aspects of The EV Project's charging infrastructure deployment activity.

EV Project personnel managed installations of these residential EVSE. As a result, The EV Project team was in a position to be able to identify "best practices" for residential installations, including the ideal residential installation site and best permitting processes.

11.2.1.2 Key Conclusions

- Although at the outset of The EV Project the local permitting AHJ typically did not have a permit designation for installation of residential EVSE, many were quick to implement a unique permit for the EVSE and introduce simple online or self-inspection processes.
- Installation of separate, metered electric service for EV charging, as implemented in some EV Project electric utility service areas, eliminated the need to upgrade the homeowner's electric service panel.
- EV Project personnel met with the local AHJ in many of the project study markets prior to installation of the first EVSE in order to educate them about The EV Project and gain their support. This helped speed up permit application reviews and maintain the project's installation schedule.

11.2.1.3 Background. In exchange for permission to collect data from their vehicle and EVSE, participating Nissan Leaf and Chevrolet Volt drivers were provided with a free Blink charging unit (i.e., EVSE; Figure 11-26) and credit toward the cost of installation at their residence. Although the participating driver (i.e., home owner) was responsible for any installation costs that exceeded the credit, the installation credit frequently resulted in the EVSE being installed at their home free of cost to the driver.

Figure 11-26. Blink residential EVSE.

A survey of the licensed electrical contractors from each of The EV Project markets was conducted to determine the appropriate installation credit for a "typical" residence and to qualify interested electrical contractors as part of The EV Project's Certified Contract Network (CCN). Qualification included technical capabilities, experience, and the ability to work under contracting requirements imposed on The EV Project, including DBA conformance. From this process, over 30 electrical contractors were qualified as part of The EV Project CCN and the initial residential installation cost credit was set to fully cover the cost of a "typical" residential installation.

The EV Project managed installation of EVSE by having the CCN use a team of two or three electrical contracting professionals that were located in each region working with the local CCN electrical contractors and permitting authorities to approve installation cost estimates and coordinate installation work. Best practices surrounding installation of the Blink residential EVSE were gathered from experience of the entire EV Project team. Experience of both field and management personnel generated observations that may be of value to future residential EVSE installations.

11.2.1.4 Observations

Permitting Practices—The typical process for obtaining a permit from the local AHJ is completing an application and submitting it in person at a local municipal office. The application is then processed and reviewed. When approved, a fee is paid and a permit is issued. In some cases, this process also includes site inspections both before and after installation.

Using this typical permit process for The EV Project, a CCN contractor spent an uncertain amount of time completing the application form with information that may have come from multiple sources (e.g., homeowner, Blink hardware, etc.), travelling to the municipal authority's office, and waiting for processing. In some instances, the CCN contractor was unable to obtain the permit on the first trip, prompting a second trip and adding to the costs for all involved.

The previously published EV Project paper, "How do Residential Charging Installation Costs Vary by Geographic Location?" [8] provides data on the cost of the permit itself. That paper identified that the average permit fee charged by the AHJs represented 8.6% of the installation cost. Although this represents less than 10% of the cost of the installation, it does not include the cost of time spent by the CCN obtaining the permit. While the costs incurred for time spent were not specifically captured, they were often cited by CCN staff in the less progressive jurisdictions as a significant administrative expense associated with and billable to the installation.

The best permitting practices observed by The EV Project were those that minimized both cost and time for the applicant. Most of the AHJs that reduced the application time also had lower permit fees.

Two practices utilized by AHJs minimized cost and time: (1) online applications and (2) self-certification by the installation contractor.

Online permitting was uncommon in late 2010 and 2011 when The EV Project began to install residential EVSE. However, in response to the permit review workload imposed by The EV Project, some AHJs implemented online permitting, significantly simplifying the permitting process. Most installations of EVSE qualified for online or simple permits, unless a plan check was required to verify that sufficient electrical service capacity existed at the home. Online permitting typically consisted of an online form and payment of fees by credit or debit card. The permit was issued electronically using the information provided on the application.

The best example of a self-certification or self-inspection program was in Oregon, where the Oregon Building Code Department included EVSE installations in a "minor installation label program." A summary of this process can be found in the appendix. It is interesting to note that the date on this document precedes the initial deliveries of Nissan Leafs and Chevrolet Volts by 10 months. Local government and businesses in Oregon consistently led by example and took action to encourage the adoption and use of PEVs and the charging infrastructure to support them.

Best Installation Conditions—In addition to identifying the best practices associated with residential permitting, managing installation of thousands of Blink charging units in homes across the country enabled The EV Project team to identify the features of an "ideal" residential EVSE installation. In this case, "ideal" is defined as the simplest and, therefore, quite likely is the least expensive installation.

The primary features of an "ideal" residential installation include the following:

- Utilization of plug-in EVSE rather than requiring the EVSE be hard-wired to its power source. This allowed installation of the circuit to be completed independent of the actual EVSE installation and presence of the PEV, providing more flexibility for contractors and home owners in scheduling installations.
- An electric service panel with at least two open spaces (to allow installation of a double-pole breaker) and at least 200 amps of total service capacity (example shown in Figure 11-27).

Figure 11-27. Circuit breaker panel and space for two circuit breakers to support AC Level 2 EVSE.

- Clear wall AND floor space around the EVSE installation location (Figure 11-28).

- Electrical distribution panel nearby (within 8 ft) the EVSE installation location (Figure 11-29 depicts good installation conditions).

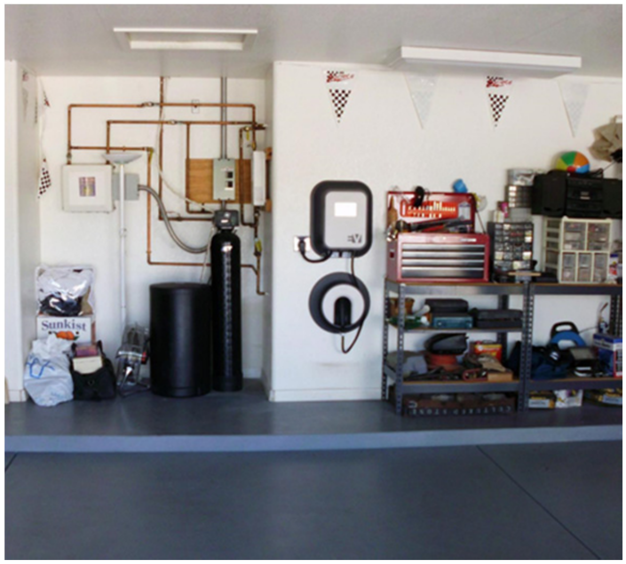


Figure 11-28. Clear floor and wall access to Blink EVSE.

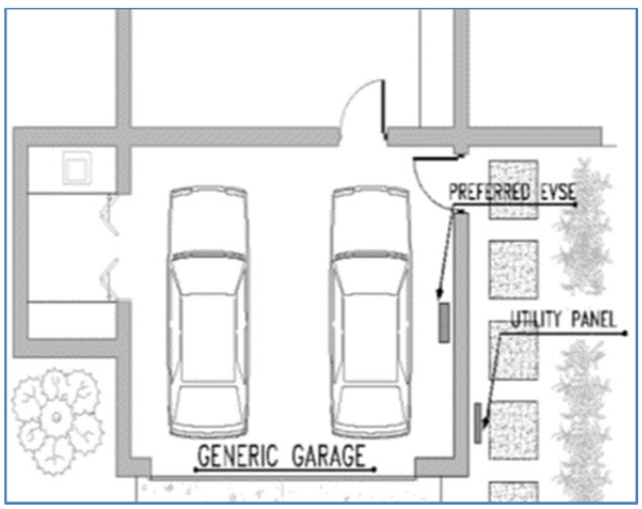


Figure 11-29. EVSE and service panel near PEV.

Other features of an ideal installation include the following:

- The EVSE installation location includes communication capability via the internet. The best methods for communication found during The EV Project include the following:
  - EVSE is easily within range of a wireless internet modem owned by the homeowner.
  - An Ethernet connection is available at the EVSE location.
  - A Wi-Fi signal booster or powerline device can be used to provide internet connectivity.
- A separate meter is installed (i.e., dedicated for EV charging, as depicted in Figures 11-30 and 11-31), allowing the EVSE to be installed without affecting the existing service and eliminating any need to upgrade the electric service panel to accommodate the EVSE load and circuit breaker.

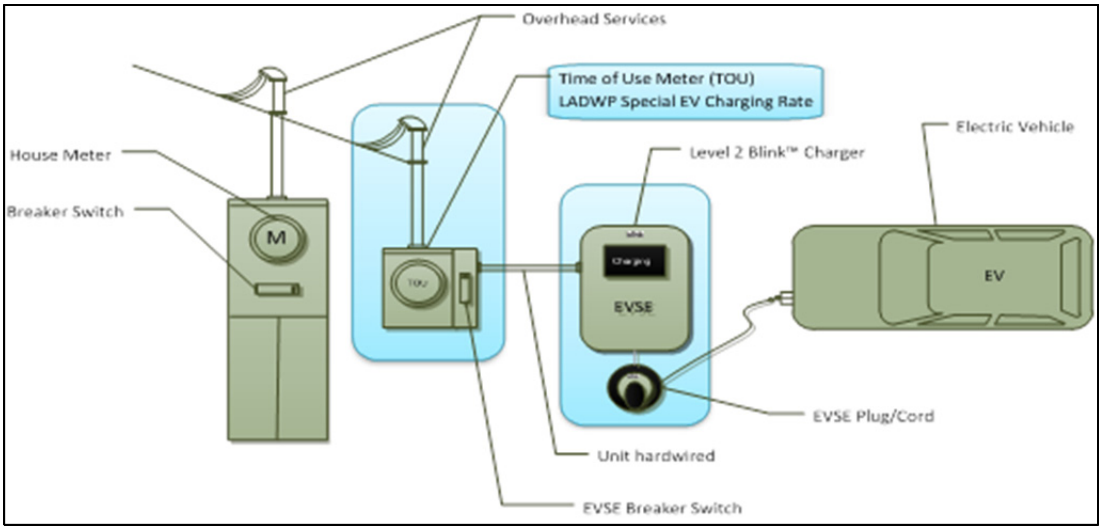


Figure 11-30. Metered circuit dedicated to EV charging and separate whole house electrical service panel.

Figure 11-31. TOU second metered circuit.

Because The EV Project trained its CCN and provided installation estimates to PEV drivers interested in participating in The EV Project, the vast majority of residential installations that proceeded to completion had many of these “ideal” conditions. The most common exception was lack of a strong wireless internet signal at the EVSE location.

The worst condition for a residential installation was the need to upgrade the electric service to the residence (e.g., new panel, larger utility service, etc.). This was particularly expensive for residences fed underground by the electric utility. The need for an electric service upgrade almost always caused the installation cost to significantly exceed the available credit, with most potential participants declining to enroll as a result.

11.2.1.5 Conclusions. By virtue of the nascent nature of the EV industry in 2010 and The EV Project’s obligation to deploy over 8,000 residential EV charging units, local electrical contractors, EV drivers, and local permitting authorities were simultaneously introduced to a new product to be installed in homes across the country.

These EVSE installations exposed electrical contractors to a new business opportunity and EV drivers to new technology in their garage. It also encouraged many local permitting authorities to use The EV Project and the installation of EVSE to streamline their permitting processes for this and other simple residential improvements. This was the most significant "best practice" for installation of residential EVSE. Today, most jurisdictions use online permitting for simple residential additions or modifications; however, this was not the case in 2011.

11.2.1.6 References

8. http://avt.inel.gov/evproject.shtml#LessonsLearned EV Project lesson learned white paper, "How do Residential Charging Installation Costs Vary by Geographic Location?"

11.2.1.7 Expediting the Permit Process for Installation of Electric Vehicle Supply Equipment

Expediting the permit process for installation of EVSE

Dennis Clements, Chief Electrical Inspector, Oregon Building Code Department

2/12/10

E-permitting

Purchasing permits on line through BCD's e-permitting program is available to electrical contractors in most areas affected by the roll out of the Nissan Leaf demonstration project. The inspection of installations of Electric Vehicle Supply Equipment, (EVSE), is the same whether the permit was purchased on line or over the counter. Below is a list of the local jurisdictions that are currently participating in the e-permitting program as of 2/1/10;

Portland, Lake Oswego, Troutdale
Washington County
Clackamas County
Yamhill County
Marion County
Salem
Corvallis
Lebanon
Lane County

Use of Minor Installation Labels

Currently, the minor label program can be used by electrical contractors for the installation of branch circuits up to 30 amps at 240 volts. Given this amperage limitation and the fact that the home based EVSE will require a 40 amp 240 volt circuit, the division is investigating another avenue of allowing the use of a minor label for the installation of a 40 amp, 240 volt branch circuit and the connection of EVSE in one and two family dwellings, where the EVSE is in an attached garage.

The minor installation label program was developed and implemented for repair and maintenance activities, and expanded to include electrical installations that are simple and straight forward. The installation labels are about a tenth the cost of a regular permit, and only a tenth of the installations get inspected.

Nine out of ten installations done under the minor label program will not be inspected to be sure that the existing service equipment has adequate capacity for the additional load of the EVSE. Older homes with 60 or 100 amp electrical services, and all-electric homes with no natural gas service may not have the capacity to safely supply the existing loads and the additional load. It may be prudent to require 100% inspection of the first hundred installations.

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11.2.2 How Do Residential Alternating Current Level 2 Charging Installation Costs Vary by Geographic Location?

11.2.2.1 Introduction. One of the objectives of The EV Project was to deploy PEV AC Level 2 charging stations in geographically diverse markets and collect data from those charging stations. These markets were selected based on sales and marketing plans of PEV partners Nissan and Chevrolet. The individual markets were further defined by zip code boundaries in order to support the EV Micro-Climate® planning process used to target locations for non-residential (i.e., publicly accessible) charging stations to support vehicles participating in The EV Project***.***

This diversity enabled the project to collect data reflecting geographic factors that impacted installation costs and use of charging infrastructure. This section provides an analysis of residential AC Level 2 charging station installation costs and discusses the geographic factors driving variations in these costs.

11.2.2.2 Key Conclusions

- During The EV Project, the average (i.e., mean) cost for installation of a residential AC Level 2 charging unit (including permit fees and service upgrades, but excluding charger cost) was $1,354.
- The median installation cost was $1,200.
- The Los Angeles market had the highest average installation cost at $1,828, while Atlanta had the lowest at $775.
- The cost of permit fees can have a significant impact on overall costs. Average permit costs varied from $49 to $206 across The EV Project markets and from 3.9% to 14.5% of overall installation costs.
- On average, EV Project participants paid $250 toward installation of their Blink home charging unit.

11.2.2.3 EV Project Residential Program. To interpret and fully understand installation cost data collected during The EV Project, one must analyze it in context of the project's history.

In order to meet the expected enthusiasm for introduction of the Nissan Leaf and Chevrolet Volt, The EV Project elected to limit participation to those vehicle purchasers residing in single-family homes that had a designated overnight parking location for the participating PEV. Installation costs, time required for installation, and level of effort to deploy charging units at multi-family dwellings (e.g., apartment buildings, condominiums, and townhouses) would vary significantly depending on each property's parking and management and was deemed to be inappropriate in meeting The EV Project objective of studying deployment and use of charging infrastructure.

The EV Project intended to provide "free home charging" to study participants who were willing to share the data generated by use of both their PEV and the charging infrastructure being installed at their home. This "free home charging" was to include the Blink charging unit and the cost of installing the unit in a "typical" residence.

To simplify The EV Project's administration and the appeal to new Leaf and Volt owners, a single credit amount was established across The EV Project study markets. The credit amount was determined by surveying licensed electrical contractors in all of The EV Project markets on their installation costs for various "typical" residences.

This survey of licensed electrical contractors from all EV Project markets not only determined the appropriate installation credit level, but also qualified interested electrical contractors as part of The EV Project's CCN. This qualification included technical capabilities, experience, and the ability to work under contracting requirements imposed on The EV Project, including DBA conformance. From this process, over 30 electrical contractors were qualified as part of The EV Project's CCN and residential installation cost credit was set at $1,200.

Deployment of residential charging units began late December 2010 when the Leaf PEVs were first introduced for sale in the United States. Within the first year of infrastructure deployment, The EV Project added Volt PEVs to the project and installed residential Blink charging units in 10 diverse markets, including the following:

1. Arizona (metro Phoenix and Tucson)
2. San Diego, California
3. Los Angeles, California
4. San Francisco, California
5. Oregon (Portland metro, Corvallis, Eugene, and Salem)
6. Seattle, Washington (Seattle metro, Tacoma, and Olympia)
7. Tennessee (entire state)
8. Washington D.C. (metro area, including homes in Maryland and Virginia)
9. Dallas, Texas
10. Houston, Texas.

The offer to participate in The EV Project was made to purchasers or leasers of a Chevrolet Volt or Nissan Leaf. The EV Project offered a free residential Blink charger and credit of up to $1,200 toward the cost of installing it in exchange for the vehicle purchaser allowing The EV Project to collect data and report on their charging patterns for the duration of the project.

The original project schedule, which was based on Nissan and Chevrolet PEV sales projections, anticipated that full residential participation (i.e., 8,300) and deployment would occur by the end of 2011.

Because PEV sales did not meet expectations, The EV Project added three more markets in 2012 in order to meet the deployment target as soon as possible. The markets were as follows:

1. Chicago, Illinois
2. Philadelphia, Pennsylvania
3. Atlanta, Georgia.

The extended deployment period and new markets added costs to The EV Project. To manage costs within the original project budget, installation credit offered to participants was reduced to $400 in all markets as of August 2012.

Figure 11-32 shows that sales momentum and the addition of three new markets overtook any negative impact from the reduced installation credit. In addition, Nissan introduced a very attractive lease program for the Leaf in the fourth quarter of 2012, which nearly doubled the pre-August participation rate (enrollment for qualified PEV drivers and residential chargers ended on January 31, 2013, resulting in the decrease in monthly installations).

11.2.2.4 Data Analyzed. The data analyzed for this paper came from reports generated from The EV Project's residential participant database. This database was populated with data from participants, PEV suppliers, EV Project administrators, and CCN installing the home charging units. The paper also benefits from the direct experience of EV Project staff, which managed deployment of more than 8,300 residential chargers over 2 1/2 years.

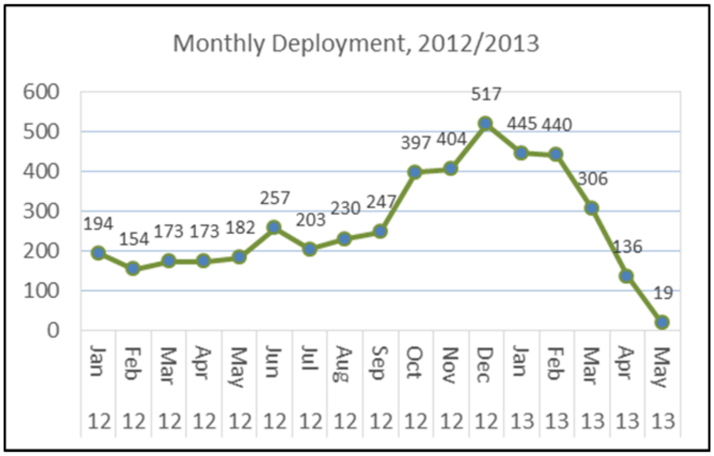

Figure 11-32. Monthly residential EVSE deployment for 2012 and 2013.

11.2.2.5 Installation Cost Breakdown. Because residential EVSE installations were only at single family residences, variation in installation costs was driven by the following:

- Materials
  - Service panel upgrade needed
  - Breaker for dedicated 40-ampere circuit
  - Wiring length
  - Conduit length
- Labor
  - ARRA funding for The EV Project required compliance with DBA. Prevailing electrician labor wages under DBA varied from over $55 per hour to under $12 per hour
  - Administrative effort to comply with DBA over the 2-plus years of the residential portion of The EV Project, including supplementary weekly payroll documentation
- Permit fees and administration
- Other market-specific conditions.

11.2.2.6 Analyses Performed. Total installation costs cited in this paper are based on fees paid to the CCN contractor performing installation. This amount included EV Project-funded credit plus whatever additional costs the residential participant paid. It does not include the cost of the Blink charger unit.

The average total cost for installation of residential charging units in each of the 13 markets analyzed was $1,354. The average for each of the markets is shown in Figure 11-33.

The average installation cost in Los Angeles was approximately 20% higher than the next highest market. The next nine markets were within 20% of each other. The three markets that have the lowest cost were the final markets added to The EV Project.

11.2.2.7 Maximum Installation Cost in Each Market. As shown in Figure 11-34, the maximum cost for a residential installation occurred in Los Angeles and represented a significant upgrade to the electrical service for this home. The second highest was nearer to the maximum in other markets at $5,900. However, it is interesting to note that Los Angeles had 22 installations over $5,000 (and 30 of the 40 highest cost installations).

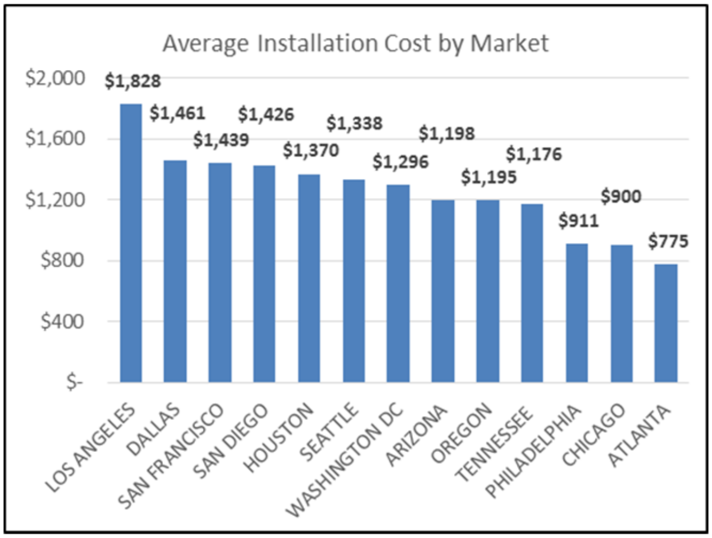

Figure 11-33. Average total installation cost by market.

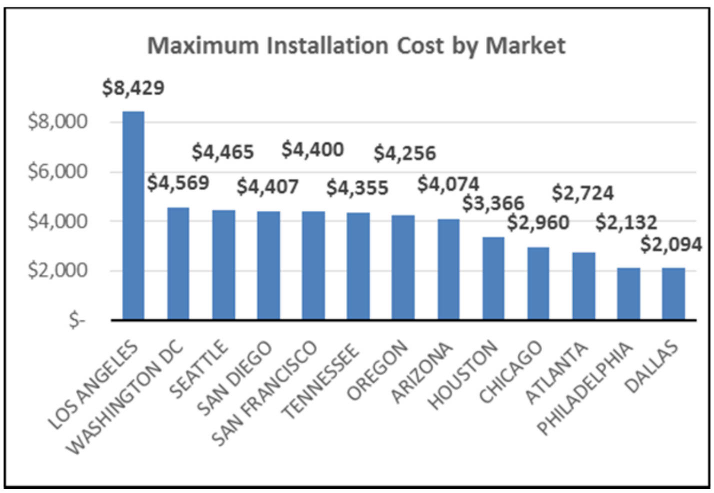

Figure 11-34. Maximum residential installation cost in each market.

These high installation costs in Los Angeles were likely the result of three market drivers. The first has to do with the coincident Charge Up LA rebate program being conducted by the Los Angeles Department of Water and Power. This rebate provided EV Project participants with an additional $800 toward the reimbursement of installation costs. With the Los Angeles Department of Water and Power Program (i.e., Charge Up LA), a total of $2,000 ($1,200 EV Project and $800 Los Angeles Department of Water and Power) was potentially reimbursed. Because The EV Project provided the free charging unit, all $2,000 could go toward installation cost reimbursement. This likely attracted Leaf and Volt drivers with more expensive installations that otherwise may have not participated in The EV Project.

Another factor associated with Los Angeles Department of Water and Power Program that significantly increased installation cost was the requirement for a second electric meter to separately meter energy supplied to the Blink charger.

The third likely contributor to higher costs in Los Angeles is the age of homes in affluent areas of greater Los Angeles. Addition of an EV charging unit to these older homes is much more likely to necessitate changes to the electric service or, at least, the service panel.

11.2.2.8 Installation Costs – Materials. Although the cost of materials did not vary significantly based on the market (i.e., wiring, conduit, and circuit breaker prices were unchanged across the various markets), there were geographic aspects regarding what materials were needed to install a dedicated 40-amp circuit that terminated at the Blink EVSE unit in the garage. Those geographic considerations were primarily associated with the age of the homes into which the EVSE unit was installed. Older homes were more likely to have lower capacity electric service panels and need a new panel in order to add the dedicated 40-amp circuit. These panels also may have been located far from the garage (e.g., in the basement, kitchen, on an outside wall, etc.), further increasing material costs.

11.2.2.9 Installation Costs – Labor. Labor costs varied significantly by geographic location. This was due not only to the DBA prevailing wage for the electricians, but administration costs associated with installations (e.g., financial accounting, reporting, permit applications, filing, etc.).

Electrician prevailing wages were over $55/hour in counties around San Francisco and Seattle, while rates in some Texas counties were as low as $11/hour. The electrician's wages were only part of the labor costs, because company costs for administration, overhead, and profit margin magnified the differences in labor costs for The EV Project. The labor element of installation cost was also affected by permitting requirements of the local government agency having jurisdiction for permitting. Some jurisdictions had very labor-intensive permitting processes, including local filing of written applications and pre and post-installation inspections. These requirements resulted in significant hourly costs associated with driving, waiting in line for permits, and waiting onsite for inspections. Other jurisdictions (e.g., Portland) offered innovative self-inspection programs that allowed CCN contractors to sign-off on installations themselves, with inspectors conducting only random sample inspections to verify compliance with code requirements.

11.2.2.10 Installation Costs – Permit Fees—In addition to labor costs associated with obtaining a permit to install a charger, fees were associated with the permit. The average permit fee in The EV Project varied from less than $50 in Oregon and Tennessee to over $206 in San Diego. Figure 11-35 shows the average permit fee for the 13 EV Project markets analyzed.

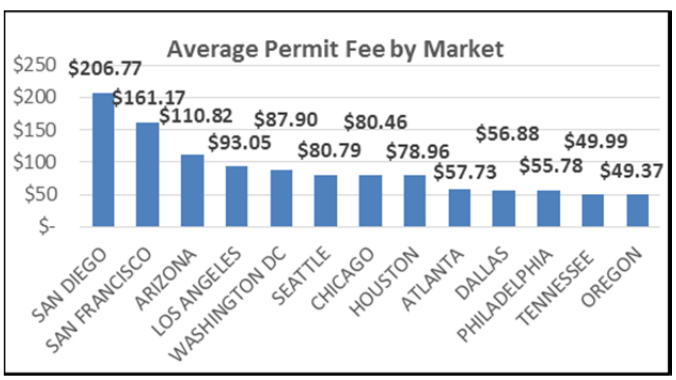

Figure 11-35. Average permit fee by market.

Figure 11-36 shows the percentage of total installation cost that was represented by the permit fees. On average, permit fees represented 8.6% of the installation cost. San Diego's higher fees also represent the highest percentage of the installation costs (14.5%).

Permits were not always required; however, The EV Project required CCN contractors to be conservative and obtain permits unless it was clearly not required. The best examples of circumstances that did not require a permit for EVSE installation were when a building permit was already open for other construction work being undertaken by the homeowner or when the Blink unit was replacing a previously permitted home charging unit. However, these were very infrequent occurrences.

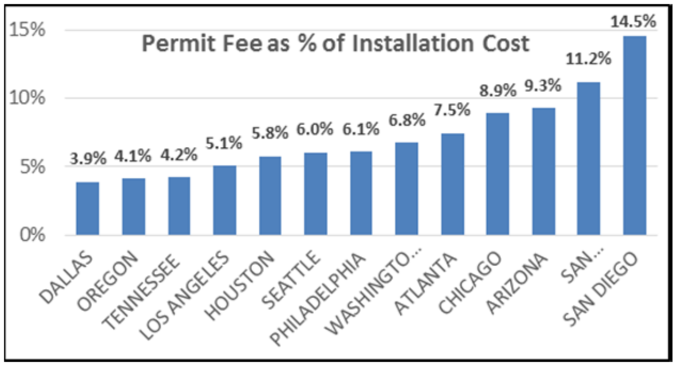

Figure 11-36. Permit fee as a percentage of installation cost by market.

The lowest permit fees (i.e., Oregon and Tennessee) resulted, in part, from local government action, which simplified a new permit item and a new process. Both of these states encouraged the use of simplified permitting. As a result, their fees were not only less expensive, but also more convenient than many of the others. “Best practices” observed for permitting in The EV Project is subject of a separate paper.

11.2.2.11 Other Market-Specific Conditions. A few other specific market conditions influenced installation costs in some markets.

The first and most obvious is those markets that were added in 2012 and only received a $400 credit toward installation. These markets (i.e., Atlanta, Chicago, and Philadelphia) had the lowest average cost for installations. Two factors contributed to their lower average costs: (1) these markets benefitted from experience gained by the company that managed these installations in The EV Project (i.e., SPX/Bosch) and (2) the more significant factor was the 18-plus months that the PEV community had matured since the start The EV Project at the end of 2010. This close-knit community was and is very active and very communicative. They knew there were installation and equipment options that were less expensive and did not include any of the requirements associated with the federally funded EV Project (e.g., DBA compliance, smart charger using home wireless internet access to transmit data, no choice of installer, etc.). Consequently, this more informed group of EV Project candidates would elect to not participate if they considered the cost to be too high. Thus, the project attracted those whose installation costs would be lower. The effect of this is borne out in the data, because these three markets had maximum installation costs amongst the lowest in The EV Project (see Figure 3).

Older homes typically required an upgrade to their electric service panels in order to accommodate the AC Level 2 charging unit’s dedicated 40-amp circuit. This was a significant cost driver, with the greatest impact on installation costs in Los Angeles.

This requirement for dedicated 40-amp service also affected participation in somewhat less affluent areas (e.g., coastal California), where homes often times did not have air-conditioning and the electrical service to the home was not sufficient to support a dedicated 40-amp charging circuit. The cost to add this additional capacity may also have affected participation in these areas.

Another factor that affected installation costs in San Diego was the concurrent TOU study being conducted by SDG&E. This program was for Leaf owners only and only those who chose to participate (although very few declined). The study required the installation of a second electrical meter, whose cost was included in EV Project installation costs when applicable. This TOU program increased the average installation cost in San Diego by about 10 to 12%.

Permit costs were not affected by this TOU program; therefore, subtracting the cost of the second meter, the actual impact from permitting costs in San Diego would be higher than the 14.5% shown in Figure 4.

11.2.2.12 Conclusions. Geographic variation in residential installation costs primarily resulted from three factors: (1) regional labor costs, (2) age of homes in the market, and (3) regional programs that were being conducted concurrently.

Although permit costs varied significantly across the geographic markets in The EV Project, it typically represented less than 10% of the total cost.

Labor cost variation reflected prevailing market wages.

Older homes typically required an upgrade to their electrical service panels in order to accommodate the AC Level 2 charging unit's dedicated 40 amp circuit. This was not only a significant cost driver, but likely affected the PEV driver's decision whether to participate in The EV Project.

11.2.2.13 Tables of Average Residential Installation Costs by Market

Table 11-21. Average permit cost.

Market	Average Permit Cost
San Diego	$206.77
San Francisco	$161.17
Arizona	$110.82
Los Angeles	$93.05
Washington, DC	$87.90
Seattle	$80.79
Chicago	$80.46
Houston	$78.96
Atlanta	$57.73
Dallas	$56.88
Philadelphia	$55.78
Tennessee	$49.99
Oregon	$49.37
Average Permit	$115.30

Table 11-22. Average total installation cost.

Market	Average Total Installation Cost
Los Angeles	$1,827.88
Dallas	$1,461.33
San Francisco	$1,438.95
San Diego	$1,425.51
Houston	$1,369.78
Seattle	$1,337.61
Washington, DC	$1,295.64
Arizona	$1,197.97
Oregon	$1,195.27
Tennessee	$1,176.32
Philadelphia	$910.54
Chicago	$900.29
Atlanta	$774.58
Average Installation	$1,354.60

11.2.3 How Do PEV Owners Respond to Residential Time-of-Use Rates While Charging The EV Project Vehicles?

11.2.3.1 Introduction. The power required to recharge an EV can be a significant electrical load for a house on the electric grid. Certain electric utilities within EV Project regions have incentivized home owners to charge their PEVs at specific times to help in managing overall electrical system load. Does behavioral data for The EV Project driver show that these incentive programs are effective?

11.2.3.2 Key Conclusions

- TOU programs do influence PEV driver charging patterns.
- 57% of survey respondents changed their utility rate subscription as a result of obtaining a PEV.
- A shift in charging demand to the TOU period is very obvious in the demand curve for PG&E. This shift causes a demand spike at or shortly after the beginning of the TOU period.
- Two factors influence the level of awareness and, ultimately, TOU program enrollment are the perceived value of the incentive and the program's outreach and education efforts.

11.2.3.3 Why is This Important? A question frequently asked relating to the adoption of EVs is "What is the impact of EV charging on the electrical grid?" The change in transportation fuel from petroleum products to electricity as the PEV transportation segment grows will certainly impact the demand for electrical power, but each electric utility views that impact differently.

The electric utilities serving The EV Project regions have a mixed response to this question. Some have shown little concern so far for overall power generation and distribution in their service territory, while others see the increase in PEV charging demand as an additional challenge to an already challenged system. This is particularly true in the southwestern states, where there is a history of power disruptions in the grid (i.e., "brownouts" and "blackouts").

11.2.3.4 Utility System Load Profiles. Figure 11-37 shows the Southern California Edison hourly load profile for the top 12 days of summer (i.e., red line), the top 3 days in winter (i.e., dashed blue line), and the average of the top 10 days in a normal winter (i.e., dashed green line) during 2004 [9].

The notes in [9] related to this graph indicate the significant load impact of air conditioning during the summer, which is absent during a normal winter, where the load is more related to lighting and some heating. This same impact can be seen in unusual winter days as noted by the dashed blue line.

Figure 11-38 contains the load profiles for the same type of days, but shows residential load rather than system load.

Figure 11-37 clearly shows the peaks and valleys in the system-wide power demand. Residential air conditioners provide a significant load for the residence. Figure 11-38 shows the clear impact of this load on the system, both in summer and on unusually warm winter days. PEV charging is a more significant load than air conditioning, but the impact of PEV charging on the residence was not shown in this in graph. Of course, the system load profile was impacted by loads from other businesses and other commercial utility customers.

Electricity-generating costs to the utility can be reduced if the peak demand is lowered by shifting some demand to the other times of the day. To do this, the electric utility, through approved rate designs, may provide TOU rates that incentivize power users to shift their loads if possible. This section focuses on incentives to home owners relating to their PEV charging needs and how they respond to those incentives.

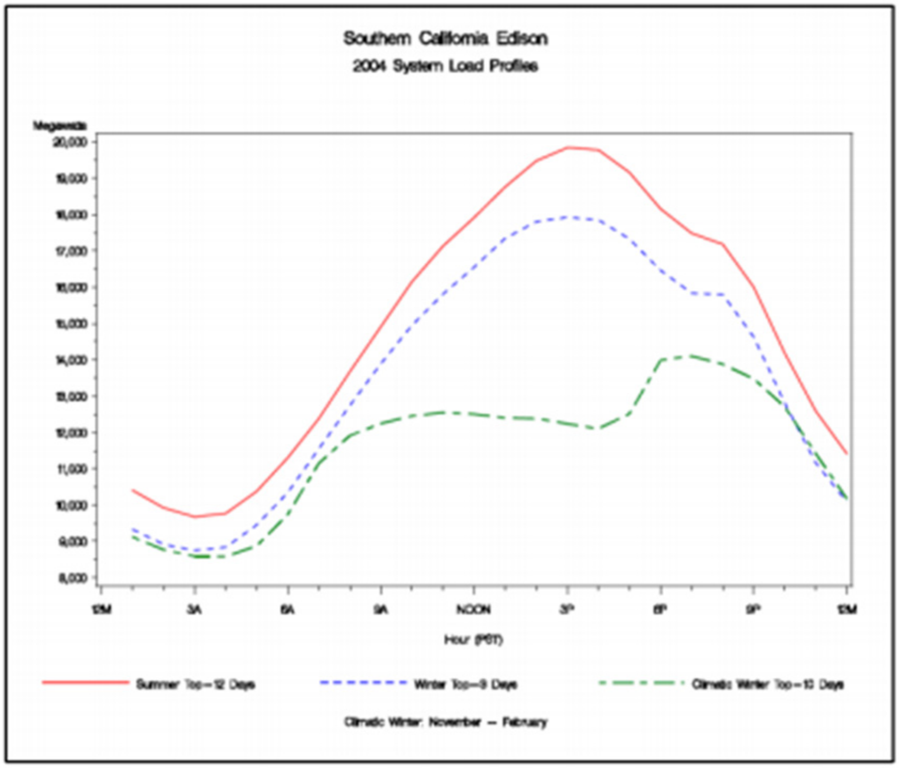

Figure 11-37. Southern California Edison hourly system load profile for 2004.

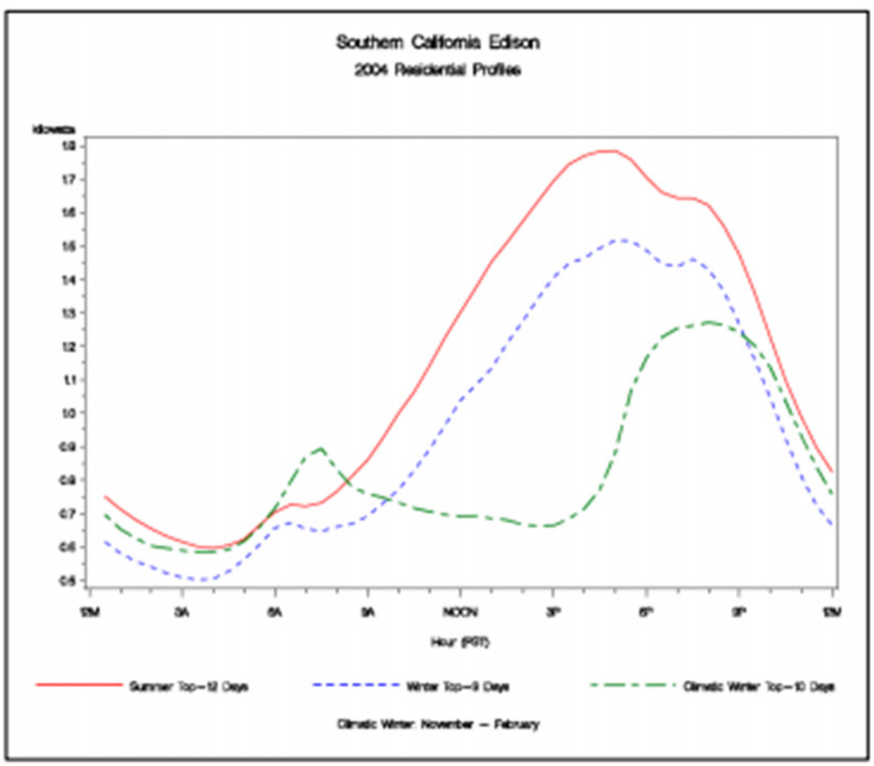

Figure 11-38. Southern California Edison hourly residential load profile for 2004.

11.2.3.5 How Do Utilities Use Time-of-Use Rates? Electric utilities may seek to shift peak loads to times of typically lower demand through TOU rates. These rates generally classify specific times of the day as on-peak and off- peak and, in some cases, a shoulder, partial-peak, or mid-peak. For example, for its TOU tiered domestic rate, Southern California Edison identifies residential hours as follows:

- On-peak: 12 to 6 p.m. weekdays
- Off-peak: All other hours [10].

Note how this on-peak time fits with the maximum demand shown in the load profile of Figure 11-37. PG&E defines summer weekday times on Electric Schedule E-9 as follows:

- On-peak: 2 to 9 p.m.
- Partial-peak: 7 a.m. to 2 p.m. and 9 p.m. to 12 a.m.
- Off-peak: All other times [11].

PGE defines summer weekday times as follows:

- On-peak: 3 to 8 p.m.
- Mid-peak: 6 a.m. to 3 p.m. and 8 to 10 p.m.
- Off-peak: 10 p.m. to 6 a.m. [12].

The price charged for power is typically lower for the off- peak times than for the on-peak times in order to incentivize the residential customer to shift loads to off- peak times. While it may not be possible to shift all loads (such as air conditioning), it is possible to shift power to operate swimming pool pumps, clothes dryers, and so forth to these off-peak times. The same is true for PEV charging. Some electric utilities have also implemented special EV rates to further incentivize the shifting of PEV charging loads to off-peak times.

Within the regions of The EV Project, electric utilities that provide TOU rates include the following:

- APS
- Georgia Power
- Los Angeles Department of Water and Power
- PG&E
- PGE
- Salt River Project
- SDG&E.

11.2.3.6 Electric Vehicle Charging Loads. The Blink EVSE provided to The EV Project participants can supply up to 7.2 kW power to a connected PEV. The actual energy transferred depends on the capability of the vehicle's onboard charger and the charge acceptance rate dictated by the PEV's battery management system. While most PEVs currently accept up to 3.6 kW, model year 2013 Nissan Leafs and other vehicle models coming to market will accept up to the EVSE's 7.2-kW rating. The peak load shown in Figure 11-38 for a residence is about 1.8 kW. If charging the PEV occurs simultaneously with the peak household loads, the new peak could be as much as 9 kW. As such, it is possible that charging the EV will increase the household demand by a factor of five.

PEV charging will significantly impact household demand at any time of day. Adding a 7.2-kW load at 3 a.m. in the summer could increase the household load by over 10 times. However, this occurs when the rest of the utility system is off-peak and helps flatten the overall system load curve.

How then do PEV owners respond to TOU rates while charging The EV Project vehicles?

11.2.3.7 Analysis Methodology. This topic was first addressed by The EV Project in 2012. The methodology and initial results were presented at EVS26 (i.e., Electric Vehicle Symposium) in Los Angeles [13]. That methodology illustrates the importance of charging availability and charging demand.

Charging availability at a point in time is the percentage of EVSE in a geographical area that are connected to a vehicle. Charging demand at a point in time is the total amount of power being drawn from the electric grid by a group of EVSE in a geographical area. These are represented by time-of-day plots. For The EV Project, these plots have been included in the quarterly reports since the first quarter of 2011 and posted on the website. They are prepared by geographic area and show the hourly percentage of EVSE connected and hourly charging demand for all weekdays and weekends for the quarter evaluated. In addition, these plots are prepared for each of the electric utilities in The EV Project areas.

Figure 11-39 shows the weekday residential charging availability for EV Project vehicles in the Nashville Electric Service territory during the first quarter of 2013. Figure 11-40 shows the weekday residential charging demand in the same service territory for the same time period. Note that the plot shows the maximum, minimum, median, and inner quartile values for all days of the quarter. Nashville Electric Service does not incentivize PEV drivers to shift charging times and the plots show that a typical PEV driver commences charge when the vehicle is connected to the EVSE.

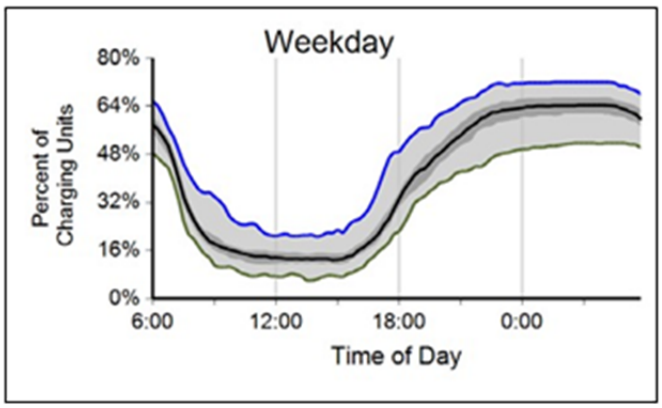

Figure 11-39. Weekday residential charging availability in Nashville Electric Service territory during the first quarter of 2013.

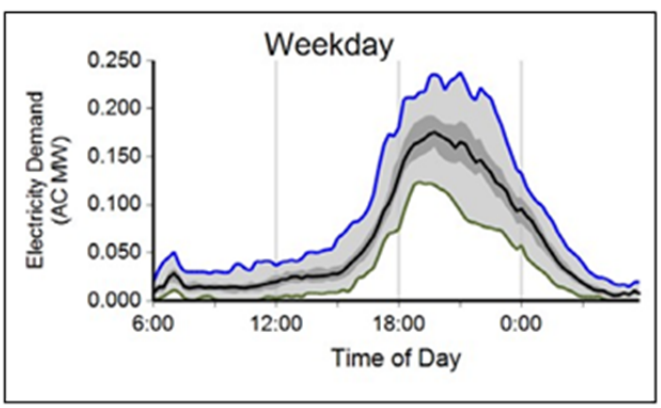

Figure 11-40. Weekday residential charging demand in Nashville Electric Service territory during the first quarter of 2013.

Figures 11-41 and 11-42 show the same plots for PG&E for the same time period of the first quarter of 2013.

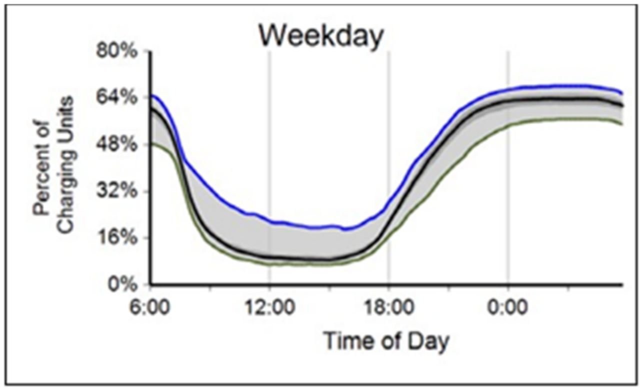

Figure 11-41. Weekday residential charging availability in PG&E territory during the first quarter of 2013.

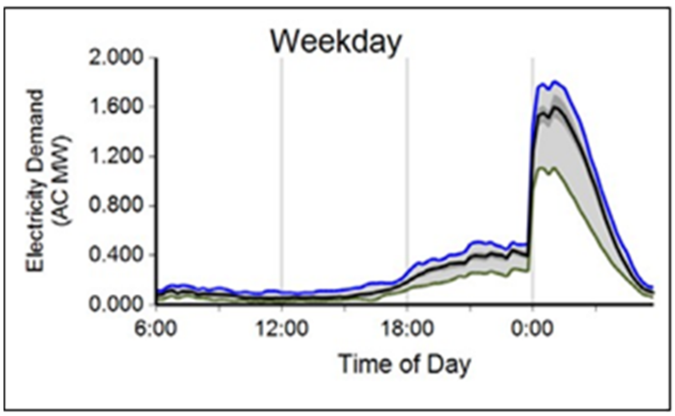

Figure 11-42. Weekday residential charging demand in PG&E territory during the first quarter of 2013.

While the general behavior of PEV drivers connecting their PEV to EVSE is the same in PG&E service territory as that in Nashville Electric Service territory, drivers in PG&E service territory generally delay the start of charging until midnight, which coincides with the beginning of the off-peak PG&E rates. Both the PEV and the EVSE provide programming features that allow the vehicle to be connected to the EVSE, but delay the start of charging until the time set.

Charging availability and charging demand plots for the PGE service territory from the first quarter of 2013 are shown in Figures 11-43 and 11-44.

Figure 11-43 shows PEV drivers in PGE service territory programming their PEVs or EVSE to commence charging at 10 p.m. has an effect at the beginning of the off- peak times. However, there are a significant number of PEV drivers who do not appear to be taking advantage of off-peak charging, which is reflected by the rise in demand with the increase in charging availability. This rise occurs during the PGE declared on-peak times.

11.2.3.8 Survey Observations. Driver behavior from the first quarter of 2013’s data clearly show, as it also did in the initial 2012 report on this topic, that the financial incentives appear to successfully shift PEV charging demand to off-peak hours. However, it also appears that TOU incentive was more effective in the PG&E service territory than in the PGE territory.

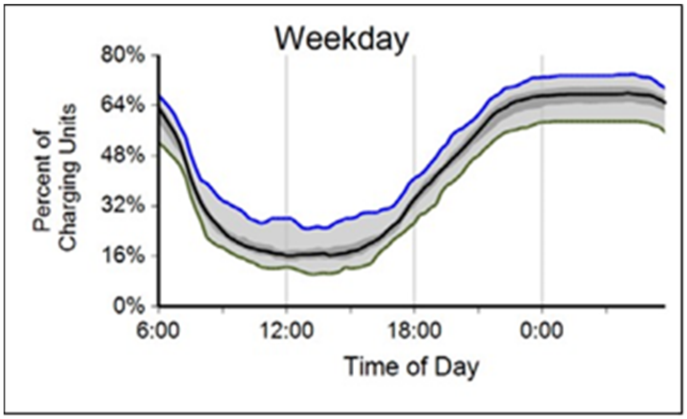

Figure 11-43. Weekday residential charging availability in PGE territory during the first quarter of 2013.

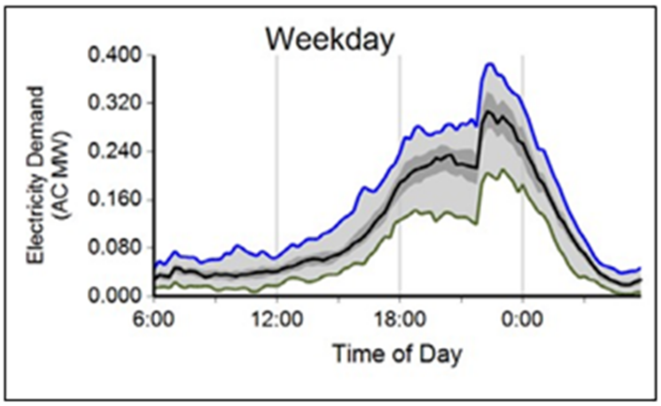

Figure 11-44. Weekday residential charging demand in PGE territory during the first quarter of 2013.

Time-of-Use Survey—A survey of EV Project participants was conducted on this topic in these two regions providing TOU rates: PG&E in the San Francisco Bay area and PGE in the greater Portland area. Because all participants reside in the region where TOU rates are available, the survey asked whether the participants were aware of the rates, how they became aware, whether they subscribed to the rate, and if the purchase or lease of the PEV caused them to change their rate choice.

Survey Results—A total of 356 responses were received from 1,088 EV Project participants, representing a 33% response rate at that time. These included 93 responses from the PGE service territory and 264 from the PG&E territory.

1. To which utility rate structure are you currently subscribed?

	PG&E	PGE
Basic	16%	68%
TOU	53%	26%
EV	28%	5%
Solar	3%	1%

The high percentage of respondents in PGE territory opting for the basic rate is a possible reason for the shape of the charging demand curves seen in Figure 11-44. The basic rate has no incentive for delaying the charge. Thus, the EV driver would be expected to commence the charge immediately upon connecting the vehicle to the EVSE (i.e., after the evening commute home). This is similar to the PEV driver behavior seen in the Nashville Electric Service territory.

2. Are you aware of the availability of the TOU rate?

   Until this survey was distributed, 3% of the PG&E responders said that they were not aware their utility provided TOU rates and 13% of the PGE customers said that they were likewise not aware.

3. Did you change your rate during or after acquiring your PEV?

   Sixty-seven percent of the PG&E responders indicated that they changed rates during or after they acquired the PEV. Only 31% of the PGE responders indicated that they changed.

4. How did you become aware of the availability of the TOU rate?

   For those who were aware of the TOU rate, the responses are identified as follows:

	PG&E	PGE
General	35%	48%
Contacted	27%	15%
Internet	8%	2%
Read	6%	6%
Friend	8%	3%
Utility	1%	8%
Installer	2%	0%
Dealer	8%	4%
Other	6%	13%

   "General" means the responder had general knowledge of the rate availability and could not pinpoint how they became aware. "Contacted" means the responder contacted the utility to inquire. Some researched the rate structure on the internet or read information on the rates. Some were made aware of the rate from a friend. For some, the EVSE installer or the vehicle dealer provided the information. The electric utility also made contact with the responder in some cases and some did not fit into any of these categories.

   Combining the General, Contacted, Internet, and Read categories indicates that efforts by the individual to identify the rate were highest, with 75% of the PG&E and 72% of the PGE responders finding the rate for themselves.

5. Do you program your EVSE, your EV, both or neither for charging?

	PG&E	PGE
EVSE	25%	18%
EV	53%	45%
Neither	9%	29%
Both	14%	8%

A significantly larger percentage of responders in the PGE service territory programmed neither the EV nor EVSE, compared to PG&E customers responding to the survey. This is consistent with the different charging demand shapes in Figures 11-42 and 11-44. This topic was explored further in the EVSE programming lesson learned also posted to The EV Project website.

Even though 68% of the responders in PGE service territory indicated they subscribed to the basic or standard utility rate, 57% of these responders indicated that they had programmed their EV, EVSE, or both. This suggests that EV drivers schedule charging for reasons other than financial incentives.

Three percent of the TOU subscribers noted that they programmed neither the PEV nor the EVSE, even though two of these eight responses indicated they changed to the TOU rate as a result of obtaining the PEV.

Comments—Other than those who were not aware of the special rate structures, some elected not to adopt the TOU rate because their PEV needs made it inconvenient to charge off-peak. Others reported they would not realize any savings with TOU rates.

11.2.3.9 Overall Observations. Data indicate the effectiveness of the TOU incentive rates in PEV drivers initiating their charge during the off-peak periods. The survey indicates the TOU program does influence PEV driver charging patterns. Overall, 57% of the respondents did change their utility rate subscription as a result of obtaining the PEV.

The charging demand and survey data from the PG&E service territory indicate that PG&E TOU rates effectively incentivize PEV drivers to both select a TOU rate plan and to delay their charging until off-peak periods. However, data from the PGE service territory suggest that PGE's TOU rate plans are not as effective as an incentive, because only 31% of responders chose a TOU rate plan. However, this could be due to lack of awareness (i.e., the survey indicates that many PEV owners were not aware that these programs exist). Furthermore, over 70% of the responders learned about TOU rate options on their own.

The shift in charging demand to the TOU period is very obvious in the demand curve of Figure 11-42 for PG&E. This shift causes a demand spike at or shortly after the beginning of the TOU period. This spike is not as pronounced in the demand curve of Figure 11-44 for PGE. It is possible that either or both electric utilities have created enough of a change in demand that their system load objectives are being met with the current enrollments.

Two factors that will influence the level of awareness and ultimately TOU program enrollment are the perceived value of the incentive and the program's outreach and education efforts. Both of these are important factors that the utilities will need to manage to meet their own objectives for affecting demand.

11.2.3.10 References

9. Southern California Edison, "Rebuttal Testimony Supporting Edison Smartconnect™ Deployment Funding and Cost Recovery: Demand Response," Rosemead, CA, February 19, 2008.

10. Southern California Edison, "Schedule TOU-D-T Time-of-Use Tiered Domestic," effective April 1, 2013.

11. PG&E Electric, "Schedule E-9," http://www.pge.com//myhome/environment/whatyoucando/electricdrivevehicles/rateoptions/, accessed 7-17-2013.

12. PGE site: http://www.portlandgeneral.com/residential/your_account/billing_payment/time_of_use/pricing.aspx, accessed 7-17-2013.

13. "A First Look at the Impact of Electric Vehicle Charging on the Electric Grid in The EV Project," Schey, Scoffield, Smart, 2012.

14. ibid.

11.2.4 Residential Charging Behavior in Response to Utility Experimental Rates in San Diego

11.2.4.1 Introduction. The power required to recharge all PEVs in a region can be a significant electrical load on the electric grid. Certain electric utilities within The EV Project regions incentivized The EV Project participants to charge their PEV at specific times to shift the load on the grid from PEV charging to off-peak periods on the electrical system. Reference [15] explored the results of the incentives in several regions of The EV Project. It observed that financial incentives successfully shifted PEV charging demand to off-peak hours.

While it was shown that TOU rates can influence charging behavior, SDG&E (one of the electric utilities providing TOU rates) desired to know what magnitude of pricing differential between the peak and off-peak rates was required to drive participant behavior to charge in off-peak times. With approval of the California Public Utilities Commission, SDG&E established three experimental rates and designed the PEV TOU Pricing and Technology Study to run concurrent with The EV Project deployment of PEVs in the San Diego region. Most of the participants enrolled in The EV Project in San Diego who purchased or leased the Leaf became participants in the study. The final evaluation of the study, as provided to SDG&E by Nexant, and can be found in “Final Evaluation for San Diego Gas & Electric’s Plug-in Electric Vehicle TOU Pricing and Technology Study” [16]. This section provides The EV Project observations from the study.

11.2.4.2 Key Conclusions

- The EV Project and the SDG&E experimental rate study confirm that price incentives can substantially influence PEV driver residential charging behavior.
- The SDG&E rate study showed that the greater the differential electrical price between the utility non-desired charge time and its desired charge time, the greater the behavioral change in driver residential charging.
- The cost of installing a second electric utility meter, required by many utilities for their special PEV charging rates, may exclude many drivers from participating.
- Participation in the electric utility incentive programs requires the considered design of electric rate structures and requires the enabling technology to set charge start times either by the residential EVSE or the PEV. It may also require the EVSE or PEV to communicate billing information to the utility for subtractive billing.

11.2.4.3 Experimental Rate Design. At the start of The EV Project, SDG&E had two PEV TOU rates: the EV-TOU schedule applied to those who installed an electric utility meter to monitor PEV charging separate from household loads and the EV-TOU-2 schedule applied to those who did not install a separate meter but relied on the existing whole house meter to monitor all loads.

The study intended EV Project participants driving the Leaf in the San Diego region to be randomly assigned one of three experimental TOU rates. These rates required a second meter for monitoring PEV charging, the expense to install this meter were paid for by SDG&E in conjunction with the installation credit provided by The EV Project.

The study required that participants be enrolled in The EV Project, they owned or leased a Nissan Leaf, they had the separate utility meter installed to monitor PEV charging, they be randomly assigned one of the experimental rates, and they agreed to participate in the study. The second meter specifically monitored PEV charging so it would not be included in the energy used by the whole house and could be priced separately. At the end of the study, the participant would be able to select an existing TOU rate schedule.

The experimental rates, as approved by the California Public Utilities Commission [17], followed the same design as the EV-TOU-2 schedule in providing for on-peak, off-peak, and super off-peak pricing by time of day. The original EV-TOU-2 schedule is shown in Figure 11-45.

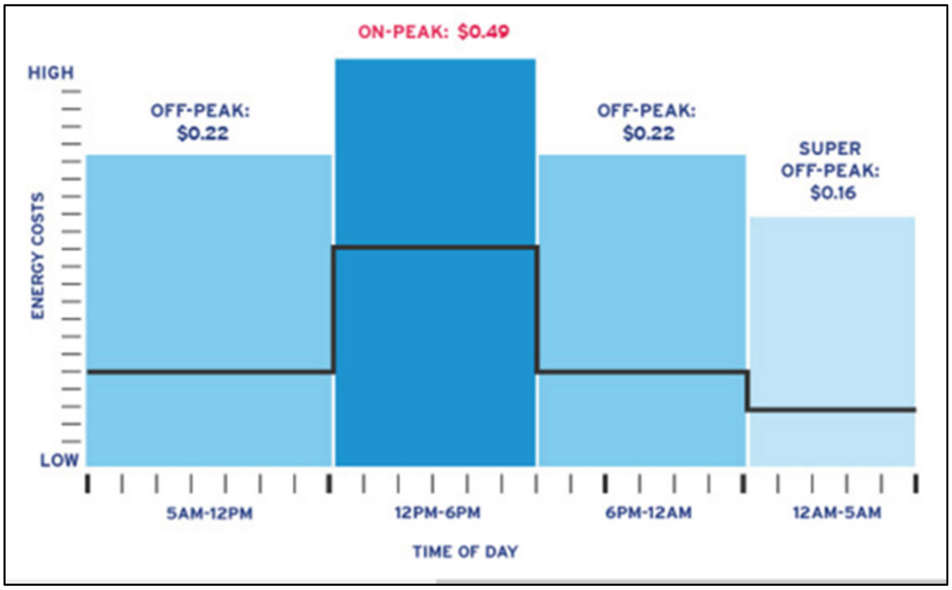

Figure 11-45. SDG&E EV-TOU-2 summer schedule [18].

The EV-TOU rate design is similar except that the on-peak time is from 12 to 8 p.m. rather than 12 to 6 p.m. of the EV-TOU-2 schedule. This rate design provides an approximate 3:1 ratio between the on-peak rate and the super off-peak rate. While this rate design provides a financial incentive to the PEV driver to charge during the off-peak and especially the super off-peak times, the driver still has the option to charge at any time of the day. The study's experimental rates were established using three different ratios between the on-peak and super off-peak rates; approximately 2:1 (the EPEV-L schedule), 4:1 (the EPEV-M schedule), and 6:1 (the EPEV-H schedule), allowing SDG&E to determine the magnitude of price difference necessary to drive participant charging behavior to super off-peak times. Figure 11-48 provides the summer period comparisons of these rates and illustrates that all the experimental rates are lower than the EV-TOU and EV-TOU-2 rates.

The EV Project installed Blink EVSE in the homes of each of its participants in the San Diego area. The Blink EVSE provides an intuitive touch screen interface, allowing the PEV owner to easily schedule a window of time during which the EVSE will provide charge power so the PEV owner can schedule charging to take advantage of the SDG&E off-peak and super off-peak rates.

11.2.4.4 EV Project Analyses. The Blink EVSE allowed The EV Project to collect EVSE usage data. Each EV Project participant gave written consent for EV Project researchers to collect and analyze data from their vehicles and EVSE. Charge data transmitted by the Blink EVSE were collected by the Blink network and subsequently transmitted to the Advanced Vehicle Testing Activity at INL. INL's data experts then qualified and aggregated the data for reporting.

The EV Project published quarterly reports on this aggregated data, which are available on the INL website: http://avt.inl.gov/evproject.shtml.

Understanding PEV driver charging behavior involves an evaluation of both charging availability and charging demand.

Charging availability at a point in time is defined as the percentage of EVSE in a geographic area that are connected to a vehicle. While the EVSE may be connected to the vehicle, it may not necessarily be charging. Charging demand at a point in time is the total amount of power being drawn from the electric grid by a group of EVSE in a geographic area. These are represented by time-of-day plots. The quarterly reports prepare these plots by geographic area and show the hourly percentage of EVSE connected and hourly charging demand for all weekdays and weekends for the quarter evaluated.

Figure 11-46 shows the weekday residential charging availability for EV Project vehicles in the SDG&E service territory during the second quarter of 2013. Figure 11-47 shows the weekday residential charging demand in the SDG&E service territory for the same time period. Note that the plot shows the maximum, minimum, median, and inner quartile values for all days in the quarter. With all these data plotted on the same time-of-day scale, it is clear that while PEV drivers typically connect their PEVs when returning home, the start of the charge is typically delayed until after the start of the super off-peak period of midnight.

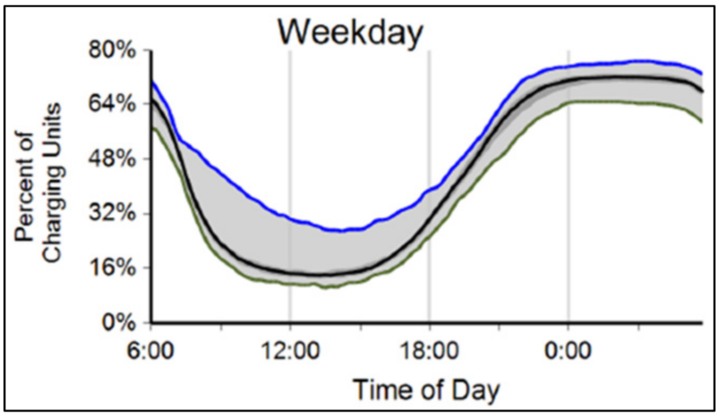

Figure 11-46. Weekday residential charging availability in San Diego during the second quarter of 2013 [19].

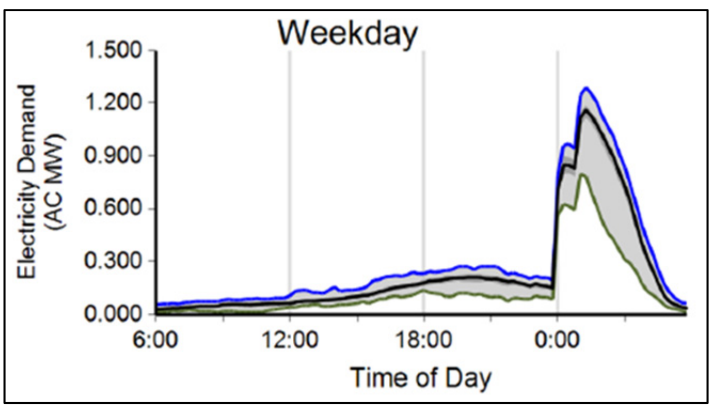

Figure 11-47. Weekday residential charging demand in San Diego during the second quarter of 2013 [19].

The EV Project achieved full participant enrollment in early 2013; Figures 11-46 and 11-47 illustrate well established behavior by the participants. Even though charging predominately occurred during the super off-peak times, residential charging occurred during the on-peak and off-peak times in spite of the pricing incentives of the study.

11.2.4.5 Discussion of Study Results. Four hundred and thirty of the 700 EV Project participants in the San Diego region agreed to participate in the Study and 272 were enrolled in the EV-TOU-2 (whole house) rate [16]. A variety of reasons were provided for those electing not to participate, including "…problems with configuration of their home, installation costs that exceeded the installation allowance offered by The EV Project or a desire to not be placed on an experimental rate." One of the configuration issues involved the existing electrical service entrance to the residence. Installing a second meter can be quite costly for some configurations, particularly when the electric service is provided by an underground connection.

The study provided the following key findings [20]:

- Key Finding 1: Participant EV charging takes place mostly during the super off-peak period using charging timers

  "…EPEV-H and EPEV-M customers had the highest percent of total charging done during the super off-peak period (85% and 83%, respectively), while EPEV-L customers had 78% of all charging done during the super off-peak period (78%)."

- Key Finding 2: Participant EV charging exhibits learning behavior

  "During the first 4 months of participation in the study, customers in the EPEV-L and EPEV-M rate groups increased their share of super off-peak charging and decreased their share of peak period charging, a trend seen for both weekday and weekends. In contrast, EPEV-H customers generally exhibited consistent charging behavior for the entire duration of the study."

- Key Finding 3: Participant EV charging behavior responds to price signals

  "Formal hypothesis tests show that providing stronger price signals to customers causes them to charge relatively more during super off-peak hours and charge less during the on-peak period on both weekdays and weekends… Compared to the EPEV-L rate with the smallest price ratio, the EPEV-M rate increased the share of weekday charging during the super off-peak period by four percentage points and reduced the share of peak period charging by two percentage points. The EPEV-H rate had a larger effect, increasing the super off-peak charging share by about six percentage points and reducing the peak charging share by three percentage points relative to the EPEV-L rate."

- Key Finding 4: EV customers are most responsive to changes in on-peak and off-peak prices

  "In order to apply findings from this study to future EV charging rates or to EV rates in other regions, a structural economic model of charging behavior was used to explicitly capture the trade-offs associated with charging during one period versus another and provide estimates of price elasticities for EV charging." See Reference [16] for specific findings in this area; however, two are repeated here:

  - Study participants are more responsive to changes in either the peak or off-peak price than to a change in the super off-peak price
  - Simulations of EV charging behavior under TOU rates with other price ratios suggest that a price ratio of 6:1 between peak and super off-peak periods would result in customers using about 90% of their electricity for EV charging during the super off-peak period and that further increases would provide only marginal additional increases in this percentage."

  "The primary conclusion from the Study is that TOU prices, in conjunction with enabling technology, such as the onboard LEAF charging timer or the timer in the charging unit, results in the vast majority of EV customers charging overnight and in the early morning rather than during on-peak times. A large body of evidence suggests that the simple enabling technology of charging timers make it easy and convenient to charge overnight so that a strong tendency for overnight charging is induced by a small rate differential."

The report notes that "…all data analyzed here represent the behavior and choices of customers who are early adopters of a new technology… the extent to which the charging behavior of early adopters represents the behavior of customers who adopt EVs over a longer time horizon is unclear."

The report also states, "SDG&E also offers an EV TOU rate that, like the experimental rates, applies to only EV load and usage. This rate requires customers to install a separate parallel meter and is rarely chosen."

The study ended in December 2013 and participants were enrolled in the previously existing rate schedules in 2014.

11.2.4.6 Conclusions. The study confirmed analysis of The EV Project in the success of incentivizing drivers to charge during off-peak times. The study also showed that the differential price between the peak and off-peak charge times is important in driving charging behavior.

The EV Project and this study identified that the cost associated with installing the second meter, if not subsidized by the utility or a third party, may limit enrollment in the specific TOU rates desired. The electric utility will need to determine whether the benefit derived from this change in charging behavior actually requires the addition of the second meter and justifies subsidizing the installation cost or whether the same benefit can be achieved by adjusting the whole house rate schedule.

Participants in The EV Project and this study utilized the timing features of their Blink EVSE to allow their PEV to be connected to the EVSE at any time, yet only charge during off-peak or super off-peak TOU periods. The convenience of this feature and the capability of the PEV to fully charge within the super off-peak period are key to supporting the charging behavior incentivized by TOU rates.

Because the existing EV-TOU-2 rate (whole house) is so similar in pricing to the EV-TOU rate, the results of this study may be valid to apply to redesign of that rate.

The use of a smart residential EVSE, such as the Blink unit, is currently under study by the California Energy Commission in the sub-metering and subtractive billing study as part of the Vehicle-Grid Integration Roadmap [21]. If the smart EVSE can meet California Energy Commission and California Public Utilities Commission requirements for accurately recording and reporting energy usage for billing purposes, it may negate the need for a second meter.

The EV Project and this study illustrate that charging behavior can be modified with the proper incentive. However, as reported in Reference [22], these changes can cause new issues in energy peaks for the electric utility. It may be possible with further work on rate design by the electric utility to incentivize charging at any time the utility desires.

11.2.4.7 References

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22. ”What Residential Clustering Effects have been Experienced in the San Diego Region?” http://avt.inl.gov/pdf/EVProj.

11.2.4.8 San Diego Gas and Electric Study Graphics

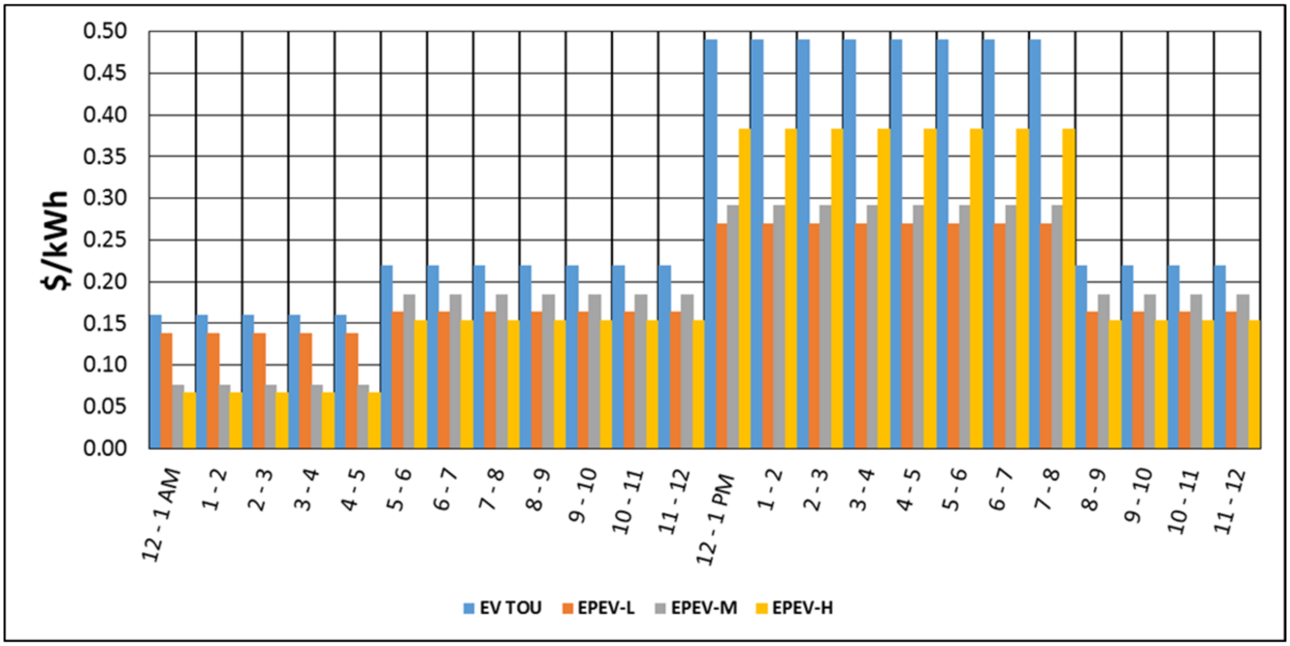

Figure 11-48. SDG&E summer rate schedules.

11.2.5 When EV Project Participants Program Their Plug-In Electric Vehicle Charge, Do They Program Their Vehicle, Their EVSE Unit, or Both?

11.2.5.1 Introduction. In certain regions of The EV Project, electric utilities provide a rate structure that charges higher rates during their peak usage times and lower rates during the off-peak usage times compared to their basic or standard rate.

These TOU rates are established to provide incentives to their customers to shift their high electrical usage to the off-peak times. The charging behavior of The EV Project participants in these regions shows this incentive to be very effective. The Blink EVSE unit provided to residential participants is programmable, as are the participating vehicles (i.e., the Chevrolet Volt and Nissan Leaf). The question is which one do participants prefer to program for their charging needs?

11.2.5.2 Why is This Important? Introduction of large-scale production of PEVs led to entry of many EVSE providers into the market. Some have selected to provide basic units, which provide power to the vehicle with no services other than the required safety features. Others provide smart units, such as the Blink units deployed in The EV Project, which contain many extra features, including the ability to program the charge start and stop times. Knowing which type of unit the customer prefers is important for car manufacturers and EVSE suppliers in deciding which features to provide with their products.

11.2.5.3 Measuring Vehicle or Electric Vehicle Supply Equipment Unit Programming. Among the many smart features of the Blink EVSE unit is its ability to provide event and charge information through the Blink Network, including the following:

- Plug-event start and stop: indicate that the charge connector is inserted or removed from the vehicle charge port.

- Charge event start and stop: indicate the contactor in the EVSE unit has closed or opened. A closed contactor means the EVSE is ready to charge the vehicle.
- Power event start and stop: indicate that charge current is flowing or has stopped flowing to the vehicle.

Once the EVSE unit is connected to the PEV and the contactor has closed, the charge is largely controlled by the PEV. While the EVSE unit signals the PEV its maximum current output capabilities, it is the PEV's onboard charger and battery management system that monitors the onboard battery to determine the best way to conduct the recharge. It draws the amount of charge current necessary to provide this control. If the vehicle is programmed to schedule charge start and/or stop times, it determines when the battery will accept the charge. Both the vehicle and the EVSE unit must be set to charge before energy will flow to the vehicle.

Using the three types of EVSE events and knowledge of the battery management system control, the following four possible scenarios are identified in the EVSE event data (Figure 11-49). Number 1 starts at the top and it continues to number 4 at the bottom of the figure.

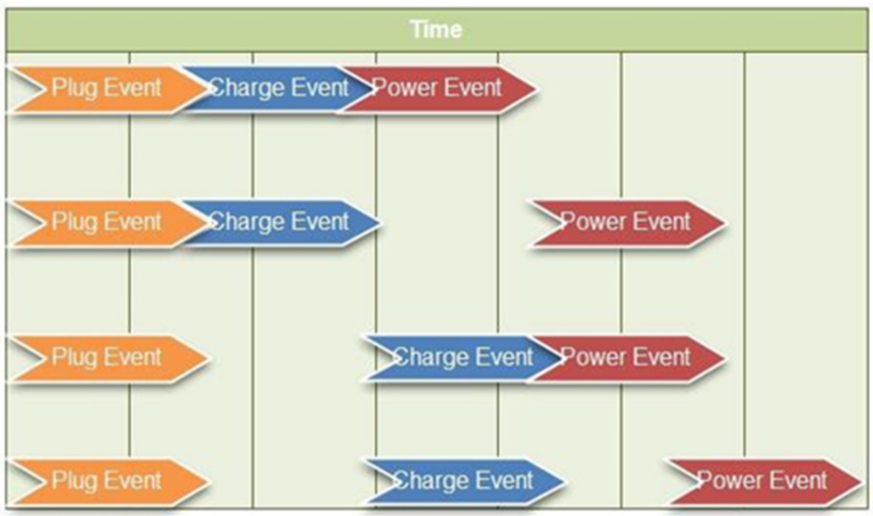

Figure 11-49. EVSE event sequence.

1. No Program: When the plug, charge and power events happen at nearly the same time, it indicates that the connector has been plugged into the vehicle, the contactor has closed, and the charge has begun. No time delay would indicate that there is no program controlling the start of the charge.
2. Vehicle Programmed: The gap between the charge event and the power event indicates that the EVSE unit is ready to charge the vehicle, but the vehicle has not yet begun drawing power.
3. EVSE Unit Programmed: The gap between the plug and charge event followed immediately by the power event indicates that the connector has been inserted into the vehicle, but the EVSE unit is not allowing the charge to commence until later. Once the EVSE unit timer allows the charge, the contactor closes and the power flows.
4. Both Programmed: As in No. 3 above, the EVSE unit timer is active. However, because the power did not flow immediately upon the EVSE unit contactor closing, the vehicle is not allowing the charge. Thus both the PEV and EVSE have been programmed by the participant.

EV Project participants have charged their vehicles according to each of these scenarios. Table 11-23 provides the proportion of plug-in events performed in each scenario. Results shown in Table 11-23 describe plug-in events that were performed in each EV Project region over the entire project to date.

Table 11-23. Percent of plug-in events by each EV Project region.

	Percent of Plug-in Events			
Territory Name	Not Scheduled	Vehicle Scheduled	EVSE Scheduled	Both Scheduled
Atlanta	72%	10%	17%	1%
Chattanooga	83%	11%	5%	0%
Chicago	86%	8%	5%	1%
Dallas/FW	95%	3%	2%	0%
Washington D.C.	87%	7%	6%	0%
Houston	93%	6%	1%	0%
Knoxville	78%	16%	5%	1%
Los Angeles	62%	18%	19%	1%
Memphis	85%	11%	4%	0%
Nashville	89%	5%	5%	0%
Oregon	75%	17%	7%	1%
Philadelphia	92%	4%	4%	0%
Phoenix	66%	17%	16%	1%
San Diego	38%	34%	25%	3%
San Francisco	43%	31%	23%	3%
Tucson	61%	24%	12%	2%
Washington State	82%	12%	5%	1%
Overall	63%	21%	15%	2%

11.2.5.4 Utilities with Time-of-Use Rates in The EV Project. Several electric utilities in The EV Project provide TOU rates for residential customers and some provide special EV rates for PEV owners. Among the larger utilities providing these special rates in The EV Project regions are APS (Phoenix region), Georgia Power (Atlanta region), Los Angeles Department of Water and Power, (Los Angeles region), PG&E (San Francisco region), PGE (Portland region), Salt River Project (Phoenix region), SDG&E (San Diego region), Southern California Edison (Los Angeles region) and Tucson Electric Power (Tucson region). These special rates provide an incentive for residential customers to charge their PEV during the off-peak times. Thus, there is a motivation for PEV drivers to program when their vehicles will start charging. The ability to program the PEV or EVSE is a convenience that enables the EV driver to plug-in when arriving home rather than having to plug-in after the start of the TOU rate period. Some TOU rates commence at midnight.

Even though special rates may apply in a region, the PEV driver may certainly determine when they will charge their vehicle, regardless of the rate.

The behavior of The EV Project participants in two of these utility service territories was examined. The electric utilities were PGE and PG&E, which provide basic or standard whole-house rates and TOU rates. PG&E also provides an EV rate.

Residential EVSE usage data from 1,097 EV Project participants in these areas was analyzed to determine the percentage of participants who had and had not scheduled home charging in the last 6 months of 2012. Those who scheduled charging were broken into groups, based on whether they program their vehicle, EVSE, or both. Figure 11-50 shows the results.

Three quarters of participants have scheduled charging, either by programming only their vehicle, only their EVSE, or programming both.

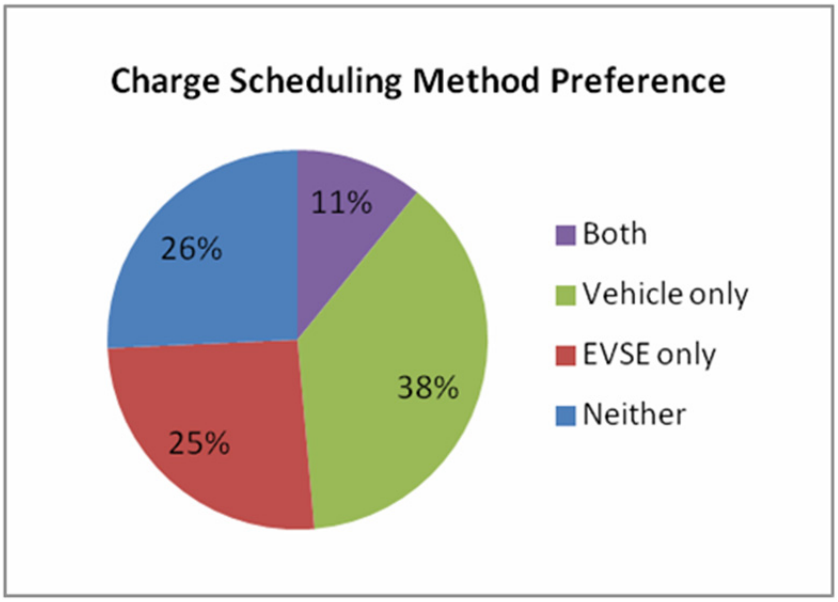

Figure 11-50. Preference for charge schedule programming.

11.2.5.5 Programming Survey. EV Project participants in the PGE and PG&E service territories were requested to respond to a survey on this topic. There were 347 responses. The participant identified their current electric rate (see Figure 11-51).

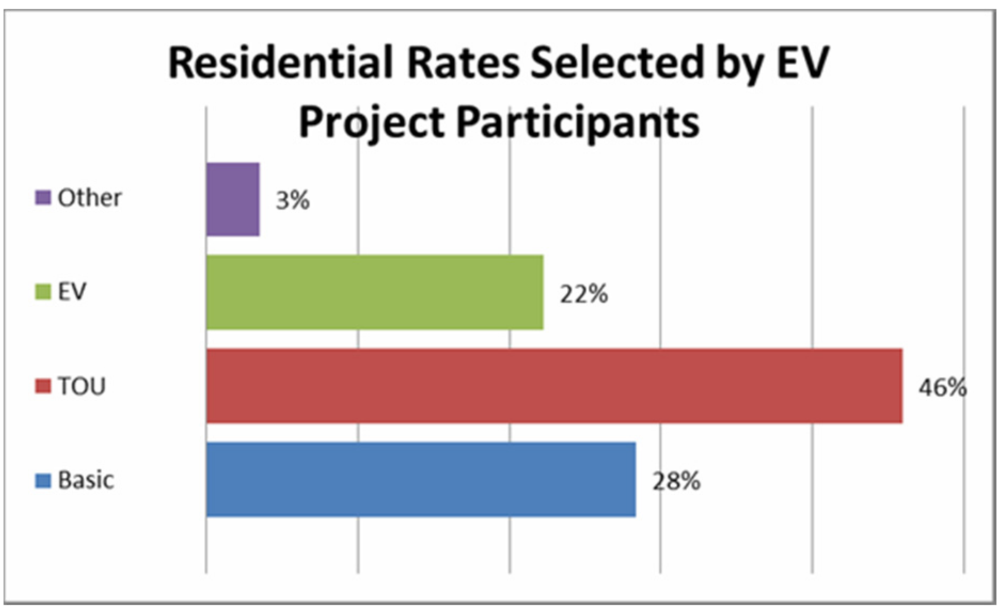

Figure 11-51. Electric rates self-identified by respondent.

The high percentage of responses indicating they had the basic rate may be because the PEV driver either needs to charge at a time during the day (peak period) or may be unaware of the special rates. The "other" rate was selected by those with a rate for home solar photovoltaic units or by those who were in process of changing rate plans.

Another survey question asked if participants have scheduled charging and, if so, by using the vehicle, EVSE, or both user interfaces. Figure 11-52 summarizes the responses to this question.

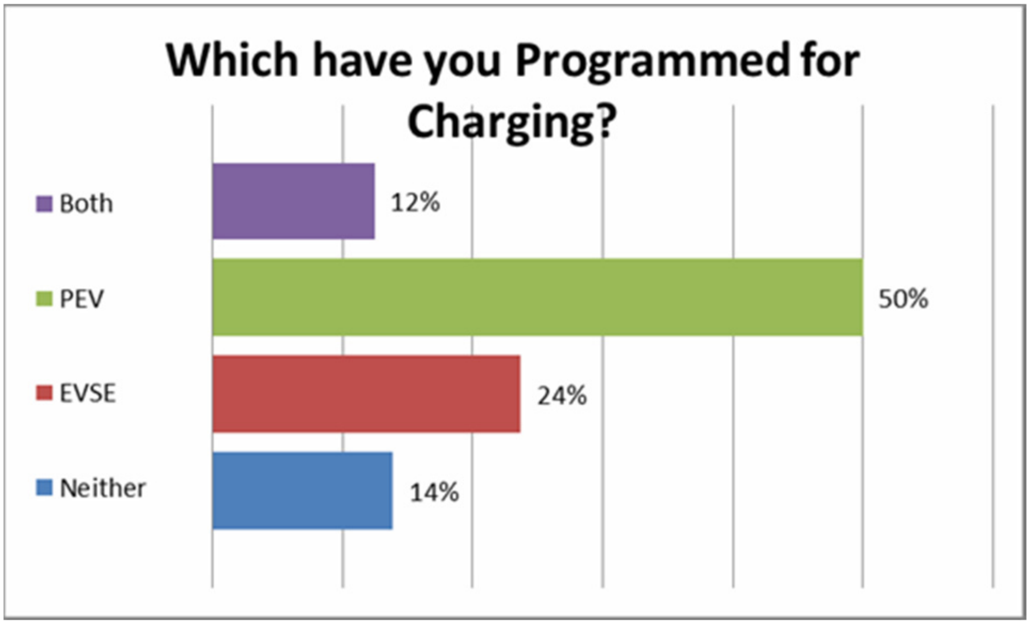

Figure 11-52. Programming medium.

Note that the percentages in Figure 11-52 are similar to the charge scheduling behavior demonstrated by EVSE event data shown in Figure 11-50. Results do not match exactly because not all participants responded to the survey.

The survey also asked those who programmed either or both, how difficult they found the process. Figures 11-53 and 11-54 show the responses.

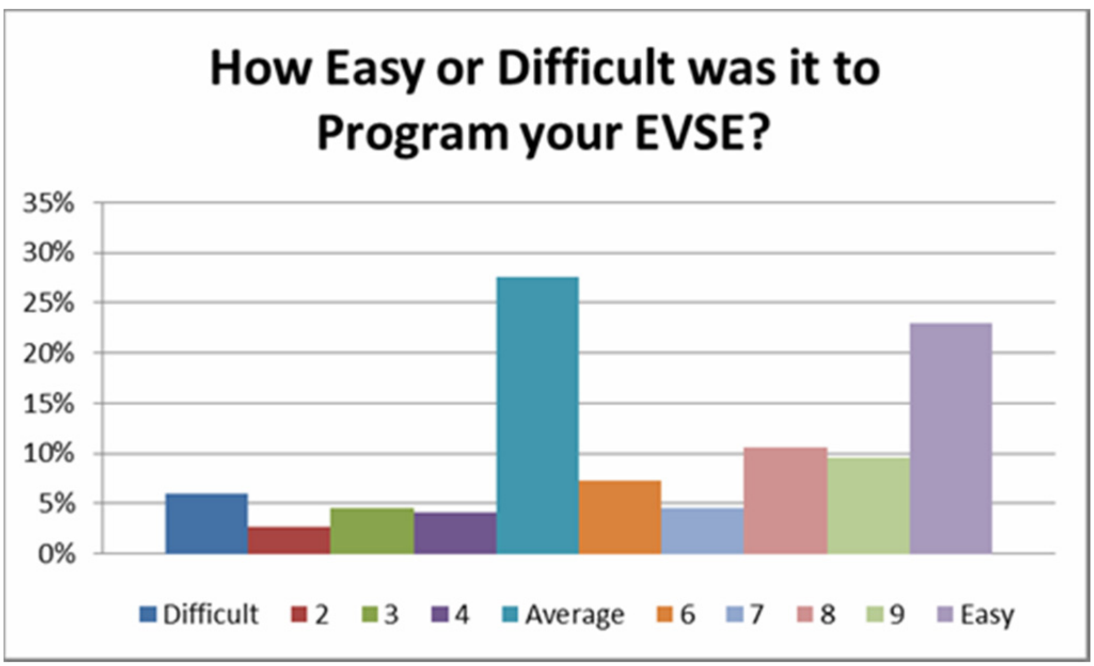

Figure 11-53. Ease of programming EVSE unit.

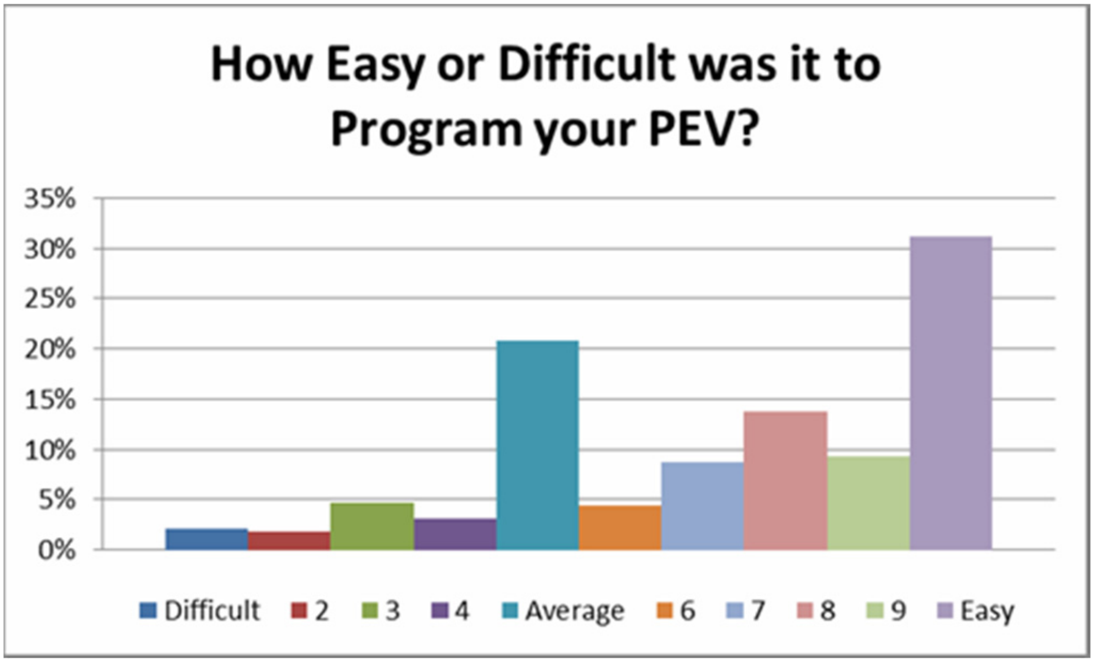

Figure 11-54. Ease of programming PEV.

11.2.5.6 Survey Respondent Comments. As shown in Figures 11-53 and 11-54, most participants found it relatively easy to program either the EVSE unit or the PEV. Some general comments reflected that some EVSE units had programming issues early in The EV Project, which caused the participant to program the PEV instead. However, all thought these issues were resolved.

Survey respondents commented on some technical aspects of charge schedule programming, which may confuse some users.

Respondents noted that there are potential conflicts if both the EVSE unit and PEV are programmed. If the PEV's programmed start time is before the EVSE's programmed start, the charge will not start until the EVSE unit programmed start is reached. Vehicle owners who have disconnected their vehicle before the programmed start time of the EVSE were disappointed when they found no charge had occurred.

If the vehicle is programmed to start charging at night and the PEV driver elects to charge at a publicly accessible EVSE unit during the day, the PEV programming must be overridden.

The programming on one of the PEVs is such that a charge will not initiate if the PEV is connected after the programmed start time unless overridden. For example, if the vehicle is programmed to start a charge at midnight and the connect event occurs at 12:05, the charge will not commence.

It has also been reported that if the vehicle is programmed to start before the EVSE unit, the vehicle can command commencement of the charge, but stops it if no current flows. The vehicle will then not charge when the EVSE unit program actually closes the contactor. Some responders noted that they would like the EVSE unit to make charging decisions based on the PEV battery's SOC. Vehicles do not yet make that information available to the EVSE.

Participants noted that once programming is completed, it is very convenient to connect upon arriving home and letting the program control the charge. Also, most felt the TOU rate (or EV rate) helped them save money.

11.2.5.7 Conclusion. Most EV Project participants in the PGE and PG&E service territories program their PEV and/or EVSE unit to schedule charging at home. About half the participants prefer to program only their vehicle. One quarter prefer to program only their EVSE. Over two-thirds of survey respondents in the PGE and PG&E service territories have selected TOU rates (either whole-house or EV rate plans), which provide an incentive for them to schedule their home charging times during off-peak hours. Whether they program the PEV or the EVSE unit appears to be a matter of consumer choice, which is not difficult to do in either case. It is understandable why participants in areas without the TOU rate do not program either (although some do anyway). Of survey respondents, 28% are on a basic rate plan, despite the fact that their electric utility offers TOU rates.

11.2.6 What Residential Clustering Effects have been Experienced in the San Diego Region?

11.2.6.1 Authors Note. The beginning of this lessons learned is similar to the beginning of the lessons learned in Section 11.2.7. It is repeated here in order to provide a background on clustering.

11.2.6.2 Introduction. The power required to recharge a PEV can be a significant contributor to the electrical load a residence places on the electric grid and, specifically, on the local residential power transformer providing energy to several nearby homes. What insight can EV Project data analysis provide relating to the magnitude of this impact on local transformers? Another EV Project [23] report analyzed the San Francisco region, while this report focuses on the San Diego region.

11.2.6.3 Key Conclusions. During a 3-month period in 2013, a review of residential charging in the San Diego region showed the following:

- The San Diego region contains several examples of residential neighbors charging PEVs simultaneously.
- Two neighbors simultaneously charging PEVs have shown a power demand nine times that of the typical San Diego residential power demand.
- Two neighbors charging their PEVs at super-off peak times can increase energy consumption by nearly five times of those without PEVs.
- Charging PEVs at other times of the day, in addition to typical super off-peak times, can nearly double the daily energy demand by two neighbors.
- Currently, the utility impact of residential PEV charging is low because overall PEV adoption is still in its infancy. However, some transformer replacements have already been linked to cluster PEV charging.

11.2.6.4 Why is This Topic Important? A question frequently asked relating to the adoption of PEVs is "What is the impact of PEV charging on the electrical grid?" This question can be directed at the big picture of total utility system load, but the focus here is on the impact to the local electrical distribution system and, in particular, the local residential electrical transformer. Higher than originally anticipated loads on this transformer can lead to damage, local power outages, and higher costs to the electric utility for replacement equipment.

11.2.6.5 Residential Power Distribution. Electric utility and power distribution companies work with local planners to design and deliver electrical power to residential neighborhoods. The final step in this delivery is a power feed from the local residential transformer (which may feed the residence using underground [see Figure 11-55] or overhead conductors) to the individual homes. Typically, more than one home is supplied by the same transformer. The transformer steps down the distribution voltage, which may range from 6 to 15 kV depending on the electric utility, to the standard North American 240-volt service. Transformer size can vary, depending on the number and size of homes served by the transformer. The number of homes served is determined by the electric utility, but could vary from one to as many as 15 homes.

During the design process, the anticipated residential power usage determines the capacity of the service supply and the combination of all residences served by that transformer determines its design requirements. The transformer's design also considers the peak power that will be concurrently demanded by all residences connected to the transformer and the resulting heating that will be experienced by that transformer. Because extended periods of high temperature reduce the life of the transformer, the utility design process attempts to minimize overheating of the transformer by matching its power rating to the anticipated residential demand.

Figure 11-55. Pad-mounted residential distribution transformer [24].

When a homeowner adds a significant new load to the home (e.g., a swimming pool, hot tub, or PEV), the permitting process typically requires a new load calculation to determine whether the electric service to the home is sufficient to safely add this new load. Unless the supply is found to be insufficient, the local electric utility may not be informed of the increased load on the transformer. In most cases, the additional circuit required for EVSE does not exceed the capability of a residential electric service.

11.2.6.6 Typical Residential Loads. SDG&E publishes the dynamic loads for residential service. Figure 11-56 shows a typical residential hourly load profile for June through August 2014 [25]. The minimum, median, and maximum loads during this time are shown.

The Blink EVSE provided to EV Project participants is capable of delivering up to 7.2 kW of power to a connected PEV. While most PEVs participating in The EV Project only accepted up to 3.3 kW, model year 2013 and newer Nissan Leafs and some other vehicle models accept energy near the EVSE's 7.2-kW rating. (The Tesla Model S offers an onboard dual charger capable of charging at 20 kW [26].) As such, it is possible that adding PEV charging to a San Diego residence could significantly increase residential demand. Where the median power demand is 1.02 kW at 8 p.m. according to Figure 11-56, charging the PEV at that time could raise that power demand to 8.2 kW, which is seven times the original load.

11.2.6.7 Time-of-Use Rates. Many electric utilities seek to shift peak loads to times of lower demand through TOU rates. For owners of PEVs, SDG&E offers two TOU plans: EV-TOU, which requires a separate electric meter to monitor the PEV charging circuit and EV-TOU-2, which uses a single meter serving the whole house, including the charger. During the summer months (May to October), the rate charged for the energy used is determined by the time of day (shown in Figure 11-57).

SDG&E sets rates based on on-peak, off-peak, and super off-peak as shown in Figure 11-57.The price charged for power is lower for the off-peak times than for the on-peak times, incentivizing the residential customer to shift loads to off peak times. Super off-peak further incentivizes PEV owners to program the charge of their PEV between midnight and 5 a.m. For convenience, the Blink EVSE and many PEVs provide programming capabilities to schedule the start of a charge. EV Project participant use of these programming features is the subject of a previously published report [28]. How PEV owners respond to these TOU rates is also the subject of a separate study [29].

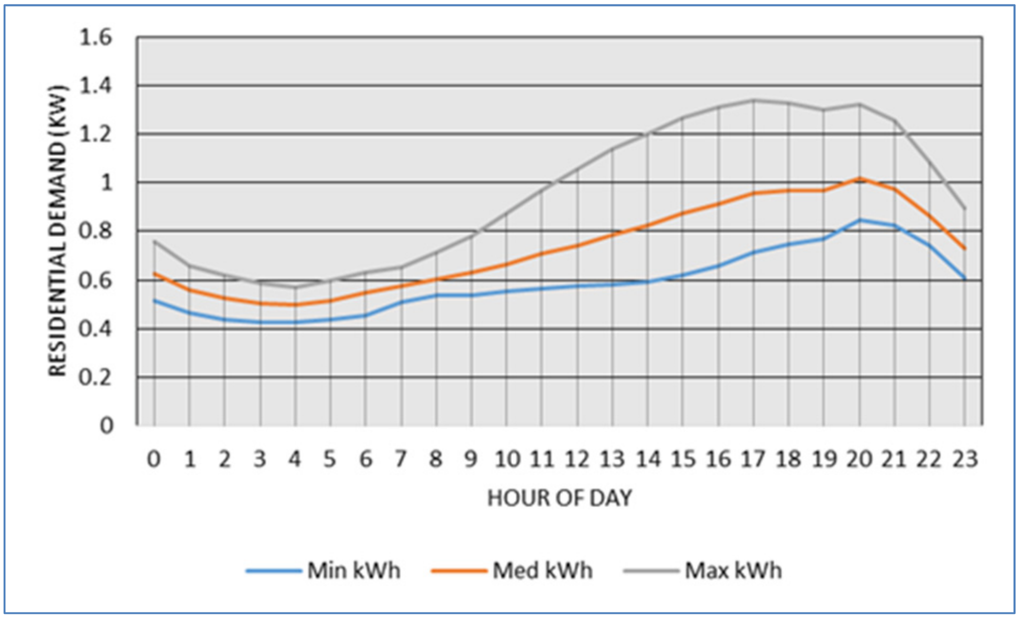

Figure 11-56. Dynamic residential load profile June/August 2014.

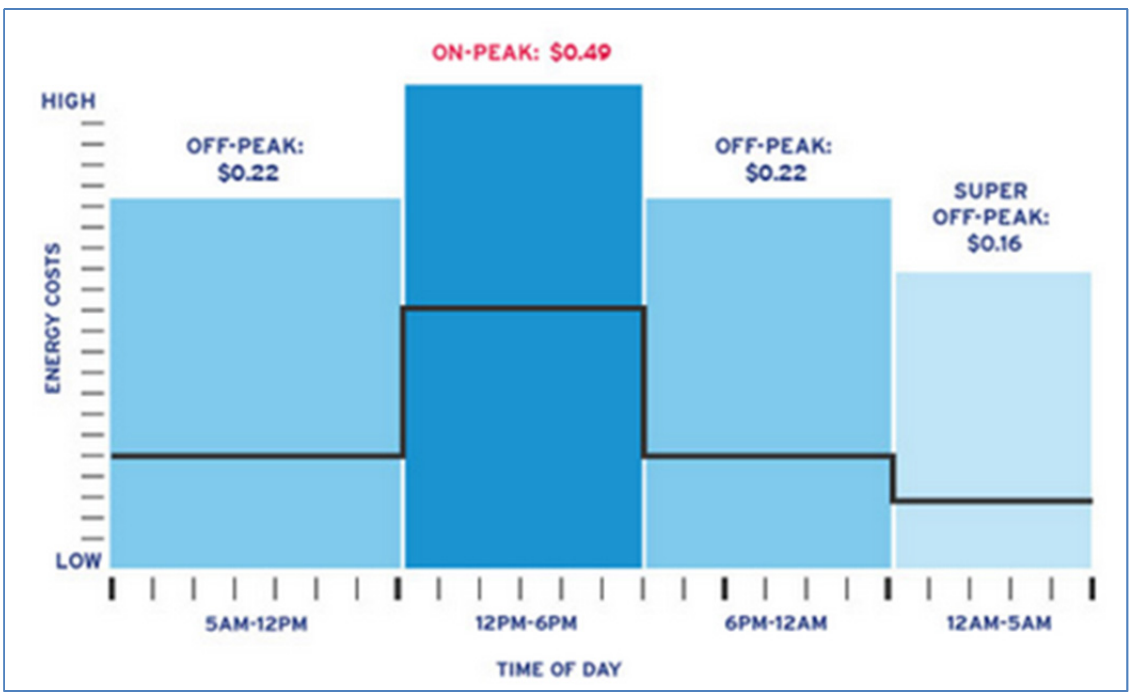

Figure 11-57. SDG&E residential peak schedule [27].

The EV Project began collecting residential charging data in 2011, providing sufficient time for participating PEV drivers to settle into habits of charging. Whether San Diego PEV drivers take advantage of TOU rates or not, this residential charging data can inform electric utilities of the potential impact on the transformer.

11.2.6.8 What is Meant by "Clustering"? Automotive manufacturers understand that one promoter of vehicle sales is the visibility of a new car in a neighbor's driveway. Neighbors are often curious and interested in the new vehicle, especially if it is a new technology vehicle such as a PEV. When several PEVs show up in the same neighborhood, where those residences are powered from the same electrical transformer, "clustering" occurs. This is a cause for concern to the local electrical utility because of the significant increase in power supplied by the transformer. While the transformer typically can accept the power demand increase from one PEV, multiple PEVs charging simultaneously may cause damage to the transformer, resulting in a service outage and the need to replace the transformer. Damage caused by overloading the transformer may occur in the short term for significant overloads or in the longer term by depriving the transformer of its normal cool-down period, typically occurring in the early morning hours.

The effects on a single transformer can also affect other residential feeders emanating from the distribution substation. Distress on a residential transformer may affect the power quality on the feeder side of the transformer.

11.2.6.9 Clustering in The EV Project. At the end of December 2013, 993 residential EVSE were installed in the San Diego region as part of The EV Project. Locations of these EVSE are shown in Figure 11-58.

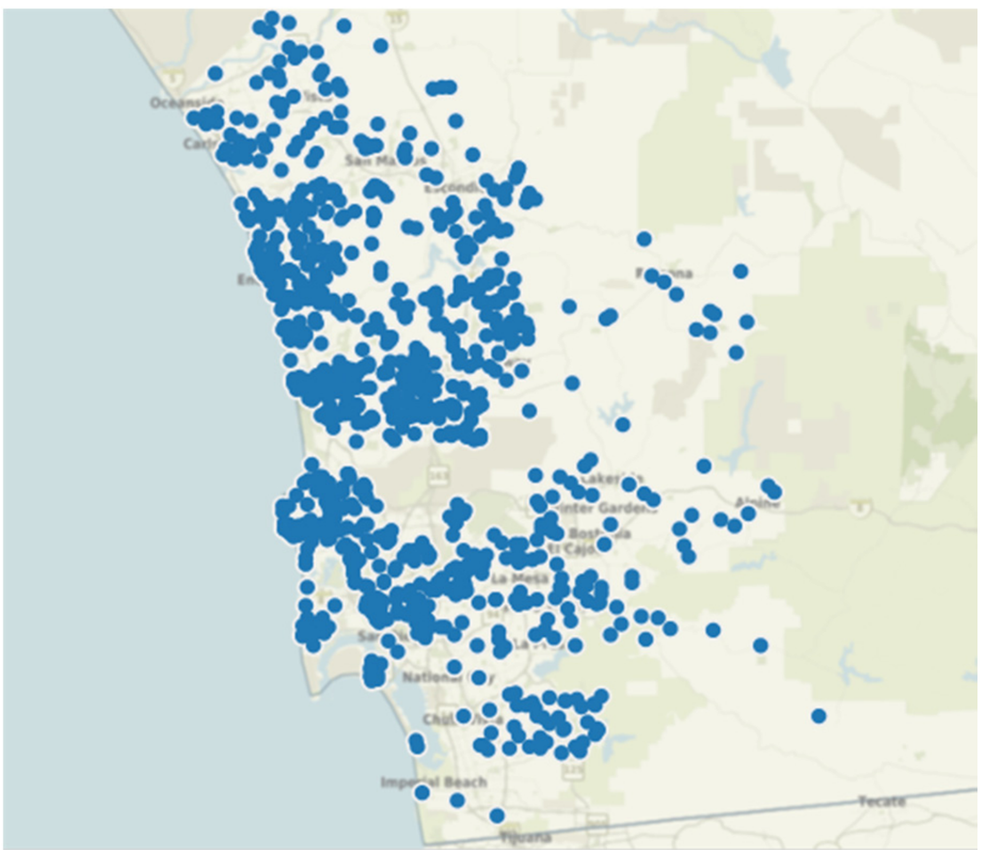

Figure 11-58. EV Project residential locations.

A detailed examination of these locations identified several sites where neighbors charged PEVs. Four of these sites are presented in the following sections.

Cluster Site 1—The first site for evaluation is shown in Figure 11-59. The street and other physical features are redacted for privacy considerations. Three residences are identified as PEV owners in The EV Project, with Houses 1 and 2 being neighbors. The third house is separated from the first two and is likely not on the same residential transformer. A review of the Blink charge data indicate that a Chevrolet Volt is charged in one home and a Nissan Leaf in the other. In both homes, the start of the evening charge is programmed, but one starts at midnight and the other at 1 a.m.; however, additional charge times might occur during the day.

Staggering of charge times has been seen in many EV Project sites as PEV owners, whether intentionally or unintentionally, attempt to either reduce peak loads or desire to ensure their start time occurs fully within the super off-peak time.

Both homes charge near the 3.3-kW rating. The PEV charging profile for these residences for a few days in August 2013 is shown in Figure 11-60.

Even though the charge start times are staggered, a peak at twice the power of a single unit is seen because both are charging at 1 a.m. Assuming the median load profile of Figure 11-56 for both houses, the cumulative load profile for these two houses at this time would be as shown in Figure 11-61.

Energy used by the houses from midnight to 3 a.m. without considering PEVs is 3.4 kWh. With the PEVs added, the energy for the same period is 18.4 kWh, which is over a four-fold increase. As shown in Figure 11-61, this increase also occurs during the typical period of expected transformer cool down.

Figure 11-59. Cluster Site 1 location [30].

Figure 11-60. PEV charging profile for Cluster Site 1.

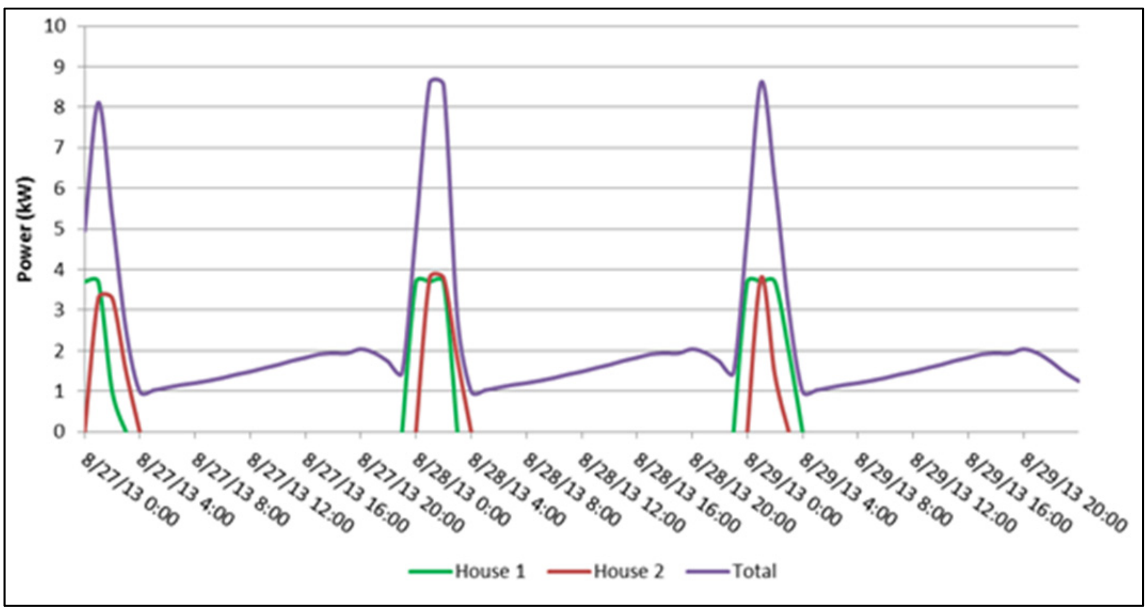

Figure 11-61. Hourly load profile for Cluster Site 1.

Charging usage superimposed on the typical residential load profile of Figure 11-56 is shown in Figure 11-62. The effects of using minimum, median, or maximum load curves are lost in the magnitude of this increase.

Cluster Site 2—Cluster Site 2, with Nissan Leafs at two neighboring homes, is shown in Figure 11-63. Charging of these Leafs is similar to Cluster Site 1 in that the home owners stagger their start times in the super off-peak times. This site was selected to illustrate the effects of additional daytime charging.

Both homes charge at approximately 3.3 kW. The charge profile, including the median household demand, is shown in Figure 11-64.

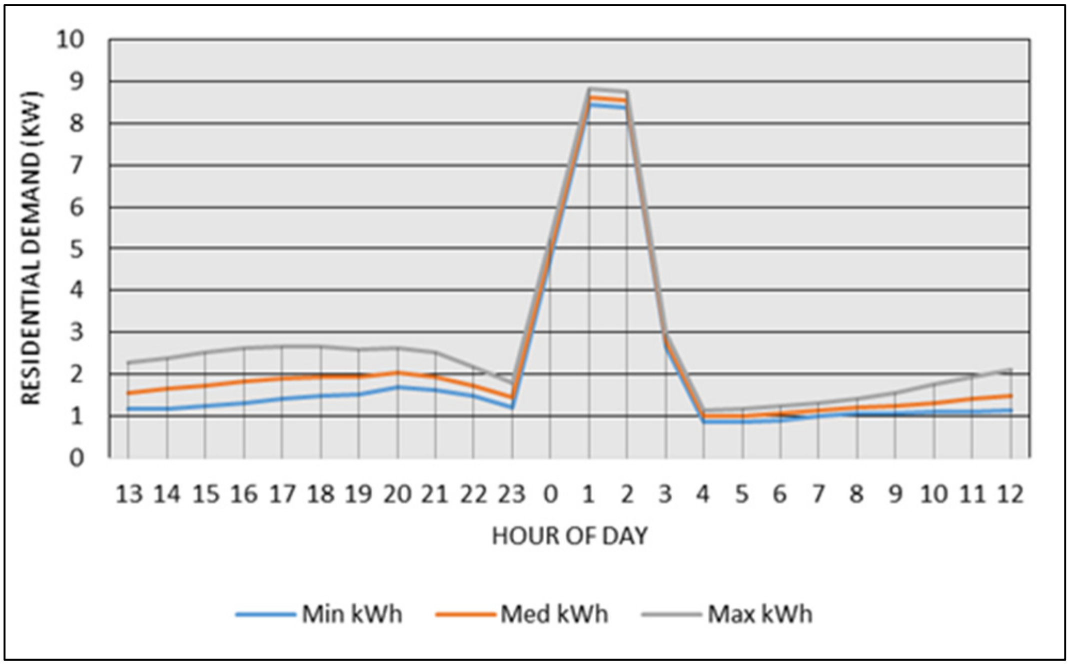

Figure 11-62. SDGE load profile with Cluster Site 1.

Figure 11-63. Cluster Site 2 location.

Without PEV charging, the total energy delivered to the neighbors on July 24, 2013, would have been 35.1 kWh. With PEV charging, it was 62.6 kWh, nearly double the energy. Because this charging behavior depends on the PEV owners' use of their PEVs, this increased load on the transformer could occur at any time, including both neighbors charging at night and during the day.

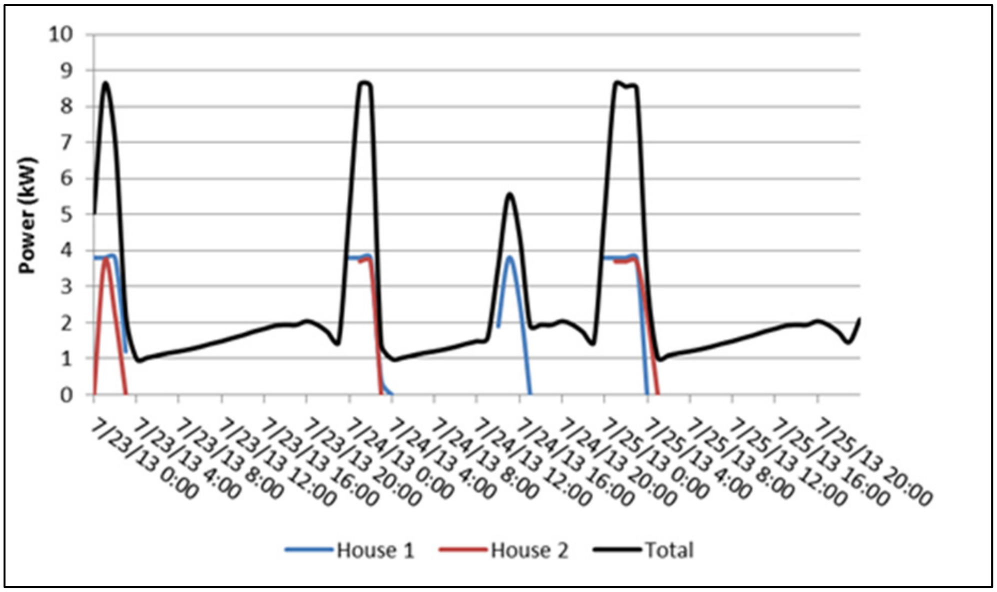

Figure 11-64. Hourly load profile for Cluster Site 2.

Cluster Site 3—The next site for evaluation is shown in Figure 11-65. A review of the Blink charge data indicates that in both homes, the start of the evening charge is programmed at midnight (i.e., at the beginning of the SDG&E super off-peak period), although additional charge times might occur during the day.

Figure 11-65. Cluster Site 3 location [29].

Data indicate one residence charging a Leaf at 6.6 kW, while the other charges a Volt at 3.3 kW. The PEV charging profile for these residences, including the median load profile, for a few days in July 2013 is shown in Figure 11-66. The peak power demand is 11.2 kW. This is nine times the peak of the household power alone.

Energy used by the houses from midnight to 4 a.m. without charging PEVs is 4.4 kWh. With the PEVs added, the energy for the same period is 25.2 kWh, which is over five times the non-PEV energy. Again, this increase also occurs during the typical period of expected transformer cool down.

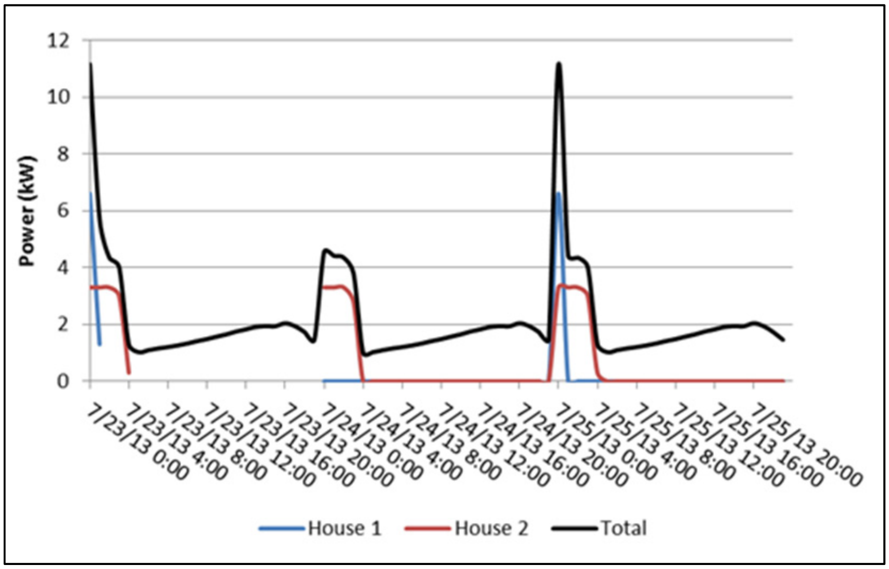

Figure 11-66. PEV charging profile for Cluster Site 3.

Cluster Site 4—The final site for evaluation is shown in Figure 11-67. Data from all three houses show typical programmed start times of midnight daily for Leaf vehicles, although some days were missed and some charging occurred at other times as well.

Figure 11-67. Cluster Site 4 location.

The charging profile for the PEVs located in these homes for a few days in July 2013 is shown in Figure 11-68.

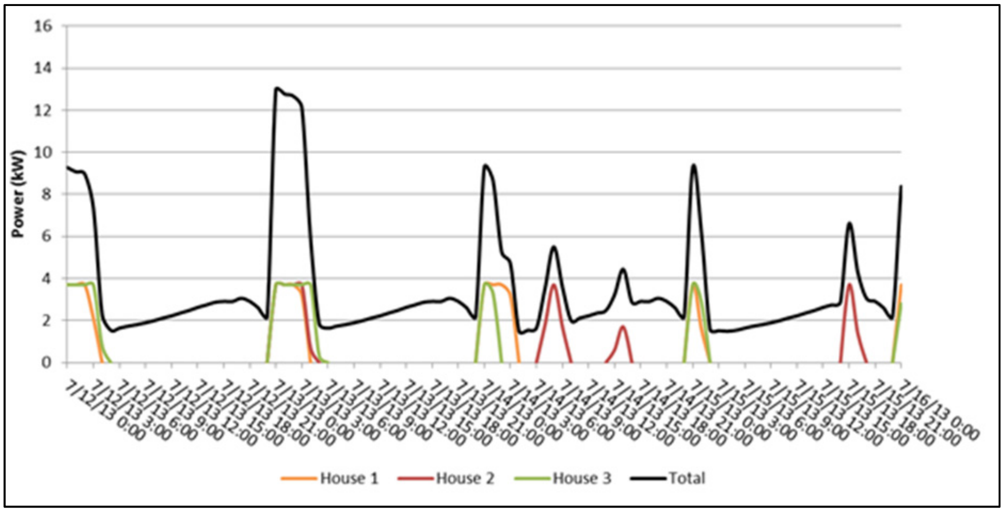

Figure 11-68. PEV charging profile for Cluster Site 4.

The Blink charge data for all three vehicles show a maximum charging power of 3.7 kW each.

This cluster illustrates the varied nature of individual charging. There were times that all three PEVs were recharging, times that two were charging simultaneously, and times of isolated charging during peak times.

As expected, the effects of three households in the cluster magnify the impacts on the transformer. The total energy increase through the transformer for the 4 days of July was 132 kWh, which is an increase of 62%. The higher peak power demand (i.e., 13 kW) compared to the normal three households at midnight (i.e., 1.9kW) and lack of cool down periods due to coincident and non-coincident charge events, significantly changes the operation of the neighborhood transformer.

11.2.6.10 Higher Power Charging. Cluster Site 3 included a PEV capable of 6.6-kW charging. If the three home owners in Cluster Site 4 also had vehicles of 6.6-kW charge capability, the use of each vehicle was the same, and the same charging energy was required, the new combined household load would be as shown in Figure 11-69.

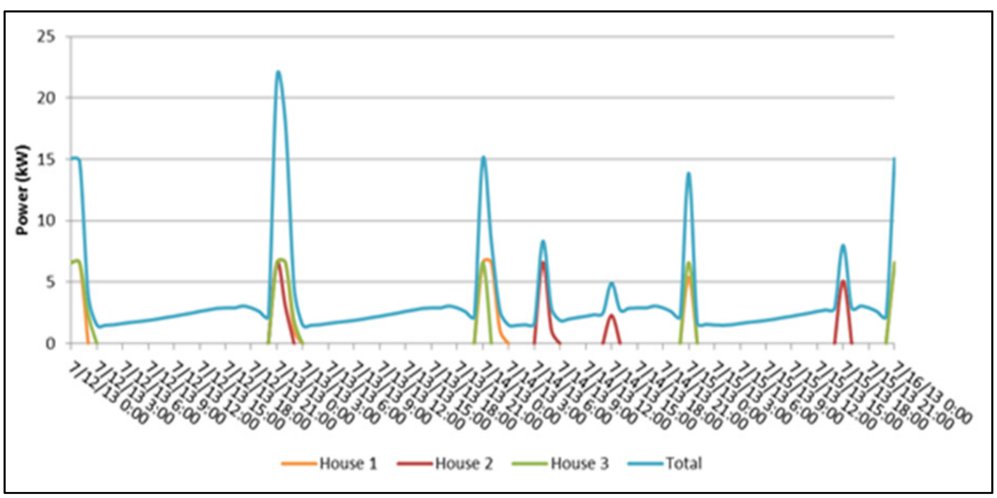

Figure 11-69. Hourly load profile for Cluster Site 3 with 6.6-kW charging.

This creates vastly higher peaks of shorter duration. The same energy requirement exists as in Cluster Site 3, but the peak power demand of 21.6 kW is 11.5 times the typical three residential households demand and remains at high power for at least 2 hours.

11.2.6.11 Utility Experience. The mild climate of San Diego leads to relatively small typical household loads, allowing smaller capacity neighborhood transformers or many houses being fed by the same transformer. While the transformer may be large relative to an individual house load (and thus, able to withstand the transient charging loads from a single PEV), the many households served creates the potential for much larger clusters as PEV adoption grows.

SDG&E was informed of residential EVSE installations during the permitting process. At this writing, the utility has, in fact, replaced a few transformers linked to cluster effects. While SDG&E is monitoring and testing some neighborhood transformers where PEV charging occurs, the low impact experienced thus far from the relatively small population of PEV owners has led to a reactive strategy (i.e. replacing the transformer should a problem arise). Special situations (e.g., when Tesla home charging occurs) require proactive analysis of the local transformer. However, utilities are actively monitoring the growth of PEV adoption, understanding that it can have major effects on their power distribution.

11.2.6.12 Conclusions. These EV Project data demonstrated the loads observed on residential transformers and confirm clustering of PEV charging has occurred among EV Project participants. At this writing, the adoption of PEVs is still in its infancy, with more PEVs sold beyond those sold to the participants within the project regions, increasing the possibility of clustering in many areas. The effects of clustering on neighborhood transformers using EV Project charging data include higher peaks, longer operation at higher power, and periods of high power demand during times when residential transformers are traditionally expected to have only low loads. The true impact of these loads varies greatly from utility to utility, depending on factors such as the age of the transformers used in each territory and the design considerations that were in place at the time they were installed.

These effects may be heightened by factors such as TOU electricity rates that influence PEV drivers to choose common charging times. The electric utility rate structures for TOUs can contribute to the impact on the local transformer by creating a new peak in demand at the beginning of the off-peak period.

The PEV market is growing. As adopters demand greater vehicle range and shorter charge times, the vehicle battery capacity is likely to increase, along with the capability for higher charging power. Doubling the recharge power from 3.3 to 6.6 kW has already occurred, with a multiplying effect on residential distribution transformer impacts.

Clustering effects may result in service outages and the need to upgrade transformers. Damage to the transformer may be caused by exceeding the transformer's load rating or by depriving it of its normal cool-down period. Electric utilities will need to be involved with PEV adoption, both for the overall system load profile and for impacts to the local neighborhood distribution transformer. Understanding the likelihood and effects of clustering will help electric utilities prepare for widespread PEV adoption.

11.2.6.13 References

23. "What Clustering Effects Have Been Seen by The EV Project," August 2013, http://avt.inl.gov/pdf/EVProj/126876-663065.clustering.pdf, accessed January 9, 2015.

24. Distribution Systems: Distribution Transformers Occupational Safety & Health Administration, https://www.osha.gov/SLTC/etools/electric_power/illustrated_glossary/distribution_system/distribution_transformers.html, accessed July 30, 2013.

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26. http://www.teslamotors.com/charging/#/basics accessed February 4, 2015.

27. http://www.sdge.com/clean-energy/ev-rates, accessed January 19, 2015.

28. "EVSE Programming," April 2013, http://avt.inl.gov/evproject.shtml#LessonsLearned, accessed January 19, 2015.

29. "PEV Driver Response to Time-of-Use Rates while charging EV Project vehicles," July 2013, http://avt.inl.gov/evproject.shtml#LessonsLearned, accessed January 19, 2015.

30. Residential pictures provided by Google Earth.

11.2.7 What Residential Clustering Effects have been Seen in The EV Project, and Specifically in the Pacific Gas and Electric Service Territory?

11.2.7.1 Introduction. The power required to recharge a PEV can be a significant electrical load for the house on the electric grid and, specifically, on the local residential power transformer providing energy to several homes. What insight can The EV Project data analysis provide relating to the magnitude of this impact on the local transformer?

11.2.7.2 Key Conclusions. The effects of clustering on the neighborhood transformers using EV Project charging data include the following:

- Higher peaks
- Longer operation at higher power
- Periods of high power demand during times when residential transformers are traditionally expected to have only low loads
- The electric utility rate structures for TOU might be contributing to the impact to the local transformer by creating a new peak in demand at the beginning of the off-peak period
- Clustering effects may result in service outages and the need to upgrade transformers
- Damage to the transformer may be caused by exceeding the transformer's load rating or by depriving it of its normal cool-down period
- Electric utilities will need to be involved with PEV adoption, both for the overall system load profile and for impacts to the local neighborhood distribution transformer.

11.2.7.3 Why is this important? A question frequently asked relating to the adoption of PEVs is "What is the impact of PEV charging on the electrical grid?" This question can be directed at the big picture of total utility system load, but the focus here is on the impact to the local electrical distribution system and, in particular, the local residential electrical transformer. Higher than originally anticipated loads on this transformer could lead to damage, local power outages, and higher costs to the electric utility for replacement equipment.

11.2.7.4 Residential Power Distribution. Electric utility and power distribution companies work with local planners to design and deliver electrical power to the residential neighborhoods. The final step in this delivery is from the local residential transformer to the individual homes. Frequently, more than one home is supplied by the same transformer (Figure 11-70). ZTHE transformer (shown in beige in Figure 11-70 and also shown in Figure 11-71) provides electrical energy to the individual residential service entrance. The supplied voltage is typically 240 volts AC, from which the residence can power its 240 and 120-volt loads.

In the design process, the anticipated residential power usage determines the capacity of the service supply, and the combination of all residences served by that transformer determines its design requirements. Appropriate standards and regulations apply in providing safety and operational margins in these calculations. The transformer design also considers the peak power that will be demanded by all residences at one time and heating effects that will be experienced on that transformer. An assumption is made for the amount of time available to allow the transformer to cool down between these peak loads.

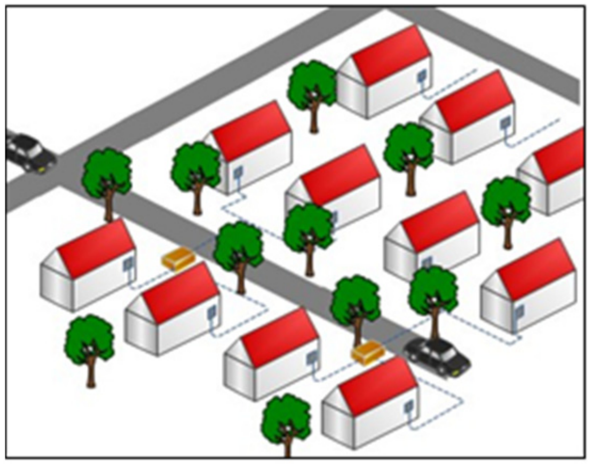

Figure 11-70. Residential distribution transformer schematic.

Figure 11-71. Pad-mounted residential distribution transformer [31].

When a homeowner desires to add significant load in his or her home (such as adding a swimming pool, welder, or PEV), the permitting process typically requires new load calculations to determine whether the residences service supply is sufficient to safely add this new load. Unless the supply is found to be insufficient, the local electric utility may not be informed of the new load on the transformer. In many cases, the addition of the EVSE for charging the PEV may not exceed the service supply design of the single residence; therefore, the electric utility may not know of the charge.

11.2.7.5 Typical Residential Loads. A typical residence in the PG&E service territory may reach a maximum electrical power demand of approximately 2.5 kW during a given year. Figure 11-72 shows a typical residential hourly load profile for 2012 [32]. The E-7 profile includes the PG&E residential TOU Schedule E-6 rates and experimental EV TOU Schedule E-9 rates. (Note: the source files show an apparent error for the 3 a.m. time period of a zero value on March 3, 2012.)

The Blink EVSE provided to The EV Project participants was capable of delivering up to 7.2 kW power to a connected PEV. While most PEVs currently on the market accept up to 3.6 kW, model year 2013 Nissan Leafs and other vehicle models will accept energy near the EVSE’s 7.2-kW rating. As such, it is possible that adding PEV charging could significantly increase residential demand. Where the median power demand is 1.5 kW at 7 p.m. according to Figure 11-72, charging the PEV at that time could raise that power demand to 8.7 kW, which is nearly 6 times the original load. If PEV charging occurs at the time of greatest demand, the total residential demand could reach 9.7 kW.

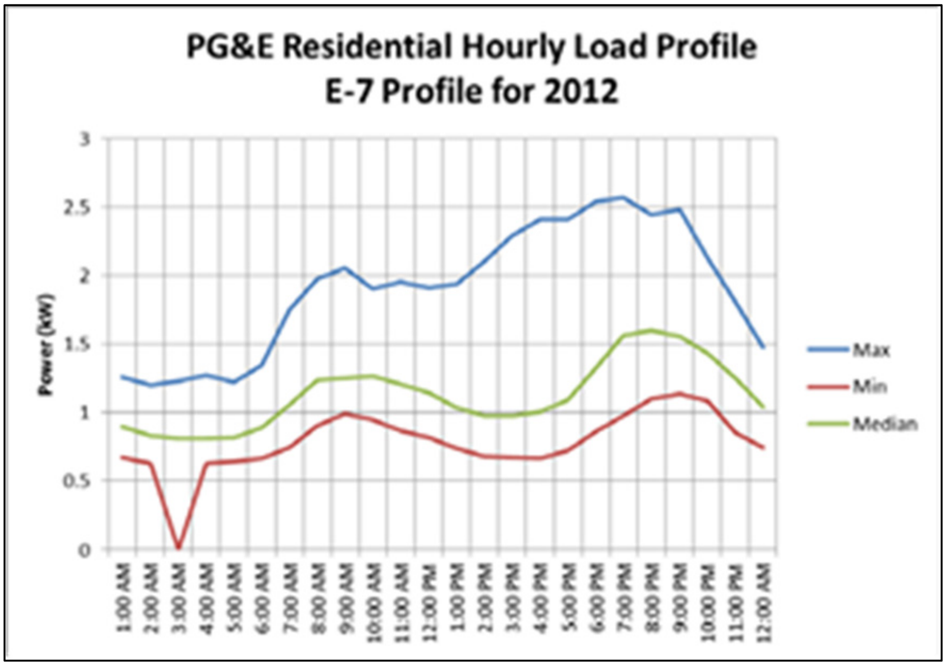

Figure 11-72. PG&E hourly residential load profile.

11.2.7.6 Time-of-Use Rates. Some electric utilities seek to shift peak loads to times of lower demand through TOU rates. These rates generally classify times of the day as on-peak and off-peak and, in some cases, a shoulder, partial-peak, or mid-peak.

PG&E defines summer weekday times on Electric Schedule E-9 as follows:

- On-peak: 2 to 9 p.m.
- Partial-peak: 7 a.m. to 2 p.m. and 9 p.m. to 12 a.m.
- Off-peak: All other times [33].

The price charged for power is typically lower for the off- peak times than for the on-peak times, in order to incentivize the residential customer to shift loads to off-peak times. While it may not be possible to shift all loads (such as air conditioning), it is possible to shift power to operate swimming pool pumps, clothes dryers, and so on, to these off-peak times. The same is true for PEV charging. For convenience, the Blink EVSE and many PEVs provide programming capabilities to schedule the start of a charge. Many EV Project participants use these tools to schedule the start of charge after the start of the utility off-peak time. EV Project participant use of these programming features is the subject of another report [34]. How PEV owners respond to these TOU rates is the subject of a separate study [35].

The EV Project has been collecting residential charging data since 2011, which is long enough for the participating PEV drivers to settle into habits of charging, regardless of motivations. Whether these PEV drivers take advantage of TOU rates or not, this residential charging data can inform electric utilities of the potential impact on the transformer.

11.2.7.7 What is Meant by "Clustering"? Automotive manufacturers understand that one promoter of vehicle sales is the visibility of a new car in a neighbor's driveway. Neighbors are often curious and interested in the new vehicle, especially if it is a new type of vehicle, such as a PEV. When several PEVs show up in the same neighborhood and where those residences are powered from the same electrical transformer, "clustering" occurs. This is a cause for concern to the local electrical utility. While the transformer may be able to accept the power demand increase from one PEV, multiple PEVs charging may cause damage to the transformer, resulting in a service outage and the need to upgrade that transformer. This damage may be caused by overloading the rating of the transformer or by depriving the transformer of its normal cool-down period, typically found in the early morning hours.

The effects on a single transformer can also affect the rest of the residential feeders from the distribution substation. Distress on a residential transformer may affect the power quality on the feeder side of the transformer. Distribution feeders are generally designed either in a radial pattern away from the substation or in an interconnected method where multiple connections may be made to other feeders [36]. In the former radial design, the closer this clustered transformer is to that substation, the greater the effects on those residential transformers farther away because power quality is diminished.

11.2.7.8 Clustering in The EV Project. Typically, residences are located within 100 ft of the local neighborhood transformer. To see whether there might be cases of clustering in The EV Project, the locations of The EV Project participants in the San Francisco region were plotted. Then 100-ft radius circles or "buffers" were drawn around each location. Areas where these buffers intersect are locations where homes may be serviced by the same neighborhood transformer.

Figure 11-73 shows a section of the San Francisco Bay Area where two or more of these 100-ft buffers intersect. Note that not all EV Project participant locations in this part of the Bay area are shown; only those where there are intersecting buffers. Twenty-one of these locations are shown in this section of the Bay Area alone.

Three sites of two or more intersecting buffers in the Bay Area were selected for evaluation.

Cluster Site 1—The first site for evaluation is shown in Figure 11-74. The street and other physical features are redacted for privacy considerations. The two residences shown within the 100-ft buffer zones are neighbors. The homes are located within the PG&E service territory. A review of the Blink charge data indicate that in both homes the start of the evening charge is programmed after midnight (after the beginning of the PG&E off-peak period), although additional charge times might occur during the day.

The PEV charging profile for these residences for the first few days of April 2013 is shown in Figure 11-75.

The Blink charge data show that both PEVs are capable of accepting up to 3.6-kW power. Assuming the median load profile of Figure 11-72 for both houses, the cumulative load profile for these two houses for April 2 through 4, 2013, would be as shown in Figure11-76.

Charging PEVs requires the neighborhood transformer to provide almost four times the amount of energy through 4 a.m. than would be provided for the houses without charging taking place.

Cluster Site 2—The second site for evaluation is shown in Figure 11-77. The two residences are shown with intersecting 100-ft buffer zones. The homes are located within the PG&E service territory. According to Blink charge data, the charge for the PEV in House 1 is programmed to start during the off-peak time at 1 a.m. For the month of June, charging was conducted at no other time of day at this house. The charge for the PEV in House 2 is also programmed to start during the off-peak time at midnight, although this program has been overridden with additional charge times when connecting at night or during the day.

The PEV charging profile for the PEVs located in these homes for the first few days of June 2013 is shown in Figure 11-78.

As before, the charge data show both vehicles can accept up to 3.6 kW charge power. Assuming the median load profile of Figure 11-72 for both houses, the cumulative load profile for these two houses for June 2 through 5, 2013, would be as shown in Figure 11-79.

Figure 11-73. Residential EVSE clusters in the Bay Area.

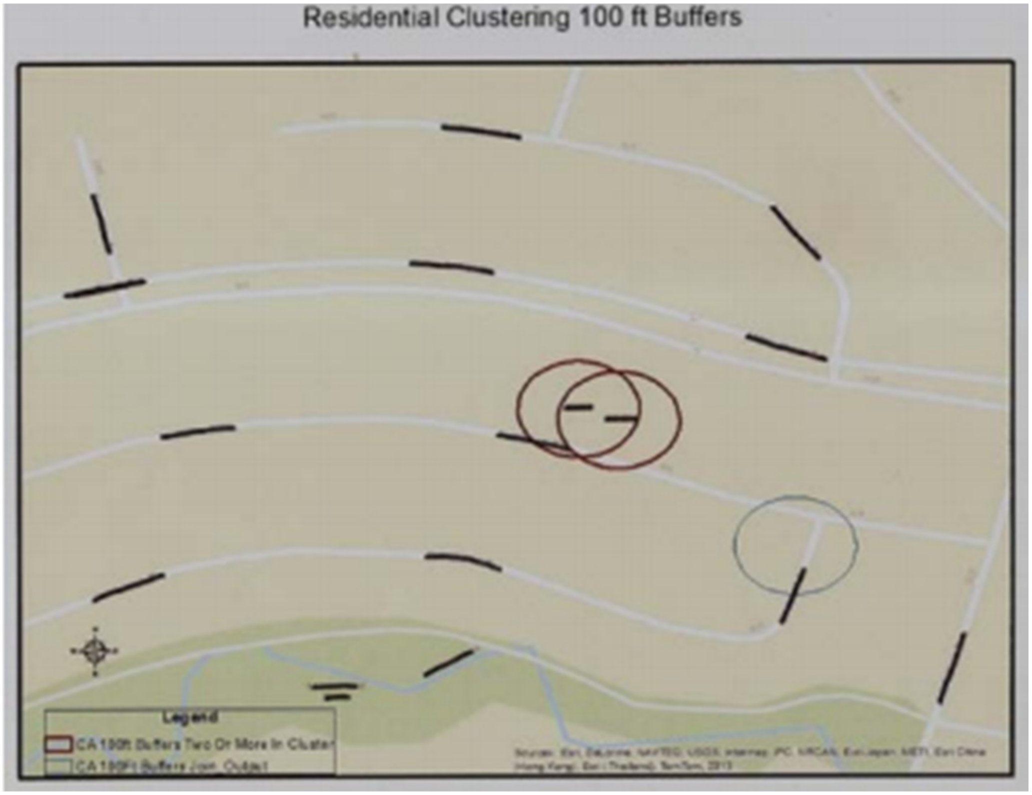

Figure 11-74. Cluster Site 1 location.

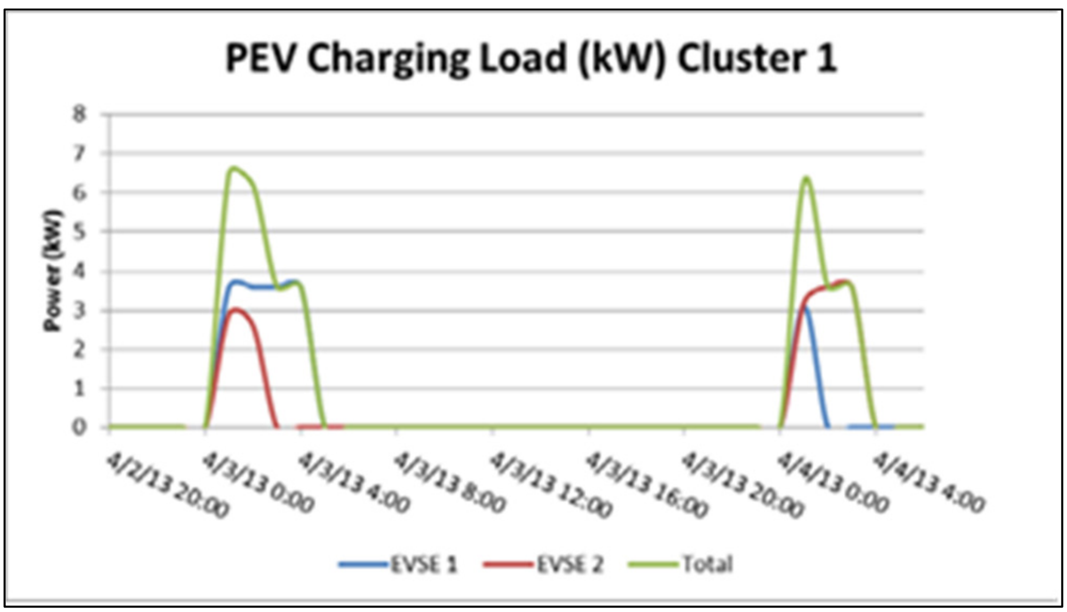

Figure 11-75. PEV charging profile for Cluster Site 1.

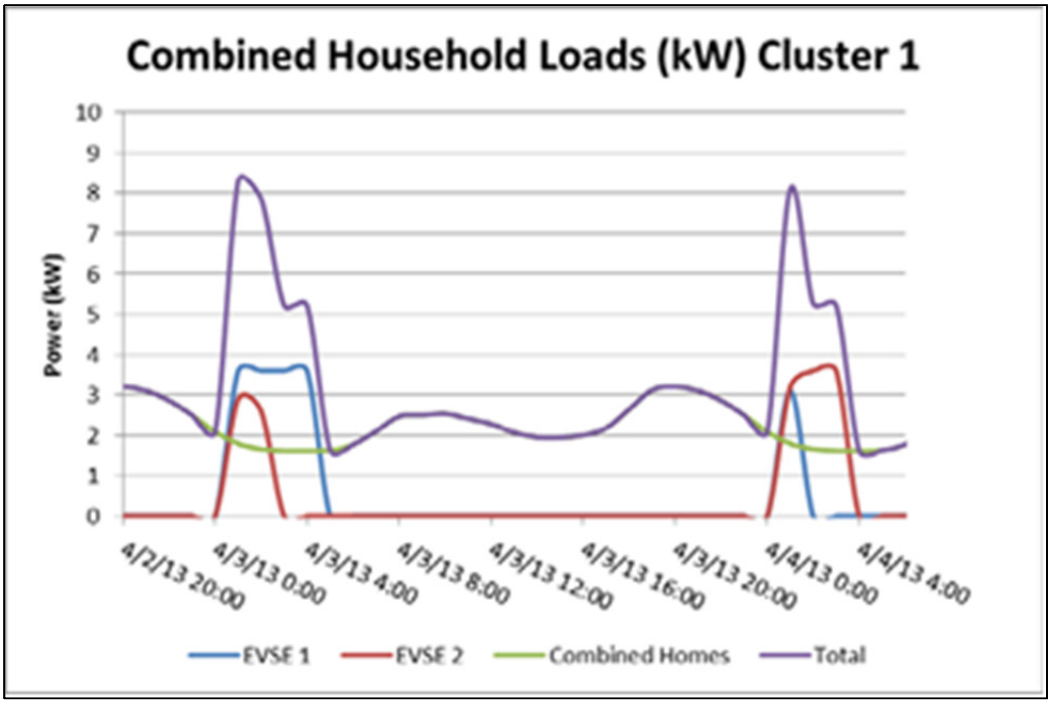

Figure 11-76. Hourly load profile for Cluster Site 1 April 2 through 4, 2013.

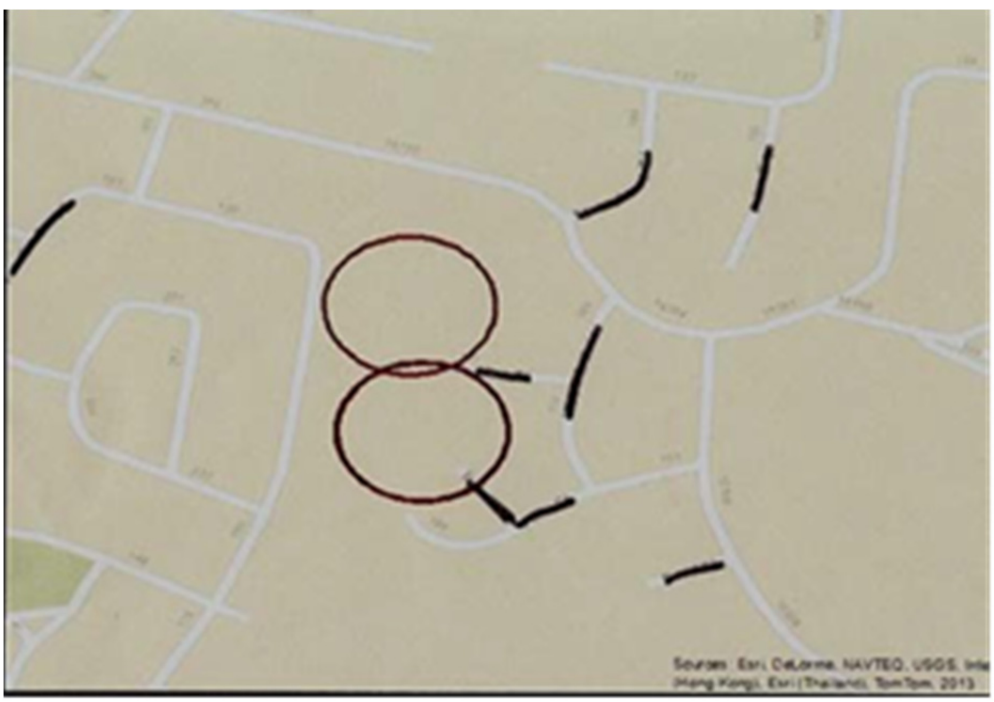

Figure 11-77. Cluster Site 2 location.

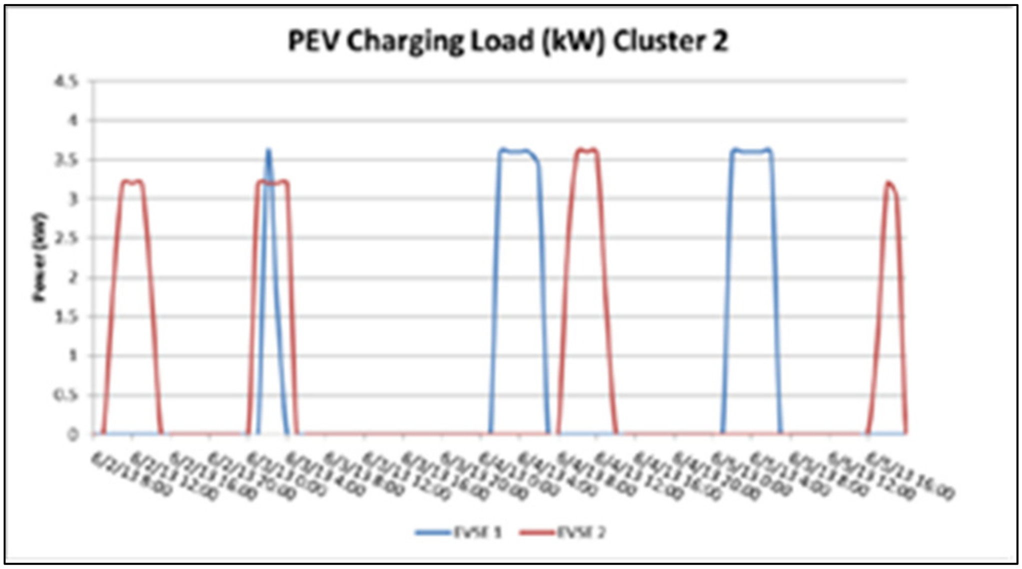

Figure 11-78. PEV charging profile for Cluster Site 2.

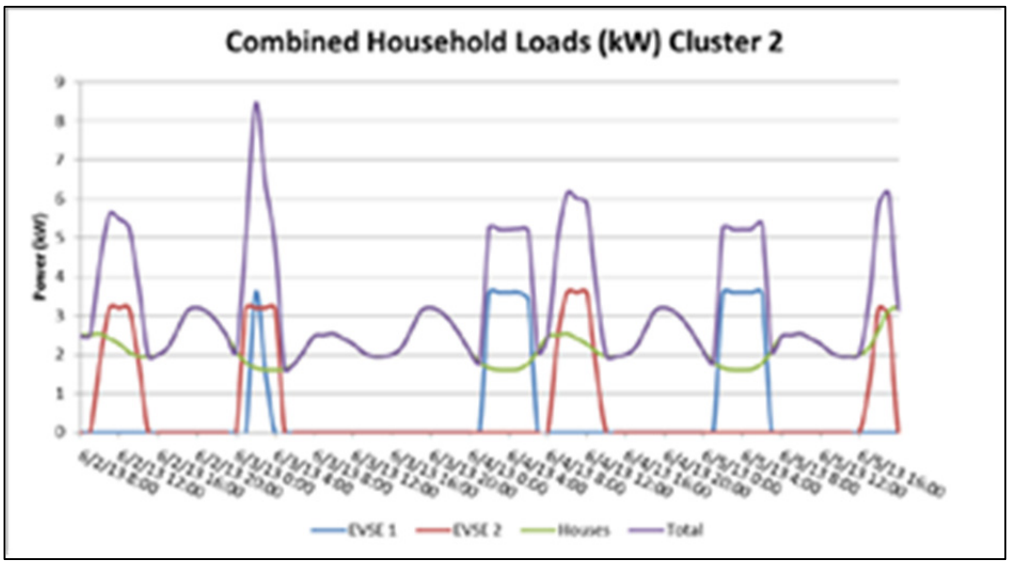

Figure 11-79. Hourly load profile for Cluster Site 2 June 2 through 5, 2013.

The PEV charging in these two homes shows three separate effects on the local transformer. First, the peak caused by simultaneous charging is shown for the early morning hours on June 3. Next, the early morning of June 4 shows the sequential charging peaks during the time when electric utilities anticipate lowest residential demand. Thus, the anticipated overnight cool-down time for the transformer is eliminated. Finally, other morning charging in House 2, as shown on June 2 and June 5, adds peaks in the daytime that also can affect transformer cool-down during other typically lower demand times.

Cluster Site 3—The third site for evaluation is shown in Figure 11-80. The three houses in the intersecting circles are neighboring houses on the same street. All are located in PG&E service territory. The charging of the PEV in House 1 showed regular programmed start times of 12:05 a.m. daily, but also frequent charging at other times. The charging of the PEV in House 2 showed regular programmed start times of 12:10 a.m. daily and had some charges at other times. Charging of the PEV in House 3 did not appear to be based on a schedule, but commenced at PEV plug-in.

Figure 11-80. Cluster Site 3 location.

The charging profile for the PEVs located in these homes for the first few days of June 2013 is shown in Figure 11-81.

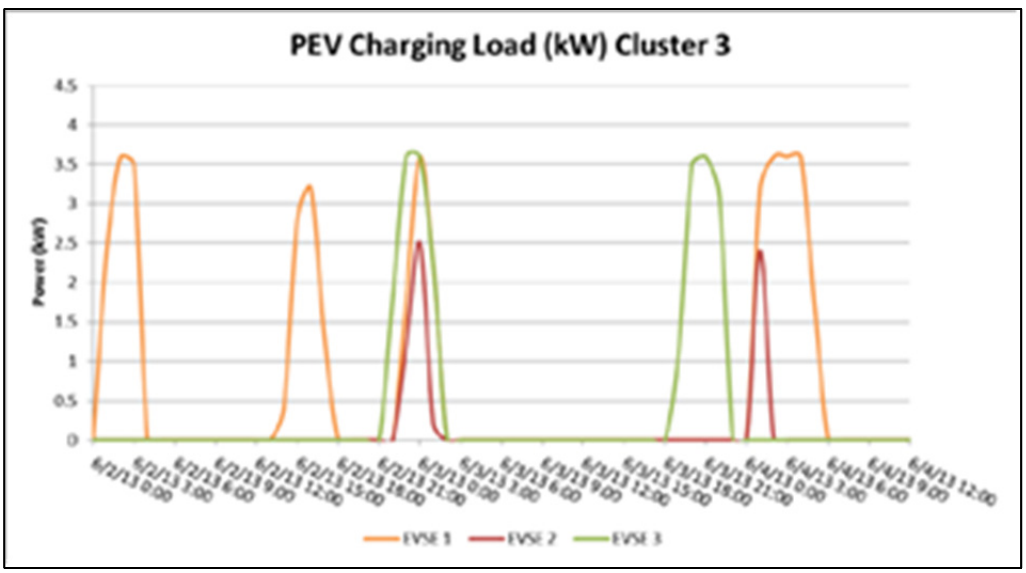

Figure 11-81. PEV Charging Profile for Cluster Site 3.

The Blink charge data for all three vehicles show a maximum charge acceptance of 3.6 kW each. It is noted that during the above days, the PEV in House 2 accepted less than 3.6 kWh because of lower recharge needs on these days. Later charging was observed at the 3.6-kW rate.

In this cluster, there are times that all three PEVs are recharging and times that two are charging simultaneously, followed by the third. Other non-coincident charges also occur. Assuming the median load profile of Figure 11-72 for all houses, the cumulative load profile for these three houses for June 2 through 4, 2013, would be as shown in Figure 11-82.

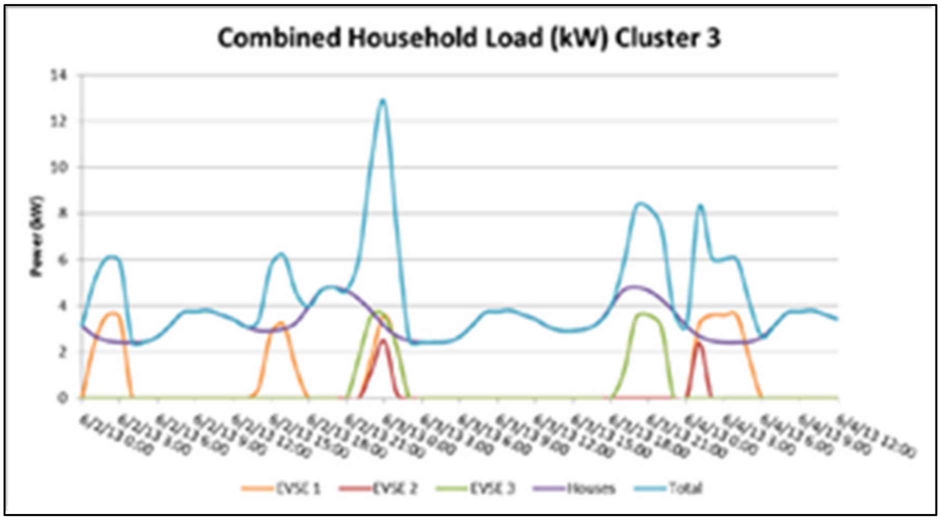

Figure 11-82. Hourly load profile for Cluster Site 3 June 2 through 4, 2013.

As expected, the effects of three households in the cluster magnify the impact on the transformer. The total energy increase through the transformer for the 3 days of June was 69.3 kWh, which is an increase of 28%. The impacts of higher peak power demand (four times the normal) and lack of cool-down periods due to coincident and non-coincident charge events could be stressing the neighborhood transformer.

11.2.7.9 Higher Power Charging. Suppose the three home owners in Cluster Site 3 trade in their current Leafs for newer models that have 7.2-kW charge capability. Assuming that the use of each vehicle is the same and the same charging energy is required, the new combined household load would be as shown in Figure 11-83.

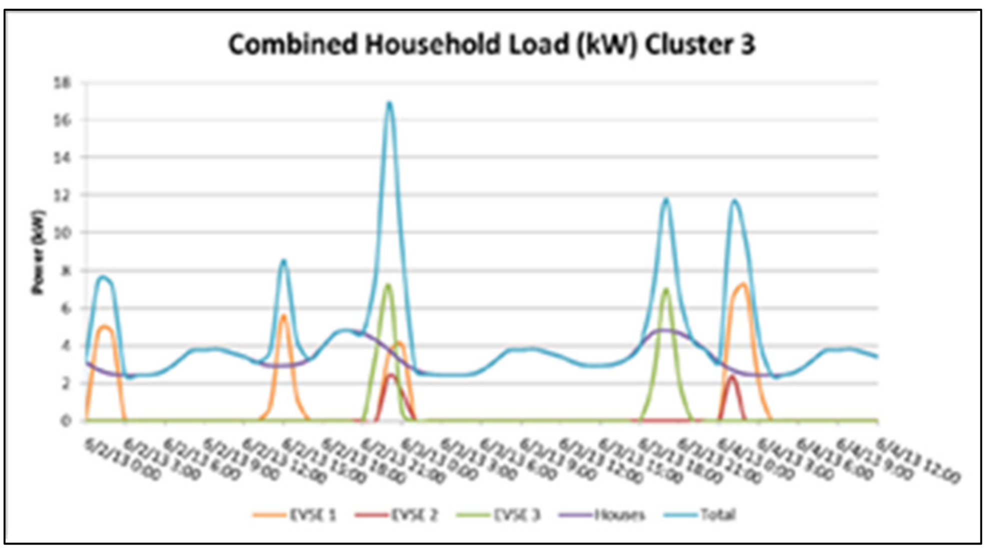

Figure 11-83. Hourly load profile for Cluster Site 3 with 7.2-kW charging.

This creates vastly higher peaks of shorter duration.

11.2.7.10 Observations

All household load curves assumed the median value for household energy usage. Usage below this median value would reduce the impact slightly, but PEV drivers would still need to charge their vehicles on the days when the whole-house demand is at its peak. This further exacerbates the impact on the transformer. These EV Project data demonstrate the possible loads on residential transformers. The true impact of these loads varies greatly from utility to utility depending on such factors as age of the transformers used in each territory and design considerations that were in place at the time they were installed (in terms of their ability to handle additional loads).

11.2.7.11 Mitigating Suggestions. It has been suggested that smart charging of the EVSE at night can mitigate these peaks and lessen the impact on the local transformer. Smart charging includes methods by which the electric utility can communicate and control the household smart EVSE by various means. Assuming the PEV driver simply requires that his or her battery is charged when the PEV is needed at a certain time of day regardless of when the charge starts and stops, the utility could determine at what time and what power the energy is delivered to the connected vehicles. The utility would then signal the smart EVSE to deliver the desired power and energy.

Assuming all three residences participate in such a program, Figure 11-84 shows a scenario by which the same energy is delivered to the three PEVs in their overnight charging. It is assumed that an engaged PEV driver would defer most charging, if possible, to the evening controlled hours. For example, House 3 could move the evening charge of June 3, 2013, to midnight. However, House 1 charge data suggests that the mid-afternoon charge on June 2, 2013, was required because the PEV was driven again after this charge. In this scenario, all controlled PEV overnight charging commences after midnight and is completed before 5 a.m.

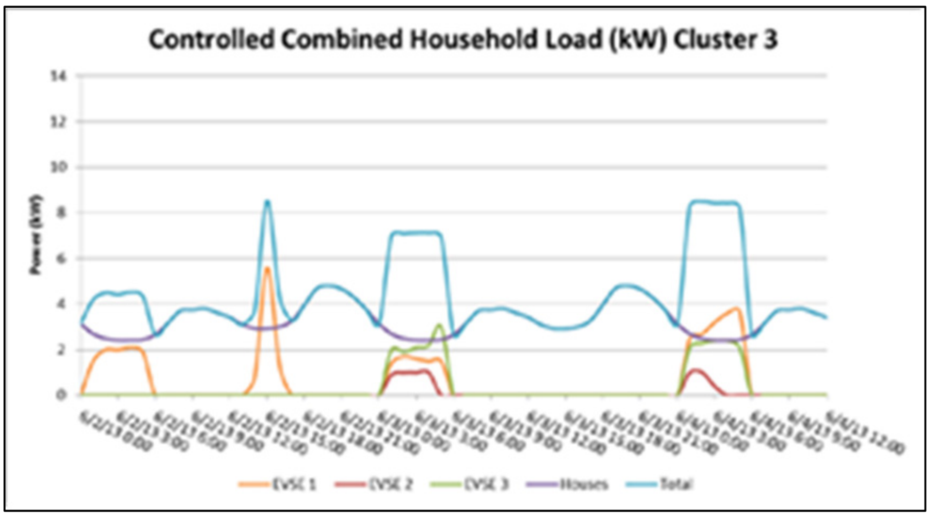

Figure 11-84. Controlled hourly profile for Cluster Site 3 with 7.2-kW charging.

The maximum peak power reached is 8.5 kW at 2 p.m. as opposed to the 17-kW actual demand at 11 p.m. shown in Figure 11-81. Because this peak occurs at a typically lower residential demand due to theoretical load control, it is only 3.4 times the normal transformer peak for these homes, opposed to 4.5 times that peak. Further reduction in the peaks could occur if the PG&E off-peak window were increased to start at 10 p.m. or if the PEV driver did not need the PEV until 6 a.m. A smart system could consider these personal preferences and utility rate structures.

11.2.7.12 Conclusions. The EV Project has observed clustering among project participants. More PEVs have been sold beyond those sold to the participants within the project regions, increasing the possibility of clustering in many areas. The effects of clustering on the neighborhood transformers using EV Project charging data include higher peaks, longer operation at higher power, and periods of high power demand during times when residential transformers are traditionally expected to have only low loads. These effects may be heightened by factors, such as TOU electricity rates, that influence PEV drivers to choose common charging times. The electric utility rate structures for TOU might be contributing to the impact to the local transformer by creating a new peak in demand at the beginning of the off-peak period.

Clustering effects may result in service outages and the need to upgrade transformers. Damage to the transformer may be caused by exceeding the transformer's load rating or by depriving it of its normal cool-down period. Electric utilities will need to be involved with PEV adoption, both for the overall system load profile and for impacts to the local neighborhood distribution transformer. Understanding the likelihood and effects of clustering will help electric utilities prepare for widespread PEV adoption.

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11.2.8 What is the Controllable Electrical Demand from Residential EVSE in the San Diego Region?

11.2.8.1 Introduction. The power required to charge a PEV can be a significant electrical load for a residence and, when all PEVs in an area are aggregated, a significant load on the electric grid.

Electric utilities seek ways to reduce their generating costs by managing the maximum (i.e., peak) load on their system. Managing residential PEV charging activity provides an opportunity for minimizing, or eliminating, any impact of PEV charging on peak load. This management may be achieved indirectly through rates that incentivize PEV owners to charge their vehicles during off-peak hours or may take the form of direct utility control of residential EVSE. What insight can EV Project data provide relating to the magnitude of this impact and the potential controllable demand? This paper quantifies the total controllable electrical load imposed on the electric grid by residential PEV charging in the San Diego region of The EV Project.

11.2.8.2 Key Conclusions

- The aggregated EV Project's residential EVSE charging demand in San Diego exceeded 100 kW from 4 p.m.to 4 a.m. during the third quarter of 2013.
- This aggregated demand during the third quarter of 2013 was sufficient for bidding into controllable demand response activities in the San Diego region.
- The positive adoption of PEVs in the San Diego region increases the probability of enlisting sufficient PEV owners in demand response activities. However, the numbers of residential EVSE must grow by a factor of 18 to make direct control minimally worthwhile at all hours of the day.
- The incentive programs promoted by SDG&E, coupled with easily programmable EVSE, are highly effective in moving residential charging to off-peak hours.

- For the foreseeable future, direct utility control of residential EVSE is not beneficial, whereas indirect control through rate incentives is beneficial.

11.2.8.3 Why is Controllable Demand Important? The electric utility is responsible for providing power to customers within its service territory. SDG&E is solely responsible for providing electricity for all customers within the San Diego region of The EV Project. SDG&E publishes its dynamic load profile, showing the power required by its customers during a specific period of time. This profile for June through August 2014 is shown in Figure 11-85, showing the maximum, median, and minimum power demand over the 3-month period for each hour of the day.

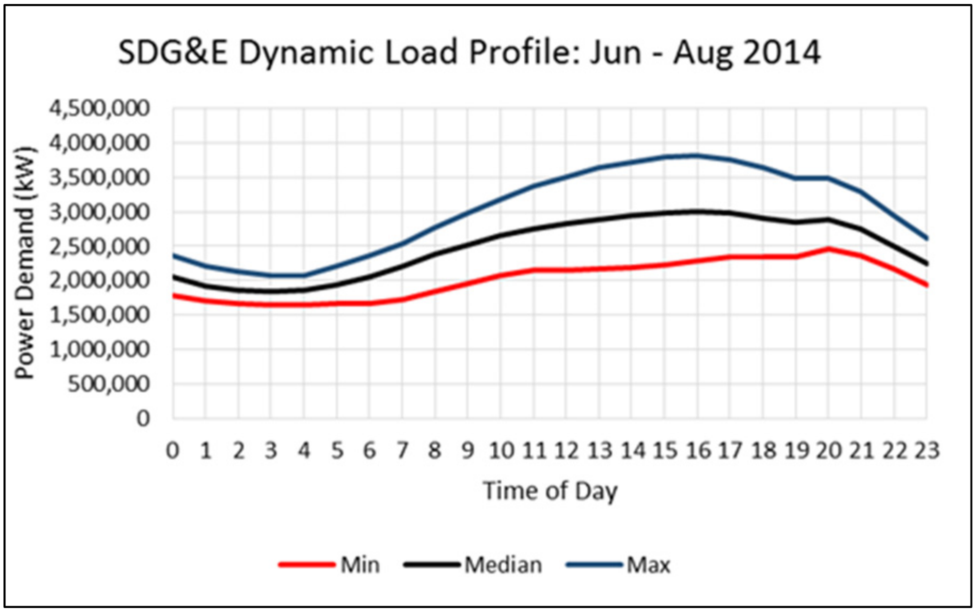

Figure 11-85. SDG&E hourly demand.

SDG&E must provide power generation to match the power demand, which, during this 3-month period, varied from a minimum of 1,649 MW to 3,814 MW. Generation is provided by first operating "base-load" generating stations. These base load power plants are generally the cheapest units to operate and are most efficient when operating at full power. Thus, these units are typically fully loaded to provide power all day. Once this base-load capability is fully utilized, other generating plants are brought into service. The last plants to be utilized are "peaking" units that are more expensive to operate, but whose output can be modulated more rapidly and used only when necessary to handle the peak loads. In some situations, utilities may need to purchase power from other sources to fulfill peak load requirements. If the utility can shift peak power demand to other times, the cost of operating peaking power plants and purchasing power from other utilities during peaks can be avoided.

In anticipation of power demand increases or problems on the grid causing a reduction in power generation, utilities typically operate "spinning reserve" generation. These are generating stations that are fully operational and, although not loaded, are fully prepared to rapidly supply power to the grid in order to "follow" the demand. During transitional increases or decreases in demand, these spinning reserves may cycle on and off. If the demand can be controlled, this cycling may be avoided and the reserve unit operated in a more stable state.

In addition to managing total power generation to match demand, the electric grid must maintain voltage and frequency. This regulation can be achieved by controlling small amounts of generation or by controlling small amounts of power demanded by customers on the electric grid.

Figure 11-86 illustrates these three major situations. Controlling the demand, even in minimal amounts, in these three areas helps the electric utility to reduce costs.

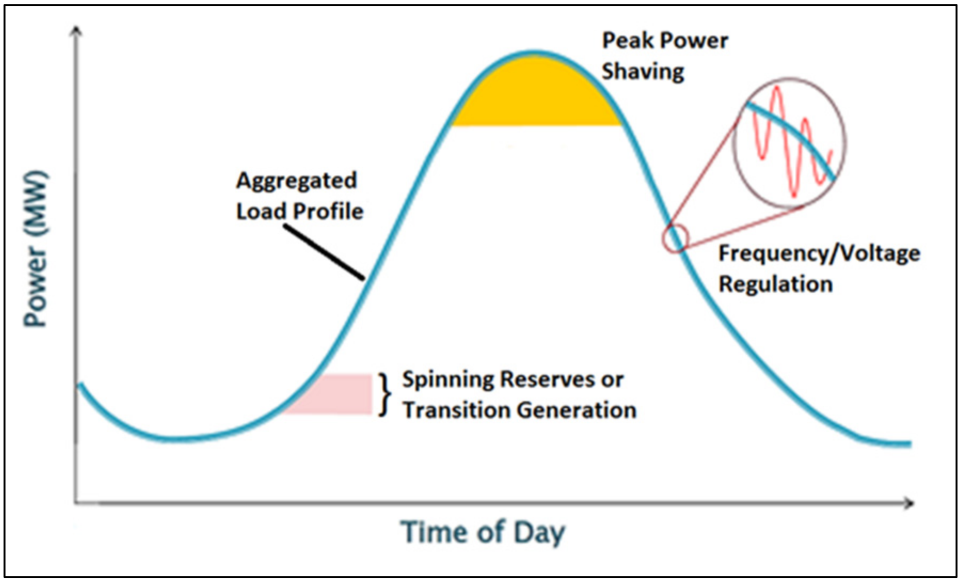

Figure 11-86. Controllable demand situations.

11.2.8.4 Residential Controllable Demand Options. The electric utility has several tools available for assisting in management of its peak power requirements. For this paper, controlling demand from residential PEV charging is of interest, including determining the effectiveness, controlling residential EVSE demand to reduce peak power requirements, assisting in loading and unloading generation, and providing frequency and voltage regulation.

Through use of rate incentives (such TOU), customers are encouraged to shift their power demand to off-peak times. Figure 11-87 shows the SDG&E EV TOU-2 rate schedule for residential PEV charging. The rates charged for electricity incentivize the residential PEV customer to charge during off-peak times, especially during super off-peak times.

The EV Project installed Blink EVSE in the homes of each of its participants in the San Diego area. The Blink EVSE provides an intuitive touch screen interface that allows the PEV owner to easily schedule a window of time during which the EVSE will provide charge power, allowing the PEV owner to schedule charging to take advantage of the SDG&E off-peak and super off-peak rates. The Blink EVSE also allows The EV Project to collect EVSE usage data and report information derived from these data in its quarterly reports. The report for the third quarter of 2013 for residential EVSE usage in the San Diego region includes charging demand by time of day and is shown in Figure 11-88.

The blue curve shows the maximum electricity demand over the 3-month period for each hour of the day; the red curve shows the minimum demand for each hour; and the black curve shows the median demand. The peak at midnight reflects the effectiveness of the SDG&E TOU rate incentive program in shifting the start of PEV charge to the super off-peak times. As a result, direct control of EVSE charging during on-peak times will have little effect in shifting the utility's overall demand, because the total peak daytime load for EVSE is about 0.4 MW, which is insignificant compared to the total SDG&E system demand of 3,000 MW. Rate incentives and readily programmable EVSE appear highly effective in reducing on-peak demand of residential EVSE; therefore, this negates any need for direct utility control of residential EVSE. Providing direct control can provide other benefits to utilities.

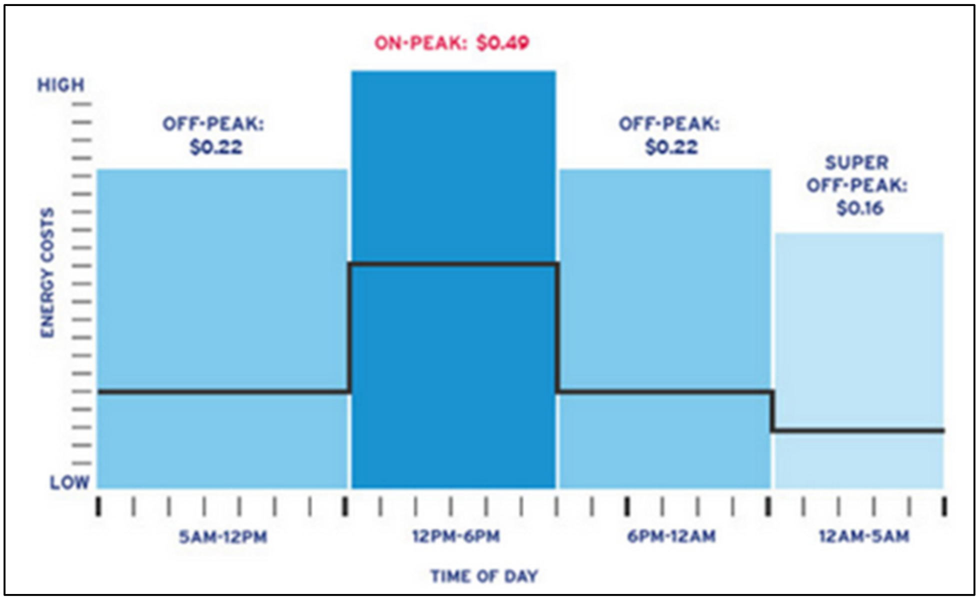

Figure 11-87. SDG&E residential peak schedule.

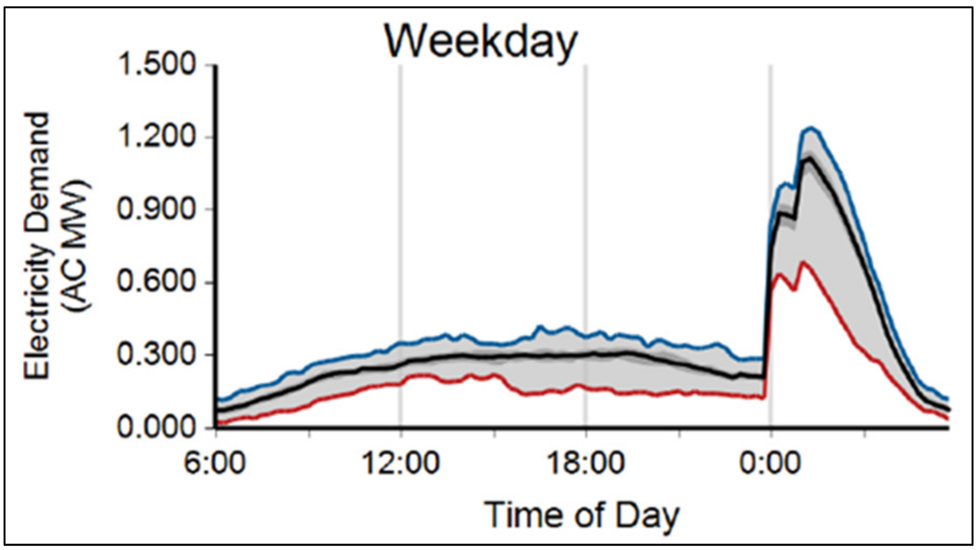

Figure 11-88. Residential charging demand for San Diego in the third quarter of 2013.

SDG&E offers a reduce-your-use voluntary program for residential customers. After enrolling in the program, residential customers receive notification the day before an event is identified by the utility and, when reducing their demand between 11 a.m. and 6 p.m., they receive reward credits on their utility bill.

Incentive programs like reduce-your-use are indirect and rely on the customer to take or not take action. In addition, they are not available for immediate actions on the day needed. For an electric utility to authoritatively use residential customer load to mitigate peak demand, greater positive control of the customer load is required. Control of PEV charging in near real-time provides this opportunity.

11.2.8.5 Utility Control of Residential Plug-In Electric Vehicle Charging. To be effective in controlling demand, a minimum of 100 kW of controllable power is generally required. For residential PEV charging, this requires aggregating many EVSE that are connected to vehicles where both the vehicle and EVSE are available for charging. Because there are financial incentives for providing this demand control, there are frequently penalties for failing to provide adequate control. Thus, this system will require the following:

- EVSE capable of remote control and monitoring
- Aggregation systems and programs
- Sufficient numbers of EVSE providing demand for aggregation
- Communication signals from the utility to the aggregator of service
- Enlistment and communications methods for participating EVSE owners.

Smart EVSE that allow for monitoring, control, and communication through the internet (such as the Blink unit deployed in The EV Project) are also capable of aggregation. Demonstrations of controllable demand from the utility through EVSE have occurred in several forms, including those conducted by the California Energy Commission grant ARV-09-005 involving SDG&E.

Control of charging may include starting and stopping charging (or regulating the rate of charging) or in some cases, discharging the PEV battery through the EVSE back to the grid. The later example, called vehicle-to-grid, requires additional PEV features and is an advanced capability that is currently being tested; however, it is not the focus of this paper. For this consideration, only curtailment or restoration of charging (i.e., frequently called V1G) is of interest.

11.2.8.6 Residential Electric Vehicle Supply Equipment Controllable Demand. Controllable demand from EVSE requires the EVSE to be connected to and charging the PEV. Unless the EVSE is actually charging the PEV (i.e., is not just connected), there is no demand to curtail.

The EV Project's quarterly reports identify the time of day the residential EVSE are connected and available for charging. Charge availability (i.e., vehicle is connected to EVSE) for San Diego in the third quarter of 2013 is shown in Figure 11-89.

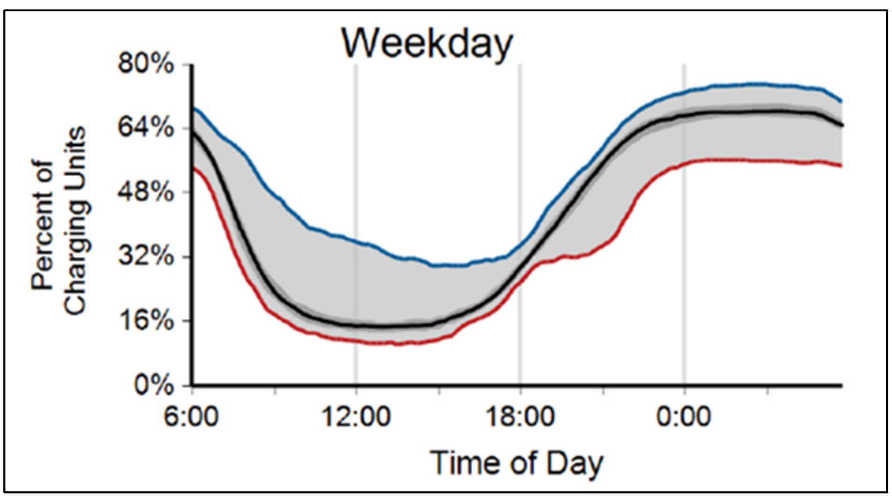

Figure 11-89. Charging availability in San Diego for the third quarter of 2013.

As might be anticipated, charging availability generally follows the typical work schedule, where PEVs begin to depart for work at approximately 6 a.m. and gradually return home and are connected to EVSE at the end of the work day until about midnight, when most are available for charging. However, it does indicate that a minimum of 10% of monitored EVSE are connected at all times of the day. It is noted that these may not be the same EVSE every day, but aggregated over the entire San Diego region, at least 10% of residential EVSE were connected at all times during the quarter.

Figure 11-88 indicates that at least some of the connected EVSE during on-peak times are, in fact, charging the PEV.

While one may suppose that the maximum number of EVSE connected would produce the maximum demand, it is not necessarily the case. The most conservative scenario in estimating available controllable demand would be using the maximum number of EVSE available and the minimum charging demand that was observed. Figure 11-90 overlays these on the same graph to more clearly see what EVSE are available and what the related demand is at the same time of day.

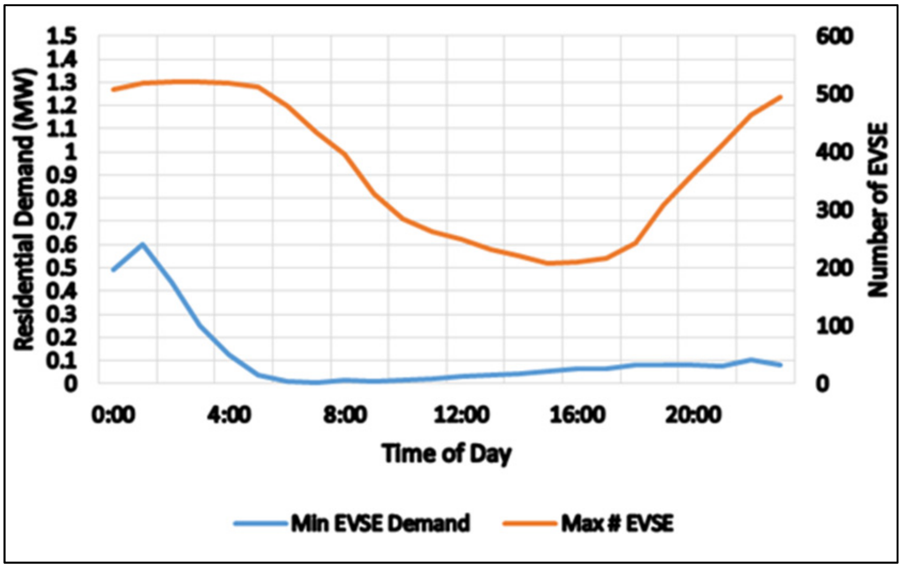

Figure 11-90. Residential EVSE availability and demand for the third quarter of 2013.

According to the third quarter 2013 report, the minimum aggregated charging demand exceeded 100 kW from midnight to 4 a.m. and again at 10 p.m. During this time, the population of EV Project residential EVSE in that analysis presented in the San Diego region was 696. During the day, the maximum number of EVSE connected was 521 or 75% of those EVSE reporting.

For analysis purposes, several qualifying factors were placed on the residential EVSE data in reporting the quarterly data, which resulted in exclusion of data from some EVSE. In addition, some EVSE, though functional, fail to report data. In the third quarter of 2013, The EV Project had installed 963 EVSE in the San Diego region. Thus, the 521 EVSE represented only 54% of the installed residential EVSE.

The results for the first quarter 2013 are similar. In both cases, the maximum number of EVSE connected at any time is approximately 75% of all reporting EVSE utilized in the quarterly report. Assuming the effects of the whole population of residential EVSE is the same as those reporting, the entire population would be expected to produce the results shown in Figure 11-91.

Therefore, with the full population of residential EVSE in The EV Project in the third quarter of 2013, the minimum aggregated charging demand exceeded 100 kW and occurred from 4 p.m.to 4 a.m. As seen in Figure 11-85, these are times of changing load; therefore, services related to spinning reserve and transitional generation may be possible. In addition, regulation services may be performed. However, this does assume all these EVSE are enrolled in an aggregation program.

Because the minimum adjusted EVSE demand is just over 5 kW at 7 a.m., the total inventory of residential EVSE would need to be increased by a factor of 18 to produce 100-kW demand at all hours of the day.

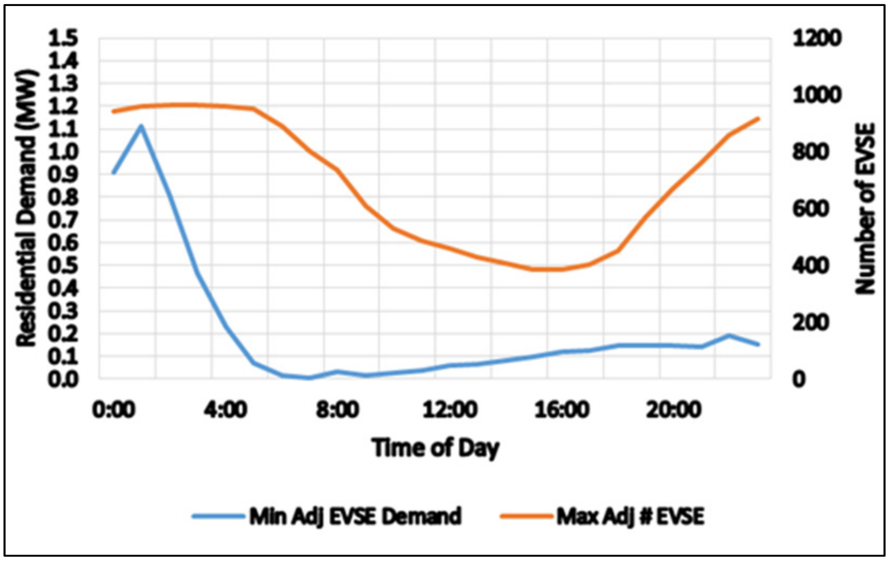

Figure 11-91. Extrapolated availability and demand.

However, third party aggregators may bid specific times or SDG&E may elect to provide services when sufficient EVSE are enrolled. SDG&E has already shown success in enlisting residential customers to select the super off-peak rate and, with the proper incentives, could enlist a significant number of residential PEV owners in a direct control demand reduction program.

11.2.8.7 Conclusions. A residential customer, who purchases and installs an AC Level 2, 240-volt EVSE, is required to obtain an electrical permit. SDG&E receives notification of this during the permitting process and has information on the total numbers of PEV owners with 240-volt EVSE. Some PEV drivers elect to charge their PEVs with a 120-volt EVSE for which permitting is not generally required. In these cases, the EVSE typically will not contain the necessary control and monitoring features to be included in a controllable demand program.

The EV Project enlisted 963 residential participants in the San Diego region by the end of 2013. The Blink EVSE provided to these participants by The EV Project incorporate the necessary control and monitoring functions to implement remote control of charging. The controllable demand represented by The EV Project residential EVSE in San Diego, if fully aggregated, was capable of over 100 kW of demand response in the third quarter of 2013. This capability was at hours of the day when demand reduction was not a priority for SDG&E. However, these are times of changing load; therefore, services related to spinning reserve and transitional generation may be possible.

As PEVs continue to be added to the San Diego area, the potentially controllable load from residential charging will continue to grow and may be attractive to SDG&E or third party aggregators as a demand reduction tool. However, EVSE installed by new PEV purchasers will require remote control capability if aggregation is to be effective.

The incentive programs promoted by SDG&E, coupled with easily programmable EVSE, are highly effective in moving residential charging to off-peak hours. This minimizes the need for directly controllable demand. However, as the number of residential EVSE continues to grow, there may be benefit to the utility having direct control. This analysis shows the population would need to grow by a factor of 18 to make direct control minimally worthwhile at all hours of the day. For the foreseeable future, direct utility control of residential EVSE is not beneficial, whereas indirect control through rate incentives is beneficial.

11.2.8.8 References

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11.3 EV Project Public Electric Vehicle Supply Equipment

11.3.1 How Do Publicly Accessible Charging Infrastructure Installation Costs Vary by Geographic Location?

11.3.1.1 Introduction. Publicly accessible charge stations are defined as those installed for businesses, institutions, and municipalities to provide charging to any and all PEV drivers. Typically, there is no prior relationship between the station owner and the station user that would prompt the installation, whereas fleet, workplace, and residential charging stations are intended to serve a specific vehicle or restricted population of vehicles.

Costs for installation of these units were an important part of The EV Project infrastructure study because these costs had an impact on host participation and, consequently, on the perception of PEV adoption.

Amongst the objectives for The EV Project was deployment of EVSE for PEV charging in geographically diverse markets. EV Project markets were selected based on the sales and marketing plans of PEV partners Nissan and Chevrolet. The diversity this provided enabled the project to evaluate the geographic considerations that affected installation costs and use of the charging infrastructure.

More than 8,000 Nissan Leafs and Chevrolet Volts purchased or leased in these markets were enrolled in The EV Project. Drivers of these vehicles agreed to allow EV Project researchers to collect and analyze data from their use of their PEVs and home EVSE, as well as their use of public charging infrastructure.

This section provides an analysis of the installation costs for this publicly accessible EVSE and discusses the geographic factors that drove variations in the cost to install this charging infrastructure.

11.3.1.2 Key Conclusions

- Average installation cost per unit for all publicly accessible AC Level 2 EVSE installed in EV Project markets was $3,108.
- The five most expensive geographic markets had per unit installation costs over $4,000 ($4,004 to $4,588).
- The five least expensive geographic markets had per unit installation costs under $2,600 ($2,088 to $2,609).
- Similar to residential EVSE and direct current DCFC installation costs, the AC Level 2 EVSE installed in California were the most expensive installations.

11.3.1.3 Data Analyzed. Information analyzed for this section came from reports generated from The EV Project database, which was populated using data from charging site hosts, project support personnel, and the electrical contractors installing EVSE. This section also benefits from the direct experience of The EV Project management team, which managed deployment of publicly accessible charging infrastructure.

Of the nearly 4,000 AC Level 2 EVSE units installed for public use, installation cost data for analysis is available for 2,479 units (approximately 60%). Although this is a good sample size and a reasonable representation of the total number of installations, the data available for analysis were not evenly collected over the study markets, as shown in Table 11-23.

Table 11-23. AC Level 2 EVSE installed, cost data available, and percentage of those installed with cost data for analysis.

Market	EVSE Installed per EV Project Status Report August 2013	EVSE with Installation Cost Data Available	Percentage of Installation Data Available for Analysis
Atlanta	202	141	69.8%
Los Angeles	440	208	47.3%
San Francisco	168	110	65.5%
Chicago	25	19	76.0%
San Diego	634	361	56.9%
Seattle	398	165	41.5%
Houston	134	52	38.8%
Philadelphia	75	33	44.0%
Oregon	527	437	82.9%
Dallas	433	167	38.6%
Tennessee	621	130	20.9%
Arizona	631	618	97.9%
Washington DC	39	38	97.4%
Total	4,327	2,479	57.3%

EV Project Commercial Deployment Approach—To interpret and fully understand installation cost data collected from deployment of publicly accessible charging infrastructure in The EV Project, one must understand the approach that was taken to recruit hosts for the charging infrastructure.

The objective for deployment of the "away from home" charging infrastructure in The EV Project was to provide charging where PEV drivers were likely to park or where hosts would like to have them park. In the first five markets of The EV Project, a local group of stakeholders participated in a detailed planning process developed by The EV Project's Micro-Climate process [42]. One of the deliverables of this process was a plan for deployment of publicly accessible EVSE in the market. Local project personnel then solicited charging site hosts in the desired geographic locations to support deployment of this infrastructure. While the remaining markets did not implement a formal Micro-Climate process, they benefitted directly from the lessons learned when placing EVSE in the first five markets.

The EV Project plan directed installation of publicly accessible EVSE to begin in April 2011, about 3 months after residential installations began. This infrastructure was placed in accordance with the plan in the parking lots of retail locations, public attraction sites, public buildings, workplace environments, and many other venues.

A typical public EVSE site included multiple charging stations, which was encouraged for the benefit of both PEV drivers (to assure availability of EVSE) and hosts (to attract more PEV drivers as customers for their business). Installation of multiple EVSE at a site often times also resulted in a lower installed cost per EVSE unit.

By the end of 2011, The EV Project installed publicly accessible Blink EVSE in the following 10 geographically diverse markets:

1. Arizona (metro Phoenix and Tucson)
2. San Diego, California
3. Oregon (Portland metro, Corvallis, Eugene, and Salem)
4. Seattle, Washington (Seattle metro, Tacoma, and Olympia)
5. Tennessee (entire state)
6. San Francisco, California
7. Los Angeles, California
8. Washington D.C. (metro area including Maryland and Virginia)
9. Dallas, Texas
10. Houston, Texas.

In spring 2012, The EV Project added the following three new markets:

1. Chicago, Illinois
2. Philadelphia, Pennsylvania
3. Atlanta, Georgia.

11.3.1.4 Observations. The average installation cost for publicly accessible AC Level 2 EVSE in all EV Project markets is shown in Figure 11-92. The overall average was $3,108 per unit installed, with installation costs varying from less than $600 per unit to over $12,000.

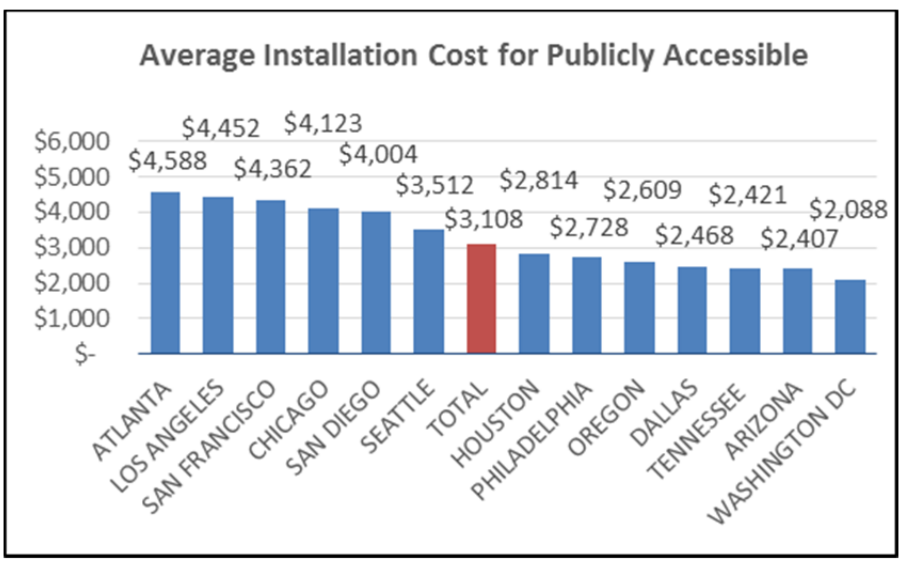

Figure 11-92. Average installation cost for publicly accessible EVSE by EV Project market.

The three California markets of Los Angeles, San Diego, and San Francisco were near the top in public EVSE costs, as they were for residential EVSE installation costs [43]. Data analyzed for all three California markets had significant installation numbers; however, the Chicago (19), Houston (52), Philadelphia (33), and Washington D.C. (38) market installation data provided far fewer samples.

A graphical representation of the comparative number of publicly accessible EVSE installations that had cost data available for analysis is shown in Figure 11-93. Three of the 13 markets defined for analysis (i.e., Arizona, Oregon, and San Diego) had 60% of the installations with cost data. Meanwhile, four identified markets are barely distinguishable in the pie chart. These low sample sizes do not provide a good basis for comparing average costs in these markets with other markets.

The Atlanta installation cost data also deserve further analysis because their installation costs were unexpectedly high when compared to their position as the least expensive market for residential installation costs.

The 40 most expensive installations in the Atlanta market (i.e., 26% of the total installations with cost data in Atlanta) had an average cost of $7,175 per unit installed. This is well over twice the average installation cost of $3,108 and is the reason the average AC Level 2 installation costs in Atlanta appear to the far left in Figure 11-92. All 40 of these installations were part of a national agreement to install Blink charging stations. There was significant funding support from the national organization hosting these EVSE, enabling it to dictate placement of the EVSE in prominent locations in the parking area. These stations were installed away from the front of the building, in conspicuous parking spaces that were not in direct competition with shoppers seeking the shortest path to and from the store. The long electrical runs from the electric service panel (typically at the back of the store) to a location well into the parking lot at the front of the store, made these installations much more expensive than typical installations in other markets.

Although the number of installations was small, the publicly accessible installations in Washington D.C. were also of interest. These EVSE installations represented the least expensive installations, in large part, because nearly 80% of them (Figure 11-94) were wall-mounted installations. These less expensive installations are discussed further in the paper, "What were the cost drivers for publicly accessible charging installations?" [45].

As with residential charging costs by region [46], labor was the primary geographic differentiator of EVSE installation cost, because the prevailing wages dictated by the DBA, which vary by market, were used for installation labor in all of The EV Project.

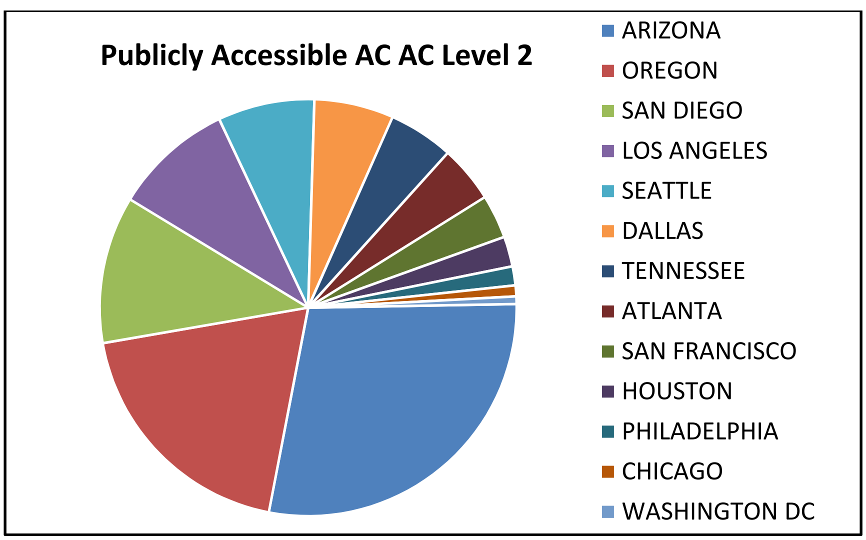

Figure 11-93. Number of publicly accessible AC Level 2 EVSE per market for which installation cost data are available.

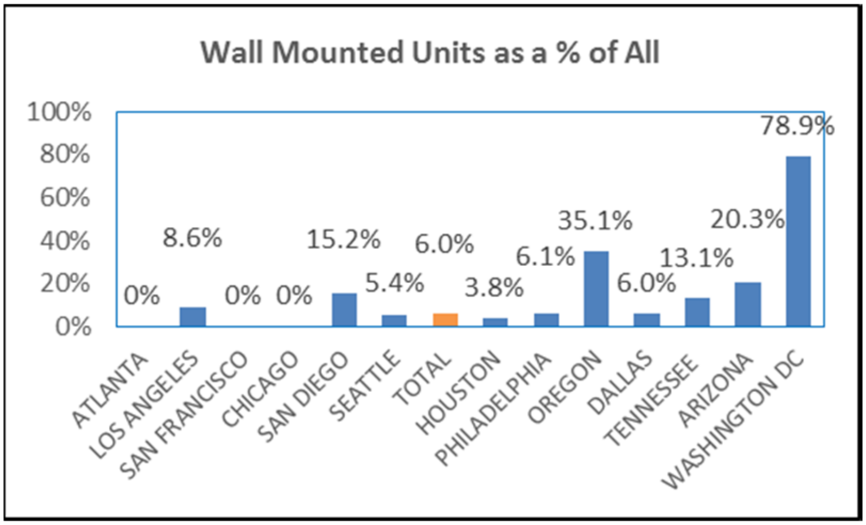

Figure 11-94. Wall-mounted units as a percentage of all non-residential units deployed.

Another factor that affected installation costs in different markets was implementation of Americans with Disability Act requirements as understood by the local permitting AHJ. While Americans with Disability Act requirements were in place during the term of The EV Project, these had not been specifically promulgated to the local level during the term of The EV Project, leaving the local AHJ to provide their own interpretations of Americans with Disability Act requirements. The AHJ interpretations varied widely from locations with no Americans with Disability Act requirements at all to others that required fully accessible EVSE (including van accessible parking spaces) and accessibility from the EVSE to buildings on the host site.

Although Americans with Disability Act compliance was an objective for all EV Project installations for publicly accessible EVSE, requirements in the San Diego market were particularly rigorous and added significantly to installation cost [47]. An example of an Americans with Disability Act-compliant site is shown in Figure 11-95. The requirements typically affected the entire site layout; therefore, overall site installation costs were higher. This requirement was most prevalent at DCFC sites, which required an Americans with Disability Act accessible AC Level 2 EVSE be installed alongside the DCFC unit.

Figure 11-95. Americans with Disability Act -access compliant EVSE installation.

The EV Project's approach to Americans with Disability Act can be found in The EV Project Lesson Learned White Paper, "Accessibility at Public EV Charging Locations" [48].

11.3.1.5 Conclusions. For markets with sufficient sample quantities for comparison, the average installation costs for publicly accessible AC Level 2 EVSE charging infrastructure varied by a factor of two across geographic markets; Arizona at $2,407 versus Atlanta at $4,588.

Some charging site hosts supplemented the installation allowance provided by The EV Project to make their EVSE installations a more visible part of their business. While these decisions on EVSE installation met the host's objectives, they also led to higher-than-average installation costs.

As with residential installation costs [49], California costs for labor and permitting of publicly accessible EVSE installations made them among the most expensive sites by geographic region. Further details on installation costs and cost drivers for publicly accessible EVSE can be found in the lessons learned paper, "What were the Cost Drivers for Publicly Accessible Charging Installations?" [50].

11.3.1.6 References

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48. http://avt.inel.gov/evproject.shtml#LessonsLearned EV Project lesson learned white paper, "Accessibility at Public EV Charging Locations."
49. http://avt.inel.gov/evproject.shtml#LessonsLearned EV Project lesson learned white paper, "How do Residential Charging Installation Costs Vary by Geographic Location?"
50. http://avt.inel.gov/evproject.shtml#LessonsLearned EV Project lesson learned white paper, "What were the cost drivers for publicly accessible charging installations?"

11.3.2 Electric Vehicle Public Charging – Time Versus Energy March 2013

11.3.2.1 Introduction. A critical factor for successful PEV adoption is deployment and use of charging infrastructure in non-residential locations. Vehicle operators utilize this infrastructure to extend the electric range of their PEV. Without charging infrastructure in commercial locations, PEVs are "tethered" to their overnight charging location.

Through The EV Project, charging infrastructure at commercial locations has been deployed in various cities across the country. To stimulate use of this charging infrastructure and familiarize EV owners with its operation, access to the infrastructure was initially provided at no cost. This lesson learned paper presents issues and options considered by The EV Project in determining the metric to be used for introducing access fees for commercial charging infrastructure.

11.3.2.2 Free Charging is Not Viable. While free access to commercial charging infrastructure provides an effective means of initializing infrastructure use, it does not support a "viral" expansion of charging infrastructure. Widespread deployment of charging infrastructure at commercial locations (Figure 11-96) must either be subsidized or it must generate sufficient income to provide a return on the investment made by the infrastructure owner. It is assumed that a small amount of charging infrastructure may be subsidized by the local, state, or federal government funding its installation and some businesses may choose to subsidize it by providing free charging as an enticement to attract customers. However, the quantity of charging infrastructure necessary to support widespread adoption of PEVs must be supported by private investment, anticipating a return. Access fees provide one mechanism for providing this return on investment.

Figure 11-96. AC Level 2 EVSE charging station at Monti's la Casa Vieja in Tempe, Arizona.

11.3.2.3 Assessing Access Fees. The EV community currently employs three means for assessing fees when an EV owner accesses commercial charging infrastructure: (1) by time connected to the unit for charge; (2) by energy used, measured in kilowatt hours (kWh); and (3) by means of a subscription, wherein all in-network charging is included in a monthly fee.

This paper intends to address only the time and energy consumption-based methods, because the networks that employ these are currently more prevalent across the country.

11.3.2.4 Time-Based Access Fees. Time-based access fees are applied to the user of the charge infrastructure for all of the time the vehicle is connected to the charge unit. This is regardless of whether or not there is energy being delivered or the rate at which it is delivered. Once authorized to charge and connected to the vehicle, the charging costs accumulate in increments of time and continue until the charge is stopped or interrupted. The total cost reflects the total time that the vehicle had access to the charging station.

Addresses Investment in Infrastructure—Total cost for an EVSE charging station installed at a business location is thousands of dollars. Normally, this investment will need to be recouped over time.

The following are items that a commercial charge infrastructure owner/host pays up-front to have an EVSE charging station installed:

- Parking space – This is typically one of the closest parking spaces to the building to provide economic access to supply power, for visibility, and access for ADA compliance.
- EVSE unit costs – This cost could range from $800 to $3,000 for the AC Level 2 charger [51] and $30,000 to $80,000 for a DCFC unit. The greater the charging rate available, the more complex and expensive the EVSE unit.
- Installation costs – This cost could range from $3,000 to $15,000 [52] per site. The fees may consist of installing the EVSE unit, concrete and asphalt cutting, trenching, connection to electrical utility box, resurfacing the asphalt parking lot, striping, signage, and replacing concrete.
- Permit costs – These costs vary from city to city and could be from a few tens to a few hundreds of dollars.

Ongoing costs, once the EVSE unit is installed, include costs to maintain the parking lot (e.g., resurfacing, cleaning, lighting, etc.), insurance costs, property taxes, and the cost of electricity consumed. The cost of electricity for EV charging is actually one of the least expensive items associated with hosting an EV charging station.

To recover the cost of owning and operating a charging station, both the fixed initial costs and the ongoing operating costs must be recovered. Access fees based on time connected to the charger reflect the significant fixed initial cost in the charging station and time based on ongoing operating costs (such as taxes), but completely ignore the cost of electricity actually transferred during a charge. Therefore, the fee assessed per unit of time to connect to the charger must reflect an average energy transfer. This average can accurately reflect energy transfer for low-power charging. For example, at a 3.3-kW AC Level 2 AC charge rate, PEVs generally charge at the full 3.3 kW until very near the end of the charge. However, at higher-power charging, particularly DCFC, the charge rate can vary significantly over time.

Discourages Charger Overuse—An EVSE charging station can be compared to a table or booth at a popular restaurant. Even though the booth may only cost a few hundred dollars itself, several factors make the booth more valuable. These include the location, cost of the building where it resides, cost of employees to service the clients at the booth, costs to maintain the building to keep the booth secure, insurance costs, food costs, etc. The business owner makes a small income every time a client sits at the booth and orders from the menu. This income over time pays for the booth, the building, the employees, and all costs related to the business. Therefore, when comparing the table at a popular restaurant to the EVSE charging station, if a customer does not order from the menu at a restaurant but occupies the table, they are preventing other customers from using the table and not providing income for the restaurant. Similarly, if the restaurant customer eats his meal but then stays and chats for 2 more hours, they are likewise preventing other customers from using the table and providing income for the restaurant. The same is true when an EV is plugged into the EVSE charging station and not charging. Charging by time connected to the charger encourages PEV owners to move their vehicles out of the charging location promptly upon charge completion. This ensures that the charger is available to as many PEVs as possible and prevents a single PEV from dominating the charger location, while providing no revenue to the charger owner.

Simple Administration—When being billed by time, an EV owner knows the amount they are going to have to pay for the time they are plugged into the EVSE charging station. They can determine how much they want to spend and how long they can visit the local business before their charging is complete.

As will be shown in Section 11.3.2.5, paying for charger access by kWh consumed can be less predictable, presenting the PEV owner with uncertainty concerning the amount they will pay for charging.

11.3.2.5 Fees Based on Energy Consumed. Fees assessed for vehicle charging based on energy consumption measure the amount of energy disbursed and bills the EV driver based on total energy consumed. The user of the charging unit only pays for the energy consumed; therefore, this requires prior authorization to charge and connection to the vehicle. The EV driver pays a set fee per kWh regardless of what the host/EVSE owner pays for energy or any other operational cost.

Investment in Infrastructure—Fee collection based on energy consumption (kWh) does not provide the same consistent benefit to the business owner or the customer. There is no real way to monitor kWh transfer, because the electrical utility meter cannot be reset every time someone begins a charge. The business owner has no real way of collecting data to know how many charges occurred in a specific time period. The charge rate that a vehicle accepts depends on battery condition and the customer does not know the amount they are going to be charged every time they use the EVSE unit, since kWh fluctuate, their charging session amount could fluctuate at every charge.

Access fees based on energy transferred during charge very accurately recover the ongoing cost of energy for charging. This provides the user of the charger consistent value (energy priced in kWh) for the fee paid to access the charger. However, because much of the investment in charging infrastructure is associated with the fixed initial cost of equipment and installation, access fees based on energy transferred during charge must be adjusted to provide an average return on this investment as well. This adjustment is complicated by charge events during which the vehicle completes charging, yet remains connected to the charger. The only cost that ceases is electricity and, with it, all revenue to the host. Much like the restaurant customer who eats their meal but then stays and chats for 2 more hours, these charge events that deliver no energy for extended periods of time must be compensated for by higher fees for energy actually transferred.

Must be Licensed to Sell Electrical Energy in Most States—Electric utilities have huge financial investments in generation, transmission, and distribution infrastructure that provide electricity to its customers. In exchange for making these investments, electric utilities are typically chartered as the exclusive provider of electricity in a specific service territory. As such, no other companies are permitted to charge for the sale of electricity. When EVSE equipment suppliers charge by the kWh, they fall into the category of an electric utility. As a result, the sale of electrical energy from an EVSE in most states (and electric utility service territories) is illegal unless specifically provided for in regulations. According to DOE's Alternative Fuel Data Center (http://www.afdc.energy.gov/laws/state), the jurisdictions that have amended regulations to allow sale of electricity by kWh from EVSE include the following:

- California
- Colorado
- Virginia
- Florida
- Washington
- Oregon
- Minnesota
- Illinois
- Maryland.

The white paper titled, "Regulatory Issues and Utility EV Rate," takes a detailed look at utility regulation in numerous states related to EV charging.

Meter Certification—In jurisdictions that do allow sale of electricity from EVSE, questions arise related to accurately measuring the amount of electricity sold. Typically, items sold by measure (in this case: energy) require third-party certification of a measurement system to ensure consumer protection. Electric utilities have rigorous meter certification programs governed by both national standards (such as ANSI C.12) and by state regulation. Additionally, electric utility meters are sealed to prevent energy theft and are removable to allow verification of accuracy by laboratory testing. Meters incorporated in EVSE typically do not meet many of these typical electric utility requirements. Efforts have currently been set in place by the California Public Utility Commission to define specific requirements for electric meters embedded in EVSE.

11.3.2.6 Conclusion. Widespread deployment of EV infrastructure requires successful implementation of fees for charger access. Currently, two prevalent means for assessing access fees are in use: (1) by time and (2) by energy consumed. Experience to-date with these fee metrics has identified the following characteristics of each.

Time-Based Fees

- Provide a simple, understandable metric for access fees
- Facilitate a simple metering scheme (clock) with uncomplicated certification of accuracy
- Discourage vehicles from parking at chargers for extended periods after charging is complete,
- Accurately represents the overall cost of providing charge infrastructure, but is not proportional to the actual quantity of energy delivered.
- Advantages
    - Simple
    - Accurate measure
    - Encourages turnover
- Disadvantages
    - Paying for blocking access for others when not getting energy from the charge unit.

Energy-Based Fees (kWh)

- Allow fees charged to be proportional to the actual amount of energy delivered
- Require regulatory changes in most states to allow non-utility entities to "sell electricity"
- Do not proportionally reflect time-related costs (e.g. equipment and installation cost) of providing PEV charging infrastructure
- Allow vehicles to remain connected to charging infrastructure at no cost.
- Advantages
    - EV driver only pays for energy used
- Disadvantages
    - EV driver can block access to charge unit for others with no penalty
    - Does not encourage turnover of potential business customers for the host
    - Not allowed in most states
    - Accuracy of energy measurement can be called into question without an established third-party qualification system.

Because one of the primary objectives for The EV Project is to encourage and determine ways to encourage the widespread adoption of PEVs, Blink has elected to charge access fees by time on the Blink network of chargers. This defines the space as a "charging space" rather than a parking space, and this approach promotes PEV charging for a greater number of drivers.

11.3.2.7 References

51. "Financial Viability of Non-Residential Electric Charging Stations," UCLA Luskin School of Public Affairs, August 2012.

52. "Public Charging Stations Fuel Desire for Electric Cars," CNN, October 24, 2012.

11.3.3 What Was the Impact of Car Sharing on Publicly Accessible Charging Infrastructure in San Diego

11.3.3.1 Introduction. Over 8,000 Nissan LEAFs™, Chevrolet Volts, and Smart ForTwo PEVs were enrolled in The EV Project. The Smart ForTwo PEVs were owned by Car2Go, a car share operator in the San Diego region of The EV Project. By the end of 2013, Car2Go had enrolled 386 Smart PEVs as part of their car share business. The business plan for Car2Go is described herein and includes charging vehicles at publicly accessible EVSE. This paper explores the impact of Car2Go car share vehicle utilization of these EVSE.

11.3.3.2 Key Conclusions

- Publicly accessible EVSE in The EV Project provided convenient drop off locations for drivers using Car2Go car share vehicles, because the EVSE are at popular destinations and the Car2Go renter is not responsible for recharge costs.
- Car2Go use of publicly accessible EVSE during The EV Project for charging their car share vehicles resulted in longer connect times than typical with other PEV drivers and negatively affected the availability of EVSE.
- Business changes initiated by Car2Go at the end of 2012 significantly reduced the negative impact associated with Car2Go car share vehicles parked at EVSE intended for public use.

11.3.3.3 Data Analyzed. The EV Project published quarterly reports from the fourth quarter of 2011 through the end of the project in the fourth quarter of 2013 [53]. The Leaf and Volt vehicles enrolled in The EV Project utilized vehicle telematics to transmit data to The EV Project's Blink Network. These data were subsequently transmitted to INL. Mileage data generated by Car2Go use of the Smart ForTwo PEVs were manually recorded and transmitted by The EV Project to INL. Access to publicly accessible EVSE required the use of Blink membership cards; therefore, each of the Car2Go vehicles was provided with a Blink membership card for charging. Use of the membership card allowed collection of charge data for these vehicles over the Blink network. For this report, Car2Go information available in The EV Project quarterly reports was reviewed and extracted. In addition, detailed charging data from publicly accessible EVSE for several time periods were analyzed. Smart ForTwo vehicles do not have a fast charge inlet; therefore, no DCFC information was included in this analysis.

11.3.3.4 Car2Go Business Overview. Car2Go provides Smart ForTwo PEVs for rent (Figure 11-97) in the "home areas" of San Diego. Members in the car sharing service locate an available Smart PEV near them using a smart phone application, swipe their Car2Go member card, answer a few questions on a touch screen, and drive as little or as much as they like. They may travel outside the home area, but cannot complete their trip outside of the home area. The PEV must be returned to an authorized location within the home area when the trip is ended. The drop-off location need not be at an EVSE, because there is no requirement for the driver to charge the vehicle. However, the Smart ForTwo PEV may be parked and charged at any EV Project publicly accessible Blink EVSE at no cost to the car share driver. For any vehicle trip ending with the battery below a 25% SOC, Car2Go personnel retrieved the car and assure it gets charged. The Car2Go website [54] provides more information and frequently asked questions related to vehicle use, charging, and parking.

Fully charging the 17.6-kWh Smart ForTwo PEV battery using AC Level 2 EVSE requires approximately 6 hours. A fully charged battery delivers approximately 68 miles of driving range [55].

Figure 11-97. Smart ForTwo PEV.

11.3.3.5 Analyses Performed

Quarterly Report Analysis—The number of Car2Go Smart PEVs enrolled in The EV Project in the San Diego region increased from 92 in November 2011 to 386 vehicles by the fourth quarter of 2013. A few vehicles were removed from service by the end of 2013, resulting in a total of 373 vehicles for which data were collected. Over the same time period, the miles driven increased from 173,000 miles per quarter to just over 400,000 miles per quarter. Figure 11-98 shows this change over the duration of The EV Project.

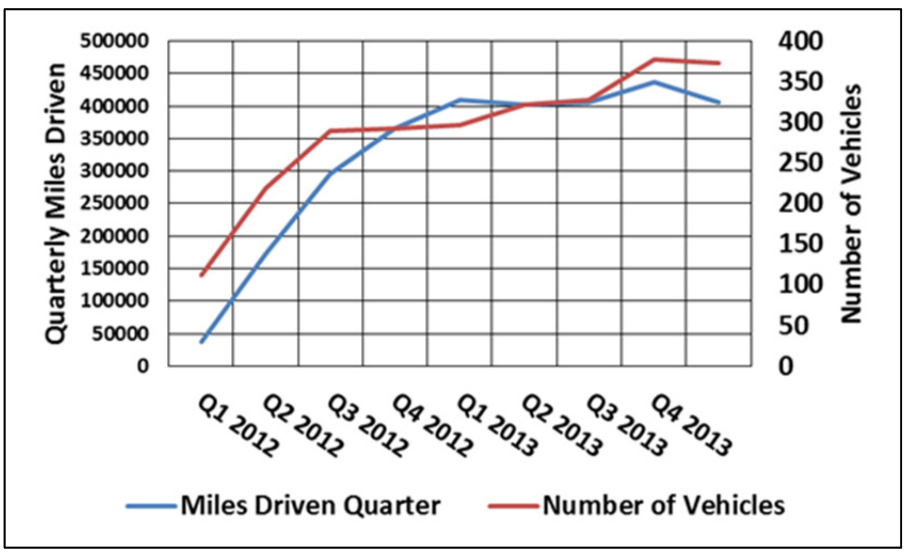


Figure 11-98. Growth of Car2Go in The EV Project in San Diego.

In early 2012, the Car2Go direction given to drivers was to terminate their trip at a publicly accessible EVSE in the San Diego region. However, many did not, which required Car2Go personnel to retrieve the PEV and return it to their facility or a nearby publicly accessible EVSE for charging. Many vehicles were left in difficult locations for Car2Go, hence, initiation of the Car2Go home area. During this time, charging at publicly accessible EVSE was no cost for Car2Go drivers; anecdotal comments were received from San Diego PEV owners that they were being denied charging because the Car2Go vehicles were parked for long durations at the publicly accessible EVSE.

Mid-year 2012, The EV Project instituted fees for charging based on the length of connect time. Car2Go paid these fees for their vehicles using publicly accessible EVSE. In December 2012, Car2Go increased the number of EVSE at their facility from eight to thirty-eight to accommodate more car charging there and also required that vehicles be returned to the Car2Go home area.

It is possible to track Car2Go charging through the use of Blink membership cards located in each Smart ForTwo PEV and to access Blink EVSE. Figure 11-99 shows the change in the percentage of vehicles charged at publicly accessible EVSE that were part of this car sharing service as reported in The EV Project's quarterly reports. It is noted that the reported number of charge events at these publicly accessible EVSE included all PEVs, not just those participating in the project.

While the number of EV Project vehicles, non-project PEVs, and publicly accessible EVSE in San Diego increased through the second quarter of 2013, the percentage of all charge events at publicly accessible EVSE by Car2Go vehicles dropped dramatically from near 80% of all events to approximately 20% of all events. At first, this drop would appear to be the result of a change in the Car2Go charging philosophy. However, with further analysis, it becomes clear that this drop was caused by a significant increase in the use of the EVSE by other PEVs.

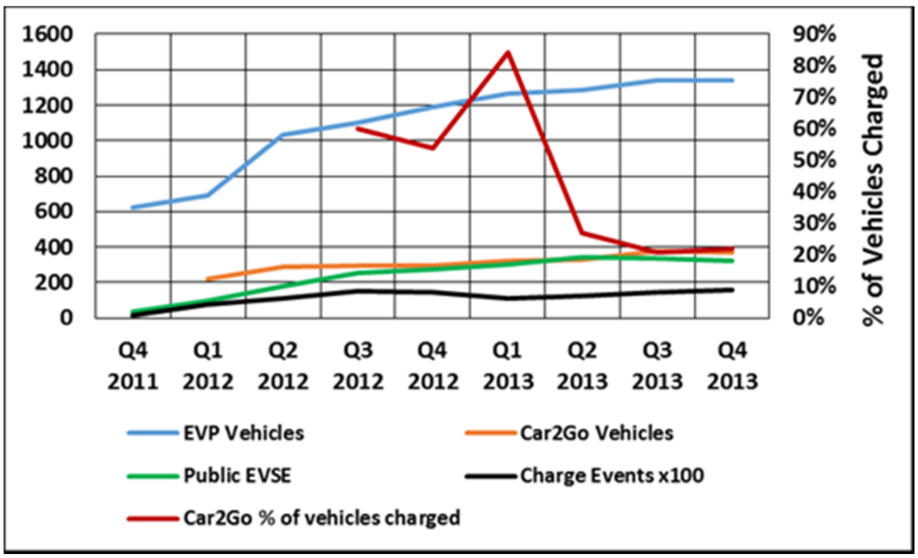


Figure 11-99. Car2Go percent of vehicles charged at publicly accessible EVSE.

Charge Data Analysis—To better understand Car2Go use of EV Project EVSE, the first and fourth quarter 2013 publicly accessible EVSE data were analyzed. All fleet and workplace EVSE installed by The EV Project were removed from consideration because the behavior of PEV drivers at these locations is much different than that at publicly accessible locations, even though some of these EVSE may also be available to the public. In the first quarter, a total of 3,500 charge events by Car2Go vehicles occurred at publicly accessible EVSE. For these EVSE, the charge commenced at the time a vehicle connects. The total time the EVSE delivered power was subtracted from the total vehicle connect time to identify the idle time for each event. Table 11-24 summarizes the results. The average energy of 12.8 kWh delivered per charge compared to the battery capacity of 17.6 kWh indicates an average battery SOC of 27% at the start of charge.

The average kWh per charge by Car2Go drivers changed little from the first to the fourth quarter of 2013. The average connect time increased, resulting in an increase in the average idle time. The miles driven by Car2Go vehicles in each quarter were nearly the same; therefore, the similarity of the average energy per charge is not surprising. Figures 11-100 and 11-101 illustrate the differences in connect and idle times between Car2Go vehicles and all other PEVs in the San Diego region.

Table 11-24. Charge characteristics during the first quarter of 2013.

Vehicles	Average Connect Time (hrs)	Average Idle Time (hrs)	Average kWh per Charge	Total kWh in Quarter
Car2Go	6.8	3.0	12.8	44,922
Others	3.7	1.7	7.8	34,417

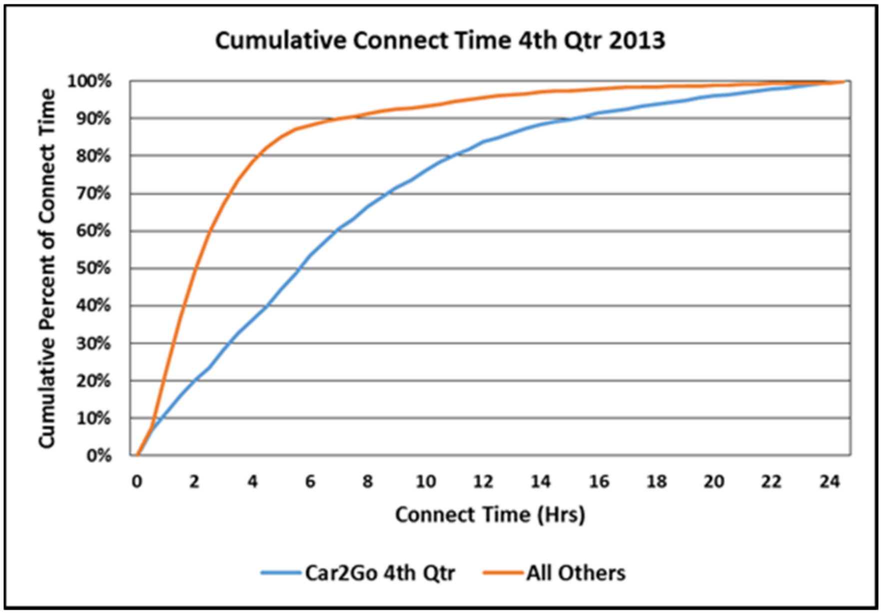


Figure 11-100. Distribution of connect time per connect event for the fourth quarter of 2013.

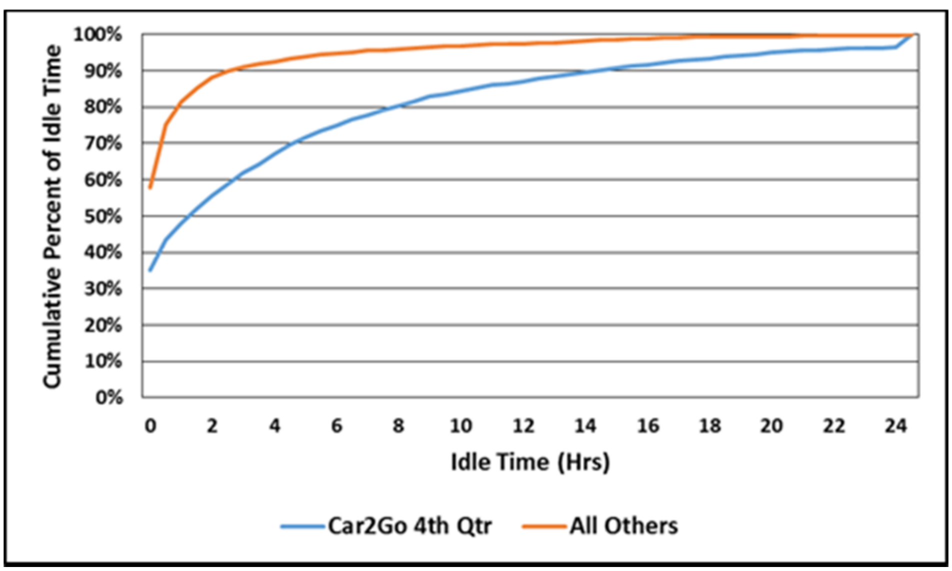


Figure 11-101. Distribution of idle time per connect event for the fourth quarter of 2013.

In the fourth quarter of 2013, there were a total of 3,689 charge events by Car2Go vehicles at publicly accessible EVSE. Table 11-25 summarizes these data.

Table 11-25. Charge characteristics during the fourth quarter of 2013.

Vehicles	Average Connect Time (hrs)	Average Idle Time (hrs)	Average kWh per Charge	Total kWh in Quarter
Car2Go	8.5	4.8	12.5	46,168
Others	4.6	2.2	9.1	72,546

The major change from the first to the fourth quarter of 2013 is the amount of energy charged by vehicles other than the Car2Go vehicles. As seen in Tables 11-24 and 11-25, the publicly accessible EVSE dispensed 34,417 kWh in the first quarter 2013 and 72,546 kWh in the fourth quarter. This results in the drop in the share of public charging events by Car2Go vehicles shown in Figure 11-99. Further, with publicly accessible EVSE access fees imposed based on time connected to EVSE, minimization of idle time by non-Car2Go drivers is to be expected. Nearly 60% of non Car2Go vehicles have no idle time following charge.

Publicly accessible EVSE charge data for the third quarter of 2012 (prior to the business changes by Car2Go) were also investigated. Car2Go vehicles charged at publicly accessible EVSE nearly 17,000 times during this period. The third quarter report identified that 60% of the publicly accessible EVSE charging was accomplished by Car2Go vehicles. Table 11-26 provides a comparison of these events to the fourth quarter of 2013.

Table 11-26. Car2Go comparison 2012 and 2013.

Quarter	Number Vehicles Enrolled	Average Connect Time (hrs)	Average kWh per Charge	Total kWh in Quarter
3rd Qtr 2012	292	4.7	10.3	174,762
4th Qtr 2013	373	8.5	12.5	46,168

As noted above, the change in the business plan by Car2Go reduced the number of charge events by Car2Go vehicles from 17,000 events in the third quarter of 2012 to 3,500 in the first quarter of 2013 or 79% reduction and energy delivered from 174,762 kWh to 44,922 kWh or 74% reduction in the same period.

Charging Locations—Use of publicly accessible EVSE by Car2Go vehicles in the fourth quarter of 2013 was further analyzed to determine if these vehicles favored specific EVSE locations. Figure 11-102 shows the relative usage (using the metric of energy consumed), number of connect events, and idle time for specific EVSE sites in the San Diego region.

The percentage of energy transferred closely follows the percentage of connect events at each EVSE site. However, there are significant differences in the relationship of idle time. Sites with high energy transfer or high connect events but low idle time would suggest the site has high vehicle turnover for Car2Go or is a destination site for the Car2Go driver (as with other PEV drivers) and the driver disconnects and continues the trip. Such sites occupied by Car2Go vehicles should not be any more of an annoyance to other drivers than other PEVs that might be parked there. On the other hand, sites with high idle time, especially those in high connect event locations, may be specifically observed by other PEV drivers and seen as an annoyance.

The top nine sites are detailed further in Table 11-27.

Notes on the PlugShare website for Site 929 state that it is a frequent Car2Go vehicle location [56]. One of the PlugShare site photos at Site 818 is shown in Figure 11-104.

The sites with the greatest percent of idle time are shown in Figure 11-103.

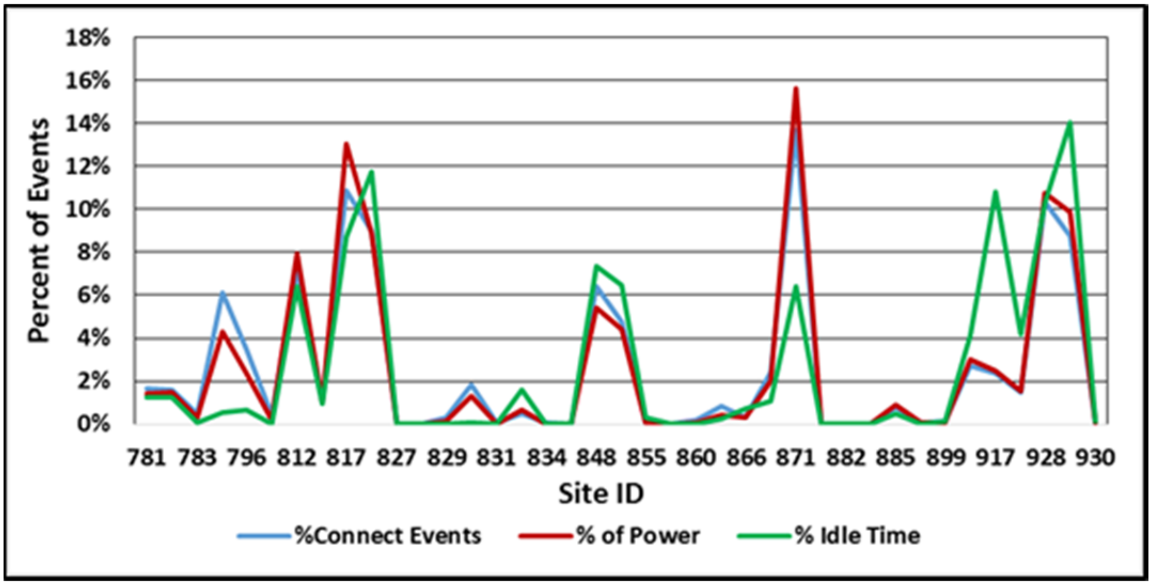


Figure 11-102. Publicly accessible usage by Car2Go vehicles.

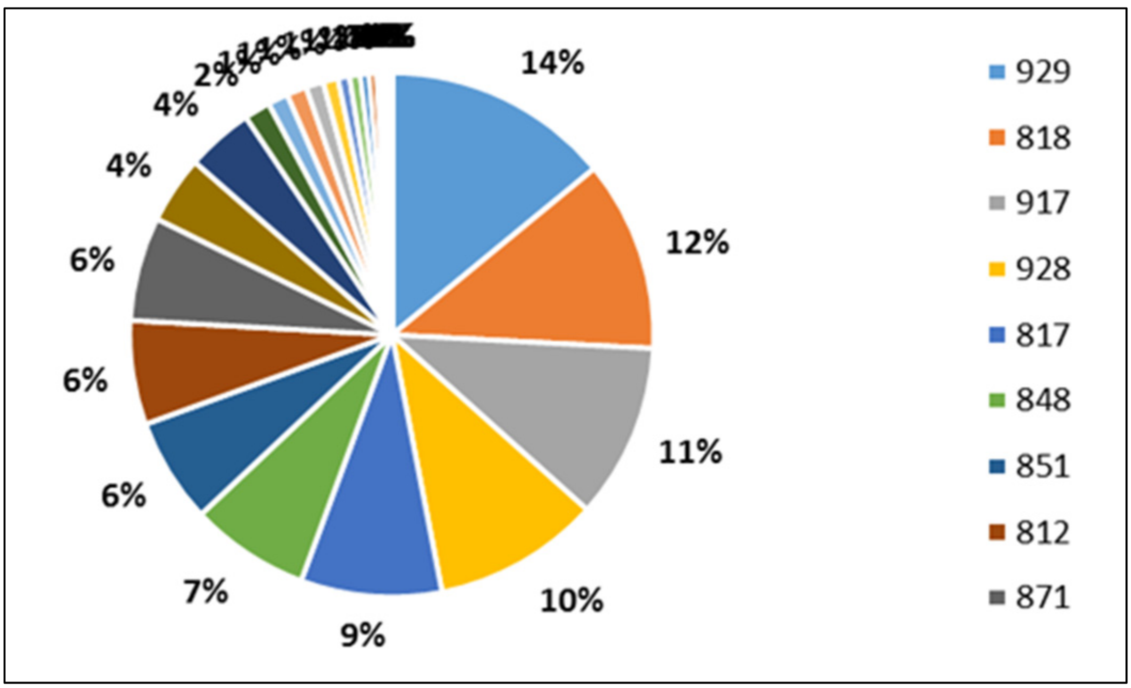


Figure 11-103. Car2Go idle time locations.

Table 11-27. Publicly accessible EVSE sites with high Car2Go idle times.

Site	Location	Venue
929	2748 Historic Decatur Rd, SD	Shopping Center
818	2590 E. Mission Bay Dr., SD	Parks and Recreation
917	373 Park Way, Chula Vista	Parks and Recreation
928	2495 Truxton Rd, SD	Shopping Center
817	1100 W. Mission Bay Dr., SD	Parks and Recreation

Site	Location	Venue
848	San Diego State University	Educational Services
851	San Diego State University	Educational Services
812	2111 Pan American Plaza, SD	Arts and Entertainment
871	4067 El Cajon Blvd, SD	Small Retail

Figure 11-104. PlugShare photo at Site 818 [57].

11.3.3.6 Discussion of Results. Use of publicly accessible EVSE by the Car2Go fleet impacted the availability of publicly accessible EVSE for other PEV drivers. However, the business changes made by Car2Go to conduct more charging at their facility reduced that impact significantly. It likely also reduced their costs because the access fee structure for publicly accessible EVSE was based on connect time, whereas charging costs at their own facility were based on the actual cost of energy. Shifting more of the charging to their own facility would have no overall impact on the electric grid because the amount of energy required would be the same. However, because charging site hosts also received a portion of the charging fees, reduction in publicly accessible charging negatively affected the charging site host's revenue share.

A car sharing service that uses publicly accessible EVSE and is charged fees based on time connected has an incentive to reduce idle time, if possible, and attempt to free the EVSE for use by others. However, the fee for use of most publicly accessible EVSE has changed to be based on the actual energy transferred, which creates no incentive for drivers (both car sharing and other PEVs) to move their vehicle upon completion of charging.

11.3.3.7 References

53. EV Project Quarterly Reports, http://avt.inl.gov/evproject.shtml.

54. Car2Go website, http://sandiego.car2go.com/.

55. Smart USA website, http://www.smartusa.com/models/electric-drive/overview.aspx.

56. www.Plugshare.com.

57. ibid.

11.3.4 What is the Impact of Utility Demand Charges on an Alternating Current Level 2 Electric Vehicle Supply Equipment Host?

11.3.4.1 Introduction. The EVSE delivered by The EV Project included both residential and non-residential units. Approximately 4,000 non-residential AC Level 2 EVSE were installed in workplace environments, fleet applications, and publicly accessible locations near retail centers, parking lots, and similar locations. The Blink AC Level 2 utilized in The EV Project is capable of charging at up to 7.2 kW power, although most vehicles in The EV Project charged at about 3.7 kW. This power can be a significant additional electrical load for the charging site host. This concern becomes greater when several EVSE are in operation on a site at the same time.

Many electric utilities include maximum power demand as part of their commercial rate structure. The demand charge incurred by a commercial customer is related to the peak power used during a monthly billing cycle. This is in contrast to the total energy usage that is the more familiar utility charge seen for residential service. A demand charge is typically calculated based on the highest average power level over a 15 minute period during the monthly billing cycle and is not a cumulative-type charge.

One objective of The EV Project was to elucidate the motivations and hindrances to potential site hosts of non-residential EVSE. The imposition of electric utility demand charges represents such a potential hindrance.

This subject was introduced in the paper: DCFC - Demand Charge Reduction [58], specifically dealing with DCFCs. The concept remains relevant to AC Level 2 EVSE, especially when several EVSE are deployed at the same site, which occurred frequently in The EV Project. In fact, the average number of AC Level 2 EVSE per site was 2.58 and varied by market from 1.79 to 3.45 per site.

This paper identifies the impact of demand charges on non-residential AC Level 2 hosts in The EV Project.

11.3.4.2 Key Conclusions

- Some electric utilities in The EV Project market areas impose demand charges on the highest power delivered to a customer in a month.
- Simultaneously charging multiple AC Level 2 EVSE can create significant increases in power demand.
- These demand charges can have a significant impact on monthly electric utility costs, especially for small businesses.
- The increased charging rate allowed by many newer PEVs will exacerbate this impact.
- Separately metered EVSE charging service may enable AC Level 2 charging site hosts to avoid most of these impacts.

11.3.4.3 Background. The EV Project recommended that all charging site hosts for fleet, workplace or publicly accessible EVSE should contact their local electric utility for guidance in selecting the optimum arrangement for providing power to their EVSE. Essentially two options were available. Either the EVSE is powered from spare capacity within the existing service to the facility or new service is added through a new electric meter. The selection of the best option would include consideration of the nature of the business, the desired location of the installed EVSE, existing facility power demand, capability of the existing service to accommodate new loads, local permitting requirements, and special rates that may be applied by the local utility.

Fleet and workplace hosts in The EV Project were responsible for the electrical power and energy costs required to operate EVSE as part of their business expenses. Publicly accessible EVSE hosts were compensated for all or part of the energy dispensed through revenue sharing of the EVSE access fees. Some of the hosts elected to provide the charging service at no cost to the PEV driver. In this case, the host was responsible for all costs for charging, including compensating Blink for their network services. Revenue from EVSE access fees was shared based upon the length of time a PEV was connected to the EVSE and did not allow for any additional costs associated with utility demand charges.

Electric utilities provide rate schedules for commercial customers based upon their history of energy and power demand. Section 11.3.4.11 provides rate schedules for an electric utility involved with The EV

Project. APS provides service to most of the metropolitan Phoenix area as well as other parts of the state. It provides rate schedules for extra small commercial businesses (i.e., 0 to 20 kW in demand), small commercial (i.e., 21 to 100 kW), medium commercial (i.e., 101 to 400 kW), large commercial (i.e., 401 kW+), and extra-large commercial (i.e., 3 MW). The effects of EVSE charging are explored for the first three rate schedules in the following subsections.

11.3.4.4 Data Analyzed. This paper utilizes typical host usage load profiles combined with actual AC Level 2 EVSE charge data collected by The EV Project to measure impact on demand charges. Using the APS rate schedules, the cost impact of each is identified. Three months of charge data were selected for analysis - June, July, and August 2013. These months were chosen because the deployment of non-residential EVSE was essentially completed by this time interval; therefore, PEV drivers were well aware of the location of these EVSE. In addition, the fee structure for EVSE access had been in place for approximately 1 year and its effect on utilization was stable.

11.3.4.5 Customer Load Profile Analysis

Extra Small Office Analysis—The extra small office rate schedule does not impose demand charges. Its maximum limit on demand is 20 kW. The addition of a PEV capable of charging at 6.7 kW would still allow over 13 kW of demand for normal business loads. This would allow this extra small business to continue typical summer loads, such as air conditioning, without impact. However, as the business grows or more PEV charging is installed, the 20 kW limit may be exceeded and the next rate schedule would apply.

Small Office Analysis—OpenEI provides analyses on renewable energy and energy efficiency. It provides load profiles [59] for various size businesses in each of the major regions of the United States. Those load profiles are used for further analysis in Phoenix.

The small office average load profile in the Phoenix area as provided by OpenEI for June through August is shown in Figure 11-105.

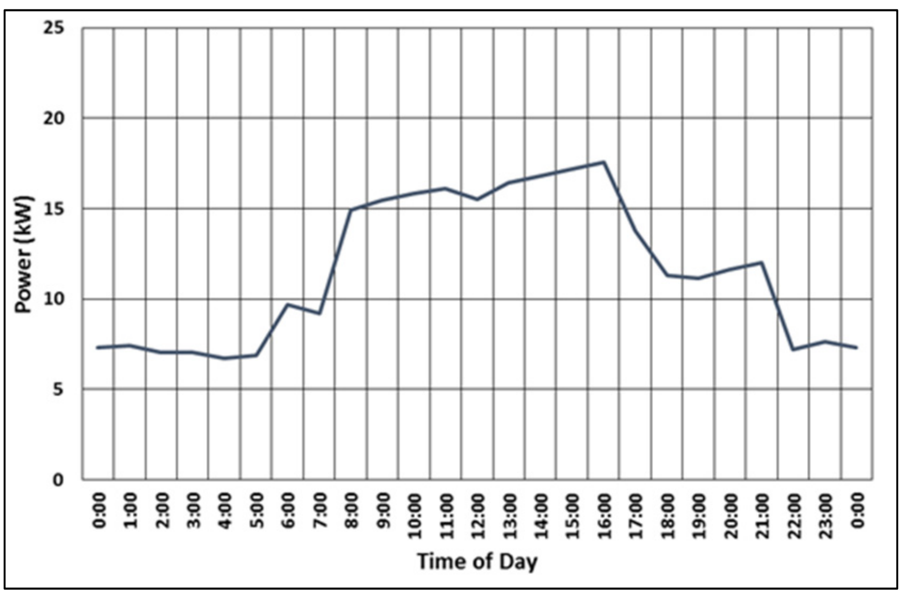


Figure 11-105. Phoenix small office profile.

Should the office desire to add charging for a single PEV with the capability of charging at 6.7 kW, the resulting load profile would be as that in Figure 11-106.

The peak demand is 6.7 kW higher during charging than the otherwise peak demand during this period, resulting in a total demand of 22.8 kW.

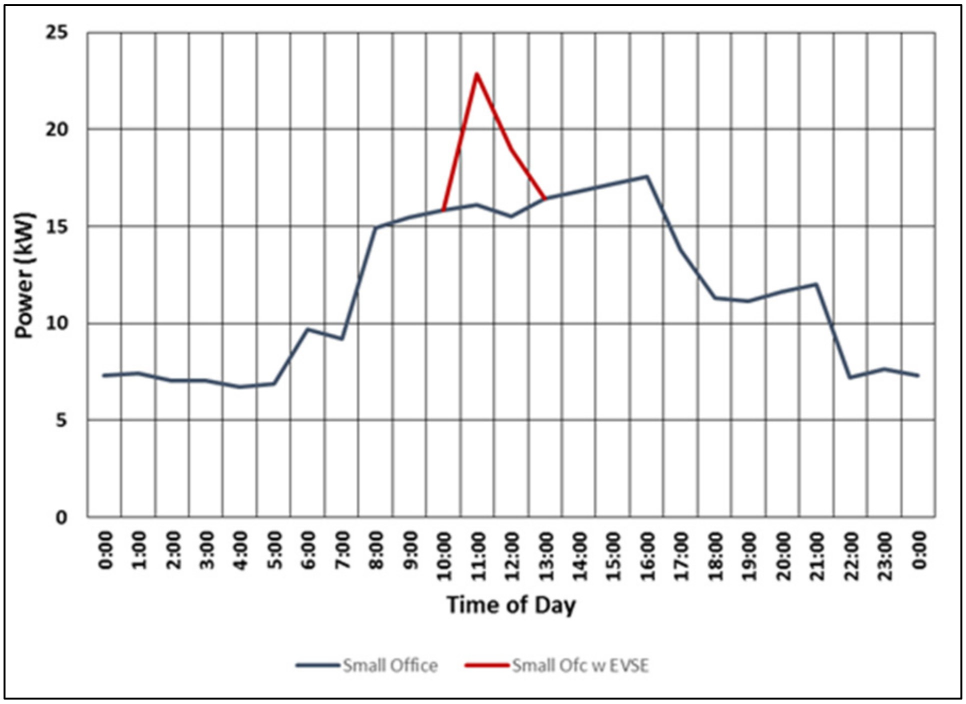


Figure 11-106. Phoenix small office with EVSE charging profile.

This peak exceeds the 20-kW limit and would result in APS placing the customer in the next highest rate schedule: E-32 S. It also results in a demand charge of $224/month and subjects the company to demand charges as long as it remains on the new schedule. According to the APS rate schedule, this demand charge is added to the monthly statement in which it occurred regardless of whether the EVSE ever charges again during the month.

Full Service Restaurant Analysis—The full service restaurant average load profile in the Phoenix area as provided by OpenEI for June through August is shown as the blue line in Figure 11-107. On June 13, 2013, a site containing seven publicly accessible EVSE in the APS service territory experienced three of these EVSE charging simultaneously with a total demand of 9.9 kW. The effect on the average profile with these three EVSE charging simultaneously is shown in Figure11-107.

This customer would typically be assigned rate schedule E-32 S. Charging at the particular time observed resulted in a peak demand 4.7 kW higher than the other peak of the day. This increases the monthly demand charge by $46/month from $705/month demand charge without EVSE charging to $751/month with charging. Had the charging peak occurred simultaneously with the normal peak, the demand charge increase would have been $97/month. While the host may be partially compensated by the revenue sharing of the access fee, the increase in demand was not compensated by The EV Project. In this situation, the host's increase is only the amount of demand caused by the EVSE whereas for the small office example, the change resulted in the host's increase for the business demand and EVSE demand.

Supermarket Analysis—The supermarket average load profile in the Phoenix area as provided by OpenEI for June through August is shown in Figure 11-108 along with the three EVSE charging event previously identified.

The supermarket would likely be on rate schedule E-32 M. Charging at the particular time observed resulted in a peak demand 2 kW higher than the other peak of the day. This increases the monthly demand charge by $10 compared to the regular demand charge of $2,374. Had the charging occurred simultaneously with the supermarket peak, the added monthly demand charge would be $53.

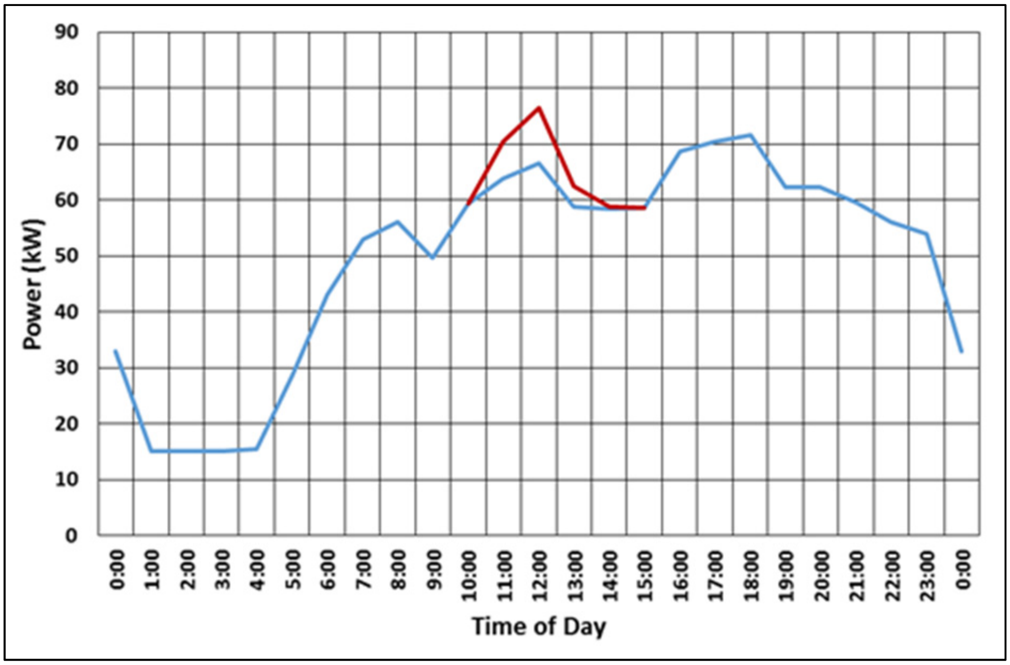


Figure 11-107. Phoenix full service restaurant with EVSE profile.

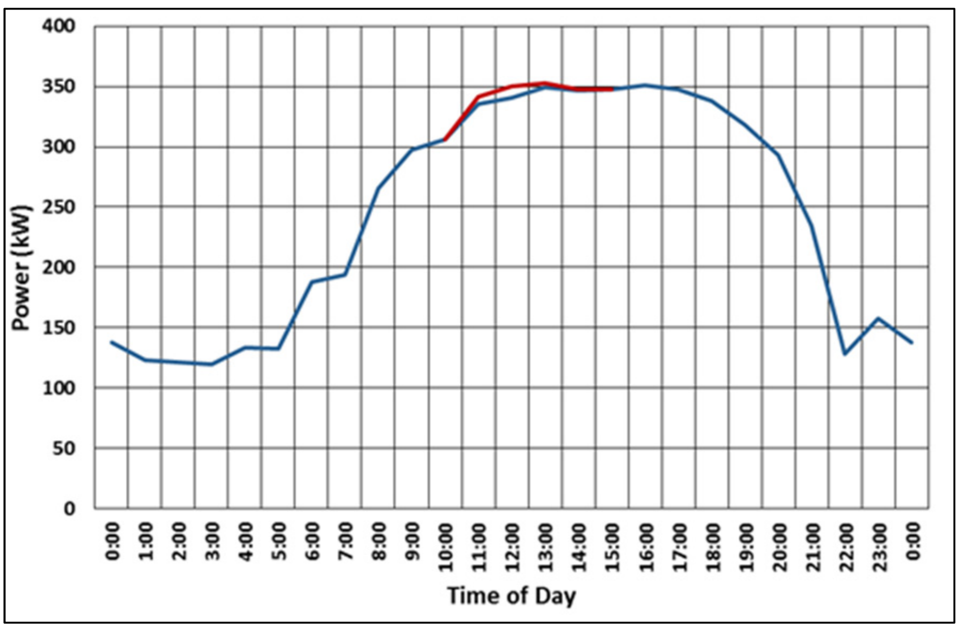


Figure 11-108. Phoenix supermarket with EVSE charging profile.

11.3.4.6 Time-of-Use Rates. Some electric utilities, such as PGE, offer commercial customers the option of applying TOU rates for PEV charging. This may require a separate electrical service, adding the costs associated with meter installation. TOU rates are provided by the electric utility to incentivize customers to charge PEVs on off-peak times. However, publicly accessible EVSE are typically available at all times of the day and are more likely to be utilized by the public during peak times. Thus, TOU rates are not likely to be helpful in reducing electricity costs for the restaurant or supermarket noted above. TOU rates may be beneficial for fleets or workplace environments where the time when charging occurs can be controlled.

11.3.4.7 Separately Metered EVSE Service. The above examples assume that the EVSE charging is added to the existing electrical service provided to the facility. In most cases, the prior consultation with the electric utility would identify that typically, separate service is desirable. This separate service incurs the added expense of the miscellaneous fees and service charges for the new service but could prevent the added expense of demand charges. The three EVSE operating simultaneously in Phoenix could be assigned to the E-32 XS schedule and thus avoid all demand charges.

11.3.4.8 Effects of Higher Rate Charging. The EVSE charge events noted above involve the original Leaf and Volt of The EV Project with a maximum charging power demand from the grid limited by the vehicle to approximately 3.7 kW. Newer models of the Leaf and many other PEVs entering the market have increased the charge capability of the vehicle to a power demand of 6.7 kW or greater. The Blink EVSE installed by The EV Project in non-residential locations is capable of delivering this increased power. Thus, the simultaneous operation of three EVSE could easily be over 20 kW rather than the 9.9 kW of that analyzed above.

11.3.4.9 Observations. The power required by the EVSE is a more significant impact to the electric utility monthly statement for smaller commercial businesses than larger ones. Each electric utility defines small commercial businesses and their rate schedules based on its own needs and as regulated by the local Public Utility Commission or municipal rules. Some of the small business owners who have included the EVSE charging as part of their existing supply, may be surprised when the utility places them on a higher rate schedule as a result of PEV charging. Although it includes more upfront costs, separately metered service for the EVSE may allow the business owner and PEV charging host to avoid demand charges associated with ACL2 EVSE charging.

11.3.4.10 References

58. http://avt.inl.gov/pdf/EVProj/DCFastCharge-DemandChargeReductionV1.0.pdf [accessed March 14, 2015]

59. Open EI Load Profiles, http://en.openei.org/datasets/files/961/pub/

60. Arizona Public Service Business Electric Rate Schedules, http://www.aps.com/en/ourcompany/ratesregulationsresources/serviceplaninformation/Pages/business-sheets.aspx

61. PGE Rate Schedules, https://www.portlandgeneral.com/our_company/corporate_info/regulatory_documents/tariff/rate_schedules.aspx

11.3.4.11 Electric Utility Overview

Arizona Public Service—APS rate schedules are provided in reference [60]. While all contain basic service charges and fees, the charges of interest are for energy and power demand.

Monthly maximum demand will be based on the highest average kW supplied during the 15-minute period during either the on-peak or off-peak hours of the billing period, as determined from readings of the company's meter.

APS has no special distinction related to businesses charging PEVs.

APS also offers TOU options related to these rates. However, public charging of PEVs are generally not limited to off-peak times and such may not be a benefit. They are omitted here for clarity.

Table 11-28 shows basic differences between rate schedules for energy usage and demand.

Table 11-28. APS rate schedules for commercial customers.

Schedule	Max kW	Energy	Demand
E-32 XS	20	$0.13537/kwh first 5,000 kWh plus $0.07427 for additional kWh	NA
E-32 S	100	$0.10337 per kWh for first 200 kWh plus $0.06257 for additional kWh	$9.828 per kW for the first 100 kW plus $5.214 for all additional kW
E-32 M	400	$0.09884 per kWh for the first 200 kWh plus $0.06091 per kWh for all additional kWh	$10.235 for the first 100 kW plus $5.385 per kW for all additional kW

11.3.5 How Well Did Non-residential EVSE Installations Match the Planned Areas in San Diego?

11.3.5.1 Introduction. The lack of public charging infrastructure for PEVs has been identified as a barrier to the widespread adoption of PEVs. Federal and state grants have been awarded to promote public charging and for retail businesses to have an interest in installing charging infrastructure. A common question for charger installations is, "Where should the chargers be placed?" One of the objectives of The EV Project was to study the interaction of PEV drivers with public infrastructure; therefore, again leading to the question of where this infrastructure should be placed.

In the early stages of PEV delivery to local markets, the options were as follows:

- Plan locations related to key attraction sites where PEV parking is anticipated
- Solicit retail and public charging hosts for random placement
- Ask early adopters where they want public infrastructure
- Identify sites near known high-traffic areas.

The EV Project chose locations related to key attraction sites where PEV parking is anticipated for planned deployment. The planning process used for San Diego is well documented in Section 11.3.5.9. This section considers how closely the final EVSE installation locations matched the planned approach.

11.3.5.2 Key Conclusions

- The San Diego planning process developed 3,333 target areas for deployment.
- The EV Project installed 530 non-residential EVSE in 160 locations in the San Diego region.
- 98% of the installed EVSE units are within target areas.
- 98% of installed sites are within target areas.
- More than 1,135 target areas (34%) were served by the 160 deployed EVSE sites.

11.3.5.3 Analysis Approach. The PEV charging stations, or more appropriately identified as EVSE, delivered by The EV Project included both residential and non-residential units. Non-residential EVSE included those installed in workplace environments, fleet applications, and those for public use that were located near retail centers, parking lots, and similar locations. The planning process identified target areas for EVSE deployment. In this analysis, the final EVSE deployment locations are plotted against the target locations to identify how well they match.

A preliminary report on this topic was prepared prior to the final installation of all project EVSE and reported in, "The Micro-Climate deployment Process in San Diego" [62]. This report updates that paper to the final installation status.

11.3.5.4 Plan Results. Section 11.3.5.9 and Reference [62] provide the details of the planning process for non-residential EVSE placement in the San Diego region. That planning effort focused on attraction or destination sites, with anticipated high turnover of PEVs. The results of that process provided 3,333 targeted areas (Figure 11-109). Each circle is a quarter-mile buffer surrounding the target location. The quarter-mile buffer was determined to be the maximum distance a person would walk from the EVSE to the attraction. The close proximity of several of the attraction sites caused overlap in many target areas, especially in the metropolitan San Diego area.

The primary focus of The EV Project's regional manager in San Diego was to solicit business and property owners to be charging site hosts in those target areas.

11.3.5.5 Challenges to Deployment. The EV Project provided an AC Level 2 EVSE unit at no cost to the host, as well as a fixed credit toward installation costs with an agreement that the host would allow The EV Project to collect and analyze data from the equipment for the duration of the project. Several factors impacted the host's decision to accept the EVSE unit and installation cost credit offered. These included installation costs exceeding that credit, impact on the existing parking, ADA compliance requirements, city permitting requirements, delays in the process, and the host company's internal legal, marketing, and strategic planning considerations.

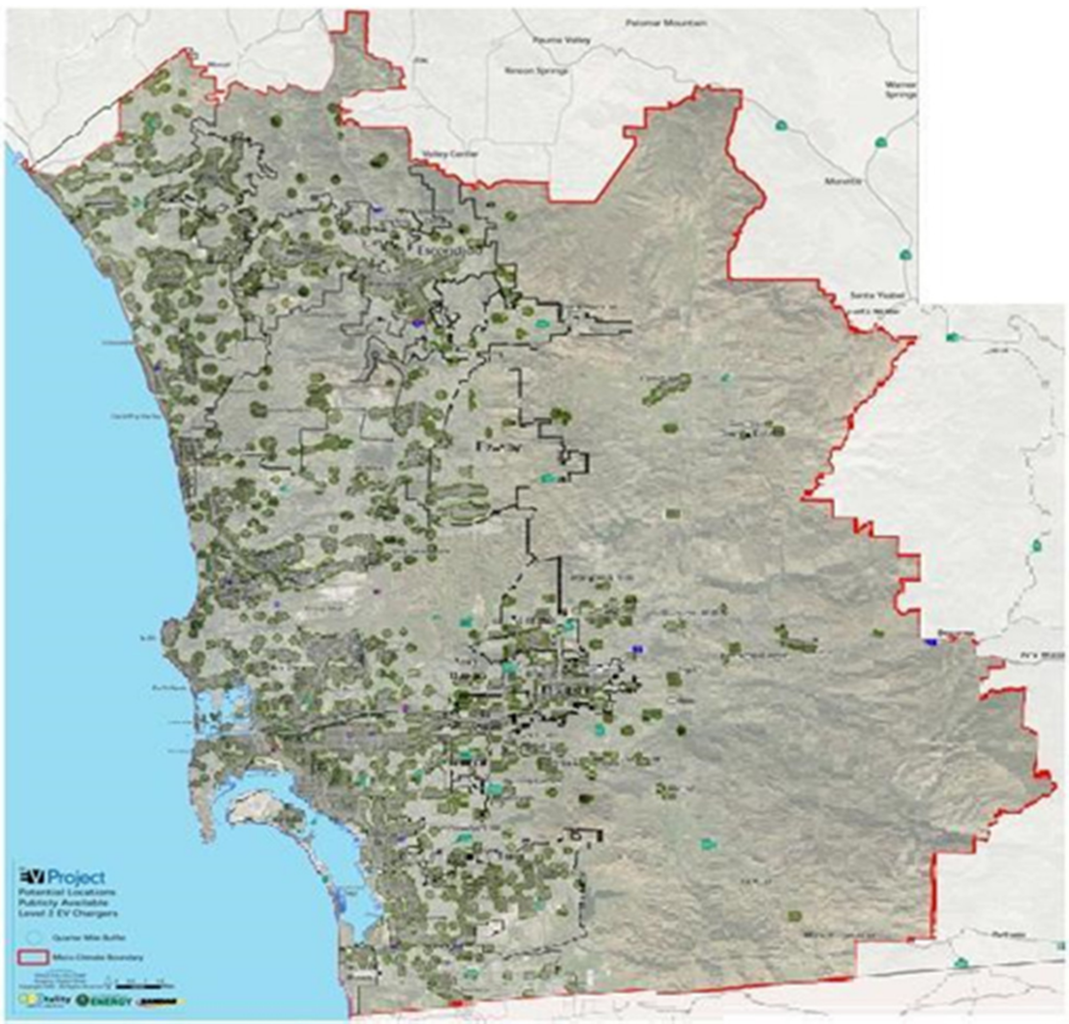


Figure 11-109. Target areas in San Diego are denoted by small gray circles. The green circles are the 1-quarter-mile buffer areas that contain an EVSE.

For the local AHJ, installation of an electrical device in public locations involved parking considerations and compliance with ADA. This was new to most AHJs and little guidance was available. The EV Project did provide ADA compliance recommendations [63], but these recommendations were unofficial. Consequently, each AHJ developed their own requirements, which varied and made installation in some jurisdictions overly conservative and prohibitively costly.

The EV Project schedule delivered residential EVSE concurrent with vehicle delivery starting in December 2010. Installation of non-residential EVSE commenced in April 2011, consistent with the original project's schedule to closely following adoption of PEVs, and had a target for completion of that infrastructure by the end of 2011. The year 2012 was devoted to data collection and analysis. According to the schedule, non-residential EVSE installations occurred prior to complete deployment of the residential component.

The resulting scarcity of the PEVs deployed, market uncertainties, permit issues, and other uncertainties identified above resulted in less than an enthusiastic response to the invitation to become a charging site host, except by the most motivated hosts.

11.3.5.6 Results. A site that is desirable for publicly accessible charging should include more than one EVSE; therefore, the charging opportunity is available for more than one PEV at a time. Installation cost per EVSE is also reduced for sites with multiple units. Thus, the hosts were encouraged to provide space for at least two units. Several of the anticipated high-utilization sites installed larger numbers of EVSE. Table 11-29 identifies the number of sites with multiple EVSE in the San Diego market.

Table 11-29. Number of EVSE per site.

EVSE Count	Number of Sites
≥10	5
9	2
8	4
7	7
6	4
5	12
4	18
3	33
2	42
1	33

Final distribution of The EV Project's non-residential EVSE included 530 EVSE in 160 different sites (see Figure 11-110).

Reference [62] reported that nine installed locations were outside the areas targeted by the planning process. However, correction of GPS coordinates reduced that to three locations. These three locations, shown in red, contain a total of 12 EVSE and all are associated with educational facilities.

Because many of the target areas overlap, an installed EVSE may actually be installed in and serve more than one target area. Reference [62] reported 1,138 target areas were served by the deployed EVSE.

11.3.5.7 Conclusions. Ninety-eight percent of the deployed EVSE units are in locations that were targeted in the San Diego planning process and 98% of the deployed sites are within the targeted areas. This success in meeting the planning goals provides a starting point for continued evaluation of the effectiveness of the planning process. Public utilization of these non-residential EVSE is evaluated in separate EV Project documents [64]. Overlapping of target sites resulted in more than 34% of the priority planned target areas being served by the 160 deployed EVSE sites.

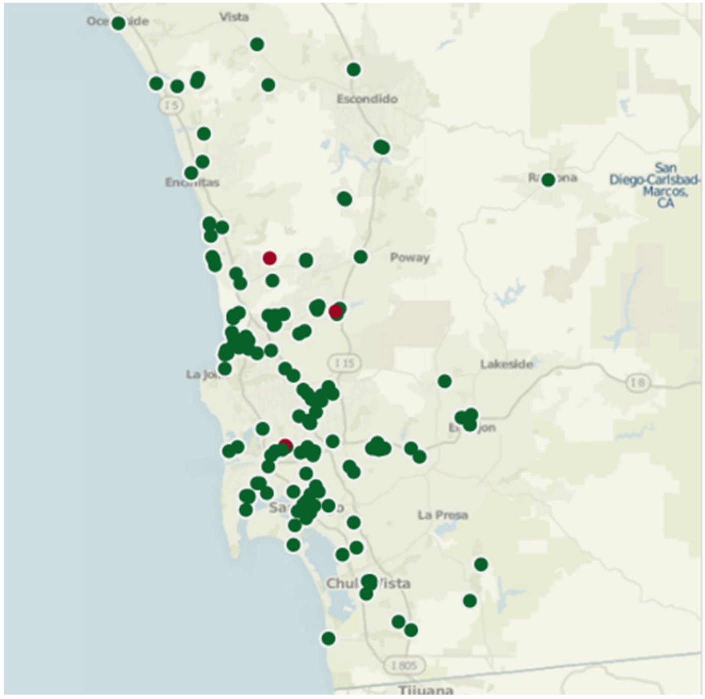


Figure 11-110. Final deployment sites of non-residential AC Level 2 EVSE. The green circles are EVSE installed in target areas. The red circles are EVSE that were not located within target areas.

11.3.5.8 References

62. "The Micro-Climate deployment Process in San Diego," Lessons Learned, avt.inl.gov/evproject.shtml.

63. "Accessibility at Public EV Charging Stations," Lessons Learned, avt.inl.gov/evproject.shtml.

64. 2013 EV Project Electric Vehicle Charging Infrastructure Summary Report http://avt.inel.gov/pdf/EVProj/EVProject%20Infrastructure%20ReportJan13Dec13.pdf.

65. 2012 EV Project Electric Vehicle Charging Infrastructure Summary Report http://avt.inel.gov/pdf/EVProj/EVProject%20Infrastructure%20ReportJan12Dec12.pdf.

66. 2011 EV Project Electric Vehicle Charging Infrastructure Summary Report http://avt.inel.gov/pdf/EVProj/EVProject%20Infrastructure%20ReportJan11Dec11.pdf.

11.3.5.9 San Diego Public EVSE Location Planning

Approach—The EV Micro-Climate® planning process was developed during The EV Project as an integrated turn-key program to ensure an area is well equipped with the needed infrastructure to support consumer adoption of electric transportation. Beginning with extensive feasibility and infrastructure planning studies, the program provided a blueprint to create a rich EV infrastructure.

The EV Micro-Climate process enlisted highly interested stakeholders in the region to provide local context, history, and drive for EV adoption. These stakeholders became the local EV Project Stakeholder Advisory Committee (SAC) and they were active throughout the planning process. The Micro-Climate process focused the interests of this highly diverse group to produce three major planning documents. The evaluation of the Micro-Climate planning process is available at http://avt.inel.gov/evproject.shtml#LessonsLearned.

The EV Micro-Climate process in San Diego produced three documents: (1) Electric Vehicle Charging Infrastructure Deployment Guidelines for the Greater San Diego Area (May 2010),

(2) Long-Range EV Charging Infrastructure Plan for Greater San Diego (October 2010), and (3) the EV Micro-Climate Plan for San Diego Region, California (February 2011). All documents are available at the same website referenced above.

Documents—The EV Infrastructure Deployment Guidelines provided indoctrination information and general guidance for starting the planning process. The Long Range Plan projected the PEV population in the greater San Diego area by the year 2020 and the projected public charging infrastructure densities that would support this population. The EV Micro-Climate Plan for San Diego narrowed the future look to the next 2 to 3 years to provide direction for the near-term installation of publicly available EVSE provided by The EV Project.

Methodology—The San Diego EV Project SAC took an aggressive municipal planning approach to identify target locations within the boundary of The EV Project in the San Diego region (shown in Figure 11-111).

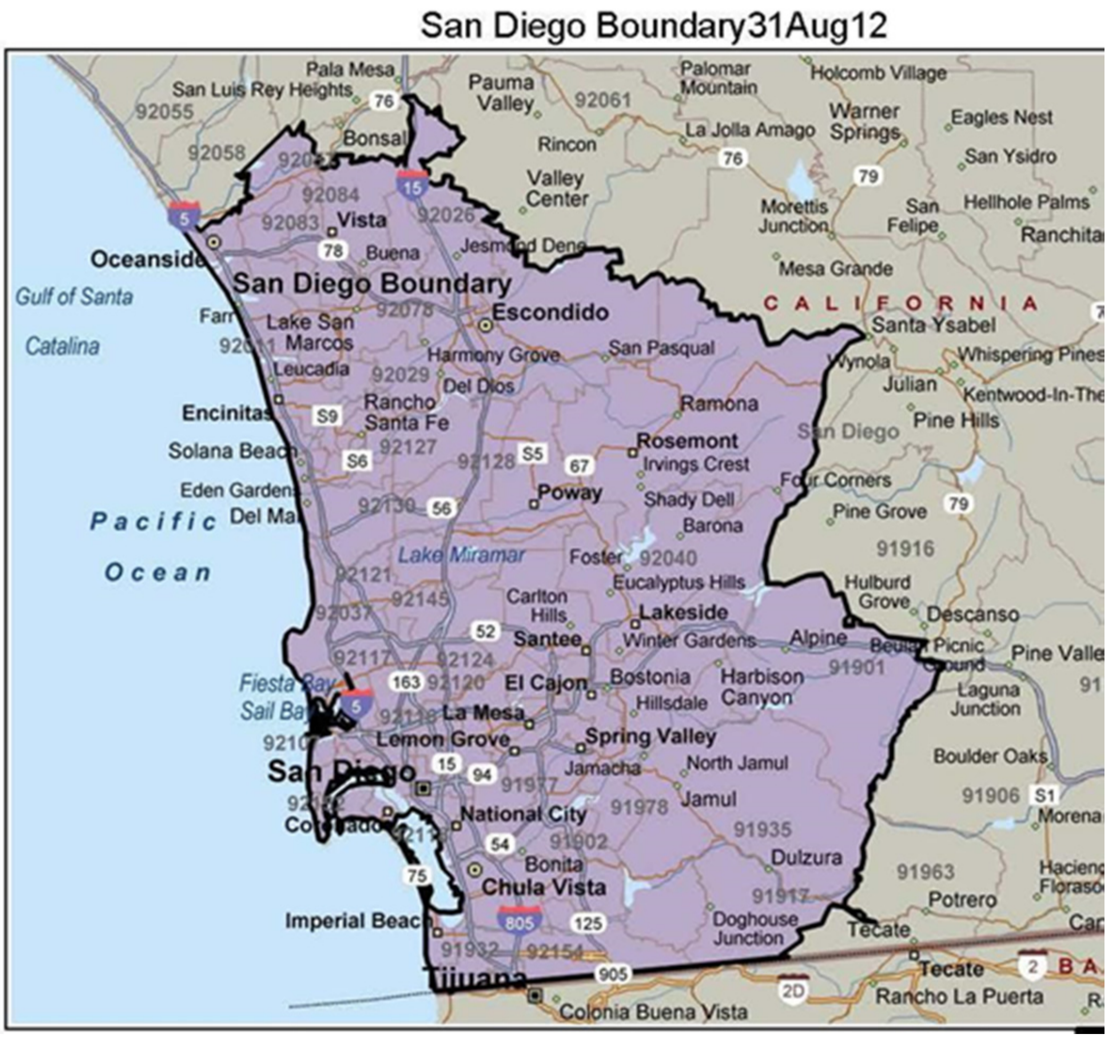


Figure 11-111. San Diego region of The EV Project.

There may be many different motivations for the host in locating public EVSE including generation of revenue from fees, promoting a public environmental image, encouraging patronage by the PEV driver demographic, and providing range extension for PEV drivers. The EV Project SAC determined optimum locations for publicly accessible EVSE would be those with the following:

- High number of users
    - Integrated into daily life
    - Available to many different users
- High frequency of vehicle turnover
    - Vehicle stay times of 45 minutes to approximately 3 hours
- Significant availability
    - Maximize the number of open days per week and per year
        - Maximize the number of open hours per day.

When planning the locations, the geographic model was the master geographic reference areas, which are proprietary data units designed and used by the San Diego Association of Governments. The 18,756 master geographic reference areas are geographic areas roughly the size of census blocks in urban and suburban areas and census block groups in rural areas. Master geographic reference areas are designed to nest into larger standard geographies, such as census tracts, zip codes, and municipal boundaries. Master geographic reference areas are polygon shapes rather than points, but contain the points of interest that were expected to attract PEV drivers. Master geographic reference areas may contain more than one point of interest.

Several factors were considered in evaluating the suitability of a master geographic reference area for its attraction to PEV drivers, and all master geographic reference areas were rated with the results normalized to provide a score of 0 to 1. Master geographic reference areas with normalized scores above 0.16 were selected for target EVSE locations (Figure 11-112). This identified 3,333 of the total 18,756 master geographic reference areas.

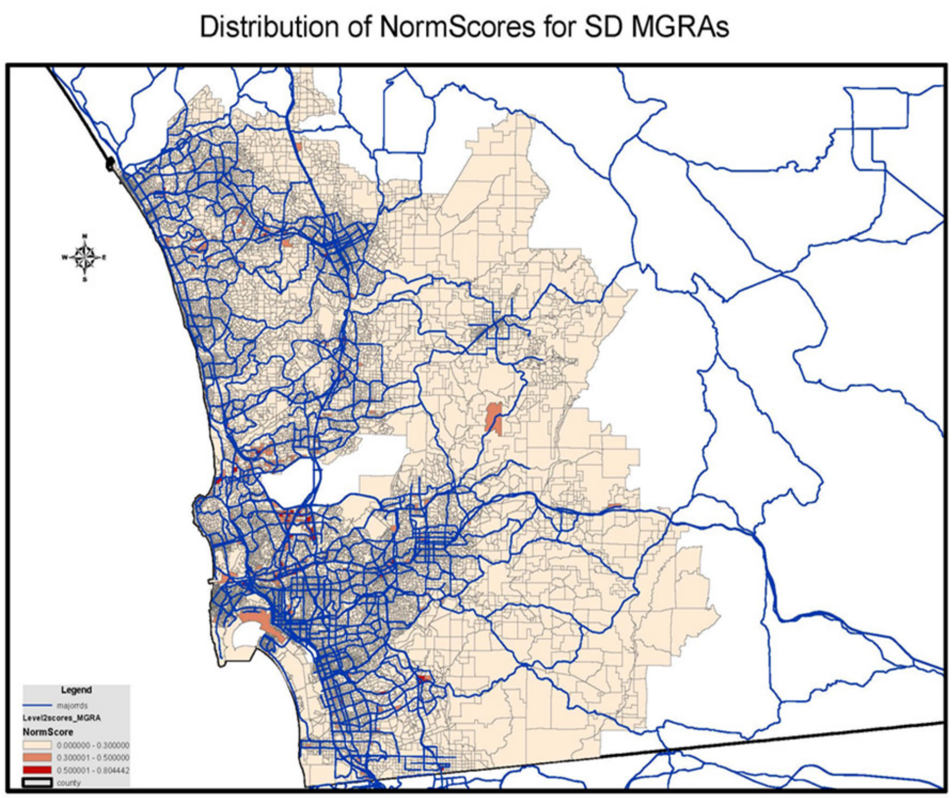


Figure 11-112. Normalized PEV attractions master geographic reference areas.

It is a generally accepted practice that a quarter of a mile is a reasonable walking distance between a parked PEV charging and the point of interest. A quarter-mile buffer circle from the center point of the MGRA provided the target location for a publicly accessible AC Level 2 EVSE unit.

Some master geographic reference areas within high population densities are smaller than the quarter-mile buffer; therefore, many of the buffers regions overlapped.

This effort then resulted in maps of the San Diego region with quarter-mile radius buffers around the top-ranked master geographic reference areas. Figure 11-113 shows one portion of the San Diego region with these buffers identified.

These buffers then were the primary targets used by The EV Project regional manager when seeking hosts for the deployment of publicly available EVSE.

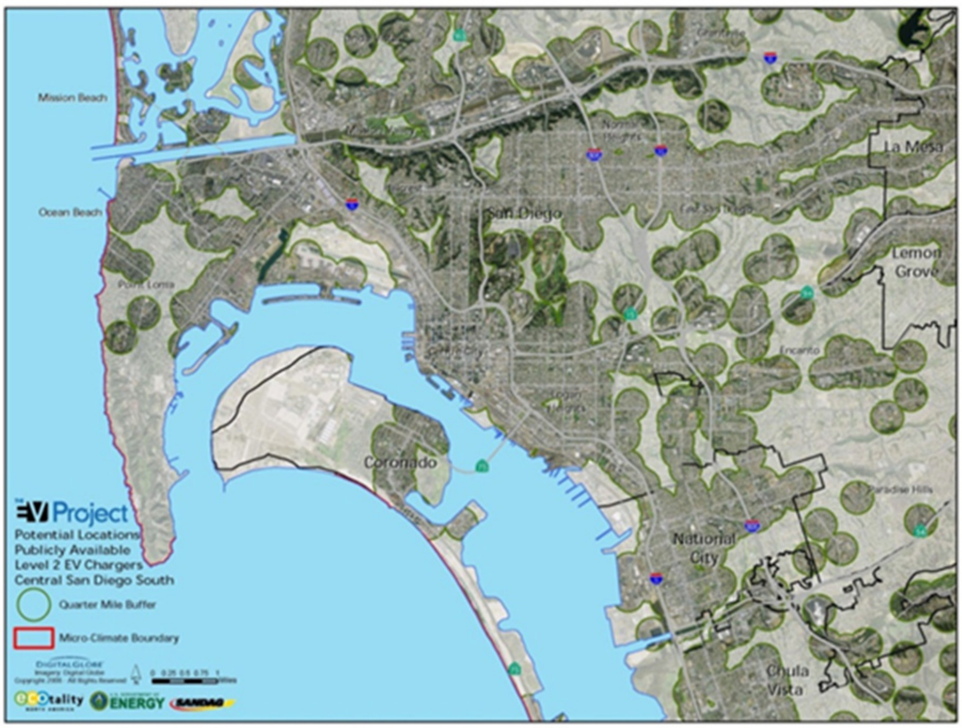


Figure 11-113. Quarter-mile buffers in San Diego region.

11.3.6 How Does Utilization of Non-Residential EVSE Compare Between those Installed in Oregon in Planned versus Unplanned Locations?

11.3.6.1 Introduction. The lack of public charging infrastructure for PEVs has been identified as a barrier to their widespread adoption. Federal and state grants have been awarded to promote public charging and retail businesses have an interest in installing charging infrastructure. A common question for charger installations is "Where should the chargers be placed?" One of the objectives of The EV Project was to study the interaction of PEV drivers with public infrastructure; therefore, that same question needed to be addressed by EV Project management prior to the first PEVs being delivered. The options available at that time for determining where chargers should be placed were as follows:

- Plan locations related to key attraction sites where PEV parking is anticipated
- Solicit retail and public charging hosts for random placement
- Ask early adopters where they want public infrastructure

- Identify sites near known high-traffic areas.

The EV Project chose the first option for planned deployment. This process was implemented in all EV Project markets.

To evaluate the effectiveness of the planning process utilized by The EV Project, two questions relevant were asked:

1. How well did final installation sites fit with planned locations?
2. How does utilization of non-residential AC Level 2 EVSE vary between those areas where it was planned versus areas where it was not planned?

The first question was addressed in a separate paper for the San Diego area [67], where 98% of installed non-residential EVSE were installed in planned areas. Therefore, a comparison of utilization between EVSE use in and outside planned areas in San Diego is not practical. The Portland, Oregon area was selected for this analysis, because the planning approach was very similar to San Diego, but a significant percentage of non-residential EVSE was installed outside the planned areas. The details of the planning approach were included in "EV Micro-Climate® Plan for Northwestern Oregon" [68] and are summarized in Section 11.3.6.10. The lessons learned during the planning process are addressed in another paper, "The EV Micro-Climate® Planning Process" [69].

11.3.6.2 Key Conclusions

- A significant planning effort for non-residential AC Level 2 EVSE placement was undertaken using the EV Micro-Climate® process in the greater Portland area during 2010.
- Fully 74% of The EV Project's available EVSE were placed in the predicted high utilization zones.
- Overall, EVSE placed in the predicted high utilization zones experienced 87% greater charge events per week than those outside these zones.
- The EVSE placed in predicted high utilization zones had average vehicle connect time periods 4.4 times longer than those outside these zones.
- The charging site host venue is an important factor in EVSE utilization, both within and outside the high utilization zones.
- The EV Micro-Climate® planning process utilized in the greater Portland area was highly successful in predicting high non-residential EVSE utilization.

11.3.6.3 Analysis Approach. The PEV charging stations or EVSE delivered by The EV Project included both residential and non-residential units. Non-residential AC Level 2 EVSE were installed in workplace environments, fleet applications, and publicly accessible locations near retail centers, parking lots, and similar locations. The planning process identified target areas for EVSE deployment. This process for the Portland area is summarized in Section 11.3.6.10. The entire greater Portland area was mapped through a collaborative process with government, industry, and public to develop a heat map, where red indicated zones predicted to have high charger utilization, green zones indicated medium utilization, and blue zones indicated low utilization. The planning process then focused on identifying venues in the high utilization zones that would attract large numbers of PEV drivers. This planning process was completed in 2010, prior to delivery of the first PEVs to the region. In this analysis, utilization of EVSE deployed in the high utilization zones are compared to EVSE deployed in the medium and low utilization zones in the Portland area.

11.3.6.4 Plan Results. By August 2013, non-residential EVSE deployment was nearly completed, with 323 EVSE reporting data to The EV Project database. These 323 EVSE were located in 129 separate sites for an average of 2.5 EVSE per site. Multiple EVSE were typically located at a site to reduce installation costs and to ensure an EVSE is available for use at all times, even when one is already in use. Table 11-30 details the number of sites and quantity of EVSE.

Table 11-30. EVSE installations per site.

Number of EVSE	Number of Sites
1	34
2	53
3	21
4	12
5 or more	9

The actual installation sites were compared to a detailed Portland density map (Figure 11-123 in Section 11.3.6.10). Table 11-32 presents the details of the deployment sites. Figure 11-114 presents these locations geographically. The colors match that of the predicted utilization zones.

The 129 sites represent 57 separate owners and include public buildings, fleet, workplace, and retail locations.

Table 11-31. EVSE deployment in predicted utilization zones.

Utilization Zone	Quantity of Sites	Percent of Sites	Quantity of EVSE	Percent of EVSE
High	95	74%	251	78%
Medium	20	15%	44	13%
Low	14	11%	28	9%

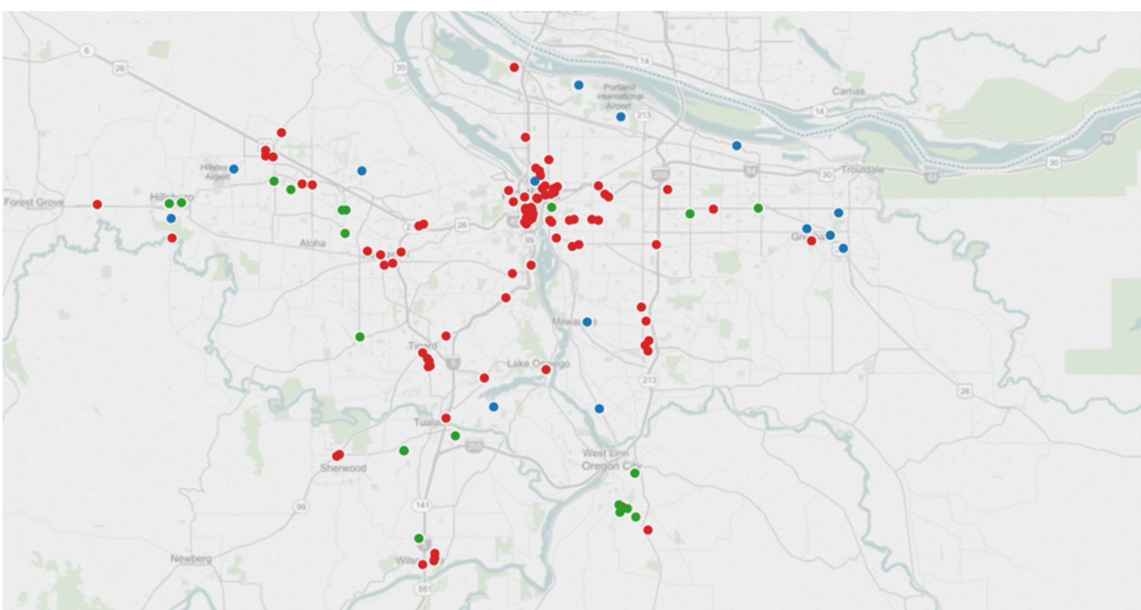


Figure 11-114. Non-residential EVSE installations in the greater Portland area.

11.3.6.5 Utilization Metric. The EV Project planning goal was to place all EVSE in locations where high utilization was predicted. High utilization was defined as high numbers of users and high turnover of charging events. However, the placement of non-residential EVSE requires approval of the charging site host. Because host motivations for placement of EVSE vary significantly, chargers were actually installed at a variety of locations, with varying predicted utilization.

Utilization of public EVSE units was still developing in August 2013 as PEV drivers explored the boundaries of their vehicle range. Some EVSE units were used on a regular basis, some occasionally, and others rarely. Additionally, an EVSE unit may have been used extensively one week but not used the next. Therefore, the time period over which the charger utilization is evaluated is also important. For this paper, the primary metric selected was the average number of connect events per week since that EVSE was installed. A "connect event" is defined as insertion of the EVSE connector into the PEV charge port for at least a 1-minute duration, during which some power is actually transferred.

At locations with multiple EVSE installed, the most conveniently located EVSE was generally more highly used. Early analyses found that high-performing and low performing EVSE, in terms of events per week, could be found at the same site. However, because it was the site being evaluated, all events for all EVSE at that site were summed in this analysis to identify the number of events per site. This metric will favor the higher numbers of EVSE only when the sites with lower numbers have maximized their utilization, which is an event that had not occurred by August 2013.

The hours EVSE were connected to a PEV were also summed and divided by the number of weeks since the EVSE was installed, producing an average weekly connect time. The total connected time at a site was divided by the total number of events and by the number of EVSE on the site to identify the average connect time per EVSE. Finally, the average amount of energy transferred per event was calculated.

11.3.6.6 Analysis Results. Table 11-32 compares analysis metrics for predicted high and medium/low utilization zones.

Table 11-32. Utilization at predicted zones as measured in average and maximum connection events per week.

Utilization Zone	Connect Events/Week (average/max)	Connect Hours/Week (average/max)	Energy (kW)/Event (average/max)
High	3.7/48.0	34.9/887.4	6.3/16.1
Medium/Low	2.0/11.7	8.0/54.8	6.4/23.0

Clearly, the high utilization zones contained the highest average and maximum number of connect events per week. The average number of connect events per week was 87% higher at the high utilization zone than the others. In addition, these sites provided the longest connect times. The average time connected was 4.4 times longer in the high utilization zones. The amount of energy transferred per event was similar for all utilization zones. This is expected, because energy transferred depends on vehicle condition (i.e., state-of-charge) rather than location. No variation in state-of-charge was expected between vehicles charging at high utilization zones versus medium/low utilization zones.

Location in a high utilization zone was not assurance of high usage. As summarized in Table 11-33, 62 of the 129 sites analyzed had an average number of events per week below the average for low and medium zone usage (i.e., two events per week). Of these 62 sites, 41 were found in predicted high utilization zones, representing 43% of all high utilization zone sites.

Table 11-33. Sites of low utilization.

Utilization Zone	Quantity of Sites	Percent of Utilization Sites
High	41	43%
Medium	15	75%
Low	6	43%

11.3.6.7 Further Evaluation

Highly Utilized Sites versus Installation Date—Figure 11-115 shows the average number of charge events per week versus the number of weeks since installation of the EVSE. Again, the color of the dot represents the utilization zone where the site was located.

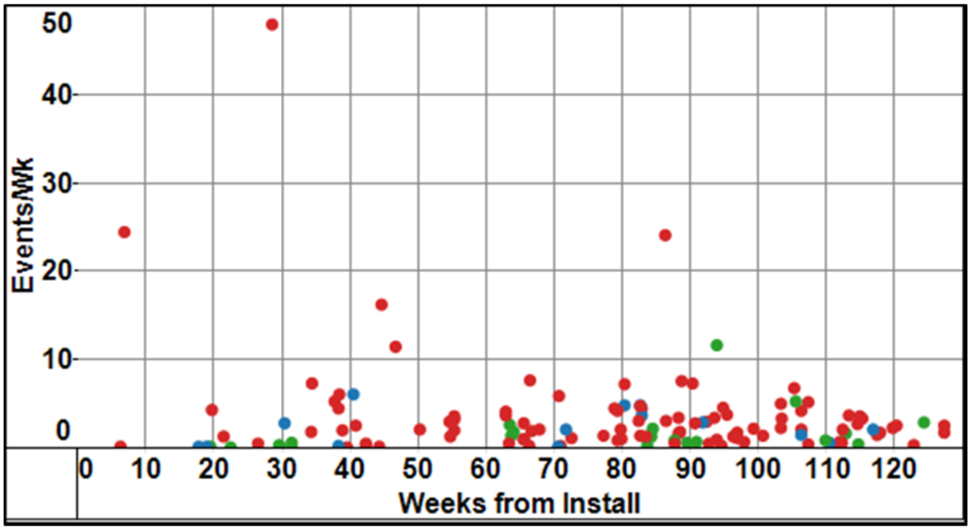


Figure 11-115. Site utilization versus weeks following installation.

Installations of EVSE into the predicted high utilization zones occurred throughout the active promotion of The EV Project, with no specific emphasis on installing these sites early in The EV Project. From Figure 11-115, there appears to be no increase in EVSE utilization over time, because the earliest installed EVSE (i.e., greatest number of weeks from installation) fare no better than others installed later. Similarly, EVSE installed most recently showed no disadvantage in utilization. Installation of EVSE in medium and low zones occurred throughout The EV Project's active promotion, and it appears the date of installation also had no effect on their utilization.

Highly Utilized Site Locations—Eighteen sites average over 5.0 events weekly, including one in the low zone and two in the medium zone. The locations are shown in Figure 11-116 and detailed in Table 11-34. The central Portland area appears to have fared the best in utilization. Location along major traffic routes also appears important.

Venue Classifications—Venue classifications are identified in another EV Project lessons learned4 report. The venues associated with these 18 highly utilized sites are included in Table 11-34.

Event Duration per Electric Vehicle Supply Equipment—The average event duration per EVSE generally varies inversely with the number of distinct users. It is noteworthy that two highly utilized sites in the medium zones were big retailers.

It is also noted that the library listed in Table 11-34 is located in a low zone, but provides a significant number of programs and events.

Distinct Users—Access to non-residential EVSE varied throughout the project period. In the beginning, charging was open to all users with no access control. In 2012, access was changed to require the user to utilize a controlled access membership card. Later, fees for use were incorporated into most sites. Table 11-34 indicates the number of distinct users from the date of installation through August 2013 based on use of The EV Project Blink membership card. Those sites that include the "+" indicate the EVSE was utilized by PEV drivers other than those using a Blink membership card. While the number of distinct "guests" in each location is unknown, the magnitude of guest use is indicative of use by PEV drivers coming from a greater distance to use the charger. This wider draw significantly increases utilization and, from Table 11-34, appears to be related to large retail, medical, and entertainment venues. These are all venues that are equally accessed by local residents and by vehicles traveling from a greater distance to specifically visit that venue.

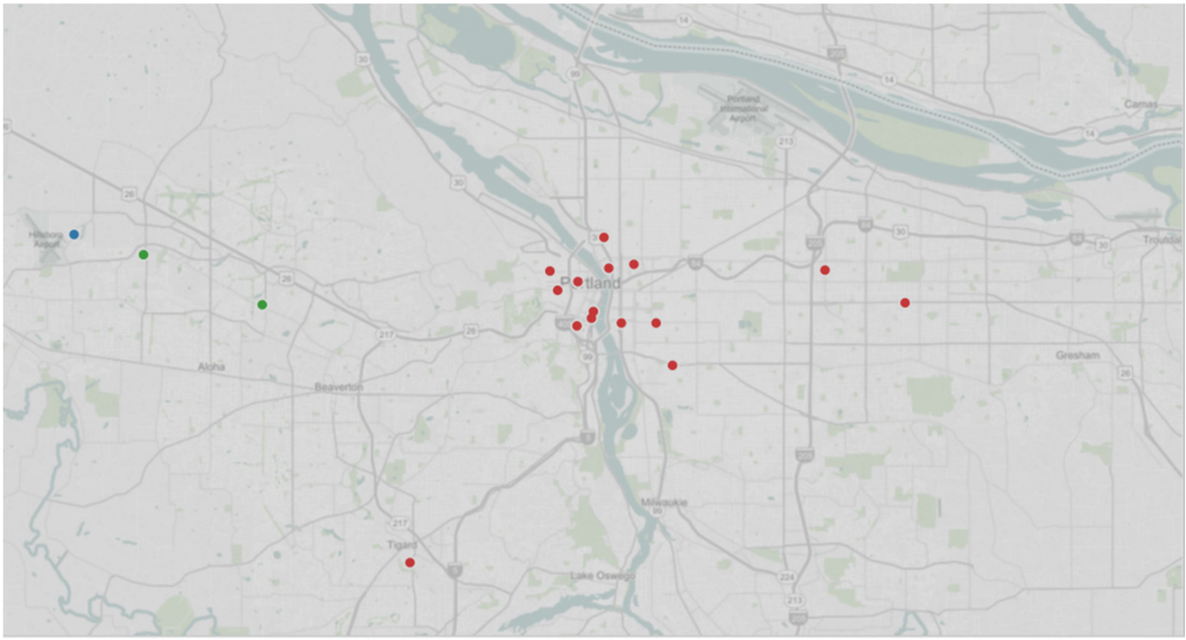


Figure 11-116. Highest utilized sites.

Table 11-34. Highest utilized sites.

Venue	Sub-Venue	Zone	Site Events/Wk	Avg Event Duration per EVSE (hours)	Number of Distinct Users
Public/Municipal	Parking Lot	High	48.0	3.7	11+
Retail	Retail – Big	High	24.5	0.5	65+
Parking lots	NA	High	24.1	2.9	36+
Fleet	NA	High	16.3	3.7	NA
Retail	Retail – Big	Medium	11.7	0.6	119+
Workplace	N/A	High	11.4	5.3	1
Retail	Retail – Big	High	7.6	1.0	182+
Medical	NA	High	7.6	1.4	113+
Medical	NA	High	7.3	1.5	63+
Retail	Retail – Small	High	7.3	2.1	8+
Leisure	Arts/Entertain.	High	7.2	0.7	114+
Retail	Retail – Big	High	6.8	0.4	324+
Fleet	NA	High	6.1	6.5	NA
Public/Municipal	Library	Low	6.0	0.6	49+
Retail	Shopping Mall	High	5.9	0.4	144+
Retail	Retail – Small	High	5.3	2.3	78+
Retail	Retail – Big	Medium	5.3	1.3	134+
Retail	Retail – Big	High	5.2	1.3	130+

Low Utilization Sites—As noted above, location in a high utilization zone is no assurance of high utilization. Table 11-35 presents the 18 lowest utilized sites.

Table 11-35. Lowest utilized EVSE.

Venue	Sub-Venue	Zone	Events/Wk
Fleet	NA	Medium	0.04
Public/Muni.	Public Works	High	0.05
Workplace	Utility	Medium	0.10
Public/Muni.	Military	Low	0.11
Public/Muni.	Senior Center	High	0.11
Workplace	Utility	Medium	0.13
Public/Muni.	Public Building	Low	0.14
Public/Muni.	Military	Low	0.16
Public/Muni.	Parking Lot	High	0.16
Workplace	Utility	Low	0.18
Hotel	NA	High	0.20
Public/Muni.	City Hall	High	0.22
Medical	NA	High	0.24
Workplace	Utility	Medium	0.27
Workplace	Utility	High	0.28
Public/Muni.	City Hall	High	0.28
Public/Muni.	Public Services	Medium	0.31
Hotel	NA	High	0.38

None of these locations are involved in retail or services, thus missing the venue criteria considered important in the planning process for high EVSE utilization.

Electric Vehicle Owner Residential Locations—The EV Project enrolled vehicle owners starting in December 2010. Enrollment in The EV Project ceased at the end of January 2013. Figure 11-117 shows the home location of The EV Project's PEV drivers in the greater Portland area. The homogeneous distribution of locations shows that utilization of non-residential EVSE in any particular zone is not influenced by a nearby concentration of residences with PEVs.

Motivation of Host—As noted above, motivations for hosts in placement of EVSE at their locations varied, meaning low utilization of sites may not be due to its location in a low utilization zone. As can be seen in Table 11-35, several EVSE located in high utilization zones actually have low utilization. Examination of these sites shows that these sites typically have (1) EVSE poorly placed on the site, making it difficult to locate or use, (2) high traffic in their zone, but are located at a low traffic facility, or (3) were installed by the charging site host simply to showcase support for PEVs, without regard to utilization. These sites are not suitable at this time for high utilization.

11.3.6.8 Conclusions. The planning effort undertaken in the Portland area identified areas with predicted high utilization for non-residential EVSE. The EV Project was successful in deploying 74% of the available EVSE into the high utilization area. Data collected from these EVSE demonstrate that utilization is greater for EVSE installed in the predicted high utilization zones than for those installed in the predicted medium and low utilization zones.

Utilization data also show that placement of EVSE in the high zone is not sufficient to ensure high utilization. The venue for the charging site host, the EVSE location on that site, and the host's motivation for installing charge infrastructure are also important.

The high number of distinct users is indicative of the sphere of influence of any particular site. The two retail locations in the medium zone had a significant number of distinct users, indicating a large draw of users from outside their immediate areas.

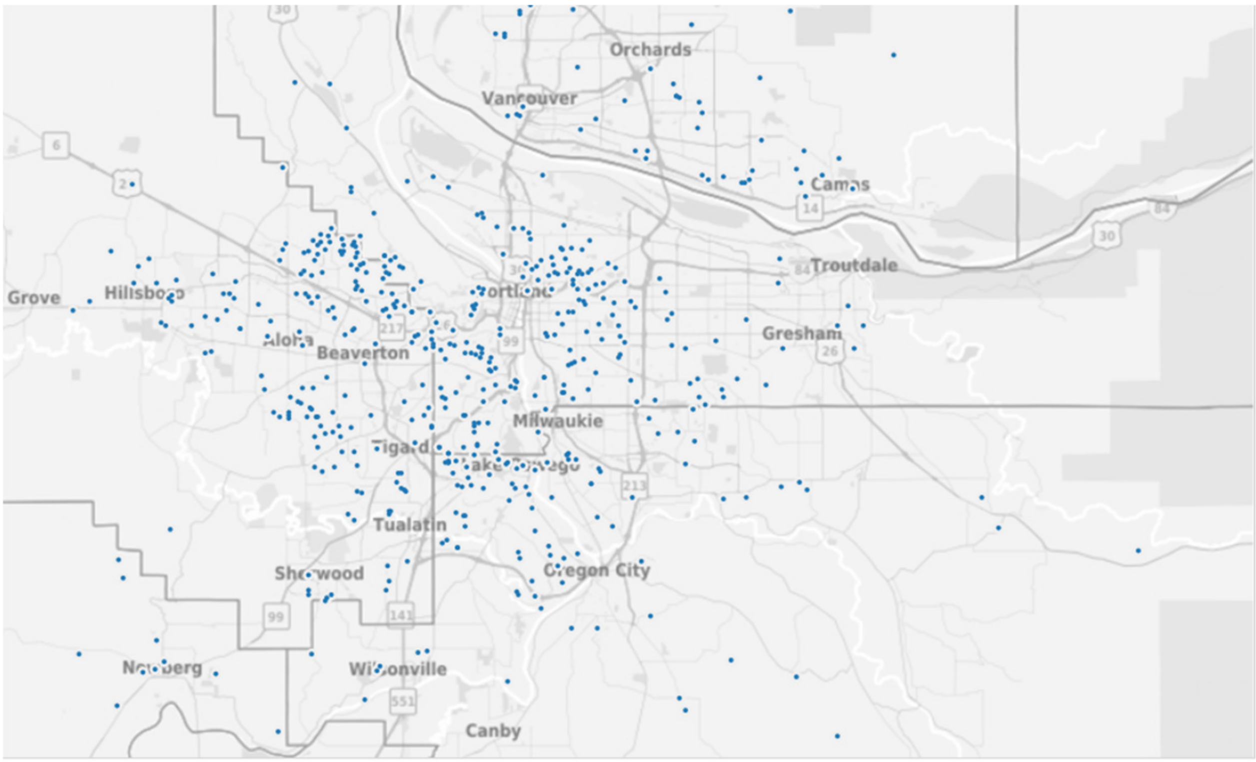


Figure 11-117. PEV drivers' home locations.

11.3.6.9 References

67. "How well did Non-residential EVSE Installations Match the Planned Areas in San Diego?" avt.inl.gov/evproject.shtml#Lessons Learned.

68. "EV Micro-Climate Plan for Northwestern Oregon" avt.inl.gov/evproject.shtm#LessonsLearned.

69. "The EV Micro-Climate Planning Process," lessons learned, http://avt.inl.gov/evproject.shtml#LessonsLearned.

70. "Categorizing EVSE Venues: Describing Publicly Accessible Charging Station Locations," lessons learned, http://avt.inl.gov/pdf/EVProj/CategorizingEVSEVenuesSept2014.pdf.

11.3.6.10 Northwestern Oregon Public Electric Vehicle Supply Equipment Location Planning

Approach—The EV Micro-Climate® planning process was developed during The EV Project as an integrated turn-key program to ensure an area is well equipped with the needed infrastructure to support the consumer adoption of electric transportation. Beginning with extensive feasibility and infrastructure planning studies, the program provided a blueprint to create a rich EV infrastructure.

The EV Micro-Climate process enlisted highly interested stakeholders in the region to provide local context, history, and drive for EV adoption. These stakeholders were active throughout the planning process. The Micro Climate process focused the interests of this highly diverse group to produce three major planning documents. The evaluation of this Micro-Climate planning process has been completed and is available for review.

The EV Micro-Climate process in northwestern Oregon produced three documents: "Electric Vehicle Charging Infrastructure Deployment Guidelines for the Oregon I-5 Metro Areas of Portland, Salem, Corvallis and Eugene" (April 2010), "Long-Range EV Charging Infrastructure Plan for Western Oregon" (August 2010), and the "EV Micro-Climate Plan for Northwestern Oregon" (November 2010). All documents are available at the same website referenced above.

Documents—The EV Infrastructure Deployment Guidelines provided indoctrination information and general guidance for starting the planning process. The Long Range Plan projected PEV population in the greater San Diego area by the year 2020, as well as the projected public charging infrastructure densities that would support this population. The EV Micro Climate Plan for San Diego narrowed the future look to the next 2 to 3 years to provide direction for the near term installation of publicly available EVSE provided by The EV Project**.**

Methodology—The stakeholders conducted a data search of state, regional, and local data that could be useful in locating EVSE. Initial inquiries included geographical information system data for the following:

- Traffic volumes (state and local)
- Employment location information by industry type
- Zoning classifications from the cities.

The three categories were used to create multiple data layers and associated values mapping. A combined, single map was then produced to show proposed density and distribution patterns for EVSE by using multivariate analysis. The analysis resulted in three categories: high, medium, and low, reflecting the anticipated utilization of non-residential EVSE to be located within those geographic areas. Figure 11-118 shows this density map for the greater Portland area.

There may be many different motivations for the host in locating public EVSE, including generation of revenue from fees, promoting a public environmental image, encouraging patronage by the PEV driver demographic, and providing range extension for PEV drivers. The stakeholders determined that optimum locations for publicly accessible EVSE would be those with the following:

- High number of users
    - Integrated into daily life
    - Available to many different users
- High frequency of vehicle turnover
    - Vehicle stay times of 45 minutes to approximately 3 hours
- Significant availability
    - Maximize the number of open days per week and per year
    - Maximize the number of open hours per day.

Following the process outlined above, a significant effort was made to solicit input from the cities and public on the map. Most suggested locations were already identified in the high or medium areas. Very few public locations were in low areas. Consequently, the map in Figure 11-118 was used by the regional manager as the focus for sites for non-residential EVSE.

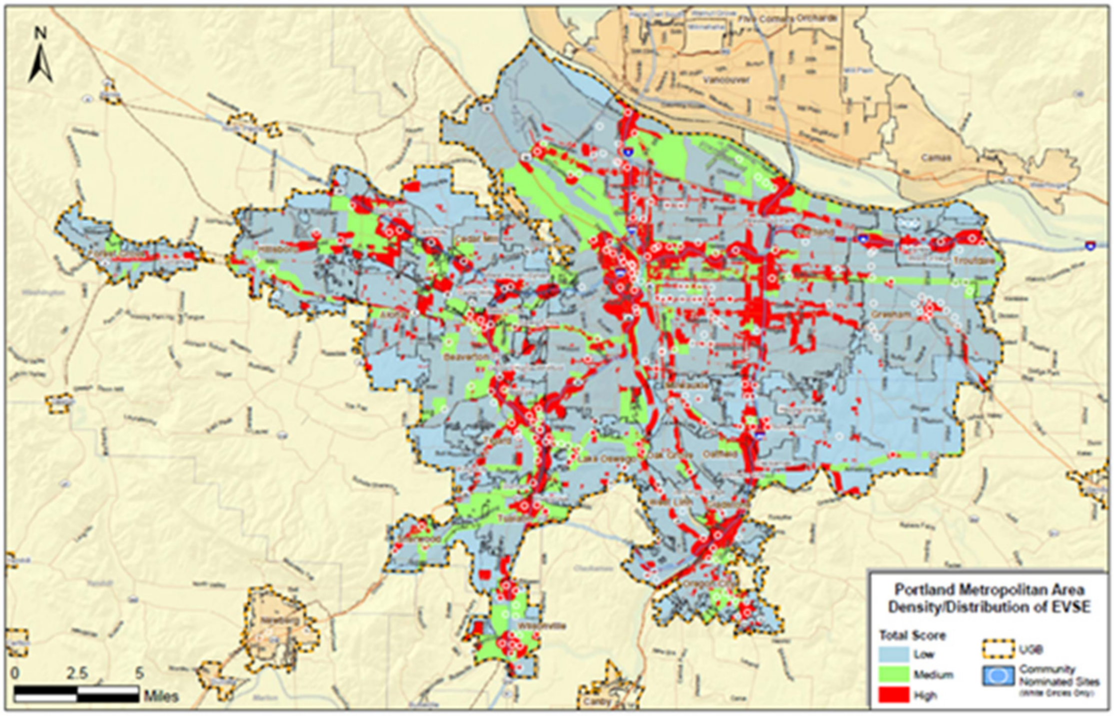


Figure 11-118. Greater Portland region of The EV Project.

11.3.7 Electric Vehicle Supply Equipment Signage

11.3.7.1 Introduction. Signage has two primary purposes: way-finding and regulatory. Way-finding signage involves assisting PEV drivers in locating charging stations. Regulatory signage determines who may park in the designated location and the allowed uses of that charging facility.

Early in the planning process of The EV Project, it was learned that several different ideas for signage were based on personal preferences, company logos, prior usage, and so forth. Signage look, location, and verbiage were subject to local jurisdictions, hosts, and state regulatory agencies. All of these constituencies needed to be accommodated. Recommended signs in one region or for one host might not fit the needs or requirements of others. Although The EV Project did not seek to impose a signage standard, The EV Project did seek to coordinate the various markets in the adoption of standard signage for all EV Project markets. Consistency in signage in any geographic area is important for the PEV driver in order to avoid confusion and to promote learning among the non-PEV owner population.

The topic of signage was first addressed in the mid-1990s (Figure 11-119) with the introduction of EVs in select markets. The way-finding and charging station signage used at that time are shown in Figure 11-120.

Almost uniformly over the five market areas, The EV Project advisory groups desired a different sign from the prevalent signage, because the symbol on the prevalent sign reflected lead acid technology that was outdated; therefore, proposals for new sign symbols emerged. In addition, it was found that during the EVSE infrastructure deployment of the 1990s, the general public was confused by the blue sign and often mistook it for ADA parking and did not recognize the charging station or its signage.

The advisory groups also considered the regulatory nature of the signage. Lessons learned from the 1990s efforts in EVSE infrastructure deployment also pointed to the need to clearly identify that the parking location was to be specifically designated for EVs. In addition to the mistaken identity of a handicap parking stall, the uninformed public did not understand the nature of an EV parking stall nor the need to keep it available for the use by an EV. ICE vehicles would often park in these locations.

Consequently, the regulatory nature of the signage was identified as an important topic for the advisory groups to consider.

Figure 11-119. EV Charging station circa 1996.

Figure 11-120. EV regulatory signs circa 1996.

11.3.7.2 Development. Widespread adoption of EVs will include maps or websites identifying charging locations. It will be helpful to post EV parking area signs on adjacent streets and access points directing EV drivers to the charging locations.

The advisory groups in the five market areas identified a variety of symbols (some are identified in Figure 11-121).

Seeking consensus on the symbol proved to be a difficult task. Inquiries were made to various state agencies inside and outside the local market area. Guidelines and plans identified by others were researched. In seeking a solution that met the regional requirements for uniformity and consideration for a wider geographic appeal, the Federal Highway Administration of the U.S. Department of Transportation was consulted.

Regulatory Issues—Recognizing that the regulatory nature of the signage would be a local enforcement action, this topic was addressed differently among the five market areas of The EV Project.

Figure 11-121. Diverse EV sign symbols.

Most of the regional advisory groups agreed that regulatory signage is important. The difference between "Electric Vehicle Parking Only" and "Electric Vehicle Charging Only" received a great deal of attention. While some markets considered advocating for towing penalties, others wanted to rely on the courtesy of ICE drivers to yield to EVs.

The EV Project also engaged the wider EV user community in this discussion through messaging and social media. While this helps with awareness of the different signs, it will be some time before community consensus begins to have an impact. However, during the interim this discussion highlights signage and helps to focus on behaviors around the use of marked EVSE parking spaces.

The engagement of hosts within this dialogue creates a different perspective, one that is obviously valuable. Consensus among hosts will also evolve over time. Hosts tend to fall into two camps of opinion. The first seeks visibility to their commitment to "clean EVs" and desires visible signs. The second is more concerned with full usage of parking spaces and tends to favor lower key less vigorous signage.

11.3.7.3 Key Options and Alternatives Evaluated. The Manual of Uniform Traffic Control Devices is published by the Federal Highway Administration under 23 Code of Federal Regulations Part 655, Subpart F. It defines the standards used to install and maintain traffic control devices on all public streets, highways, bikeways, and private roads open to the public.

The Manual of Uniform Traffic Control Devices establishes the specific requirements for signs, including color, size, shape, letters, or other symbols. It also establishes standards for placement of signs to ensure they are visible, legible, and enforceable. The requirements also vary along a freeway that is in open country versus a freeway through a metropolitan area.

The process by which signage is approved allows for "experimentation" (i.e., ideas for a new traffic control device or re-application of an existing device can be requested of the Federal Highway Administration). These experimental suggestions generally originate with state agencies responsible for managing the roadway. The recommendations by the Manual of Uniform Traffic Control Devices can be included in the approved signage managed by the state agencies.

The Department of Transportation for the states of Washington and Oregon submitted a request for the Federal Highway Administration to consider an EV charging general service symbol which existed in the 2009 Edition of the Manual of Uniform Traffic Control Devices. The Federal Highway Administration responded with interim approval (see Section 11.3.7.7).

This approval does not preclude the approval or interim approval of other symbols.

Regulatory Issues—In considering the regulatory purposes of signage, some jurisdictions did not want to publish prohibitions without considering enforcement. For example, if signage existed that prohibited parking by ICE vehicles and an ICE vehicle did park in the location, what corrective action would be applied? If signage indicated that the space was for EV charging and an EV was parked but not charging, would enforcement actions be required? Would it be obvious to enforcement that a vehicle that was connected was in fact charging? It would also be possible that at the time of parking, the EV was charging, but by the time enforcement arrived, the charging was complete.

On the other hand, it was generally agreed that without regulatory signage, EVs that were in need of a charge and expecting an open stall would be disappointed if such were occupied by an ICE vehicle. ICE drivers could view EV parking stalls as a preferred parking location and, without negative consequences, would regularly park in such locations. To the general public, observing ICE vehicles in an EV only stall would reduce confidence that publicly available charging would in fact be available. This becomes more of an issue when reservation systems for EVs are employed.

In the early years of EV adoption, EV parking stalls may be vacant for significant periods of time. The availability of these locations is important for EV driver range confidence and for encouraging the general public that charging is available and that EVs should be considered for personal transportation. At the same time, those opposed to EV adoption would suggest that the high vacancy is indication that EV adoption is not occurring. Thus, a secondary discussion revealed that the EV parking stall may not be ideally placed in the most prominent or advantageous location with respect to the facility visited. Rather, secondary choices further from the entrance should be considered.

For those locations that did address punitive actions, the severity of those actions received considerable discussion. This is particularly relevant when considering an EV parked in a charging only stall that is not actually charging. The severity of the consequences could have a negative effect on the driving behavior of EV drivers who then avoid these charging locations and thus result in continuously vacant charging stalls. Instead of encouraging the use of publicly available EVSE, the penalties discourage it.

11.3.7.4 Recommendations

Symbol—The recommendations provided here are designed to streamline the deployment of EVSE infrastructure and to be used as a guide for areas contemplating this deployment. These recommendations are not the only means by which the question of signage can be addressed; uniform symbol and messaging presented here can have a significant effect in public education and reduce EV driver and non-EV driver confusion. In addition to providing way-finding, the use of the same symbol from highway to local street to parking entrance to above the charging station itself, will create a common visual identity that will increase the general public's awareness of electric transportation. Another advantage of sign consensus is the reduced cost of product and inventory since multiple designs need not be printed or retained. It was recommended that this symbol be approved by all jurisdictions as a national symbol.

The recommendations provided here were uniformly adopted by the Advisory Groups in the five EV Project market areas.

The California PEV Collaborative is a multi-stakeholder public-private partnership, working together to ensure a strong and enduring transition to a PEV market in California. The collaborative embodies all key California PEV stakeholders, including elected and appointed officials, automakers, utilities, infrastructure providers, environmental organizations, research institutions and others. The mission of the collaborative is to facilitate deployment of PEVs in California to meet economic, energy, and environmental goals. The PEV collaborative provided the following statement:

> "The PEV collaborative supports the use of standardized signs to minimize confusion and provide the greatest ease of use for EV drivers. To this end, the collaborative recommends that Cal Trans adopt the use of the candidate signs currently being tested in Oregon and Washington, and that local jurisdictions request the use of those signs during the test period with the expectation that they

will ultimately be approved at the federal level and become the uniform standard nationally."

The recommended symbol is shown in Figures 11-122, 11-123, and 11-124.

Location of the symbol on a sign post or painted on the parking surface is a matter of preference but, as seen, the parking stalls are visibly and clearly identified.

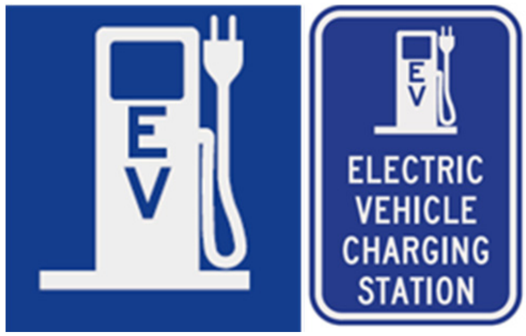


Figure 11-122. Federal Highway Administration approved symbol.

Figure 11-123. EV parking stall with recommended symbol on pavement.

Figure 11-124. EV parking stall with sign at head of stall.

Regulatory Signs—The use of regulatory signs that permit the stall to be used only for the purpose of EV charging was recommended. Lacking local ordinance enactment, these signs will largely be informational and rely on acceptance by the public that the parking stall is for this special purpose. Private property owners have the option of taking action, but it is likely that a destination facility will overlook the infraction to avoid losing a customer. Once ordinances are in place, the sign should identify that ordinance by number; therefore, the driver is aware that enforcement is by the local authorities rather than the destination owner.

Previous experience has shown that signs that follow the red-on-white no parking standards found in the Manual of Uniform Traffic Control Devices work best to keep non-EV drivers from occupying charging station parking spaces. The example in Figure 11-125 follows Manual of Uniform Traffic Control Devices standards.

Recommended wording for the no parking sign is “No Parking Except for Electric Vehicle Charging.” EV drivers in Southern California, where there is an existing network of publicly available charging stations, reported increasing incidences of drivers of Hybrid EVs such as the Toyota Prius parking in front of charging stations believing that “No Parking Except for Electric Vehicles” did not apply to them1. Using “No Parking Except for Electric Vehicle Charging” will help prevent hybrid EVs and conventional ICE vehicles from occupying a charging station parking space.

Figure 11-125. No parking sign.

It was found that combining the symbol and regulatory sign provides an efficient, cost effective, and esthetically pleasing appearance to the charging station.

The sign in Figure 11-126 may be accompanied with a sign that identifies the times the station will be publicly available.

Figure 11-126. Combination sign.

As noted previously, in order for regulatory signs to be enforceable, they must be supported by local ordinances.

11.3.7.5 Budget/Fiscal/Schedule Implications. Way-finding and regulatory signage are highly recommended for all EV parking stalls. While the cost of the sign is added to the cost of installation, this can be reduced if the combination sign is used. Marking the pavement with the symbol is a matter of preference, but it not required. Indeed, it will increase periodic maintenance to continue the appearance following significant use and weathering. However, it will have the effect of reducing the incidence of ICE vehicles parking in EV charging locations.

Placement of the sign during installation of the station will not add significant cost or time delay to the project, and the cost of the sign is minimal compared to the benefit.

11.3.7.6 Lessons Learned. Signage for EV charging infrastructure is an appropriate topic for consideration by local stakeholder groups when preparing for EVs. The choice of the symbol was found to be confusing and even divisive at times with significant difference of opinions. While the recommended symbol may not be universally desired by all stakeholders, it does represent an approved symbol in use by many states. Its adoption early in the evaluation process will significantly reduce the deliberation time. Should local stakeholders select an alternate symbol, it may be used on the EVSE itself or otherwise in conjunction with the standard symbol.

Municipal and state regulatory bodies have a wide range of divergent opinions regarding signage, which will hamper widespread adoption. Some of the divergence will be eroded with time; however, it is anticipated that multiple options and diversity in requirements will persist for some time. This will complicate compliance and add to the overall cost of EVSE deployment.

Hosts add another dimension to the process of selection. Their desires are not universal and even for the same host; preference for signage may be different from one location to another. While there needs to be some time for host preference and input to play out over time, this will be an easier group to achieve some level of uniformity. Hosts are under agreements, which can be used to narrow the options. The cost of individuality can be borne by the host reducing interest in divergence and mitigating the cost impact on the installer.

11.3.7.7 References

71. Puget Sound Regional Council | Washington State Department of Commerce, “Plug in America Web-based Electric Vehicle Consumer Survey,” May 4, 2010.

11.3.7.8 Manual of Uniform Traffic Control Devices Interim Approval

Memorandum

U.S. Department
of Transportation
Federal Highway Administration

Subject: **INFORMATION:** MUTCD- Interim Approval for Optional Use of an Alternative Electric Vehicle Charging General Service Symbol Sign

Date: APR 1 – 2011

From: Associate Administrator for Operations

In Reply Refer To: HOT0-1

To: Federal Lands Highway Division Engineers
Division Administrators

Purpose: The purpose of this memorandum is to issue an Interim Approval for the optional use of a General Service symbol sign that provides road users direction to electric vehicle charging facilities that are open to the public. Interim Approval allows interim use, pending official rulemaking, of a new traffic control device, a revision to the application or manner of use of an existing traffic control device, or a provision not specifically described in the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD).

Background: The Oregon and Washington departments of transportation have requested that the Federal Highway Administration (FHWA) consider alternative symbols for the current Electric Vehicle Charging General Service symbol (D9-11b) sign shown in Figure 2I-1 of the 2009 Edition of the MUTCD in anticipation of deploying electric vehicle charging facilities in these and four other states. The current symbol is a modification of the existing Gas General Service symbol (D9-7), into which the legend EV has been incorporated, similar to Alternative Fuel symbols such as diesel (D), compressed natural gas (CNG), and ethanol (E85). The request was predicated on the presumption that, for electric vehicle charging facilities, the fuel pump and hose of the Alternative Fuel symbols do not apply or could be confusing. Instead, the representation of an electrical cord was thought to be more appropriate. A new symbol was evaluated and subsequently recommended by a Traffic Control Devices Pooled-Fund Study report. However, the requesting agencies believe that the presence of a lightning bolt within this symbol suggests a risk of electrical shock, which would discourage the use of electric vehicles.

Research on the Alternative Electric Vehicle Charging Symbol Sign: In November 2010, a report of the Traffic Control Devices Pooled-Fund Study that evaluated several alternative symbols for electric vehicle charging was released. The symbol that had the greatest comprehension and legibility distance was a modification of the symbol used on the Electric Vehicle Charging (D9-11b) sign in the 2009 MUTCD, with the hose replaced by a power cord and plug and the addition of a lightning bolt within the pump window to convey an electrical charge. A similar version without the lightning bolt element was not evaluated in the subject study. In March 2011, a comprehension evaluation was completed that evaluated the 2010 Pooled-Fund Study recommended symbol and a modified version that deleted the lightning bolt element. Comprehension was found to be similar both with and without the lightning bolt. Additional questions were asked of the test subjects regarding their perception of the relative risk of electrical shock for the new symbols with and without the lightning bolt. The responses indicated that the presence of the lightning bolt did not increase the perceived risk of electrical shock. In addition, overall, the perceived risk of electric shock at an electric vehicle charging facility was relatively low when compared with other items that could pose risks of electric shock.

The results included in the Final Report for this evaluation showed that the correct meaning of the alternative sign was identified by a sufficient percentage of the survey participants for this application. The removal of the lightning bolt element from the symbol reduces its visual complexity and this modification is expected to provide at least comparable recognition and legibility.

FHWA Evaluation of Results: The Office of Transportation Operations has reviewed the available data and considers the alternative sign (see attachment, p. IA-13-1) to be satisfactorily successful for the application of providing direction to an electric vehicle charging station. The alternative sign provides agencies with a means of directing road users to an electric vehicle charging station without the use of a word legend sign or supplemental plaque, thus reducing the informational load presented to the observer and promoting a uniform symbol for this general service.

The design of the alternative Electric Vehicle Charging symbol sign is not proprietary and can be used by any jurisdiction that requests and obtains interim approval from the FHWA to use the sign. The FHWA believes that the alternative Electric Vehicle Charging symbol sign has a low risk of safety or operational concerns.

This Interim Approval does not create a new mandate compelling the use of this new sign, but will allow agencies to install this sign, pending official MUTCD rulemaking, to provide direction to road users to electric vehicle charging stations.

Agencies may also continue to use the ELECTRIC VEHICLE CHARGING (D9-11bP) plaque as an educational message mounted below the alternative Electric Vehicle Charging symbol sign in a Directional Assembly.

Agencies may use the alternative Electric Vehicle Charging symbol in General Services (D9-18 Series) guide signs.

Conditions of Interim Auuroval: The FHWA will grant Interim Approval for the optional use of an alternative Electric Vehicle Charging symbol sign (see attachment, p. IA-13-1) to any jurisdiction that submits a written request to the Office of Transportation Operations. A State may request Interim Approval for all jurisdictions in that State. Jurisdictions using the sign under this Interim Approval must agree to comply with the technical conditions detailed below, to maintain an inventory list of all locations where the signs are installed, and to comply with Item Din Paragraph 18 of Section IA.lO of the 2009 MUTCD, which requires:

"An agreement to restore the site(s) of the Interim Approval to a condition that complies with the provisions in this Manual within 3 months following the issuance of a Final Rule on this traffic control device; and terminate use of the device or application installed under the interim approval at any time that it determines significant safety concerns are directly or indirectly attributable to the device or application. The FHWA's Office of Transportation Operations has the right to terminate the interim approval at any time if there is an indication of safety concerns."

1. General Conditions:

   The use ofthe alternative Electric Vehicle Charging symbol sign is optional. However, if an agency opts to use this sign under this Interim Approval, the following design and installation requirements shall apply and shall take precedence over any conflicting provisions ofthe MUTCD.

2. Allowable Uses:

   Installation and use ofthe alternative Electric Vehicle Charging symbol sign shall conform to the general provisions for General Services signs in accordance with MUTCD Chapter 2I.

3. Sign Design and Size:

   a. The design of the alternative Electric Vehicle Charging symbol sign shall be as shown in the attached sign detail.

   b. The minimum size ofthe alternative Electric Vehicle Charging symbol sign shall be 24 inches in width by 24 inches in height.

   c. The size of the alternative Electric Vehicle Charging symbol sign shall otherwise be in accordance with those of other D9-11 series signs.

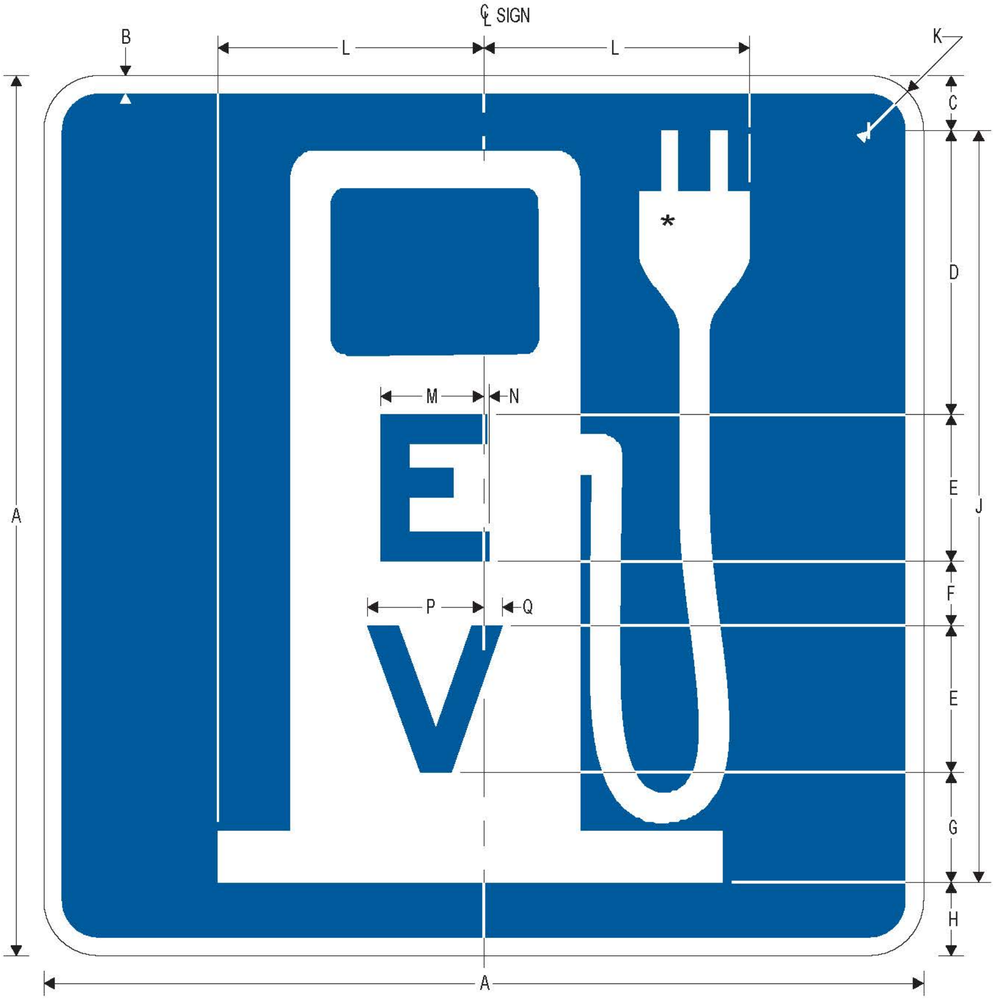
4. Other:

   Except as otherwise provided above, all other provisions of the MUTCD applicable to signs shall apply to the alternative Electric Vehicle Charging General Service symbol sign.

Any questions concerning this Interim Approval should be directed to Mr. Kevin Sylvester at Kevin.Sylvester@dot.gov.

Attachment

cc:
Associate Administrators
Chief Counsel
Chief Financial Officer
Directors ofField Services
Director of Technical Services



D9-11b (Alternate)

Electric Vehicle Charging (Alternate Symbol)

A	B	C	D	E	F	G	H	J	K	L	M
24	0.5	1.5	7.75	4 E(m)	1.75	3	2	20.5	1.5	7.25	2.814
30	0.75	1.875	9.625	5 E(m)	2	4	2.5	25.625	1.875	9.063	3.518

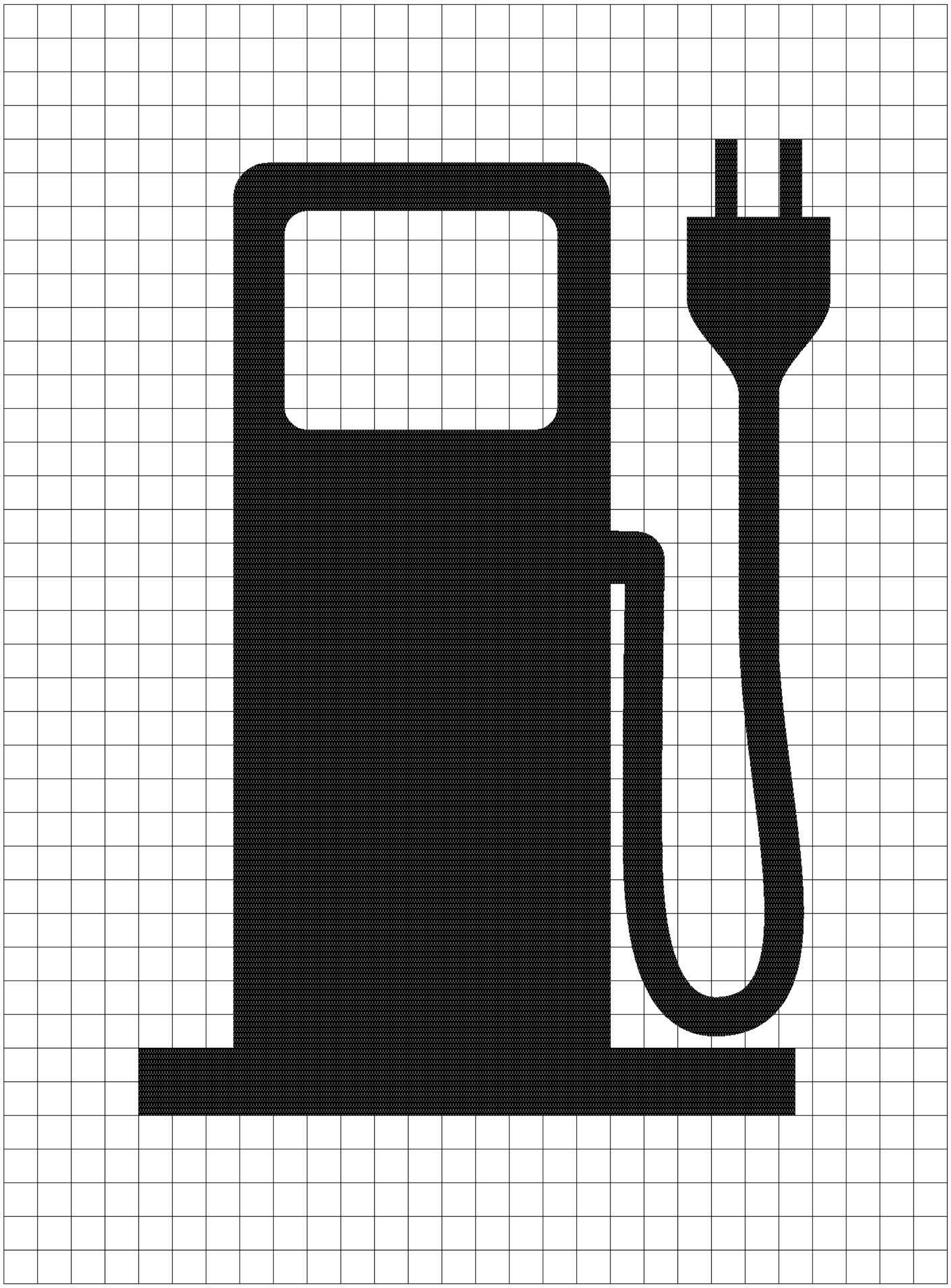
N	P	Q
0.148	3.174	0.507
0.185	3.968	0.635

* See page IA-13-2 for symbol design

COLORS: LEGEND, BACKGROUND — BLUE (RETROREFLECTIVE)
SYMBOL, BORDER — WHITE (RETROREFLECTIVE)

IA-13-1

Issued 4/1/2011



IA-13-2

11.3.8 The EV Micro-Climate® Planning Process

11.3.8.1 Statement of Need. Concerns with global climate change, United States reliance on foreign oil, increasing global demand for petroleum-based fuels, and increasing gas prices, along with the rapid rise of more fuel-efficient vehicles, are clear motivators in changing consumer preferences and industry direction toward more fuel-efficient and alternative energy vehicles. Several automotive manufacturers have successfully introduced a new generation of PEVs and more have announced plans to launch additional PEVs. CARB mandates that one in seven automobiles sold in California in 2025 will be electric or zero emission vehicles, which will drive manufacturers to compete to deliver such vehicles. This illustrates that the future of transportation is being propelled by a fundamental shift to cleaner and more efficient electric drive systems. These vehicles draw some or all of their motive power from onboard storage batteries that are recharged from the electric grid. In order for PEVs to be commercialized, electric charging infrastructure must be deployed. Charging infrastructure must be safe, financially viable, and convenient.

Conventional wisdom suggests (and early EV Project data confirms) that the primary location for recharging PEVs will be at the owner's residence. Extending the range of BEVs and PHEVs will be important through publicly available and workplace charging. Charging opportunities away from home increase consumer confidence that they can return home without fully depleting their battery along the way and thus becoming stranded. The counter to this "range anxiety" is the range confidence provided by an abundance of available EVSE in locations where the driver is likely to travel.

The rapid adoption of PEVs is likely to depend on the availability of commercially based accessible charging. However, this statement quickly points out the dilemma that hosts are unlikely to install EVSE at their retail location without a substantial number of PEVs in use and consumers are not likely to invest in PEVs without the substantial infrastructure.

There are many proponents of PEVs, but few with the financial resources to implement public infrastructure. Therefore, when such funds are available, it is important that the location of the public EVSE be planned to be in the most effective and visible location so that it will be available and used by the PEV driver. Using EVSE utilization as the key metric, the challenge is to optimize the placement of the limited number of EVSE within the geographic boundary. One of the stated objectives of The EV Project is to study business models associated with public EVSE. It is likely that the rapid adoption of public EVSE has to be via a business model that makes sense to the retail hosts.

The readiness of the initial market areas of The EV Project for the placement of public EVSE infrastructure varied considerably. Some locations had devoted little or no resources or efforts in the consideration of public charging, while other locations had significant effort already underway. However, even in the markets where significant effort had been started, the model did not entirely match those of The EV Project; especially in the utilization and business sense.

Therefore, it became imperative that a detailed planning effort be undertaken in each of the original five market areas that focused on the optimized placement of publicly available EVSE. It also was important to enlist the support of the stakeholder groups that existed in each of the market areas or to form new stakeholder groups if none existed, because they had excellent knowledge of local conditions upon which this infrastructure would depend. The EV Project timeline was aggressive; therefore, planning the location for the public infrastructure and creating a common unified plan with the local community was determined to be highly desired.

11.3.8.2 Background

Previous Infrastructure Deployments—EVs made a significant entry into the automotive transportation market in the mid-1990s with the introduction of the GM EV1, the Ford Ranger EV, the Toyota RAV4 EV, and others. This introduction was relatively short lived and general public adoption did not result. In Arizona, Edison EV installed the EVSE in residential settings and both Edison EV and Electric

Transportation Engineering Corporation were in business to install publicly available EVSEs. Edison EV also installed publicly available EVSEs in California and other locations. State incentives and grants were available to commercial hosts to offset some of the installation costs. There was no uniform standard for vehicle charging and automotive manufacturers selected conductive or inductive methods for charging and each type had several variations. Consequently, charging stations typically required at least two types of EVSE. A major improvement for consumers in the present environment is the acceptance of a uniform standard in the conductive connector by SAE in standard J1772. All current and planned PEVs in the United States will utilize this standard connector.

The typical publicly available EVSE in the 1990s was also the AC Level 2 AC unit. The challenge then was to find commercial hosts who would participate in the cost of the EVSE and its installation with no revenue capabilities. Consequently, the strategy for locating units was to find willing hosts. Often the locations did not match locations where the PEV would normally drive, but the early enthusiasts would accept that inconvenience. It was not a sustainable model for widespread adoption.

Many of these stations still exist but are not compatible with the J1772 connection standard. Some locations will be selected for replacement with current equipment and others may wait for future funding or local host actions.

EV Micro-Climate® Approach—Award of The EV Project demanded a better approach. A specific number of publicly available EVSE would be installed in a short period of time and there were no standardized plans in the market areas for locating these units. Furthermore, it was desirable to build a local presence and partnership in the selected markets to create synergy in the process. From these points, the EV Micro-Climate® was created.

The EV Micro-Climate® was designed as a three-step process to identify publicly available charging locations. The three phases included the following:

- EV Charging Infrastructure Deployment Guidelines
- EV Infrastructure Long-Range Plan
- EV Micro-Climate Plan.

Charging Infrastructure Deployment Guidelines: In each of the initial market areas, Blink established an area office staffed with an area manager, field services manager, and office administrator. The area manager was responsible for establishing a close working relationship with the various stakeholders in the area and to facilitate the EV Micro-Climate® process.

In each of the project areas, key stakeholders were identified who were highly motivated to support the widespread adoption of EVs in their region. Additional stakeholders were identified to support formation of a project SAC (Figure 11-127). Committee participants included members from the local electrical utility, local city/county agencies, state transportation agencies, universities, EV enthusiasts/advocates, EV manufacturers, Clean Cities Coalitions, AHJ members, business development agencies, chambers of commerce, EV associations, and association of governments.

While each of these organizations promoted the adoption of PEVs, their motivation and interests in accomplishing this varied considerably. The first phase of the Micro-Climate process was to create synergy and unity in accomplishing the goals of The EV Project. The EV charging infrastructure deployment guidelines (Figure 11-128) effort was the selected means for accomplishing this.

A draft deployment guidelines document was prepared for review and comment by the local SACs. This document not only served to provide focus for the stakeholders in the process, but also provides the foundation for future work. It established a common language concerning PEVs and EVSEs and the basics related to EVSE installation processes and considerations. Several local decisions are necessary for the successful deployment of an EVSE, which then encourages further adoption of EVs in the community. The SACs reviewed and provided comments on the draft guidelines to create the local version. It became a public document to which any additional stakeholders and enthusiasts could refer to understand the local deployment of EVs and charging stations. Typical topics addressed in this document are general terms and nomenclature, EVSE descriptions, EV descriptions, charging scenarios, permitting, codes and standards, accessibility, point of sale, EVSE ownership, and utility integration.

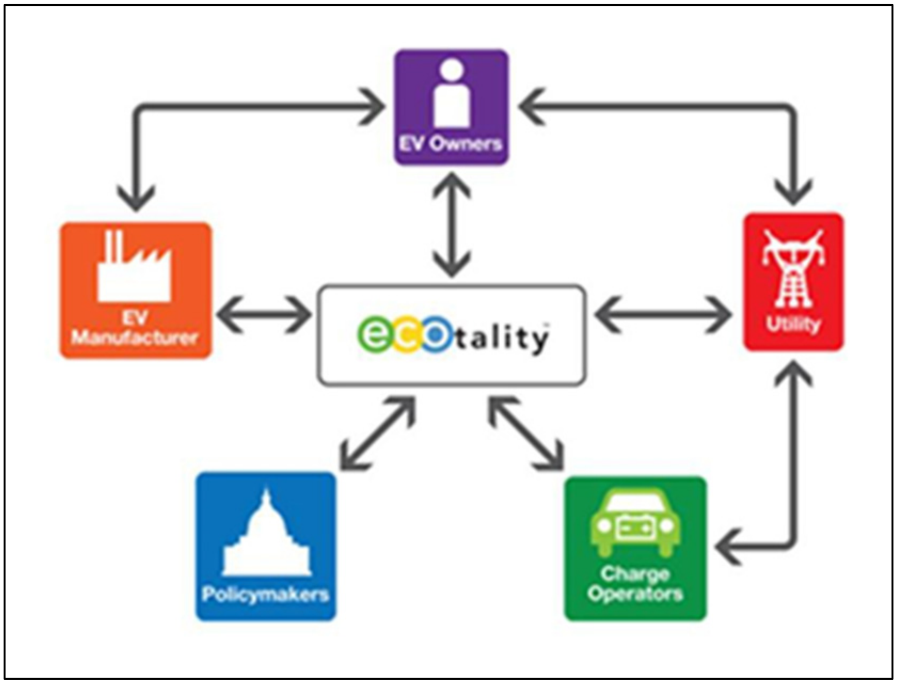


Figure 11-127. SAC.

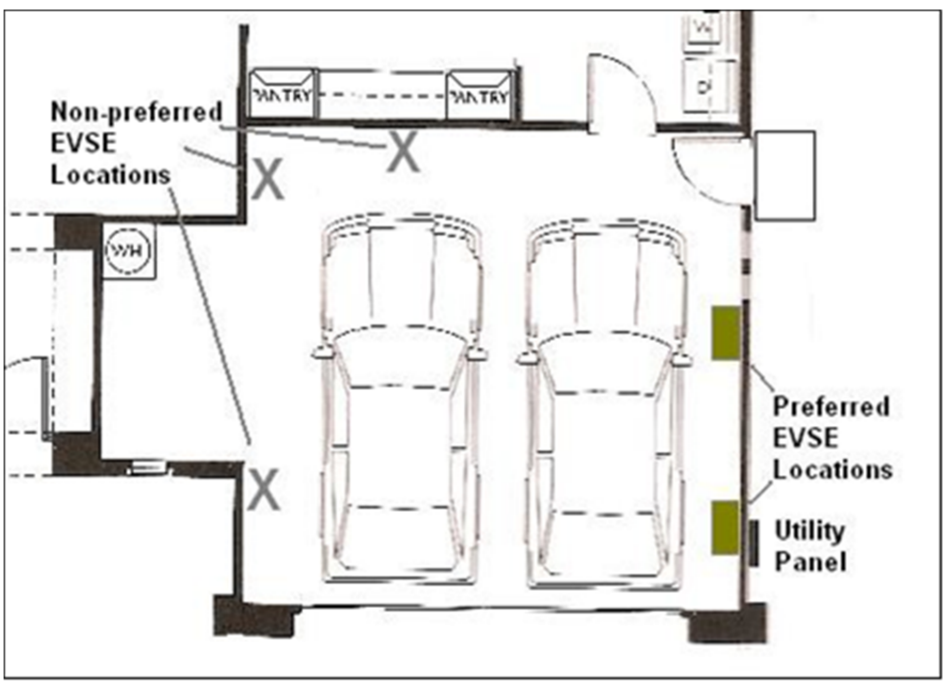


Figure 11-128. Deployment installation guidelines.

After completion of the guidelines document, the SAC then considered long-range planning.

EV Infrastructure Long-Range Plan: By 2020, there will be a variety of PEVs produced by many original equipment manufacturers and current PEVs will be in their second or third owner; therefore, PEVs will appeal to all demographic groups. In addition, the adoption of PEVs will spread well beyond the major metropolitan areas to be generally available everywhere (Figure 11-129). The long-range plan investigates the quantities of PEVs projected to be introduced into the region and the infrastructure required to support them. These include those EVSEs in metropolitan areas and along the corridors that connect those areas. Some EVSEs will be range extenders to allow drivers who live some distance from metropolitan areas to access the local infrastructure grid.

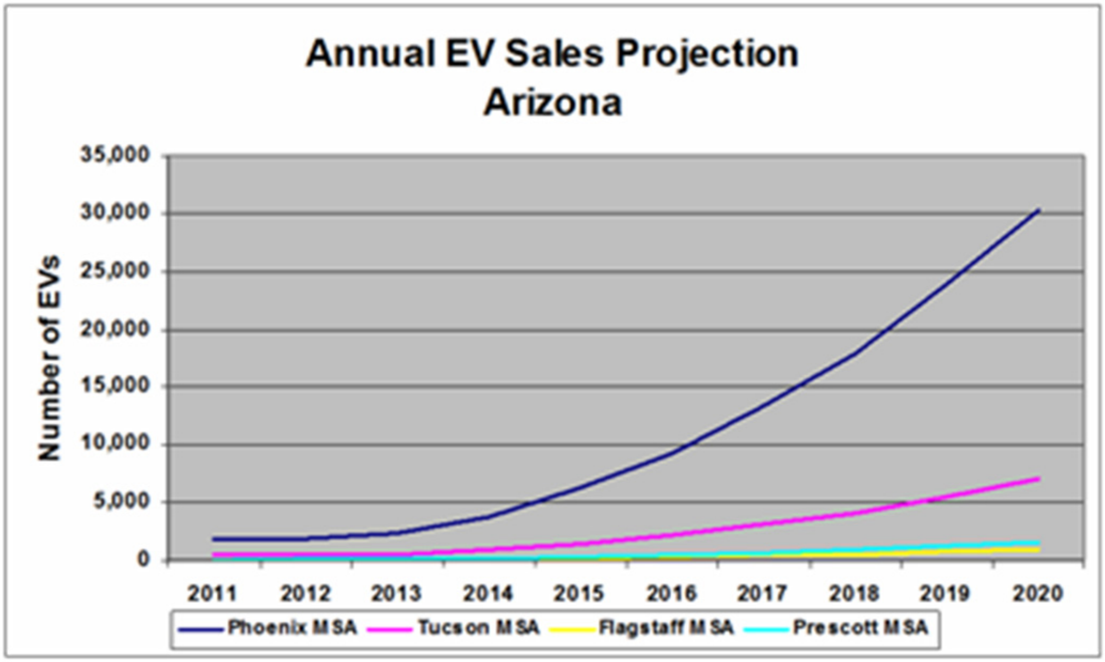


Figure 11-129. Projected annual PEV sales in Arizona.

Blink presented the SAC a draft of the long-range plan for review and comment. It was intended as a starting point to develop the near-term strategy for infrastructure deployment of The EV Project and provide a basis for the direction of future deployment. Many SAC participants were uncomfortable in addressing deployment plans for the early adopters of PEVs because demographically they represented a small segment of the population. The EV Project is an infrastructure study and it would make sense to study how the early adopters use the infrastructure. It would not make sense to install public infrastructure in locations not frequented by these early adopters. The long-range plan could eliminate this specific demographic and view the community as a whole. It also could identify the surrounding community needs, which may not be included in the specifics of The EV Project.

The SAC then could evaluate the impact that PEV demand and local requirements play in determining whether a location would truly make sense as part of a complete EV ecosystem. The plan then considered local demographics, traffic patterns, AC Level 2 and DCFC distribution, EV consumer analysis, and so forth to provide context for the plan. Resources of the SAC (e.g., geographic information systems, mapping capabilities, transportation data, etc.) were provided in some markets to help execute this portion of the project. In essence, the plan would represent the expected density of EVSE in the metropolitan area in the year 2020. The infrastructure density plan for Portland, Oregon (Figure 11-130) was taken from the long-range EV Charging infrastructure plan for western Oregon.

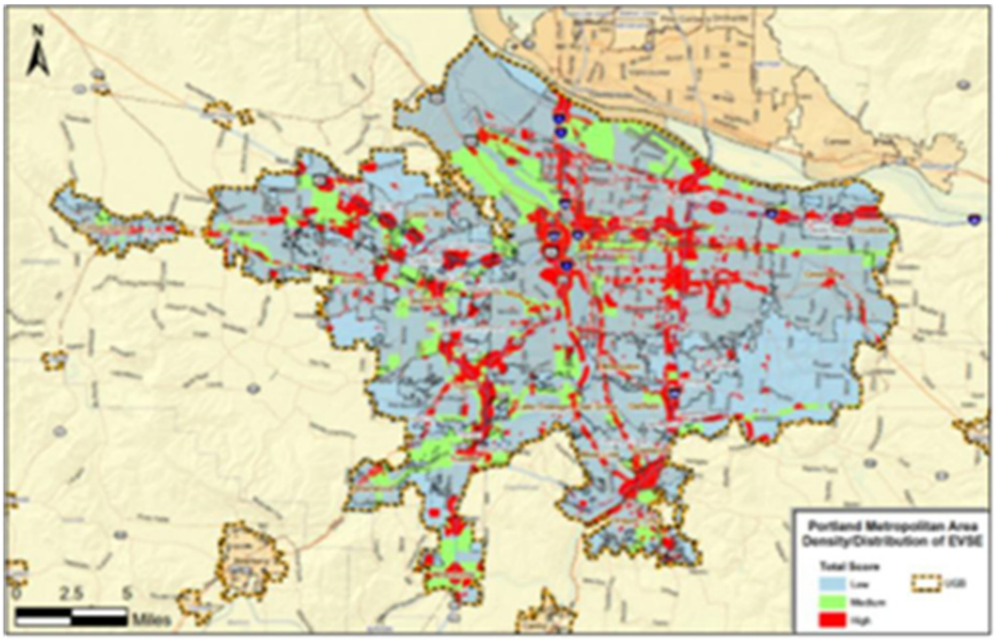


Figure 11-130. Portland density distribution of EVSE.

EV Micro-Climate Plan: Following completion of the long-range plan, the EV Micro-Climate® Plan was established and intended to identify a shorter-term deployment strategy for the first few years of the long-range plan, in addition to immediate local opportunities, which will result in a specific location-driven approach to PEV infrastructure deployment. Projections from the long-range plan were used to predict the rate of PEV penetration and the charging infrastructure needs to support that penetration in the very near future. Rather than blanket the area with infrastructure by simply finding agreeable hosts, this plan judiciously evaluated the demographics of the likely innovators and early adopters of EVs to establish a near-term EV infrastructure. The main objective of this plan was to begin focusing on specific geographic locations that would identify the optimal placement of publicly available DCFCs and AC Level 2 EVSE infrastructure in the metropolitan areas and along these corridors. It was generally thought that a PEV driver would walk approximately a quarter mile from an EV parking location to their desired destination. The goal then was to establish target zones surrounding the major destinations and attractions within the specific market area and along the transportation corridors.

From this document, the process of soliciting charging site hosts would commence. If successful, the hosts would recognize that their location was at an attractive location for PEV drivers and this would expedite site selection and EVSE infrastructure deployment.

Boundaries—Specific boundaries around each metropolitan area were required to identify the locations of qualified participants. Because The EV Project is an infrastructure study, it was determined that the boundary would be a circle of approximately 45 miles from the city center, which would be sufficient for a Nissan Leaf driver to drive to and from on one battery charge. From this area, the utilization and effectiveness of the installed public infrastructure could be measured. Qualification rules were put in place to select participants only from these selected zip codes and aside from a few participants who were incorrectly accepted, participants were located in these areas.

For example, the initial markets for The EV Project included Chattanooga, Knoxville, and Nashville in Tennessee. Later, Memphis was added along with the remaining cities in the state. Consequently, the boundary became the state of Tennessee. The planning efforts centered on the larger metropolitan areas and 5-mile circles around the smaller towns.

The boundary of the long-range plan was specifically selected to be a much larger geographic area because planning envisioned a much higher population of EVs and a widely spread ownership distribution. It also included the corridors for DCFC planning (Figure 11-131).

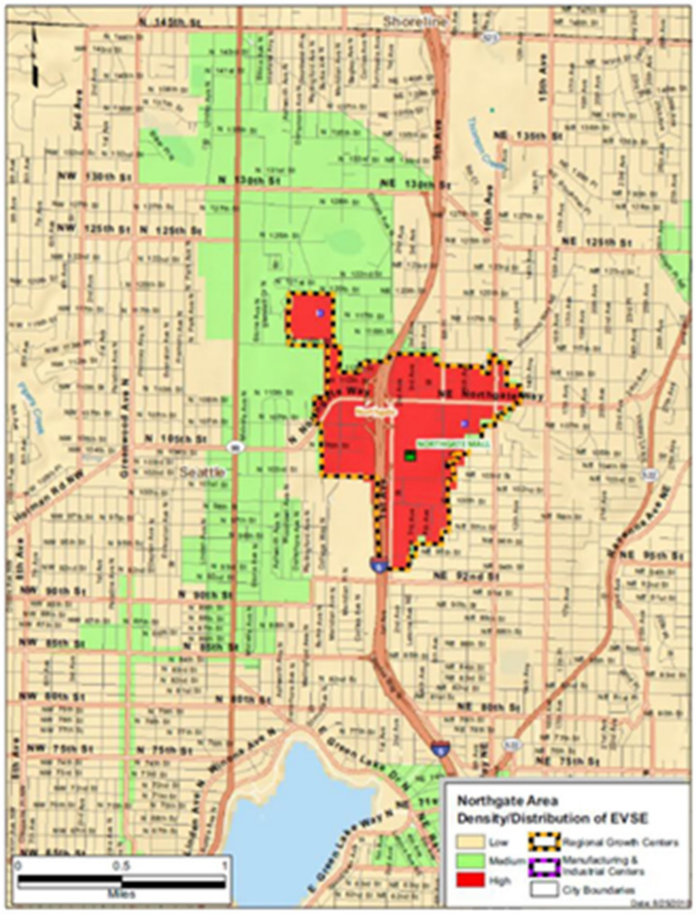


Figure 11-131. Seattle area Micro-Climate local density map.

The boundary of the EV Micro-Climate public infrastructure, on the other hand, was again brought close to the zip code boundaries, but EVSE were not required to be within the specific boundary. If it could be shown that the proposed location was a highly desirable destination location, it was approved for inclusion in the infrastructure. This applied to both the AC Level 2 AC EVSE and DCFCs.

Schedule—The EV Project was officially launched in October 2009, with infrastructure planning commencing early in 2010 in parallel with the EVSE design and Underwriter Laboratories certification testing. Preparation of the Blink Network would also commence in 2010. Installation of residential EVSE would coincide with the delivery of the original equipment manufacturer PEVs with commercial EVSE installations to follow once there were a baseline number of residential EVSE in the local community.

Selection of the area managers commenced immediately and the last site was initiated in February 2010. All sites established the local area office and commenced the search for the appropriate SAC members. All locations commenced the PEV charging infrastructure deployment guideline phase by March 2010 and the final EV Micro-Climate® plan was completed in November 2010. The overall planning process was planned and expected to take approximately 8 months.

11.3.8.3 Lessons Learned

Overview of Process—The EV Micro-Climate® process was set prior to first market area implementation. Several alternatives were reviewed, including elimination of the long-range plan effort. However, it was retained in the overall plan. It was also discovered early on that a competitor also providing EVSE infrastructure had no detailed plan for installation and was soliciting hosts directly. It was thought that a comparison of the deployed charging stations with the planning efforts versus no plan would provide valuable insight and a relevant final report lesson learned**.**

The EV Micro-Climate® Plan was discussed during the first quarterly review with DOE; The EV Project received encouragement to continue the process.

The planning process was rather strictly followed in the initial steps to provide a baseline of information for later lessons learned. While all areas followed the guideline process fairly directly, some conflicts were generated early on that led to specific issues.

Stakeholder Advisory Committee—In general, formation of the SAC was fairly straight forward. Members were eager to participate and were enthusiastic about The EV Project. Most of the key stakeholders knew others who could properly represent other important views and they were successfully enlisted. All area SACs were enthusiastic and supportive through the guidelines phase.

One area had a particularly difficult time in unifying the SAC. Several key stakeholders in the area had commenced their own planning efforts prior to the arrival of The EV Project and, while supportive of the infrastructure planning effort, did not seem to desire the leadership or direction provided by The EV Project. Part of this issue was based on personality conflicts. The issues were later resolved and a good working relationship was formed.

As expected, the various SAC members had their own motivations and focus for deployment of EVSE. In some locations, no progress had been accomplished on any EVSE infrastructure planning. Many SAC members contributed significant effort and the efforts of their organizations to assist in planning efforts. Some contributed geographic information system planning efforts, while at other sites, geographic information system was not used or paid separately by The EV Project.

As planning progressed into the long-range plan effort, many stakeholders felt they had little or no expertise to contribute but retained interest and enthusiasm through its completion. By the time the EV Micro-Climate® plan was in progress, many SAC members were weary of the meetings. One market area decided to skip the long-range plan to focus directly on the local placement of EVSE as provided in The EV Micro-Climate® plan.

Some SAC members objected to the long-range planning efforts following the deployment guideline phase and desired to immediately start enlisting EVSE hosts.

Most SACs disbanded following completion of the EV Micro-Climate plan. In one location, the group was reformed under a different lead facilitator in a new assignment related to EVs. Another region met on an ad hoc basis for status updates, while a third region continued to meet on a regular basis.

Overall, the SAC was an appropriate planning approach. Extremely valuable information and support was provided by the local members. Their involvement was also valuable in soliciting charging site hosts and promoting public education and information.

Draft Documentation—Providing the SAC with draft documents to review and comment was a valid approach. It would have been extremely difficult to complete the three distinct phases in the short period of time if a focused document were not available. Most SAC members appreciated the effort and information provided by the draft documents and supported the general approach and unified approach between the various EV Project markets. The EV market projections through 2020, as presented by The EV Project, were generally validated by the local SACs, although one market area decided not to publish the information as being too speculative.

Widespread Issues—The deployment guidelines document addressed signage as an issue that required a unified response. It was determined early on that it did not want to direct or suggest a unified symbol for signage. It became apparent early on that there was going to be wide disagreement on any selected signage. Every symbol that was presented was disliked by several of the SAC members in several market areas. In one area, a symbol that was copyrighted was suggested, which would have led to royalties paid to the owner. The Department of Transportation for the states of Washington and Oregon submitted a request for the Federal Highway Administration to consider an EV charging general service symbol, which existed in the 2009 Edition of the Manual of Uniform Traffic Control Devices. The Federal Highway Administration responded with interim approval of the symbol shown in Figure 11-132.

Figure 11-132. Federal Highway Administration interim approved symbol.

Another issue identified in the deployment guidelines document was public charging accessibility by persons with disabilities. The position that was suggested in the guidelines draft was found to be incompatible with some local thinking and one area promoted a deeper development of the issue and solution. More information on this topic is included in the accessibility at public EV charging locations lessons learned paper.

Following publications of the deployment guidelines in the market areas, SAE and the National Electric Code revised the charging nomenclature for the various charging levels. The current designations are shown in the J1172 EV and PHEV conductive charge coupler standard by SAE (see Table 11-36).

Table 11-36. EVSE circuit ratings.

AC Charging	AC Level	DC Charging
Circuit Rating: 120 VAC, Up to 16 Amps Power: <1.92 kW	1	Circuit Rating: 200 to 450 VDC, Up to 80 Amps Power: <36 kW
Circuit Rating: 240 VAC, Up to 80 Amps Power: <19.2 kW	2	Circuit Rating: 200 to 450 VDC, Up to 200 Amps Power: <90 kW
To be determined	3	To be determined

The electric utilities became interested in several topics first introduced in the deployment guidelines. Among these was the possibility of clustering. It was thought that if an EV owner displayed and discussed with neighbors the desirability of the PEV and promoted The EV Project benefits, several other people in that neighborhood would buy a PEV, creating a higher demand on the local distribution transformer. Methods were put in place for The EV Project to inform the electric utility when participants were selected for The EV Project. In addition, utilities requested the original equipment manufacturers provide this information when possible. Questions of customer privacy were raised and for The EV Project, permissions from the participants were obtained before providing this information.

Locally Determined Topics—Mapping programs can provide significant insight into infrastructure deployment plans. The role of the geographic information system capabilities was left to the local SACs to discuss and utilize as desired. Two of the areas used relatively simple laptop mapping programs, while others developed very sophisticated geographic information system mapping layer strategies. In two of these three areas, the geographic information system support was donated by members of the SAC, while The EV Project paid for the service in the third market area. Those resulting geographic information system maps provided excellent visibility and a highly professional look to the long-range plan and the EV Micro-Climate® plan. The maps generated by the laptop program were also very effective in communicating the plans but lacked the visual clarity the others provided.

Encouraging the SAC to assist in promotion of the adoption of EVs, The EV Project was left to the individual markets. In some areas, the SAC was very active in promoting public education and outreach, conducting hosting partner forums, displays, and other public events. In other areas, no action was taken by the SAC as a whole, but was left to individual members.

Site Selection Guidance—The EV Project provided significant resources in the market areas for EV infrastructure. There may be competing interests in the location of these resources between local interests and the requirements of The EV Project. The following was provided as a guide for site selection to fulfill the requirements of The EV Project.

The EV Project provides the resources to develop an infrastructure and study the infrastructure deployment and driver behavior in order to learn lessons from this study and refine the deployment methodology. The installed infrastructure must support project objectives. To do that, the following areas must be considered:

Data Collection:

- Matching Data: Data collection is vital to success of The EV Project. Data from The EV Project EVSE is matched to the participant's vehicle data by INL to be considered valid and used by The EV Project. Data from The EV Project EVSE that do not match a participant vehicle is not used and, likewise, data from a participant's vehicle that does not match an EV Project EVSE is not used. This means: EV Project EVSE should be placed where it is likely to be used by the participant's vehicle. Participant demographics must be considered in this placement. These demographics include where the likely buyer will live, work, or frequent as a destination. It is expected that the participants (i.e., early adopters) will be of higher than average income, college, and education, and slightly older than the average driver (i.e., 45 years and above). It is also expected that the demographics will closely match hybrid vehicle owners. They will own their own home or condo and will own two or more vehicles.
- High Use: Site selection should favor those areas where the use of the EVSE will be frequent throughout the day and evening; weekday and weekend.
- Special Project: Some of the EVSE will be placed specifically to support special projects and data collection of The EV Project. Those will be identified specifically. Workplace or employer EVSE (fleet) are examples and will be evaluated individually.

Long-Range Plan:

- Local stakeholders should provide input into the long-range plan. Some areas have done significant work already on this subject. Where possible, that input should be considered.
- Placement of The EV Project EVSE should support locations identified in the area's long-range plan.
- Placement of The EV Project EVSE should consider leveraging of these free units for additional units by the retailer. For example, two units provided by The EV Project yield additional units purchased for use. For local companies, these new locations should be supportive of the long-range plan.

- Demographic data analyzed in the long-range plan (i.e., traffic patterns) should also support location of EV Project EVSE.

Utility Concerns:

- Placement of publicly available EVSE will be of interest to the electric utility, especially in the case of DCFC. Electric utilities should be given an opportunity to review placement with respect to their local grid capabilities.
- Clustering of residential EVSE is another concern to the electric utility. While there is no control over who will obtain a PEV, The EV Project should provide as much information about residential EVSE installations as soon as possible within the privacy guidelines.

Budget:

- The cost of each AC Level 2 AC and DCFC are fairly rigid in The EV Project budget. There is little room for adding more equipment in each area and for substituting more expensive EVSE in the budget.
- The cost for installation of AC Level 2 and DCFC are fairly rigid in The EV Project budget. Simple installations for residential and commercial EVSE will be the norm. Additional costs for service upgrades cannot be borne by The EV Project.
- Special projects are budgeted items and there is little room for additional projects. However, savings in some areas might allow projects of significance to be undertaken.
- Expenditures in the placement and installation of EVSE must be directly tied to The EV Project objectives.
- Vendors and subrecipients must abide by DOE contract requirements.

Schedule:

- The schedule of The EV Project is fixed. Placement of EVSE must support this schedule. Locations where future PEV penetration might occur do not support this schedule or data collection requirements.
- EV Project partners providing locations for EVSE placement can assist in meeting the schedule; these locations need to meet the provided guidance provided.

Visibility:

- A strong effort should be made to locate EVSE in a highly visible location. While perhaps not the prized location with respect to the business entrance, the EVSE should be in a location easily noticed by others entering the business.
- Signage should be included at each location to assist those not familiar with EVs to recognize the purpose of the station.

Motivations—In the early planning stages, it was assumed that all SAC members would be in agreement with the siting philosophy of The EV Project. Recall that one of the stated objectives of The EV Project is to study business models associated with public EVSE. It is likely that the rapid adoption of public EVSE would be via a business model that makes sense to retail hosts. Consequently, the guidelines for The EV Project in site selection were provided to the area managers. Some SAC members had different motivations for site selection.

This is not intended to point out that other motivations are wrong or incorrect, but that some motivations can be in conflict. A lesson learned is to ensure that the motivations are clearly identified at initiation of the planning process. In most cased noted below, exceptions were made to The EV Project placement guidelines to accommodate motivations of the SAC members. These locations will be studied, along with the other sites selected for utilization and lessons learned prepared accordingly.

Utility Ownership Models: In some market areas, the electric utility had plans to own and operate public infrastructure. Cost was planned to be rate-based (i.e. the costs would be borne by all rate payers in the service territory to provide service in the public good). In this way, access to the EVSE could be provided to all and the fee for service could be at no cost or as determined by the rate case. With EVSE ownership, the utility would also be responsible for placing the units and a long-range and micro-climate plan would be unnecessary. By the terms of The EV Project, the project needs to retain ownership of the publicly available EVSE for the duration of the project to ensure data collection and transmittal. In addition, this utility plan has obvious motivational conflicts with the goals of The EV Project, where business models are required.

While this subject has been raised to some public utility commissions, during the early stages of The EV Project, no public utility commission had yet agreed with the electric utility ownership model.

Public Messaging: In some market areas, great emphasis is placed on alternative transportation methods. Some SAC members saw that placement of public EVSE could support these promotions and lobbied for specific locations that are transition points for public transit. Such places could include park and ride locations or long-term parking at airports. While the location can emphasize and promote the public transit modes, the location is not suitable for business models in that it would be likely that one vehicle would park at the EVSE all day when only a short time would be required to recharge the battery; therefore, the EVSE would receive no other use.

Projects Showcasing: In one market area, it was desired to showcase EV charging in a public venue and several EVSE suppliers were requested to provide EVSE for this location. A significant concentration of EVSE then occurred, which provided a great visual message. However, it would be many years before utilization would approach the business models desired by The EV Project.

Political Motivation: Some municipal government members of the SAC had a strong desire to place public EVSE at government facilities such as city hall or public libraries. Many of the early adopters of EVs are politically active and the reasons for this placement seemed more political than showing concern with high utilization.

Public Image: Some organizations and universities appeared interested in hosting publicly available EVSE at their facilities because of the image it would convey to others. However, placing EVSE in a student parking area at a university may not be a good place if utilization is the desired goal. Some businesses also seemed to desire EV Project EVSEs for their location to promote a public image. However, the location was truly limited to employees and access to the public was difficult or not available.

Workplace: At initial scoping discussions for The EV Project, it was determined that public charging would require general access by the public for most of the day. Some locations were rejected because they did not provide this access. It was later determined that the placement of a limited number of EVSE in the workplace environment could have some value in the overall evaluation of infrastructure and specific project areas were established for study.

Roles and Responsibilities Documentation for the Stakeholder Advisory Committee—The SAC was organized without specific guidance on their roles and responsibilities, including any support actions that may be required from their respective home offices. In many cases, members volunteered the support that was desired, but at other times, the members attended or called into meetings without providing support or ideas. A clearer "job description" could have been provided that outlined the expectations of their participation, including the length of the project, the number of meetings and other support required and the specific stages of the project. A clear understanding of the SACs function, if any, following completion of the project would have been desirable.

Market Additions—When The EV Project was expanded to include the Chevrolet Volt and the cities of Los Angeles, San Francisco, Dallas/Ft Worth, Houston, Memphis, and Washington D.C., there was insufficient time to conduct detailed planning activities, because these areas needed to move immediately into charging site host selection. At first, it was thought these areas would not receive public infrastructure as an additional source of study. The question arose if participants behavior would be different between areas where a substantial infrastructure existed and those where it did not. Certain areas were allowed to proceed with some infrastructure, mostly in support of workplace or fleet charging while still retaining some areas with no public infrastructure.

Effectiveness of the Planning Effort—One of the key elements of the EV Micro-Climate® planning process is the actual plan for seeking public charging hosts. It was originally thought that The EV Project's offer to charging site hosts would be attractive enough that significant effort would not be required to enlist sites. This was not the case, because it was not always possible to follow the EV Micro-Climate® plan for placement of EV Project assets. Site host market acceptance for offering EV charging was a significant factor for final charger placement. Therefore, most of the market areas will complete installation phase of The EV Project with public EVSE installed in locations that may not coincide with the plan. Part of the final evaluation of the effectiveness of the overall planning effort will be to evaluate utilization and performance of all the EVSE to determine if the planning effort contributed to successful placement of EVSE.

11.3.8.4 Recommendation/Conclusion

Overall Conclusion—As noted above, the following objectives were identified for the EV Micro-Climate® planning process:

- Create a local presence in the market area
- Establish leadership in the market area
- Establish relationships with key stakeholders in the community
- Create a synergistic focus for stakeholders already interested/involved in PEV promotion
- Establish a common ground for nomenclature and discussion
- Identify specific areas that require local action in the deployment of EVSE
- Create a plan for placement of EVSE
- Communicate regularly with stakeholders, area government, and potential hosts
- Message potential hosts the benefits they might accrue with the placement of EVSE.

The plan was effective in accomplishing all of these objectives. The area manager was quickly recognized in the community as The EV Project spokesperson. Focusing the SAC on the PEV charging infrastructure deployment guidelines created synergy to gain momentum in the planning process. The area manager, as facilitator and provider of the draft documents, was the recognized leader who was required to keep the overall planning process to the 8 to 9-month timeframe.

Documentation—This process was approached in three specific phases; it was intended that the documents approved in the process would signal completion of that phase. The following documents were generated:

EV Charging Infrastructure Deployment Guidelines: This document was approved locally by the SAC and made a public document. Copies of this document for Phoenix, Arizona; Tucson, Arizona; Central Puget Sound Area (Seattle, Washington); Portland, Salem, Corvallis, and Eugene Oregon; the state of Tennessee; and San Diego, California are posted on The EV Project website (http://avt.inel.gov/evproject.shtml). Credits to the support of the SACs are included in the documents.

Long-Range EV Charging Infrastructure Plans: This document was approved locally by the SAC and made a public document. Copies of this document for Arizona, western Oregon, Tennessee, and San Diego, California are posted on The EV Project website. Some of the information used in the creation of these documents was considered proprietary to Blink; therefore, the unclassified versions were posted. Again, credits to support of the SACs are included in the documents.

EV Micro-Climate Plans: This document was approved locally by the SAC and made a public document. The documents for Arizona, Oregon, Tennessee, Central Puget Sound and Olympia Areas of Washington State, and San Diego, California are in final tech review and the unclassified versions will be posted on The EV Project website.

Time and Schedule Impact—The overall planning process was found to be an 8 to 9-month process. This did not add time or cost to The EV Project because it was conducted in parallel with the equipment design and build functions of the project. The final EV Micro-Climate® planning phase was completed coincident with the availability of residential Blink EVSE and delivery of the first Nissan LEAF vehicles. This also preceded delivery and installation of the first publicly available EVSE by approximately 6 months.

Future Work—Following the work completed in the initial five market areas, The EV Project has proposed the same or similar planning process in several other areas. Work is in progress, or has been completed, in many areas at the time of this writing with very favorable reviews. This is seen as an endorsement of this overall planning process. Improvements to the process are proprietary and are not identified here.

Micro-Climate reviews are not limited to The EV Project or even solely to government. There are a number of examples of private application of Micro-Climate reviews that could be successfully applied. Some community organizations have already shown interest and discussions have begun with large industrial facilities. It is anticipated that as the housing market picks up, developers of large planned communities will begin applying Micro-Climate within their site plans.

11.4 The EV Project Plug-In Electric Vehicle Gasoline and CO_2 Savings, Carbon Credits, and Greenhouse Gases

11.4.1 EV Project Gasoline and CO_2 Savings Extrapolated Nationally

11.4.1.1 Single EV Project Plug-In Electric Vehicle Gasoline Savings. This section takes a look at the amount of petroleum that was avoided by Leaf and Volt drivers in The EV Project. It also extrapolates the petroleum savings to the national fleet of light-duty vehicles, on a percentage replacement basis.

A previously developed EV Project lessons learned paper titled, "How many electric miles do Nissan Leafs and Chevrolet Volts in The EV Project travel?" (see Section 11.6.1) identified the monthly eVMT for the Leafs and Volts in The EV Project (see Table 11-37). Because the Leaf can only be driven in electric mode, all of the Leaf miles are eVMT. The Volt can be driven in both EVM and ERM (i.e., during which its ICE uses gasoline).

If we concern ourselves with eVMT and the amount of petroleum reduction that can be associated with eVMT, we can estimate the petroleum savings associated with BEVs and PHEVs (when charged and driven in EVM). There are cradle-to-grave issues with electricity generation and petroleum extraction and refining; however, this discussion is limited to vehicle-specific petroleum reduction potential.

Table 11-37. Total number of vehicles, monthly miles driven, monthly eVMT, and monthly miles driven with gasoline for the two PEV models in The EV Project.

	EV Project Vehicles	Monthly Miles Driven	Monthly eVMT	Monthly Miles Driven Gasoline
Leafs	5,789	808.1	808.1	NA
Volts	2,023	1,019.8	759.3	260.5
	7,812			

Source: How many electric miles do Nissan Leafs and Chevrolet Volts in The EV Project travel? http://avt.inel.gov/pdf/EVProj/eVMTMay2014.pdf

If it can be assumed that the 7,812 Leafs and Volts in The EV Project eVMT study were driven year round, they would accumulate 75 million eVMT annually (Table 11-38).

Table 11-38. Monthly eVMT is used to calculate the equivalent annual eVMT.

	EV Project Vehicles	Annual Miles Driven	Annual eVMT	Annual Miles Driven Gasoline	Total Equivalent Annual eVMT
Leafs	5,789	9,697	9,697	NA	56,135,933
Volts	2,023	12,238	9,112	3,126	18,433,576
					74,569,509

Table 11-39 provides the basis that was used by INL to develop the methodology behind DOE's eGallon tool, which provides users with the cost of fueling a vehicle with electricity compared to a similar vehicle that runs on gasoline. The eGallon website provides results for individual states (see http://energy.gov/maps/egallon). Vehicles comparative to the Volt (Chevrolet Cruze) and to the Leaf (Nissan Versa) were established (Table 11-39) to support the methodology for the eGallons tool.

Table 11-39. PEV and equivalent ICE vehicle use of fuel developed and used for DOE's eGallon tool.

PEV Model	kWh/100 Miles Combined[1]	2013 Fuel Economy Guide Page	ICE Model	Combined MPG[1]	2013 Fuel Economy Guide Page
Chevrolet Volt	35	P. 26	Chevrolet Cruze[4]	30	P. 12
Ford Focus EV	32	P. 25	Ford Focus[5]	31	P. 10
Honda Fit EV	29	P. 25	Honda Fit[6]	30	P. 15
Nissan Leaf (2012)[2]	34	See Note 2	Nissan Versa[7]	35	P. 11
Average[3]	32.50		Average[8]	31.50	

1. Model Year 2013 Fuel Economy Guide http://www.fueleconomy.gov/feg/pdfs/guides/FEG2013.pdf.
2. The 2013 Nissan Leaf data were not available in the model year 2013 Fuel Economy Guide. Instead, the 2012 data from the 2012 Guide were used.
3. Average (mean) (35 + 32 + 29 + 34) / 4 = 32.50 average kWh per 100 miles.
4. Chevrolet Cruze A-S6, 1.4L, 4 cyl.
5. Ford Focus AM-6, 2.0L 4 cyl.
6. Honda Fit A-S5, 1.5L, 4 cyl.
7. Nissan Versa AV, 1.6L 4 cyl.
8. Average (mean) (30 + 31 + 30 + 35) / 4 = 31.50.

Using the Table 11-39 results to populate the equivalent vehicle mpg, the annual calculated gasoline gallons saved can be calculated. The Volts and Leafs in The EV Project would save 2.2 million gallons of gasoline per year and 44 million pounds of CO_2 on annual basis (Table 11-40). The CO_2 savings analysis is based on the 2013 Fuel Economy Guide (see page 3, ninth paragraph, "Every gallon of gasoline your vehicle burns puts about 20 pounds of CO_2 into the atmosphere," at https://www.fueleconomy.gov/feg/pdfs/guides/FEG2013.pdf).

Table 11-40. Annual gasoline gallons saved each year by vehicles in The EV Project.

	EV Project Vehicles	Total EV Project Annual Total eVMT	Equivalent Vehicle MPG	Annual Calculated Gasoline Gallons Saved	Annual Pounds of CO_2 Avoided at 20 Pounds CO_2 per Gallon Avoided
Leafs	5,789	56,135,933	35	1,603,884	32,077,680
Volts	2,023	18,433,576	30	614,453	12,289,060
Totals	7,812	74,569,509		2,218,331	44,366,740

Using the combined eVMT of Leafs and Volts in Table 11-38, average eVMT for our sample vehicles would be 9,405 eVMT annually ((9,697 + 9,112) / 2). Using the average mpg of all four models in Table 11-39, we get an average of 31.5 mpg. Dividing this into our 9,405 eVMT for EV Project PEVs, a single PEV would save on average 299 gallons of gasoline annually (Table 11-41). Taking this one step further, a PEV would avoid the generation of 5,980 pounds of CO_2. (It is assumed for national calculations, not all PEVs will be Leafs and Volts).

Table 11-41. Annual gallons of gasoline saved annually by driving a PEV.

Number of PEVs	Average Annual eVMT of a Combined Technology PEV	Average MPG	Annual Gallons of Gasoline Avoided	Annual CO_2 Avoided at 20 Pounds CO_2 per Gallon Avoided
1	9,405	31.5	299	5,980

11.4.1.2 National Potential Plug-In Electric Vehicle Gasoline and CO_2 Savings When Plug-In Electric Vehicle are Used. The most recent data from the U.S. Department of Transportation lists 183,171,882 vehicles as the total number of light-duty, short-wheel base vehicles in the United States (as of 2012). This appears to be the most reasonable citable estimation of vehicles that light-duty PEVs are capable of replacing. This information comes from: http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_11.html and will be used to estimate the potential annual gallons of gasoline and pounds of CO_2 that can be avoided if PEVs are used for transportation instead of an ICE vehicle. Again, the CO_2 savings analysis is based on the 2013 Fuel Economy Guide.

As a reference, Electric Drive Transportation Association states that 357,768 PEVs have been sold in the United States since 2010. (EDTA Electric Drive Market Snapshot: August 2015. See: http://electricdrive.org/index.php?ht=d/sp/i/20952/pid/20952). Therefore, if we very conservatively estimated that 304,103 (85% of all light-duty, short-wheel base vehicles) of the PEVs are still in operation, and they would have been driven 2.9 billion eVMT (304,103 x 9,405), and the use of approximately 91 million gallons of gasoline (2,860,088,715 / 31.5) can be avoided annually if the PEVs in the United States are recharged by drivers in a manner similar to The EV Project Volts and Leafs. The generation of 1.8 billion pounds of CO_2 would also be avoided annually (90,796,407 x 20).

Table 11-42 details the gasoline use and the generation of tailpipe CO_2 that could be avoided if various percentages of light-duty vehicles in the United States were replaced by PEVs with similar charging and driving patterns as the PEVs driven by the general public in The EV Project.

Table 11-42. Annual gallons of gasoline and CO_2 that can be avoided if various percentages of the 183,171,882 total short-wheel base, light-duty vehicles in the United States were replaced by light-duty PEVs and recharged in a manner similar to The EV Project Volts and Leafs.

Percentage of U.S. Light-Duty Vehicles Replaced by PEVs	Number of PEVs	Average Annual eVMT Miles at 9,405 Miles/Year	Annual Gallons of Gasoline at 31.5 Avoided	Annual Pounds CO_2 Avoided at 20 Pounds CO_2 per Gallon Gasoline Avoided
0.10%	183,172	1,722,731,550	54,689,890	1,093,797,810
0.125%	228,965	2,153,414,438	68,362,363	1,367,247,262
0.15%	274,758	2,584,097,325	82,034,836	1,640,696,714
0.20%	366,344	3,445,463,100	109,379,781	2,187,595,619
0.25%	457,930	4,306,828,876	136,724,726	2,734,494,524
0.5%	915,859	8,613,657,751	273,449,452	5,468,989,048
0.75%	1,373,789	12,920,486,627	410,174,179	8,203,483,572
1%	1,831,719	17,227,315,502	546,898,905	10,937,978,097
2%	3,663,438	34,454,631,004	1,093,797,810	21,875,956,193
5%	9,158,594	86,136,577,511	2,734,494,524	54,689,890,483
10%	18,317,188	172,273,155,021	5,468,989,048	109,379,780,966
25%	45,792,971	430,682,887,553	13,672,472,621	273,449,452,414
50%	91,585,941	861,365,775,105	27,344,945,241	546,898,904,829
75%	137,378,912	1,292,048,662,658	41,017,417,862	820,348,357,243
100%	183,171,882	1,722,731,550,210	54,689,890,483	1,093,797,809,657

11.4.1.3 Summary. PEVs have significant potential as a light-duty vehicle transportation option to reduce both petroleum consumption and tailpipe emissions if they are utilized (i.e., charged and driven) in a manner similar to The EV Project PEVs. It was demonstrated by The EV Project PEV drivers that they can achieve the high levels of eVMT required to achieve these benefits. If just 10% PEV market replacement occurred, there would be 18.3 million PEVs on the road in the United States, and these PEVs would avoid the use of 5.5 billion gallons of gasoline and the generation of 109 billion pounds of CO_2.

11.4.2 How Many of California's Low-Carbon Fuel Standard Credits were Generated by Use of Charging Infrastructure Deployed During The EV Project?

11.4.2.1 Introduction. In January 2007, Governor Schwarzenegger issued an Executive Order to enact LCFS credits in the State of California. This standard calls for reduction in the carbon intensity of California's transportation fuels, including tailpipe emissions and all other associated emissions from production, distribution, and use of transport fuels within the state. CARB established regulations for meeting the target of reducing carbon intensity by at least 10% by 2020.

LCFS includes emissions trading as a means for the state of California to meet its overall emissions objective. Credits are earned for emissions reduction and these credits can be sold to entities that need credits in order to comply with regulation.

By providing a lower-carbon fuel, relative to gasoline, The EV Project's charging stations, also identified as EVSE, earned an LCFS credit for each metric ton of CO_2-equivalent emissions avoided.

Although generation of LCFS credits was not a named objective of The EV Project, it is another means of generating revenue for EV service providers. This section provides an overview of the regulation as it applies to electricity used as a transportation fuel, how LCFS credits were earned, and their value.

This section is not intended to provide an explanation of California's LCFS Program. Details of this program can be found on CARB's website at http://www.arb.ca.gov/fuels/lcfs/lcfs.htm.

11.4.2.2 Key Conclusions

- As an EV service provider dispensing electricity as a transportation fuel in California, the charging infrastructure deployed in The EV Project was eligible to generate LCFS credits.
- The EV Project dispensed over nine gigawatt hours of energy that were eligible for LCFS credits.
- The measure of LCFS credits is megatons of CO_2 averted. The EV Project generated over 5,500 credits (megatons).

11.4.2.3 Data Analyzed. In order to earn LCFS credits for electricity provided as a transportation fuel, an EVSP must be able to quantify the kilowatt hours of energy that were dispensed as transportation fuel. The Blink smart EVSE measures the amount of electricity (in kWh) dispensed as transportation fuel using its integral, revenue grade meter and network connectivity. It transmits this use data via the internet or a cellular data network to a central database.

These EVSE energy data were transmitted to INL as part of The EV Project. Data experts at INL then captured the relevant charge data from each EVSE operating in California and reported it to EV Project management, who in turn reported it to CARB via their online LCFS reporting tool.

11.4.2.4 Analyses. The LCFS regulation refers to entities who supply electricity through EVSE as regulated parties. By providing a lower-carbon fuel relative to gasoline, regulated parties can earn an LCFS credit for each metric ton of CO_2 equivalent emissions avoided through use of electricity—a transportation fuel with a much lower carbon intensity (as defined in the regulation) than the 2020 standard specified in the LCFS regulation.

When LCFS was first established for regulated parties, ambiguous language in the regulation allowed both electric utilities and non-utility EVSE providers to earn credits for EVSE used in single-family and multi-family homes.

In January 2013, the regulation was amended to state that electric distribution utilities would be recognized as the regulated party for single-family and multi-family residences. It also clarified that the regulated party for publicly accessible EVSE would be either the third-party non-utility EV service provider or the electric distribution utility that installed (or contracted the party who did the installation of) the publicly accessible charging equipment.

At its outset, the regulation allowed The EV Project to claim credits for use of both residential and publicly accessible charging stations that it had deployed as part of the project. However, with amendment to the regulation, The EV Project could only claim credits in 2013 for use of charging stations it deployed outside of single-family and multi-family residences. Figure 11-133 shows the energy dispensed for 2011 through 2013 that was eligible for LCFS credit. The effect of the amendment at the start of 2013 is very apparent in the graph.

The EV Project, as the regulated party, did not generate carbon emissions; therefore, all credits accumulated could be sold to carbon emitters who were subject to LCFS.

11.4.2.5 Discussion of Results. The process for accumulating and accounting for LCFS credits utilized the capabilities of the Blink smart charging unit and network. The Blink AC Level 2 and DCFCs measure energy dispensed by each charging unit with its onboard meter, transmitting information to a Blink database and, ultimately, to the data center at INL via a wired internet connection or a cellular network. INL data experts tally and report to EV Project management the results of EV charging with the project's EVSE on a quarterly basis. These data were submitted as a total number of kWh in the quarter to the CARB via its LCFS reporting tool. This tool calculates metric ton of CO_2e avoided and accumulates the associated LCFS credits earned from the charging activity.

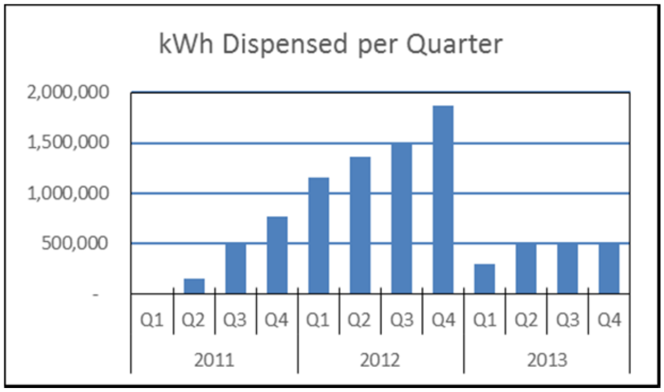


Figure 11-133. Energy dispensed during The EV Project that was eligible for California's LCFS credits.

The credits (and metric ton of CO_2e avoided) accumulated based on use of charging infrastructure, which increased in numbers each quarter as more infrastructure was installed by The EV Project.

The quarterly credits and metric ton of CO_2e avoided can be seen in Figure 11-134. Accumulation over The EV Project can be seen in Figure 11-135. By the end of 2013, The EV Project had accumulated 5,618 LCFS credits, representing 5,618 megatons of CO_2e avoided.

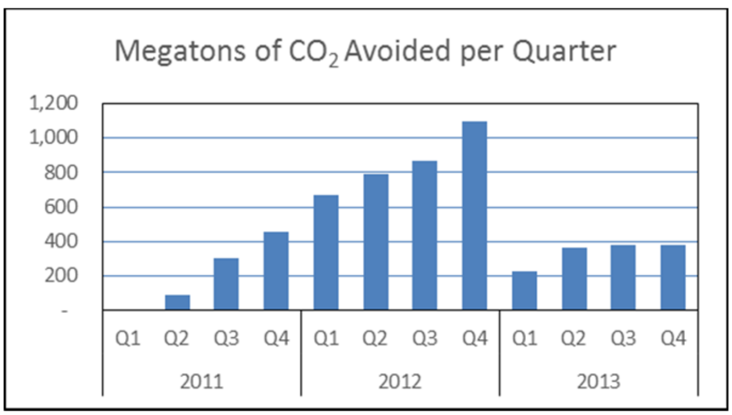


Figure 11-134. Megatons of CO2e avoided per quarter during The EV Project per California ARB LCFS calculations.

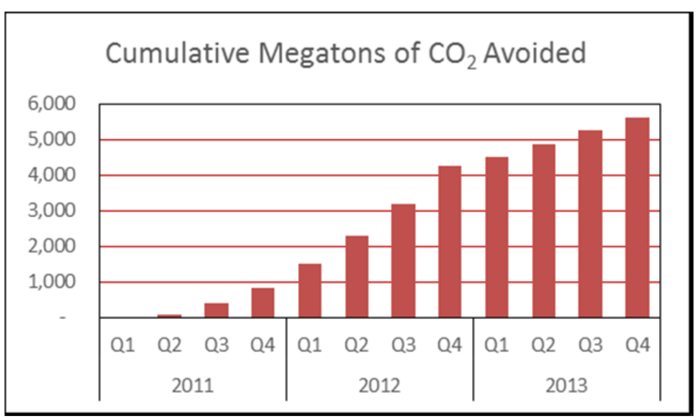


Figure 11-135. Cumulative megatons of CO_2 averted through use of EV Project charging infrastructure.

11.4.2.6 Market Price for LCFS Credits. LCFS credits can be transferred (sold) to other regulated parties. These other regulated parties can use the credits obtained to meet their regulatory requirements to reduce the carbon intensity of the transportation fuel they produce or distribute. These credits are exchanged between regulated parties either directly or through commodity brokers operating in California.

Three important factors governed these transactions: (1) an agreed price for the credits exchanged, (2) evidence of fuel dispensed to generate the credits that satisfied the buyer, and (3) recording transfer of credits within CARB's LCFS system.

Because this is a transfer between two parties voluntarily agreeing on a price for the transfer, the value of the LCFS credits is subject to market conditions. Supply and demand plays a large part in the prices paid for the credits. Figure 11-136 demonstrates the variation in the average price per credit according to reports found on CARB's LCFS website. However, these averages show only a portion of the fluctuation in prices paid for credits.

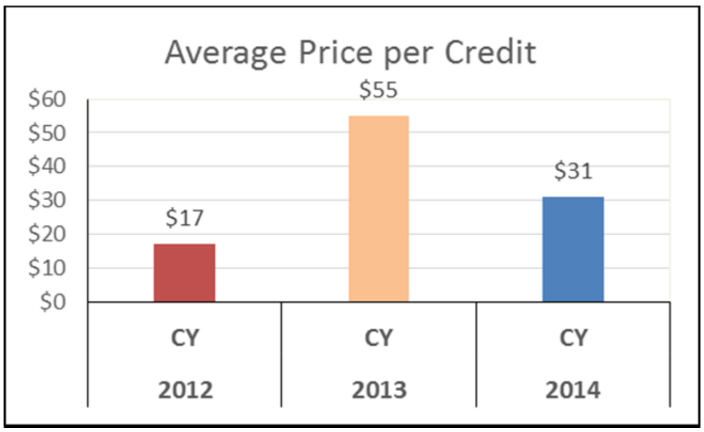


Figure 11-136. Average price paid per LCFS by calendar year.

Although the average was $17, reports from CARB state that the prices paid for credits in 2012 varied from $10 to $31 per credit.

When examining prices in a bit more detail, Figure 11-137 shows the quarterly averages for 2013 and 2014. LCFS credit prices increased from an average of $17 per credit in 2012 to $75 to $85 per credit in November 2013 and dropped to around $50 per credit in December 2013.

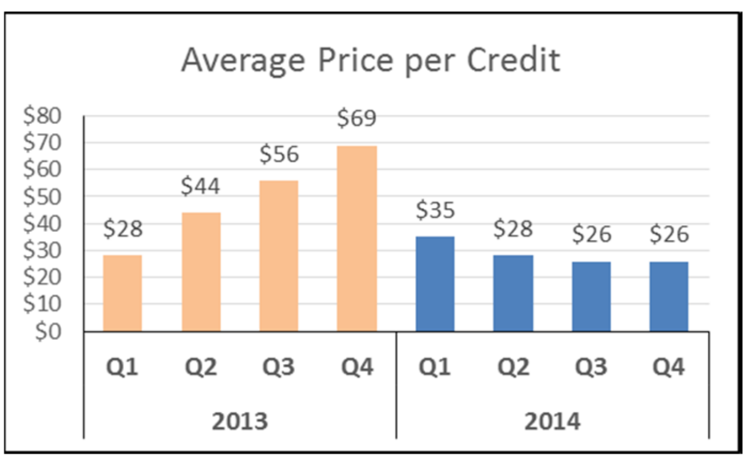


Figure 11-137. Average price paid for LCFS credits by quarter in 2013 and 2014.

The price rise shown in Figure 11-137, which tripled over the course of 2013, stabilized in 2014. CARB reported in its April 2014 LCFS trading activity report that the price range for credits bought and sold in the month ranged from $18 to $54, which compared with $30 to $85 in March. For the year 2014, the average price was $31.

Price stabilization in 2014 was likely due to proposed controls on the credit prices and reports that excess credits had been generated (increasing supply) at the same time that California was on schedule to deliver the 10% reduction in carbon intensity by 2020.

11.4.2.7 Conclusion. Amongst The EV Project's objectives was examination of additional revenue and value streams for away-from-home charging.

The EV Project, which was an EV infrastructure study, assumed that on its own the sale of electricity at away-from-home locations could not sustain the installation and operating costs of the charging stations. Either the price of this electricity would be too high to attract sufficient use or the credit price would be too low to cover the cost to install and operate the charging infrastructure. Without additional value propositions, the low cost of charging at home would keep EVs tethered to their overnight parking location.

In California, the sale of LCFS credits proved to be one way of adding value for EV service providers and supporting their business plans to establish a sustainable commercial charging business.

In February 2014, Blink transferred all 5,241 LCFS credits it had accumulated for $213,640 ($40 per credit).

11.4.2.8 References

72. LCFS regulation, reports, and notifications cited in this paper came from the CARB website at http://www.arb.ca.gov/fuels/lcfs/lcfs.htm.

11.4.3 Greenhouse Gas Avoidance and Cost Reduction

Authors Note: This section was originally published in June 2012 and the scope of The EV Project changed somewhat after June 2012. The section is a partial reproduction of the June 2012 lessons learned white paper and it includes the status of The EV Project Scope as it was in June 2012.

11.4.3.1 Introduction. The EV Project involves installation of and usage data collection from nearly 14,000 residential and publicly accessible PEV charging infrastructure units. These units will support deployment of vehicles by Nissan North American and GM in their partnership with The EV Project. Nissan North America will deploy up to 5,700 Nissan LEAF EVs and GM will deploy up to 2,600 Chevrolet Volt PHEVs. The objective of The EV Project was to collect usage data from the deployed EVSEs to elucidate the charging behavior and habits of users and motivations and hindrances to EVSE and PEV ownership. To this end, it is important to consider the various factors that a prospective PEV owner will weigh when deciding to purchase a vehicle.

The benefits of EVs (and PHEVs, when in all-electric mode) include zero tailpipe emissions and reduction in costs for refueling. However, there are pervasive myths surrounding EVs that suggest the avoided tailpipe emissions are simply transferred to the power plant and that the reduced fuel costs are balanced by the cost of electricity to charge the batteries.

A report by the Union of Concerned Scientists examined this issue in detail [73]. The report compared the various grids throughout the United States and calculated how the GHG emissions of an EV would compare with ICE vehicles in the regions. The comparisons gave rise to three categories for how EVs fared: "Good," "Better," and "Best." These categories correspond to vehicles with the following fuel economies, respectively, 31 to 40 mpg, 41 to 50 mpg, and greater than 50 mpg. The report states that 45% of the U.S. population lives in the "Best" regions and, in some of the cleanest regions, the GHG emissions avoided by driving an EV were equivalent to an ICE vehicle that achieves over 70 mpg. Then, 37% live in the “Better” regions and 18% live in the “Good” regions. The report also looked at fuel-cost savings for the 50 largest cities in the United States for EVs versus ICE vehicles over the lifetime of vehicle ownership. For regions with the lowest-cost electricity rates, the yearly savings ranged from $750 to $1,200 (when compared against an ICE vehicle with a 27 mpg fuel economy). In 44 out of the 50 cities, the standard electricity plan results in fuel-cost savings for EVs over even ICE vehicles that achieve 50 mpg. The only exceptions were in California, where TOU rates were required to be used to meet the same GHG emissions avoided. The report is a very useful contribution in the effort to understand the various benefits of EV ownership.

The purpose of this document is to further demonstrate that the myths surrounding EVs are false: EVs are both more environmentally friendly and cheaper to operate than conventional vehicles. There are several rationales for publishing this paper in light of the Union of Concerned Scientists study. First, the Union of Concerned Scientists study uses a well-to-wheel analysis, while this paper will use the more simplistic tank-to-wheel technique. Well-to-wheel analysis is still in its infancy and, as the boundary of the analysis grows, confidence in the results decrease. The results of a tank-to-wheel technique analysis may be more reliable. The Union of Concerned Scientists study examined regional grids, while the current study is more granular and looks at individual states and ranks each in terms of the GHG intensity of the electrical grid (i.e., what quantity of GHGs are emitted for a given unit of electrical energy. This study also looks at per capita GHG emissions for the individual states and presents the per capita GHG emissions that would be avoided for EV ownership. The Union of Concerned Scientists study took an average gasoline cost while this study has attempted to use more contemporary numbers for the individual states to illustrate more starkly the differences across the regions. The total cost of ownership is also included in this study and not just fuel cost reductions. Finally, science progresses by replication or refutation of the results of other research groups, and this study was deemed to be another valuable contribution. A comparison of a representative EV with a representative ICE vehicle with respect to GHG emissions and fuel costs is conducted in the following sections.

11.4.3.2 Greenhouse Gas Emissions Avoidance. In order to demonstrate that owning an EV will result in real GHG reductions (and that the tailpipe emissions are not transferred in their entirety to the power plant), the objective is to calculate the amount of GHGs avoided by charging (and driving) an EV as opposed to the emissions released when driving an ICE vehicle (note that the ICE vehicle can be either a conventional ICE vehicle or a hybrid electric vehicle because gasoline provides both with all of the off-board energy). As mentioned above, a full well-to-wheel analysis is possible, but considering the range of emission levels from the myriad sources, methods of extraction, and delivery of fossil fuels, it was decided that only direct combustion of the fossil fuels is to be considered in order to minimize the assumptions. The kWh of electricity consumed by the EV during the charge process—energy consumed from the grid—as well as the gasoline transferred to the ICE vehicle will be considered. The following emissions associated with fossil fuel usage are omitted:

- Extraction of the fossil fuels
- Delivery of the fossil fuels
- Refinement of the fossil fuels
- Losses in transmission of the electricity.

In order to minimize the controversy over this calculation, some of the assumptions are fairly conservative. Attempts have been made to use figures and conversions provided by U.S. government agencies with the expectation that these have been well vetted.

For the ICE vehicle, the Corporate Average Fuel Economy value used for mid-size vehicles is 28.6 mpg, based on 2004 figures from the National Highway Traffic Safety Administration [74]. This assumption masks the true average fuel economy of U.S. light-duty vehicles, which is much lower (according to the National Highway Traffic Safety Administration, the average fuel economy for all light-duty vehicles was 24.6 in 2004).

The mid-sized Nissan LEAF will represent the EV. The emissions for the LEAF are those emitted in producing electricity for the vehicle. The energy consumption for the LEAF according to the EPA tests is 340 kWh/mile (AC electricity) [75]. Thus, traveling 100 miles would require 34.0 kWh AC.

In the following sections, the GHG emissions avoided by using an EV rather than an ICE vehicle are considered. It should be noted that the U.S. grid is introducing clean energy sources at a rapid rate. For example, wind power accounted for 39% of new power plant capacity installed in the U.S. in 2009 [76]. Coal plant electricity production peaked in 2007 and has dropped by 3.2% per year since [77]. If no emissions are released during the electricity production stage, the EV can be considered to be a zero-emission vehicle (if the embedded energy due to the production of vehicle and power plant are ignored). Thus, the avoided emissions calculated in this document represent only a snapshot in time, and the avoided emissions will grow quickly as clean energy sources continue to be introduced and more emission-intensive sources such as coal power are retired.

Internal Combustion Engine Vehicle Greenhouse Gas Emissions—The GHGs associated with the ICE vehicle will be considered first. The initial step is to determine the amount of GHGs that will be produced by the ICE vehicle. Combusting one gallon of gasoline (perfectly) yields 19.60 lb CO_2. However, CO_2, although the most significant, is not the only GHG released during the combustion of gasoline. The two other important GHGs released during combustion of gasoline are methane (CH_4) and nitrous oxide (N_2O). The unit pounds-of-CO_2-equivalent, or lb-CO_2e, is introduced to incorporate the effects of these other gases released when combusting gasoline. According to the EPA, the ratio of CO_2 emissions to total emissions (including CO_2, CH_4, and N_2O, all expressed as CO_2e) for combustion of gasoline is 0.977 [78]. Therefore, the rate of GHG emissions for the ICE vehicle increases to 20.1 lb-CO_2e/gallons.

Over the course of 100 miles, the CO_2e emitted by the ICE vehicle would be as follows:

$$CO_2e\ emitted_{ICEV} = \frac{100\ miles}{28.6\ mpg} \cdot 20.1 \frac{lb-CO_2e}{gallon} \qquad (1)$$
$$= 70.3\ lb-CO_2e$$

Electric Vehicle Greenhouse Gas Emissions—The emissions are estimated for the U.S. grids and the individual are stated in the following subsections.

U.S. Grid Average: The GHG emissions associated with the Nissan Leaf will now be considered. Generating one kWh AC of electricity on the U.S. grid generates, on average, 1.52 lb-CO_2 (non-base load values are used in this calculation since electricity usage reductions generally lower this type of generation and not base load generation) [79]. Again, emissions must be converted to lb-CO_2e to account for the other GHGs that are emitted in the electricity production process, although the calculation will be done differently than for the ICE vehicle above. Here, the 'global warming potential,' which is a measure of the relative strength of a GHG (where CO_2, has a global warming potential of 1), of CH_4 is defined as 23 and that of N_2O as 296 [80]. The rates of CH_4 and N_2O emissions for the U.S. grid are, on average, 32.23 lb-CH_4/GWh and 18.41 lb-N_2O/GWh, respectively. Accounting for the contribution of the non-CO_2 GHGs increases the rate to 1.53 lb-CO_2e per kWh of electricity produced. The amount of CO_2 e emitted to produce the amount of electricity required to travel 100 miles would be as follows:

$$CO_2e\ emitted_{EV} = 34.0\ kWh \cdot 1.53\ \frac{lb-CO_2e}{kWh} \qquad (2)$$
$$= 52.0\ lb-CO_2e$$

The CO_2e avoided by charging an EV rather than using gasoline in an ICE vehicle can now be calculated as follows:

$$\begin{aligned} CO_2e\ avoided &= CO_2e\ emitted_{ICEV} - CO_2e\ emitted_{EV} \\ &= 70.3\ lb - CO_2e - 52.0\ lb - CO_2e \\ &= 18.3\ lb - CO_2e \end{aligned} \quad (3)$$

The generic equation for the amount of CO_2e avoided by driving an EV rather than an ICE vehicle, as it relates to the amount of AC electricity used by the EV is then:

$$CO_2e\ avoided = X\ kWh \times 0.54 \frac{lb\text{-}CO_2e}{kWh} \quad (4)$$

The 0.54 lb-CO_2e/kWh is called the 'multiplication factor' and is used to determine the GHG emissions avoided by an EV by simply multiplying by the amount of AC electricity that is used. As long as the multiplication factor is positive, the EV will emit fewer GHG emissions than an ICE vehicle that achieves a fuel economy of 28.6 mpg.

The total of U.S. emissions in 2005 was 5.8 billion metric tons of CO_2 (CO_2e numbers were not available), and the population in that year was estimated to be 280,852,543, for a per capita emission value of 20.6 tons. If the Nissan Leaf were to be driven 12,000 miles per year, then this would mean that the total amount of energy used by the vehicle battery would be 4,080 kWh (AC). Therefore, the amount of avoided CO_2 in a full year would be 1.0 metric tons or 5% of the total per capita emissions of the average U.S. resident driving the Corporate Average Fuel Economy-averaged mid-size vehicle.

In order for an ICE vehicle to achieve the same level of GHG emissions as the Nissan Leaf (with the U.S. average grid), Equation (1) can be used to determine that the fuel economy required would be 38.7 mpg. A generic equation can be derived so that both the fuel economy (Y, in mpg) of the ICE vehicle and the electricity consumption (Z, in Wh/mile) of the EV can be input with the U.S. average grid numbers to obtain the CO_2e avoided:

$$CO_2e\ avoided = \frac{2010}{Y\ mpg} - Z\ {}^{Wh}/_{mi} \times 0.153 \quad (5)$$

Equation 4 will be used throughout the rest of the document, meaning that the fuel economy of the ICE vehicle is fixed at 28.6 mpg.

State Grid Averages: The real advantages of the Nissan Leaf become clearer when individual states are considered. Generating one kWh AC of electricity in each state generates the CO_2, CH_4, and N_2O values contained in Table 11-43 (2005 data) [81]. A total value in units of lb-CO_2e per kWh AC is also presented in the right-most column for each state. The states are listed from the least carbon intensive (in terms of electricity production) to the most carbon intensive. To skip the details of the calculations, the results for the avoided emissions for residents of each state is presented in Table 11-43.

Table 11-43. State and national electricity production emission rates.

	Electricity Production Emission Rates (Non-Base Load)			
State	CO_2 (lb/MWh)	CH_4 (lb/GWh)	N_2O (lb/GWh)	CO_2e (lb/kWh)
Vermont	173.96	1,016.50	136.04	0.24
Idaho	653.57	72.11	13.81	0.66
Oregon	999.75	42.47	11.1	1.00
Rhode Island	1,053.31	21.14	2.2	1.05
California	1,061.13	39.98	4.9	1.06
Texas	1,138.47	20.71	5.83	1.14
Arizona	1,175.38	20.04	9.39	1.18

State	Electricity Production Emission Rates (Non-Base Load) CO_2 (lb/MWh)	CH_4 (lb/GWh)	N_2O (lb/GWh)	CO_2e (lb/kWh)
Washington	1,240.81	71.56	21.36	1.25
Nevada	1,254.35	22.07	7.26	1.26
Maine	1,261.17	264	37.23	1.28
Oklahoma	1,293.63	21.57	10.08	1.30
Louisiana	1,294.94	27.53	10.02	1.30
Massachusetts	1,295.66	44.94	12.48	1.30
New Hampshire	1,362.59	63.24	15.84	1.37
Florida	1,382.92	47.46	14.04	1.39
New Jersey	1,464.80	35.42	17.03	1.47
Alaska	1,470.56	40.63	8.87	1.47
Mississippi	1,473.67	29.27	16.86	1.48
New Mexico	1,480.82	24.85	10.41	1.48
Connecticut	1,478.77	77.68	17.37	1.49
New York	1,517.76	51.98	13.83	1.52
Arkansas	1,572.16	45.7	24.18	1.58
Colorado	1,606.13	22.1	20.35	1.61
Virginia	1,612.42	55.13	24.39	1.62
Georgia	1,654.63	33.18	24.93	1.66
Michigan	1,698.29	29.59	26.93	1.71
Alabama	1,723.00	41.29	28.23	1.73
South Carolina	1,760.87	28.36	25.34	1.77
Wisconsin	1,789.46	36.34	25.23	1.80
Hawaii	1,800.75	185.69	29.99	1.81
Utah	1,838.57	24.47	24.85	1.85
Pennsylvania	1,845.16	34.63	25.71	1.85
Delaware	1,947.85	39.23	23.37	1.96
North Carolina	1,952.11	29.8	31.41	1.96
Maryland	1,964.52	50.19	31.08	1.98
West Virginia	1,965.62	22.52	33.1	1.98
Ohio	1,988.51	24.17	32.48	2.00
Missouri	2,031.97	25.04	31.25	2.04
Tennessee	2,050.63	26.41	34.99	2.06
Illinois	2,097.08	25.51	32.78	2.11
Minnesota	2,102.88	72.75	36.74	2.12
Kentucky	2,113.67	25.68	35.31	2.12
Indiana	2,120.76	25.55	33.93	2.13
Wyoming	2,141.24	25.98	33.46	2.15
Nebraska	2,172.49	29.03	29.49	2.18
South Dakota	2,224.28	29.49	29.9	2.23

State	Electricity Production Emission Rates (Non-Base Load) CO_2 (lb/MWh)	CH_4 (lb/GWh)	N_2O (lb/GWh)	CO_2e (lb/kWh)
Iowa	2,240.01	27.16	36.15	2.25
Kansas	2,351.42	37.22	34.58	2.36
Washington D.C.	2,432.30	104.97	21	2.44
North Dakota	2,508.90	41	41.71	2.52
Montana	2,760.93	75.25	50.35	2.78
U.S	1,520.11	32.23	18.41	1.53

Using Equation (2) for each of the lb-CO_2e/kWh values in Table 11-43, the amount of CO_2e emitted in producing the amount of electricity required to travel 100 miles in the Nissan Leaf for all of the states can be calculated. The results are presented in Table 11-44, again in the order from the least GHG-intensive states to the most.

Table 11-44. Emissions for 100 miles of travel in Nissan Leaf for each state and the nation.

State	Emissions for 100 Miles of Nissan Leaf Travel (lb-CO_2e)	State	Emissions for 100 Miles of Nissan Leaf Travel (lb-CO_2e)
Vermont	8.2	Alabama	58.9
Idaho	22.4	South Carolina	60.2
Oregon	34.1	Wisconsin	61.1
Rhode Island	35.9	Hawaii	61.7
California	36.2	Utah	62.8
Texas	38.8	Pennsylvania	63.0
Arizona	40.1	Delaware	66.5
Washington	42.5	North Carolina	66.7
Nevada	42.7	Maryland	67.2
Maine	43.5	West Virginia	67.2
Oklahoma	44.1	Ohio	68.0
Louisiana	44.2	Missouri	69.4
Massachusetts	44.2	Tennessee	70.1
New Hampshire	46.5	Illinois	71.7
Florida	47.2	Minnesota	71.9
New Jersey	50.0	Kentucky	72.2
Alaska	50.1	Indiana	72.5
Mississippi	50.3	Wyoming	73.2
New Mexico	50.5	Nebraska	74.2
Connecticut	50.5	South Dakota	76.0
New York	51.8	Iowa	76.5
Arkansas	53.7	Kansas	80.3
Colorado	54.8	Washington D.C.	83.0
Virginia	55.1	North Dakota	85.8
Georgia	56.5	Montana	94.4
Michigan	58.0	U.S	52.0

Using Equation (3), the CO_2e avoided by charging an EV rather than using gasoline in an ICE vehicle can now be calculated for all of the states, and the results are presented below in Table 11-45, from least to most GHG-intensive. From the table, it is apparent that the EV GHG emissions are lower for most states, but there are states where the average ICE mid-size vehicle emits fewer GHGs (i.e., the avoided emissions is a negative number). These regions account for a total of 13.1% of the total U.S. population, meaning that for the vast majority of U.S. residents, an EV will emit fewer GHG emissions than will an ICE vehicle. Furthermore, the average vehicle driven in these states may not be comparable to the representative ICE vehicle used in these calculations.

Table 11-45. Avoided emissions for 100 miles of Nissan Leaf driving for each state and the nation.

State	Avoided Emissions ($lb\text{-}CO_2e$)	State	Avoided Emissions ($lb\text{-}CO_2e$)
Vermont	62.1	Alabama	11.4
Idaho	47.9	South Carolina	10.1
Oregon	36.2	Wisconsin	9.2
Rhode Island	34.4	Hawaii	8.6
California	34.1	Utah	7.5
Texas	31.5	Pennsylvania	7.3
Arizona	30.2	Delaware	3.8
Washington	27.8	North Carolina	3.6
Nevada	27.6	Maryland	3.1
Maine	26.8	West Virginia	3.1
Oklahoma	26.2	Ohio	2.3
Louisiana	26.1	Missouri	0.9
Massachusetts	26.1	Tennessee	0.2
New Hampshire	23.8	Illinois	-1.4
Florida	23.1	Minnesota	-1.6
New Jersey	20.3	Kentucky	-1.9
Alaska	20.2	Indiana	-2.2
Mississippi	20.0	Wyoming	-2.9
New Mexico	19.8	Nebraska	-3.9
Connecticut	19.8	South Dakota	-5.7
New York	18.5	Iowa	-6.2
Arkansas	16.6	Kansas	-10.0
Colorado	15.5	Washington D.C.	-12.7
Virginia	15.2	North Dakota	-15.5
Georgia	13.8	Montana	-24.1
Michigan	12.3	U.S	18.3

The multiplication factor for the amount of CO_2e avoided per unit of AC electricity used in the form of Equation (4) is then calculated, and is presented in for each state below in Table 11-46. The values for the states (from Illinois to Montana in the right-hand columns), where the EV will emit more GHG emissions than an ICE vehicle, are given as a negative avoidance multiplication factor in Table 11-46.

Table 11-46. Multiplication factor for avoided emissions for each state and the nation.

State	Multiplication Factor ($lb\text{-}CO_2e/kWh$)	State	Multiplication Factor ($lb\text{-}CO_2e/kWh$)
Vermont	1.83	Alabama	0.34
Idaho	1.41	South Carolina	0.30
Oregon	1.06	Wisconsin	0.27
Rhode Island	1.01	Hawaii	0.25
California	1.00	Utah	0.22
Texas	0.93	Pennsylvania	0.21
Arizona	0.89	Delaware	0.11
Washington	0.82	North Carolina	0.11
Nevada	0.81	Maryland	0.09

State	Multiplication Factor ($lb-CO_2e/kWh$)	State	Multiplication Factor ($lb-CO_2e/kWh$)
Maine	0.79	West Virginia	0.09
Oklahoma	0.77	Ohio	0.07
Louisiana	0.77	Missouri	0.03
Massachusetts	0.77	Tennessee	0.01
New Hampshire	0.70	Illinois	-0.04
Florida	0.68	Minnesota	-0.05
New Jersey	0.60	Kentucky	-0.06
Alaska	0.59	Indiana	-0.06
Mississippi	0.59	Wyoming	-0.09
New Mexico	0.58	Nebraska	-0.11
Connecticut	0.58	South Dakota	-0.17
New York	0.54	Iowa	-0.18
Arkansas	0.49	Kansas	-0.29
Colorado	0.46	Washington D.C.	-0.37
Virginia	0.45	North Dakota	-0.46
Georgia	0.41	Montana	-0.71
Michigan	0.36	U.S	0.54

The total and per capita emissions for all states are presented in Table 11-47, from the least to the most GHG intensive (again, CO_2e values are not available) [81]. Using the same amount of energy of 4,080 AC kWh to power the Nissan Leaf for one year (for 12,000 miles of driving), the percentage of emissions that the use of the EV would reduce for the average resident of each state can be calculated. The amount of avoided CO_2e in a full year (by driving an EV) and the percentage of the total emissions for the residents of each state are also provided below in Table 11-47. The state where the Nissan Leaf will make the biggest difference in terms of CO_2e avoidance is Vermont, where the avoided emissions are 31.9% of the average Vermont resident yearly per capita emissions. The avoided emissions are highest because this state has the lowest carbon intensity and a low total emissions value. Conversely, Montana has the highest carbon intensity and an EV owner would see an increase of 3.6% in yearly per capita GHG emissions.

Table 11-47. Total and per capita emissions avoided for residents of each state and the nation.

State	Total CO_2 Emissions (million metric tons/year)	Per Capita CO_2 Emissions (million metric tons/year)	Yearly Avoided Emissions ($tons-CO_2e$)	Percentage Reduction of Yearly Per Capita GHG Emissions
Vermont	6.5	10.6	3.4	31.9%
Idaho	14.2	11.0	2.6	23.8%
Oregon	40.4	11.8	2.0	16.7%
Rhode Island	11.4	10.8	1.9	17.4%
California	389.0	11.5	1.9	16.2%
Texas	670.2	32.1	1.7	5.3%
Arizona	88.8	17.3	1.6	9.5%
Washington	78.7	13.3	1.5	11.4%
Nevada	43.3	21.7	1.5	6.9%
Maine	23.3	18.3	1.5	8.0%
Oklahoma	103.3	29.9	1.4	4.8%
Louisiana	179.1	40.1	1.4	3.6%
Massachusetts	87.0	13.7	1.4	10.4%
New Hampshire	20.5	16.6	1.3	7.8%

State	Total CO_2 Emissions (million metric tons/year)	Per Capita CO_2 Emissions (million metric tons/year)	Yearly Avoided Emissions (tons-CO_2e)	Percentage Reduction of Yearly Per Capita GHG Emissions
Florida	243.9	15.3	1.3	8.3%
New Jersey	123.7	14.7	1.1	7.5%
Alaska	44.8	71.4	1.1	1.5%
Mississippi	62.1	21.8	1.1	5.0%
New Mexico	57.6	31.7	1.1	3.4%
Connecticut	42.4	12.4	1.1	8.7%
New York	214.3	11.3	1.0	8.9%
Arkansas	62.4	23.3	0.9	3.9%
Colorado	89.7	20.9	0.8	4.0%
Virginia	122.6	17.3	0.8	4.8%
Georgia	168.0	20.5	0.8	3.7%
Michigan	184.9	18.6	0.7	3.6%
Alabama	136.0	30.6	0.6	2.0%
South Carolina	79.2	19.7	0.6	2.8%
Wisconsin	104.8	19.5	0.5	2.6%
Hawaii	21.5	17.8	0.5	2.6%
Utah	62.4	27.9	0.4	1.5%
Pennsylvania	271.4	22.1	0.4	1.8%
Delaware	17.2	21.9	0.2	0.9%
North Carolina	146.2	18.2	0.2	1.1%
Maryland	78.8	14.9	0.2	1.2%
West Virginia	114.4	63.3	0.2	0.3%
Ohio	265.5	23.4	0.1	0.5%
Missouri	137.2	24.5	0.0	0.2%
Tennessee	120.1	21.1	0.0	0.1%
Illinois	230.0	18.5	-0.1	-0.4%
Minnesota	102.4	20.8	-0.1	-0.4%
Kentucky	143.0	35.4	-0.1	-0.3%
Indiana	235.1	38.7	-0.1	-0.3%
Wyoming	62.9	127.3	-0.2	-0.1%
Nebraska	43.2	25.2	-0.2	-0.8%
South Dakota	13.7	18.1	-0.3	-1.7%
Iowa	78.9	27.0	-0.3	-1.3%
Kansas	79.9	29.7	-0.5	-1.8%
Washington D.C.	NA	10/25.1	-0.710*	-2.7%10*
North Dakota	50.7	79.0	-0.8	-1.1%
Montana	32.7	36.2	-1.3	-3.6%
U.S	5800	20.6	1.0	4.8%

11.4.3.3 Fuel and Ownership Cost Reduction. In addition to emissions reduction, an analysis of the fuel costs and total cost of ownership of an EV versus those of a conventional ICE vehicle is important because these costs will be a major factor in the adoption of EVs into the transportation fleet.

Fuel Costs—The average price for gasoline (on May 1, 2012) is provided for each state and for the nation in Table 11-48. Using the fleet average of ICE vehicles and hybrid electric vehicles (28.6 mpg), the annual cost to travel 12,000 miles is estimated and presented in Table 11-48 for the state and national averages. On May 1, 2012, the average U.S. cost per gallon for regular gasoline ($3.809) [83] results in an annual cost of $1,598.18. Using the calculated AC consumption per mile for the Nissan Leaf EV (340 Wh/mile) over 12,000 miles and the average U.S. electricity cost per kWh in 2010 ($0.0983) [84] results in an annual cost of $401.06. Therefore, the "fuel" costs of the Nissan LEAF are 75% less than those for the fleet average vehicle and the yearly savings would be $1,197.12. The largest savings across the country would be experienced by a resident of the state of Washington, where an owner of a mid-sized vehicle would enjoy $1,437.22 in savings. The smallest savings across the country would be experienced by a resident of Hawaii, with an annual savings of $895.94. Even though the cost of gasoline in Hawaii is the highest in the country, the electricity costs are also the highest by an even larger margin. The cost of gasoline in May has historically been higher than the yearly average, but it is felt that gasoline costs are likely to remain elevated and will not return to the sub-$3.00/gallon costs of the past.

Table 11-48. State and national annual EV fuel savings (May 1, 2012).

State	Average Gasoline Price [83]	Average Annual ICEV Fuel Costs	Average Retail Price, Residential Electricity [84] (cents/kWh)	Average Annual EV Electricity Costs	Annual EV Savings
Alabama	$3.66	$1,536.92	8.89	$362.71	$1,174.21
Alaska	$4.36	$1,829.37	14.76	$602.21	$1,227.16
Arizona	$3.83	$1,606.15	9.69	$395.35	$1,210.80
Arkansas	$3.61	$1,515.94	7.28	$297.02	$1,218.92
California	$4.16	$1,746.29	13.01	$530.81	$1,215.49
Colorado	$3.87	$1,622.94	9.15	$373.32	$1,249.62
Connecticut	$4.10	$1,719.44	17.39	$709.51	$1,009.93
Delaware	$3.77	$1,579.72	11.97	$488.38	$1,091.34
Florida	$3.79	$1,588.53	10.58	$431.66	$1,156.87
Georgia	$3.68	$1,541.96	8.87	$361.90	$1,180.06
Hawaii	$4.58	$1,920.84	25.12	$1,024.90	$895.94
Idaho	$3.77	$1,582.24	6.54	$266.83	$1,315.41
Illinois	$4.00	$1,679.58	9.13	$372.50	$1,307.08
Indiana	$3.84	$1,612.87	7.67	$312.94	$1,299.93
Iowa	$3.61	$1,515.52	7.66	$312.53	$1,203.00
Kansas	$3.58	$1,502.10	8.35	$340.68	$1,161.42
Kentucky	$3.73	$1,565.03	6.73	$274.58	$1,290.45
Louisiana	$3.69	$1,546.57	7.8	$318.24	$1,228.33
Maine	$3.90	$1,637.62	12.84	$523.87	$1,113.75
Maryland	$3.82	$1,601.12	12.7	$518.16	$1,082.96
Massachusetts	$3.87	$1,622.10	14.26	$581.81	$1,040.29
Michigan	$3.82	$1,602.38	9.88	$403.10	$1,199.27
Minnesota	$3.70	$1,553.29	8.41	$343.13	$1,210.16
Mississippi	$3.67	$1,539.86	8.59	$350.47	$1,189.39
Missouri	$3.54	$1,483.22	7.78	$317.42	$1,165.79
Montana	$3.77	$1,581.82	7.88	$321.50	$1,260.31
Nebraska	$3.69	$1,546.99	7.52	$306.82	$1,240.18
Nevada	$3.92	$1,643.50	9.73	$396.98	$1,246.51
New Hampshire	$3.82	$1,603.64	14.84	$605.47	$998.16
New Jersey	$3.75	$1,571.33	14.68	$598.94	$972.38
New Mexico	$3.74	$1,567.13	8.4	$342.72	$1,224.41
New York	$4.10	$1,719.44	16.41	$669.53	$1,049.91
North Carolina	$3.78	$1,586.85	8.67	$353.74	$1,233.12
North Dakota	$3.79	$1,588.53	7.11	$290.09	$1,298.44
Ohio	$3.73	$1,565.87	9.14	$372.91	$1,192.96
Oklahoma	$3.55	$1,489.09	7.59	$309.67	$1,179.42

State	Average Gasoline Price [83]	Average Annual ICEV Fuel Costs	Average Retail Price, Residential Electricity [84] (cents/kWh)	Average Annual EV Electricity Costs	Annual EV Savings
Oregon	$4.02	$1,685.45	7.56	$308.45	$1,377.01
Pennsylvania	$3.86	$1,617.90	10.31	$420.65	$1,197.25
Rhode Island	$3.93	$1,646.85	14.08	$574.46	$1,072.39
South Carolina	$3.59	$1,505.03	8.49	$346.39	$1,158.64
South Dakota	$3.72	$1,561.26	7.82	$319.06	$1,242.20
Tennessee	$3.64	$1,526.85	8.61	$351.29	$1,175.57
Texas	$3.70	$1,552.45	9.34	$381.07	$1,171.38
Utah	$3.70	$1,552.45	6.94	$283.15	$1,269.30
Vermont	$3.95	$1,657.34	13.24	$540.19	$1,117.15
Virginia	$3.74	$1,568.39	8.69	$354.55	$1,213.84
Washington	$4.07	$1,708.95	6.66	$271.73	$1,437.22
Washington D.C.	$4.03	$1,689.23	13.35	$544.68	$1,144.55
West Virginia	$3.86	$1,617.90	7.45	$303.96	$1,313.94
Wisconsin	$3.82	$1,604.48	9.78	$399.02	$1,205.45
Wyoming	$3.64	$1,526.85	6.2	$252.96	$1,273.89
U.S.	$3.81	$1,598.18	9.83	$401.06	$1,197.12

Ownership Costs—It is important to look not only at fuel costs, but also upfront costs so that prospective EV owners can compare financing implications. The Nissan Leaf manufacturer's suggested retail price is $35,200 [85]; however, with the $7,500 federal tax credit for which Leaf purchases are eligible reduces the price to $27,700. The Leaf is classified as a midsize vehicle. The average midsize manufacturer's suggested retail price for major original equipment manufacturer 2012 models is $35,674 [86]. The surprising implication is that the Leaf is actually nearly $8,000 less expensive than the average vehicle in the same class. Even the higher-trim version of the Leaf (SL, at $37,250) is nearly $6,000 less than the average vehicle in the same class. Furthermore, some states like California, Tennessee, and Colorado have state incentives that bring down the cost even more.

The fuel costs and upfront costs can be combined in a total cost of ownership analysis that allows for prospective EV owners to clearly understand the financial implications of an EV purchase. The popular site, Kelley Blue Book, provides an estimate of 5-year total cost of ownership for new vehicles. The 5-year cost for the 2012 Nissan Leaf is $38,559 (with an assumption of 15,000 miles per year). The total cost of ownership for the most popular midsize vehicle, the 2012 Toyota Camry, is listed as $34,966 [87]. However, this value does not include the $7,500 federal tax credit (or the various state credits); therefore, the Nissan Leaf's total cost of ownership is reduced to $31,059. Therefore, the Nissan Leaf is approximately 11% less expensive to own over 5 years than the most popular vehicle in its class (provided the EV owner is eligible for the full tax credit).

11.4.3.4 Conclusion. The purpose of this white paper is to demonstrate the differences in GHG emissions and fuel costs with EV ownership for residents of the United States. While the general case of an ICE vehicle and EV comparison has been presented, it is hoped that the methodology presented here has sufficient details to allow for individuals to calculate their particular emissions and fuel costs based on the fuel economy of their vehicle and the electricity generation details of their state. Using the study assumptions, the average U.S. resident would see a percentage reduction in yearly per capita GHG emissions of 4.8%. Residents of Vermont would see the greatest percentage reduction in yearly per capita GHG emissions, at nearly 32%.

It is apparent from the data and calculations provided that for a large majority of U.S. residents (approximately 87%), driving an EV as opposed to a comparable ICE vehicle will result in reductions in emissions, while all U.S. residents will enjoy a reduction in fuel and ownership costs. A small minority will see their GHG emissions rise, depending on the state in which they reside. However, as the push to adopt cleaner electricity sources across the country continues, the emissions reduction numbers will continue to become more and more favorable. The grid transition may raise the price of electricity, but the volatility of oil prices and the specter of constrained oil supplies mean that the price of gasoline is also likely to rise, affirming the fuel cost benefit for the foreseeable future. The results generally confirm the conclusions of the Union of Concerned Scientists report, and there can thus be confidence in the results of this white paper.

11.4.3.5 References

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11.4.3.6 Utility Rates. Due to the length of this document, it is not included in this report, but it can be found at: http://avt.inel.gov/pdf/EVProj/106077-891082.ghg.pdf.

11.5 EV Project Participants

11.5.1 Who Are the Participants in The EV Project?

11.5.1.1 Introduction. The EV Project participants purchased or leased a Nissan Leaf or Chevrolet Volt and have been among the first to explore this new electric drive technology. The EV Project participant has generally been very cooperative and enthusiastic about his/her participation in the study and very supportive in providing feedback and information. The demographics of these innovators and early adopters of EV were speculated by many but little was actually published, so demographics information was solicited from The EV Project participants in a recent survey.

11.5.1.2 Key Findings

- Overall 63% of the primary PEV drivers are male, but this percentage reaches nearer 70% in Texas, Washington D.C., and Chicago.
- Oregon presents the highest percentage of female drivers at 34%.
- The mean age for All Regions was 50.9 years, but the distribution can vary by region.
- The average household income is $148,811.
- Almost 50% of households had average income above $150,000.
- There was little difference between types of vehicle purchased or leased based upon income.
- Leaf drivers were more likely than Volt drivers to have graduate degrees (46% versus 38%).

11.5.1.3 Why is This Important? Everett Rogers sought to explain how new technologies can spread through a culture in his book *Diffusion of Innovations*. According to the theory, new technology products must be successful for the innovators and early adopters before it can be accepted by the larger market. Any market consists of the groups identified in Figure 11-138 which also shows their typical share of that market.

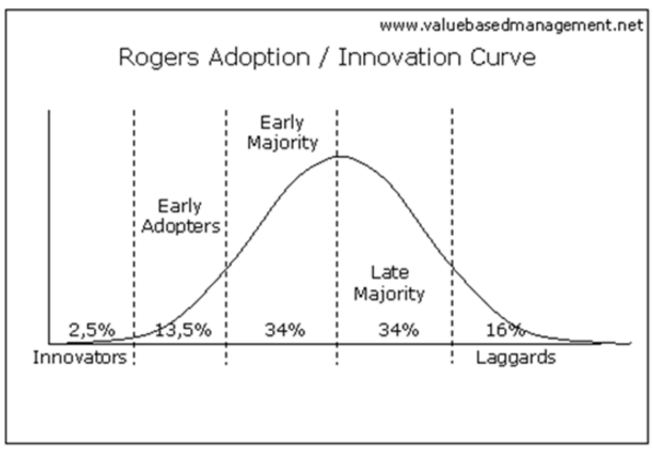


Figure 11-138. Rogers adoption/innovation curve [88].

The demographics of the innovators and early adopters of electric transportation then are of interest because they are the leaders in bringing this new technology into use.

11.5.1.4 Participation Requirements. Every study has boundary conditions. The EV Project had boundaries for participation that included time and budget constraints as well as physical geographic limitations. Because the Nissan Leaf is a battery-only EV, it was essential that the residential installation process be expeditious.

In exchange for allowing the collection and use of their charging data in the study, The EV Project provided the Blink EVSE, used to recharge the PEV battery, and credit toward the installation of the EVSE at their residences. The installation credit was constrained by the overall Project budget and costs exceeding this credit were borne by the participant. Single-family homes with their electrical service entrance near the garage would be the least costly installation. Installation costs for multi-unit dwellings and older homes with long electrical conduit runs or insufficient electrical service proved to be a significant barrier for many potential participants. (The residential installation experience and costs will be explored in another report [89] to be posted at http://avt.inel.gov/evproject.shtml#LessonsLearned.)

Because the Nissan Leaf is a battery-only PEV, it was essential that the residential installation process be expeditious. At the beginning of The EV Project, there were almost no publicly accessible EVSE units, so the EV driver would have to recharge at home where most of the charging would be expected to occur. The AC Level 1 cordset provided with the Leaf would require up to 20 hours to fully recharge the battery. Multi-unit dwellings and rental property would require approvals of owners or home owners associations or property managers, and these approvals would likely be a lengthy and variable process. The single-family home that was owner occupied proved to be the circumstance with the shortest installation time.

Figure 11-139. Washington D.C. participant boundary.

The initial regions of The EV Project, which were based on the Nissan Leaf sales roll-out plan, included areas where innovators and early adopters of PEVs could be found. The regions were later expanded to include 16 metropolitan areas in nine states plus the District of Columbia. Within these regions, the physical study boundary also had to be established.

Because this was an infrastructure study, the charging behavior of the residential participant with the publicly accessible EVSE was a primary interest. Consequently, the residential participant needed to reside within roughly 40 miles from the city center; approximately one-half the Leaf's advertised range.

11.5.1.5 Regional Participation. The local PEV supplier promotions, along with local incentives and local market adoption rates, determined the interest by the public which led consequently to the enrollment figures in The EV Project. The enrollment in The EV Project was complete early in 2013, and the final composition of the participants is identified in Table 11-49. Because of another DOE project in the area, the Chevrolet Volt drivers were not included in The EV Project in the San Francisco region.

The original completion date of The EV Project was December 2012. It was later extended to December 2013 so some of the participants retired from the Project at the end of the original period. In addition, some other participants have been retired because they sold their vehicles or their vehicles were destroyed in accidents.

Table 11-49. Regional Participation in The EV Project.

	Leaf	Volt
Arizona	376	156
Los Angeles	471	344
San Diego	722	277
San Francisco	1874	-
Oregon	558	136
Wash State	969	177
Tennessee	942	144
Texas	34	288
Wash DC	50	291
Atlanta	176	77
Chicago	34	129
Philadelphia	32	54
Overall	6238	2073

11.5.1.6 Participant Survey. With full enrollment achieved, The EV Project desired to know participant experience and attitudes toward many aspects of their EV usage. A survey was sent to 7,730 EV Project participants and responses were received from 3,236 for a 42% response rate. Among the topics identified were questions on their personal situations such as education and income levels. Information and observations based on the responses received from EV Project participants are included below.

Thirty-four of the respondents reported having both a Leaf and a Volt in The EV Project and 13 reported they were no longer participating. Table 11-50 presents responses received by region and single vehicle type.

Table 11-50. Survey Responses by Region.

	Leaf Responses	Volt Responses
Arizona	159	74
Los Angeles	133	120
San Diego	244	109
San Francisco	553	-
Oregon	211	74
Wash State	378	83
Tennessee	345	54
Texas	11	119
Wash DC	13	114
Atlanta	74	39
Chicago	15	67
Philadelphia	13	26
Unknown	159	2
Overall	2308	881

11.5.1.7 Electric Vehicle Driver Gender. Participants were asked “What is the gender of the primary driver of the EV?” 3,063 responses were received. Figure 11-140 provides the responses by region.

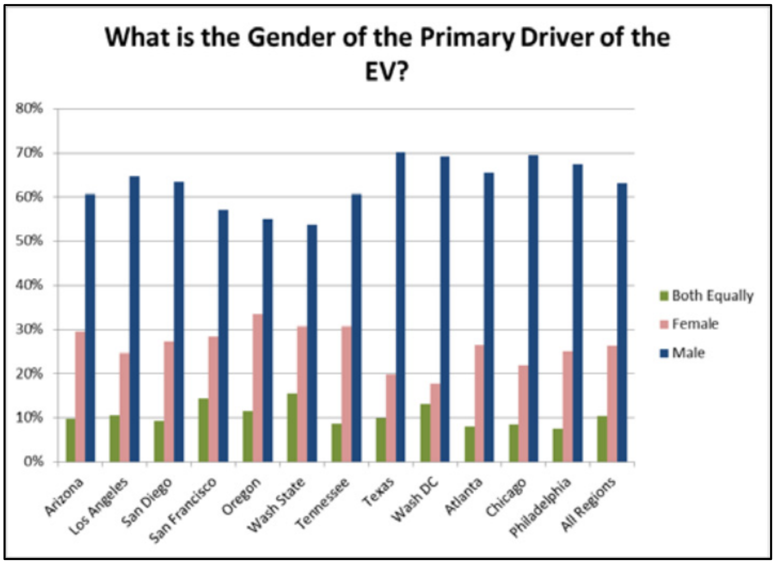


Figure 11-140. Gender of EV primary driver.

Overall 63% of the primary EV drivers are male, but this percentage reaches nearer 70% in Texas, Washington, D.C., and Chicago. On the other hand, Oregon presents the highest percentage of female drivers at 34%. Figure 11-141 compares the gender of the primary driver by Leaf or Volt for the regions. Overall, the Volt driver is more predominantly male than the Leaf with 69% of Volt drivers and 59% of Leaf drivers male.

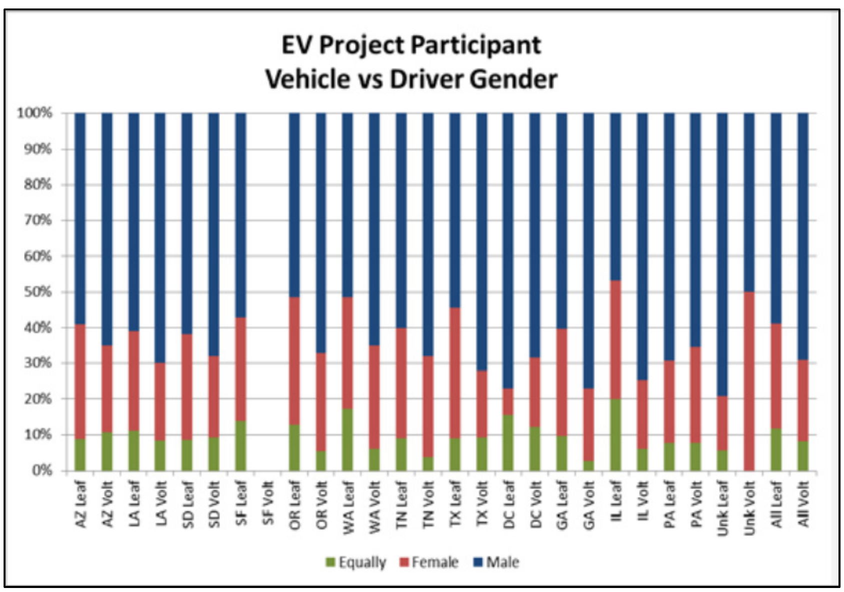


Figure 11-141. Gender versus vehicle type by region.

11.5.1.8 Participant Age. Participants were asked "What is the age of the primary driver of the EV?" 3,065 responses were received. Figure 11-142 provides the responses by region. The average age in that region is shown above the bars.

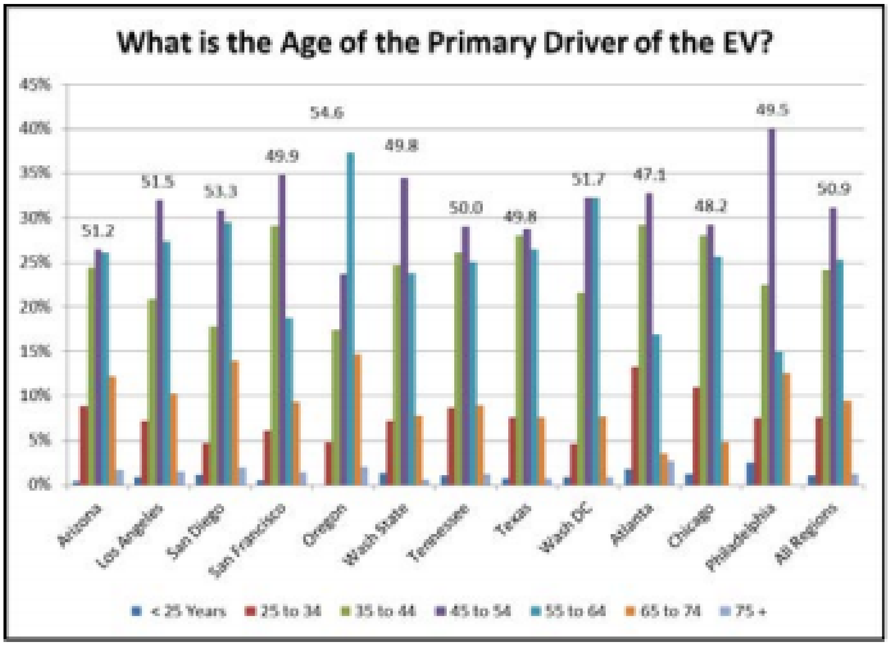


Figure 11-142. EV driver age by region.

The bars for All Regions shows a regular distribution of the age groups, with the mean age being 50.9 years, but the distribution can vary significantly in each region. Oregon and San Diego have slightly older drivers (means of 54.6 and 53.3 years, respectively), whereas Atlanta and Chicago have slightly younger drivers (means of 47.1 and 48.2 years, respectively).

Figure 11-143 shows the comparison of driver age by vehicle type for each region. The comparison of the All Leaf and All Volt shows that overall; the average Leaf driver is slightly younger (average age 50.6 years) than the average Volt driver (average 51.6 years). This age difference appears to be most significant in Oregon, Washington State, Tennessee, Washington DC and Philadelphia.

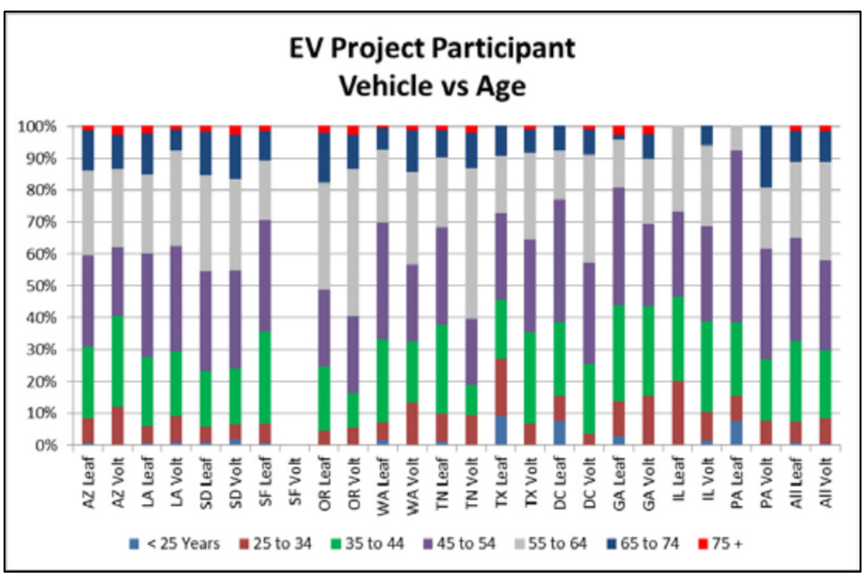


Figure 11-143. EV driver age by vehicle type by region.

11.5.1.9 Participant Income. Participants were asked "What is your approximate average household income?" 2,813 responses were received. Figure 11-144 provides the overall response distribution. Figure 11-145 provides the responses by region.

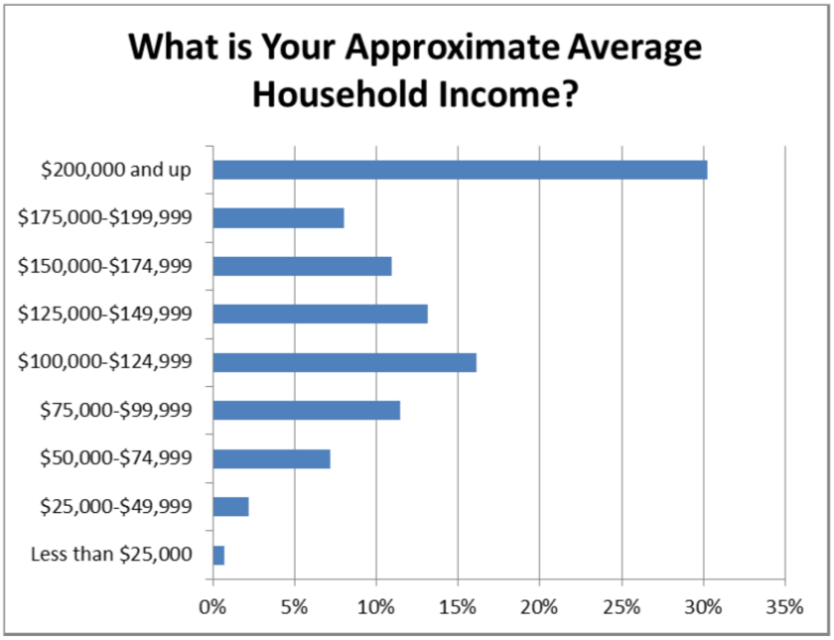


Figure 11-144. Household income distribution.

Using the midpoint of each range and a cap at $212,500, the average household income is $148,811.

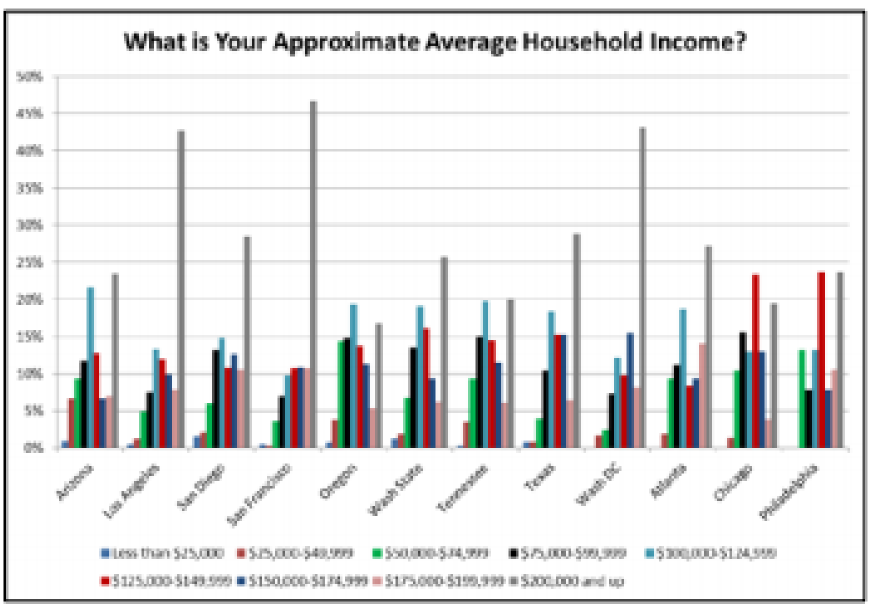


Figure 11-145. Household income by region.

San Francisco, Washington DC and Los Angeles showed the highest average household income, which probably reflects actual population demographics. Figure 11-146 continues the evaluation by considering the vehicle type obtained by the participant.

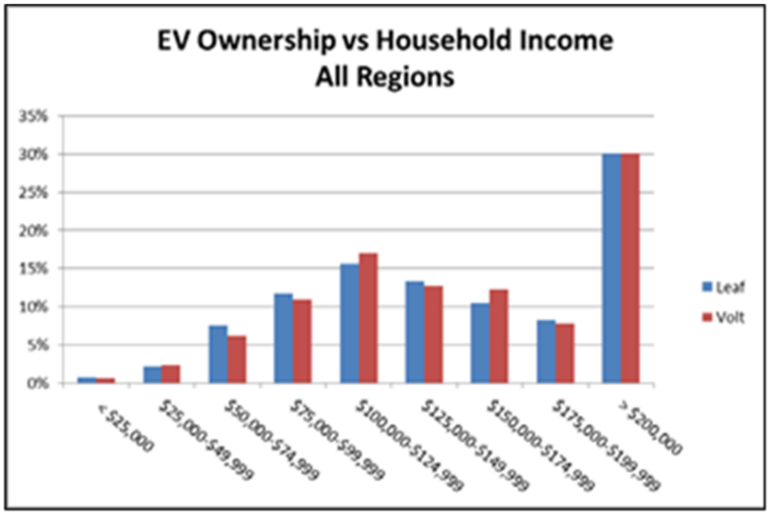


Figure 11-146. Household income versus vehicle type.

For the combined regions of The EV Project, there is little difference between types of vehicle purchased or leased based upon income.

11.5.1.10 Participant Education

Participants were asked "What is the highest level of education for the primary EV driver?" 3,040 responses were provided. Figure 11-147 provides the overall response distribution.

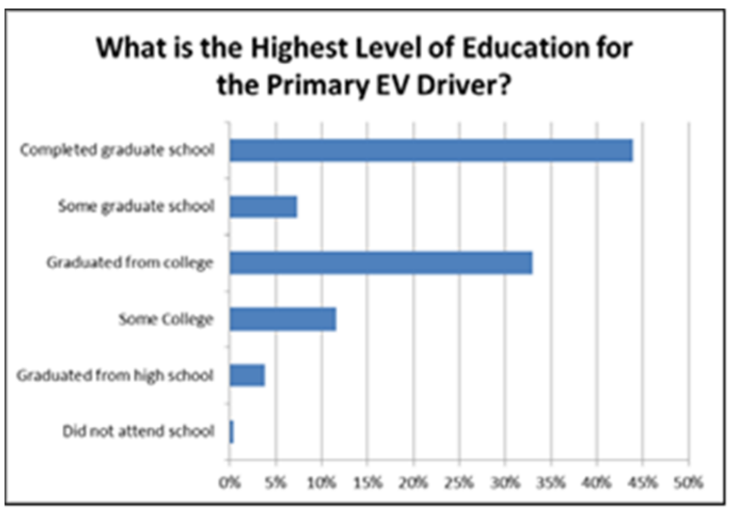


Figure 11-147. Primary driver education.

Eighty-four percent of the primary drivers have college degrees with 44% having advanced degrees. Figure 11-148 continues the evaluation by considering the education achieved by the participant versus the type of EV.

Leaf drivers are slightly more likely than Volt drivers to have completed some graduate-level work (7% versus 6%) and noticeably more likely than Volt drivers to have graduate degrees (46% versus 38%). Figure 11-149 provides the same comparison by region.

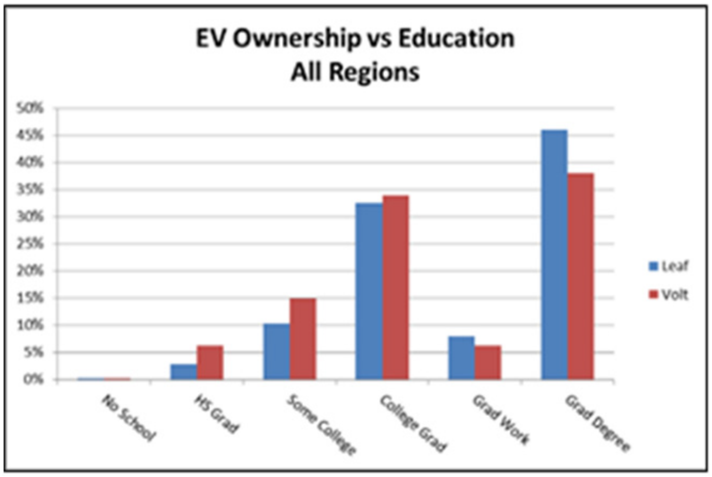


Figure 11-148. Primary driver education versus vehicle type.

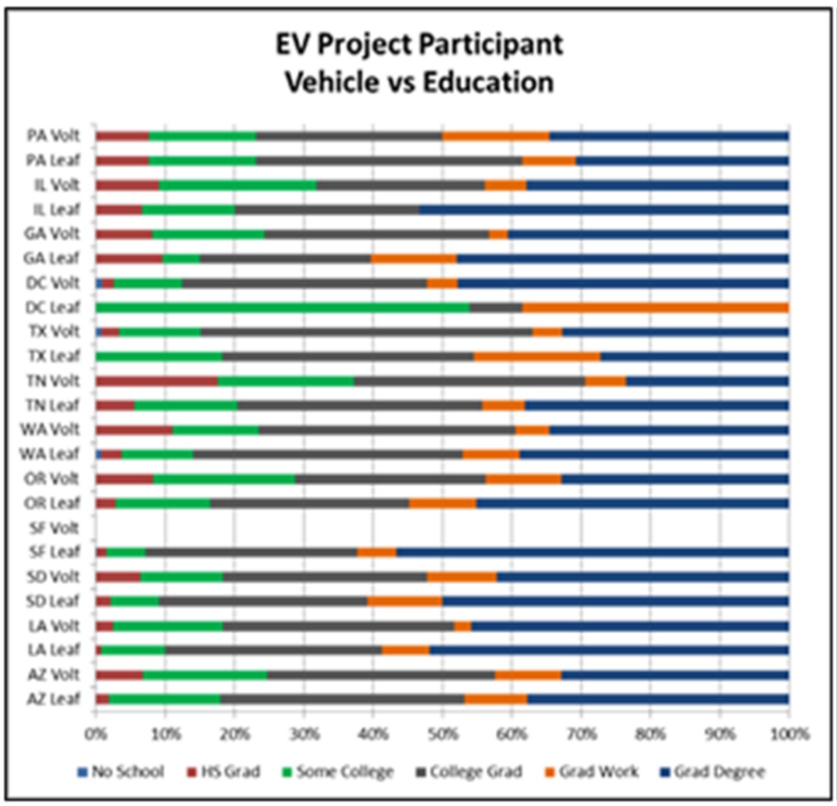


Figure 11-149. Driver education by vehicle type by region.

11.5.1.11 How Has this Changed over Time? At the end of February 2012, there were a total of 4,135 residential participants in The EV Project or about 50% of the final enrollment. These are the "earliest" of the early adopters and innovators because the EVs had been available on the market for only one year at that point. The Nissan Leaf was still being marketed to those who had reserved the vehicle in advance. How do the demographics of this group compare to the final complement?

The survey responses were screened to include only those whose EVSE installation occurred prior to March 2012. A total of 1465 responses then were valid. This represents 35% of the participants at that time.

11.5.1.12 Primary Driver Gender Comparison. There are 1,453 valid survey responses for the "What is the gender of the primary driver of the EV?" question for those enrolled prior to March 2012. The responses are shown in Figure 11-150.

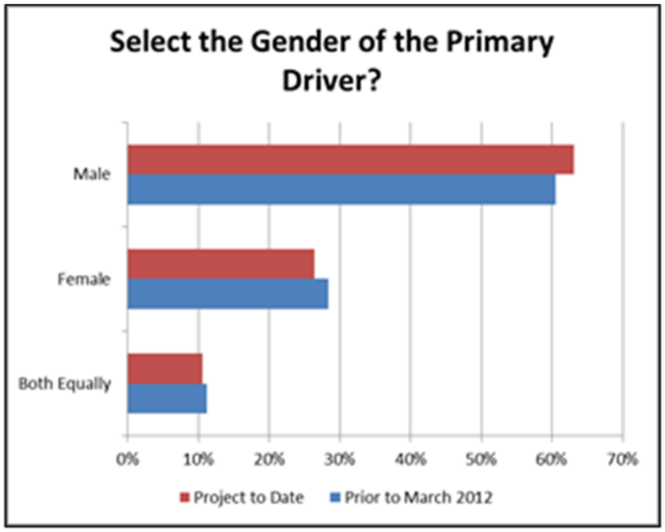


Figure 11-150. Primary driver gender comparison.

As noted above, the PEV driver is predominately male and Figure 11-150 illustrates that the driver gender has gotten more so since March 2012. However, it is noted that prior to March 2012, 8.2% of the participants were Volt owners, which grew to 24.9% by the end of the enrollment. As noted above, more Volt drivers are male than Leaf drivers, which could account for the change noted in Figure 11-150.

11.5.1.13 Participant Age Changes. There are 1,454 valid survey responses for the "What is the age of the primary driver of the EV?" question for those enrolled prior to March 2012. The responses are shown in Figure 11-151. An adjustment to the present day responses was conducted because the age of the participant would have been 1 year less if the survey had been taken in March 2012.

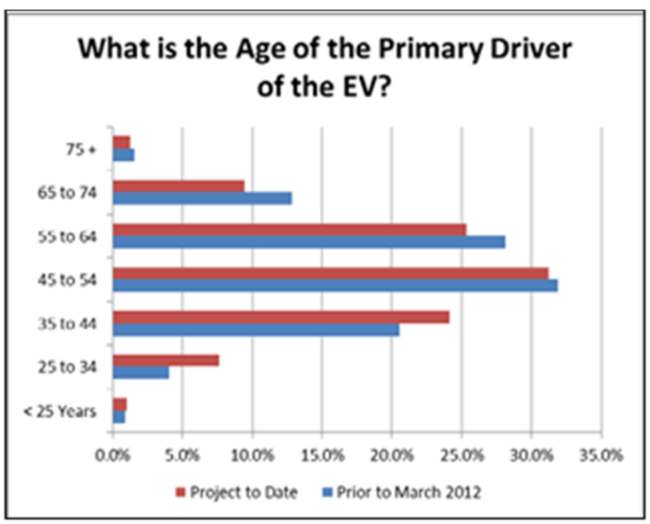


Figure 11-151. Primary driver age comparison.

The age of the primary driver has shifted to be slightly younger than when The EV Project was 50% subscribed. The average age prior to March 2012 would have been 51.7 years old compared to 50.9 when The EV Project was fully subscribed.

11.5.1.14 Participant Household Income Changes. There are 1,316 valid survey responses for the "What is your approximate average household income?" question for those enrolled prior to March 2012. The responses are shown in Figure 11-152.

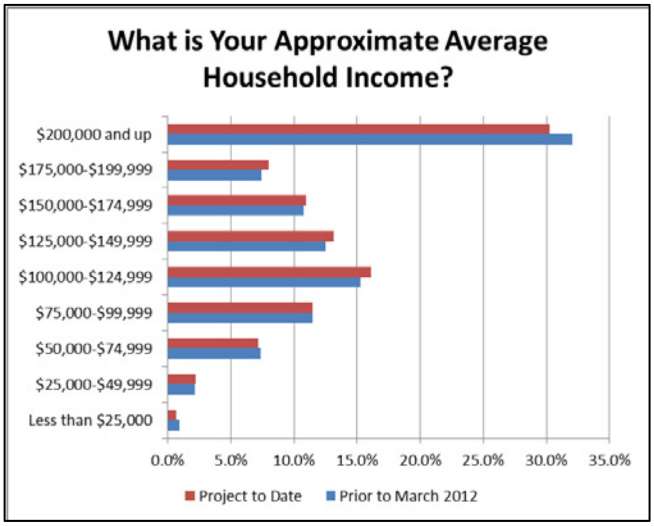


Figure 11-152. Household income comparison.

Average income prior to March 2012 was $149,688; slightly higher than the fully subscribed average income of $148,811.

11.5.1.15 Participant Education Changes. There are 1,443 valid survey responses for the "What is the highest level of education for the primary EV driver?" question for those enrolled prior to March 2012. The responses are shown in Figure 11-153.

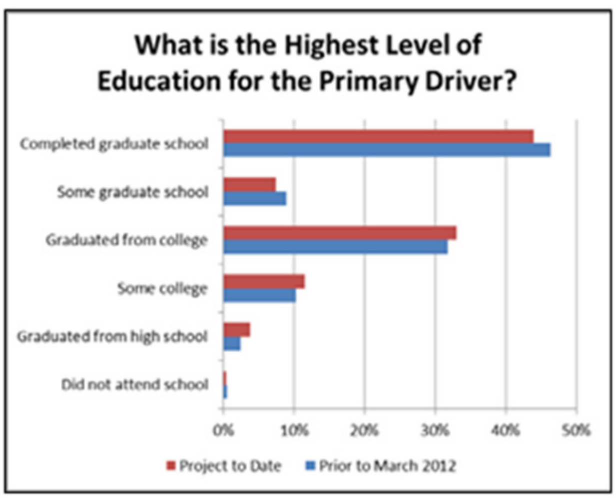


Figure 11-153. Primary driver education comparison.

Prior to March 2012, 87% of all participants had earned a college degree. After full enrollment 84% had achieved this degree.

11.5.1.16 Observations. Prior to the delivery of PEVs starting late in 2010, it was postulated that the PEV adopter would be more highly educated with higher household income than the majority of vehicle buyers. This has been proven to be the case. In addition, the typical EV driver is a male about 51 years old.

Age, education and household income are related naturally, however, it should be noted that there are many in The EV Project that contrast significantly with the typical participant. Approximately 16% of the participants do not have a college degree, 10% have incomes less than $75,000, and 8.6% are under the age of 34.

11.5.1.17 Conclusions. Although PEV adoption continues to be very strong in the United States, very little has changed in the demographics of these drivers when comparing the total to the very first year. However, there does appear to be the start of a shift to a younger and less wealthy demographic. Perhaps the adoption trend is moving closer to the early majority noted in Figure 11-138.

11.5.1.18 References

88. "Acceptance and Diffusion of Innovations", http://www.valuebasedmanagement.net/methods_rogers_innovation_adop tion_curve.html, accessed August14, 2013

89. "Residential Installation Costs and Challenges" – Lessons Learned, www.theevproject.com.

11.5.2 How Do The EV Project Participants Feel About Their EVs?

11.5.2.1 Introduction. The EV Project participants purchased or leased a Nissan Leaf BEV or Chevrolet Volt EREV and were among the first to explore this new electric drive technology. Collectively, BEV, EREV, and PHEVs are called PEVs. The EV Project participants were very cooperative and enthusiastic about their participation in the project and very supportive in providing feedback and information. The information and attitudes of these participants concerning their experience with their PEVs were solicited using a survey in June 2013. At that time, some had up to 3 years of experience with their PEVs.

11.5.2.2 Key Observations from the Survey of The EV Project Participants

- In June 2013, EV Project survey respondents were very satisfied with their PEVs, and 96% would replace their current PEV with another PEV.
- The EV Project survey respondents had an average of 2.6 vehicles in their household and 70% reported the PEV as their primary vehicle.
- The number one reason EV Project survey respondents selected the PEV was that PEVs are energy efficient and cheaper in the long run than gasoline vehicles.
- 94% of survey respondents reported they drove their PEVs the same or more miles per day than when they first acquired it.

11.5.2.3 Why is Plug-In Electric Vehicle Satisfaction Important? Everett Rogers sought to explain how new technologies can spread through a culture in his book, Diffusion of Innovations. According to the theory, the innovators and early adopters must be satisfied with a new technology product before it can be accepted by the larger market. Any market consists of the groups identified in Figure 11-154, which also shows their typical share of that market.

Were The EV Project participants satisfied with electric drive transportation? These participants were the innovators and early adopters and their feedback on how they felt about their PEVs is of interest because it can shape this new technology for wider adoption.

11.5.2.4 Participant Information. Understanding the demographics of The EV Project participants is important in understanding their choices and attitudes toward electric transportation. The age, gender, average household income, and education level were explored in "Who are the Participants in The EV Project?" [90]

The Nissan Leaf sales rollout plan defined the initial five regions of The EV Project, anticipating them to be the locations of the innovators and early adopters of EVs. Later expansion of The EV Project included 16 metropolitan areas in nine states plus the District of Columbia. Within these regions, physical study boundaries were established. The views and attitudes of project participants nationally and regionally are explored in this report.

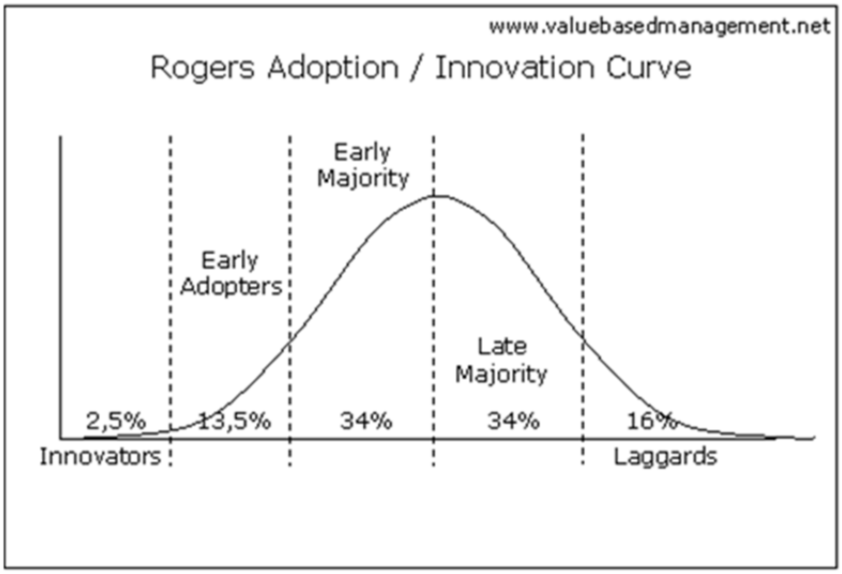


Figure 11-154. Rogers adoption/innovation curve [91].

11.5.2.5 Which Plug-In Electric Vehicle Did They Acquire? The EV Project achieved full enrollment of residential participants early in 2013. The final enrollment in each market was ultimately determined by the PEV market conditions, which was driven by local PEV dealer promotions, along with local government incentives and local demographics. Table 11-51 identifies the number of participants driving Nissan Leafs and Chevrolet Volts in each region. Because of other DOE projects in the area, Chevrolet Volt drivers were not included in The EV Project in the San Francisco region.

The original completion date of The EV Project was December 2012. Later expansion of the project also extended the completion date to December 2013. Some participants retired from the project at the end of the original period. In addition, some other participants retired because they sold their vehicles or their vehicles were destroyed in accidents.

Table 11-51. Regional participation in The EV Project.

	Leaf	Volt
Arizona	376	156
Los Angeles	471	344
San Diego	722	277
San Francisco	1,874	–
Oregon	558	136
Washington State	969	177
Tennessee	942	144
Texas	34	288
Washington D.C.	50	291
Atlanta	176	77
Chicago	34	129
Philadelphia	32	54
Overall	6,238	2,073

11.5.2.6 Participant Survey. One goal of The EV Project is to gain an understanding of the participants' experience and attitudes toward many aspects of their PEV usage. In support of this goal, an online survey was sent to 7,730 active EV Project participants. The survey solicited 3,236 responses for a 42% response rate. Among the topics identified were questions related to participants' PEV use and attitudes. Table 11-52 presents the responses received by region and vehicle type.

Table 11-52. Survey responses by region.

	Leaf Responses	Volt Responses	Leaf and Volt Responses
Arizona	159	74	1
Los Angeles	133	120	7
San Diego	244	109	7
San Francisco	553	–	4
Oregon	211	74	2
Washington State	378	83	3
Tennessee	345	54	2
Texas	11	119	2
Washington D.C.	13	114	2
Atlanta	74	39	1
Chicago	15	67	–
Philadelphia	13	26	1
Unknown	159	2	2
Overall	2,308	881	34

Thirty-four of the respondents reported having both a Leaf and a Volt in The EV Project and 13 reported they were no longer participating. One hundred and sixty-three responses were provided that identified the type of vehicle, but not the region of The EV Project.

11.5.2.7 Why Did They Purchase or Lease Their Electric Vehicle? Participants were asked, "Why did you purchase or lease your Volt or Leaf?" They were provided with six possible responses and asked to rank them in order of importance, with 1 being the highest rank. The response choices were as follows:

- EVs are environmentally friendly and reduce GHG emissions.
- EVs are energy efficient and cheaper in the long run than gasoline vehicles.
- For philosophical reasons (i.e., I like being an adopter of high-tech/advanced technologies, I like the image of driving a "green" car, etc.)
- I'm doing my part to reduce U.S. reliance on imported petroleum.
- For performance benefits (i.e., quite ride and smooth acceleration).
- To have access to high-occupancy vehicle traffic lanes.

In all, 3,034 responses were received. Figure 11-155 shows the spread of the responses.

Table 11-53 presents the overall average ranking of the responses.

The highest-ranking responses deal with energy efficiency and financial savings, which are more pragmatic responses than most of the other possible responses. This is important in moving the EV market beyond the innovators of Figure 11-154. It is noted that having access to high occupancy vehicle lanes received the lowest ranking overall; however, there were 198 responses (7%) where this was listed as the highest-ranking reason.

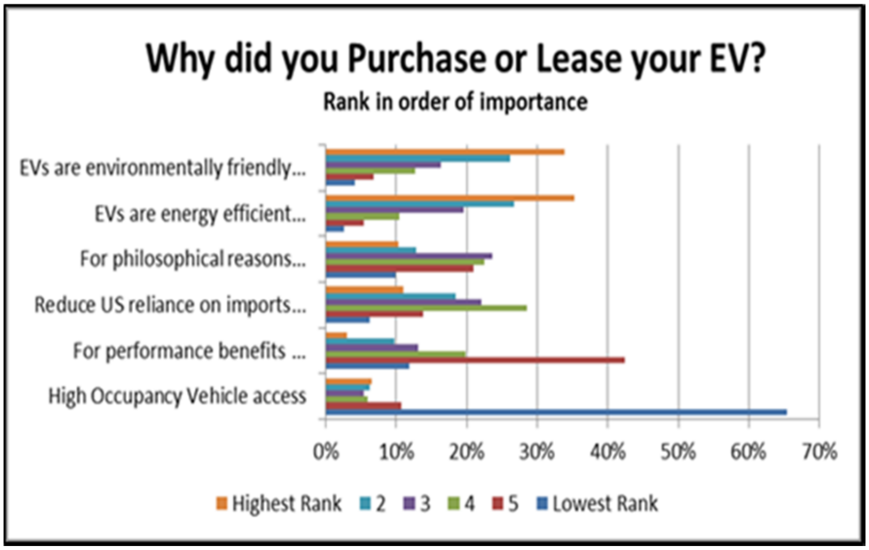


Figure 11-155. EV purchase motivation.

Table 11-53. EV purchase motivation.

Response Choice	Average Rank
EVs are environmentally friendly…	2.44
EVs are energy efficient…	2.32
For philosophical reasons…	3.61
Reduce U.S. reliance on imports…	3.34
For performance benefits…	4.24
High occupancy vehicle access	5.04

11.5.2.8 How Many Vehicles are in the Participant's Household? Participants were asked, "Please select the amount of vehicles in your household, including your EV." The survey provided six choices of vehicle types (Table 11-54) and quantities of 0, 1, 2, or 3 or more for each vehicle type. For example, a response may show three or more BEVs, two gasoline, and one diesel vehicle. The question did not ask the specific number of vehicles above three, but assuming that "3 or More" is exactly three, the total number of cars in the household is shown in Figure 11-156.

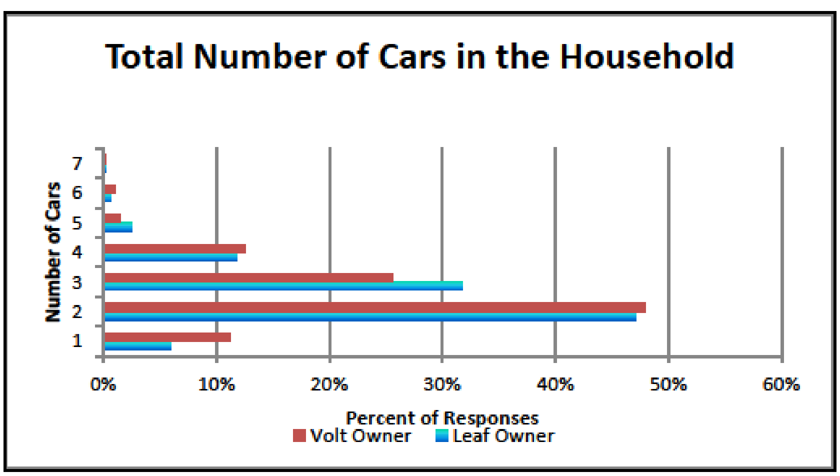


Figure 11-156. Total number of vehicles in the household.

On average, the Leaf Owner has 2.61 vehicles in the household and the Volt Owner has 2.49 for an overall average of 2.58 vehicles per household. Fifteen percent of Leaf owners and 15% of Volt owners report having more than three vehicles in the household.

The vehicle choices in the question were as follows:

- All battery EV (like the Nissan Leaf)
- Plug-in hybrid/EREV (like the Chevrolet Volt)
- Hybrid vehicle (does not plug in)
- Natural gas/compressed natural gas
- Diesel vehicle
- Conventional gasoline vehicle.

In all, 3,004 responses were received. Figure 11-157 provides the responses.

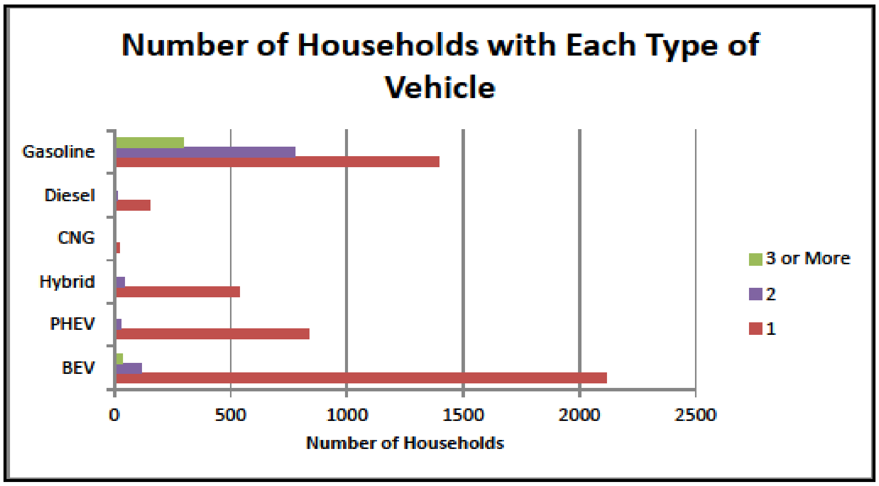


Figure 11-157. Number of households with vehicle types.

Fifty-two Volt drivers and 48 Leaf drivers did not identify their vehicle as that type in this question, even though the choices identified the specific model in that category and they selected their type in a previous question.

Table 11-54 provides this information in tabular form. For each category, the total number of vehicles in that category is reported with the percent of responders with that response identified below it. Because more than one response is allowed, the total may sum to more than 100%.

Table 11-54. Number of vehicles in household by type.

Number of Households Reporting Vehicle Type and Quantity	1	2	3 or More
All battery EV (like the Nissan Leaf)	2,116/68%	116/4%	31/1%
Plug-in hybrid (like Chevrolet Volt)	836/27%	26/1%	1/0%
Hybrid vehicle (does not plug in)	537/17%	38/1%	1/0%
Natural gas/CNG	18/1%	5/0%	1/0%
Diesel vehicle	148/5%	13/0%	2/0%
Conventional gasoline vehicle	1,395/45%	775/25%	298/10%

A comparison of responses by Leaf or Volt owners is shown in Figure 11-158. Figure 11-158 shows that 98% of Leaf owners identified they have at least one BEV. In addition, 3% of Leaf owners identified they also had at least one PHEV and 80% indicated they also had at least one conventional gasoline vehicle.

Ninety-four percent of Volt owners identified they had at least one PHEV, 7% identified they owned at least one BEV, and 78% identified they owned at least one conventional gasoline vehicle. There were six Volt owners who reported one PHEV and three or more BEVs.

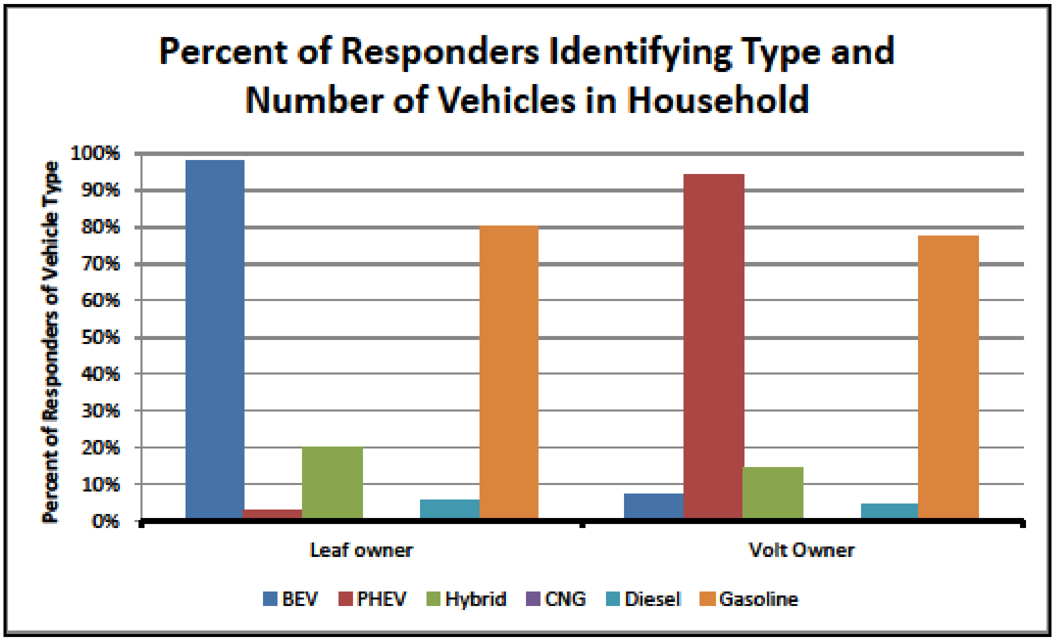


Figure 11-158. Percent of responders on vehicle type and number.

For unknown reasons, not all Leaf owners identified owning a BEV and not all Volt owners identified owning a PHEV.

Twenty-five Leaf owners identified they owned three or more BEVs, while 166 Leaf owners (7%) reported having only PEVs (i.e., no other vehicle type) and 338 Leaf owners had one BEV and one conventional gasoline vehicle only.

Twenty-five Volt owners identified owning two or more PHEVs, while 105 Volt owners report they had PEVs, but no other vehicle type and 153 Volt owners had one PHEV and one conventional gasoline vehicle only.

11.5.2.9 Primary Vehicle. Participants were asked, “Which of your vehicles would you consider your family’s primary vehicle?” In all, 3,124 responses were received (shown in Figure 11-159).

Segmenting the responses by vehicle owner provides the responses shown in Figure 11-160.

As might be expected, Leaf owners relied more heavily on their conventional gasoline vehicle than the Volt owners; however, it is revealing that 17% of the Volt owners identified that their conventional gasoline vehicle was their primary vehicle.

It is noted that for those who had both BEVs and PHEVs, 9% of Volt owners identified that the BEV was their primary vehicle, whereas 1% of Leaf owners identified the PHEV as their primary vehicle.

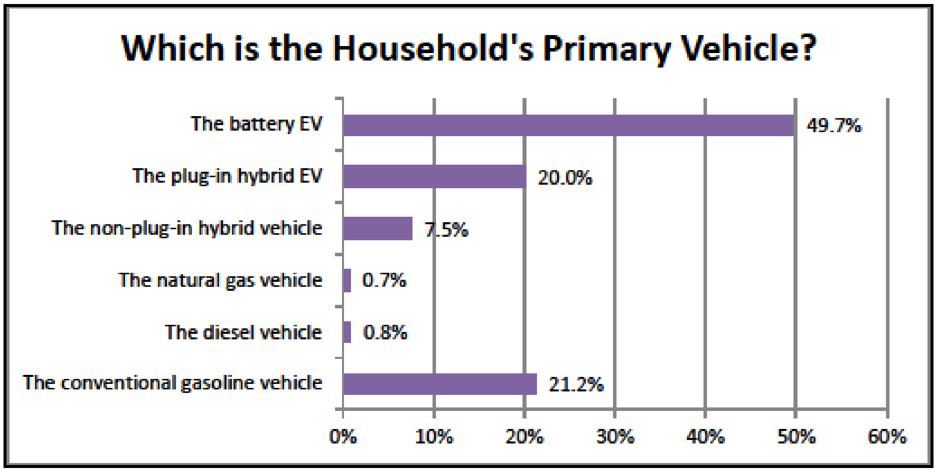


Figure 11-159. Household primary vehicle.

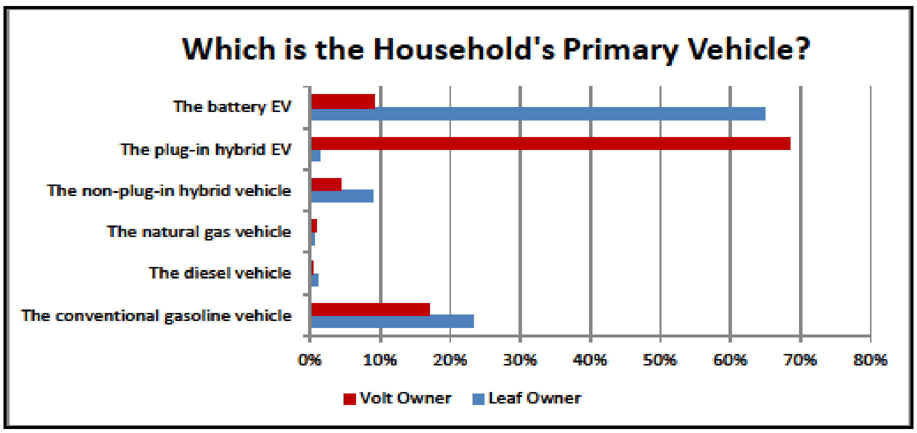


Figure 11-160. Household primary vehicle by vehicle owner.

11.5.2.10 Electric Vehicle Use. Participants were asked, "Which of the following describes how you use your PEV today?" Respondents were allowed to select all that apply and to specify other uses. Response choices were as follows:

- I use my EV for work commuting.
- I use my EV for occasional short-distance trips for shopping, errands, or office visits.
- I use my EV for most of my vehicle uses (it is my primary vehicle.)
- I use my EV for all of my trips (It is my only vehicle).
- Other (please specify).

Multiple responses were allowed, with 3,222 responses being received (see Figure 11-161).

Responses for work commuting, short trips, and primary vehicle choices were nearly equal for both the Volt and Leaf owners, with the primary vehicle choice getting the most responses from Volt owners (71%) and the work commuting choice getting the most responses from Leaf owners (72%).

Fifty-three respondents provided unsolicited additional information related to their present use. They were categorized into the comments noted in Figure 11-162.

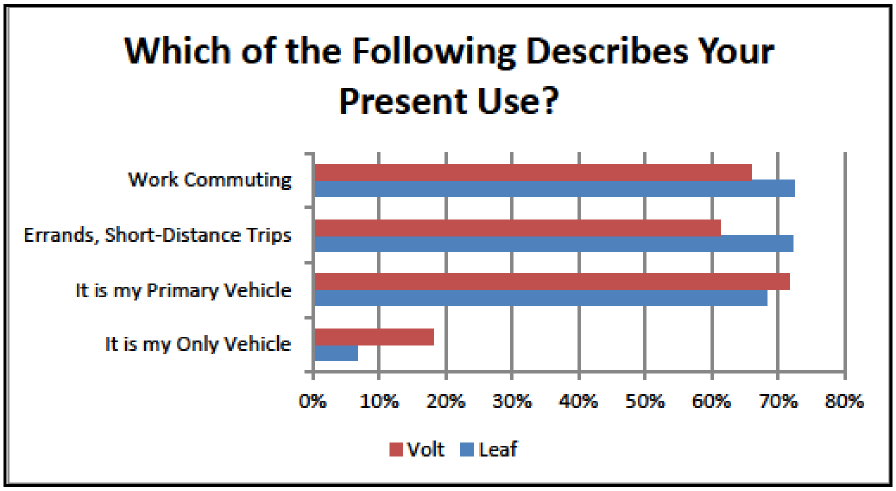


Figure 11-161. Present day EV use.

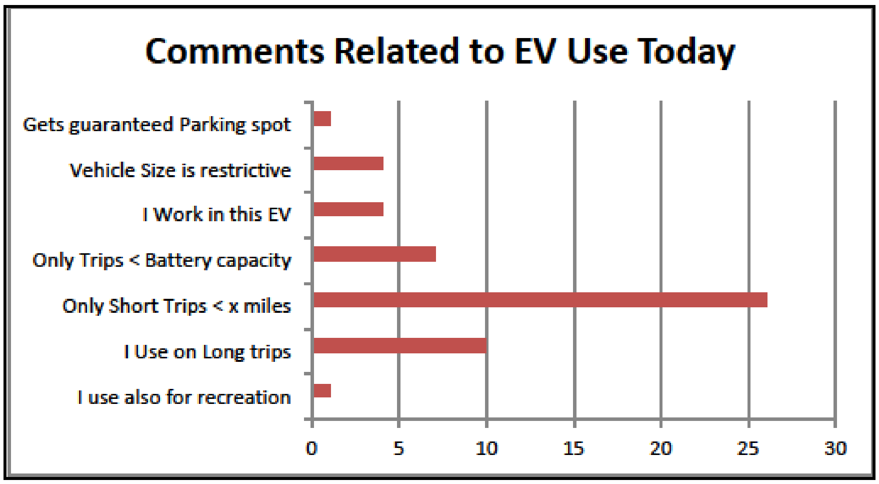


Figure 11-162. Comments related to present-day EV use.

"Gets guaranteed parking spot" was reported by one person as a reason for selecting the PHEV. "Vehicle size is restrictive" summarizes comments indicating that the respondent would use the vehicle more, but finds the passenger or cargo area is too small to meet all needs (i.e., carpooling or carrying luggage). "I work in this EV" were comments related to the vehicle being a tool for their work (e.g., appraisers, etc.). "Only trips < battery capacity" was reported, indicating they only select the PEV for trips that would be less than the battery capacity. Some specified a specific maximum distance as the criterion for selecting the PEV. Some made a point of identifying that they like their Volt for long trips and for recreation.

The survey then asked, "Think back to when you first bought your EV. Are you using it for the same purposes today as you had originally intended?" 95% responded in the affirmative.

11.5.2.11 Daily Miles Traveled. Participants were asked, "Has the daily miles driven on your EV changed since you brought it home?" This question, like the one above, was intended to identify whether driving habits have changed with more experience. The responses are shown in Figure 11-163.

Overall, 94% of responders reported they drove the same or more miles in June 2013 than when they purchased their PEV, with 41 responders specifying a difference as categorized in Table 11-55.

This question is also being evaluated by reviewing driver charging and travel data obtained through the charging stations and vehicle telematics. This will be the subject of a separate report.

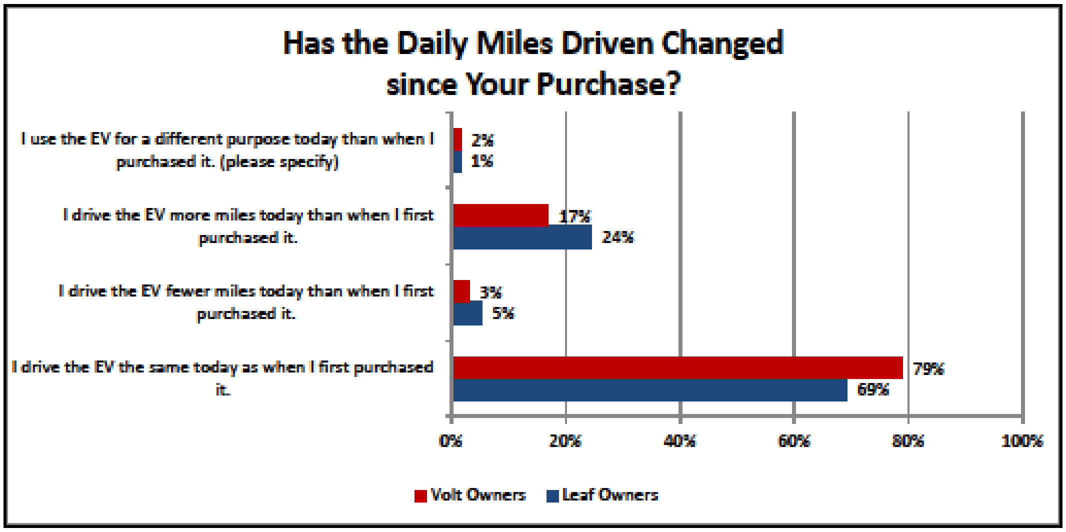


Figure 11-163. Change in daily miles traveled.

Table 11-55. Change in owner miles driven.

Comment	Number
Changed use from commuting to running errands	1
My confidence has grown and I use public charging more	1
My vehicle's range has diminished	3
I was driving for errands only, but now I'm driving more	1
A different family member is now using the EV	1
My job/school change is now beyond the range of the EV	2
The EV has a more limited range than I was told or thought	2
I was commuting only, but now have expanded its use	6
I am now retired or work less than before, so drive less	24

11.5.2.12 Meeting Driving Needs. Participants were asked, "What percent of your driving needs are met by your EV?" In all, 3,029 responses were received and are shown in Figure 11-164.

Ninety-four percent of Volt owners and 87% of Leaf owners reported more than 60% of their driving needs were met by their PEV. Figure 11-165 considers this question on a regional basis. Over 85% of responders in all regions noted that more than 60% of their driving needs were met by their PEVs. Variations between the top two categories are reflected in Figure 11-166, where Los Angeles and Texas reported the highest percentages of needs met.

11.5.2.13 How Do You Decide which Vehicle to Drive? Participants were asked, "Since you may have a choice of vehicles, how do you decide between using your EV and choosing the other vehicle?" Response choices were provided, along with an open-ended response for other comments. The response choices were as follows:

- I generally use the EV for specific purposes.

- I generally use the EV for trips I know I can make on battery power only without recharging away from home.
- I will use the EV for longer ranges if I know there is public charging available where I'm going.
- I'm cautious about putting too many miles or battery charges on my EV.
- I try to use my EV whenever I can.
- Another member of the household uses one vehicle and I use the other.
- Other (please specify).

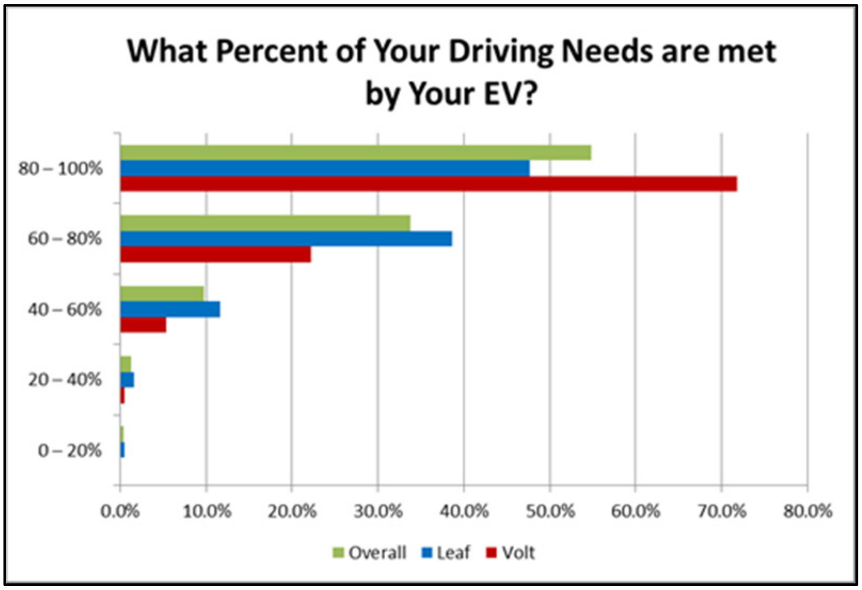


Figure 11-164. Driving needs met by EV.

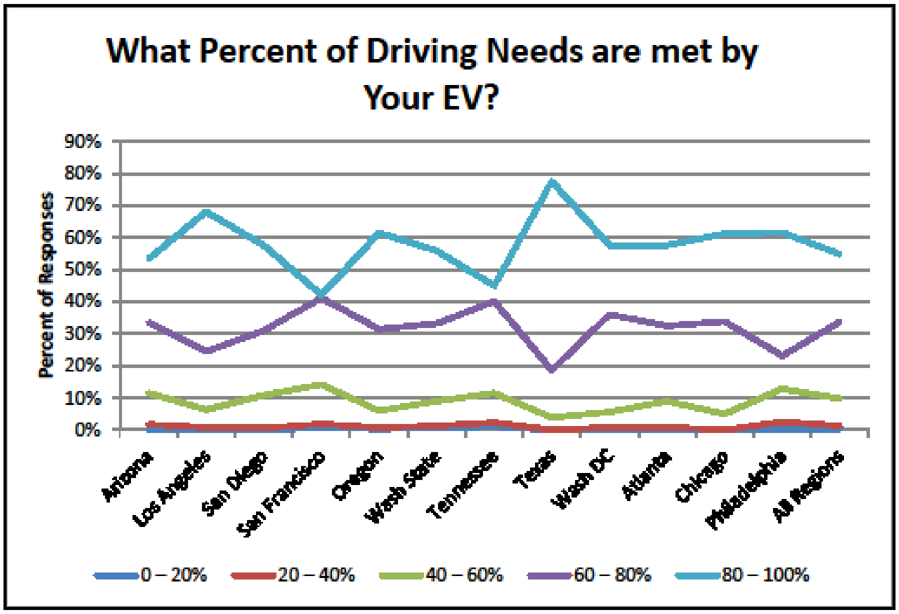


Figure 11-165. Driving needs met by The EV Project region.

Participants could select all that apply; therefore, response totals could be greater than 100%. In all, 3,246 responses were received and are shown in Figure 11-166.

It is noted that 53% responded that they would use the PEV for trips within the capacity of their battery; therefore, they would not have to use public charging, and 25% would use the PEV if they knew that public charging would be available.

Of all responses, 190 respondents offered comments in the "Other" category. Those responses are summarized in Table 11-56.

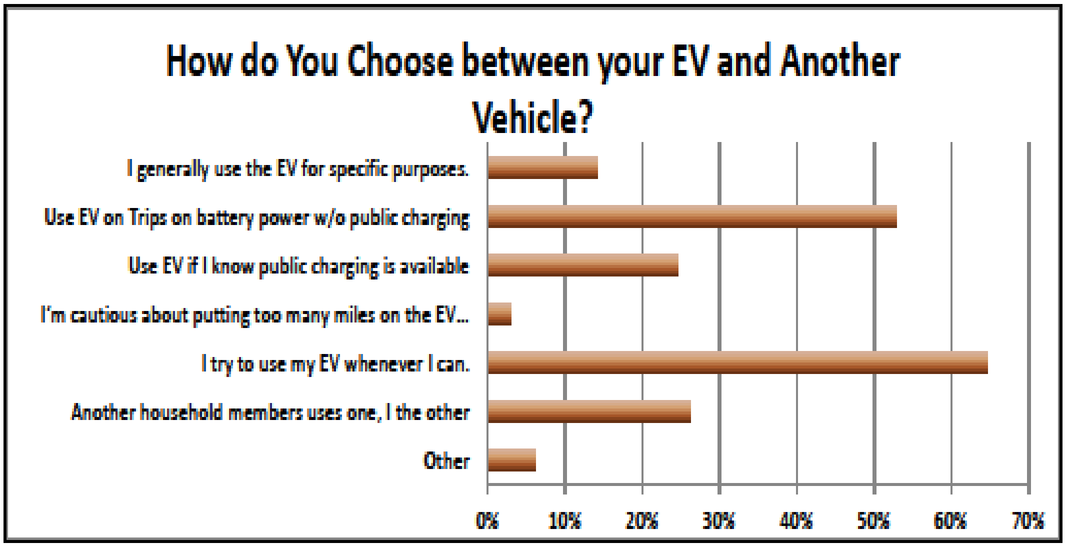


Figure 11-166. Choosing vehicles.

Table 11-56. Other comments on choice of vehicle.

Other Comments on Choice	Number of Responders
EV vehicle characteristics can be too restrictive for passengers or cargo	31
I avoid away-from-home charging	13
I avoid using too many public chargers on one outing	1
I would use the EV more if DCFC were available	7
We enjoy driving the other vehicle (i.e., convert)	4
Our PEV is our first choice always	44
We limit the miles to avoid lease issues	10
For longer trips, we use the PEV	9
Sometimes we need to use both at the same time	1
EV is our only car	41
Spouse always uses one and I the other	3
We use the EV only for short trips	19
It is used for work commute primarily	7

Attitudes toward public and workplace charging will be explored further in other EV Project reports. Regional variations in responses were considered. The results are shown in Figure 11-167.

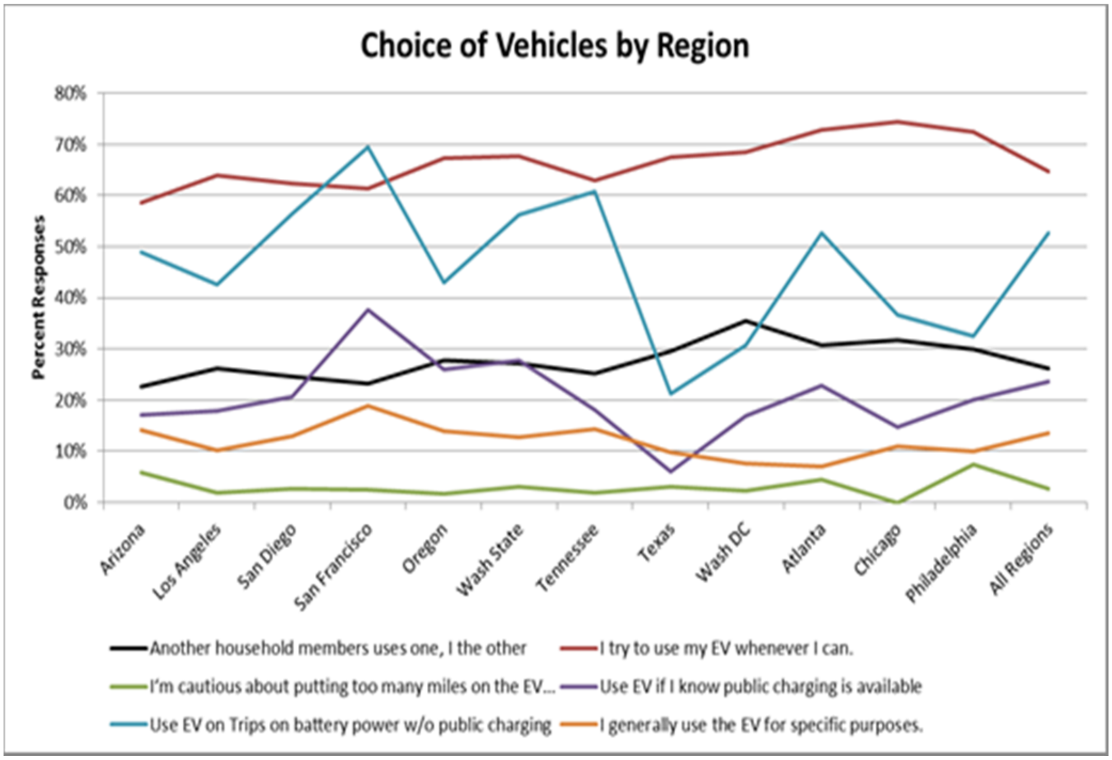


Figure 11-167. Choice of vehicle by EV Project region.

Consistently between regions, the EV owners tried to use the EV whenever they could. It also appears to be common practice that one household member typically used the EV, while another member used a different vehicle.

While overall, 53% of drivers avoided trips beyond the capacity of their PEV battery, this attitude varied widely between regions, with San Francisco having the greatest agreement (69%) and Texas showing the greatest acceptance of charging away from home (21%). At the same time, 38% of the San Francisco responders noted they would use the EV for longer ranges if they knew public charging was available.

For San Francisco, the total response for these two questions is greater than 100%, indicating some responders selected both answers. For these, and perhaps many others, the key may be whether they have the knowledge of the availability of public charging where they want to go.

11.5.2.14 Replacing Your Electric Vehicle. Finally, participants were asked "If you were to replace your current EV, would you:" and the following choices were provided:

- Replace it with a BEV
- Replace it with a PHEV
- Replace it with a conventional hybrid vehicle
- Replace it with a conventional gasoline vehicle.

In all, 3,035 responses were received (Figure 11-168).

Overwhelmingly, the PEV owner would replace their existing PEV with another, with 96% of responders saying they would buy a PEV, while only 4% would buy a hybrid or gasoline vehicle. It is noted that owners of both vehicles in The EV Project would select a BEV as a replacement over the PHEV by 84% to 16%. As noted above, there were many survey respondents who own both BEVs and

PHEVs. Fully, 81% of Leaf owners would replace their Leaf with another BEV, while 70% of Volt owners would replace their Volt with another PHEV. Twenty-seven percent of Volt owners would replace their Volt with a BEV and 15% of Leaf owners would replace their Leaf with a PHEV.

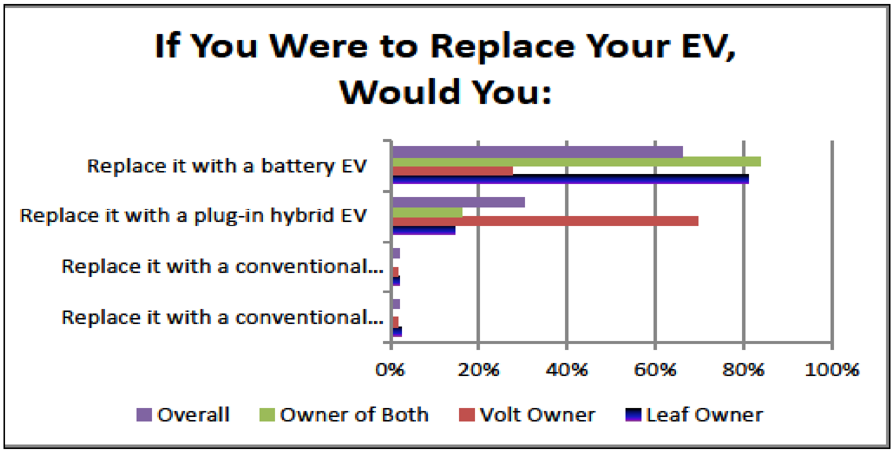


Figure 11-168. Replacing the current EV.

11.5.2.15 Observations. PEV owners in The EV Project were very satisfied with their PEV. While most had a choice of vehicles in the household, 70% selected the PEV as their primary vehicle and used it as much as possible. Ninety-four percent drove as much or more in June 2013 as they did when they bought it, and 96% would select another PEV if they were to replace the one they have.

This satisfaction is important in expanding the PEV market to the early majority noted in Figure 11-154.

11.5.2.16 References

90. "Acceptance and Diffusion of Innovations," http://www.valuebasedmanagement.net/methods_rogers_innovation_adoption_curve.html, accessed August14, 2013.

91. "Who are the Participants in The EV Project," lessons learned, avt.inl.gov/evproject.shtml.

11.5.3 How Do The EV Project Participants Feel about Charging Their Electric Vehicle at Home?

11.5.3.1 Introduction. The EV Project participants were very cooperative and enthusiastic about their participation in the project and very supportive in providing feedback and information. The information and attitudes of these participants concerning their experience with their PEVs was solicited in a 2013 survey. At that time, some participants had up to 3 years of experience with their PEVs.

11.5.3.2 Key Observations from the Survey of The EV Project Participants

- In June 2013, 72% of EV Project survey respondents were very satisfied with their home charging experience.
- 21% of survey respondents relied totally on home charging for all of their charging needs.
- Volt owners relied more on home charging than Leaf owners, who reported more use of away-from-home charging.
- 74% of survey respondents reported that they plug in their PEV every time they park at home. Others plugged in as they determined necessary to support their driving needs.

- 40% of survey respondents reported that they would not have or are unsure that in June 2013 whether they would have purchased an AC Level 2 EVSE for home charging if it had not been provided by The EV Project.
- 61% of survey respondents reported that The EV Project incentive was very important or important in their decision to obtain a PEV.

11.5.3.3 Why Is How the Owner is Feeling About Home Charging Important? PEVs require recharging to sustain the battery for electric drive transportation. The owner of the PEV essentially has three choices for charging: home, workplace, or publicly accessible locations. The EV Project participants were the innovators and early adopters of electric drive transportation. Their feedback on how they felt about charging their PEV is of interest because it can shape this new technology for wider adoption.

11.5.3.4 Participant Information. Understanding the demographics of The EV Project participant is important in understanding their choices and attitudes toward electric transportation. The age, gender, average household income, and education level were explored in "Who are the Participants in The EV Project?" [92].

Satisfaction of participants with their PEVs was explored in "How do The EV Project Participants Feel About their EVs?" [93].

The Nissan Leaf sales rollout plan defined the initial five regions of The EV Project, anticipating them to be the locations of the innovators and early adopters of PEVs. Later expansion of The EV Project included 16 metropolitan areas in nine states plus the District of Columbia. Within these regions, physical study boundaries were established. The views and attitudes of project participants nationally and regionally are explored in this report.

11.5.3.5 Which Plug-In Electric Vehicle did they Acquire? The EV Project achieved full enrollment of residential participants early in 2013. Final enrollment in each market was ultimately determined by the PEV market conditions, which were driven by local PEV dealer promotions and local government incentives and local demographics. Table 11-57 identifies the number of participants driving Nissan Leafs and Chevrolet Volts in each region. Because of other DOE projects in the area, Chevrolet Volt drivers were not included in The EV Project in the San Francisco region.

Table 11-57. Regional participation in The EV Project.

	Leaf	Volt
Arizona	376	156
Los Angeles	471	344
San Diego	722	277
San Francisco	1,874	–
Oregon	558	136
Washington State	969	177
Tennessee	942	144
Texas	34	288
Washington D.C.	50	291
Atlanta	176	77
Chicago	34	129
Philadelphia	32	54
Overall	6,238	2,073

The original completion date of The EV Project was December 2012. Later expansion of the project also extended the completion date to December 2013. Some participants retired from the project at the end of the original period. In addition, some other participants retired because they sold their vehicles or their vehicles were destroyed in accidents.

11.5.3.6 Participant Survey. For participants in The EV Project, residential charging is accomplished through the use of the AC Level 2 EVSE. AC Level 2 uses a 240-volt circuit in the home similar to that used for a clothes dryer or hot water heater. The EV Project participants were provided the Blink AC Level 2 charging station for their residence at no cost, along with a specified credit toward the cost of installation of that station, in exchange for their agreement to allow The EV Project to collect and use their residential and non-residential charging and vehicle data.

One goal of The EV Project was to gain an understanding of participant experience and attitudes toward their PEV usage. In support of this goal, an online survey was sent to 7,730 active EV Project participants. The survey solicited 3,236 responses for a 42% response rate. Among the topics identified were questions related to charging their PEV battery at home. Table 11-58 presents the responses received by region and vehicle type.

Table 11-58. Survey responses by region.

	Leaf Responses	Volt Responses	Leaf and Volt Responses
Arizona	159	74	1
Los Angeles	133	120	7
San Diego	244	109	7
San Francisco	553	-	4
Oregon	211	74	2
Washington State	378	83	3
Tennessee	345	54	2
Texas	11	119	2
Washington D.C.	13	114	2
Atlanta	74	39	1
Chicago	15	67	-
Philadelphia	13	26	1
Unknown	159	2	2
Overall	2308	881	34

Thirty-four of the respondents reported having both a Leaf and a Volt in The EV Project and 13 reported they were no longer participating; 163 responses were provided that identified the type of vehicle, but not the region of The EV Project.

11.5.3.7 Charging at Home. The EV Project's quarterly reports have identified that about 74% of all charging events for the Leaf and 80% of all charging events for the Volt occur at home [94].

Charging Needs—Participants were asked, "How much of your charging needs are met by home charging?" They were provided with seven possible responses. The response choices were (in increasing order of away-from-home charging) as follows:

- Away-from-home charging is not available in my area.
- Never use charging away from home.
- Occasionally use charging away from home.
- Frequently use charging away from home.

- Rely on away-from-home charging as much as home charging.
- Mostly use charging away from home.
- Rarely, if ever use home charging.

In all, 3,129 responses were received. Figure 11-169 shows the responses.

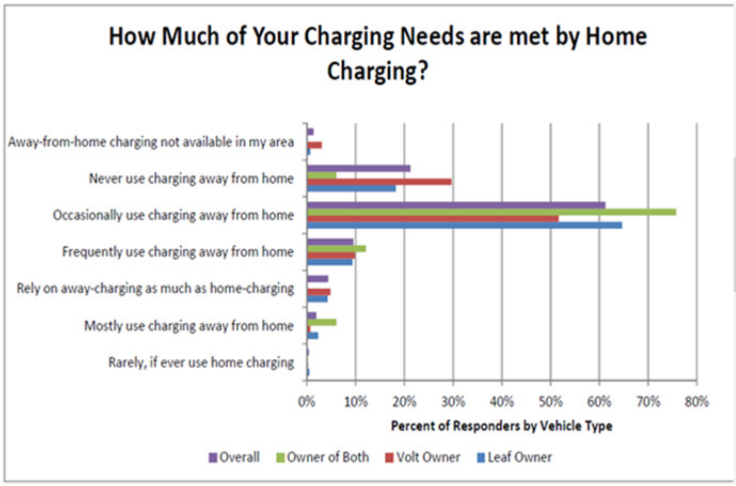


Figure 11-169. Charging needs.

For analysis, the responses were grouped in order to summarize whether the PEV owner's charging needs were met by home charging (see Figure 11-170).

Forty-two responses (1%) indicated that away-from-home charging was not available in their area. However, in all locations of The EV Project, public infrastructure was installed by The EV Project and others also may have installed public charging. This is interpreted as either the respondent was unaware of this availability or the EVSE was not in an area frequented by the respondent.

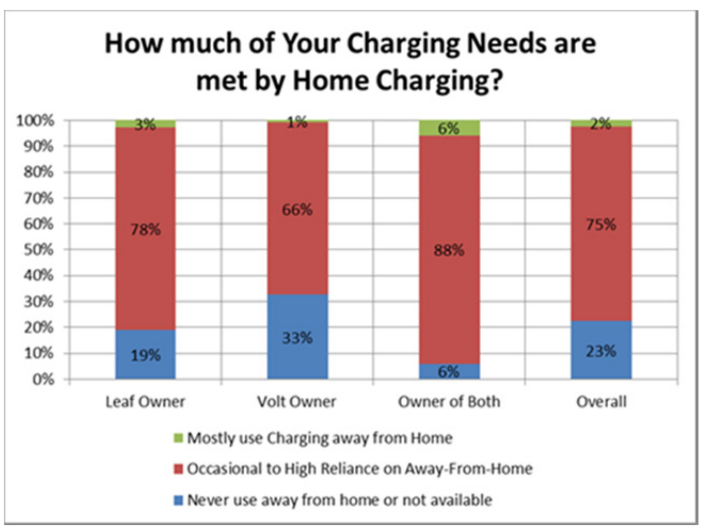


Figure 11-170. Charging needs met.

It is also of interest that 21% of the responders reported they never use away-from-home charging. How EV Project participants feel about away-from-home charging is explored in another report [95].

The “Occasional to high-reliance on away-from-home charging” included the occasional, frequent, and those that rely on away-from-home charging as much as home charging. This was the highest ranking selection with 75% choosing this response.

Segmented Charging Needs—Prior to sending the survey, the participants were segmented by their vehicle type and charge data, which indicated they never charged away from home, they occasionally charged away from home, they frequently charged away from home, and those whose typical behavior could not be determined because of GPS or other data inconsistencies. In all, 3,049 of the responses self-identified in the segments reflecting their actual charging pattern, with 104 respondents skipping this question. The segmented groups are identified in the columns and their responses to this question are in the rows of Table 11-59.

Table 11-59. Segmented responses to charging needs met.

Meeting Charging Needs	Leaf Never	Leaf Occasional	Leaf Frequent	Leaf Unknown	Volt Never	Volt Occasional	Volt Frequent	Volt Unknown
Away from home charging is not available	2	4	0	10	9	11	1	4
Rarely use home charging	0	2	0	7	0	1	1	0
Mostly use away from home charging	0	4	7	22	0	2	4	0
Rely on both home and away from home equally	0	14	16	33	2	14	19	5
Frequently use away from home charging	1	67	19	84	0	32	43	8
Occasionally charge away from home	49	783	22	552	51	320	36	36
Never charge away from home	87	162	1	146	120	106	5	21

The red responses show inconsistency between the survey respondents’ responses and their charge data. For example, 50 Leaf Owners’ charging data show all charges were conducted at their residence, but their survey responses indicate they occasionally or frequently use away-from-home charging. In addition, 12 Volt owners whose charging data show they occasionally or frequently charge away from home responded that away-from-home charging is not available to them.

Yellow highlighted cells indicate questionable consistency and green indicates good consistency between the charge data and participant responses. Eight-seven percent of the responses displayed consistency between their charge data and survey responses.

However, it must be recognized that subjective descriptions such as “never” or “rarely” may lose distinction for some. It is also possible that past charging at away-from-home locations occurred, but the intent of the participant is that they no longer charge away from home or even that they no longer desire to charge away from home.

Connecting to Home Charging—Participants were asked, “Do you intend to plug in your EV every time you park at home?” For those who responded “no,” additional comment space was allowed. In all, 2,970 responses were provided (see Figure 11-171).

Responses by Volt owners indicating the frequency of plugging-in at home is consistent with the charge data reported in The EV Project quarterly reports [96], which also indicate that the Volt owner plugs in more at home than the Leaf owner. However, it is quite interesting that Leaf owners intended to plug in at home only 67% of the time, while Volt owners were above 90%. Nissan has informally suggested that the Leaf should be routinely recharged to 80% capacity and as necessary to meet the respective range needs. It does not need to be plugged in at every opportunity nor recharged to 100% on every charge [97].

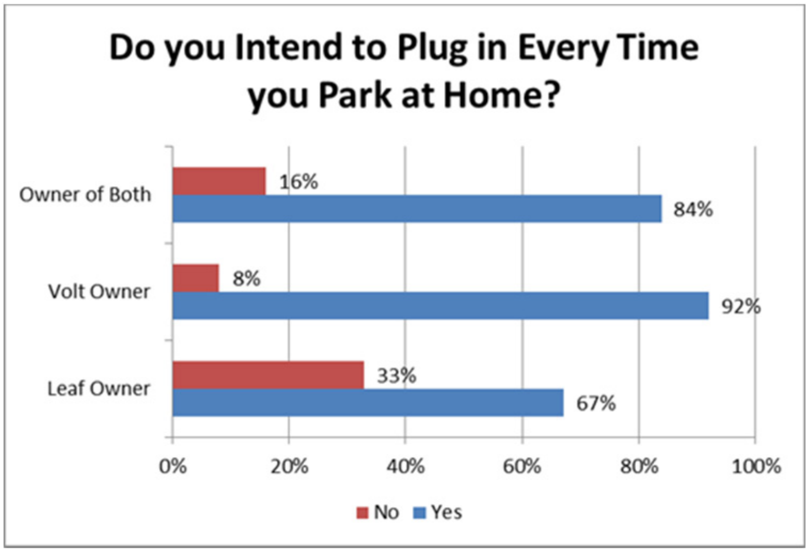


Figure 11-171. Intentions of plugging in.

The regional "yes" responses to this question by Leaf and Volt owners are shown in Figure 11-172.

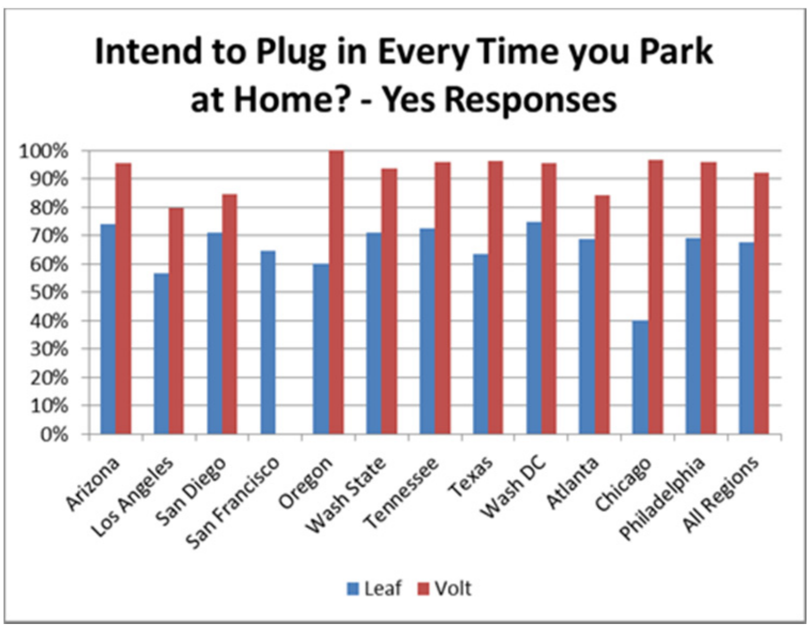


Figure 11-172. Regional responses to plugging-in intention.

Over all of the regions, the Volt drivers' intent to plug in every time, more so than the Leaf owners' intent, is evident and overall, 74% of respondents intend to plug in every time they park at home.

The average distance traveled per day when driven for the second quarter of 2013 is shown in Figure 11-173. This figure correlates closely with the responses of Figure 11-172, although the spread between Leaf and Volt owners evident in Oregon and Chicago are not borne out by distances traveled.

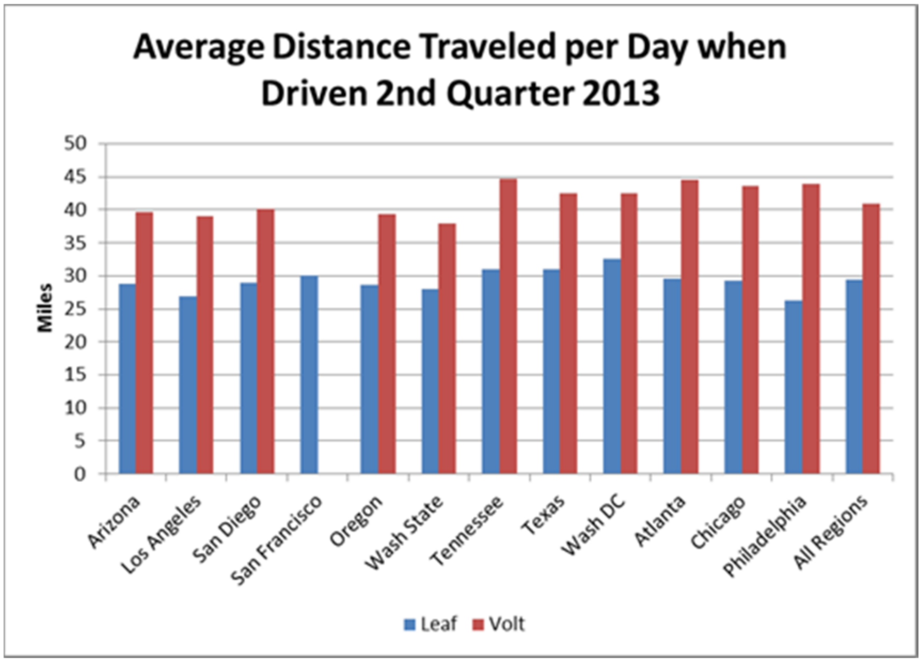


Figure 11-173. Average distance traveled per day in the second quarter of 2013 [97].

Seven hundred and seventy-seven free-form comments were received related to why a respondent did not intend to plug in on every park at home. The responses were aggregated into several typical responses as noted in Table 11-60. Overall, 9% of the responses indicated the decision to plug-in was based on personal criteria from information displayed by the vehicle (e.g., the battery SOC or miles remaining or a sense that the charge is "low"). Overall, 5% of the responders noted that while they do not plug in every time at home, they do charge nightly. Some reported this as a nightly routine to plug-in as one might check that the doors are locked.

The most commonly stated reason for not plugging in every time when parked at home was the owner's desire to plug in when it was necessary for the next day or next trip. This represents 8% of all survey responses received. Only 2% indicated that they mostly plug in at work.

Home Charging with Alternating Current Level 2 Electric Vehicle Supply Equipment—Participants were asked, "If you had not received an AC Level 2 charging station from The EV Project, do you think you would have purchased one?" For those who responded "no," additional comment space was allowed to "please explain why your vehicle's AC Level 1 cordset would meet your needs." In all, 3,010 responses were provided and are shown in Figure 11-174.

The percentage of "No" or "Not sure" responses is significant. This can reflect the responder considering his/her desires at the time of purchase and/or his/her understanding of current driving and charging needs. Whether the PEV driver has changed his/her driving habits over time will be the subject of another report.

The specific comments of those who reported "no" to this question are shown in Table 11-61. There may have been some confusion about this question, because the number one reason survey respondents provided for not purchasing the AC Level 2 for home use was that they needed it and would have purchased it. This comment is inconsistent with their "no" response. It is recognized that this question tries to understand a previous purchasing motivation but is also tainted by the owners experience since that purchase, which may be reflected in this specific response.

Table 11-60. Comments related to home charging intentions.

Decision to Plug-In Other than Every Time	Leaf	Volt	Total
I plug in when I need to for my known next trip	223	14	237
I plug in nightly unless I need to more often	124	30	154
I plug in mostly at work	51	8	59
I plug in if battery is below 80%	34	1	35
I plug in if battery is below 70%	19	2	21
I plug in if battery is below 60%	12	-	12
I plug in if battery is below 50% or less than 40 miles	61	1	62
I plug in if battery is below 40% or less than 30 miles	22	1	23
I plug in if battery is below 30% or less than 25 miles or "low"	75	5	80
I plug in if battery is belows 20% or less than 15 miles	29	2	31
I plug in only every other day	33	1	34
Nissan recommended or I think I am to charge infrequently	8	1	9
I almost always plug in	8	-	8
I plug in at free public charging	4	-	4
I have Solar so I plug in when best times	2	1	3
I plug in based on cost of charging options	2	-	2
I no longer have AC L2 available at home	1	1	2
I plug into 120 VAC whenever I can	1	-	1

These comments for "no" responses represent just 8% of the total.

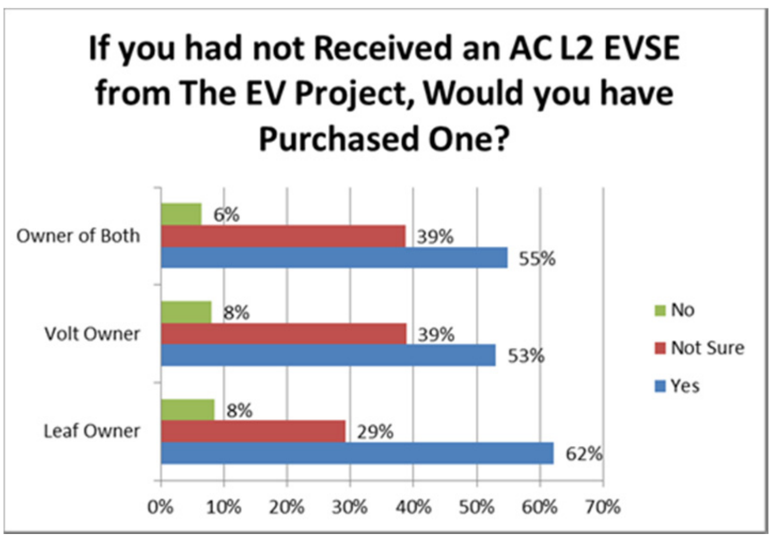


Figure 11-174. AC Level 2 EVSE desired at home.

Electric Vehicle Supply Equipment and Installation Cost—Participants were asked, "When you decided to buy/lease an EV, how important was it to you that you could get a free AC Level 2 charging station and installation credit from The EV Project?" The response choices were as follows:

- Not Important – I appreciated the charging unit and credit but it did not factor in my decision.
- Not Important – I did not need AC Level 2 at home to meet my planned EV needs anyway.
- Somewhat important – I would have purchased the EV anyway, but this simplified the process.
- Important – I would have purchased the EV anyway, but overall cost was a significant concern.

- Very important – I would not have purchased the EV without The EV Project incentives.

Table 11-61. Comments on why respondent would not have purchased a home AC Level 2 EVSE.

Why would you not have purchased AC L2?	Leaf Owner	Volt Owner	Overall
I need the AC L2 and would have purchased one.	54	5	59
I have plenty of time to charge with AC L1.	27	28	55
The AC L2 EVSE was too expensive	12	22	34
I would not have purchased or leased an EV.	34	4	38
I found, made or would have made a cheap AC L2.	24		24
I would have changed my use of my vehicles to match AC L1.	3	3	6
I thought at the time that AC L1 would be sufficient but it is not.	5	1	6
I would have used public charging.	5		5
I charge at Work	5		5
I already had an AC L2.	1	1	2
I thought the cordset was emergency only.	1		1

In all, 3,116 responses were received and the results are shown in Figure 11-175.

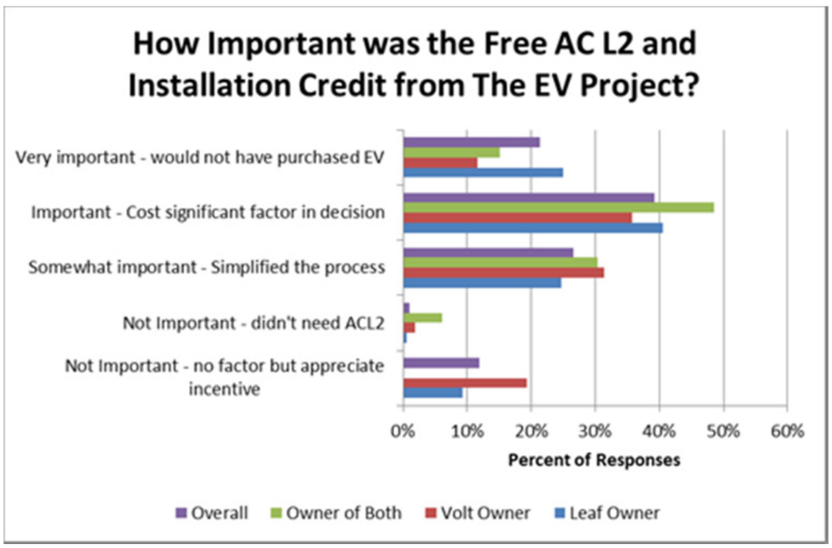


Figure 11-175. Importance of incentive in decision.

Sixty-one percent of all responders identified this incentive as "very important" or "important" in that it affected their decision on whether to purchase or lease a PEV, with 66% of Leaf owners and 47% of Volt owners in these categories. Twenty-five percent of Leaf owners responded that they would not have obtained their PEV without this incentive.

This response is somewhat unexpected. The early adopters of electric drive transportation are typically highly educated with a median household income of $149,000 [98]. It was expected that the incentive would motivate owners to allow The EV Project to use their charging and vehicle data, but would not factor highly in a purchase decision.

Figure 11-180 provides the responses by region. Tennessee, San Diego, and Los Angeles reported the highest percentage of "important" or "very important" responses.

Programming the Residential Electric Vehicle Supply Equipment—The Blink AC Level 2 residential EVSE and the Leaf and Volt vehicles have programming features that allow selection of a preset time at which the charge will begin. The vehicle may be connected to the EVSE, but the charge will not begin prior to this preset time, unless overridden by the driver. For those in electric utility service territories, where there are TOU rates, this can be important in reducing charging costs. Participants were asked, “Which of the following responses best reflects your situation?” The response choices provided are as follows:

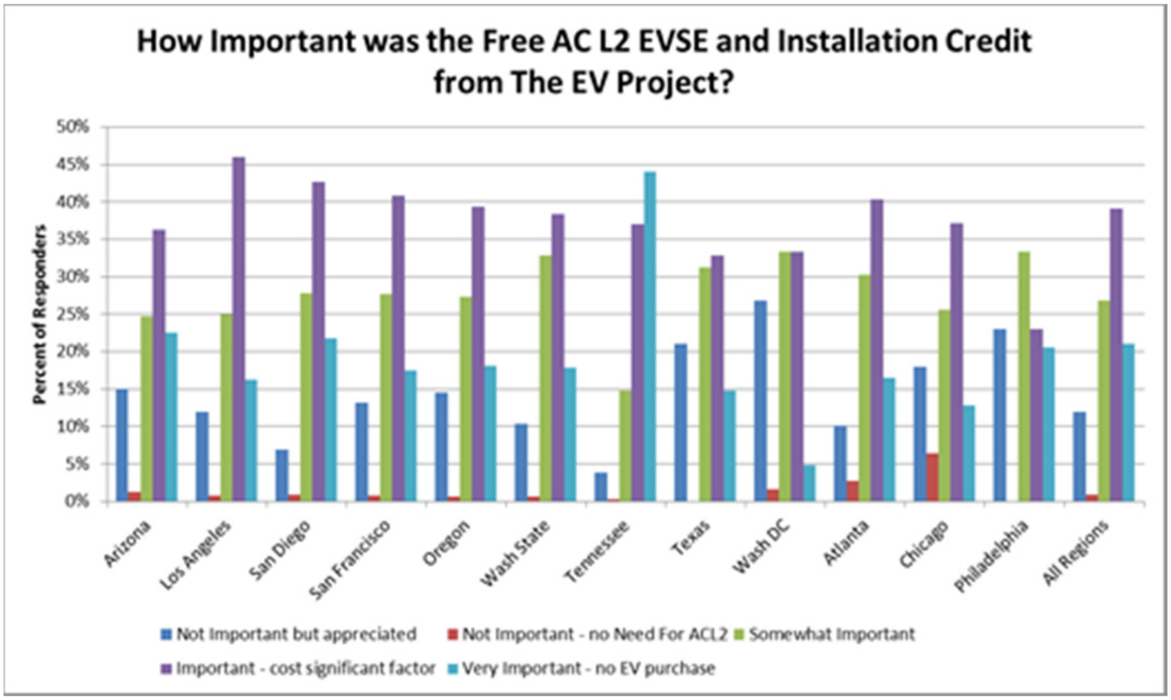


Figure 11-176. Importance of incentives by region.

- My electric utility does not provide TOU rates and I do not program the charging unit or EV.
- My electric utility does not provide TOU rates, but I program either my charging unit or EV to start at a specific time anyway.
- My electric utility does provide TOU rates, but I do not program my charging unit or EV.
- I am on the TOU rate for my electric utility and I program the charging unit only.
- I am on the TOU rate for my electric utility and I program the EV only.
- I am on the TOU rate and I have programmed both the charging unit and the EV.
- I am on a special rate with my electric utility (such as home solar) and I do not program the charging unit or EV.
- I am on a special rate with my electric utility (such as home solar) and I do program either the charging unit and/or the EV.

In all, 3,124 responses were received and are shown in Figure 11-177.

A review of the regional responses shows a strong correlation between the areas where TOU rates are available and those who program their PEV, their EVSE, or both. It is noted that a significant percentage (i.e., 12%) of respondents live in areas where TOU rates are available, do not program to take advantage of these rates. It is also interesting to note that 11% program the timing of their charge, even though TOU rates are not available and there is no apparent financial incentive to do so. These and other factors are investigated further in another report on PEV driver responses to TOU rates [99].

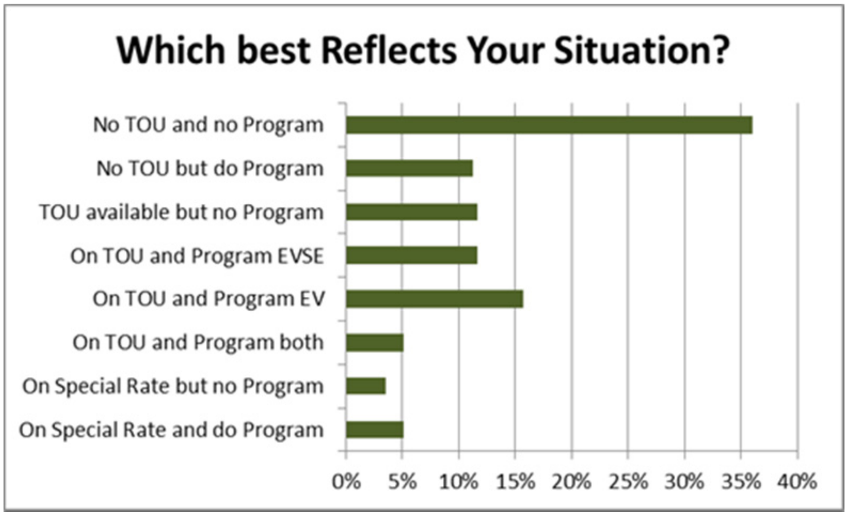


Figure 11-177. Programming the EVSE and/or EV.

11.5.3.8 Satisfaction with Residential Charging. Participants were asked, "How satisfied are you today with your residential charging experience?" A scale of 1 to 5 was provided with 1 = Very dissatisfied and 5 = Very satisfied. In all, 3,004 responses were received and Figure 11-178 provides the responses.

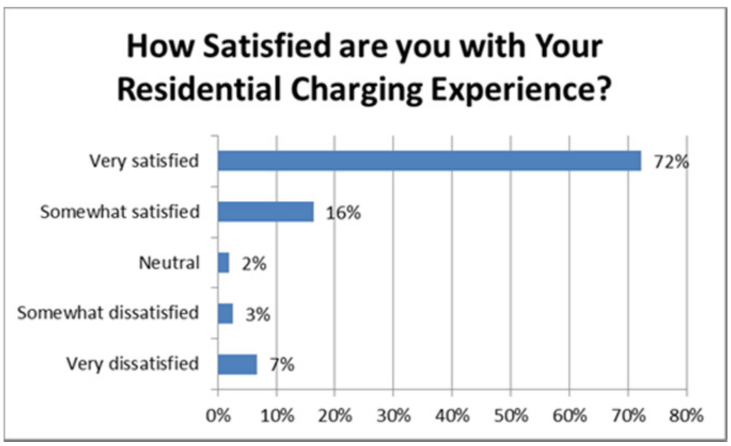


Figure 11-178. Participation satisfaction with residential charging.

The overall ranking was 4.45 on this scale. This indicates that 88% of respondents were satisfied with their home charging experience.

11.5.3.9 Conclusions. Overall, PEV owners in The EV Project are satisfied with their home charging experience. Twenty-one percent of responders report they never use charging away from home for their charging needs, 74% report they plug in every time they come home, and another 5% make sure they charge nightly. Overall, 60% reported they would have purchased an AC Level 2 EVSE at home if it had not been provided by The EV Project, although 61% reported the incentive was important or very important to their purchase decision.

This satisfaction is important in expanding the PEV market to the early majority.

11.5.3.10 References

92. "Who are the Participants in The EV Project," Lessons Learned, avt.inl.gov/evproject.shtml.

93. “How do The EV Project Participants feel about their EV?” Lessons Learned, avt.inl.gov/evproject.shtml.

94. EV Project EVSE and Vehicle Usage Report 2nd Quarter 2013, avt.inl.gov/evproject.shtml.

95. “EV Project Participants and Away-From-Home Charging,” Lessons Learned, avt.inl.gov/evproject.shtml.

96. op.cit. 2nd Quarter 2013.

97. http://www.torquenews.com/1075/nissan-answers-questions-about-optimally-charging-nissan-leaf.

98. op.cit. Who are the Participants.

99. http://avt.inl.gov/pdf/EVProj/125348-714937.pev-driver.pdf.

11.5.4 How Do The EV Project Participants Feel About Charging Their EV Away From Home?

11.5.4.1 Introduction. The EV Project participants were very cooperative and enthusiastic about their participation in the project and very supportive in providing feedback and information. The information and attitudes of these participants concerning their experience with their PEVs were solicited using a survey in June 2013. At that time, some had up to 3 years of experience with their PEVs.

11.5.4.2 Key Observations from the Survey of The EV Project Participants

- In June 2013, 41% of survey respondents who used their PEV for work reported having the availability of charging at their workplace.
- For those who had workplace charging available, nearly twice as many reported AC Level 2 being available as AC Level 1.
- 36% of survey respondents reported that workplace charging was very important or essential to meeting their PEV driving needs.
- 69% of survey respondents reported they very rarely or never used publicly accessible charging.
- 34% of survey respondents suggested that expanding the availability of public charging would result in its greater use.

11.5.4.3 Why Is How the Owner Feels About Away-From-Home Charging Important? PEVs require recharging to sustain the battery for electric drive transportation. The owner of the PEV essentially has three choices for charging: home, workplace, or public locations. How the participant felt about home charging was explored in “EV Project Participant and Charging at Home” [100]. This current report focuses on their away-from-home charging experience.

The EV Project participants were the innovators and early adopters of electric drive transportation. Their feedback on how they felt about charging their PEV is of interest because it can shape this new technology for wider adoption.

11.5.4.4 Participant Information. Understanding the demographics of The EV Project participant is important in understanding their choices and attitudes toward electric transportation. The age, gender, average household income, and education level were explored in “Who are the Participants in The EV Project?” [101].

Satisfaction of participants with their PEVs was explored in “How do The EV Project Participants feel about their EVs?” [102].

The Nissan Leaf sales rollout plan defined the initial five regions of The EV Project, anticipating them to be the location of the innovators and early adopters of PEVs. Later expansion of The EV Project included 16 metropolitan areas in nine states plus the District of Columbia. Within these regions, physical study boundaries were established. The views and attitudes of project participants nationally and regionally are explored in this report.

11.5.4.5 Which Plug-In Electric Vehicle did they Acquire? The EV Project achieved full enrollment of residential participants early in 2013. Final enrollment in each market was ultimately determined by the PEV market conditions, which were driven by local PEV dealer promotions and local government incentives and local demographics. Table 11-62 identifies the number of participants driving Nissan Leafs and Chevrolet Volts in each region. Because of other DOE projects in the area, Chevrolet Volt drivers were not included in The EV Project in the San Francisco region.

The original completion date of The EV Project was December 2012. Later expansion of the project also extended the completion date to December 2013. Some participants retired from the Project at the end of the original period. In addition, some other participants retired because they sold their vehicles or their vehicles were destroyed in accidents.

Table 11-62. Regional participation in The EV Project.

	Leaf	Volt
Arizona	376	156
Los Angeles	471	344
San Diego	722	277
San Francisco	1,874	0
Oregon	558	136
Washington State	969	177
Tennessee	942	144
Texas	34	288
Washington D.C.	50	291
Atlanta	176	77
Chicago	34	129
Philadelphia	32	54
Overall	6,238	2,073

11.5.4.6 Participant Survey. For participants in The EV Project, residential charging is accomplished through the use of the AC Level 2 EVSE. AC Level 2 uses a 240-volt circuit in the home similar to that used for a clothes dryer or hot water heater. The EV Project participants were provided the Blink AC Level 2 charging station for their residence at no cost, along with a specified credit toward the cost of installation of that station, in exchange for their agreement to allow The EV Project to collect and use their residential and non-residential charging and vehicle data.

One goal of The EV Project was to gain an understanding of participant experience and attitudes toward their PEV usage. In support of this goal, an online survey sent to 7,730 active EV Project participants. The survey solicited 3,236 responses for a 42% response rate. Among the topics identified were questions related to charging their PEV battery away from home. Table 11-63 presents the responses received by region and vehicle type.

Thirty-four of the respondents reported having both a Leaf and a Volt in The EV Project and 13 reported they were no longer participating; 163 responses were provided that identified the type of vehicle but not the region of The EV Project.

11.5.4.7 Charging Away from Home. The EV Project's quarterly reports have identified that about 20% of all charging events for the Leaf and 14% of all charging events for the Volt occur away from home [103]. This includes both publicly accessible and workplace charging. The first series of questions deals with workplace charging.

Table 11-63. Survey responses by region.

	Leaf Responses	Volt Responses	Leaf and Volt Responses
Arizona	159	74	1
Los Angeles	133	120	7
San Diego	244	109	7
San Francisco	553	–	4
Oregon	211	74	2
Washington State	378	83	3
Tennessee	345	54	2
Texas	11	119	2
Washington D.C.	13	114	2
Atlanta	74	39	1
Chicago	15	67	–
Philadelphia	13	26	1
Unknown	159	2	2
Overall	2,308	881	34

11.5.4.8 Workplace Charging

Availability and Use of Workplace Charging—Participants were asked, "Do you have access to charging at work?" The response choices provided were as follows:

- Yes, I often or sometimes use it.
- Yes, I have access, but I never or rarely use it.
- No, but I would use it if it were available.
- No and I would not use it if it were available.
- I don't know.
- NA, I don't use my EV for work.

In all, 2,961 responses were received. Of those, 382 indicated they did not use their EV for work. The responses from the remaining 2,579 are shown in Figure 11-179.

Workplace charging was available for 1,058 of The EV Project survey respondents. It is significant that this many employers provided this benefit for employees, given the early stage in EV deployment. It is not clear from the survey whether the availability of workplace charging was a factor in the participant's decision to purchase a PEV.

The regional availability of workplace charging for those who used their EV for work is shown in Figure 11-180.

Overall, 41% of the respondents who used their PEV for work commuting had access to workplace charging. For those who had availability of workplace charging, proportionally more Volt owners declined to use it. The responses of the Leaf and Volt owners about availability and use are shown in Figure 11-181.

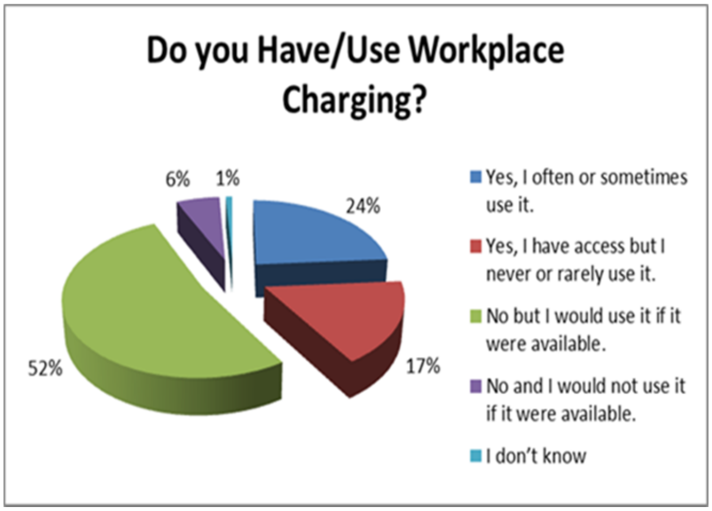


Figure 11-179. Availability and use of workplace charging.

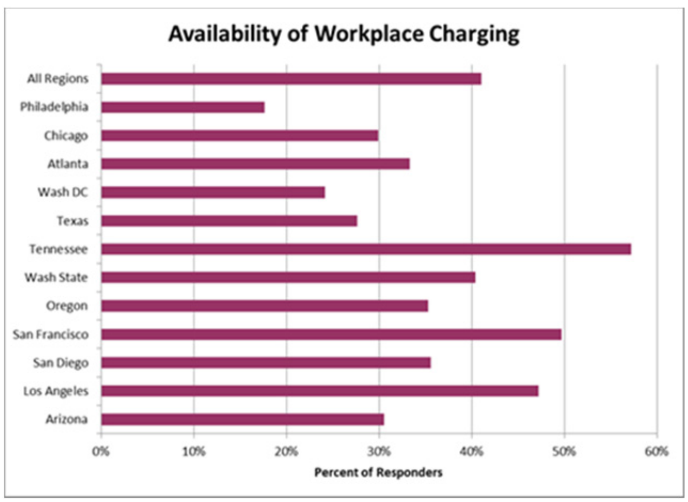


Figure 11-180. Availability and use of workplace charging by region.

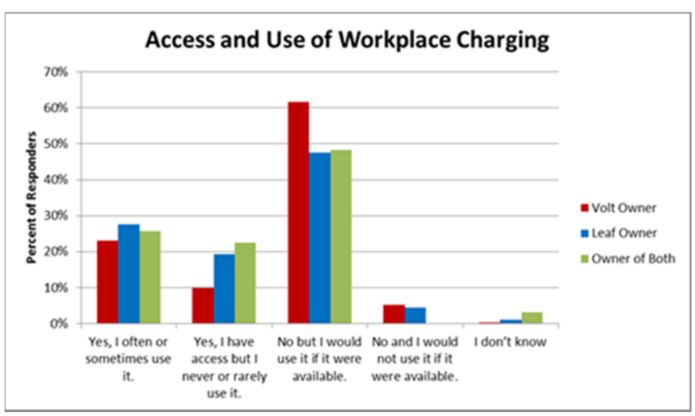


Figure 11-181. Availability and use of workplace charging by vehicle.

Workplace Chargers—The participants who had access to workplace charging were asked, "Is your workplace charging station…:" The response choices provided were as follows:

- AC Level 1 (120-volt AC – it may be a typical wall outlet to plug in the vehicle cordset)
- AC Level 2 (240-volt AC – equipment similar to your Blink unit at home, but could be supplied by other manufacturers)
- Direct Current (DC) Fast Charge (the connector plugs into the DCFC inlet on your Leaf).
- More than one answer was allowed. The results are shown in Table 11-64.

The quantity of available DCFCs at work was not expected, although most responses were from San Francisco and Tennessee, where a significant number of DCFCs were installed.

Table 11-64. Workplace charger type.

Type	Responders
AC Level 1	411
AC Level 2	802
DC Fast Charger	148
Total	1,361

Importance of Workplace Charging—The participants who had access to workplace charging were asked, "How important is workplace charging in meeting your EV driving needs?" The response choices provided were as follows:

- Essential – could not use my EV without workplace charging
- Very important – strongly desire full charge flexibility when leaving work
- Important – nice to have the added flexibility
- Somewhat important – I rely on workplace charging for my peace of mind
- Not important – I do not need workplace charging to meet my planned EV needs.

Figure 11-182 shows distribution of the 1,166 responses received.

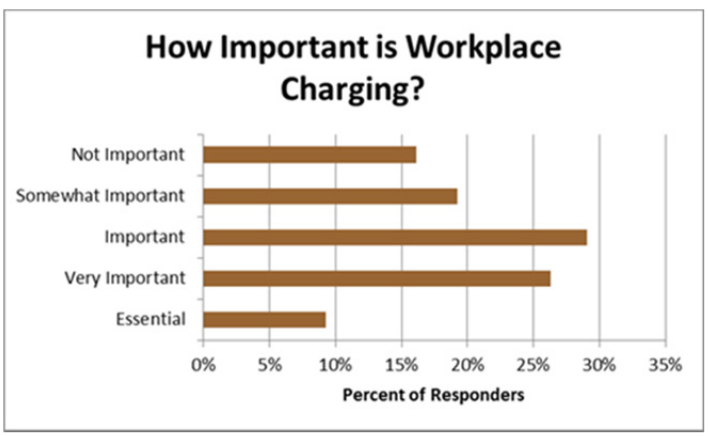


Figure 11-182. Importance of workplace charging.

Thirty-six percent of the responders reported that workplace charging was very important or essential to meeting their EV driving needs.

One of the questions explored in the report on home charging dealt with how much of the participant's charging needs are met by home charging. The importance of workplace charging was compared to the responses on where charging needs are met. Table 11-65 shows the results with workplace charging in the columns and charging needs met in the rows.

Table 11-65. Importance of workplace charging versus charging location.

Importance of Workplace Charging vs Where Charging Needs are Met	Total Responses	Workplace Essential	Workplace Very Important	Workplace Important	Total of Workplace Importance	% of Total Responses
Away from home charging is not available in my area.	42			1	1	2%
Never use charging away from home	664			36	36	5%
Occasionally use charging away from home	1916	30	115	246	391	20%
Frequently use charging away from home	298	34	103	38	175	59%
Rely on away-from-home charging as much as home charging	136	38	54	6	98	72%
Mostly use charging away from home	60	6	26	11	43	72%
Rarely, if ever use home charging	13		3	1	4	31%

Seventy-two percent of the responders who reported a significant amount of charging away from home (i.e. “mostly use charging away from home” or “rely on away-from-home charging as much as home charging”) rated workplace charging as important. Overall, 9% of responders reported workplace charging to be essential to their use of the EV. For others, the availability of workplace charging may not be essential, but they certainly relied on it as part of their daily routine.

Of the 663 responders who reported workplace charging was available and they often or sometimes used it, 52% reported it was very important or essential in meeting their planned PEV needs. Of the 448 who reported workplace charging was available but they rarely or never used it, 40 reported it was very important or essential in meeting their planned PEV needs. The apparent inconsistency in response of these 40 people could either be an incorrect understanding of the question or that they see their occasional use as very important or essential.

11.5.4.9 Publicly Accessible Charging

Use of Publicly Accessible Charging—Participants were asked, “How often do you use public charging?” In all, 2,912 responses were received and are shown in Figure 11-183.

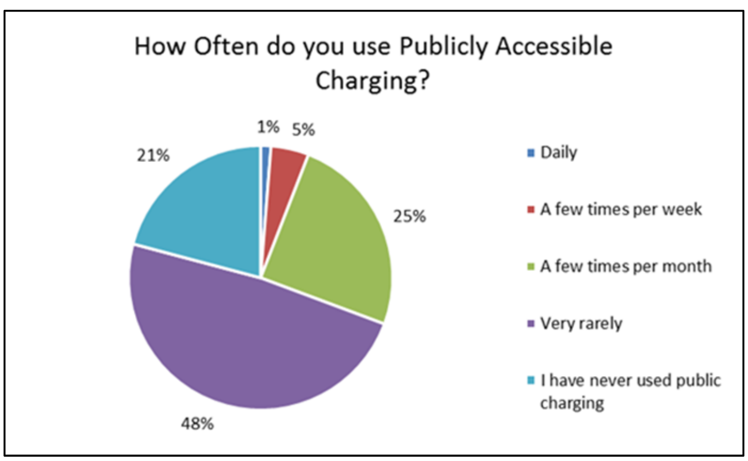


Figure 11-183. Use of publicly accessible charging.

Sixty-nine percent of responders reported they very rarely or never use public charging.

Prior to sending the survey, the participants were segmented by their vehicle type and charge data, which indicated one of the following: they never charged away from home, they occasionally charged away from home, they frequently charged away from home, and those whose typical behavior could not be determined because of GPS or other data inconsistencies. The response to this question was analyzed using the segmented group. The segmented groups, based on data collected, are represented by the columns and their responses to this question are in the rows of Table 11-66.

Table 11-66. Use of public charging by segmented groups.

Use of Public Charging Locations	Leaf Never	Leaf Occasional	Leaf Frequent	Leaf Unknown	Volt Never	Volt Occasional	Volt Frequent	Volt Unknown
Daily	1	6	4	16	0	2	2	4
A few times per week	0	40	8	40	1	16	8	2
A few times per month	14	307	20	219	6	105	23	18
Very Rarely	51	548	24	436	52	242	50	27
Never used public Charging	72	125	8	132	121	118	23	21

The red responses show inconsistency between the participant's responses and their charge data. For Leaf owners whose charge data indicated they had never charged away from home, 15 reported that they did so daily or a few times per month. Yellow highlighted responses indicate a potential inconsistency. There may be inconsistencies for 133 Leaf owners whose charge data showed occasional or frequent away from home charging, but the responses reported never using public charging (although they may have used workplace charging).

Of the 42 responders who reported that away-from-home charging was not available in their area, 13 reported they had used public charging. Of the 664 responders who reported that they never used charging away from home, 232 reported that they had used public charging. The reasons for these inconsistencies by individuals in different questions but in the same survey instrument are unknown.

Workplace and Public Charging—The survey questions concerning home charging previously reported [104] included the question "How much of your charging needs are met by home charging?" Table 11-67 compares the top responses involving the most away-from-home charging to the responses on the use of workplace and the use of publicly accessible charging. Because the responses came from separate questions, the responses in each category may not be equal. For example, in the question on home charging, 13 reported that they rarely if ever use home charging. In the question on Workplace charging, of those 13, two reported they have access but rarely use it and five reported they often or sometimes use it, while one of those original 13 reported they use public charging a few times per month. The other five of the original 13 responded with different choices.

For those most familiar with away-from-home charging and who used it, workplace charging appears to hold a higher level of importance than public charging.

Describe Use of Publicly Accessible Charging—Responders were asked to describe their use of publicly accessible charging. Free-form responses were allowed and the 750 responses generally fell into 18 separate categories as shown in Table 11-68.

Generally, it can be expected that publicly accessible charging will only be used if it is relatively convenient to the destination of the PEV driver or along their intended route, which is shown by the most common comments provided. The difference between responses 2 and 3 is interpreted as the former is a planned excursion beyond the range of the Leaf while the latter is an instance of the Leaf owner traveling beyond the vehicle range, due to extra errands or stops that were not planned at the outset of the trip. In both cases, public charging is required to complete the trip home. The responses of "I use if no other option is available/emergency use only" typically reflected planned trips that were expected to be well within the battery range of the vehicle and depleting the battery charge was an unexpected event.

Table 11-67. Away-from-home charging summary.

Home Charging	Total Responses	Workplace Charging	Public Charging
Rarely, if ever use home charging	13		
Yes, I have access but I never or rarely use it.		2	
Yes, I often or sometimes use it.		5	
A few times per month			1
A few times per week			
Daily			
Total	**13**	**7**	**1**
Mostly use charging away from home.	60		
Yes, I have access but I never or rarely use it.		6	
Yes, I often or sometimes use it.		37	
A few times per month			11
A few times per week			10
Daily			3
Total	**60**	**43**	**24**
Rely on away-from-home charging as much as home charging.	136		
Yes, I have access but I never or rarely use it.		2	
Yes, I often or sometimes use it.		102	
A few times per month			26
A few times per week			16
Daily			11
Total	**136**	**104**	**53**

Table 11-68. Participant's use of public charging.

Describe your use of public charging.	Responses
I use it if it is convenient to my destination	208
I use it to extend the range of my EV	117
Occasionally when beyond Leaf range and I need to get home	88
I only use public EVSE that are free of charge	70
There are no public chargers where I go	64
I've tried it once or twice only	42
I primarily charge on DC Fast Chargers	35
I don't use because there are always other cars parked at the EVSE	29
I use if no other option is available/Emergency use only	25
I use to demonstrate support for public charging	15
I tried it just to check it out with my EV	15
It allows me preferential parking	11
I don't use because stations are out of service or unreliable	11
I try to use public EVSE in a lot of different places	8
I will choose a business to patronize if it has public EVSE	8
I will charge only if I am there for > X hours	3
It helps me reduce my gas usage in the Volt	1

Increasing Public Charging—Participants were asked, "What do you suggest could be done to increase use of public charging?" This was a free form comment section. In all, 2,253 individual informative responses were received.

The responses were aggregated into 23 suggestions (see Table 11-69).

Table 11-69. Comments on increasing public charging.

Comment	Responses
Provide more charging in more locations (especially where I want to go)	774
Install more DC Fast Chargers	501
The fee is a concern. Make them free or more comparable to home charging	465
Provide better signage, smart apps, maps, location information	138
Enforce EV parking only by fining or towing non-Evs	82
Provide credit card readers or interoperability between network providers	52
Provide greater equipment reliability and operational readiness	40
Hosts could reduce costs with marketing incentives, coupons, advertising, etc.	37
Add more chargers to current locations. These are always in use.	36
Provide a reservation system so I know a charger will be available for me	33
Provide government subsidies and incentives to charging site hosts	31
The use will naturally expand with increasing PEV sales	19
Public Charging is pointless or unnecessary.	10
Provide better instructions on how to use	7
Provide more user friendly chargers	7
Combine the charging site with Solar to reduce costs	6
Use more AC Level 1 in public	6
Standarize practices for parking lots and chargers to eliminate surprises	3
Standardize the plugs for use by all EVs (i.e. DCFC, Tesla, etc)	2
Employers should extend employee benefits to encourage public charging	1
Add design features to stations to allow vehicle-to-grid payments	1
Provide bikes or other transportation at charger to get to destination	1
Design full service charging station including convenience store and valet	1

It is of interest to segregate responses by those who most frequently charge away from home; both by written response and by vehicle charge data. Participant responses to previous questions in the survey that they "rarely use home charging", "mostly charge away from home", or "rely on away-from-home charging as much as home charging" are shown in the first 3 columns of Table 11-70. For those who provided the specific comment, their actual vehicle charge data were queried to identify whether they indeed had frequent away-from-home charging. Those responses are shown in the two right columns of Table 11-70. Because the survey information and the vehicle charge data come from different sources, the totals in the right two columns may be different from those in the left three columns. This may also reflect inconsistencies in the individual's responses (e.g. vehicle charge data demonstrates frequent use of away-from-home charging, but the individual does not respond as such in the survey).

The most frequent response (i.e., 34%) was to expand the deployment of public charging to more locations. Typically, responses indicated that drivers were not able to find public charging in locations they frequent. The next highest suggestion indicates that there is a strong desire for more DCFCs in all regions. Although the Volt does not have fast charge capability, this was recognized by some Volt responders as important. Third, a high percentage of respondents identified the cost of public charging as a negative. Many thought that public charging should be at no cost or at most, the same cost, as they would be charged at home.

Table 11-70. Increasing use of public charging comments from high users.

Comments From Responders who Report HIGH use of Away-from-home charging	Rarely Use Home Charging	Mostly Charge Away from Home	Rely on Away from Home Charging	Charge Data Leaf Frequent	Charge Data Volt Frequent
Provide more charging in more locations (especially where I want to go)	2	13	38	20	30
The fee is a concern. Make them free or more comparable to home charging	3	15	24	7	29
Install more DC Fast Chargers	3	7	16	17	2
Provide better signage, smart apps, maps, location information		3	7	1	8
Enforce EV parking only by fining or towing non-Evs			3	2	2
Hosts could reduce costs with marketing incentives, coupons, advertising, etc.		1	2		3
Provide greater equipment reliability and operational readiness			2		1
Standarize practices for parking lots and chargers to eliminate surprises			1		
Use more AC Level 1 in public			1		
Provide better instructions on how to use			1		
The use will naturally expand with increasing PEV sales			1		
Provide government subsidies and incentives to charging site hosts		1	1		3
Provide a reservation system so I know a charger will be available for me		1	1		
Add more chargers to current locations. These are always in use.			1		1
Public Charging is pointless or unnecessary.		1			1
Provide credit card readers or interoperability between network providers		1		1	5

Just as it was important to view the responses of those who frequently charged away from home, it might be instructive to view the comments from those who do not. Table 11-71 provides the results of the comments from those who self-identified that away-from–home charging was not available to them or that they never charged away from home; they are represented in the first two columns of Table 11-71. A review of their actual vehicle charge data also identified those who never charge away from home, both for the Leaf and the Volt. Those responses are shown in the two right columns of Table 11-71. As before, the totals in the right two columns may not match the totals in the left two columns.

Table 11-71. Increasing use of public charging comments from non-users.

Comments From Responders who Report NO use of Away-from-home charging	Away from Home Unavailable	Never Charge Away from Home	Charge Data - Leaf Never	Charge Data - Volt Never
Provide more charging in more locations (especially where I want to go)	17	143	26	49
The fee is a concern. Make them free or more comparable to home charging	5	89	8	28
Install more DC Fast Chargers	3	73	30	6
Provide better signage, smart apps, maps, location information	2	23	5	12
Provide credit card readers or interoperability between network providers		16	4	1
Enforce EV parking only by fining or towing non-Evs		14	3	4
Provide government subsidies and incentives to charging site hosts	1	7	2	4
Provide a reservation system so I know a charger will be available for me		6	1	2
Public Charging is pointless or unnecessary.		5		
The use will naturally expand with increasing PEV sales	1	5		2
Hosts could reduce costs with marketing incentives, coupons, advertising, etc.		5	2	4
Provide more user friendly chargers		4	2	1
Add more chargers to current locations. These are always in use.	2	4	2	1
Provide greater equipment reliability and operational readiness		4	2	1
Provide better instructions on how to use		3	1	
Add design features to stations to allow vehicle-to-grid payments		1		

The top three suggestions are the same for those not using public charging as those using public charging. However, responses from non-users also emphasized making it easier for people to find public charging in maps or apps, to know how to use it through education and easier to use EVSE, and to have it available when they arrive through reservations, including interoperability of membership cards, etc. It appears that for those who have not used public charging, there is apprehension about trying it.

11.5.4.10 Conclusions. Overall, 15% of all charging events by The EV Project participants were performed away from home. This away-from-home charging can occur either at work or at publicly accessible EVSE. The survey responses showed that a significant percentage (i.e., 41%) of the survey respondents had access to workplace charging. For those who had charging available at work, over one-third reported that using workplace charging was very important or essential to their use of the PEV. Many others would use workplace charging if it were provided to them.

Publicly available charging, on the other hand, was not as accepted for meeting PEV charging needs. A significant percentage (i.e., 69%) reported never using or very rarely using public charging. While many comments suggest that expanding the infrastructure would provide more public EVSE in places they frequent, it is unclear whether they would be willing to pay the access fees necessary to support that expansion.

11.5.4.11 References

100. "EV Project Participant and Charging at Home," Lessons Learned, avt.inl.gov/evproject.shtml.

101. "Who are the Participants in The EV Project," Lessons Learned, avt.inl.gov/evproject.shtml.

102. "How do The EV Project Participants feel about their EV?" Lessons Learned, avt.inl.gov/evproject.shtml.

103. EV Project EVSE and Vehicle Usage Report 2nd Quarter 2013, avt.inl.gov/evproject.shtml.

104. op.cit. Charging at home.

11.6 EV Project Vehicle Use

11.6.1 How Many Electric Miles Do Nissan Leafs and Chevrolet Volts in The EV Project Travel?

11.6.1.1 Introduction. BEVs, such as the Nissan Leaf, are powered exclusively by electricity. The maximum driving range between refueling – in this case recharging – of a BEV is limited by the energy storage capacity of the vehicle's battery. EREVs, such as the Chevrolet Volt, can also be powered exclusively by electricity; however, they have smaller batteries and, therefore, shorter EVM range than BEVs. EREVs provide range extension using an ICE. The electric ranges of BEVs and EREVs are quantified by auto manufacturers and third parties such as the U.S. EPA. However, it is the owners' driving and charging behavior that determines how much distance is actually traveled using electric power.

This paper investigates the observed monthly distance traveled when powered solely by electricity, or eVMT of Nissan Leafs and Chevrolet Volts enrolled in The EV Project.

11.6.1.2 Key Conclusions

- Between October 2012 and December 2013, Nissan Leaf drivers in The EV Project averaged 808.1 eVMT per month. Chevrolet Volt drivers in The EV Project Volt averaged 759.3 eVMT per month and 1,019.8 total vehicle miles traveled per month.
- The distributions of eVMT per month for Leafs and Volts overlap significantly, indicating that many Volts drove the same or more electric miles than Leafs, despite a large difference in electric range.
- Change in eVMT from month to month over the 15 month study period was similar for Leafs and Volts, suggesting that seasonal effects influence drivers of both vehicles in the same way.

11.6.1.3 Which Vehicles Are Being Studied? Private owners of Nissan Leafs and Chevrolet Volts in 19 metropolitan areas across the United States participated in The EV Project. They agreed to allow project researchers to electronically monitor the usage of their vehicles throughout the project.

Data collection from Leafs and Volts in The EV Project began in January 2011 and August 2011, respectively. It ended for both groups of vehicles on December 31, 2013. Parameters recorded by the vehicle telematics system included the vehicles' odometer reading. The set of parameters logged by EV Project Volts was expanded on October 1, 2012, to include the EV-mode odometer. This parameter provides the distance driven in EVM. In order to compare Leaf and Volt eVMT, this study considers data from Leafs and Volts logged from October 1, 2012, through December 31, 2013. Table 11-172 describes the size of the Leaf and Volt data sets that were analyzed in this study.

Table 11-72. Description of The EV Project Leaf and Volt data sets.

	Nissan Leaf	Chevrolet Volt
Number of vehicles	4,039	1,867
Number of vehicle months	35,294	20,545
Total distance traveled (miles)	28,520,792	20,950,967
Distance traveled in EVM (miles)	28,520,792	15,599,508
Percent of distance traveled in EVM	100%	74.5%

11.6.1.4 Discussion of Results. Monthly eVMT was determined by calculating the change in the Leaf's odometer and the Volt's EV-mode odometer across each vehicle month when sufficient data were reported. Monthly total vehicle miles traveled (VMT) by Volts was also calculated in the same way using the Volt odometer. Volt VMT includes all distances driven, either when in EVM or in ERM. VMT and eVMT in each vehicle month in the Leaf and Volt data sets were averaged to provide a simple comparison. Table 11-73 shows these results.

Table 11-73. Average monthly total and eVMT.

	Nissan Leaf	Chevrolet Volt
Average monthly total VMT	808.1	1,019.8
Average monthly eVMT	808.1	759.3

The EPA's electric range of the Leaf is approximately double that of the Volt [105]. However, Leaf drivers in The EV Project averaged only 6% more actual electric miles per month than Volt drivers.

To see the variation of VMT and eVMT among vehicles and from month to month, the distributions of these metrics were examined. Figure 11-184 shows the frequency distributions of the average VMT and eVMT from each vehicle. Each data point in the distributions represents a single vehicle's average over the entire study period. The number of vehicles represented is shown in Table 11-74.

The range of Volt average monthly VMT extends farther to the right than the range of Leaf eVMT, indicating that some Volt drivers averaged more total miles per month than any Leafs. This is not surprising given that the overall range between refueling of the Chevrolet Volt is five times higher than the Leaf [106]. However, there is significant overlap between the Volt VMT and Leaf eVMT curves. This means that many Leaf drivers averaged the same or more miles per month than many Volt drivers, despite the Volt's much longer overall range. This illustrates the fact that some drivers have a driving routine that accommodates either vehicle. (Naturally, consumers do not make choices based on their average behavior, but rather their day-to-day driving needs. Such analysis is beyond the scope of this paper, however.)

The distributions of Volt and Leaf average monthly eVMT in Figure 11-184 are remarkably similar. A large number of Volts averaged the same or higher monthly eVMT than many Leafs, despite having a much shorter electric range. The disparity between electric range and eVMT can be explained by three reasons. First, Volt drivers in The EV Project have been shown to charge more frequently, on average, than Leaf drivers [107]. Frequent charging extends the effective EV-mode range of the vehicle. Secondly, Volt drivers can fully deplete their batteries and continue to their destinations in ERM, if necessary. Leaf drivers, on the other hand, are less likely to realize their full electric range, because of the impracticality of planning stops for charging precisely when the battery is fully depleted. Finally, Leaf drivers may have purchased their vehicles with the understanding that they do not require long driving range or they have the option of driving a different vehicle on long trips.

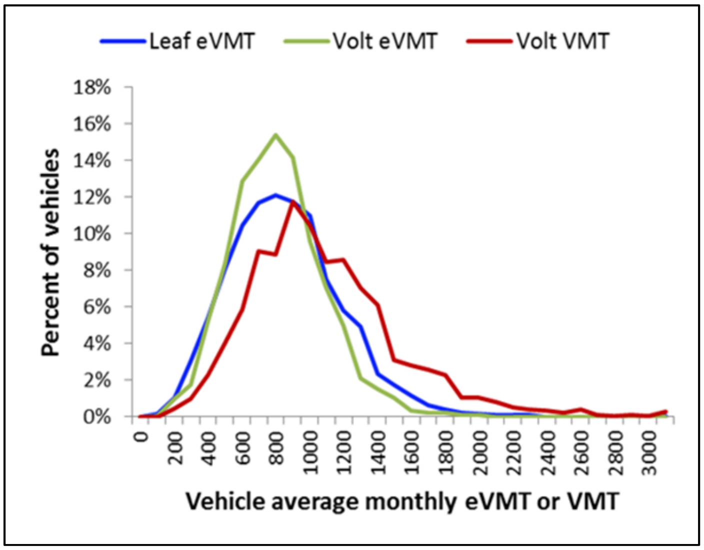


Figure 11-184. Distribution of vehicle average monthly eVMT and VMT, where each data point in the distributions represents a single vehicle's average over the entire study period.

Figure 11-185 shows the frequency distributions of VMT and eVMT per vehicle month. Each data point in these distributions represents a single vehicle month. All vehicle months in the data sets were included. The number of vehicle months represented is shown in Table 11-72. The numeric data for the distributions shown in Figures 11-184 and 11-185 are included in the tables in Section 11.6.1.6.

One would expect the distributions in Figure 11-185 to be wider than the distributions in Figure 11-184, because they represent the variation of eVMT and VMT in individual months, rather than variation between one vehicle's average eVMT or VMT to another's vehicle's average. For example, a driver may hypothetically drive 800 miles each month for 14 months and 1,500 miles in 1 month. The single month with an unusually high VMT would not affect the driver's overall average much; therefore, it would not noticeably shift the VMT distribution in Figure 11-184. However, this single month outlier would be included in the VMT distribution in Figure 11-185 and it would act to widen the distribution. In light of this, it is significant that the distributions in Figure 11-185 are only slightly wider than those in Figure 11-184. This means that the majority of the variation in eVMT and VMT is between drivers, rather than between months for each driver.

In addition to calculating the distributions of eVMT and VMT per vehicle month for the entire study period (Figure 11-185), these distributions were calculated separately for each of the 15 months in the study period. Descriptive statistics describing these monthly distributions were examined to identify changes in behavior over time. Figure 11-186 shows lines that connect the median values of the Leaf and Volt eVMT and Volt VMT distributions in each of the 15 months in the study period.

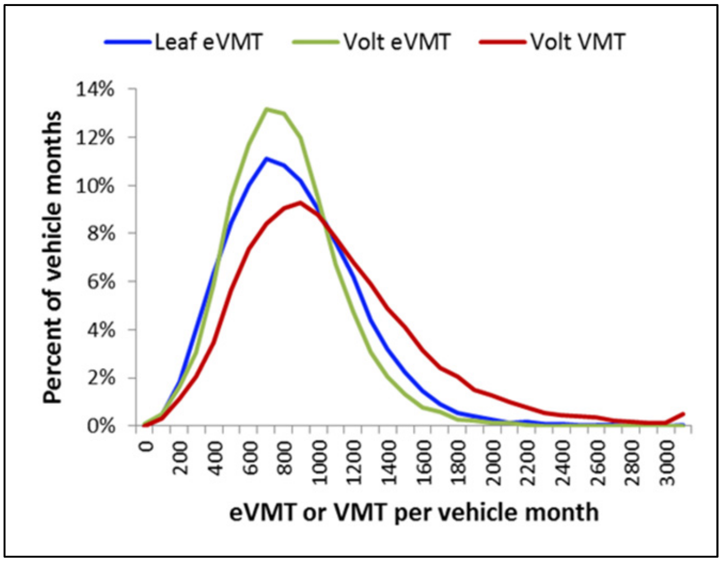


Figure 11-185. Distribution of eVMT and VMT per vehicle month, where each data point in the distributions represents a single vehicle month.

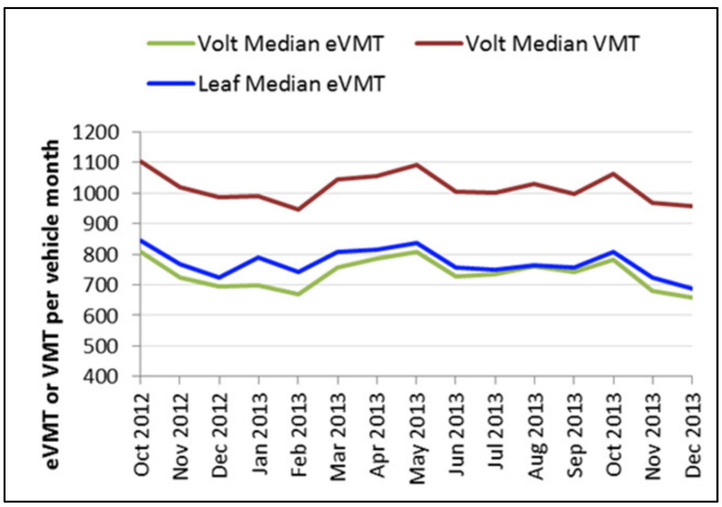


Figure 11-186. Median eVMT and VMT per vehicle month over time.

The Leaf's median eVMT (blue line) is slightly higher than the Volt's median eVMT (green line) throughout the 15-month study period; however, the medians are nearly equal in August 2013. The eVMT medians rise and fall fairly proportionally, with only a few exceptions. The 25th and 75th percentile values for the distributions each month (not shown) rise and fall with the medians, indicating that the shapes of the distributions are relatively constant month after month. This proportional shifting of the distributions overtime suggests that seasonal effects influence both Leaf and Volt drivers in the same way. Regional analysis is needed to confirm this hypothesis.

The ratio of the Volt's median eVMT to its median VMT (red line) is the percentage of distance traveled in EVM each month. Visual inspection of Figure 11-186 shows this value remained relatively consistent. There was seasonal variation, however; the months of April through October saw 74% to 77% of distance in EVM, whereas vehicles averaged 70% to 74% miles in EVM in November through March. This metric by month is included in the Table 11-76, along with descriptive statistics for the monthly eVMT and VMT distributions.

11.6.1.5 References

105. www.fueleconomy.gov gives an EPA-estimated electric range of 73 miles for MY2011/2012 Nissan Leafs and 75 miles for the MY2013 Leaf; the EPA electric range is 35 miles for MY2011/2012 Volts and 38 miles for MY2013 Volts. Leafs and Volts enrolled in The EV Project include a mix of these model years.

106. www.fueleconomy.gov gives an EPA-estimated overall range of 380 miles for the MY2011-2013 Chevrolet Volt.

107. The report "Observations from The EV Project in Q4 2013" explains that EV Project Leafs have consistently averaged 1.1 charging events per day driven and Volt have averaged between 1.4 and 1.5 charging events per vehicle day driven since the beginning of the project. See http://avt.inl.gov/pdf/EVProj/EVProjectSummaryReportQ42013FINAL.pdf About The EV Project.

11.6.1.6 Appendix

Table 11-74. Values used to create the frequency distributions shown in Figure 11-184.

Distance Bin (miles)	Leaf Frequency	Volt Frequency (Total Miles)	Volt Frequency (EV-mode Miles)
0	0	0	0
>0 - 100	7	0	1
>100 - 200	43	8	18
>200 - 300	122	18	33
>300 - 400	219	42	98
>400 - 500	328	76	157
>500 - 600	423	110	240
>600 - 700	472	169	262
>700 - 800	488	166	287
>800 - 900	475	219	264
>900 - 1000	444	195	179
>1000 - 1100	304	158	131
>1100 - 1200	234	160	93
>1200 - 1300	200	132	39
>1300 - 1400	94	114	28
>1400 - 1500	70	58	19
>1500 - 1600	46	52	6
>1600 - 1700	26	48	4
>1700 - 1800	15	43	4
>1800 - 1900	10	20	2
>1900 - 2000	7	19	2
>2000 - 2100	3	15	0
>2100 - 2200	3	10	0
>2200 - 2300	4	7	0
>2300 - 2400	0	6	0
>2400 - 2500	0	4	0
>2500 - 2600	0	7	0
>2600 - 2700	0	2	0
>2700 - 2800	0	1	0
>2800 - 2900	0	2	0
>2900 - 3000	1	1	0
>3000	1	5	0
	4039	1867	1867

Table 11-75. Values used to create the frequency distributions shown in Figure 11-185.

Distance Bin (miles)	Leaf Frequency	Volt Frequency (Total Miles)	Volt Frequency (EV-mode Miles)
0	0	0	16
>0 - 100	158	62	97
>100 - 200	648	233	339
>200 - 300	1410	416	629
>300 - 400	2235	716	1214
>400 - 500	2987	1161	1952
>500 - 600	3540	1511	2409
>600 - 700	3921	1725	2703
>700 - 800	3818	1860	2671
>800 - 900	3592	1905	2465
>900 - 1000	3173	1800	1942
>1000 - 1100	2701	1604	1377
>1100 - 1200	2200	1400	971
>1200 - 1300	1546	1209	632
>1300 - 1400	1131	1006	420
>1400 - 1500	783	842	267
>1500 - 1600	511	649	161
>1600 - 1700	319	498	119
>1700 - 1800	194	419	56
>1800 - 1900	145	312	41
>1900 - 2000	94	261	28
>2000 - 2100	48	205	21
>2100 - 2200	55	155	9
>2200 - 2300	24	111	2
>2300 - 2400	20	93	1
>2400 - 2500	10	82	0
>2500 - 2600	9	72	0
>2600 - 2700	4	43	1
>2700 - 2800	1	38	1
>2800 - 2900	0	29	1
>2900 - 3000	2	29	0
>3000	15	99	0
	35294	20545	20545

Table 11-76. eVMT/VMT descriptive statistics by month and overall for the distributions whose median values are depicted in Figure11-186.

	Month	Number of vehicle months	Total miles	Percent of miles in EV mode	avg	std dev	max	95th	75th	median	25th	5th	min
Leaf	Oct 2012	2304	2043334	--	886.9	399.8	3460.1	1571.5	1127.3	845.5	600.1	303.8	41.4
	Nov 2012	2376	1895713	--	797.9	361.8	3236.9	1408.5	1013.6	767.9	542.1	278.1	68.2
	Dec 2012	2683	2032197	--	757.4	334.2	2221.2	1351.3	961.1	724.8	510.9	275.0	41.0
	Jan 2013	2807	2287247	--	814.8	367.9	3448.7	1441.9	1049.1	788.8	545.1	277.9	32.7
	Feb 2013	2709	2094318	--	773.1	352.0	3139.4	1378.6	990.0	742.7	523.1	252.9	36.1
	Mar 2013	2518	2113081	--	839.2	375.7	3242.5	1497.3	1068.5	807.7	567.6	290.8	25.9
	Apr 2013	2511	2141590	--	852.9	394.8	3658.2	1531.9	1092.6	815.9	564.6	273.3	55.1
	May 2013	2506	2168769	--	865.4	389.5	3485.6	1542.6	1100.5	836.4	583.2	292.1	35.5
	Jun 2013	2472	1954500	--	790.7	362.3	3616.4	1439.9	1007.1	755.0	529.8	264.1	27.8
	Jul 2013	2474	1940921	--	784.5	373.8	4050.0	1432.5	1001.8	748.3	518.7	251.9	59.8
	Aug 2013	2406	1941879	--	807.1	374.0	3822.2	1474.8	1038.6	764.7	542.4	276.3	49.8
	Sep 2013	2255	1776002	--	787.6	358.9	2578.8	1419.9	1019.8	756.9	524.4	255.4	36.4
	Oct 2013	2268	1904190	--	839.6	385.4	3630.1	1497.9	1092.7	806.0	560.2	267.4	23.1
	Nov 2013	1891	1425968	--	754.1	334.4	3074.3	1320.2	956.8	724.1	501.0	284.5	42.0
	Dec 2013	1114	801080	--	719.1	318.8	2311.9	1305.7	913.3	686.9	492.7	259.5	67.8
	Overall	35294	28520792	--	808.1	370.3	4050.0	1457.5	1033.2	772.0	541.5	273.1	23.1
Volt EV mi	Oct 2012	976	802293	0.744	822.0	326.1	2023.4	1417.5	1008.6	808.1	590.6	346.3	70.8
	Nov 2012	981	722734	0.724	736.7	294.2	1778.5	1273.8	909.9	723.6	530.4	302.2	0.0
	Dec 2012	1014	717850	0.718	707.9	278.8	1819.2	1184.9	877.9	696.1	518.8	280.1	0.0
	Jan 2013	1037	749123	0.730	722.4	291.3	2105.5	1248.8	891.0	699.3	518.8	305.2	6.3
	Feb 2013	1119	771020	0.729	689.0	282.0	1831.5	1210.9	850.6	668.8	497.0	251.0	21.6
	Mar 2013	1608	1243684	0.739	773.4	311.0	2270.8	1328.4	949.6	755.5	553.8	315.6	33.8
	Apr 2013	1655	1332180	0.762	804.9	324.2	2115.9	1375.6	990.7	784.3	575.5	328.0	16.7
	May 2013	1647	1369228	0.761	831.3	338.7	2035.3	1424.1	1048.7	805.8	594.4	322.1	0.0
	Jun 2013	1551	1181475	0.757	761.8	304.6	2141.2	1294.1	947.8	727.3	544.4	309.1	39.9
	Jul 2013	1548	1173096	0.757	757.8	324.4	2111.7	1324.0	946.8	735.2	538.6	265.3	0.0
	Aug 2013	1560	1208159	0.752	774.5	336.9	2816.7	1345.7	971.8	759.5	529.9	282.6	0.0
	Sep 2013	1588	1214348	0.766	764.7	326.6	2760.4	1324.5	956.3	741.2	538.1	296.3	0.0
	Oct 2013	1575	1264589	0.756	802.9	336.6	2628.8	1379.9	998.0	783.5	572.3	303.0	0.0
	Nov 2013	1556	1089834	0.724	700.4	290.8	1910.8	1224.0	871.9	679.6	505.9	256.5	0.0
	Dec 2013	1130	759894	0.703	672.5	269.4	1966.1	1133.2	831.0	659.4	482.5	256.6	0.0
	Overall	20545	15599508	0.745	759.3	316.0	2816.7	1319.4	942.1	733.9	537.7	294.1	0.0
Volt total mi	Oct 2012	976	1077949	--	1104.5	561.3	5501.2	2144.2	1376.9	1008.2	707.1	402.8	70.8
	Nov 2012	981	998797	--	1018.1	510.7	3450.3	1973.5	1269.5	932.5	650.6	375.8	66.5
	Dec 2012	1014	1000147	--	986.3	494.8	4507.2	1865.1	1247.8	908.9	648.1	351.2	47.0
	Jan 2013	1037	1025511	--	988.9	489.9	3132.7	1908.8	1213.9	914.2	650.0	366.4	44.2
	Feb 2013	1119	1056934	--	944.5	503.1	4070.0	1873.2	1177.7	858.8	606.1	296.1	21.6
	Mar 2013	1608	1682036	--	1046.0	521.8	5153.7	1966.0	1300.1	960.9	690.1	374.9	33.8
	Apr 2013	1655	1748657	--	1056.6	516.5	3778.9	2022.1	1330.2	961.9	700.5	392.8	16.7
	May 2013	1647	1799082	--	1092.3	530.7	4808.6	2058.3	1392.8	1019.2	710.2	384.0	70.9
	Jun 2013	1551	1560323	--	1006.0	503.8	4499.0	1945.8	1267.6	918.6	652.7	348.6	42.6
	Jul 2013	1548	1549903	--	1001.2	522.7	4993.1	1965.4	1246.7	928.2	651.2	321.5	93.7
	Aug 2013	1560	1606429	--	1029.8	541.1	4581.9	1985.2	1295.4	935.1	652.7	326.4	84.8
	Sep 2013	1588	1585188	--	998.2	493.7	3811.6	1922.9	1277.2	925.2	652.6	347.6	57.0
	Oct 2013	1575	1672355	--	1061.8	529.3	4180.7	2061.2	1334.8	979.1	708.1	350.2	34.1
	Nov 2013	1556	1505982	--	967.9	495.2	4162.9	1876.0	1228.8	875.8	636.5	328.4	49.0
	Dec 2013	1130	1081674	--	957.2	480.1	3651.3	1852.9	1212.0	877.2	617.4	339.3	29.1
	Overall	20545	20950967	--	1019.8	516.1	5501.2	1969.1	1283.0	935.5	660.7	350.1	16.7

11.6.2 What Kind of Charging Infrastructure Did Nissan Leaf Drivers in The EV Project Use and When Did They Use It?

11.6.2.1 Which Vehicles Are Being Studied? Over 6,400 private owners of Nissan Leafs in 17 regions across the United States participated in The EV Project. They agreed to allow project researchers to monitor the usage of their vehicles throughout the project. Data collected between October 1, 2012, and December 31, 2013, (i.e., the end of EV Project data collection) from a sample of 4,038 participating Leafs were analyzed to determine how these vehicles were used. This set of vehicles was driven 24 million miles and performed over 860,000 charging events in the 15-month study period. On average, these vehicles drove 32.4 miles per day and were charged 1.1 times per day on days when the vehicle was driven.

11.6.2.2 Key Conclusions

- A sample of 4,038 Nissan Leaf drivers who participated in The EV Project performed 867,293 charges at AC Level 1, AC Level 2, and DCFC units over a 15-month period.
- Leaf drivers relied on home charging for the bulk of their charging. Of all charging events, 84% were performed at drivers' home locations. Over 80% of those home charges were performed overnight and about 20% of home charges were performed between trips during the day.
- The remaining 16% of charging events were performed away from home. The vast majority of these were daytime AC Level 1 or AC Level 2 charges.
- Overall, usage of DCFC by drivers of vehicles in this study, all having access to a AC Level 2 charging unit at home and some having workplace charging access, was low. DCFC (all away from home) represented only about 1% of all charging events and charging energy consumed. Ignoring charges by vehicles that never charged away from home, DCFC were used for 6% of all away-from-home charging events. However, some drivers used DCFC more than others and may have relied on fast charging to meet their need for driving range.
- Not everyone used away-from-home charging infrastructure equally. In fact, three quarters of the away-from-home charging was performed by 20% of the vehicles. A significant portion of vehicles (i.e., 13%) were never charged away from home.
- Half of the away-from-home charging was performed by a group of vehicles who averaged 1.5 charging events per day driven. Drivers of these vehicles supplemented near-daily home charging with frequent away-from-home charging. This allowed these vehicles to average 43 miles per day driven, a 72% increase over vehicles that were never charged away from home.
- Although all vehicles in this study had access to home charging, some vehicles rarely charged at home. Instead, they relied on frequent away-from-home charging during the day. This demonstrates the viability of publicly accessible and/or workplace charging infrastructure for drivers of EVs without access to home charging.

11.6.2.3 What Kind of Charging Infrastructure Did the Vehicles Use? Leaf owners have a number of options for charging their vehicles' batteries. Each Leaf comes with an AC Level 1 cordset that can be plugged into almost any 120-volt outlet to charge at 1.4 kW. The Leaf can also be charged at 3.3 or 6.6 kW, depending on model year, if connected to an AC Level 2 (240-V) charging unit equipped with a SAE J1772-compliant connector. Each EV Project participant had an AC Level 2 charging unit installed at their home. Finally, all Leafs in The EV Project were capable of using CHAdeMO-compliant DCFC, allowing them to charge at up to 50 kW.

Charging events performed by the vehicles studied were identified and categorized by location, charge power level, and time of day. For each charging event, the vehicle's charge location was classified as either at home (meaning at the vehicle owner's primary residence) or away from home. Also, charging events were categorized as either AC Level 1/AC Level 2 or DCFC. The data collected from The EV Project's Leafs were such that it is not possible to accurately distinguish between AC Level 1 and AC Level 2 charges, but DCFC events can be identified. Finally, charging events were categorized by time of day. A charge occurred during the daytime if it occurred between the vehicle's first and last trips of the day. A charge was classified as an overnight charge if it occurred after the vehicle's last trip of the day. In this analysis, a day starts and ends at 4 a.m. The overall split of the 867,293 charges by location, power level, and time of day is shown in Figure 11-187.

The vast majority (84%) of charging events performed by the Leafs occurred at home, leaving only 16% of charges being performed away from home. Almost all overnight charges happened at home locations. Daytime charging was split evenly between home and away-from-home locations, with each making up about 15% of all charges.

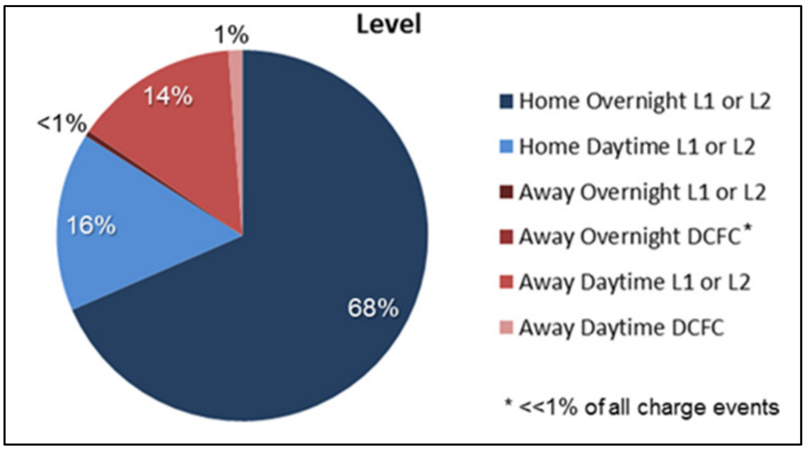


Figure 11-187. Percent of charging events performed by location, power level, and time of day.

Leafs were charged overnight at home for 68% of all charge events and at home during the day for 16% of all charges. Considering only home charges, 81% were overnight and 19% were performed during the daytime.

Of the 16% of charges that were performed away from home, 88% were daytime AC Level 1/AC Level 2 charges. DCFCs (all away from home) during the daytime accounted for slightly more than 1% of all charging events and 6% of away-from-home charges. The few overnight charges that occurred away from home represented less than 1% of all charge events; these were nearly all AC Level 1/AC Level 2 charges. There were only seven overnight DCFC events.

Figure 11-188 shows the amount of charging energy consumed by vehicles during the charging events described in Figure 11-187.

More than three quarters of all energy consumed came from overnight charges at home. Overnight charging away from home accounted for less than 1% of all energy consumed, and overnight DCFC energy (which is too small to be seen in Figure 11-188) was nearly 0. Although daytime charging frequency was split almost evenly between home and away (as shown in Figure 11-187), daytime away-from-home charging consumed a greater percentage of energy than daytime home charging. This suggests that during the day, drivers were somewhat more likely to be charging away from home for longer periods of time than when at home. This is probably due to the influence of workplace charging, where vehicles tend to stay plugged in for many hours. At least a portion of the drivers in this study had regular access to workplace charging, but it is not known exactly how many. Charging and driving behavior of a subset of Leafs in this data set whose drivers are known to have had access to workplace charging is discussed in other papers [108].

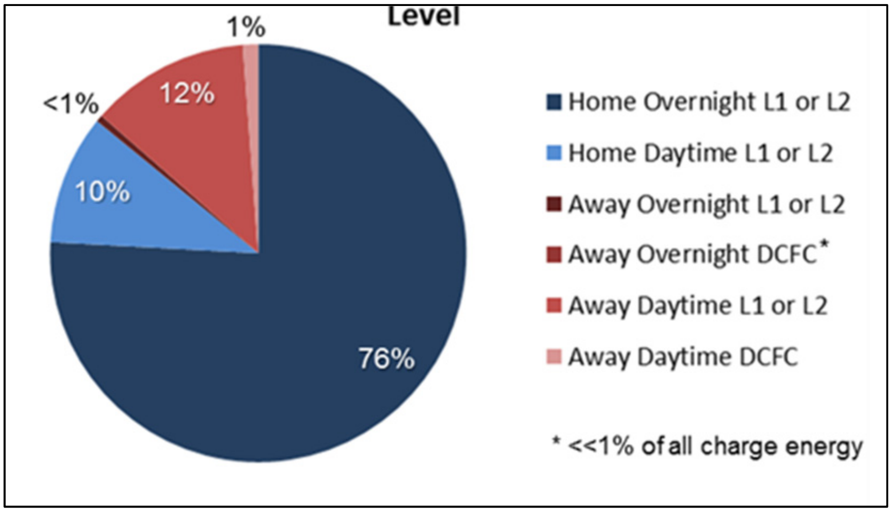


Figure 11-188. Percent of energy charged by location, power level, and time of day.

DCFC charging frequency and energy consumption were about the same, representing only about 1% of all charging events and charging energy consumed. Ignoring charges by vehicles that never charged away from home, DCFC were used for 6% of all away-from-home charging events and consumed 7% of the charging energy. Even though overall use of DCFC was low, some drivers may have relied on occasional or even frequent fast charging to extend their driving range or otherwise charge their batteries sufficient to meet their needs for driving range.

11.6.2.4 How Did Infrastructure Usage Vary from Vehicle to Vehicle? To understand the drivers' usage of away-from-home charging infrastructure, data were analyzed on a per-vehicle basis. First, the relative contribution of away-from-home charging events from each vehicle was calculated. It was determined that 20% of the vehicles with the most away-from-home charging performed 74% of all away-from-home charging events. This indicates that drivers did not uniformly utilize away-from-home charging infrastructure, but rather a minority of drivers were the predominant users.

To explore this idea further, vehicles were grouped based on how much away-from-home charging they performed relative to home charging. The percent of vehicles in each group is plotted in Figure 11-189.

Figure 11-189 shows that 48% of the vehicles studied performed 5% or fewer of their charging events away from their home locations and 13% of vehicles had zero away-from-home charges. On the other hand, some vehicles were charged most of the time away from home. A few vehicles were charged away from home 100% of the time.

Away-from-home charging can be either AC Level 1/AC Level 2 or DCFC; therefore, breaking down away-from-home charges by power level is important to further understand drivers' charging habits. Figure 11-190 shows the percent of charges at each power level performed by the vehicles in the groups defined in Figure 11-189.

It is apparent that most away-from-home charging occurred at AC Level 1 or AC Level 2. It is interesting that vehicles that were charged away from home 35% of the time or less tended to use DCFCs for a higher percentage of their away-from-home charges than vehicles with more frequent away-from-home charging. The relationship between DCFC usage and driving behavior will be explored further in future studies.

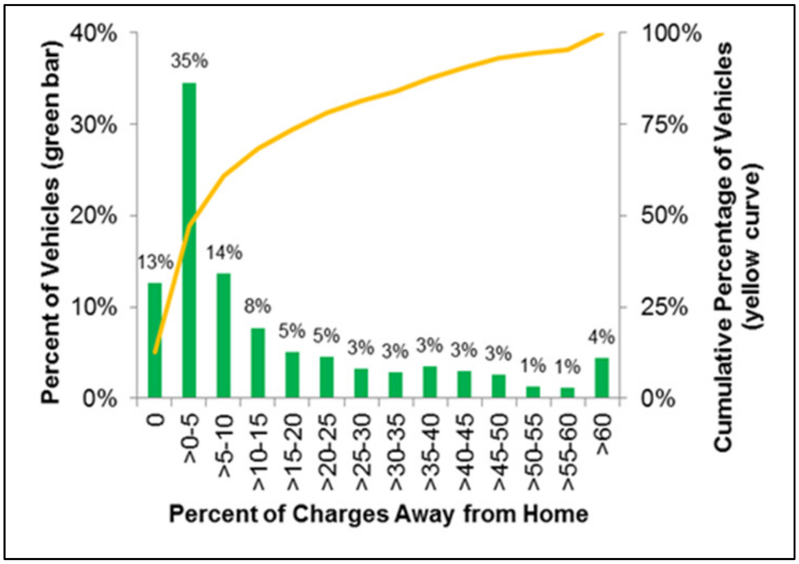


Figure 11-189. Distribution of the percent of charges performed away from home by each vehicle.

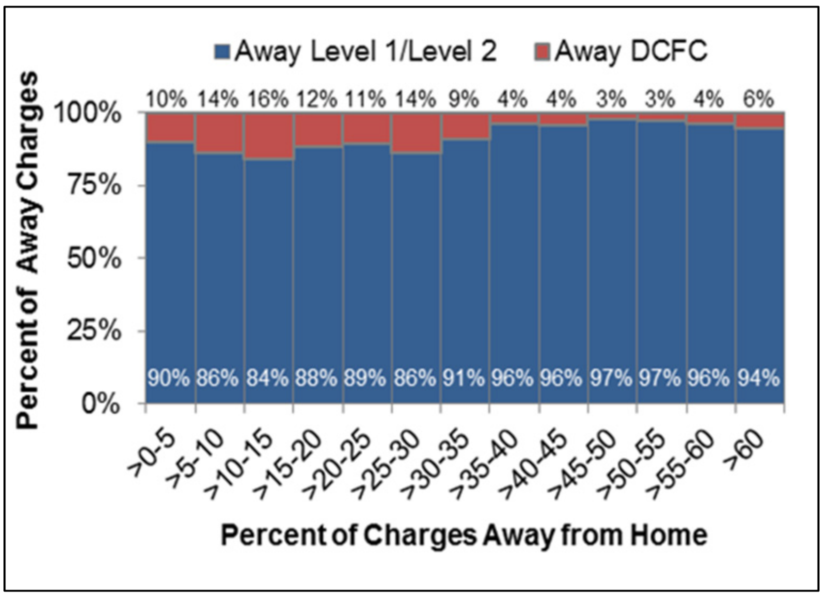


Figure 11-190. Occurrence of AC Level 1/AC Level 2 and DCFC charging for groups of vehicles with different amounts of away-from-home charging.

11.6.2.5 Did Away-From-Home Charging Enable Increased Driving Range? Vehicle data were further analyzed based on away-from-home charging frequency to identify any differences in overall charging and driving behavior. Several metrics were calculated for each group and have been consolidated into four groups. These metrics are presented in Table 11-77.

Vehicles that were never charged away from home averaged 0.8 home overnight charges per day and an additional 0.1 home daytime charges per day. Home overnight charges tended to charge the vehicles' battery packs more than daytime charges at home. On average, these vehicles were charged nearly every day, resulting in a one-third increase in battery SOC due to charging each day. These vehicles were driven 25 miles per day on average.

Table 11-77. Average driving and charging metrics of vehicles grouped by percent of charges performed away from home.

% of Charging Away from Home	0%	>0 to 30%	>30 to 60%	>60%
Vehicles (% of total)	507 (13%)	2,774 (69%)	578 (14%)	179 (4%)
Percent of All Away-from-Home Charging Events	–	36%	48%	16%
Home Overnight Charges Per Day Driven	0.8	0.8	0.8	0.2
Home Overnight SOC Increase Per Charge	39%	41%	42%	40%
Home Daytime Charges Per Day Driven	0.1	0.2	0.1	0.04
Home Daytime SOC Increase Per Charge	25%	24%	24%	25%
Away-from-Home Overnight Charges Per Day Driven	–	0.004	0.01	0.01
Away-from-Home Overnight SOC Increase Per Charge	–	40%	41%	48%
Away-from-Home Daytime Charges Per Day Driven	–	0.1	0.6	0.8
Away-from-Home Daytime SOC Increase Per Charge	–	28%	33%	38%
Total Charge Events Per Day Driven	0.9	1.1	1.5	1.1
Total SOC Increase from Charging Per Day	33%	41%	56%	41%
Average Miles Per Day Driven	25	31	43	32

Groups of vehicles that were charged away from home greater than 0 to 30% of the time and vehicles that were charged greater than 30 to 60% of the time both averaged about the same amount of home charging as the group of vehicles that were never charged away from home. Drivers of vehicles that were charged away from home greater than 0 to 30% of the time supplemented home charging with occasional away-from-home charging. This additional away-from-home charging pushed this group's average charging frequency to just over one charge per day. This group drove 31 miles per day on average.

Vehicles that charged away from home between 30 and 60% of the time supplemented home charging with an away-from-home charge about every other day. These vehicles averaged 1.5 total charging events per day driven. This frequent charging enabled these vehicles to average 43 miles per day, which is 72% farther than those that never charged away from home and about 35% farther than the two groups that charged more or less often away from home. These vehicles averaged enough energy consumption during charging to recharge over half the battery's capacity each day. Because the energy consumed to charge the battery pack is limited by how much energy was depleted by driving, this suggests that these vehicles could have been driven even farther, had the drivers had the need.

Drivers of the group of vehicles that were charged away from home more than 60% of the time charged away from home during the day nearly once per day. They supplemented away-from-home daytime charging with occasional at-home overnight charging. These vehicles' overall charging frequency, energy consumption, and daily driving distance matched vehicles that charged away from home between 30 and 60% of the time.

It is interesting to note that average charging energy consumption, as measured by SOC increase, was nearly the same for all groups at a particular location and time of day. Home overnight charging resulted in an average SOC increase of around 40% per charge for all groups, irrespective of a vehicle's away-from-home charging frequency. The few away-from-home overnight charges also had similar energy consumption. All groups averaged around 25% SOC increase when charging at home during the day. Only daytime away-from-home charging energy consumption varied from group to group. This was likely due to the influence of workplace charging. The vehicles that were charged most frequently away from home are believed to have had access to workplace charging. Drivers of these vehicles charged at work instead of at home; therefore, their daytime away-from-home charging energy was similar to home overnight charging energy for other groups. This demonstrates the viability of publicly accessible and/or workplace charging infrastructure for supporting drivers of EVs without access to home charging.

11.6.2.6 References

108. "Where do Nissan Leaf drivers in The EV Project charge when they have the opportunity to charge at work?" at http://avt.inl.gov/pdf/EVProj/ChargingLocation-WorkplaceLeafsMar2014.pdf.

11.6.3 What Kind of Charging Infrastructure Do Chevrolet Volt Drivers in The EV Project Use and When Do They Use It?

11.6.3.1 Introduction. Over 2,000 private owners of Chevrolet Volts in 16 regions across the United States participated in The EV Project. They agreed to allow project researchers to monitor the usage of their vehicles throughout the project. Data collected between October 1, 2012, and December 31, 2013, (i.e., the end of EV Project data collection) from a sample of 1,867 participating Volts were analyzed to determine how these vehicles were used. This set of vehicles drove more than 20 million miles and performed over 763,000 charging events in the 15-month study period. On average, these vehicles drove 40.0 miles per day, 29.9 of which were in EVM, and charged 1.5 times per day on days when the vehicle was driven.

11.6.3.2 Key Conclusions

- A sample of 1,867 Chevrolet Volt drivers participating in The EV Project performed 87% of their charging events at home and 13% away from home over a 15-month study period.
- Although the majority (i.e., 59%) of all charging events was performed at home overnight, 28% of all events were performed at home during the day. Only 12% of charging events were performed away from home during the day. The fact that 70% of daytime charging was performed at home is significant, because typically daytime "opportunity" charging has been thought of as away-from-home charging.
- All vehicles in this study had access to AC Level 2 (240 V) charging at home; therefore, it is not surprising that nearly all home charging was conducted using AC Level 2 charging equipment. Away-from-home charging was split evenly between AC Level 2 charging units and AC Level 1 (120-V) charging units or standard 120-volt outlets.
- Not everyone used away-from-home charging infrastructure equally. In fact, three quarters of the away-from-home charging was performed by 20% of the vehicles. A small portion of vehicles (i.e., 5%) were never charged away from home.
- Drivers who performed 30 to 60% of their charging events away from home tended to supplement daily home charging with regular away-from-home charging. All together, these drivers averaged 2.0 charges per day. Frequent charging allowed them to average 40.3 miles driven in EV EVM per day, which is a 60% increase in daily EV miles over the group of vehicles that never charged away from home.
- Drivers who charged away from home for more than 60% of their charging events tended to supplement frequent away-from-home charging with home charging. Their away-from-home charging frequency was the same as the home charging frequency of the group of drivers that never charged away from home.
- Across all of the away-from-home charging frequency groups, groups averaged 74 to 80% of their distance driven in EVM. Overall average charging frequency increased as average daily distance driven increased, suggesting that drivers changed their charging behavior in order to extend EVM operation.

11.6.3.3 *What Kind of Charging Infrastructure Did the Vehicles Use and When Did They Use It?*

Volt owners have a number of options for charging their vehicles' batteries. The Chevrolet Volt is capable of charging at both AC Level 1 (120-V) and AC Level 2 (240 V) charge rates. Each Volt comes with an AC Level 1 cordset that can be plugged into almost any 120-volt outlet. The Volt can also be charged using any AC Level 2 charging unit equipped with an SAE J1772-compliant connector. Each EV Project participant had an AC Level 2 charging unit installed at their home.

Charging events from the 1,867 vehicles studied were identified and categorized by location, charge power level, and time of day. For each charging event, the vehicle's charge location was classified as either at home (meaning at the vehicle owner's primary residence) or away from home. Most charging events were categorized as either AC Level 1 or AC Level 2. The power level of some events could not be determined due to incomplete data. Finally, charging events were categorized by time of day. A charge occurred during the daytime if it occurred between the vehicle's first and last trips of the day. A charge was classified as an overnight charge if it occurred after the vehicle's last trip of the day. For this analysis, a day begins and ends at 4 a.m. The overall split of the 763,002 charges by location and power level is shown in Figure 11-191.

It is apparent that the majority of the charging events occurred at home, accounting for 87% of all charges. AC Level 2 home charging made up at least 73% of all charging events, with home overnight AC Level 2 charges accounting for 49% of all charges and home daytime AC Level 2 charges accounting for 24% of all charging events.

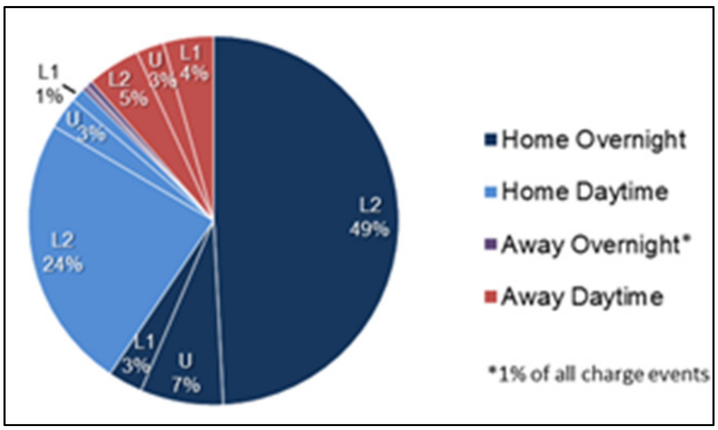


Figure 11-191. Percent of charging events performed by location, power level, and time of day. L2 refers to AC Level 2 charges, L1 refers to AC Level 1, and U refers to charges of an unknown power level.

There were instances of drivers using AC Level 1 charging at home both during the day and overnight; however, these cases were relatively infrequent and accounted for only 4% of all charges. This is reasonable considering that AC Level 2 charging units were available at each vehicle's home location. Away-from-home charging occurred almost exclusively during the daytime. AC Level 1 charges were performed about as frequently as AC Level 2 charges when away from home. Very few (i.e., 1%) of away-from-home charges occurred overnight at any level.

Of all events, 28% were performed at home during the day. Only 12% of charging events were performed away from home during the day. Daytime charging typically has been thought of as being performed away from home. However, drivers of the vehicles in this study performed 70% of daytime charging events at home. They found an opportunity to return home during the day and favored charging there over charging away from home during the daytime.

Figure 11-192 shows the amount of charging energy consumed by vehicles during charging events described in Figure 11-191.

The proportion of energy charged at home versus away from home was similar to the percentage of charging events performed in each, with 90% of energy consumed at home and 10% of energy consumed away from home. At home, the major differences between charge frequency and energy were seen between daytime and overnight charging. Overnight home charging accounted for much more of the energy charged than daytime home charging. This is consistent with the traditional expectation that most of a vehicle's charging energy can be provided by long overnight charging events at home.

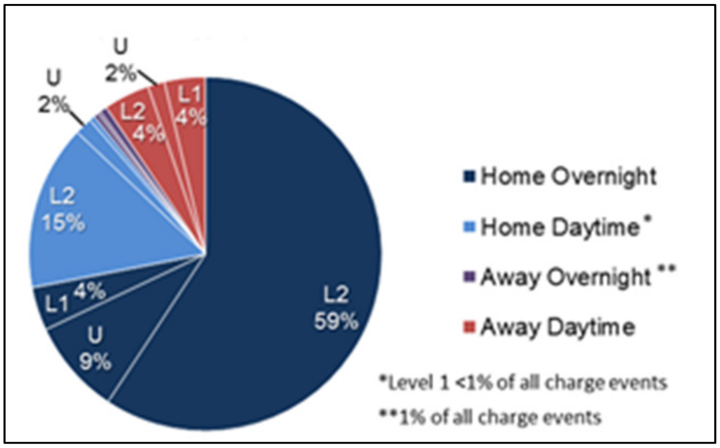


Figure 11-192. Percent of energy charged by location, power level, and time of day. L2 refers to AC Level 2 charges, L1 refers to AC Level 1, and U refers to charges of an unknown power level.

Away-from-home daytime charging consumed a greater percentage of energy than home daytime charging. This suggests that, during the day, drivers were somewhat more likely to be charging away from home for longer periods of time than when at home. This is probably due to the influence of workplace charging, where vehicles tend to stay plugged in for many hours. At least a portion of drivers in this study had regular access to workplace charging, but it is not known exactly how many. Charging and driving behavior of a subset of Leafs in this data set whose drivers are known to have had access to workplace charging is discussed in other papers [109].

When charging away from home, the percent of energy charged at AC Level 1 and AC Level 2 was similar to the percent of charge events performed at each power level. This means that the energy charged per away-from-home charging event was nearly equal for AC Level 1 and AC Level 2 charging events, even though AC Level 1 charging occurs at half the power of AC Level 2. This fact is particularly significant for away-from-home charging, where daytime "opportunity" charge time is typically expected to be short. This is consistent with the assumption that charging away from home was conducted at locations where the vehicle was parked for long periods of time, such as at work.

11.6.3.4 How Did Infrastructure Usage Vary from Vehicle to Vehicle? To understand drivers' usage of away-from-home charging infrastructure, data were analyzed on a per-vehicle basis. First, the relative contribution of away-from-home charging events for each vehicle was calculated. It was determined that 20% of vehicles with the most away-from-home charging performed 76% of all away from-home charges. This indicates that drivers did not uniformly utilize away-from-home charging infrastructure, but rather a minority of drivers were the predominant users.

To explore this idea further, vehicles were grouped based on how much away-from-home charging they performed relative to home charging. The percent of vehicles in each group is plotted in Figure 11-193.

Figure 11-193 shows that 57% of the vehicles studied performed 5% or fewer of their charging events away from their home locations and 5% of vehicles had zero away-from-home charges. On the other hand, some vehicles did most of their charging away from home and a few charged away from home 100% of the time.

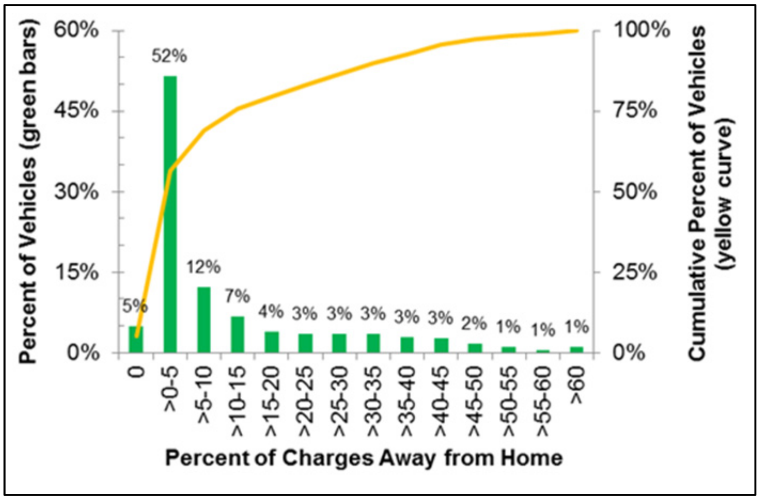


Figure 11-193. Distribution of the percent of charges performed away from home by each vehicle.

Away-from-home charging can be either AC Level 1 or AC Level 2; therefore, breaking down away-from-home charges by power level is important to further understand drivers' charging habits. Figure 11-194 shows the percentage of charges at each power level performed by the vehicles in the groups defined in Figure 11-194.

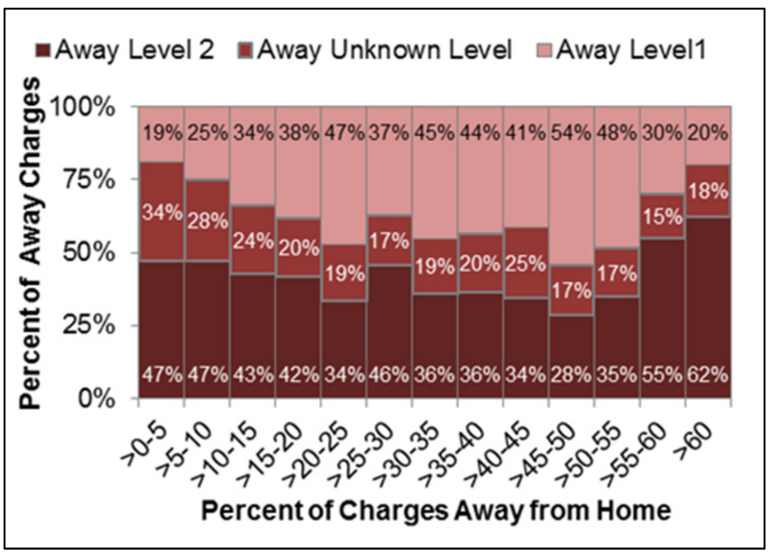


Figure 11-194. Occurrence of AC Level 1 and AC Level 2 charging for groups of vehicles with different amounts of away-from-home charging.

Overall, away-from-home charging was split roughly in half between AC Level 1 and AC Level 2. While it is difficult to quantify exactly because of the number of events with an indeterminate power level, it appears that drivers who performed about a third to half of their charging away from home slightly favored AC Level1 charging. However, the sample size of each of these groups is relatively small (as shown in Figure 11-193); therefore, this result may be skewed by atypical charging habits of just a few vehicles in these groups.

11.6.3.5 Did Away-from-Home Charging Enable Increased Driving in EV Mode? The vehicles grouped by the percent of charges away from home were analyzed to identify any differences in overall charging and driving behavior. Several metrics were calculated for each group and have been consolidated into four groups. These metrics are presented in Table 11-78.

Home overnight charging was quite similar for the groups with 60% or fewer of their charges away from home. They all averaged slightly less than one charge per day with an average SOC increase of about 65% of the battery's capacity per charge. Those that charged away from home more than 60% of the time only charged at home overnight 0.3 times per day and received an average SOC increase of 56% per charge.

All groups averaged 0.3 to 0.4 home daytime charges per day, except those charging away from home more than 60% of the time, who averaged just 0.1. All groups had an average SOC increase for home daytime charging of around 33% of the battery's capacity, roughly half the increase of overnight charging for the same groups. This reinforces the observation made previously that Volt drivers used their home charging units to perform daytime "opportunity" charging.

Away-from-home overnight charging occurred very infrequently (i.e., the average charges per day for all groups rounded to 0.0). When drivers found the rare opportunity to charge overnight when they were not at home, the SOC increase from these charges was on the same order as those that occurred overnight at home.

When charging away from home during the daytime, drivers most likely used publicly accessible and/or workplace charging infrastructure, the group with 0 to 30% of their charges away from home occasionally charged away from home during the daytime, averaging 0.1 charges per day with an SOC increase of 40% per charge. The two groups with more away-from-home charging charged during the daytime away from home about once per day and increased their SOC by around 45% of the battery's capacity per charge.

Table 11-78. Average driving and charging metrics of vehicles grouped by the percent of charges performed away from home.

% of Charging Away from Home	0%	>0 to 30%	>30 to 60%	>60%
Vehicles (% of total)	94 (5%)	1,520 (81%)	233 (13%)	20 (1%)
Percent of All Away-from-Home Charging Events	–	44%	51%	5%
Home Overnight Charges Per Day Driven	0.9	0.9	0.9	0.3
Home Overnight SOC Increase Per Charge	64%	65%	68%	56%
Home Daytime Charges Per Day Driven	0.3	0.4	0.3	0.1
Home Daytime SOC Increase Per Charge	32%	33%	34%	33%
Away-from-Home Overnight Charges Per Day Driven	–	0.01	0.03	0.02
Away-from-Home Overnight SOC Increase Per Charge	–	72%	68%	67%
Away-from-home Daytime Charges Per Day Driven	–	0.1	0.8	1.0
Away-from-Home Daytime SOC Increase Per Charge	–	40%	47%	44%
Total Charge Events Per Day Driven	1.2	1.4	2.0	1.4
Total SOC Increase from Charging Per Day	67%	78%	108%	64%

% of Charging Away from Home	0%	>0 to 30%	>30 to 60%	>60%
Average Miles Per Day Driven	31.5	39.0	50.3	33.9
Average EV Miles Per Day Driven	24.9	28.7	40.3	25.7
Percent of Miles Driven in EVM	79%	74%	80%	76%

The group with 30 to 60% of their charges away from home utilized home charging more than once per day and supplemented that charging with nearly one away-from-home charge per day for a total daily SOC increase of 108%. This charging allowed the vehicles in that group to drive more than 40 miles in EVM per day, which is 60% farther than the vehicles that never charged away from home. All of the four groups were able to drive a significant portion of their miles in EVM, with percentages ranging from 74 to 80%.

Across all of the away-from-home charging frequency groups, vehicles averaged 74 to 80% of their distance driven in EVM. Overall average charging frequency increased as average daily distance driven increased, suggesting that drivers changed their charging behavior in order to extend EVM operation.

11.6.3.6 References

109. See "Where do Chevrolet Volt drivers in The EV Project charge when they have the opportunity to charge at work?" at avt.inl.gov/pdf/EVProj/ChargingLocation-WorkplaceVoltsMar2014.pdf

11.6.3.7 Appendix A

Figure 11-195 shows the number of vehicles included in this study in each of the 16 regions where Chevrolet Volts were enrolled in The EV Project. Note that Oregon includes the Corvallis, Eugene, Portland, and Salem metropolitan areas. Washington State includes the Seattle and Olympia metropolitan areas.

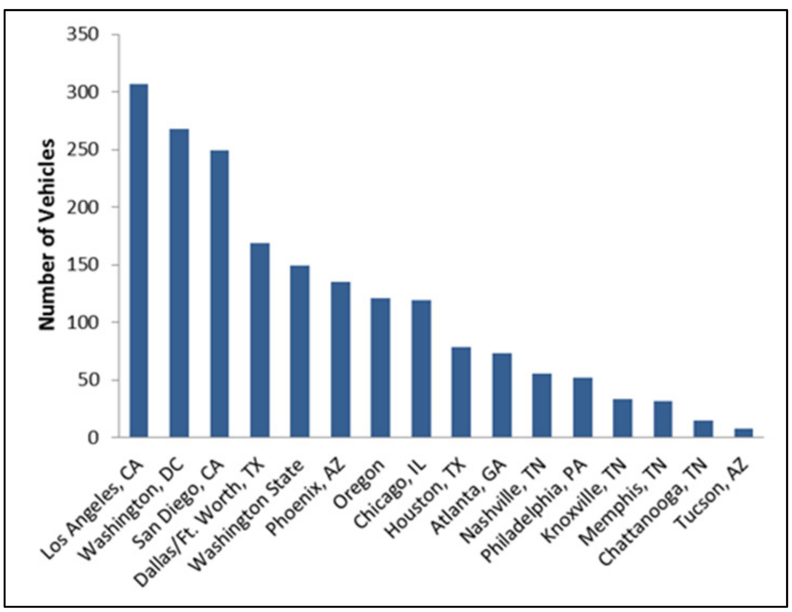


Figure 11-195. Number of The EV Project Chevrolet Volts by region.

11.6.4 How Much are Chevrolet Volts in The EV Project Driven in EV Mode?

11.6.4.1 Introduction. Owners of Chevrolet Volts in 18 metropolitan areas across the United States are participating in The EV Project. They agreed to allow project researchers to monitor the usage of their vehicles throughout the project. In-use data collected between October 1, 2012, and May 31, 2013, from a sample of 1,154 participating Volts were analyzed to determine how these vehicles were being used. This set of privately owned vehicles drove more than 6 million miles and performed over 220,000 charging events in the 8 month study period.

11.6.4.2 Key Conclusions

- A sample of 1,154 Chevrolet Volt drivers participating in The EV Project drove 73% of their total miles in electric EVM over an 8-month study period.
- 70% of vehicles were driven more than 70% of their total miles in EVM, while 131 vehicles (11%) were driven more than 95% of their miles in EVM.
- Volt drivers who drove farther per day also tended to consume more charging energy, either through more frequent charging, longer charge sessions, or both.
- The average amount of energy delivered per charging event varied widely from vehicle to vehicle, even among vehicles whose batteries were typically fully depleted prior to charging.
- Drivers with a high percentage of miles in EVM averaged fewer trips of shorter length between charging events. They also tended to charge more frequently for shorter durations.

11.6.4.3 How Much Do These Vehicles Drive in EV Mode? As an EREV, the Chevrolet Volt has two operating modes. When in EVM, the vehicle is powered by electricity from the grid. In ERM, the vehicle's gasoline-powered auxiliary power unit produces electricity to power the vehicle. This offers drivers flexibility to drive as far as they like before recharging the battery from the grid. The Volt's EPA-estimated EVM range is 35 miles for the 2011 to 2012 models and 38 miles for the 2013 model year. These range estimates are based on standardized testing. Actual EVM range varies with driving style and conditions. To classify the amount of driving a vehicle does in EVM, the number of miles driven in EVM reported by participating EV Project Volts was divided by the total number of miles driven. For this paper, this metric is called EV%. For the selected set of Chevrolet Volts, the overall EV% was 73%. A distribution of EV% from vehicle to vehicle is shown in Figure 11-196.

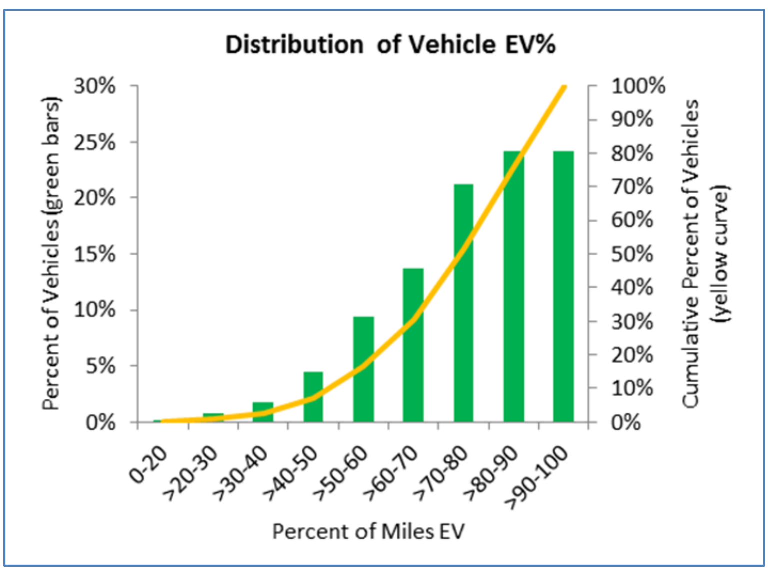


Figure 11-196. Histogram of EV% on a per-vehicle basis with cumulative distribution curve.

Approximately 70% of Volt drivers drove more than 70% of their miles in EVM. It was not uncommon for a vehicle's EV% to exceed 95%. In fact, there were more vehicles with an EV% above 95% (131) than below 50% (84).

Electronic displays in the Chevrolet Volt provide a considerable amount of information to the driver about the vehicle's mode of operation and efficiency. For example, the driver can see the amount of electricity and gasoline consumed and distance driven in EVM versus ERM since the previous charging event. Cumulative fuel economy, in mpg, is displayed to the driver as a measure of the vehicle's efficiency over time. This metric takes into account all miles driven and gasoline consumed since it was last reset by the driver. Because EV% is not displayed cumulatively, it is possible that some drivers do not have an inherent sense for their vehicle's long term EV%. However, a vehicle's EV% is directly proportional to its fuel economy. A larger fraction of miles in EVM means the vehicle drives fewer miles powered by gasoline, and thus fuel economy is higher.

For this paper, fuel economy values were determined by dividing the total miles driven in either EVM or ERM by the total gasoline used. The overall gasoline fuel economy for vehicles in the data set was 130 mpg. (Note that fuel economy shown considers gasoline consumption only – it is not comparable to EPA fuel economy estimates because it does not combine gasoline and electricity into mpge.)
Figure 11-197 shows the fuel economy distribution on a per-vehicle basis.

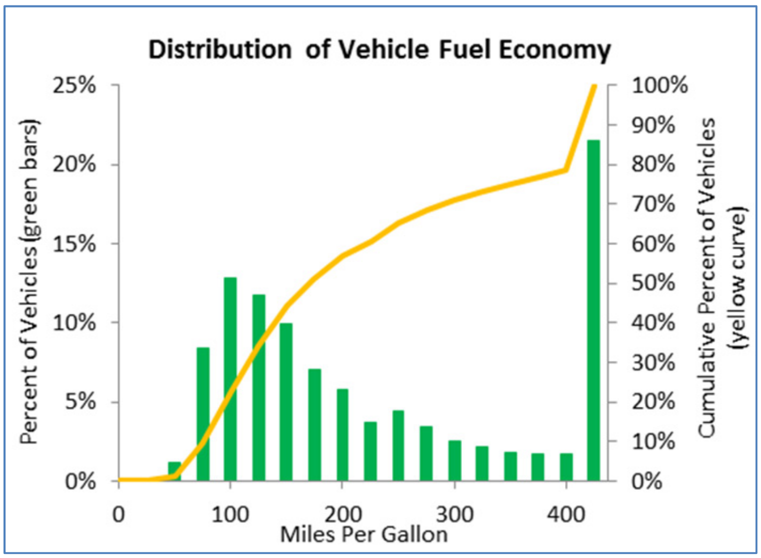


Figure 11-197. Histogram of fuel economy on a per-vehicle basis with cumulative distribution curve.

More than 90% of the Volts in this set achieved greater than 75 mpg. A significant portion of vehicles saw fuel economy well into the triple digits. In fact, over 20% of vehicles averaged over 400 mpg, including a small number of vehicles with 99% of their miles driven in EVM and near zero gasoline consumed.

Regardless of whether drivers were concerned with EV-only driving or fuel economy (or neither), the vehicles in this study drove a significant number of miles powered solely by electricity.

11.6.4.4 How are Drivers Achieving These Results? A vehicle's EV% is determined by the combination of its driving and charging. Figure 11-198 shows the relationship between driving and charging for each vehicle in the study set.

The average distance driven per day for each vehicle was plotted against the average amount of energy charged from the grid each day, in terms of battery SOC. Only days when a vehicle was driven were considered. SOC used in this plot and other calculations in this paper is the battery's usable SOC. It ranges from 0 to 100%, where 0% represents the point when the vehicle switches from EVM to ERM. Figure 11-198 also shows the actual EV% each vehicle achieved, represented by the color of each data point.

It is apparent that drivers who drove farther per day also tended to consume more charging energy. However, not all drivers drove and charged at proportional rates. Vehicle usage varied widely because drivers' daily routines and needs for their vehicle vary widely. Driver motivation to charge varies as well.

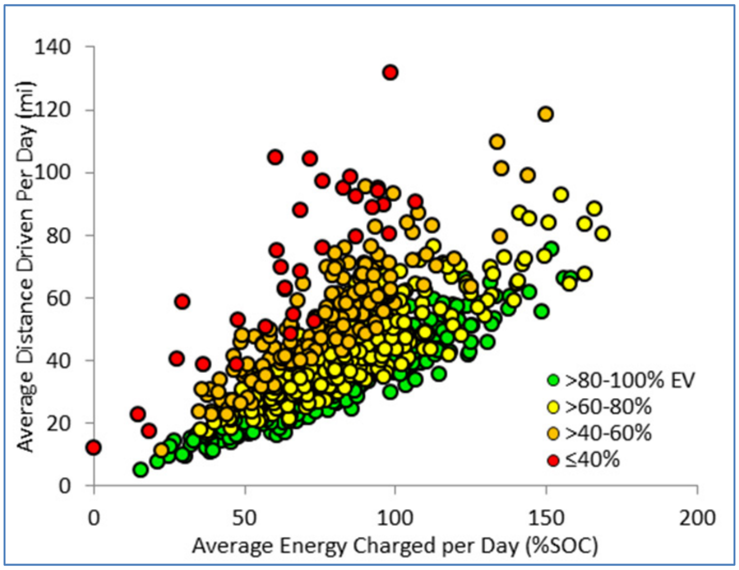


Figure 11-198. Average daily driving and charging for each vehicle, with EV% denoted by color.

It appears that some drivers valued driving in EVM, as demonstrated by frequent charging and high EV%. For example, one driver had 94% of miles in EVM when averaging 66 miles per day, because he consumed energy equivalent to 1.6 full charges each day. This vehicle was charged, on average, 4.3 times each day driven with an increase of 37 %SOC each charge. Another vehicle was driven the same distance per day, charged the same energy, and achieved the same EV%. However, this second vehicle averaged 1.7 charges per day driven and an average increase of 91 %SOC each charge.

Other drivers do not seem as motivated toward high EV%. As extreme examples, one vehicle was never charged in the study period and two other vehicles averaged only 1 charge in every 4 days when the vehicle was driven.

In addition to the total amount of energy charged, the order in which driving and charging occur is an important factor in determining EV%. After all, the amount of driving performed in a day does not matter to the vehicle, but rather the amount of driving before the next charge. As illustrated in the examples above, vehicle batteries can be charged any number of ways: by long infrequent charging sessions, by short frequent charging sessions, or any combination of frequency and duration. Charging frequency is best described in terms of how far a vehicle has driven between charges (rather than how much time has elapsed). Figure 11-199 shows the average distance each vehicle traveled between consecutive charging events and the average energy consumed per charging event. Each vehicle's EV% is represented by the color of each data point.

The majority of vehicles in Figure 11-199 were driven relatively short distances between charging events. In fact, 75% of drivers averaged less than 35 miles between charges. However, not all vehicles consumed the same amount of energy per charge. Many vehicles were consistently charged enough per charging event, relative to miles driven prior to charging and driving conditions, to maintain high EV%. These vehicles are represented by green data points. Other vehicles were charged at the same mileage interval, but averaged less energy per charging event. This variation in charging energy consumed from vehicle to vehicle results in varying EV% for the same distance driven. This is also a reason why some vehicles achieved an EV% of far less than 100%, even though they were consistently driven less than the expected EV range of the vehicle prior to recharging.

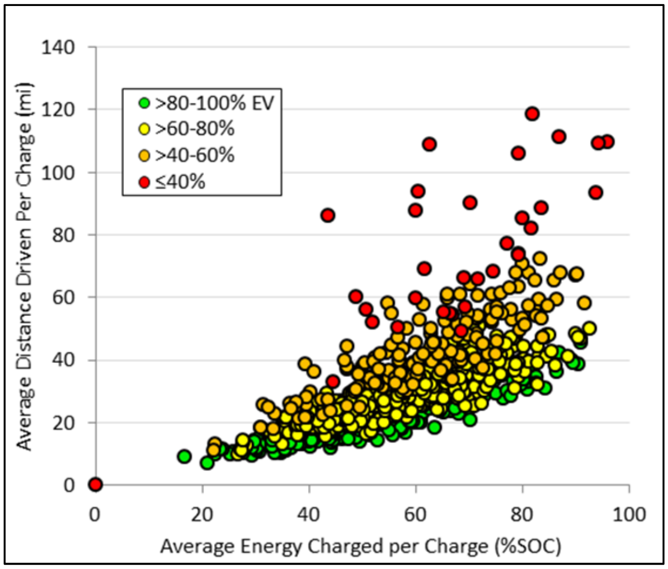


Figure 11-199. Average distance driven between charging and average charging energy per charge for each vehicle, with EV% denoted by color.

Vehicles averaging over 50 miles before charging would be expected to often have fully depleted batteries by the time they charge. Ideally, these vehicles would have their batteries fully recharged each charging event, resulting in a high average SOC increase per charge. However, Figure 11-199 shows that many vehicles averaging over 50 miles between charging events averaged less than 70 %SOC per charge. Drivers of these vehicles may not have had time to fully recharge their vehicles or may not have had access to charging equipment in convenient locations. Volt driver preference for charging equipment type and location is the subject of another paper.

Further inspection of the data revealed additional patterns in behavior between groups of vehicles with varying EV%. Table 11-79 shows several driving and charging metrics for vehicles in the data set, grouped by EV%.

Table 11-79. Overall driving and charging metrics for vehicles in each group of EV%.

EV%	≤40%	>40-60%	>60-80%	>80-100%
Vehicles (% of Vehicles)	32 (3%)	161 (14%)	403 (35%)	558 (48%)
Charges per Day	1.0	1.4	1.5	1.5
%SOC per Charge	66%	59%	57%	51%
Trips per Charge*	5.0	3.6	3.2	3.0
Miles per Trip*	14.0	11.0	8.8	7.2

* Trips are defined as the intervals between key-on and key-off where the vehicle traveled farther than 0.1 mile

Drivers of vehicles with high EV% typically took fewer trips of shorter length between charging events. They also charged more frequently for shorter durations.

11.7 EV Project Workplace Charging

11.7.1 What Were the Cost Drivers for Workplace Charging Installations?

11.7.1.1 Introduction. Because workplace charging is the second most popular place to charge a PEV, after home charging [110], the cost of EVSE installations for employers is of interest and one of the subjects that The EV Project was designed to examine.

For the purpose of this evaluation, workplace charge stations are defined as EVSE that were installed for the private use of employees and guests of a particular business. Charging stations installed for public use, but whose use is dominated by a single daytime user during work hours, are not included in this analysis. This paper analyzes the costs of installing workplace charge stations.

The original intent of The EV Project's non-residential AC Level 2 EVSE deployment was to focus on units whose purpose would be to serve the broader EV marketplace (i.e., publicly accessible charging infrastructure). As the project unfolded, it became more apparent that workplace charging was of significant interest to PEV drivers and potential PEV owners. By the beginning of 2012, deployment efforts began to shift to more workplace charging sites. In the end, approximately 10% of all non-residential AC Level 2 EVSE deployed during The EV Project were installed as workplace chargers. Because this focus on workplace deployment emerged later in the project, a number of workplace installation locations were identified, but not installed before The EV Project terminated. However, costs for these installations, in the form of firm contractor pricing, were available for evaluation.

This paper is a companion to the paper titled, "What were the Cost Drivers for Publicly Accessible Charging Installations?" [111], which discusses, in greater depth, the basis for installation costs of non-residential AC Level 2 EVSE. This paper will analyze the circumstances associated with installation of workplace charging infrastructure that differentiate the cost to install EVSE under these conditions.

11.7.1.2 Key Conclusions

- The average cost for installation of EVSE at workplace locations was $2,223.
- The average installation cost for workplace charging EVSE was 75% of the average cost to install publicly accessible EVSE ($2,979).
- Twenty-seven percent of the workplace EVSE installed were wall-mount units, while 17% of the publicly accessible EVSE units were wall-mount units.
- Greater flexibility in the location of the workplace installations provided installation cost savings opportunities not typically available to EVSE installed for public use.
- Future expansion of workplace charging infrastructure represents a significant installation cost concern for employers, because these expansions will frequently require additional electrical service capacity.

11.7.1.3 Data Analyzed. The primary source for data and information analyzed for this paper came from reports generated from The EV Project database. This database was populated with data from hosts, EV Project administrators, and electrical contractors installing EVSE.

The total costs of installations cited in this report include all costs paid to the electrical contractors to install the Blink AC Level 2 EVSE. These costs would typically include permit costs, contractor's installation and administration labor, subcontracted construction labor or equipment (e.g., concrete, asphalt, trenching, boring, etc.), engineering drawings (when required), and materials other than the AC Level 2 EVSE itself, which was provided by The EV Project. Installation cost data from 280 workplace installations were utilized for these analyses.

11.7.1.4 Analyses Performed. Installation cost and utilization data recorded from The EV Project charging infrastructure installed as workplace charging stations were segregated from the rest of the AC Level 2 EVSE data for this analysis. The average workplace installation costs and how they compared to other non-residential AC Level 2 EVSE installation costs are shown in Table 11-80.

Further analysis in Table 11-81 shows that the minimum costs were comparable, while the maximum installation cost for units that were publicly accessible was more than twice the maximum workplace installation cost.

Table 11-80. Average installation costs for EV Project non-residential AC Level 2 EVSE.

Average Installation Cost			
	All Non-Residential	Publicly Accessible	Workplace
All	$2,979	$3,108	$2,223
Pedestal Units	$3,209	$3,308	$2,305
Wall-Mount Units	$2,035	$2,042	$2,000

Table 11-81. Maximum and minimum installation costs for EV Project non-residential AC Level 2 EVSE.

Maximum and Minimum Installation Costs			
	All Non-Residential	Publicly Accessible	Workplace
Maximum	$12,660	$12,660	$5,960
Minimum	$599	$599	$624

Figure 11-200 shows that installation costs for workplace stations were not only 30% less than stations installed for public use, but 80% of the workplace stations were installed at costs that were below the average installation cost of $3,108 for stations installed for public use.

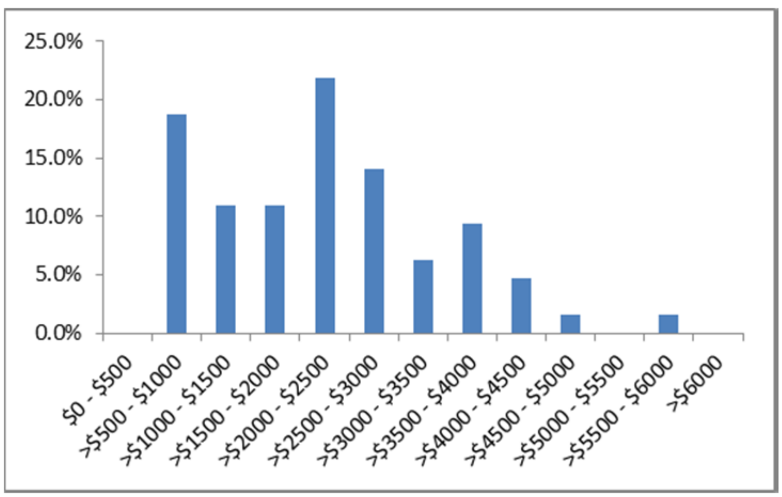


Figure 11-200. Distribution of per unit workplace installation costs.

11.7.1.5 Discussion of Results. Three primary factors drove average workplace EVSE installation costs markedly lower than publicly accessible AC Level 2 EVSE. These factors were location of the site relative to the electric service panel, number of wall mounted stations, and fewer restrictions on accessibility.

Location Relative to the Facility—AC Level 2 EVSE installed at workplace charging stations were typically installed in existing employee parking lots, which are normally at the rear of the workplace or at the side of the building. In either case, this typically puts the EVSE closer to the building's power distribution panels than for a typical publicly accessible AC Level 2 EVSE. These installation locations resulted in shorter electrical conduit runs and, therefore, less expensive installation costs.

Some workplace charging stations were installed in multi-level parking garages. These EVSE were also located away from the front of the building and were more likely to be nearer electrical service. These units typically utilized surface-mounted electrical conduit, which is less expensive to install than conduit buried underground. This installation cost advantage affected stand-alone pedestal EVSE and wall-mounted units. In fact, the average installation cost for Blink pedestal EVSE units designated as a workplace charger was $2,305, which is more than 30% less than pedestal units installed to be publicly accessible.

This cost advantage, based on proximity to the electrical service panel, can be seen in the average cost to install a pedestal EVSE (typically using buried conduit). For all non-residential AC Level 2 pedestal EVSE installed in The EV Project, the average installation cost was $3,209, but for those pedestal EVSE installed at workplace charging stations, the average was $2,305, which is 28% less than the overall average.

Wall-Mounted Installations—The greater freedom as to the installation location at a site also led to more wall-mounted installations. Wall-mounted EVSE were typically less expensive to install, because they did not require underground conduit to supply power, which is typical for a pedestal unit. The average installation cost for a wall-mounted AC Level 2 EVSE unit in The EV Project was $2,035, while the average cost to install a pedestal unit was $3,209.

Twenty-seven percent of the AC Level 2 EVSE units installed as workplace chargers were wall-mounted. This compares to 17% of AC Level 2 EVSE units installed for all non-residential use. The lower average installation cost for wall-mounted units and the much greater ratio of wall-mounted installations, significantly contributed to the lower average installation cost for workplace chargers.

Flexibility of the Installation Location—The third workplace cost factor contributing to lower workplace EVSE installation costs was the ability to install the units with fewer accessibility requirements. For example, typically there were few, if any, parking signage or striping requirements; ADA accessibility, including an accessible pathway to the workplace building, was only necessary if an employee was a PEV driver and required this accessibility; units did not need to be in conspicuous locations; and public accessibility during hours outside of normal business hours was also not a concern.

Another Installation Cost Consideration when Planning for Workplace Chargers—One workplace installation cost factor that did emerge over the course of The EV Project, was the cost to install additional EVSE. Many of the employers who provided workplace charge stations for their employees found that the offer of refueling commuter vehicles while at work (whether at a cost to the driver or free) encouraged more employees to obtain PEVs for their work commute. This put pressure on employers to add more stations, with the “easy” installations often being the first ones (i.e., ones already done). Additional electrical service and parking places further from the electrical distribution panel usually were required for additional EVSE, which added to the cost of these subsequent installations.

11.7.1.6 Conclusions. The cost of installation for AC Level 2 EVSE at workplace charging stations in The EV Project was markedly lower than the cost of EVSE installed for public use. This was primarily due to fewer restrictions on where the charging stations were located on the site. The installation cost savings could be found in three factors: location of the charging stations relative to the electrical power distribution panel; the ability to more frequently utilize surface-mounted conduit for wall-mounted units and ; and fewer accessibility restrictions compared to EVSE installed for public use.

11.7.1.7 References

110. “Where do Nissan Leaf Drivers in The EV Project Charge When They have the Opportunity to Charge at Work?” http://avt.inel.gov/pdf/EVProj/ChargingLocation-WorkplaceLeafsMar2014.pdf.

111. http://avt.inel.gov/evproject.shtml#LessonsLearned EV Project lesson learned white paper, “What were the Cost Drivers for Publicly Accessible Charging Installations?”

11.7.2 Workplace Charging Frequency of Nissan Leafs and Chevrolet Volts in The EV Project at Six Work Sites

11.7.2.1 Introduction. With an increase in the number of PEVs on the road, many employers are offering opportunities to charge PEVs at work. The work site seems to be an ideal place for PEV charging because employees are typically parked there between 4 and 10 hours per day. (See Section 11.7.2.10 for more information on the time vehicles are parked at work.) Charging while parked at work can provide energy for extended commuting and provide range confidence. This paper examines work site charging behavior of The EV Project participants who parked and charged at six different work sites in California. Background information on these work sites was obtained directly from the company or from the report, "Amping up California Workplaces: 20 Case Studies on Plug-in Electric Vehicle Charging at Work," published in November 2013 [112]. The frequency of workplace charging was examined, as well as key factors that may have contributed to workplace charging.

11.7.2.2 Key Conclusions

- Use of PEV charging infrastructure at six work sites in California varied from site to site, based on a number of factors that include the following:
  - The cost of charging
  - Employee commute distance
  - Demand for charging station use
  - Policies for how long a vehicle can be connected to workplace charging stations.
- In general, drivers with longer commutes tended to charge more often at work. However, some employees with short commutes still charged at work when cost was low.
- The work sites studied employed a mix of policies to manage charging station use, including levying fees for charging, requiring the use of a reservation system, providing employees tools to self-manage charging, and requiring drivers to move their vehicles upon completion of charging. At three work sites, the combination of policies employed effectively enabled numerous vehicles to frequently use a fixed number of charging stations. At the other three work sites, the combination of policies chosen resulted in infrequent vehicle charging at work.

11.7.2.3 Which Vehicles and Work Sites Were Studied? For this study, data were analyzed from 47 Nissan Leafs and five Chevrolet Volts participating in The EV Project that frequently charged and/or parked at six different workplaces in California. Four of these work sites were in the San Francisco Bay area and two were in southern California. The number of employees at each company varied from around 100 to over 5,000. The study period for this paper was approximately 2 years, ending December 31, 2013. The starting date at each location varied, based on when charging stations were installed.

The owners of the vehicles reporting data used in this study agreed to allow data to be collected from their vehicles as a term of their participation in The EV Project. Data sets were filtered to only include vehicles whose drivers had a high probability of being employees, rather than visitors, at the work sites in this study. The number of PEVs enrolled in The EV Project at each of these work sites ranged from four to 17. Table 11-82 summarizes the number of vehicles from which data were collected that parked at each work site.

Table 11-82. Number of EV Project vehicles that frequently parked at each work site.

Work Site	Number of PEVs Reporting Data	Vehicle Work Days
Company A	5 Leafs	566
Company B	17 Leafs	2,350

Work Site	Number of PEVs Reporting Data	Vehicle Work Days
Company C	5 Leafs	650
Company D	4 Leafs	685
Company E	3 Leafs, 5 Volts	1,379
Company F	11 Leafs	3,009

11.7.2.4 Work Site Descriptions. Company A's facility consisted of one building and an employee parking garage. Ten AC Level 2 charging stations and one DCFC were located in the parking garage. These charging stations were available for use by employees and the public through the end of the study period. Over 45 employees at Company A owned PEVs by the end of the study period.

Company B's campus included numerous buildings in an office park spanning multiple city blocks. The campus contained 31 AC Level 2 and 12 AC Level 1 charging stations that were located in its buildings' parking lots and garages that were available only for the company's fleet and employees. Company B reported that over 100 employees were driving PEVs by fall 2013.

During the study period, Company C had 12 AC Level 1 charging stations, 22 AC Level 2 charging stations, and one DCFC at its main campus. These EVSE units were installed over time as the number of employees owning PEVs and the demand for workplace charging increased. The charging units were available for use by employees, visitors and the general public. The estimated number of Company C employees driving PEVs by the end of the study period was 50.

Company D had one AC Level 2 charging station that was located in an office building parking lot. This charging unit had two charge ports that reached to four different parking spaces. This charging unit was only allowed to be used by employees.

The Company E lot is spread out over an entire city block. On the lot, there were four parking structures, with each containing four charging stations. There were also four more charging stations that were distributed across the lot. These chargers were supplied for use by employees, fleet vehicles, and visitors. Company E had 40 to 50 employees owning PEVs by fall 2013.

Company F had 43 charging stations that were located across six company locations. These charging stations were provided by the company for its employees and its electric fleet vehicles. At the end of the study period, there were approximately 45 Company F employees driving PEVs.

Figure 11-201 summarizes the number of EVSE, number of EV Project vehicles, and the estimated total number of PEVs driven to work by employees at all six work sites. The light blue arrows indicate that charging stations were open for use by non-employees, such as business-related visitors or the general public.

11.7.2.5 How Often Did Charging Occur? The data were collected over a total of 8,639 vehicle work days at the various work sites. During those work days, there were 10,718 parking events and 2,901 charges performed by the PEV drivers. Figure 11-202 shows the percentage of days when EV Project vehicles were charged and not charged at each work site. For example, Company A employees enrolled in The EV Project charged their vehicles on over 70% of their work days. In contrast, the employees at Company F charged their vehicles on only 8% of their work days.

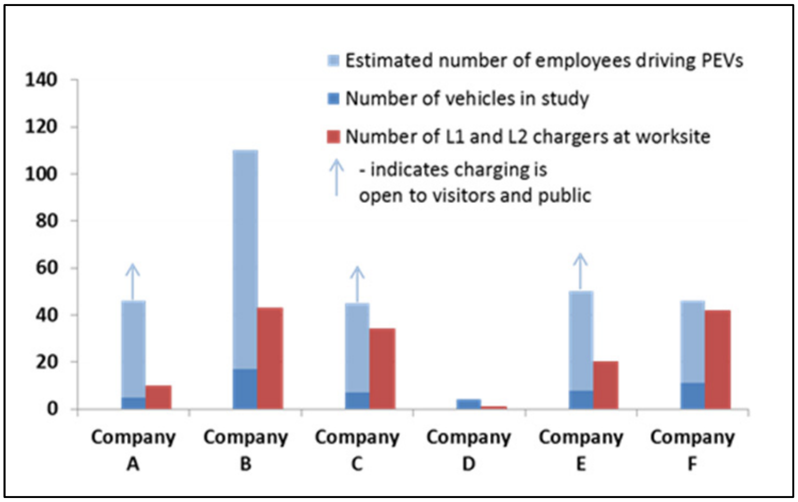


Figure 11-201. Comparison of the number of PEV drivers and EVSE at each work site.

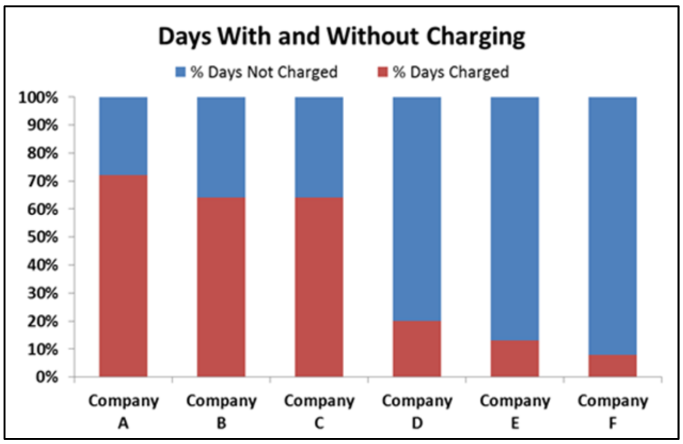


Figure 11-202. Work site charging frequency.

Figure 11-202 shows that the usage frequency of workplace charging units at the work sites studied varied from work site to work site. It also varied from vehicle to vehicle at a single work site. Some vehicles were charged every day when they were parked at the work site, others were charged periodically, and other vehicles were never charged.

11.7.2.6 Factors Influencing Charging Behavior. Several factors contributed to the PEV drivers' use of workplace charging, including the following:

- The cost of charging (free versus cost)
- Round-trip commuting distance relative to the electric range of the vehicle
- Demand for charging station use, indicated by the ratio of number of PEVs to the number of EVSE at a work site
- The policy for how long a vehicle can be connected to workplace EVSE.

11.7.2.7 Discussion of Results at Each Work Site

Company A—During the study period, charging stations were free to employees. Data available from the AC Level 2 units at this location indicated that these units were highly utilized. The chargers were managed by an online reservation system, which designated a daily time for each participant to use.

Company A had a PEV-to-EVSE ratio of 4.6; however, they overcame this limitation through use of the reservation system.

There were five Leafs enrolled in The EV Project, which frequently charged and/or parked at this site. Average charging frequency of these vehicles varied from charging daily to charging once every 4 days. This varied proportionally with the vehicles' average commuting distances.

Data collected from the DCFC at Company A showed it was used heavily, averaging 70 charging events per week. However, drivers of the five Leafs contributing data for this study did not use the DCFC during the study period. This suggests that AC Level 2 charging was sufficient for these drivers' workplace charging needs.

Company B—As of fall 2013, Company B charged a fee for employees to use the charging stations. There was no limit to the time a vehicle can charge, provided employees registered their vehicle with the company and signed a liability waiver.

Out of over 100 PEVs owned by Company B employees, there were 17 EV Project Leafs who regularly parked at this work site. These vehicles were charged on 64% of the vehicle work days in the study. On first glance, it appears that, like at Company A, charging frequency at Company B was proportional to commuting distance. Twelve of the 17 vehicles were charged on at least 50% of the days. These 12 frequently charged vehicles had an average round-trip commute distance of 48 miles, compared to a 43-mile average commute distance for the five vehicles that were rarely charged. However, examination of individual driver behavior uncovered that four of the vehicles that were charged at work on most work days averaged less than 35 miles round trip between home and work. Why would these drivers be willing to pay to charge often at work when their typical commute was well within their vehicle's range? The cost to charge at Company B was $0.14 per kWh plus $0.41 per charge. This fee is in the range of some residential electricity rate plans in northern California. Therefore, for some drivers, there may have been little or no cost difference between charging at home and work.

Although the fee charged at Company B did not deter some drivers who live close to work from charging, it appears to have served as an effective tool for managing charging. Even though there were 2.6 vehicles for every EVSE at Company B and there were no rules limiting the time a vehicle spent connected to a charging station, the PEV-driving employees at Company B were able to charge on nearly 2 out of 3 work days.

Company C—Use of the charging stations at Company C was free for anyone in the study period. Charging station usage at Company C was coordinated using social media.

There were seven vehicles enrolled in The EV Project that frequently charged and/or parked at Company C. Of these seven vehicles, five of them were charged on over 96% of the days when they parked at work. The other two were never charged at work. There was a strong correlation between commute distance and charging frequency. The five vehicles that were charged nearly every day had an average round-trip commute distance of 56 miles, while the other two vehicles had an average commute distance of 22 miles.

Analysis of data from numerous charging stations at Company C indicated that the units were nearly constantly in use. Turnover at charging stations was high and many vehicles were charged each day. This was made possible by Company C's decision to allow free charging, its policy encouraging employees to move their vehicles after charging was completed, and providing employees a system for coordinating charging. (For more information on workplace charging at Company C, see [2]).

There was a DCFC installed at Company C. However, no vehicles in this study used the DCFC during the study period. It seems that AC Level 1 and AC Level 2 charging met the workplace charging needs of these drivers.

Company D—Charging at Company D was free for employees during the study period. PEV drivers were asked to park in the assigned charging spaces and to move their vehicle when it completed charging.

Four EV Project Nissan Leafs frequently parked at Company D. Overall, these vehicles were only charged on 20% of vehicle work days. Further inspection revealed that two vehicles were charged often, while the other two vehicles were rarely charged. There was only a slight correlation between commuting distance and charging frequency. The disparity in charging frequency, despite similar commuting distances and free charging, suggests that there were other local factors motivating behavior.

Company E—Employees at Company E were required to pay a fee to charge onsite. There was also a policy in place that required drivers to move their vehicles after they had completed charging. This policy was enforced by parking security.

Five Chevrolet Volts and three Nissan Leafs enrolled in The EV Project charged and/or parked at this site. These vehicles were only charged at Company E on 13% of their work days. Of the eight vehicles in the study, one Volt did most of the charging, with that vehicle's average round-trip commute distance exceeding its electric-only operating range. The rest of the vehicles had short commutes, relative to their vehicles' electric-only operating range; therefore, there was not a strong need for charging at work. The cost to charge at Company E was $1.00 per hour connected, which equates to about $0.33 per kWh for the Leafs and Volts in this study.

Company F—PEV drivers at Company F paid a fee of $0.17 to $0.27 per kWh, depending on the time of year, to use the charging stations. There were no time limits involved with using the charging stations. However, drivers were encouraged to display a card on the vehicle's dashboard, indicating when the vehicle was expected to be fully charged, so that another driver could use the charging station after that time.

Company F had a PEV-to-EVSE ratio of 1.1, the lowest of the six work sites in the study. Despite this low ratio, Company F had the fewest number of work days where charging occurred (i.e., 8%). This may have been due to low commuting distance. The 11 EV Project Nissan Leafs that frequently parked at Company F averaged 24 miles round-trip between home and work. Nearly 90% of daily round-trip commutes were 40 miles or less.

Summary—Figure 11-203 summarizes the discussion above by overlaying information about each work site on the charging frequency chart shown in Figure 11-202. The range of average round-trip commuting distances for the vehicles at each work site is shown in the figure, with the overall average round-trip commuting distance of all vehicles at a work site represented by a blue diamond.

In general, charging frequency was proportional to commuting distance. This correlation was stronger at the two work sites that charged fees that substantially exceeded the cost of charging at home.

Company A, Company C, and Company B employed different policies and tools, which effectively allowed a large number of PEV drivers to charge frequently at work. Charging frequency was low at Company D, even though the equipment installed and policy for use should have been enough to support frequent charging. This highlights the need to understand local nuances at companies with a small number of PEV drivers and EVSE. The combination of low commuting distance and fees at Company E and Company F, as well as the strictly enforced policy for length of TOU at Company E, led to low charging frequency at these work sites.

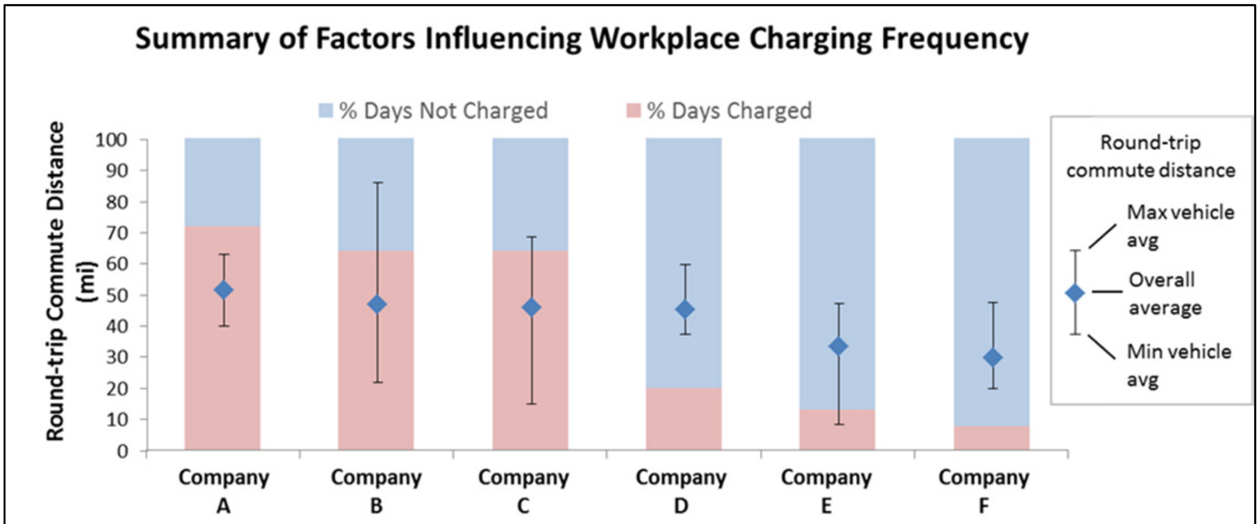
11.7.2.8 Considerations for Policy Decisions. Some considerations for managing workplace charging can be taken from this study.

First, imposing a fee to charge at work will likely reduce charging station use. However, if fees are too high and/or employee commuting distances are low, charging equipment may be seldom used.

Second, providing PEV-owning employees tools to self-manage charging can be an effective way to maximize charging station use and accommodate a lot of vehicles, even if charging is free.

Third, an enforced policy requiring drivers to move their vehicles from parking spaces designated for charging is a deterrent to workplace charging. Employees may be disinclined to risk a reprimand or fine if they are unable to interrupt their work day to unplug and move their vehicles at the required time.

Finally, corporate culture may affect employees’ workplace charging behavior. For example, if a company executive owns a PEV, lower-ranking employees may be reluctant to use a charging station the executive uses. Likewise, employees with a particular status or background may feel entitled to occupy a charging station for as long as they want, without regard to other employees’ desire to charge. Naturally, these cases could occur at any work site, but they may be more likely to occur and will have a more significant effect at smaller work sites.



Cost	Free	Cost per kWh	Free	Free	Cost per hour	Cost per kWh
Policy	Online reservation system	None	Move after charged (unenforced)	Move after charged (unenforced)	Move after charged (enforced)	None
PEV/EVSE Ratio	4.6	2.6	1.5	2.0	2.5	1.1

Figure 11-203. Summary of factors influencing workplace charging frequency and observed charging frequency at the six work sites.

11.7.2.9 References

112. “Amping up California Workplaces: 20 Case Studies on Plug-in Electric Vehicle Charging at Work,” California Plug-in Electric Vehicle Collaborative, November 2013, www.pevcollaborative.org/sites/all/themes/pev/files/WPC_Report4web.pdf.

113. “Workplace Charging Case Study: Charging Station Utilization at a Work Site with AC Level 1, AC Level 2, and DC Fast Charging Units,” INL, June 2014, avt.inl.gov/pdf/EVProj/WorkplaceEVSEUtilizationAtFacebookJun2014.pdf

11.7.2.10 Appendix A

Time Spent Parked at Work—The distribution of time that each vehicle was parked per day at any of the six work sites in this study is shown in Figure 11-204. Days were only included in this analysis if vehicles were parked at work for more than 4 hours. The time represents the total time parked during a work day, even if that parking was broken up by driving throughout the day.

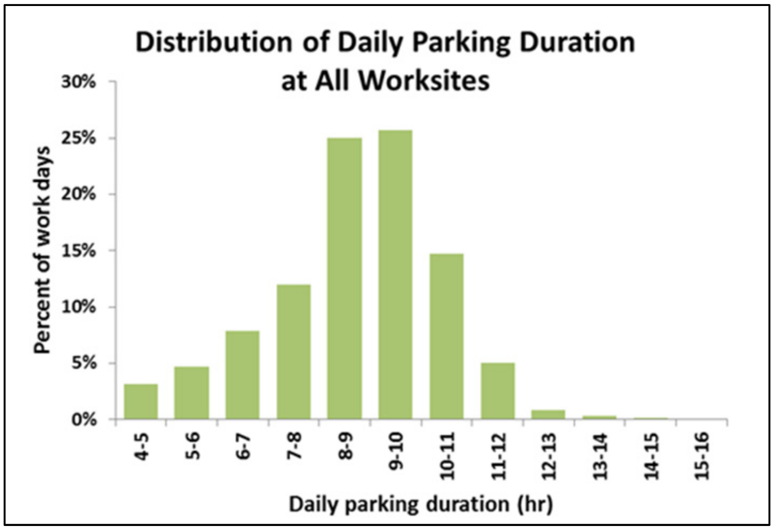


Figure 11-204. Distribution of time parked per day at work.

This figure shows that vehicles in this study spent between 8 and 10 hours parked at work on over half of their work days.

Calculation of Commute Distance—For this analysis, the round-trip commute distance was defined in the following manner. A vehicle's round-trip commute distance is the sum of all miles driven from home to work and work to home, including any driving in between (such as going to lunch). For example, if a driver has to drop off a child at school before going to work in the morning, that total distance (from home to school to work) is included in their daily round-trip commute distance. If at lunch, they leave work and go to a restaurant and then drive back to work, then those distances are also included (from work to restaurant to work). Finally, the distance from work to home is added to complete the round-trip distance for that day. Any more driving miles that occur after arriving at home from work are not included in the round-trip commute distance (such as a trip to the grocery store). Figure 11-205 depicts this example, with the distance components included in the round-trip commute calculation as green lines.

All daily commutes by the vehicles in this study were included in a single distribution, which is shown in Figure 11-206.

This figure shows that 64% of round-trip commutes were 40 miles or less.

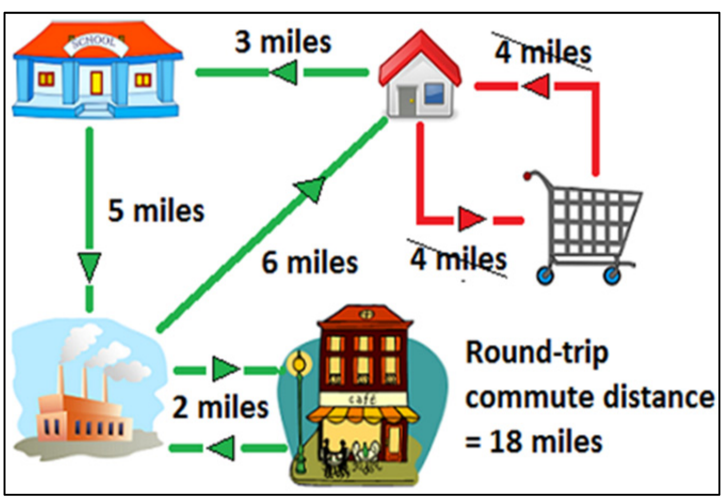


Figure 11-205. Components of a round-trip commute.

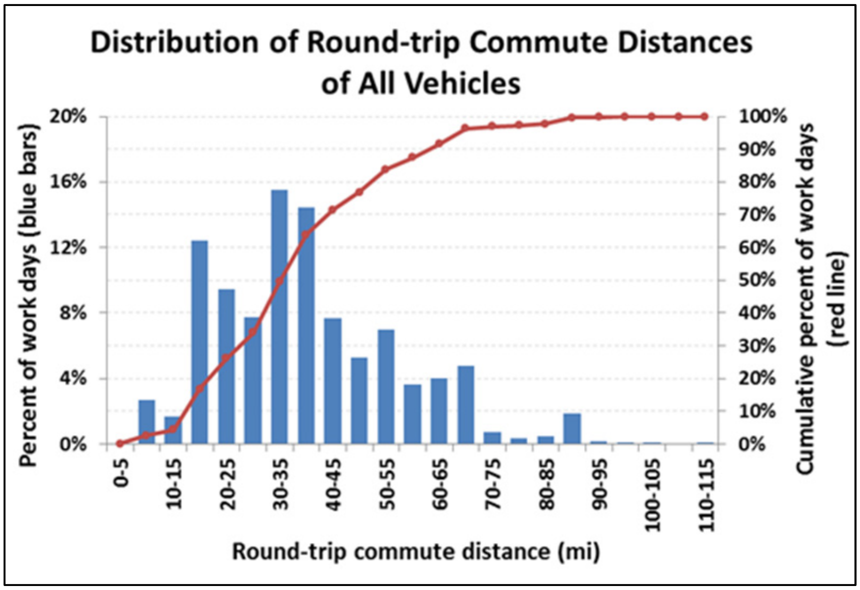


Figure 11-206. Distribution of round-trip commute distance.

11.7.3 Where Do Nissan Leaf Drivers in The EV Project Charge When They Have the Opportunity to Charge at Work?

11.7.3.1 Introduction. There has been much discussion about where EV charging infrastructure should be installed. Some researchers have proposed that EVs will be charged primarily at locations, where vehicles are naturally parked for the longest time. Travel surveys have shown that most vehicles are parked for the vast majority of time at home and at the work place [114]. Therefore, many researchers have assumed that most charging will be performed at home and work. This concept is commonly represented with a triangle similar to that shown in Figure 11-207. This figure represents the expectation that the majority of the charging will be performed at home, a significant amount of charging will be performed at work locations, and only a small amount of charging will be performed at other locations.

This paper investigates the actual charging location preferences of Nissan Leaf drivers in The EV Project who had the opportunity to charge at work. Charging location preference is described in terms of the percentage of charging events performed and charging energy consumed at home, at the workplace, and at non-workplace away-from-home locations.

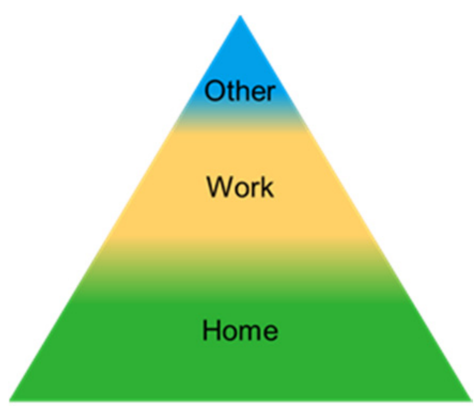


Figure 11-207. Common representation of expected EV charging frequency by location.

11.7.3.2 Key Conclusions

- A group of 707 Nissan Leafs from The EV Project, whose drivers had the opportunity to charge at work, performed 65% of their charging events at home, 32% at work, and 3% at other locations over the period between January 1, 2012, and December 31, 2013. The proportion of charging energy consumed by location during this time period was similar.
- During this study period, this group charged their vehicles away from home more than twice as much as the overall group of Nissan Leaf drivers enrolled in The EV Project.
- This study's drivers of Nissan Leafs with workplace charging performed 91% of their away-from-home charging events at work and 9% at non-workplace away-from-home locations.
- On days when this study's drivers of Nissan Leafs went to work, they performed 98% of their charging events either at home or work and only 2% at other locations.
- On days when this study's drivers of Nissan Leafs did not go to work, they performed 92% of their charging events at home and 8% at other locations.

11.7.3.3 Which Vehicles are Being Studied? Owners of Nissan Leafs in 19 metropolitan areas across the United States participated in The EV Project. They agreed to allow project researchers to monitor the usage of their vehicles throughout the 3-year project. From the overall group of participants, vehicles were selected that frequently parked at 277 work sites with known EV charging. These work sites are located in 11 metropolitan areas across the United States and vary in size from individual office buildings with small parking lots to large corporate complexes with multiple parking lots and garages. The type and amount of charging equipment also varies widely between sites, as well as the number and type of vehicles that could potentially charge at each site. Charging at some sites is open to the general public, while other sites restrict access to employees only. Some sites exact fees for charging and others offer free charging.

A group of 707 Nissan Leafs enrolled in The EV Project was found to have frequently parked at these sites between January 1, 2012, and December 31, 2013. This set of privately owned vehicles performed over 200,000 charging events during the 2-year study period. This paper will describe the proportion of these charging events that occurred at home, work, and other locations. The 707 Nissan Leafs in the sample hereafter will be referred to as "workplace vehicles."

As a requirement for participation in The EV Project, drivers of all workplace vehicles had the ability to charge at home. Each participant had an AC Level 2 (i.e., 240-volt) charging unit installed in their residence. They also had the opportunity to charge at work, based on the fact that they frequently parked at work sites where EV charging is available. It is important to note that workplace vehicles were included in the sample regardless of whether they were actually charged at work. This is a subtle but important distinction because some EV drivers may choose not to charge at work, even though they have the opportunity to do so.

11.7.3.4 Discussion of Results. Prior to analyzing workplace vehicles, the percentage of charging events performed, or charge frequency, and charge energy consumed by location was determined for all Nissan Leafs in The EV Project during the 2-year study period. These results are shown in Figure 11-208, which shows 84% of charging events were performed at the vehicle's home location and 16% of charging events were performed away from home. Nearly the same proportion of energy was consumed at home and away from home.

The proportion of charge events performed and energy consumed by the workplace vehicles in the 2-year study period was then determined for home, work, and other away-from-home non-work locations (hereafter referred to as "other" locations). Figure 11-209 shows these results.

Similar to the overall set of vehicles, the relative proportions of charge frequency and energy consumption by location for the workplace vehicles was nearly equal, with only slightly more energy per charge at home than at work or other locations. The frequency and energy of home charging was considerably lower for workplace vehicles than for the overall group of EV Project Nissan Leafs, indicating that workplace vehicles performed significantly more charging away from home.

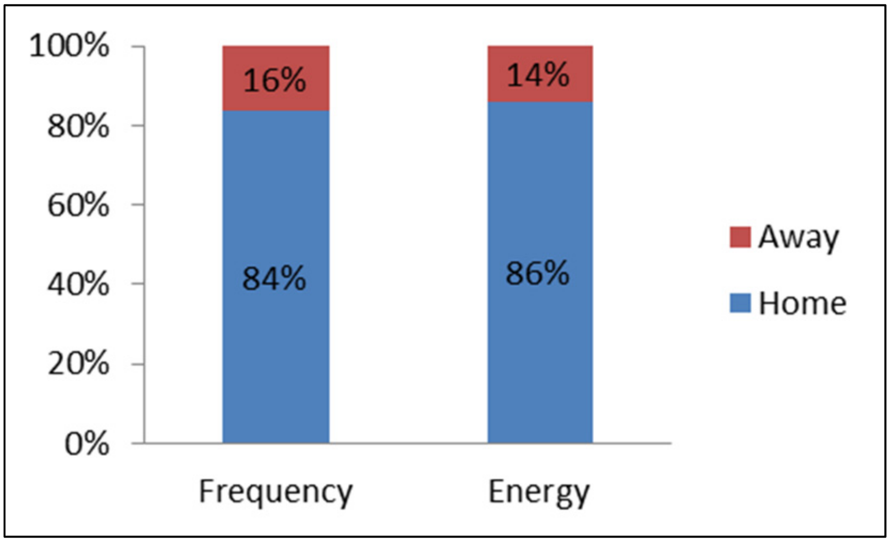


Figure 11-208. Charging frequency and energy consumption by location for all EV Project Nissan Leafs in 2012 and 2013.

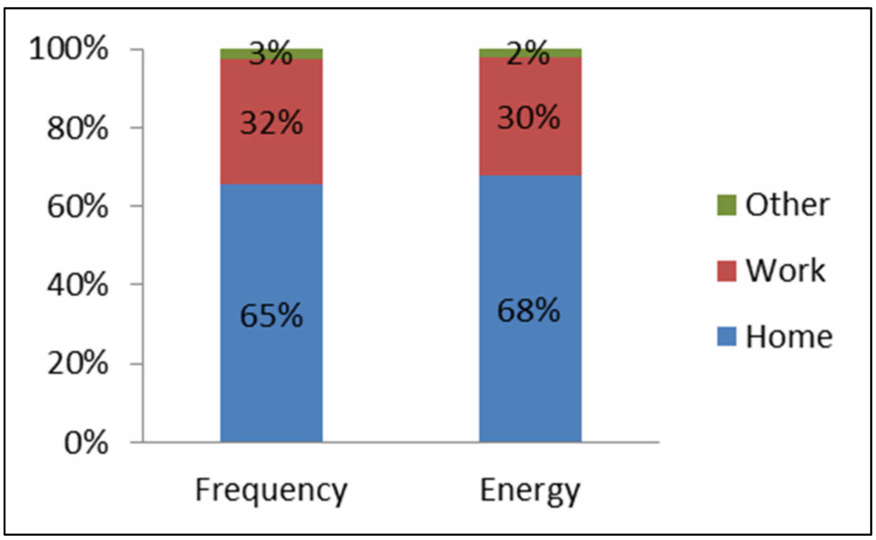


Figure 11-209: Charging frequency and energy consumption by location for workplace vehicles in 2012 and 2013.

Figure 11-209 also distinguishes the away-from-home charging between work and other locations. Comparing the sums of the work and other location charging frequency and energy in Figure 11-209 to the away-from-home charging in Figure 11-208 reveals that the workplace vehicles charged away from home more than twice as much as the overall group of EV Project Nissan Leafs.

In addition, Figure 11-209 shows that workplace vehicle drivers performed only 3% of charge events and consumed 2% of charge energy at other locations. These locations could be any dedicated public or private charging station or 120-volt outlet outside of the work sites or the drivers' residences. Comparing charging at work to other locations, workplace vehicles performed 91% of their away-from-home charging at their work location and only 9% at other locations. This indicates that not only did the workplace vehicles conduct more away-from-home charging than the overall group of EV Project Nissan Leafs, but the vast majority of that charging was at work.

Charge frequency of workplace vehicles by location is visualized in Figure 11-210 as a triangle, drawn to scale. This representation of actual results is similar to expected results often cited by researchers [115].

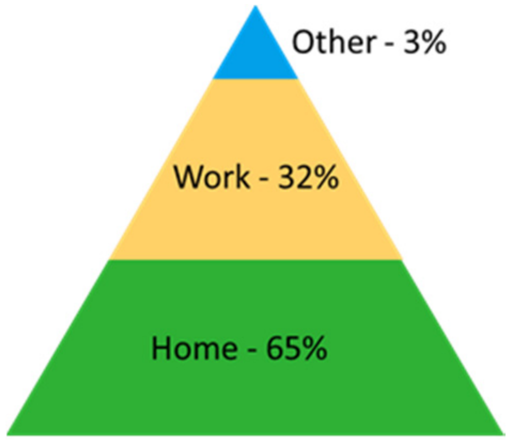


Figure 11-210. Charging frequency triangle for workplace vehicles drawn to scale.

Charging of workplace vehicles on the days they were parked at the work sites is displayed in Figure 11-211. On these days, charging at home and work accounted for 98% of charge events and 99% of charge energy. Very little charging occurred at other locations. This shows that, in aggregate, workplace vehicle drivers had little use for non-workplace public charging infrastructure on days they went to work.

Figure 11-212 shows charging of workplace vehicle on days when they were not parked at work sites. On these days, 8% of the charge events and 7% of the charge energy occurred at other locations. This is a significant increase over days when workplace vehicles went to work. However, non-work days represented only 33% of workplace vehicle calendar days in the study period.

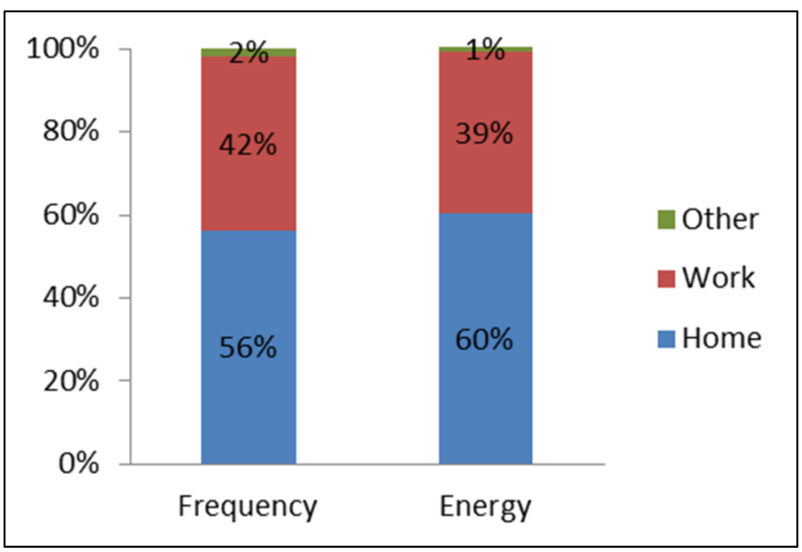


Figure 11-211. Charging frequency and energy consumption by location for workplace vehicles on days when they were parked at work sites.

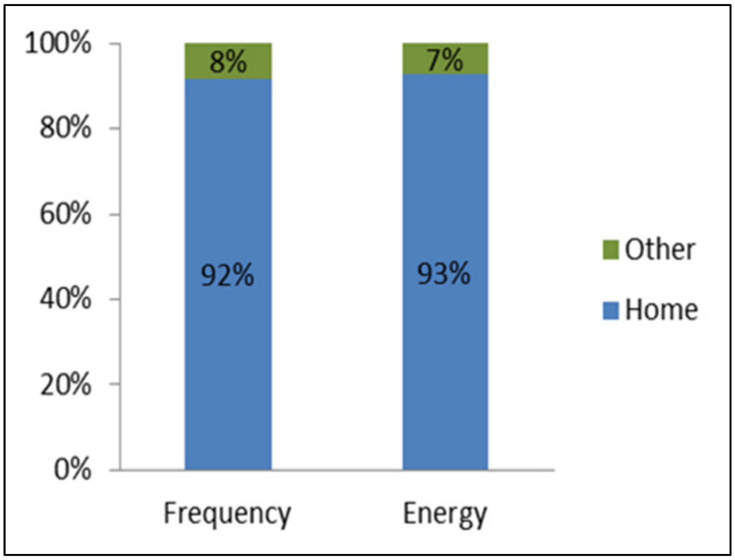


Figure 11-212. Charging frequency and energy consumption by location for workplace vehicles on days when they were not parked at work sites.

It is not yet clear how much the drivers of workplace vehicles depended on other charging locations to meet their driving needs. This question will be explored in future works to better understand the value of public charging infrastructure. Other factors need to be explored as well, such as the influence of commuting distance and the cost of charging on charging behavior.

11.7.3.5 References

114. E. Tate and P. Savagian, "The CO_2 Benefits of Electrification: E-REVs, PHEVs and Charging Scenarios," SAE 2009-01-1311, April 2009.

115. D. Bowermaster, "Plug-in Electric Vehicles Where Are We and What's Next?" Electric Power Research Institute, November 2013.

11.7.4 Charging and Driving Behavior of Nissan Leaf Drivers in The EV Project with Access to Workplace Charging

11.7.4.1 Introduction. Over 6,400 private owners of Nissan Leafs in 17 regions across the United States participated in The EV Project. They agreed to allow project researchers to electronically monitor the usage of their vehicles throughout the project.

Of The EV Project vehicles, 622 were identified as frequently having access to charging at one or more of 248 work sites known to offer workplace charging. The distribution of vehicles by region can be seen in Appendix A. Data collected from these Leafs from March 2011 through December 2013 were analyzed to determine how these vehicles were driven and charged on days when they went to work. To simplify the analysis, days were selected when the vehicle started and ended the day at its home location and spent over 4 hours parked at work. Also, the day could only include charging at the vehicle's home and work locations; days when the vehicle charged at other locations were excluded. The days when the vehicles were charged at locations other than home and/or work accounted for only 4% of the total days, which is consistent with previous findings [116]. Finally, care was taken to only include days that fell within the time period when charging equipment was installed for use at the work locations where the vehicle parked. This resulted in 76,321 total vehicle workdays, 53,351 of which included workplace charging.

All participants in The EV Project had AC Level 2 charging units installed in their homes. Therefore, the vehicles in this data set represent those who had access to charging at both home and work.

11.7.4.2 Key Conclusions

- A sample of 622 Nissan Leaf drivers participating in The EV Project with access to workplace charging charged at work on 53,351 vehicle days between March 2011 and December 2013.
- On nearly a quarter of those days, drivers drove far enough that they could not have completed their daily driving without workplace charging, even if they fully charged at home.
- On about half the days, drivers fully charged at home and "topped off" at work. On about a quarter of the days, drivers only charged at work, even though they had access to home charging.
- While 14% of vehicles needed workplace charging to complete their daily commutes most of the time, 43% of vehicles needed it some of the time (i.e., on at least 5% of commuting days). This shows that workplace charging is valuable as a range extender for drivers who live far from work, as well as drivers who sometimes need additional driving range beyond their typical commute.
- On days when drivers charged at work, they drove an average of 15% farther than days when they did not charge at work. This demonstrates that workplace charging provides a significant benefit for increasing eVMT.
- In fact, on days when drivers needed workplace charging, they drove 15 more miles, on average, than they would have been able to drive without workplace charging. The average commute on those days was 73 miles.

11.7.4.3 Classifying Daily Charging Behaviors. Drivers with access to both home and workplace charging may use their charging opportunities in different ways; therefore, it is helpful to categorize charging behaviors. In this analysis, days were assigned to one of the five following daily charging behaviors:

- *Enabling*: Days when the driver needed to charge at work in order to complete their daily driving, even if they charged to the fullest extent at home.
- *Top Off*: Days when the vehicle was fully charged at home before and after work and drivers "topped off" at work.
- *Some Home*: Days when the vehicle was fully charged at home before or after work, but not both. The vehicle was also charged at work.
- *Only Work*: Days when the vehicle was only charged at work; the driver did not do any home charging.
- *Everything Else:* Days when the vehicle was charged at work and some amount of home charging was performed, but the home charging did not fit into the above categories.

For enabling days, workplace charging enabled driving beyond the range provided by home charging alone. Drivers could not have performed all of the driving they did on enabling days without charging at work. For days in all of the other categories, home charging could have provided enough range to complete driving on those days; therefore, workplace charging was not strictly needed. However, if a driver did not fully charge at home, workplace charging could have had an enabling effect.

11.7.4.4 Percent of Days in Each Daily Charging Behavior. The dominant daily charging behaviors can be determined by looking at how often each of the behaviors occurs. Figure 11-213 shows the percentage of days in each charging behavior.

For nearly a quarter of the days analyzed (i.e., 22%), the daily driving could not have been completed without workplace charging. On these days, drivers were using workplace charging to extend their driving range beyond what could be achieved from home charging alone.

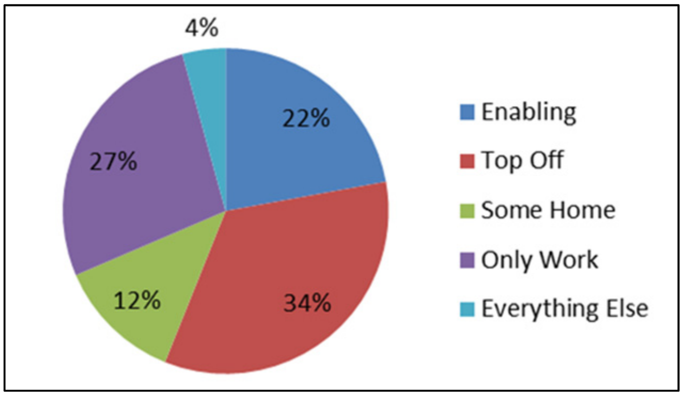


Figure 11-213. Percent of vehicle workdays in each behavior classification.

When considering vehicles with access to home charging, it would be natural to think that most vehicles would charge at home every night and add workplace charging when necessary; this is true for the top off and enabling days. This sentiment is shared by many in the EV community. However, this behavior only includes 56% of days. The remaining 44% of days showed that other behaviors were prevalent. In fact, on over one quarter of the days (i.e., 27%), drivers only charged at work. Presumably, a driver would do this to reduce charging costs, because many workplaces offer free charging for employees.

11.7.4.5 Classifying Vehicles Based On Dominant Daily Charging Behavior. After the days had been classified, the vehicles themselves could be classified, based on each vehicle's dominant behavior. If at least half of a vehicle's work days fell into one of the five daily charging behaviors, the vehicle was assigned to that behavior. Those vehicles that did not have a majority of their days in any one behavior are classified as mixed. The breakdown of the 622 vehicles into each category is shown in Figure 11-214.

As explained in the previous section, top off (35%) and enabling (14%) behaviors align with commonly held beliefs about drivers with access to workplace charging, yet less than half of the vehicles fall into these categories. Almost one third (i.e., 29%) of the vehicles did not even charge at home most of the time and regularly offset home charging with work charging instead. This behavior may provide monetary benefit to the driver, but it also may have an adverse effect on the electric grid.

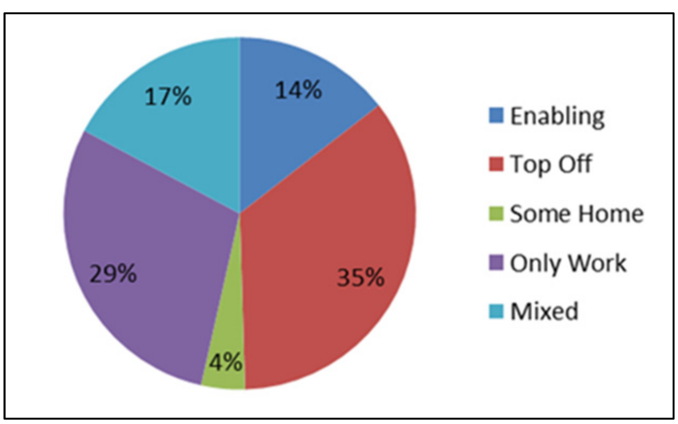


Figure 11-214. Percent of Leafs in each behavior classification.

About one sixth (i.e., 17%) of the vehicles did not have a dominant behavior and were categorized in the mixed category. These results illustrate that not only is there wide variation in behavior from vehicle to vehicle, but there is also day-to-day variation in behavior for individual vehicles. Because of this variation, dominant vehicle behaviors do not always tell the whole story. It is also important to understand that drivers of many vehicles exhibit certain behaviors some of the time.

This idea is evident when looking at the Enabling classification. While 14% of vehicles needed workplace charging most of the time, 43% needed it some of the time (i.e., on at least 5% of commuting days). This shows that workplace charging is valuable as a range extender for a large portion of drivers, whether they consistently need it because they live far from work, or they sometimes need additional driving range beyond their typical commute.

Applying the same idea to the Some Home behavior can provide different insights. It is the dominant behavior for very few drivers, but drivers of 64% of vehicles exhibit Some Home behavior on at least 5% of their days. Many of these drivers frequently charged at home, but occasionally forgot to or were not able to charge at home overnight. Not charging at night sometimes made workplace charging necessary to complete the next day's driving. Therefore, whether a driver regularly uses it or not, workplace charging can provide them with peace of mind, knowing they can still accomplish their daily driving if they forget to, or cannot, charge at home.

11.7.4.6 Miles Enabled By Workplace Charging. For all of the days in which workplace charging is classified as Enabling, some portion of the miles driven in that day could not have been driven without charging at work. There are a few ways of looking at how many miles workplace charging enabled. The first method takes the difference between the actual distance driven and the distance that could have been driven without workplace charging. This method can be thought of as a lower bound of the miles that workplace charging enabled. For example, consider a day when a vehicle drove 120 miles and the vehicle left home with a full battery capable of driving 85 miles. Workplace charging was required to provide energy for the remaining 35 miles; therefore, workplace charging enabled 35 miles for that day. The second method is based on the idea that if a vehicle could not have completed its daily driving without workplace charging, then that vehicle would not have been taken to work at all. Therefore, the entire commuting distance would be enabled by workplace charging. This method can be thought of as an upper bound of the miles that workplace charging enabled. The results of these methods can be seen in Table 11-83.

Table 11-83. Miles enabled by workplace charging.

Metric	Lower Bound	Upper Bound
Total miles enabled	187,030	882,961
Average enabled miles per vehicle day on days when workplace charging was needed	15	73

On days when drivers needed workplace charging, they drove 15 more miles, on average, than they would have been able to drive without workplace charging. The average commute on those days was 73 miles. This demonstrates that workplace charging provides a significant benefit for increasing eVMT.

11.7.4.7 Effect of Workplace Charging on Daily Miles Driven. Up to this point, only days when workplace charging was performed have been analyzed. However, it is important to understand how these days compare to workdays without workplace charging. In order to do so, data from vehicles that had workdays with and without workplace charging were analyzed. For each vehicle, average daily driving distance was calculated for both types of days. It was determined that on those days when drivers charged at work, they drove an average of 15% farther than days when they did not charge at work. When looking at days when drivers did not need to charge at work but charged anyway (top off, some home, only work, and everything else days), they drove an average of 12% farther than days when they did not charge at work. This shows that even on days when workplace charging is not needed, it still increases eVMT.

11.7.4.8 References

116. See "Where do Nissan Leaf drivers in The EV Project charge when they have the opportunity to charge at work?" at t http://avt.inel.gov/pdf/EVProj/ChargingLocationWorkplaceLeafsMar2014.pdf

11.7.4.9 Appendix A. Figure 11-215 shows the number of vehicles included in this study in 13 of the 17 areas where Nissan Leafs were enrolled in The EV Project.

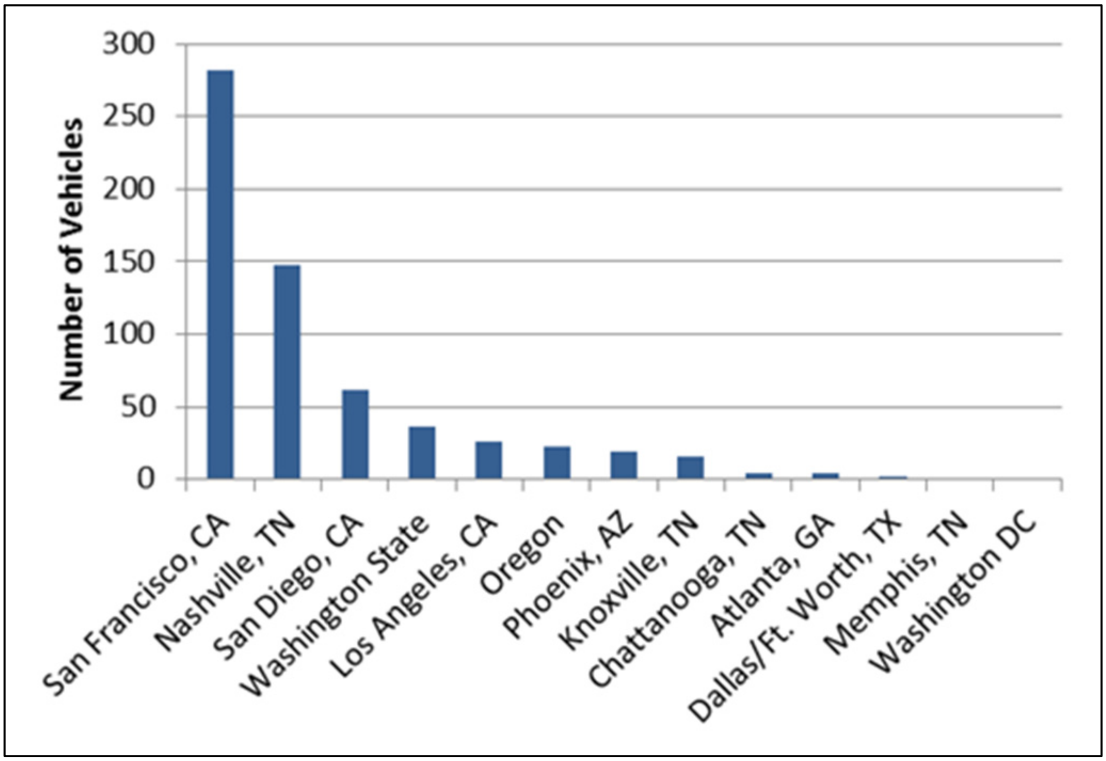


Figure 11-215. Number of vehicles included in this study.

11.7.5 Where Do Chevrolet Volt Drivers in The EV Project Charge When They Have the Opportunity to Charge at Work?

11.7.5.1 Introduction. There has been much discussion about where EV charging infrastructure should be installed. Some researchers have proposed that EVs will be charged primarily at locations where vehicles are naturally parked for the longest time. Travel surveys have shown that most vehicles are parked for the vast majority of time at home and at the work place [117]. Therefore, many researchers have assumed that most charging will be performed at home and work. This concept is commonly represented with a triangle similar to that shown in Figure 11-216. This figure represents the expectation that the majority of the charging will be performed at home, a significant amount of charging will be performed at work locations, and only a small amount of charging will be performed at other locations.

This paper investigates the actual charging location preferences of Chevrolet Volt drivers in The EV Project who had the opportunity to charge at work. Charging location preference is described in terms of the percentage of charging events performed and charging energy consumed at home, at the workplace, and at non-workplace away-from-home locations.

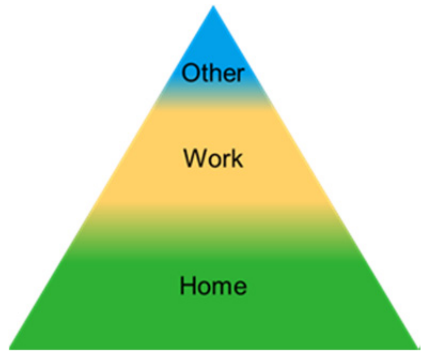


Figure 11-216. Common representation of expected EV charging frequency by location.

11.7.5.2 Key Conclusions

- A group of 96 Chevrolet Volts from The EV Project, whose drivers had the opportunity to charge at work, performed 57% of their charging events at home, 39% at work, and 4% at other locations over the period between January 1, 2013, and December 31, 2013. The proportion of charging energy consumed by location was similar.
- During this study period, this group charged their vehicles away from home more than 2.5 times as much as the overall group of Chevrolet Volt drivers enrolled in The EV Project.
- This study's drivers of Chevrolet Volts with workplace charging performed 92% of their away-from-home charging events at work and 8% at non-workplace away-from-home locations.
- On days when this study's drivers of Chevrolet Volts went to work, they performed 98% of their charging events either at home or work and only 2% at other locations.
- On days when this study's drivers of Chevrolet Volts did not go to work, they performed 89% of their charging events at home and 11% at other locations.

11.7.5.3 Which Vehicles are Being Studied? Owners of Chevrolet Volts in 18 metropolitan areas across the United States participated in The EV Project. They agreed to allow project researchers to monitor the usage of their vehicles throughout the 3-year project. From the overall group of participants, vehicles were selected that frequently parked at 97 work sites with known EV charging. These work sites are located in 15 metropolitan areas across the United States and vary in size from individual office buildings with small parking lots to large corporate complexes with multiple parking lots and garages. The type and amount of charging equipment also varies widely between sites, as well as the number and type of vehicles that could potentially charge at each site. Charging at some sites is open to the general public, while other sites restrict access to employees only. Some sites exact fees for charging and others offer free charging.

A group of 96 Chevrolet Volts enrolled in The EV Project was found to have frequently parked at these sites between January 1, 2013, and December 31, 2013. This set of privately owned vehicles performed over 29,000 charging events during the 1-year study period. This paper will describe the proportion of these charging events that occurred at home, work, and other locations. The 96 Chevrolet Volts in the sample hereafter will be referred to as "workplace vehicles."

As a requirement for participation in The EV Project, drivers of all workplace vehicles had the ability to charge at home. Each participant had an AC Level 2 (i.e., 240-volt) charging unit installed in their residence. They also had the opportunity to charge at work, based on the fact that they frequently parked at work sites where EV charging is available. It is important to note that workplace vehicles were included in the sample regardless of whether they were actually charged at work. This is a subtle but important distinction because some EV drivers may choose not to charge at work, even though they have the opportunity to do so.

11.7.5.4 Discussion of Results. Prior to analyzing workplace vehicles, the percentage of charging events performed, or charge frequency, and charge energy consumed by location was determined for all Chevrolet Volts in The EV Project during the 1-year study period. These results are shown in Figure 11-217, which shows 84% of charging events were performed at the vehicle's home location and 16% of charging events were performed away from home. Nearly the same proportion of energy was consumed at home and away from home.

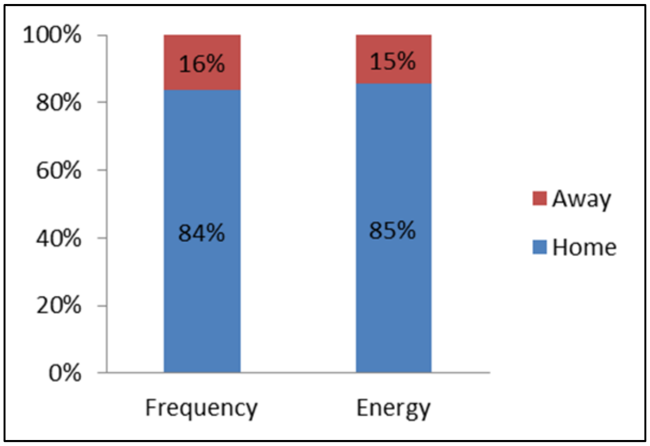


Figure 11-217. Charging frequency and energy consumption by location for all EV Project Chevrolet Volts in 2013.

The proportion of charge events performed and energy consumed by the workplace vehicles in the 1 year study period was then determined for home, work, and other away-from-home non-work locations (hereafter referred to as "other" locations). Figure 11-218 shows these results.

Similar to the overall set of vehicles, the relative proportions of charge frequency and energy consumption by location for the workplace vehicles was nearly equal, with only slightly more energy per charge at home than at work or other locations. The frequency and energy of home charging was considerably lower for workplace vehicles than for the overall group of EV Project Chevrolet Volts, indicating that workplace vehicles performed significantly more charging away from home.

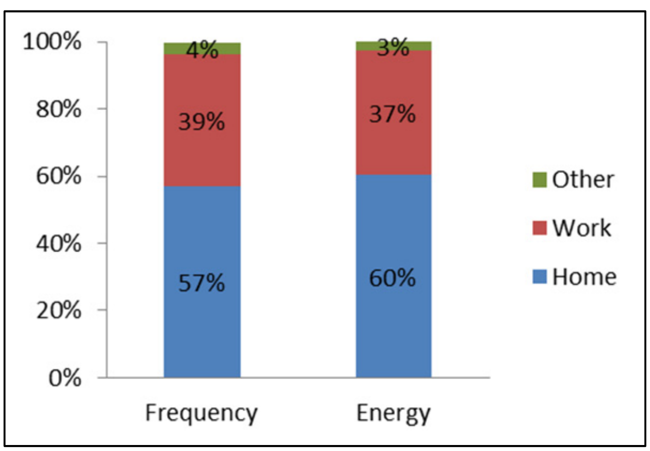


Figure 11-218. Charging frequency and energy consumption by location for workplace vehicles in 2013.

Figure 11-218 also distinguishes the away-from-home charging between work and other locations. Comparing the sums of the work and other location charging frequency and energy in Figure 11-218 to the away-from-home charging in Figure 11-217 reveals that the workplace vehicles charged away from home more than 2.5 times as much as the overall group of EV Project Chevrolet Volts.

In addition, Figure 11-218 shows that workplace vehicle drivers performed only 4% of charge events and consumed 3% of charge energy at other locations. These locations could be any dedicated public or private charging station or 120-volt outlet outside of the work sites or the drivers' residences. Comparing charging at work to other locations, workplace vehicles performed 92% of their away-from-home charging at their work location and only 8% at other locations. This indicates that not only did the workplace vehicles conduct more away-from-home charging than the overall group of EV Project Chevrolet Volts, but the vast majority of that charging was at work.

Charge frequency of workplace vehicles by location is visualized in Figure 11-219 as a triangle, drawn to scale. This representation of actual results is similar to expected results often cited by researchers [118].

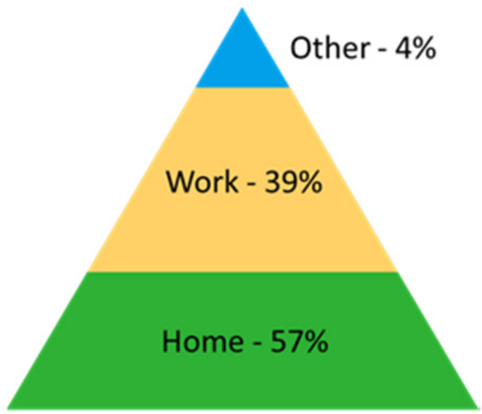


Figure 11-219. Charging frequency triangle for workplace vehicles drawn to scale.

Charging of workplace vehicles on the days they were parked at the work sites is displayed in Figure 11-220. On these days, charging at home and work accounted for 98% of charge events and 99% of charge energy. Very little charging occurred at other locations. This shows that, in aggregate, workplace vehicle drivers had little use for non-workplace public charging infrastructure on days they went to work.

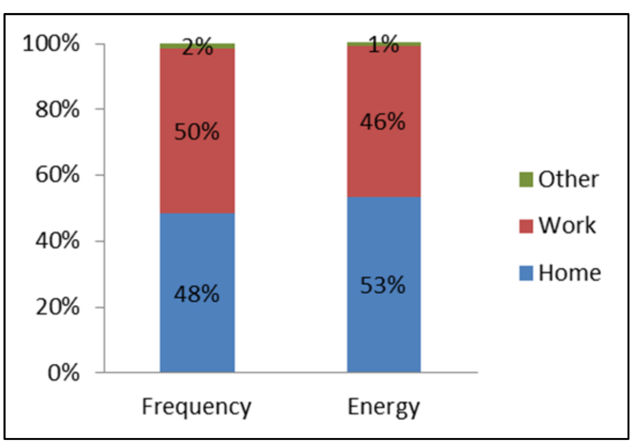


Figure 11-220. Charging frequency and energy consumption by location for workplace vehicles on days when they were parked at work sites.

Figure 11-221 shows charging of workplace vehicle on days when they were not parked at work sites. On these days, 11% of the charge events and 11% of the charge energy occurred at other locations. This is a significant increase over days when workplace vehicles went to work. However, non-work days represented only 30% of workplace vehicle calendar days in the study period.

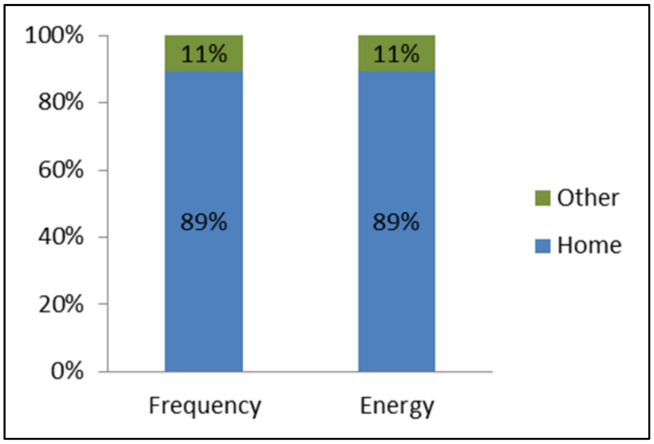


Figure 11-221. Charging frequency and energy consumption by location for workplace vehicles on days when they were not parked at work sites.

It is not yet clear how much the drivers of workplace vehicles depended on other charging locations to meet their desire for driving in electric-only mode. This question will be explored in future works to better understand the value of public charging infrastructure. Other factors need to be explored as well, such as the influence of commuting distance and the cost of charging on charging behavior.

11.7.5.5 References

117. E. Tate and P. Savagian, "The CO2 Benefits of Electrification: E-REVs, PHEVs and Charging Scenarios," SAE 2009-01-1311, April 2009.

118. D. Bowermaster, "Plug-in Electric Vehicles Where Are We and What's Next?", Electric Power Research Institute, November 2013.

11.7.6 Accessibility at Public Electric Vehicle Charging Locations

11.7.6.1 Introduction. One purpose of The EV Project was to identify potential barriers to the widespread adoption of PEVs and the deployment of EVSE to support them. This process identified topics of national interest in the early deployment of PEV charging stations in order to facilitate discussion and resolution. This section documents the issues associated with The EV Project's approach to compliance with the U.S. ADA (28 CFR Part 36).

The EV Project deployed more than 4,000 AC Level EVSEs and DCFC in non-residential locations. These AC Level 2 EVSE provide recharge services to all PEVs manufactured or sold in the United States utilizing the standard J1772 connector. As many of these EVSE are publically available, requirements of ADA are applicable. However, current state and federal regulations do not provide design standards that specifically address PEV parking and charging.

New standards may be developed; therefore, interpretations and recommendations herein constitute the best guidance to-date.

11.7.6.2 Lessons Learned

Applicability—Federal statutes and national standards that guide accessibility requirements include the following:

- 2009 International Building Code/2003 ANSI A117.1 standards
- U.S. ADA (28 CFR Part 36)

Generally, agencies or companies that build new facilities or alter existing facilities must comply with the ADA Standards for Accessible Design. The ADA also requires that all state and local government programs and services and all goods and services offered to the public by businesses be accessible to people with disabilities.

The Federal ADA requirements as well as state and local disability laws require services provided to the public by business and government to be offered equally to persons with disabilities. Because AC Level 2 commercial charging stations and DCFC stations deployed under The EV Project are a service offered to the public, they must be manufactured and installed to meet the accessibility requirements of federal, state and local laws.

The ADA Accessibility Guidelines for Buildings and Facilities does not specifically address charging station design. However, equal access for persons with disabilities to publicly available EV charging stations is still required even absent Accessibility Guidelines for Buildings and Facilities design guidelines. Accessibility to the EVSE and accessibility to the facility are both important, although separate, considerations.

In the absence of specific accessibility guidelines for PEV charging stations, states such as California, Oregon, and Washington were utilizing preliminary guidance documents, past and present, to assist with application of accessibility standards to EVSE deployment efforts1. Many cities and counties are also developing their own charge station deployment guidelines.

Because The EV Project had to install charging stations in multiple states and local jurisdictions with the potential for varying interpretations of accessibility requirements, it was necessary to conduct an assessment of the application of existing accessibility requirements to charging station design in order to assist The EV Project in developing methodology for compliance with accessibility requirements from the Federal Regulations, the 2009 International Building Code/2003 ANSI A117.1, and the 2010 California Building Code. Results of this assessment are presented in the following paragraphs.

General Parking Accessibility Requirements—An accessible space is at least 8-ft wide by 18-ft deep (Figure 11-222 and Table 11-84), which includes an access aisle of 5 ft on the passenger side.
Two accessible spaces can share the common access aisle. A van accessible space is the same size with an 8-ft access aisle on the passenger side.

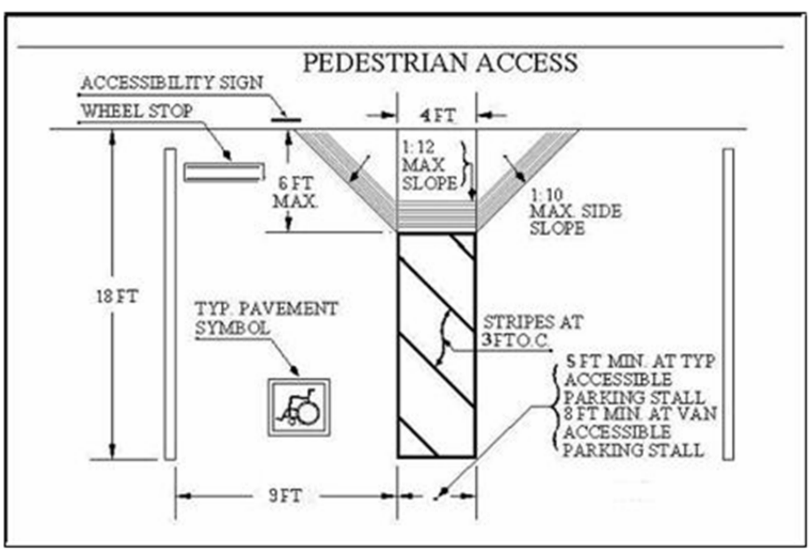


Figure 11-222. Typical accessible parking space.

In general, for every 25 parking spaces, one parking space should be accessible. For every six parking spaces that are accessible, one parking space should be van accessible.

Table 11-84. Accessible and van accessible spaces.

Parking Spaces	Accessible Spaces	Van Accessible Spaces
1	1	1
2 to 25	1	1
26 to 50	2	1
51 to 75	3	1
76 to 100	4	1

A summary of the elements required for accessibility is found in Table 11-85.

Table 11-85. Accessible requirements.

Element	ADA/ABA 2004 ANSI A117.1 2003	CA Building Code 2010
Accessible Route Width	Minimum 36 in. wide	Minimum 48 in. wide
Accessible Route Slope/Cross Slope	Maximum 1:20 (5%) running slope and 1:48 (2%) cross slope; Accessible vehicle spaces 1:48 (2%) in all directions	Maximum 1:20 (5%) running slope and 1:50 (2%) cross slope; Accessible vehicle spaces 1:50 (2%) in all directions
Reach Range	48-in. front and side	54-in. side reach range and 48-in. front reach range
Accessible Controls	Operable with one hand, and not requiring grasping, pinching, or twisting of the wrist or force more than 5 lb. Exception: Gas pumps.	Same
Side Access Aisle	Side access aisle of 60 in." wide	Side access aisle of 60 in. wide
Accessible Card Reading Devices		One card reader and two card readers if multiple to be within 54-in. reach range; Accessible route; 30 in. x 48-in. clear floor space centered on the reader (±9 in.), with the face of the reader maximum 10-in. deep

The general requirements for accessibility can be applied to PEV charging stations. A person with disabilities utilizing an accessible EVSE parking space must be able exit their vehicle, enter a side access aisle to access the EVSE, operate the charging station, insert the EVSE connector into the EV and access the services onsite. In addition, the EVSE must comply with the specific ADA requirements noted in Table 11-85.

Restrictions for Electric Vehicle Charging Only—Establishing a PEV charging infrastructure has unique challenges in that the public is not used to seeing EVSEs in public and may be unfamiliar with its purpose and use. Without specific signage to the contrary, ICE vehicles may park in spaces equipped with an EVSE because they are convenient and vacant. When a PEV arrives, the driver finds the space occupied and is unable to connect. For that reason, it is recommended that municipalities adopt specific ordinances to prohibit non-PEVs from parking in spaces marked (Figure 11-223) for "EV Charging Only" and require that PEVs parked in spaces marked for “EV Charging Only” must be connected to the EVSE while parked.

Therefore, it may not be feasible to install EVSE in existing accessible parking spaces because that space then becomes exclusively designated for a PEV and would remove one of the accessible spaces originally required for the facility.

Figure 11-223. PEV charging only sign.

Facility Accessibility—The introduction of EVSEs into an existing parking area brings several challenges. While there is significant interest and incentive to install EVSEs to promote range confidence for PEVs, there are several practical considerations as well. Without a substantial quantity of PEVs in the local market, businesses are wary of investing in the new technology and potential business benefits. The market is still nascent and making the business case is difficult. Consequently, business owners who are interested in providing EV charging are interested in completing the installation for the least cost.

The lowest costs for EVSE installations are typically found closer to the electrical supply where any concrete or asphalt cuts are minimal. These locations are typically not near the business entrance.

It has been found that placing the PEV charging in only the parking spaces in prime locations in a parking lot can be detrimental to the image of PEVs in that ICE drivers feel the preferential treatment given is unfair and especially so if the space is frequently vacant.

Thus, PEV parking spaces in preferential locations near the entrance are generally discouraged.

For these reasons, providing an accessible path of travel to the business entrance may also be difficult.

Disproportionality—Subpart D of 28 CFR Part 36 does provide some guidance when considering costs associated with the design and installation of improvements to a parking area.

Alterations made to provide an accessible path of travel to the altered area will be deemed disproportionate to the overall alteration when the cost exceed 20% of the cost of the alteration to the primary function area [120].

In addition, this section identifies examples of costs that may be considered including “costs associated with providing an accessible entrance and an accessible route to the altered area, for example, the cost of widening doorways or installing ramps;…and costs associated with making restrooms accessible, such as installing grab bars, enlarging toilet stalls,…” [121].

The reference to enlarging toilet stalls as an example would infer costs associated with widening of a parking space could be included. If the cost to widen a parking space and the associated changes to the parking lot exceed 20% of the cost of the alteration to the primary function area, the cost would be disproportional.

Exclusivity—ADA sets out design requirements for an accessible bathroom. However, an accessible bathroom stall is not reserved exclusively for a person with disabilities. The same is true for accessible hotel rooms. Likewise, an accessible EVSE parking space need not be reserved exclusively for an accessible PEV. As noted in the advisory, “Enforcement of motor vehicle laws, including parking privileges, is a local matter” [122].

Card Reading Devices—Requirements for card reading devices are identified in Table 11-86. The AC Level 2 Blink EVSE does not contain a card reading device. It does contain a radio frequency identification device reader, which is used to turn on the charging station by placing a radio frequency identification device card close to the onboard antenna. Placement of an accessible EVSE unit shall allow a 48-in. reach to the radio frequency identification device antenna and the EV connector and cable management system.

AC Level 2 EVSE—AC Level 2 EVSE refer to the EVSE category that is powered by 240-Volt AC current. This is typical of most of the expected EVSE in the workplace and publicly available at destination locations. AC Level 2 EVSE must be designed for accessibility.

The EV Project provided for accessibility in the AC Level 2 EVSE by adjusting the height of the unit (Figure 11-224).

Figure 11-224. EV Project AC Level 2 EVSE.

Direct Current Fast Charger Connector—The DCFC is designed to return a significant recharge to the EV in a short period of time. It is expected that a PEV will remain connected to this DCFC for a short time, similar to that involved in refueling an internal combustion car. To accomplish this, the equipment is designed to provide the high current necessary. The weight of the DCFC connector and cable is the biggest impediment to full, unassisted access to the DCFC station (Figure 11-225).

Table 11-86. PEV accessibility requirements.

Element	ADA/ABA 2004 ANSI A117.1 2003	California Building Code 2010
Accessible Route Width	Minimum 36 in. wide	Minimum 48 in. wide
Accessible Route Slope/Cross Slope	Maximum 1:20 (5%) running slope and 1:48 (2%) cross slope; Accessible vehicle spaces 1:48 (2%) in all directions	Maximum 1:20 (5%) running slope and 1:50 (2%) cross slope; Accessible vehicle spaces 1:50 (2%) in all directions
Reach Range	48 in. front and side	54-in. side reach range and 48-in. front reach range
Accessible Controls	Operable with one hand, and not requiring grasping, pinching, or twisting of the wrist or force more than 5 lb. Exception: Gas pumps.	Same
Side Access Aisle	Side access aisle of 60 in. wide	Side access aisle of 60 in. wide
Accessible Card Reading Devices		One card reader and two card readers if multiple to be within 54-in. reach range; Accessible route; 30-in. x 48-in. clear floor space centered on the reader (±9 in.), with the face of the reader maximum 10 in. deep.

Figure 11-225. EV Project DCFC.

The closest comparison of accessibility requirements for DCFC stations is with retail gasoline stations. The gasoline-dispensing nozzle typically presents impediments to full unassisted access that are similar to those encountered with the DCFC connector and cable. Access can typically be achieved only by the use of an attendant to assist with fueling. Although ADA requires self-serve gas stations to provide equal access to their customers by the use of an attendant, it provides an exception when the station is operated on a remote control basis with only a single employee. In California, gas stations staffed with two or fewer employees are exempt from accessibility requirements. Such stations are required to post signage indicating that they provide the refueling service as well as signs alerting customers that they cannot provide the accessible service based on a lawful exemption (California Business and Profession Code § 13660). Other examples that do not provide for any back-up attendant service for disabled users are electronic parking lots and street parking meters, bank ATM machines, drive-up ATM machines, security intercom devices for both pedestrian and vehicular use, and private parking lot ticket machines.

Thus the business nature of the DCFC host and other factors such as employee availability, the location of the unit, and costs associated with a local call system will determine whether support services can be available. The exceptions noted above suggest that these support services are not required.

To the Maximum Extent Feasible—Installing an ADA accessible EVSE parking space affects the balance of parking for a facility because of the increased width of the access aisle. In many cases, the access aisle will reduce the total number of parking spaces by at least one. Giving up more parking spaces may be difficult for the business owner when the size of the parking lot is already limited. The following guidance is provided by the 2010 ADA Standards for Accessible Design:

The phrase "to the maximum extent feasible," as used in this section, applies to the occasional case where the nature of an existing facility makes it virtually impossible to comply fully with applicable accessibility standards through a planned alteration. In these circumstances, the alteration shall provide the maximum physical accessibility feasible. Any altered features of the facility that can be made accessible shall be made accessible. If providing accessibility in conformance with this section to individuals with certain disabilities (e.g., those who use wheelchairs) would not be feasible, the facility shall be made accessible to persons with other types of disabilities (e.g., those who use crutches, those who have impaired vision or hearing, or those who have other impairments)" [123].

Creating an accessible PEV Van parking space may not be feasible, but an accessible PEV parking space may be feasible. This requirement will be the primary guidance for EVSE installation.

11.7.6.3 Recommendations. Federal accessibility standards do not specifically address PEV charging stations. Nevertheless, it is required to incorporate ADA accessibility requirements in the design of commercial charging station equipment and installation plans. For the purpose of The EV Project and early market deployment of commercial EVSEs, it was found that reasonable efforts to incorporate accessibility requirements during installation of its commercial AC Level 2 and DCFC stations can be accomplished.

Recommendations for AC Level 2 EVSE—The following recommendations will enable persons with disabilities to have access to a charging station and comply with the ADA and International Building Code:

- Parking is required in order to use the charging station. An accessible space is required to park, exit vehicle and access the charging station. The accessible charging station space should have a 96 in. wide space with a 60 in. wide access aisle similar to a standard accessible parking space.
- Operable controls within 48 in. front and side reach range; a 30-in. x 48-in. clear floor space is required.
- If the accessible charging station is located at a site with other amenities, such as at a convenience store, coffee shop, etc., then the space needs to be connected by a minimum 36 in. wide accessible route to the entry of the building. Accessible routes must have maximum 1:20 (5%) running slope and 1:48 (2%) cross slope. It is not an accessible route where wheelchair users and others with mobility impairments need to compete with vehicular traffic in the traffic aisles.

Compliance Recommendations:

- When an accessible AC Level 2 EVSE is added to an existing accessible parking space, the parking space must still meet all of the criteria of an accessible space, including being reserved exclusively for the use of disabled persons. However, because this accessible parking space is part of the original accessible parking design, it cannot be reserved exclusively for EV Charging Only.
- Accessible charging station spaces should have a 96 in. wide space with a 60 in. wide access aisle, and be provided in the ratio of 1 per 25 charging station spaces installed. Accessible EV van spaces should be provided with a 96 in. wide access aisle. Table 11-87 illustrates the requirements for EV parking spaces.

Table 11-87. EV parking space requirements.

EV Parking Spaces	Accessible EV Spaces	Accessible EV Van Spaces
1	1	1
2 to 25	1	1
26 to 50	2	1
51 to 75	3	1
76 to 100	4	1

In instances where widening an existing parking space or eliminating a parking space is required to establish an accessible space, a project cost analysis may be conducted to identify costs associated with establishing the accessible space. If the costs for alterations required to provide an accessible space exceed 20% of the unaltered project cost, the alteration costs may be deemed disproportionate to the overall project cost.

- Access aisles must take into consideration use from either side to accommodate differences in location of charging inlets across vehicles. The differences in charging inlets across vehicles and the design of the EVSE may require the EV driver, both able bodied and disabled, to back into the parking space.
- As charging is considered the primary purpose of parking spaces equipped with PEV charging equipment, the charge station facility is not a parking facility. When an accessible PEV charger is added to a new accessible parking space, the accessible charging station does not need to be located immediately adjacent to the building entrances. New accessible charging stations should be located in a reasonable proximity to the building or facility entrance (consistent with the economical installation of electrical service to the charging equipment).
- If an accessible charging station is located on the site of a building that is required to be accessible, (e.g., convenience store, coffee shop, etc.), then the charging station must be connected by an accessible route to the entry of the building. Provision of an accessible route through a parking lot may require curb ramps, crosswalks or other alterations. As an alternative, establishing an accessible route may involve moving the proposed charging station adjacent to an existing accessible parking space that has an existing accessible route. In instances where alterations to an existing site or relocation of the charging station are required to establish an accessible route, a project cost analysis may be conducted to identify costs associated with establishing the accessible route. If the costs for alterations required to provide an accessible route from the charging station to the building entrance exceed 20% of the unaltered project cost, the alteration costs may be deemed disproportionate to the overall project cost. In this case, the path of travel will be made accessible to the extent that it can be without incurring disproportionate costs. The disabled person will have access to the charging station but may need to move the vehicle to obtain access to the entry of the building.
- Distinct signage must be utilized at accessible charging station parking spaces indicating that the space is only for PEV charging purposes. It is not necessary that this signage designate the accessible PEV charging station exclusively for the use of disabled persons. When not in use by a disabled person, the accessible charging station can be used by able bodied persons similar to the use of accessible hotel rooms, except when the accessible AC Level 2 EVSE is added to an existing accessible parking space (see compliance recommendation, the first bullet).

Recommendations for DCFC—The DCFC shall be designed for accessibility. In addition, the recommendations above for the AC Level 2 EVSE apply along with the following recommendations. The Blink DCFC does not contain a card reading device.

- Proposed locations for DCFC station installations may have an attendant (such as at a gas station/convenience store) or not, as in an unattended parking lot or minimally staffed location.

Where available, attendants may be used to provide equal access to DCFC stations. Signs or notification on or near the DCFC stations will let customers know that individuals with disabilities can obtain charging assistance by honking their horn or otherwise signaling an employee. A call button may be provided.

- The cable and connector for DCFC stations weigh approximately 19 lb. The force required to operate the DCFC connector lever and insert it into the EV inlet exceeds the 5 lb maximum operating force for accessible controls. However, the exemption allowed for gasoline-dispensing nozzles is applicable here.

11.7.6.4 Summary. Federal accessibility standards do not specifically address EV charging stations. Nevertheless, it is required to incorporate ADA accessibility requirements in the design of commercial charging station equipment and installation plans.

In general, design requirements provided by the 2010 ADA Standards for Accessible Design can be accommodated in the design and installation of publicly available EVSE. In some cases, strict interpretation of these design requirements may increase the project costs disproportionally or create such facility design issues that compliance is not feasible. Public policy and direction is favoring the expansion of the EV charging infrastructure and strict interpretation may impede its development. Consideration for this situation is already provided in the ADA Standards related to “disproportionality” and “maximum extent feasible.”

For the purpose of The EV Project and early market deployment of commercial EVSE, it was found that reasonable efforts to incorporate accessibility requirements during installation of its commercial DCFC stations can be accomplished under the above parameters

11.7.6.5 References

119. California Department of General Services – Division of the State Architect – Policies, DSA – 2011 California Access Compliance Reference Manual Policies, 97-03 (Revised 6/05/97); State of Oregon Building Codes Division – Local Building Department Newsletter, “Electric Vehicle Charging Stations and ADA” (12/08/10), www.bcd.oregon.gov/bldg_newsletter/index.html; Washington Department of Commerce and Puget Sound Regional Council – “Electric Vehicle Infrastructure – A Guide for Local Governments in Washington State,” July 2010.

120. Subpart D of 28 CFR Part 36, § 36.403(f)

121. ibid

122. Subpart D of 28 CFR Part 36, § 502.6

123. Subpart D of 28 CFR Part 36, § 36.402(c)

12. COMBINED PROJECTS LESSONS LEARNED

12.1 Categorizing Electric Vehicle Supply Equipment Venues: Describing Publicly Accessible Charging Station Locations

12.1.1 Introduction

Many stakeholders in the PEV industry are interested in how non-residential EVSE units are used at various types of locations. The EV Project, ChargePoint America Project, and West Coast Electric Highway Project provided the opportunity to collect data from Blink, ChargePoint, and AeroVironment brand charging stations installed around the United States. Over 6,000 EVSE charge ports were installed at publicly accessible sites as part of these demonstrations.

In order to analyze EVSE usage by location, it was necessary to create a system for categorizing EVSE sites by location type or venue. A two-level classification system was selected, in which EVSE sites were assigned a primary venue and a sub-venue. The primary venue is a coarse classification that broadly defines the site location and provides a general perspective on why a PEV driver would be parking at that location. Primary venue categories were chosen to be compatible with other PEV charging infrastructure demonstrations [1]. A sub-venue subdivides the primary venue category to provide an additional level of detail.

Information provided about EVSE sites by The EV Project, ChargePoint America, and AeroVironment, as well as publicly available information, were used to classify EVSE sites into venue categories. The publicly available information sources that were used included Google Earth, Google Maps, Google Street View, PlugShare, ReCarGo, and various ESRI geographic layers. Geospatial data were visually inspected and cross-referenced with project data to classify each EVSE site.

The purpose of this document is to define each primary venue and sub-venue category. The results from analysis of EVSE usage by venue will be presented in future papers.

12.1.2 Primary Venues

- Education: Training facilities, universities, or schools.
- Fleet: EVSE known to be used primarily by commercial or government fleet vehicles.
- Hotels: Hotel parking lots provided for hotel patron use.
- Leisure Destination: Parks and recreation facilities or areas, museums, sports arenas, or national parks or monuments.
- Medical: Hospital campuses or medical office parks.
- Multi-Family: Parking lots serving multi-family residential housing (also referred to as multi-unit dwellings).
- Non-Profit Meeting Places: Churches or charitable organizations.
- Parking Lots/Garages: Parking lots or garages that are operated by private parking management companies, property management companies, or municipalities that offers direct access to a variety of venues.
- Public/Municipal: City, county, state, or federal government facilities.
- Retail: Retail locations both large and small, such as shopping malls, strip malls, and individual stores.
- Transportation Hub: Parking locations with direct pedestrian access to other forms of transportation, such as parking lots at airports, metro-rail stations, or ferry port parking lots.

- Workplace: Business offices, office parks or campuses, or industrial facilities.

12.1.2.1 Sub-Venues

- Arts and Entertainment: Museums, sports arenas, concert halls, or theaters.
- Auto Dealer: A retail location that sells automobiles.
- Business Office: Large office buildings and business office parks.
- Church: Religious meeting houses or places of worship.
- City: City buildings, facilities, or parking areas.
- County: County buildings and facilities.
- Educational Services: Education facilities, such as colleges, training facilities, and K-12 schools.
- Fleet: EVSE known to be used primarily by commercial or government fleet vehicles.
- Healthcare/Medical: Hospital campuses or medical office parks.
- Hotels: Hotel parking lots provided for hotel patron use.
- Mall/Shopping Center: Indoor or outdoor shopping areas containing multiple national chains and/or local retailers.
- Multi-Family: Parking lots serving multi-family residential housing (also referred to as multi-unit dwellings).
- Parking Lots/Garages: Parking lots or garages that are operated by private parking management companies, property management companies, or municipalities that offers direct access to a variety of venues.
- Parks and Recreation: Parks or public recreation facilities, such as soccer complexes and tennis parks.
- Professional/Technical: Establishments that provide intellectual services, such as law offices, architects, or consulting groups.
- Restaurant: Restaurants, such as fast food establishments or fine dining facilities.
- Retail-Big: Retail stores that occupy large amounts of physical space and offer a variety of products to their customers, such as Kohl's or Fred Meyers.
- Retail-Small: Retailers operating in smaller storefronts, often specializing in niche products or services. Specific examples are hair salons, gas stations, wineries, and car rental facilities.
- State: State buildings or facilities.
- Transportation Hubs: Parking locations with direct pedestrian access to other forms of transportation, such as parking lots at airports, metro-rail stations, or ferry port parking lots.
- Utility: Organizations that maintain energy-related infrastructure for a public service, such as power plants or natural gas lines.

12.1.3 Relationship of This Paper to Prior Works

This document builds on a previous publication entitled, "What are the best venues for publicly accessible EVSE units? (A first look)," published in May 2013 [2]. The venue category definitions provided in this document supersede the definitions presented in the May 2013 paper.

12.1.4 References

1. EVSE Cluster Analysis Electric Vehicle Supply Equipment Support Study, http://www.transportationandclimate.org/sites/default/files/EVSE_Cluster_Analysis.pdf.

2. http://avt.inl.gov/pdf/EVProj/111608-673919.vu-rev-a.pdf.

12.2 Analyzing Public Charging Venues: Where are Publicly Accessible Charging Stations Located and How Have They Been Used?

12.2.1 Introduction

Stakeholders interested in providing AC Level 2 EVSE units and DCFC are looking to INL to analyze data collected from Blink, ChargePoint, and AeroVironment EVSE installed around the United States as part of PEV charging infrastructure demonstrations. Many stakeholders are considering supporting the emerging EV market by installing or funding EVSE. They have asked where the best locations are to install public charging stations and how EVSE will be used in those locations. Data collected by INL can provide insight regarding real-world usage of EVSE at various locations.

Defining the "best" location for EVSE is a complex undertaking. Businesses, government agencies, and other organizations have many reasons for providing EVSE; therefore, their definition of the "best" location for EVSE varies. Some are concerned with installing EVSE where it will be highly used and provide a return on investment. This return may come in the form of direct revenue earned by fees for EVSE use, or indirectly by enticing customers to stay in their businesses longer while they wait for their vehicle to charge, or by attracting the PEV driver customer demographic. Other organizations have non-financial interests, such as supporting reduction of GHG emissions, petroleum reduction, or furthering other sustainability initiatives. Others install EVSE to boost their public image. Additionally, employers provide them as a benefit for attracting employees [1].

Furthermore, characterizing an EVSE location is not straight forward. First, the immediate vicinity surrounding the EVSE, referred to in this paper as the venue, may influence EVSE usage. Other aspects of location may also contribute to an EVSE site's popularity (or lack thereof), such as the site's geographic proximity to a large business district or an interstate highway. The general location of the EVSE site, such as the part of town, city, or region where it is located, may also influence its use.

To begin addressing these factors, this paper presents a simple analysis of EVSE usage by venue to provide a basic comparison of how public charging units are used in different locations. This paper uses two simple metrics to quantify EVSE usage at different venues and identifies whether EVSE at some venues were consistently used more than EVSE at other venues.

12.2.2 Key Conclusions

- The majority of the AC Level 2 charging stations discussed in this paper was located at retail locations and parking lots/garages.
- DCFCs were not broadly distributed across venue categories; they only existed at eight types of venues. Most of the venues showed similar use ranges. This indicates that the venue may not be drawing the customers to DCFCs.
- The workplace venue was the most utilized venue for AC Level 2 EVSE. People are likely to use AC Level 2 charging infrastructure for longer periods of time while they are working.
- All DCFC venues had a median average of 4 to 7 charging events per week per site. All AC Level 2 EVSE had a median average of 9 to 38 charging events per week per site. DCFCs only require

approximately 30 minutes to charge a vehicle; therefore, it's expected that they would have a higher number of daily charging events.

- EVSE sites were not evenly distributed across venues. If a venue contained a small number of EVSE sites, there may not have been enough data to accurately describe potential usage.
- Data presented in this paper were collected at the beginning of EV adoption across the United States. Also, charging infrastructure was being deployed throughout the data collection effort. Because the number of vehicles increased and the number of available EVSE increased, this paper demonstrates the potential for each venue, but it may not accurately describe a mature market.

12.2.3 Venues Described

Blink, ChargePoint, and AeroVironment's publicly accessible charging sites containing EVSE that reported usage data to INL were given a primary venue classification. This venue classification is a coarse classification that gives a broad definition of the site location and provides a general perspective on the reason a PEV driver would be using that location. Primary venue categories were chosen to be compatible with other PEV charging infrastructure demonstrations [2]. Future white papers will subdivide the primary venues into sub-venues that provide more detail about each primary venue. Descriptions of the primary venue and sub-venue classifications are provided in the whitepaper "Categorizing EVSE Venues: Describing Publicly Accessible Charging Station Locations" [3].

12.2.4 Which Electric Vehicle Supply Equipment Were Being Studied?

This report presents findings from data reported to INL by publicly accessible Blink AC Level 2 EVSE and DCFC in The EV Project, ChargePoint AC Level 2 EVSE in the ChargePoint America Project, and AeroVironment AC Level 2 EVSE and DCFC on The West Coast Electric Highway in Washington State and Oregon. EVSE were grouped by site to facilitate analysis by venue. An EVSE site is a location where one or many EVSE were available for use. Sites discussed were comprised of as few as one and as many as 18 EVSE. EVSE sites were not evenly distributed geographically across the United States.

This study only included EVSE sites that averaged more than three charging events per week and were publicly available. There were many reasons a site averaged less than three charging events per week. EVSE at underperforming sites may have had erroneous location data, were broken, logged data incorrectly, or were poorly located.

The first 4 weeks of usage of EVSE at a site were not included in the calculation of performance metrics for that site. This provided a grace period to allow PEV drivers time to discover the charging site. The subset of data chosen for this research was restricted between September 1, 2012, and December 31, 2013. This period of study was chosen because much of the infrastructure was in place by September 1, 2012, and data collection ended for two of the EVSE brands on December 31, 2013.

The results presented within this paper are divided into two sections based on EVSE type: (1) AC Level 2 and (2) DCFC. Normally, PEVs connected to AC Level 2 EVSE have a charge rate of 3.3 to 6.6 kW. Most DCFC are designed to provide a charge rate up to 50 kW. This results in dramatically different charging times. Because usage of the two EVSE types varies, it is necessary to analyze their usage separately.

12.2.5 Which Venues Have the Most Highly Used Electric Vehicle Supply Equipment?

12.2.5.1 Alternating Current Level 2 Electric Vehicle Supply Equipment. AC Level 2 EVSE are less expensive to produce, install, and operate than DCFC. As a result, there are more AC Level 2 EVSE sites than DCFC sites. Also, most AC Level 2 EVSE sites were installed before DCFC in the infrastructure demonstrations being studied; therefore, they had more opportunity to be discovered and utilized. Conceptually, AC Level 2 EVSE are more likely to be used in places where people park for significant amounts of time. People charging at AC Level 2 sites likely use the amenities the venue has to offer. In fact, it is expected that they park at that venue with a primary purpose other than charging their vehicles, such as visiting a business or facility at that location.

Figure 12-1 categorizes the 774 public AC Level 2 sites in this study into primary venues. Over 89% of the sites were contained within six venue types, including retail, parking lots/garages, workplace, public municipal, education, and medical. The retail and parking lots/garages venues contained over 45% of all AC Level 2 sites.

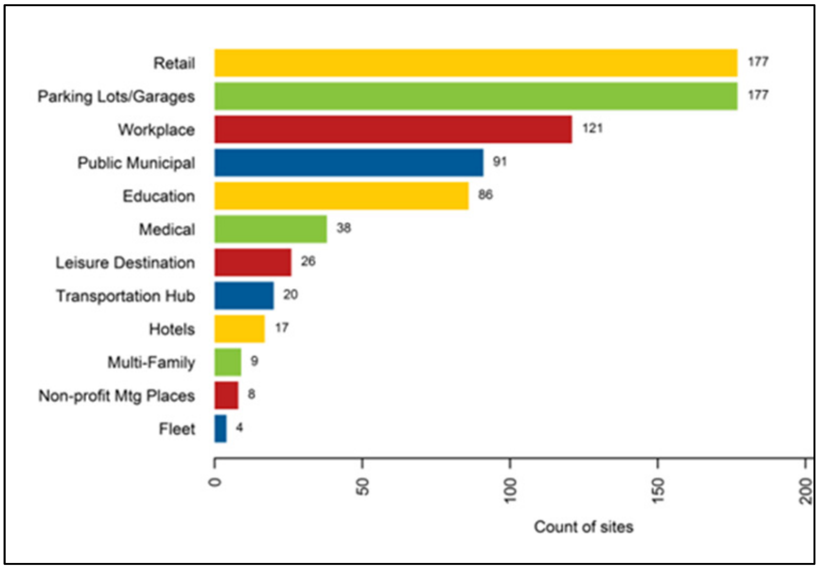


Figure 12-1. AC Level 2 EVSE sites categorized by their primary venue. The number at the end of the bar indicates the number of sites within that venue type.

The average number of charging events performed per week at each site was calculated as a measure of site usage frequency over the study period (excluding the first 4 weeks of operation). Figure 12-2 shows distribution of the average number of charging events per week per site for each venue category.

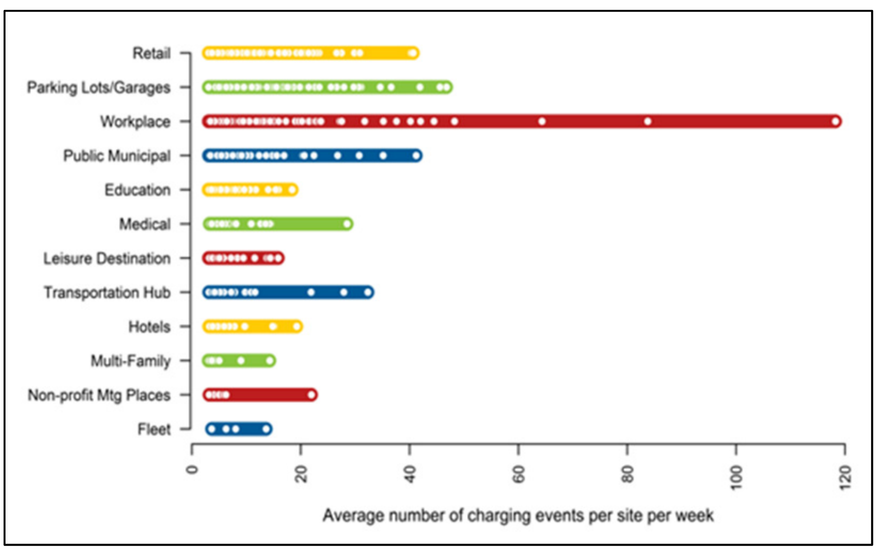


Figure 12-2. Distribution of average charging events per week per site. Each site's average number of charging events is displayed using a white circle. This figure depicts the range and distribution of usage frequency at sites within each venue type.

The white circles in Figure 12-2 represent each site's average charging frequency and range is shown by the colored bar. For example, the site with the greatest number of average charging events per week at retail venues averaged 40 average events per week. Alternatively, the site with the lowest number had three average charging events per week. This means the range in the retail venue was 3 to 40 average charging events per week.

All charging events performed using any EVSE installed at a charging site were included in the calculation of average charging frequency for a site. For example, the top seven workplace sites averaged over 40 charging events per week or over six events per day. These sites all have at least four AC Level 2 EVSE. On many days, multiple EVSE at each site were used on the same day. It would have been difficult to achieve such high usage frequency at these AC Level 2 sites if they only contained one EVSE.

For each venue type, the distribution of site average charging frequency was skewed to the left, meaning that most sites did not experience much usage. The median average number of charging events ranged from four to seven events per week. This means that more than 50% of all charging sites averaged less than seven events per week. Also, 75 to 100% of the sites for each venue type had usage frequency that fell between three and 14 charging events per week. Because there was so little difference in median usage frequency from venue type to venue type and the bulk of the sites all fell within the same range, it is not possible to say that charging sites of a certain venue type were consistently used more than sites at other venue types.

Another way to measure charging site usage is by calculating the average energy consumed per week per site. Figure 12-3 details distribution of the average energy consumed per week per site for each venue type.

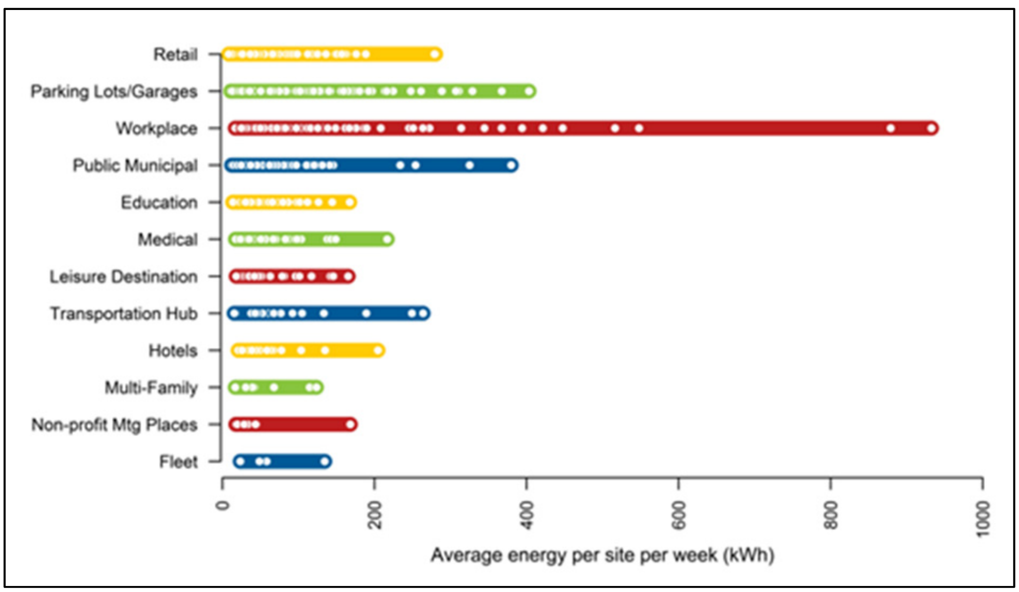


Figure 12-3. Distribution of average energy used per week per site. Each site's average energy value is displayed using a white circle. This figure demonstrates the range and distribution of energy consumed at sites within each venue type.

Figure 12-3 provides the range of average charging energy used per week per site. The white circles represent each individual site's average energy per week. Both the number of charging events and the energy used at sites are important measures of usage. However, Figures 12-2 and 12-3 show that overall distribution does not change between the two different metrics. Therefore, in this paper it is reasonable to use either energy or charging frequency to represent usage.

Figures 12-2 and 12-3 both show a relatively small number of sites that are highly used. These outliers demonstrate the potential for high usage at sites in numerous venue categories, namely, retail, parking lots/garages, workplace, and public/municipal. Similar potential may exist at sites within other venue types; however, this information is not possible to determine in this study because of the low number of sites within several venue types. The top 10 sites with respect to charging frequency were located at workplace and parking lots/garages venues.

12.2.5.2 Direct Current Fast Chargers. DCFC typically can charge an EV (such as the Nissan Leaf) to 80% SOC in about 30 minutes. In this way, DCFC are useful for quickly extending the range of BEVs. Individuals charging via DCFCs may be parking at the location specifically to charge at the DCFC and are not necessarily using the amenities offered by the DCFC venue. Many DCFC have repeat daily and weekly users.

DCFC technology was introduced to the market later than AC Level 2 EVSE in the demonstrations being studied. They also were more expensive to deploy than AC Level 2 EVSE. Site selection was more difficult because high-power DCFC have electrical service requirements that cannot be met at some facilities. As a result, during the study, there were significantly fewer DCFC and their venue distribution was less varied than that of the AC Level 2 EVSE.

DCFC data in this study were collected from AeroVironment and Blink units. There were 102 DCFC sites containing more than three average charging events per week. Similar to AC Level 2 EVSE, there were not an equal number of DCFC sites within each venue category. Figure 12-4 shows the distribution of DCFC sites with respect to venue. The retail venue contains 62% of all deployed DCFC.

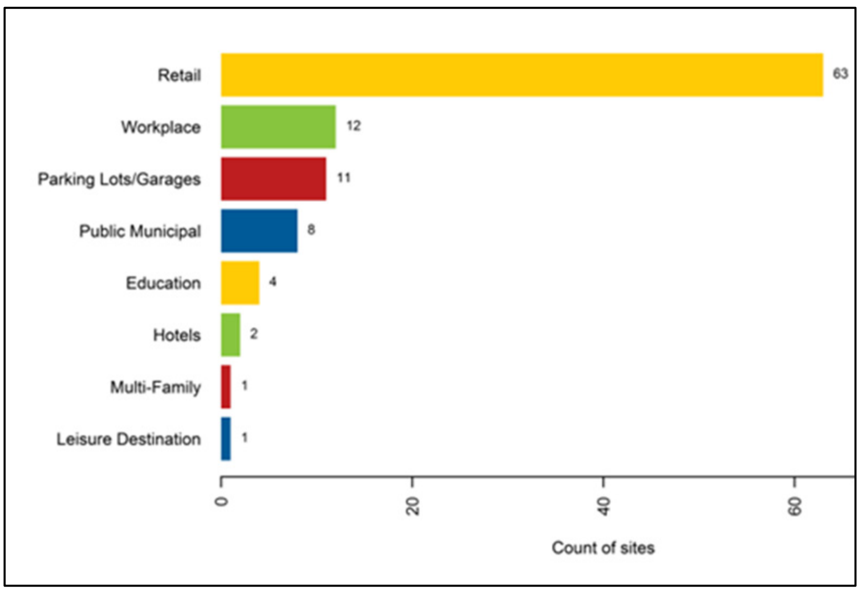


Figure 12-4. The number of DCFC sites per primary venue. The number at the end of the bar indicates the number of sites within that venue type.

Figure 12-5 shows the average number of charging events per week per site for DCFC sites by venue. The site with the most usage is at a workplace venue. However, the ranges of charging frequency between sites for venue types having more than two sites are similar.

DCFC utilization ranged from three charging events to just over 60 per week. Workplace DCFC saw the greatest number of charging events per week. Median values for Figure 12-5 range from nine to 38 events per week. This is a much larger spread than was seen for AC Level 2 EVSE sites. Workplace and education venues had the highest median charging frequency at 25 and 38 events per site per week, respectively. However, there is still considerable overlap between the range of average charging frequency at these sites and sites within other venue types.

Figure 12-6 presents average energy usage per week per site for each venue type. When measured by energy use, the top retail venue used nearly as much energy as the top workplace venue. This demonstrates that the two venues have similar potentials for usage.

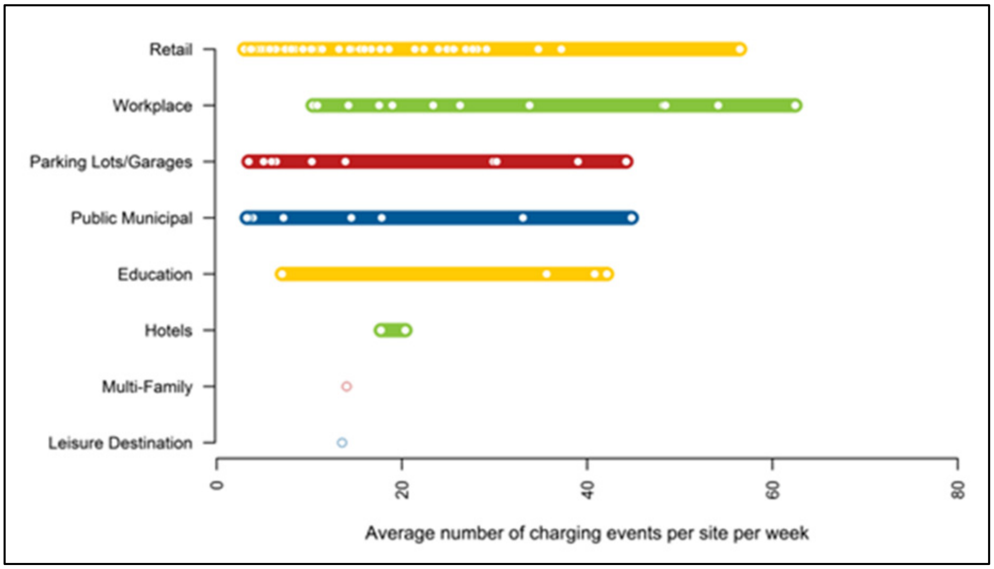


Figure 12-5. Distribution of average charging events per week per site. The white circles represent each site's average number of charging events per week. This figure depicts the range and distribution of usage frequency at sites within each venue type.

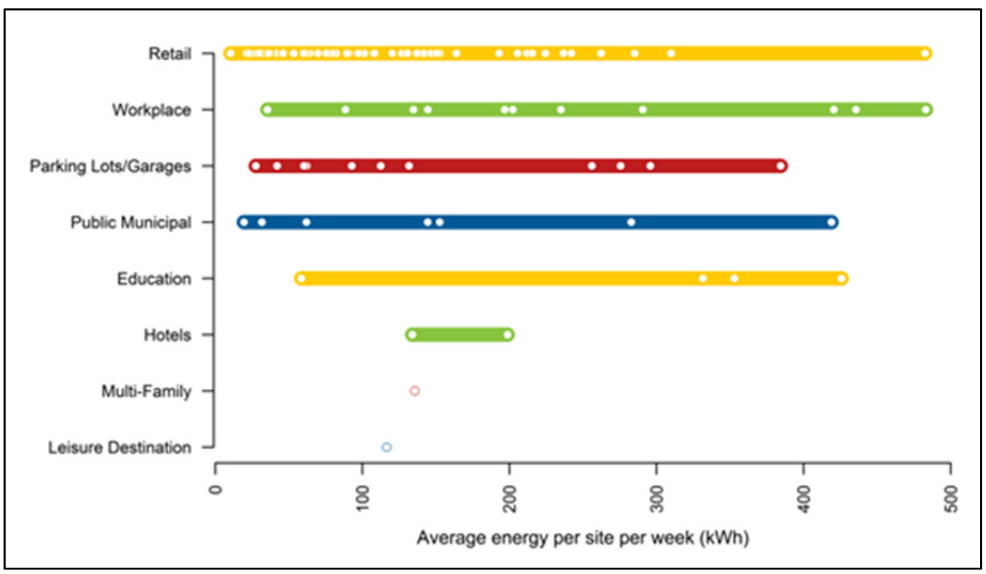


Figure 12-6. Distribution of average energy used per week per site. The white circle represents each site's average energy used per week. This figure demonstrates the range and distribution of energy consumed at sites within each venue type.

12.2.6 Understanding the Frequency of Public Charging Events on a Per Site Basis

As seen in Figures 12-7 and 12-8, some sites have an average number of charge events per week that exceed 20 charge events per week. However, it should be noted that the vast majority of the sites had less than seven charge events per week at each site on average. Note that Figures 12-7 and 12-8 present the same data in different formats.

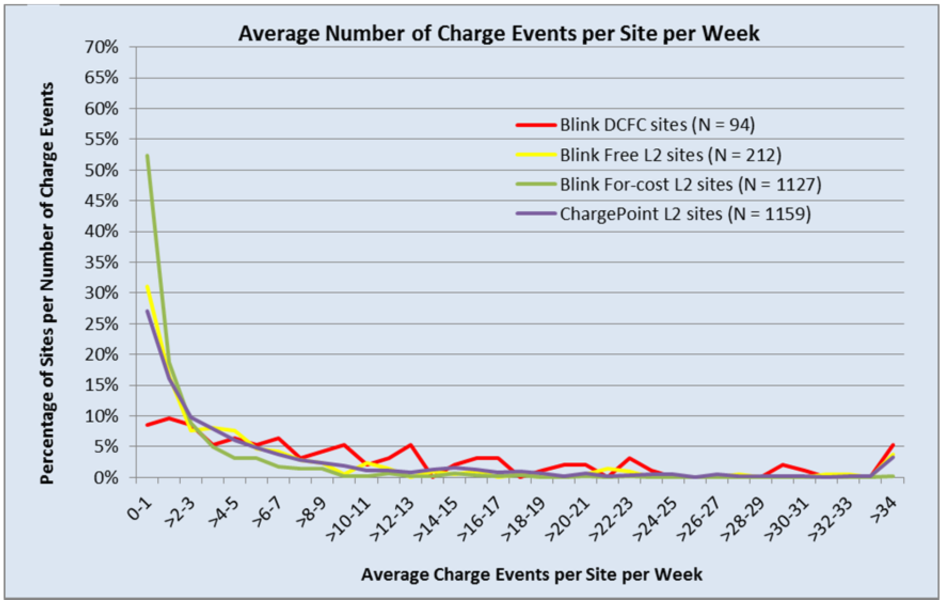


Figure 12-7. Average number of charge events per site per week. This graph provides the non-binned events per site, down to the exact number of sites.

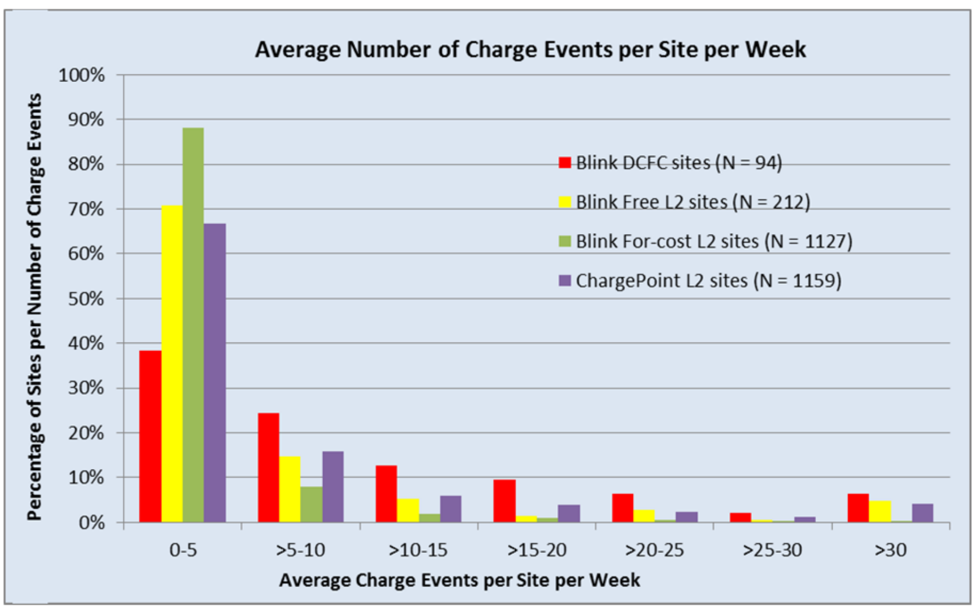


Figure 12-8. Average number of charge events per site per week. This graph provides the binned events per site by bins of five events per site per week, down to the exact number of sites.

Figure 12-7 includes 94 Blink DCFC sites, 212 Blink sites with free AC Level 2 EVSE charging, 1,127 Blink sites with For-Cost AC Level 2 EVSE charging, and 1,159 ChargePoint sites with AC Level 2 EVSE charging. Note that the Blink charging infrastructure is part of The EV Project. The ChargePoint data are from the ChargePoint America Project and the sites are believed to be free to use at approximately 70% of the sites.

Figure 12-8 includes 94 Blink DCFC sites, 212 Blink sites with free AC Level 2 EVSE charging, 1,127 Blink sites with For-Cost AC Level 2 EVSE charging, and 1,159 ChargePoint sites with AC Level 2 EVSE charging. Note that the Blink charging infrastructure is part of The EV Project. The ChargePoint data are from the ChargePoint America Project and the sites are believed to be free for use at approximately 70% of the sites.

Looking at each category of charging event (Table 12-1) and the percentage of sites with seven or less charge events, it is clear that most public sites are only used, on average, one or less times per day. This is not to suggest that public charging should not be installed. Rather, it argues that public sites should be chosen judiciously. A bit of an exception is the Blink DCFC sites because “only” 50% of these sites are used less than once per day on average. Given the relatively high cost of installing a single DCFC site (i.e., $24,000 per DCFC mean installation cost, plus hardware costs) that may only be used, on average, one or less times per day, careful consideration should be given to site selection, especially if there is an expectation that the DCFC will be installed with private funding and the DCFC will have a positive payback within 10 years.

Table 12-1. Percentage of weekly charge events per site for the four categories of charging infrastructure and payment plans.

Number of Charge Events per Site	Blink DCFC Sites (N = 94)	Blink Free AC Level 2 Sites (N = 212)	Blink For-Cost AC Level 2 sites (N = 1,127)	ChargePoint AC Level 2 Sites (N = 1,159)
0 to 1	8.5%	31.1%	52.4%	27.0%
Greater than 1 to 2	9.6%	16.5%	18.7%	16.0%
Greater than 2 to 3	8.5%	7.5%	8.8%	9.8%
Greater than 3 to 4	5.3%	8.0%	5.1%	7.9%
Greater than 4 to 5	6.4%	7.5%	3.1%	6.0%
Greater than 5 to 6	5.3%	4.7%	3.1%	4.8%
Greater than 6 to 7	6.4%	4.2%	1.7%	3.8%
Totals	50.0%	79.5%	92.9%	75.3%

12.2.7 Future Work

This paper provides a simple description of usage across venues. Future papers will provide more detailed analysis regarding each specific EVSE site venue type. To understand how EVSE might be used at a venue, it is necessary to look at more specific metrics, such as total time used, time of day used, and more information about the site locations. Another future topic will determine if the sites that contained both AC Level 2 and DCFC EVSE were utilized differently than those with only one type of EVSE available.

12.2.8 References

1. “What are the best venues for publicly accessible EVSE units? (A first look),” http://avt.inl.gov/pdf/EVProj/111608-673919.vu-rev-a.pdf.

2. "EVSE Cluster Analysis - Electric Vehicle Supply Equipment Support Study," www.transportationandclimate.org/sites/default/files/EVSE_Cluster_Analysis.pdf.
3. "Categorizing EVSE Venues: Describing Publicly Accessible Charging Station Locations," http://avt.inl.gov/pdf/EVProj/CategorizingEVSEVenuesSept2014.pdf.
4. See the West Coast Electric Highway website at www.westcoastgreenhighway.com/electrichighway.htm.

12.3 Workplace Charging Case Study: Charging Station Utilization at a Work Site with Alternating Current Level 1, Alternating Current Level 2, and Direct Current Fast Charging Units

12.3.1 Introduction

An increasing number of organizations are installing PEV charging stations at their facilities to allow employees and others to charge their PEVs while they work. The EV Project and ChargePoint America, two large PEV charging infrastructure demonstrations, provided the opportunity to collect data from the Blink and ChargePoint brand charging stations installed around the United States, including many installed at work sites. This paper examines the use of EVSE units at a large work site where multiple types of EVSE were installed and where a variety of PEVs were charged.

12.3.2 Key Conclusions

- Usage of numerous workplace charging stations from May to August 2013 at Facebook's office campus in Menlo Park, CA was studied. The charging stations at this facility included alternating AC Level 1 and AC Level 2-capable units and a DCFC unit. The AC Level 2 charging units were the most heavily utilized, accounting for 83% of the charging events, with 11% of the charging events being performed using the DCFC. Drivers opted for AC Level 1 charging only 6% of the time.
- The AC Level 2 charging units were used heavily during the work day, averaging 8.7 hours connected per cord per work day. Drivers tended to stay connected to AC Level 2 cords for around 4 hours or 9 hours – either half a work day or an entire work day. Most of the time, vehicles fully charged their batteries in less than 5 hours.
- AC Level 1 outlets were used infrequently and typically remained connected to vehicles for 8 or more hours per charging event. Because of the slower charge rate, many charging events required 5 to 10 hours to fully charge the vehicles' batteries. However, a significant number of charging events required only 2 to 3 hours to reach full charge because the vehicles being charged had small battery packs.
- Drivers overwhelmingly preferred AC Level 2 charging over AC Level 1 charging. Data were collected from 10 charging units at this work site that were capable of both AC Level 1 and AC Level 2 charging. When drivers arrived at these units and both AC Level 1 and AC Level 2 options were available, they chose to use the AC Level 2 cord 98% of time. With only a few exceptions, the AC Level 1 outlet was only used if the AC Level 2 cord was already connected to another vehicle.
- Facebook followed a few simple guidelines to encourage employees to self-manage EVSE usage. First, charging units were installed to allow access from multiple parking spaces. Drivers were encouraged to plug in neighboring vehicles after their vehicle completed charging. Second, employees were provided with an online message board – in this case, a Facebook page – allowing them to coordinate charging station usage. Data from the EVSE suggest that drivers leveraged these resources to minimize the time EVSE were not in use. Thirty-seven percent of the time when one charging event ended and the next began at the same AC Level 2 EVSE during the same work day, less than 30 seconds elapsed between the two charging events. Sixty percent of the time, less than 3 minutes elapsed between consecutive charging events.

- The DCFC was typically used between 2 and 6 times per work day for 24 minutes or less per charging event. Eleven percent of the time when a DCFC event ended and another event began on the same work day, a vehicle had been connected to the second DCFC cord prior to the end of the first vehicle's charging event.

12.3.3 Which Work Site Is Being Studied?

Facebook has installed numerous EVSE at its office campus in Menlo Park, CA. These charging stations included ChargePoint EVSE units capable of AC Level 1 and AC Level 2 charging rates, Blink AC Level 2 EVSE units, and a Blink DCFC that were part of The EV Project and ChargePoint America Project. These EVSE were installed over time as the number of employees owning PEVs and the demand for workplace charging increased. This study examines the usage of these EVSE from May 1, 2013 to August 15, 2013, which is the period when data were available from the greatest number of ChargePoint and Blink EVSE at this work site.

During the study period, usage data were reported from 12 ChargePoint units, 10 Blink AC Level 2 units, and a single Blink DCFC. The ChargePoint units were equipped with an SAE J1772-compliant AC Level 2 cord set and a standard 120-volt outlet capable of providing AC Level 1 charge power. The ChargePoint units were capable of providing charge power to both the AC Level 2 cord set and a connected AC Level 1 cord set simultaneously. The Blink AC Level 2 units each had a single cord with a J1772 connector. The Blink DCFC was a dual-cord unit. Both cords were equipped with a CHAdeMO-compliant connector. The DCFC was designed to provide up to 50 kW of power to one vehicle at a time.

Access to all EVSE and the parking lots at the work site where the EVSE were installed was open to employees, visitors, and the general public. Usage of EVSE by the general public is believed to have been low, because the work site is in a relatively isolated location. Non-employee PEV drivers would need to make a dedicated trip to the work site to use the EVSE.

ChargePoint EVSE usage was free at this location but required a ChargePoint membership card. The Blink AC Level 2 units were also free to use and required a Blink membership card. The Blink DCFC also required a Blink membership card to access; however, it was free for a majority of the study period, but during July 2013, a flat fee of $5.00 per charge session was instituted for all Blink DCFC card holders.

The host company encouraged drivers to move their vehicles after they were done charging. However, the company did not enforce this policy.

The number of PEVs owned by employees or others who regularly used these EVSE is not known. However, it is known that a variety of PEV makes and models with varying battery sizes regularly parked and charged at this work site.

12.3.4 Discussion of Results

The study period consisted of 75 work days, excluding weekends and federal holidays. A total of 3,086 charging events were performed during this time period, with 83% of the charging events being performed and 87% of the energy being consumed using the AC Level 2 EVSE cords. Drivers performed 11% of the events and consumed 9% of the energy using the DCFC. Six percent of the events were conducted using the AC Level 1 outlets on the ChargePoint EVSE. AC Level 1 charging accounted for 4% of the total energy consumed. Table 12-2 gives a summary of EVSE usage during the study period. Overall, charging with the AC Level 2 cords and DCFC was vastly more popular than using the AC Level 1 outlets in the ChargePoint EVSE.

Table 12-2. Summary of EVSE usage by EVSE power level.

	AC Level 1	AC Level 2	DCFC
Number of EVSE ports	12 (34%)	22 (63%)	1 (3%)
Number of charging events	194 (6%)	2,553 (83%)	339 (11%)
Total energy consumed (kWh)	1,273 (4%)	30,743 (87%)	3,150 (9%)

12.3.4.1 Electric Vehicle Supply Equipment Utilization. The DCFC's high charge power made many short charging events in a day possible. It was used an average of 4.5 times per work day, with an average connection time of 22 minutes per charging event. The host company reported that employees typically only used the DCFC for "emergencies." This refers to instances when drivers needed to charge their vehicles to have sufficient energy to travel to their next destination, but they had not had the opportunity for a longer charge using AC Level 1 or AC Level 2 EVSE. The data also show that some users of the DCFC only parked at the work site when they used the DCFC. These instances are believed to be the general public.

The AC Level 2 EVSE cords were popular, and, on average, were used 1.5 times per work day for 5.6 hours per charging event. Power was drawn by the vehicle for an average of 2.9 hours per charging event. Over the course of a work day, vehicles were connected to AC Level 2 charge cords for an average of 8.7 hours per cord, which represents high utilization with respect to connection time. However, AC Level 2 cords averaged 4.4 hours of transferring power to a vehicle per cord, indicating that often vehicles remained connected to AC Level 2 cords for several hours longer than was needed to completely charge their batteries.

The AC Level 1 outlets were used the least frequently, averaging only 0.2 charging events per work day (or once every 5 work days). Drivers tended to keep their vehicles connected to AC Level 1 ports the longest, averaging 8.9 hours connected per charging event. AC Level 1 ports provided power to vehicles for 4.6 hours per charging event (on average).

Table 12-3 provides several metrics for summarizing the average use of AC Level 1 outlets, AC Level 2 cords, and the DCFC at this work site.

Table 12-3. Summary of EVSE average usage by charge power level.

	AC Level 1	AC Level 2	DCFC
Average number of charging events per cord per work day	0.22	1.5	4.5
Average time connected to a vehicle per charging event (hour)	8.9	5.6	0.36
Average time transferring power to a vehicle per charging event (hour)	4.6	2.9	0.36
Average time connected to a vehicle per cord per work day (hour)	1.9	8.7	1.6
Average time transferring power to a vehicle per cord per work day (hour)	1.0	4.5	1.6

Distributions of the number of charge events per cord or outlet per work day for the AC Level 1 (i.e., L1), AC Level 2 (i.e., L2), and DCFC charge power levels are shown in Figure 12-9. AC Level 1 outlets were not used at all on 79% of the outlet work days. AC Level 1 outlets were used only once per day on 21% of the outlet work days and were used twice per outlet work day only four times. AC Level 2 cords experienced one or two charging events on 84% of the cord-work days. At most, an AC Level 2 cord was used five times in one work day. DCFC frequency varied between zero and 12 charging events in one day, with 49% of the days having four to six charging events.

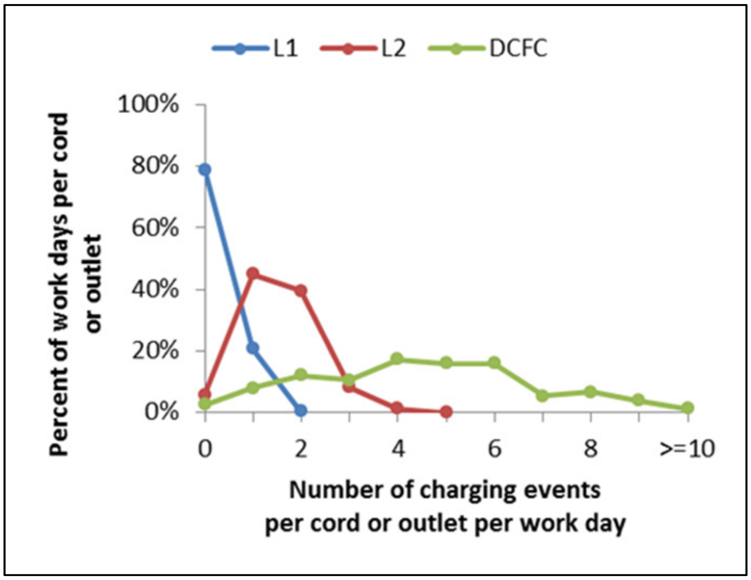


Figure 12-9. Frequency distributions of a number of charging events per cord or outlet per work day for different charge power levels.

The DCFC was connected to a vehicle for 24 minutes or less for 92% of its charging events. It was never connected for longer than 48 minutes per charging event. On the other hand, for AC Level 2 cords and AC Level 1 outlets, there was significant variation in time spent connected to a vehicle per charging event. Figure 12-10 shows the distributions of connection time per charging event for AC Level 1 and AC Level 2 events.

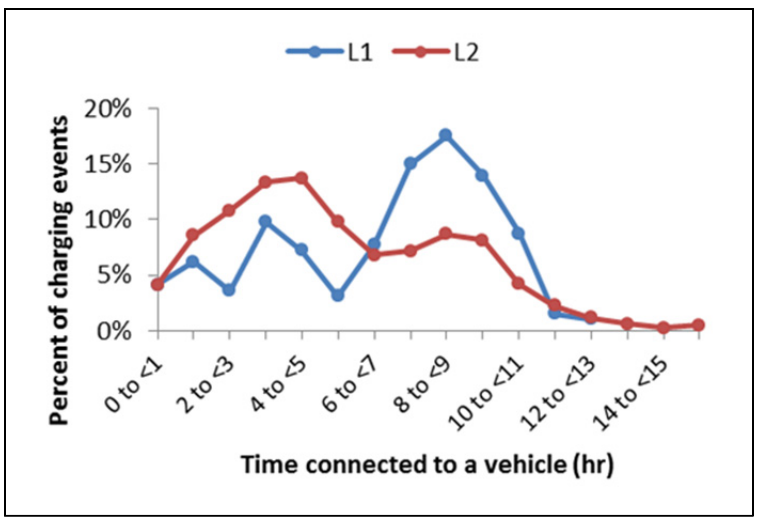


Figure 12-10. Frequency distributions of time AC Level 1 outlets and AC Level 2 cords were connected to a vehicle per charging event.

These distributions are bimodal, with humps centered around 4 and 8 hours. This indicates a tendency for drivers to leave their vehicles connected for about half a work day or for a full work day. Drivers more often stayed connected to AC Level 1 outlets for a full work day, whereas they more often used AC Level 2 cords for half a day.

The time vehicles spend connected to EVSE at work compared to the time they actually draw power for charging is particularly interesting to those studying how much charging infrastructure should be installed at work sites. Nearly always, the reason power stops flowing while the vehicle is still connected is because the vehicle's battery has reached full charge.

Data from this work site revealed that drivers disconnected their vehicles from the DCFC while it was still drawing power from the charger or within minutes after the end of power flow. By contrast, Table 12-3 shows vehicles connected to AC Level 1 outlets and AC Level 2 cords remained plugged in for almost twice as long, on average, as was needed to complete a full charge. However, investigation of the distributions underlying these averages revealed a more nuanced story. Figure 12-11 presents the distributions of time EVSE spent transferring power to a vehicle during AC Level 1 and AC Level 2 charging events.

During most AC Level 2 charging events, power stopped flowing in less than 5 hours, meaning that most charging events were able to completely charge vehicles in about half a day. Leaving vehicles connected for a full day was typically unnecessary.

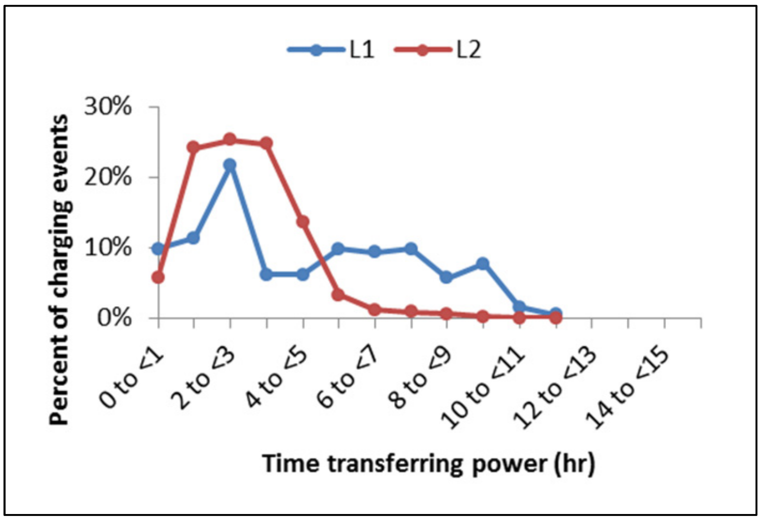


Figure 12-11. Frequency distributions of time AC Level 1 outlets and AC Level 2 cords transferred power to a vehicle per charging event.

For AC Level 1 charging, the distribution of time transferring power per charging event shows two distinct behaviors. First, a large number of charging events resulted in a fully charged battery in less than 3 hours. A second group of charging events required between 5 and 12 hours to fully charge vehicles. Examination of charging events with power flow lasting 2 to 3 hours uncovered that most of these events were performed by vehicles with small battery packs. These vehicles were more likely to arrive at the work site with an empty pack. Fully charging these packs at the AC Level 1 charge rate consistently took 2 to 3 hours. An in-depth discussion on the differences in charging behavior for different makes and models of vehicles is included in Section 12.3.5.

Comparison of the blue lines in Figures 12-10 and 12-11 shows that the AC Level 1 cords were more efficiently utilized than the averages in Table 12-3 would suggest. A significant number of charging events required more than 5 hours for a full charge, and there were a large number of charging events when the vehicle was left connected for more than 5 hours. The high occurrence of charging events with power flow ending in 2 to 3 hours pulled down the average time transferring power. For many of these charging events, EVSE were left connected to the vehicle long after the vehicle was fully charged.

Comparison of the red lines in Figures 12-10 and 12-11 shows that the AC Level 2 cords were also more efficiently utilized than the averages in Table 12-3 would suggest. For many charging events, vehicles required less than 5 hours to fully charge their batteries and many vehicles were, in fact, unplugged in less than 5 hours. Nevertheless, there was a significant number of charging events with vehicles connected for longer than 5 hours, even though, in most cases, power stopped flowing before the vehicles were unplugged. It is reasonable to expect that PEV-owning employees at this work site did not always have opportunities to unplug or move their vehicles during the work day.

The comparison of time connected and time transferring power can be summarized by counting how often power transfer stopped prior to the time when the vehicle was unplugged. Figure 12-12 provides the percent of charging events that ended with a full battery for charging events with a varied connection time.

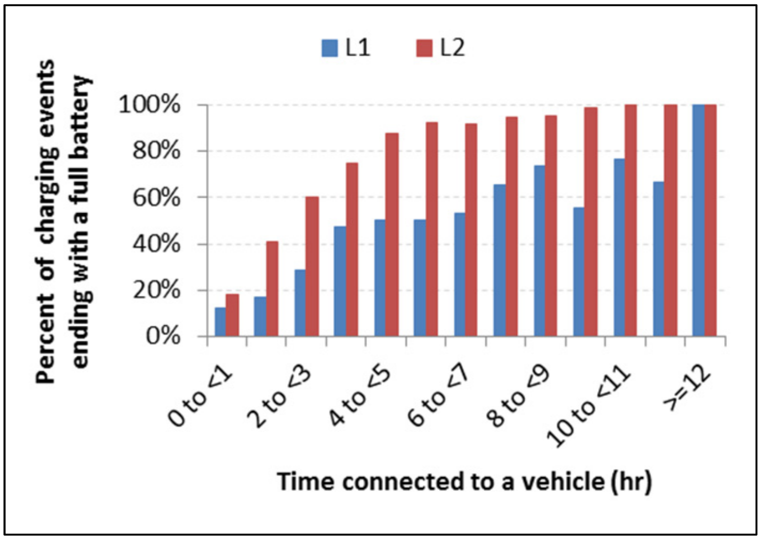


Figure 12-12. Percentage of charging events ending with a full battery for charging events of varying length.

Figure 12-12 shows that most AC Level 2 charging events lasting longer than about half a work day resulted in a full battery; 75% of AC Level 2 events between 3 and 4 hours and 87% of AC Level 2 events lasting between 4 and 5 hours ended with a full battery. For AC Level 1 charging, a full work day was required to completely charge vehicles for the majority of charging events; 66% of AC Level 1 events lasting between 6 and 7 hours and 74% of AC Level 1 events lasting between 8 and 9 hours ended in a full battery.

Note the occurrence of short charging events (i.e., less than 3 hours for AC Level 1 charging and less than 1 hour for AC Level 2 charging) that ended with a full battery. These are consistent with the charging behavior of the vehicles with the small battery packs that were discussed previously. Also, regardless of battery size, these short charging events could have been cases when the vehicle had not been driven very far since the previous charge and the battery had not been depleted much. Driving behavior of vehicles using workplace charging stations will be the subject of a future paper.

The fact that vehicles spend some time connected to EVSE after being fully charged presents an opportunity for the host company to reduce charging congestion and increase the efficient use of its charging stations. If so inclined, the company could choose to enforce its policy requiring employees to unplug and move their vehicles after they have reached full charge in order to provide opportunity for others to use the charging equipment. This could be accomplished by parking attendants, electronic monitoring, or by levying a fee for use that is proportional to time connected. Of course, the company may be reluctant to risk disrupting its employees' work day routines. A highly motivated company could provide a valet to move vehicles or swap cords. A company could also arguably restrict use of certain EVSE to vehicles with larger batteries or vehicles whose batteries are more fully depleted due to longer commutes. However, this kind of policy may be problematic, because it may be construed as giving preferential treatment to certain employees, which is an issue that is already under debate, even without such restrictions.

The least expensive and least invasive option for managing EVSE use is to rely on employees to self-manage their use of charging equipment. The facility manager at the worksite being studied chose this option and followed a few simple guidelines to increase the accessibility to and efficiency of workplace charging. First, EVSE were installed to be within reach of vehicles parked in two or three parking stalls. This allowed drivers to “queue in place.” It was customary for drivers wanting to charge, who arrived after an EVSE was already connected to a vehicle, to park next to that vehicle and leave their charge port door open. When the driver of the vehicle using the EVSE returned to unplug their vehicle, they would disconnect their vehicle and plug in the neighboring vehicle with the open charge port. The first driver would use their Blink or ChargePoint membership card to begin the neighboring vehicle’s charging session. This practice was made possible by the fact that there was no cost to use the EVSE; therefore, drivers could initiate charging sessions for other vehicles without paying for them. Second, PEV-owning employees were provided with an online message board that allowed them to communicate with each other to coordinate EVSE usage. This message board included license plate and contact information; therefore, employees could contact owners of specific vehicles.

By looking at the data, it is apparent that drivers took advantage of these resources. The time between consecutive charging events was measured to determine how much time elapsed between disconnecting the cord from one vehicle and plugging into another during the same work day. For AC Level 2 cords, 37% of the change-overs took less than 30 seconds and 60% of the change-overs occurred in less than 3 minutes. This fast turn-around time was a reason the AC Level 2 cords experienced high overall utilization.

The DCFC generally experienced longer time between charging events, but there was some queuing in place. Eleven percent of its change-overs lasted less than 10 seconds. These were instances when a driver connected his vehicle to one of the DCFC’s cords when the other cord was already connected to another vehicle. Power began flowing to the second vehicle within seconds after completion of the first vehicle’s charging event.

The DCFC was installed next to a group of AC Level 2 EVSE. The host company reported that sometimes drivers parked in front of the DCFC but connected to the AC Level 2 EVSE, thereby blocking others from using one of the DCFC ports.

12.3.4.2 Charging Energy Consumption. The amount of energy consumed by vehicles per charging event at this work site varied greatly. AC Level 2 cords provided an average of 12 kWh per charging event. The DCFC delivered an average of 9.3 kWh per charging event. AC Level 1 charging events averaged 6.6 kWh per event. Figure 12-13 shows the distributions of energy consumed per charging event by charge power level. This figure highlights the wide variation of energy consumed per charging event. The average for AC Level 2 charging energy was high because many charging events consumed over 24 kWh. These high-energy charging events were performed by vehicles with a large battery capacity, such as the Tesla Model S or Toyota RAV4 EV.

Most of the vehicles using the DCFC were Nissan Leafs, which is a BEV with a 24-kWh battery; therefore, it is no surprise that DCFC events consumed less than 20 kWh. (See Section 12.3.5 for more discussion on differences in charging behavior among vehicle makes and models.)

12.3.4.3 Driver Preference for AC Level 1 versus AC Level 2 Charging. Because the ChargePoint EVSE offered both AC Level 1 and AC Level 2 charging, a simple analysis of driver preference was conducted. When drivers arrived at a ChargePoint EVSE and there was no one already connected to the EVSE, drivers opted to use the AC Level 2 cord 98% of time. The AC Level 1 outlet was only selected first for 2% of the charging events. This means that nearly every time a driver chose to use an AC Level 1 outlet, it was because the AC Level 2 cord was already in use. Drivers may have consciously chosen the faster charge rate to charge their batteries more quickly to ensure they received a full charge before they needed to depart. Otherwise, drivers may have been motivated simply by convenience. The AC Level 2 cord was available on the EVSE, whereas a driver would need to retrieve their own AC Level 1 cord to plug into the AC Level 1 outlet on the EVSE.

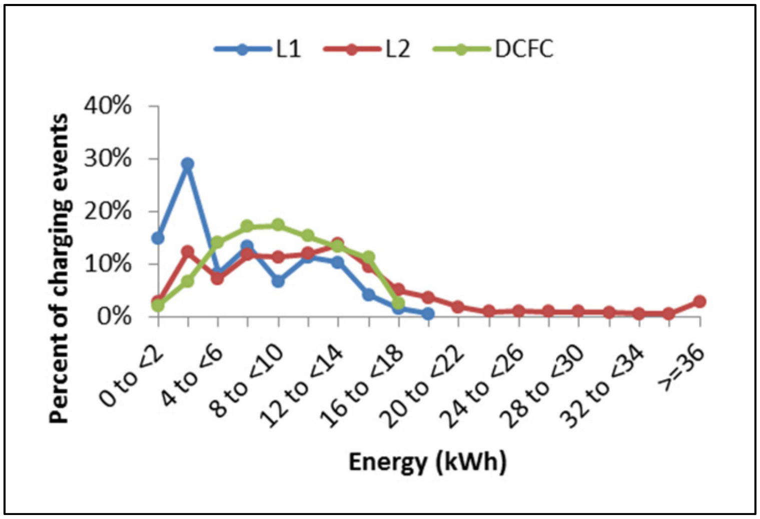


Figure 12-13. Distribution of energy consumed per charging event by charge power level.

Figure 12-14 depicts how much time the ChargePoint EVSE had only its AC Level 2 cord connected to vehicles, only its AC Level 1 outlet in use, and both the AC Level 2 cord and AC Level 1 outlet in use. This figure further supports the finding that drivers preferred to use the ChargePoint AC Level 2 cord over the AC Level 1 outlet. In fact, the time vehicles spent connected to AC Level 1 outlets would have been even lower, were it not for a single AC Level 1 charging event that lasted 3 weeks.

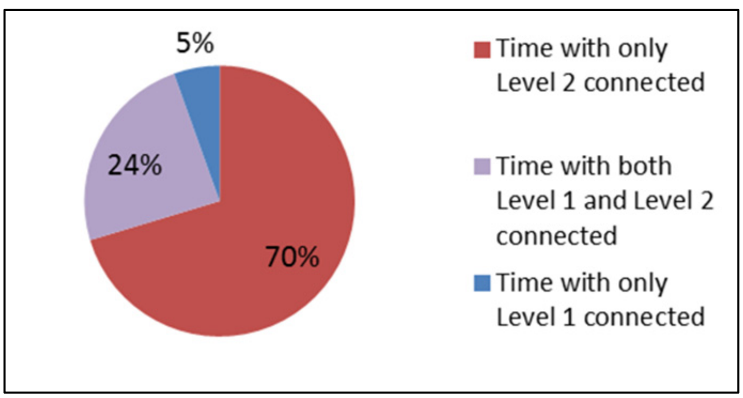


Figure 12-14. Percent of time ChargePoint EVSE had their AC Level 1 outlet, AC Level 2 cord, or both in use.

12.3.5 Discussion on Variation in Charging Behavior for Different Vehicle Makes and Models

Figure 12-15 shows the distributions of average power per charging event for AC Level 1 and AC Level 2 charging at the work site studied.

AC Level 1 charging was limited by the power limit of the EVSE or, in rare cases, the vehicle's onboard charger. Figure 12-15 indicates that most AC Level 1 charging occurred at around 1.4 kW, as would be expected for a 120-volt system with a continuous current rating of 12 amps. Charge power was occasionally as low as 0.6 kW, limited by the vehicle for an unknown reason.

AC Level 2 charging was limited by the power limit of the vehicle's onboard charger. This varies by vehicle make and model. Analysis of average charge power per AC Level 2 charging event provided some insights into the makes and models of PEVs being charged. AC Level 2 charging occurred across a wide range of power; however, there were obvious groups of charging events averaging around 2.0 kW, between 3.0 and 3.8 kW, and above 6.0 kW. This is consistent with the nominal charge rates of vehicles expected to have charged at this work site (e.g., the Toyota Prius Plug-in, Chevrolet Volt, Nissan Leaf, Ford Focus EV, Tesla Model S, and others).

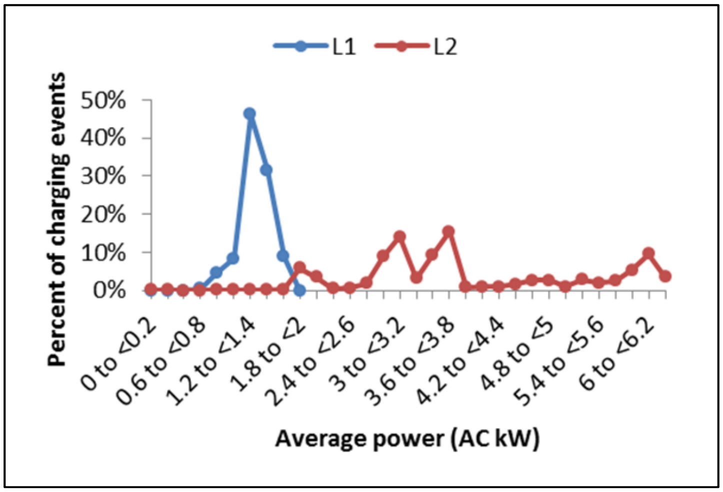


Figure 12-15. Distributions of average power per charging event for AC Level 1 and AC Level 2 charging.

Figure 12-16 presents the distribution of average power per charging event for DCFC (DC kW) at the work site studied. DCFC power also varied significantly, but for a different reason than AC Level 2 charging. DCFC power level is controlled by the vehicle and is a function of a number of factors, including vehicle SOC. The Nissan Leaf, the only vehicle known to have used the DCFC at the work site during the study period, is capable of charging at up to 50 DC kW. However, the charge power drops quickly as SOC increases. Therefore, the average power per charging event for the Leaf was always less than 50 kW.

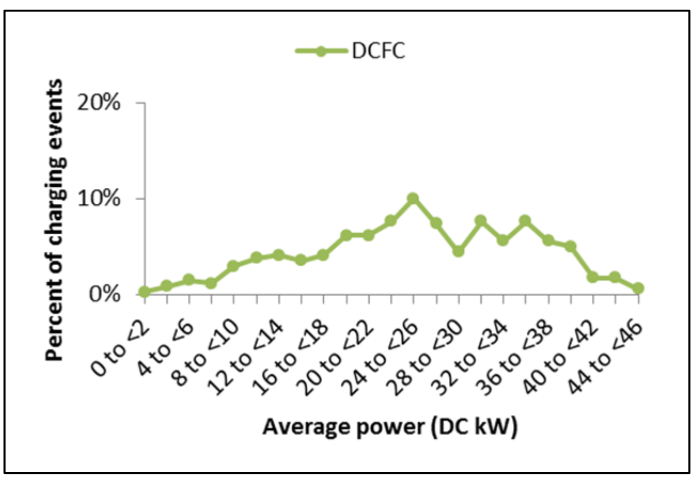


Figure 12-16. Distribution of average power per charging event for the DCFC.

AC Level 2 charging events were grouped by average charge power in order to look for trends in charging behavior by different types of PEVs.

12.3.5.1 Low-Power Charging (1.8 to 2.2 kW). There were 237 charging events with an average power in the range of 1.8 to 2.2 kW. These represent 9% of all AC Level 2 charging events in this study. Vehicles whose onboard chargers operate in this power range include the Toyota Prius Plug-in. Figure 12-17 shows the distribution of energy consumed by charging events in this average power group.

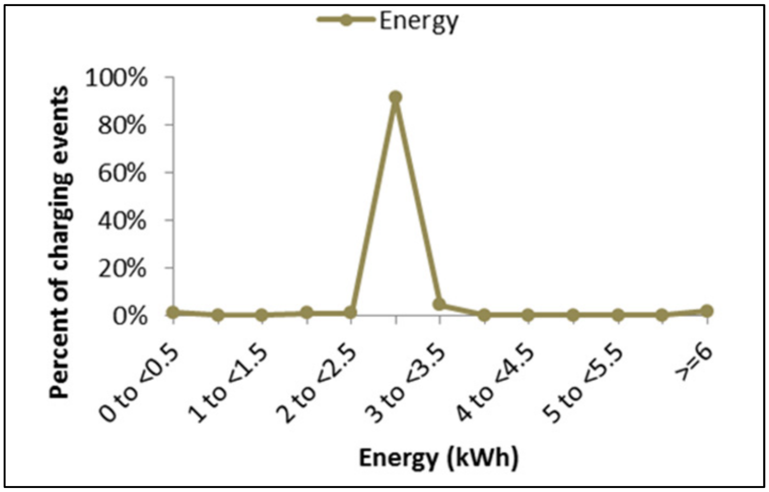


Figure 12-17. Distribution of energy consumed per charging event for AC Level 2 charging events with average power between 1.8 and 2.2 kW.

Figure 12-17 shows that 98% of the charging events in this group consumed less than 3.5 kWh and most consumed from 2.5 to 3 kWh. This narrow range of energy consumption per charging event is a result of vehicles arriving at the work site each day to day with their batteries depleted to nearly equal levels. It is highly unlikely that this occurred based on driving routines alone. Instead, this repeatable behavior was caused by special circumstances.

The vehicles being charged in this group were likely PHEVs with a 3-kWh battery (e.g., the Prius Plug-in). The Prius Plug-in has a CD range of about 10 miles, after which it can continue to drive using an ICE. Drivers of Prius Plug-ins, or similarly designed vehicles, probably routinely drove more than 10 miles prior to arriving at the work site. When they plugged in at work, their batteries were all starting from empty and were frequently fully charged, resulting in consistent energy consumption at the work site.

Figure 12-18 shows the time connected and time transferring power for AC Level 2 charging events in this average power range. This figure confirms the assertion that most, if not all, charging events in this group ended with a full battery.

All but two of the 237 charging events in this group completely charged the vehicle’s battery in less than 3 hours, yet vehicles were often left plugged in for considerably longer. Furthermore, the average charge power of these events was only a fraction of a kilowatt higher than could be achieved using AC Level 1 outlets. Therefore, drivers performing these charging events could have used AC Level 1 outlets with similar results, leaving AC Level 2 cords available for vehicles with higher charge rates and larger batteries. Companies installing workplace charging equipment who are interested in maximizing EVSE utilization could consider educating employees on the differences in charge rates and institute a policy encouraging drivers of vehicles with low charge power to use AC Level 1 equipment.

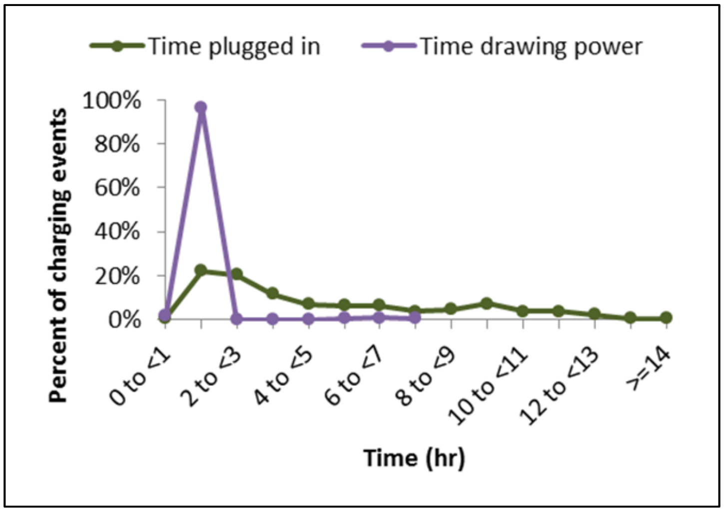


Figure 12-18. Distributions of time connected and time transferring power per charging event for AC Level 2 charging events with average power between 1.8 and 2.2 kW.

12.3.5.2 Medium Power Charging Group 1 (2.8 to 3.3 kW). There were 619 charging events with an average power between 2.8 and 3.3 kW, representing 24% of the AC Level 2 charging events in this study. The MY2011-2013 Chevrolet Volt is known to charge in this power range.

Figure 12-19 shows the distribution of energy consumed by charging events in this average power group. The Volt has a usable battery capacity of about 12.5 kWh. The spike in energy distribution between 12 and 13 kWh represents instances when the Volt's battery was charged from empty to full. It is possible for the Volt to arrive at the work site with a fully depleted battery because it has a range-extended ICE.

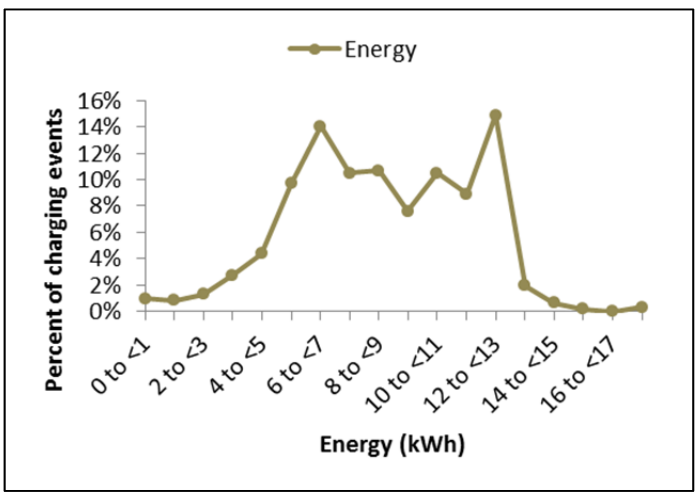


Figure 12-19. Distribution of energy consumed per charging event for AC Level 2 charging events with average power between 2.8 and 3.3 kW.

Figure 12-20 gives distributions of time connected and time transferring power for AC Level 2 charging events in this average power range. All charging events completely charged the battery in under 5 hours. Some drivers disconnected their vehicles in less than 5 hours, while others left their vehicles connected for the entire work day. It is not known whether the drivers who disconnected their vehicles in under 5 hours did so because their batteries reached full charge and they were honoring company policy to make the AC Level 2 cord available to other drivers or because they unplugged their vehicle in order to drive it.

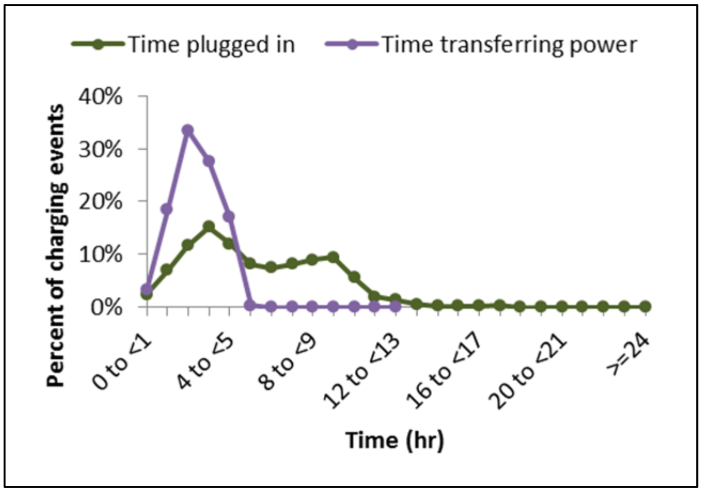


Figure 12-20. Distributions of time connected and time transferring power per charging event for AC Level 2 charging events with average power between 2.8 and 3.3 kW.

12.3.5.3 Medium Power Charging Group 2 (Above 3.3 to 3.8 kW). A third group of charging events was analyzed with average power from above 3.3 kW to 3.8 kW. The MY2011-2012 Nissan Leaf's onboard charger is known to operate in this range.

Figure 12-21 shows the distribution of energy consumed by charging events in this average power group. The absence of a spike in energy at a single value supports the idea that the vehicle or vehicles producing charging events in this group were BEVs (such as the Nissan Leaf), without range extension capability. These vehicles obviously cannot fully deplete their batteries prior to arriving at the worksite. Therefore, there is no natural point to which drivers would consistently discharge their batteries. Instead, their batteries would be depleted proportional to the distance driven since the previous charge, which would vary according to individual driver routines. When batteries are subsequently charged, the energy consumed to recharge them would vary fairly evenly.

Furthermore, drivers of BEVs (such as the Nissan Leaf) would likely not allow (or at least not frequently allow) their batteries to approach full depletion out of concern for running out of charge prior to reaching their destination. Also, the range of BEVs is considerably longer than the typical commute. Therefore, it is reasonable to expect that the energy consumed to charge the batteries of these vehicles would be well less than the battery capacity. For the Nissan Leaf, battery capacity is 24 kWh. Figure 12-21 shows that most charges were about half this capacity and batteries were never charged beyond 20 kWh.

Figure 12-22 shows the distributions of time when connected and time when transferring power for AC Level 2 charging events in this average power range. Charging behavior in this group, in terms of time connected and time transferring power, is similar to the previous group, although the time transferring power is slightly longer. This is consistent with the supposition that events in this group came from BEVs with larger batteries.

12.3.5.4 High Power Charging Group (Greater Than or Equal to 5.6 kW). A fourth group of charging events was analyzed with an average power of 5.6 kW or greater. The MY2013 Nissan Leaf, Ford Focus EV, Tesla Model S, and other vehicles fall in this range. Figure 12-23 shows the distribution of energy consumed by charging events in this average power group.

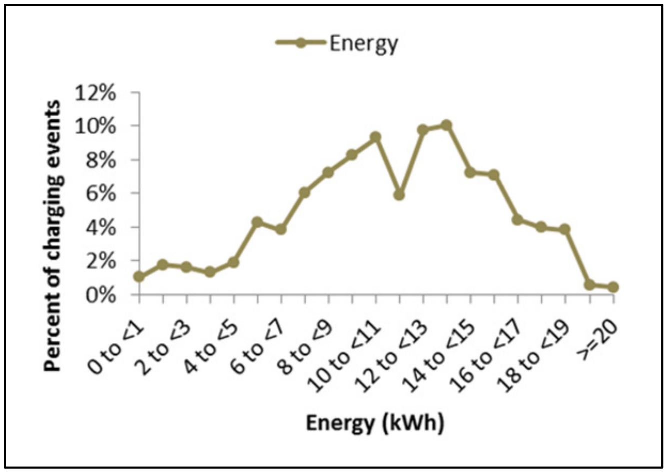


Figure 12-21. Distribution of energy consumed per charging event for AC Level 2 charging events with average power between 3.3 and 3.8 kW.

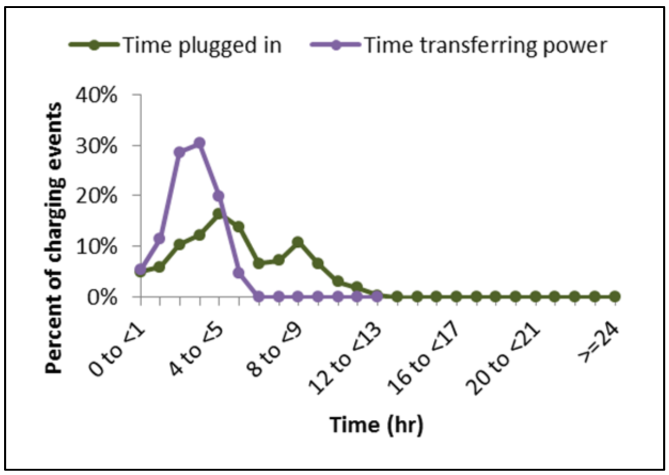


Figure 12-22. Distributions of time connected and time transferring power per charging event for AC Level 2 charging events with average power between 3.3 and 3.8 kW.

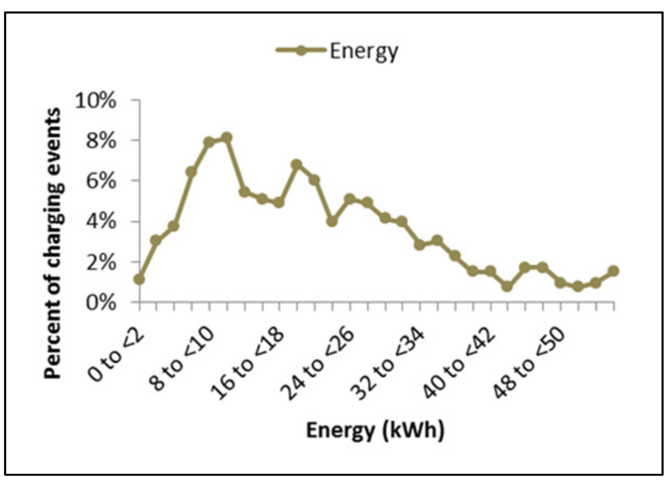


Figure 12-23. Distribution of energy consumed per charging event for AC Level 2 charging events with average power of 5.6 kW or greater.

The vehicles with onboard chargers capable of power in this range are mostly BEVs with large batteries. The Tesla Model S, for example, has either a 60 or 85-kWh battery, which provide estimated ranges of 170 and 220 miles, respectively. Figure 12-23 shows that there were several charging events consuming over 50 kWh. Barring those with exceedingly long commutes, this suggests drivers may have forgone charging at other locations in favor of charging at work. They may have been motivated to save money by charging at work for free or workplace charging may have been their most convenient option. Drivers who live in multi-unit dwellings, for example, may not have the ability to charge at home.

Figure 12-24 shows distributions of time connected and time transferring power for AC Level 2 charging events in this average power range. Charging times for this group are similar to the two previous groups, except that the time transferring power is longer still. Again, this is consistent with the assumption that these charging events were performed by BEVs with larger batteries.

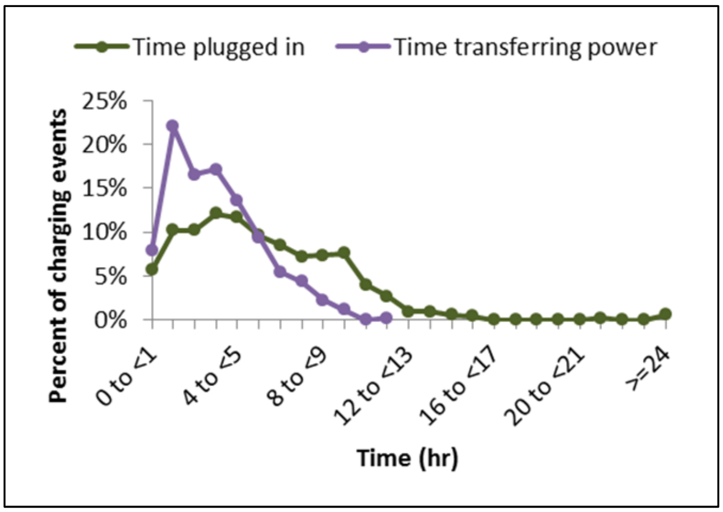


Figure 12-24. Distributions of time connected and time transferring power per charging event for AC Level 2 charging events with average power of 5.6 kW or greater.

12.3.6 References

1. Vehicle specifications cited in this paper were taken from manufacturer's websites, www.fueleconomy.gov, or INL's Advanced Vehicle Testing Activity test reports available at avt.inl.gov.

12.4 Direct Current Fast Charger Usage in the Pacific Northwest

12.4.1 Introduction

The deployment of DCFCs is a major topic of discussion within the EV community. DCFCs are a type of EVSE that charge EVs by providing DC power directly to the EV's battery pack. Generally, DCFCs can charge vehicles at 50 kW or higher (compared to charge rates of 1 to 7 kW when vehicles charge using AC Level 1 and AC Level 2 EVSE), allowing vehicles to be charged quickly. For example, under the right conditions, the Nissan Leaf can charge its battery pack from near full depletion to around 80% SOC in 30 minutes or less using a DCFC [1]. For this reason, many believe that DCFCs should have a major role in public EV charging infrastructure.

Most BEVs currently on the market typically require recharging after driving less than 100 miles. Most BEVs offer a driving range sufficient to meet the needs of most drivers most of the time. However, if drivers of these BEVs want to take long trips, even infrequently, they need a convenient way to charge during the trip. One concept to overcome BEV range limitation is to install DCFCs along transportation corridors to provide BEV drivers opportunities to recharge quickly along their journey. This section describes the use of DCFCs that have been installed for this purpose along major highways in the Pacific Northwest of the United States to determine whether they enable long distance travel in BEVs.

12.4.2 Key Conclusions

- The West Coast Electric Highway Project established a network of DCFCs in the states of Oregon and Washington. In addition, The EV Project installed a dozen DCFCs in metropolitan areas throughout the region. Data from these two networks were analyzed to determine how often the DCFCs were used between September 1, 2012, and December 31, 2013. The most highly used DCFCs were located in the Seattle, Washington, metropolitan area. Other highly used DCFCs were found in Portland and Salem, Oregon, and along Interstate 5 (I-5) north from Salem to Vancouver, British Columbia. Usage generally decreased as distance from I-5 increased.
- When Nissan Leafs in The EV Project based in Washington and Oregon used DCFCs located inside Seattle and Portland, they tended to use them during round-trip outings of less than 75 miles. This is less than the range of the Leaf on a single charge.
- Leaf drivers used DCFCs located outside city boundaries to support longer travel, often driving 150 miles or more before returning home. For these drivers, the West Coast Electric Highway successfully enabled significant range extension.

12.4.3 What Was Studied?

The West Coast Electric Highway Project was launched in 2011 to provide a widespread charging network of AeroVironment brand DCFCs located along highways to enable BEV drivers to travel along the western coast of the United States. Also in 2011, The EV Project was launched to install a network of Blink brand EVSE in metropolitan areas of the Pacific Northwest, among other regions. In the states of Washington and Oregon, a total of 56 AeroVironment and 12 Blink DCFCs were installed within 1 mile of Interstate 5 and other highways as a result of these two projects. The DCFC were spaced 25 to 50 miles apart [2].

INL received charging data from 45 AeroVironment brand DCFCs and 12 Blink brand DCFCs along highways in Oregon and Washington. These data were analyzed, along with data from 1,063 privately owned Nissan Leafs enrolled in The EV Project in Oregon and Washington. Analysis determined how often each DCFC was used and how far vehicles were driven on journeys during which they were charged at the DCFCs.

The period of study for this paper was September 1, 2012, through December 31, 2013. During the study period, the 57 corridor DCFCs reporting data were used 36,846 times by 2,515 distinct BEVs. Of the 1,063 Nissan Leafs whose data were analyzed, 319 Leafs were charged at least once using any of the 57 DCFCs in this study. These 319 vehicles performed 3,325 total charging events at these DCFCs during the study period.

All DCFCs had CHAdeMO connectors during the study period. Any CHAdeMO compatible BEV could have used these DCFCs, regardless of whether they were participants in The EV Project.

12.4.4 Weekly Usage of Direct Current Fast Chargers on the West Coast Electric Highway

The usage frequency of each DCFC was determined using the data logged by the DCFC themselves. Figure 12-25 shows a histogram of usage frequency in terms of the average number of charging events performed at each DCFC per week.

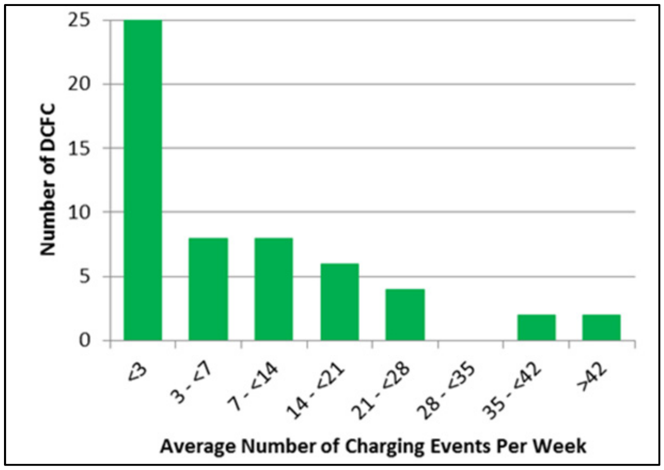


Figure 12-25. Distribution of usage frequency of DCFCs on the West Coast Electric Highway.

There was a wide range in the usage of DCFCs. The majority were used less than seven times per week or once per day. However, four were used 35 or more times per week or 5 or more times per day. A map was created to show how usage frequency varied geographically. This map is shown in Figure 12-26.

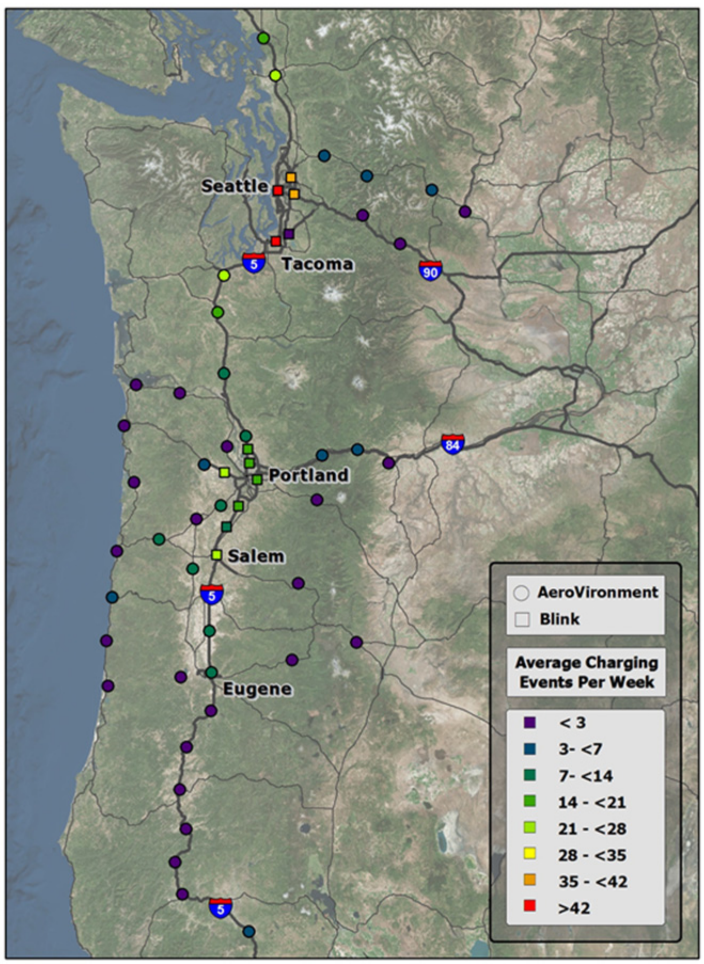


Figure 12-26. Usage frequency of DCFCs on the West Coast Electric Highway. The color of each symbol represents usage frequency. Symbol shape denotes the DCFC brand.

The figure shows a trend in DCFC usage related to its location. Generally, DCFCs that are closer to large cities were used more frequently than those in more sparsely populated areas. The DCFCs directly between the larger cities (i.e., Portland, Seattle, and Vancouver, British Columbia) also had high usage. DCFCs installed farther from large cities, especially to the east and west of I-5 and south of Eugene, were generally used less than 7 times per week. This low usage may not create high value for DCFC owners if they are counting on charger usage to produce revenue or bring in customers to their businesses. However, each individual charge may have been highly valued by the BEV driver. It is important to note that the sites of the West Coast Electric Highway DCFC were not necessarily chosen based on projected usage; more important was to allow EV drivers to take longer trips and to raise awareness and visibility of EVs and charging infrastructure [3].

12.4.5 How Have Battery Electric Vehicle Drivers Used Direct Current Fast Chargers?

To understand the usefulness of DCFCs located along highways to EV drivers, it is important to know how drivers incorporated the DCFCs into their travel. Were they using the DCFCs because they happened to be located where the drivers normally spent time or did they use them truly to enable long-distance travel along a highway corridor? To answer this question, data from Nissan Leafs in The EV Project that used the DCFC in this study were analyzed. Data from each vehicle were broken up into outings. An outing, which is sometimes also referred to as a journey or tour, represents all driving done from when a driver leaves home to when they return home. Outings can span multiple days and include numerous charges or they can be a single drive around the block.

A map was produced to show all of the places where EV Project Leafs parked when away from home during outings. This map is shown in Figure 12-27. Light blue points denote where parking occurred during outings when, at some point during the outing, a DCFC was used. Parking locations were shown as black points if DCFCs were not used during the outing. For reference, the regions within which EV Project participants lived were shaded in light gray.

This map shows that when DCFCs were used, drivers covered a much larger geographic area than they did on outings without DCFCs. During outings when DCFCs were not used, drivers rarely parked outside EV Project regions. From Figure 112-27, it is obvious that the West Coast Electric Highway DCFCs allowed drivers to cover more ground, but it is also important to quantify how far vehicles were driven before and after using these DCFCs.

For each outing during which a DCFC was used, the total distance driven in that outing was calculated. If a vehicle used a certain DCFC in multiple outings, those outing distances were averaged to remove any skewing effects that may arise from a single vehicle using a DCFC more than other vehicles. For each DCFC, this analysis produced a list of every vehicle that used it and each vehicle's average outing distance when they used the DCFC. The median of vehicle average outing distances for each DCFC was then used to represent the outings using that charger. The distribution of median outing distances for all DCFCs is shown as a histogram in Figure 12-28. To be included in this analysis, a DCFC had to be used in 30 or more outings. Many of the least frequently used DCFCs were not used enough by Nissan Leafs in The EV Project to be included in the outing analysis.

The median outing distances are fairly evenly distributed, with 75 to 150 miles being most common. The map from Figure 12-26 was updated to reflect the median outing distance values for each DCFC using stars of increasing size. This map can be seen in Figure 12-29. The symbols for the DCFCs not included in the outing analysis remain unchanged from Figure 12-26.

The DCFCs with the shortest median outing distances were almost all near the city centers of Seattle and Portland, which are the largest cities in Oregon and Washington. The median outing distances for these DCFCs were less than 75 miles, or less than the full charge range of the Leaf. This suggests that, in general, these DCFCs were not used to support corridor travel, but rather were used because they were in areas with high concentrations of EV Project Leafs.

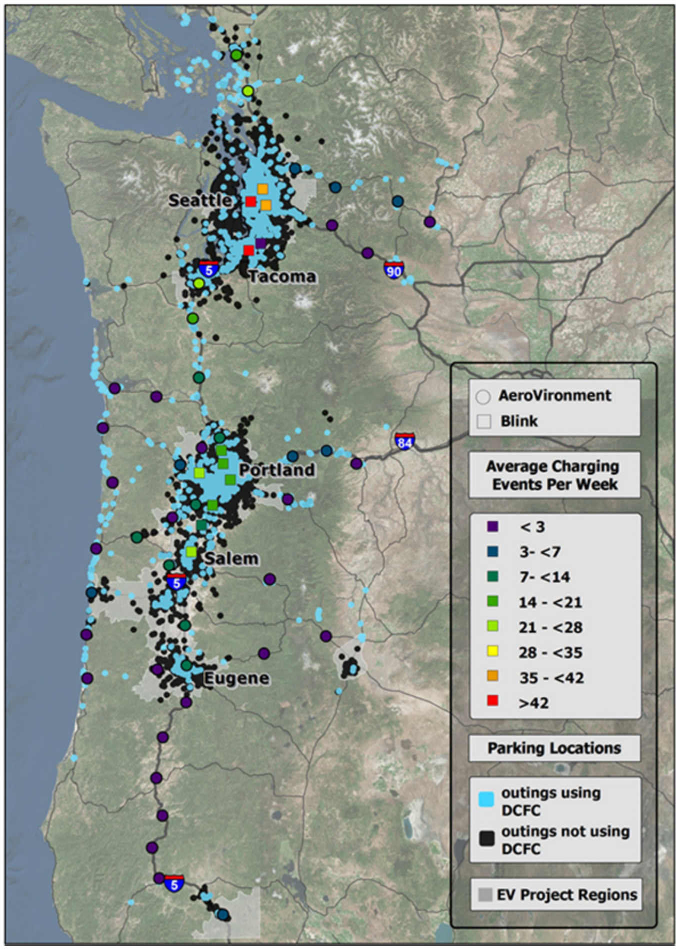


Figure 12-27. Away-from-home Nissan Leaf parking locations during outings were added to the map showing DCFC usage frequency. The color of the parking location points indicates whether a DCFC was used during the outing.

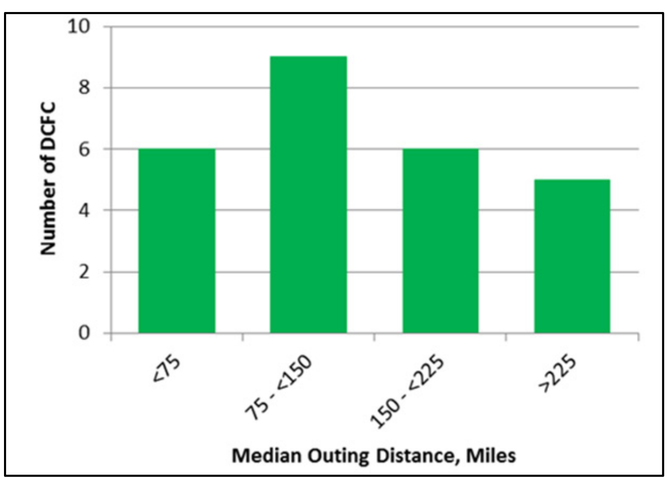


Figure 12-28. Histogram of median outing distance for DCFCs used during 30 or more outings by Nissan Leafs in The EV Project.

Generally, the farther the DCFC was from the larger cities, the higher the median outing distance was. Those that were used in the longest outings were between Portland and Seattle, on the Oregon Coast, and north of Seattle toward Vancouver, British Columbia. These DCFCs are similar because they are not near large population centers; therefore, it is unlikely the vehicle owners lived close to them and used them for convenience.

Looking at DCFCs on I-5 between Portland and Seattle, as well as north of Seattle, they were all used one to four times per day. All of them had median outing distances of greater than 150 miles and some were greater than 225 miles, requiring at least three full charges of the Leaf battery. These results suggest that the West Coast Electric Highway in these areas is being used by BEV drivers to support a considerable amount of long distance travel. In fact, further inspection of the data found that there were 19 outings longer than 500 miles. The longest of these outings was 770 miles. To accomplish this, the driver performed 16 fast charges at nine different DCFCs throughout the region.

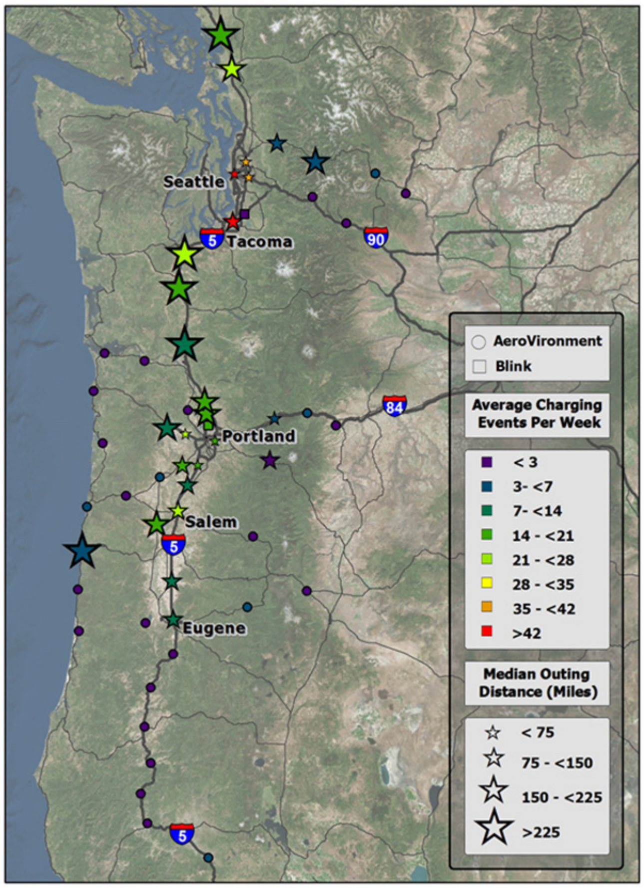


Figure 12-29. Stars of varying size were added to the map in Figure 12-26 to denote median outing distance of EV Project Leafs when using DCFCs on the West Coast Electric Highway.

12.4.6 References

1. See http://www.nissanusa.com/electric-cars/leaf/owner-questions.
2. Botsford, C., "The West Coast Electric Highway," www.energycentral.com/enduse/electricvehicles/articles/3017.
3. Powers, C., "Supporting the Plug-In Electric Vehicle Market Best Practices from State Programs," Georgetown Climate Center, www.georgetownclimate.org/sites/GCC-Supporting-PEV-Market-December-2014.pdf.

13. MISCELLANEOUS OBSERVATIONS

13.1 Top 10 Electric Vehicle Cities and American Recovery and Reinvestment Act of 2009 Charging Infrastructure Deployments

ChargePoint recently released what they calculated as the 10 cities [1] in the United States with the highest number of EVs (Table 13-1). Although details of how this was calculated are not known and it can only be assumed that PHEVs and EREVs are included, it is interesting to note the correlation (perhaps not causation) between these 10 cities and the cities involved in the two charging infrastructure projects that were conducted as part of DOE's ARRA activities.

Between The EV Project and the ChargePoint America Project, charging infrastructure was deployed in seven of the top 10 cities. The EV Project deployed infrastructure in six of the top 10 and the ChargePoint America Project in four of the 10. When looking at the four metropolitan areas with the most PEVs, the two DOE projects were in all four. It should be noted that observations about the number of EVSE deployed are only based on the number of EVSE reporting data to INL.

It is difficult to claim that the highest rate of acceptance and purchase of EVs in the United States was driven solely by the DOE infrastructure deployments, because many other factors can influence purchase behavior, including demographics, tax incentives (e.g., Atlanta [2]), ultra-low off-peak special charging rates for PEVs, distances driven, access to high-occupancy lanes, and strength of the local environmental movement. Regardless of other influences, the two DOE ARRA projects were deployed in 80% of the metropolitan areas in the United States with the most EVs, suggesting that the two projects may have helped the acceptance of EVs. At a minimum, it appears the project planners, with input from DOE, were able to correctly anticipate metropolitan areas that were excellent candidates for deployment and use of charging infrastructure.

Table 13-1. DOE ARRA charging infrastructure deployments for the 10 most EV friendly cities in the United States.

	Charging Infrastructure Deployed and Reporting Data to INL	
Metropolitan Area	EV Project	ChargePoint
San Francisco, CA	2,071	1,317 (includes Sacramento)
Los Angeles, CA	1,176	919
Seattle, WA	1,515 (statewide)	142 (statewide)
San Diego, CA	1,485	
Honolulu, HI		
Austin, TX		350
Detroit, MI		571 (statewide)
Atlanta, GA	384	
Denver, CO		
Portland, OR	1,195 (statewide)	

Deployment locations for both projects can be seen in Figure 13-1; the map of the top 10 cities can be seen in Figure 13-2.

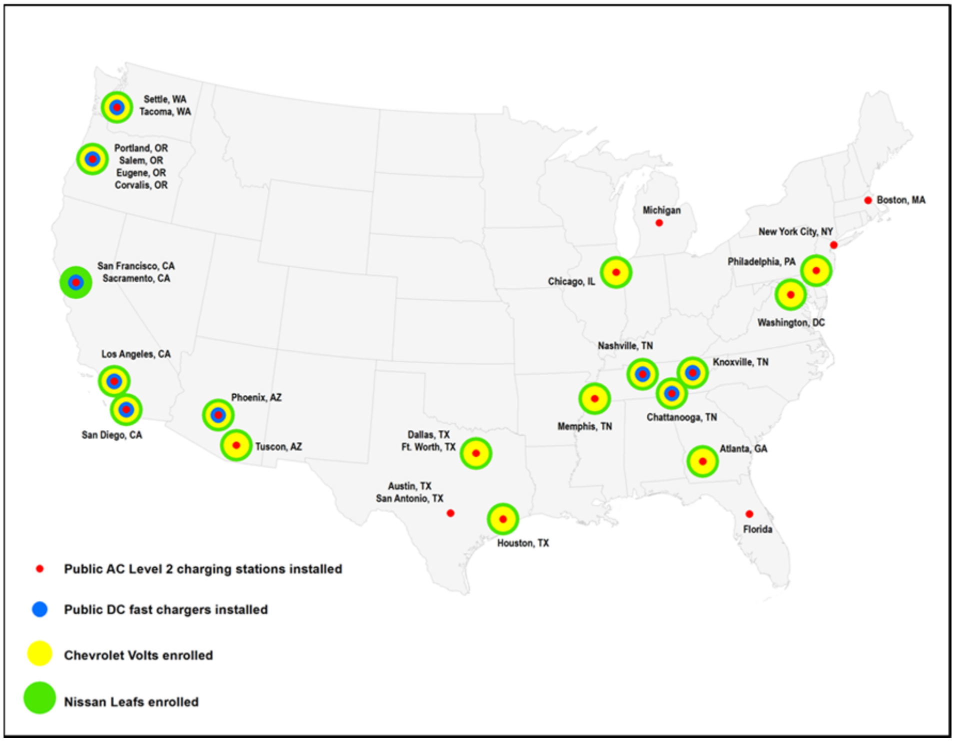


Figure 13-1. Total deployment locations for The EV Project and the ChargePoint America Project.

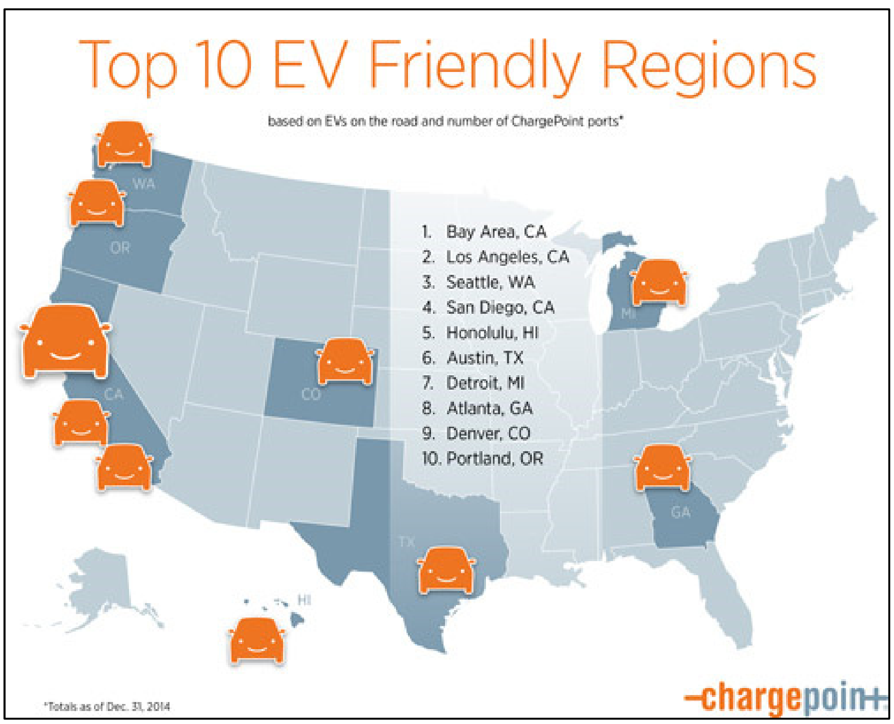


Figure 13-2. Locations of the 10 most EV friendly cities in the United States per ChargePoint.

13.1.1 References

1. "Top 10 Cities For Electric Cars: San Francisco Leads, But It's Not All California," see: http://www.greencarreports.com/news/1097174_top-10-cities-for-electric-cars-san-francisco-leads-but-its-not-all-california.

2. "Sparks Fly," *The Economist*, March 21, 2015, see: http://www.economist.com/news/united-states/21646758-georgias-breaks-electric-vehicles-may-be-too-good-last-sparks-fly.

13.2 Comparing Driver Influence on Plug-In Electric Vehicle Petroleum Reduction Benefits

13.2.1 Introduction

The intent of this section is to benchmark the large impact driver behavior can have on the capability of PEV technologies to reduce petroleum consumption.

Chevrolet Volts operating in commercial fleet missions (146 Volts in electric utility fleets) and the general public's use of Volts (1,895 Volts purchased and operated by private vehicle owners were used to highlight how plug-in technology can maximize petroleum reduction. Results for the second quarter of 2013 (April through June) were chosen for comparison because this reporting quarter saw the most commercial fleet Volts reporting the highest quarterly miles driven and it was also the reporting quarter when the most privately operated Volts in The EV Project reported the highest quarterly miles driven.

13.2.2 Analysis Results

Vehicle use profiles and charging behavior of the two groups of Volts were examined to understand why the Volts driven by the general public achieved more than double the fuel economy results compared to commercial fleet operators (i.e., 142 versus 68 mpg). Table 13-2 provides summary statistics describing driving and charging behavior of the two groups. The key differences are as follows:

- The single largest variable was the amount of eVMT by private drivers. The private Volt drivers averaged 79% more eVMT than the commercial Volt drivers, resulting in more gasoline being used by commercial drivers because their vehicles were operated more often in ERM, during which the gasoline engine must operate in order to drive the Volt. (Section 7 for the GM Chevrolet Volt Vehicle Demonstration contains explanations for EVM and ERM.)
- Based on electrical energy efficiency given in terms of AC Wh/mile, commercial vehicles were likely driven more aggressively, with AC Wh/mile about 9% higher than The EV Project Volts. However, this difference could also have been influenced by the private vehicle drivers' desire to maximize all electric miles by minimizing the use of auxiliary loads and impacts from different climates. Commercial drivers may have been more focused on "getting their job done."
- Privately owned Volt drivers charged their Volts more often, with about 35% more charge events on days the Volts were driven. This factor was the strongest influence on the higher mpg results for The EV Project Volts.
- Figures 13-3 and 13-4 show how commercial Volts were driven for longer trips than the general public drove their Volts. These longer trips, especially the ones beyond 40 miles, which is beyond the Volt's approximate single charge EVM range, would clearly necessitate the use of ERM operations and use of gasoline for propulsion.

There was only a 1% difference in gasoline fuel economy when both sets of Volts were operating in ERM, suggesting that use of auxiliary loads and other settings that may reduce overall fuel economy results were approximately equal for both The EV Project and commercial fleet Volts.

The SOC at the being of charge events (Figure 13-5) in the commercial Volts is significantly higher that SOC at the beginning of charge events in the public Volts (Figure 13-6), suggesting more full discharges in the commercial Volt batteries.

The end-of-charge SOC is very similar for both the commercial Volt charge events (Figure 13-7) and the at-home location charge events for the privately owned Volts (Figure 13-8). The away-from-home charge events for the privately owned Volts and their SOC is indicative of opportunity charging that often ends before 100% SOC is reached.

Table 13-2. Data collection results that quantify Volt use in The EV Project's public and the commercial fleets. Data in this report are for the second reporting quarter of 2013, both for The EV Project Volts and DOE commercial fleet Volt demonstration.

Parameters	Public Volts	Commercial Volts
Number of Volts	1,895	146
Total miles driven (miles)	5,753,009	407,245
Overall mpg	142	68
Overall AC Wh/mile	231	157
ERM mpg	36.1	36.5
Percentage of miles driven in EVM	75%	42%
ERM efficiency (AC Wh/mile)	310	338
Charging events per day on days driven	1.5	1.1
Average trip distance (miles)	8.3	12.3
Average distance between charge events (miles)	27.6	50
Average number of trips per charge event	3.3	4.1

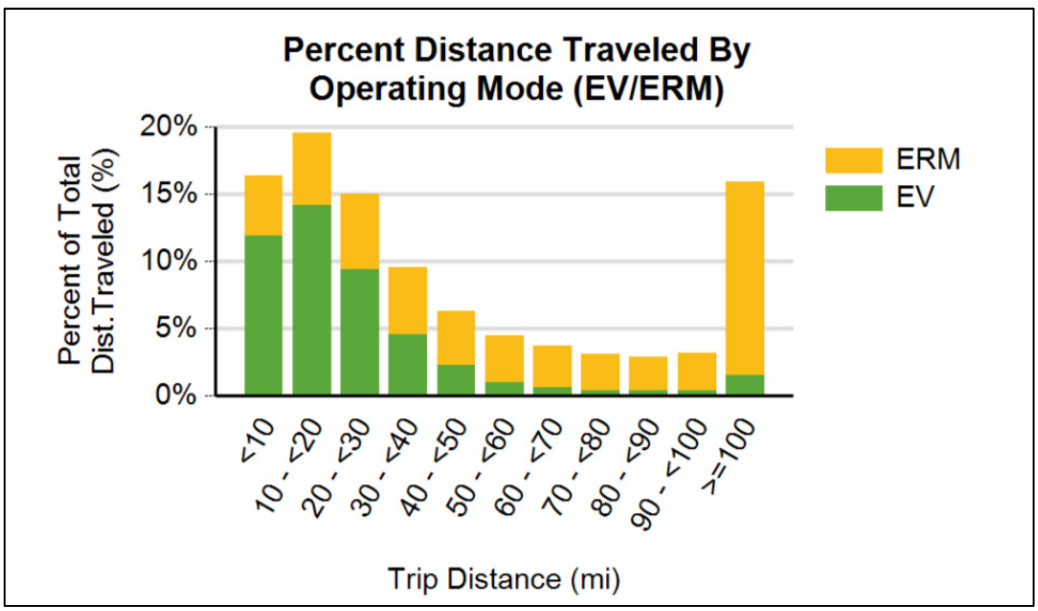


Figure 13-3. Percentage of total miles driven by trip distance and operating mode for Volts operated by commercial drivers.

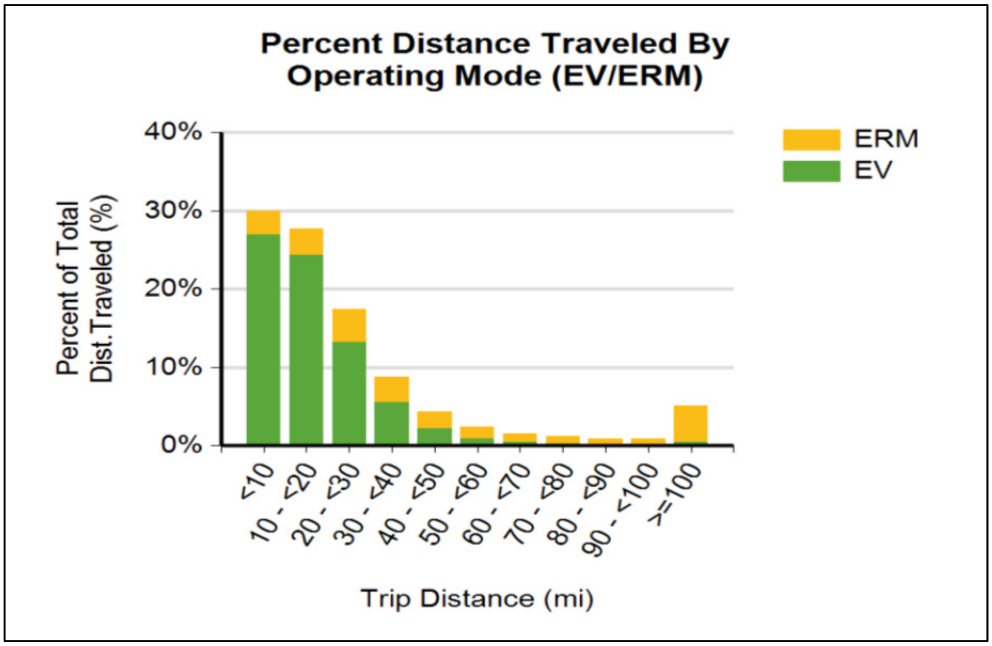


Figure 13-4. Percentage of total miles driven by trip distance and operating mode for Volts operated by private EV Project drivers.

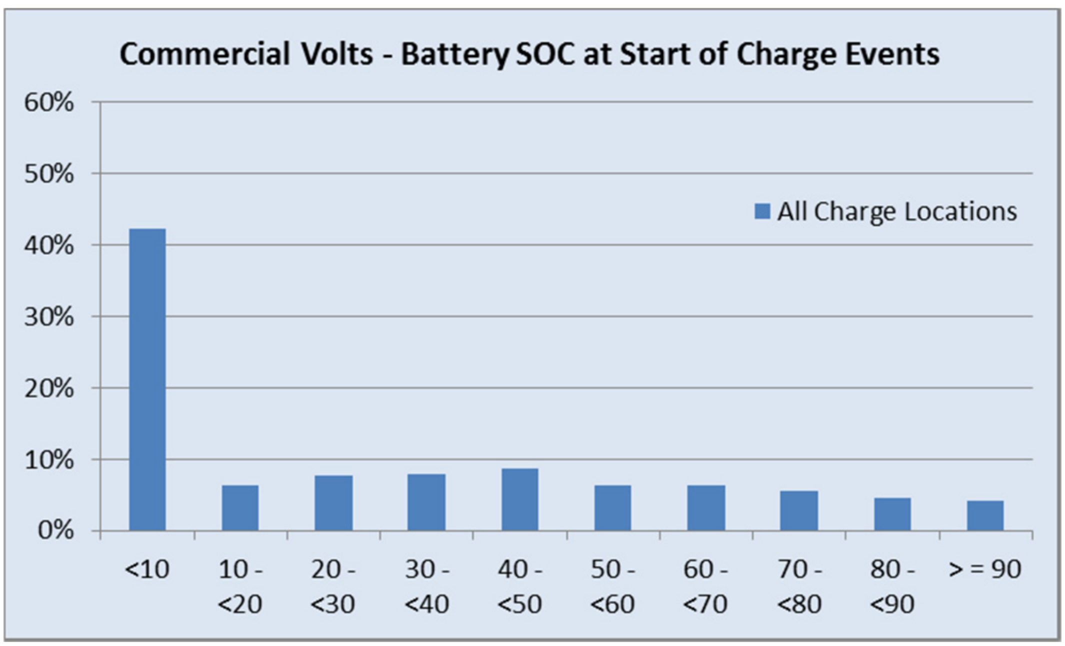


Figure 13-5. Battery SOC for Volts in commercial fleets at the start of charge events.

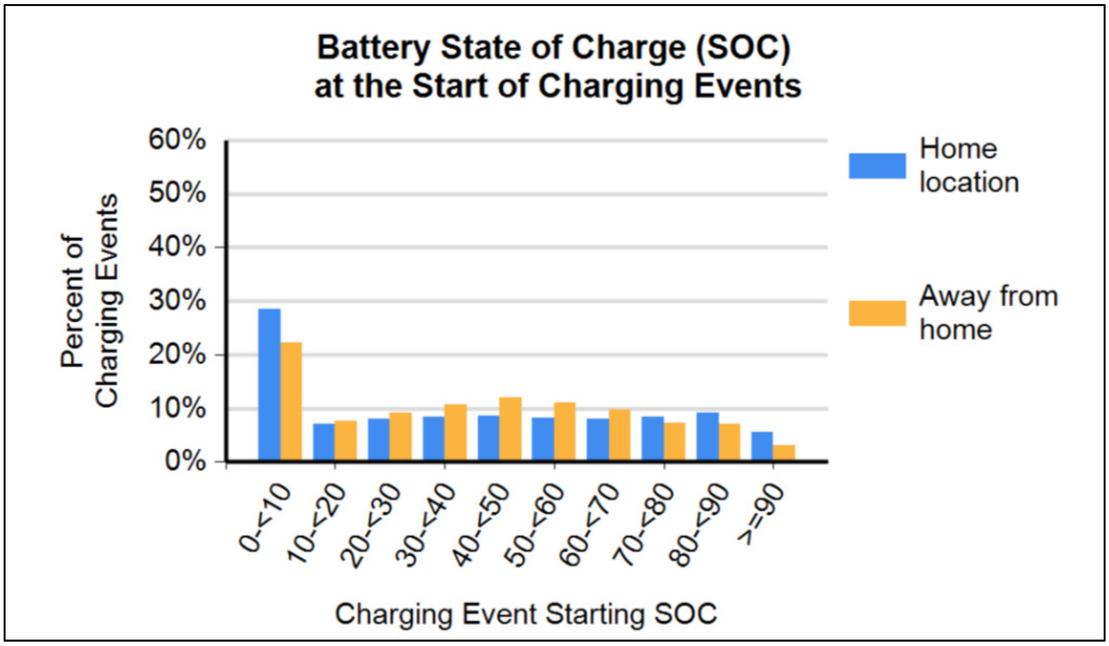


Figure 13-6. Battery SOC for Volts driven by the general public at the start of charge events.

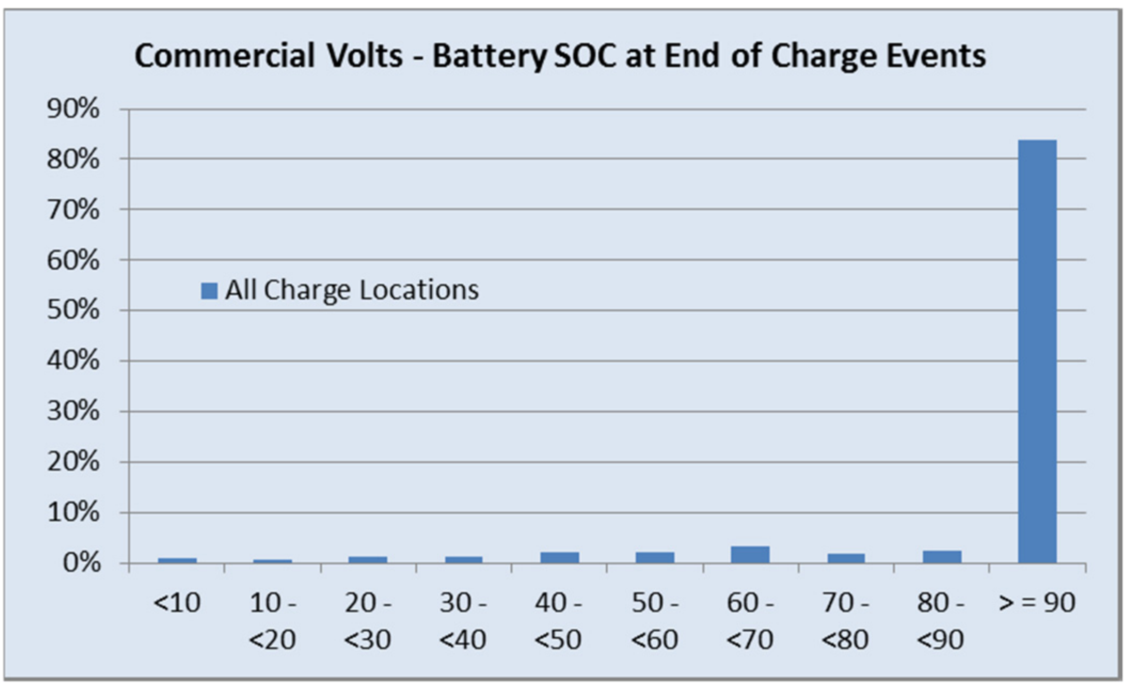


Figure 13-7. Battery SOC for Volts in commercial fleets at the end of charge events.

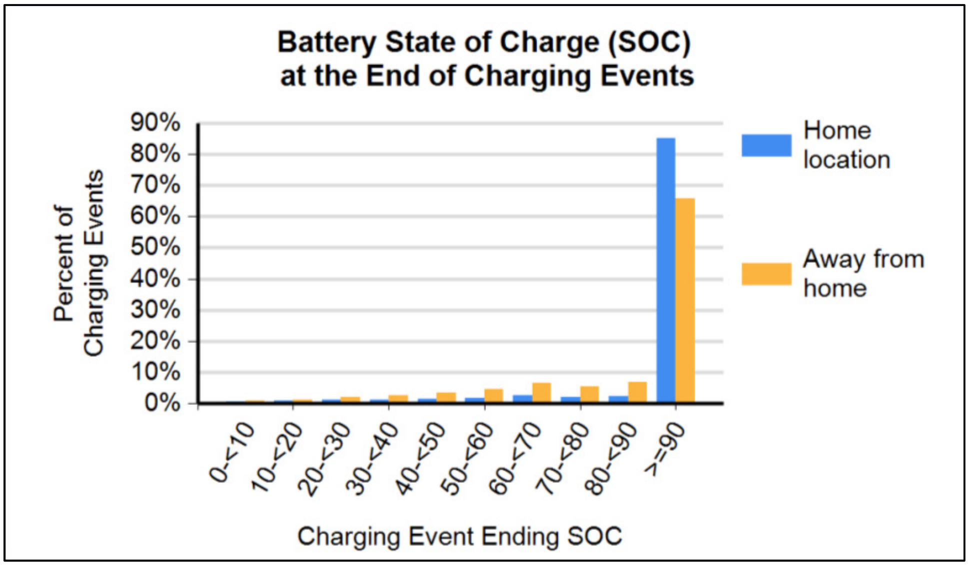


Figure 13-8. Battery SOC for Volts driven by the general public at the end of charge events.

13.3 Comparing EV Project Chevrolet Volt Use and Nissan Leaf Use

13.3.1 Introduction

The intent of this section is not to determine if the Leaf or the Volt is a "better" vehicle or better technology. Both vehicles have distinct technology designs and advantages and it appears that PEV drivers may decide to purchase and use one or the other technologies due to self-perceived driving needs. The goal of this section is to demonstrate driver behavior impacts when using technologies that can significantly reduce petroleum use while still providing functionality similar to a comparative ICE vehicle. Driver behaviors that influenced variables such as charge times, SOC at the beginning and end of charges, and miles driven per charge and per day driven are discussed in the following subsections.

By using a single reporting quarter during which INL was able to report driver behavior of a significant number Volts and Leafs in The EV Project, comparative examples can be used to highlight how different plug-in technologies can maximize petroleum reduction. The results for the second quarter of 2013 (i.e., April through June) were chosen for comparison because this reporting quarter saw the highest volume of Leafs and Volts in The EV Project provide data that represented the most miles driven during a single reporting quarter.

13.3.2 Analysis Results

The sample size is different for the Leafs and Volts: 4,261 Leafs provided data and 1,895 Volts provided data during the second quarter of 2013. Although there were about 2.25 times as many Leafs providing data, the total miles reported was only 1.4 times more for the Leafs than the Volts. Table 13-3 provides summary statistics describing the driving and charging behavior of the Leaf and Volt groups. The following are key differences:

- Volts were driven by drivers about 28% more miles on days they were driven
- The average trip distance for Volt drivers was 17% longer than for Leaf drivers
- Leaf drivers took 15% more trips than Volt drivers per charge event
- Miles driven per charge event were nearly the same, with Volt drivers driving 3% more miles per charge event

- Volt drivers charged their vehicles 36% more often than Leaf drivers on days the vehicles were driven.

Table 13-3. Common analysis results that quantify Volt and Leaf use in The EV Project. Data in this table are for the second reporting quarter of 2013, when the most EV Project Volts and Leafs provided data and reported the most miles driven by the most respective vehicle models.

Parameters	EV Project Leafs	EV Project Volts
Number of Volts	4,261	1,895
Total miles driven (miles)	8,040,300	5,753,009
Average trip distance (miles)	7.1	8.3
Average distance traveled per day when the vehicle was driven (miles)	29.5	41.0
Average number of trips between charging events	3.8	3.3
Average distance traveled between charging events (miles)	26.7	27.6
Average number of charging events per day when the vehicle was driven	1.1	1.5
Percent of home charging events	74%	80%
Percent of away-from-home charging events	20%	14%

As can be seen in Figure 13-9, SOC for Leaf drivers at the start of charging reflected a traditional bell curve, which was likely due to their driving needs and perhaps drivers' reluctance to more fully discharge traction battery packs (this is what some like to call "range anxiety").

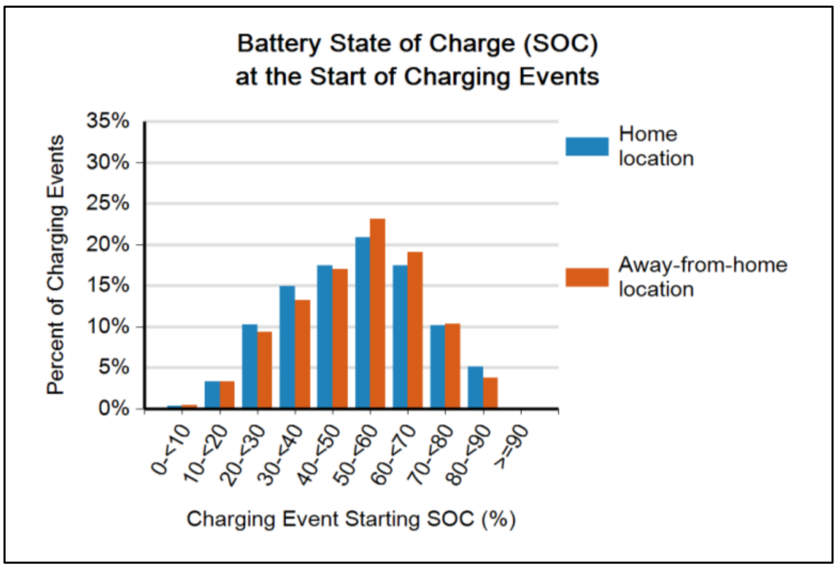


Figure 13-9. Battery SOC at start of Leaf charge events.

Figure 13-10 shows SOC for the Leaf at the end of charge, with about 60% of home charges resulting in a near 100% SOC. Away-from-home charging events result in a similar near 100% SOC about 50% of the time. Note that approximately 80% SOC at the end of a charge occurred about 22% of the time, which reflects the Leaf drivers' use of the Leaf's so-called long life mode, which ceases charging (regardless of charge rate) to stop at about 80% SOC. Drivers can instruct charging to continue to 100% SOC. The feature that stops charging at approximately 80% is intended to extend the life of the Leaf traction battery.

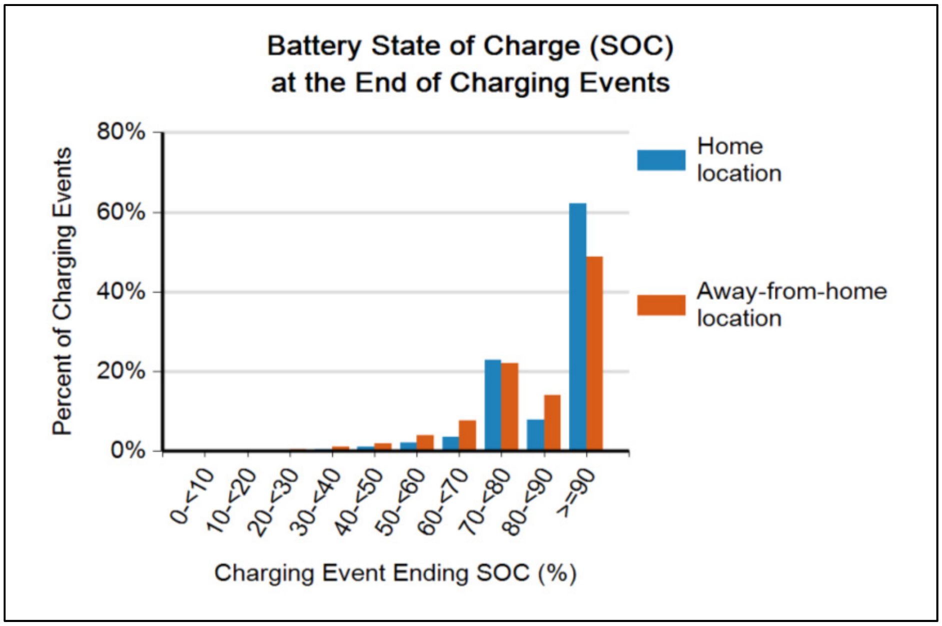


Figure 13-10. Battery SOC at the end of the Leaf charge events.

Volt drivers have a much flatter pre-charge SOC profile (Figure 13-11). Note that 20 to 30% of the time Volt drivers do not start recharging their packs until they are at less than 10% SOC. However, Volt drivers have the luxury of having an ICE as a backup for propulsion if they fully discharge their traction battery packs.

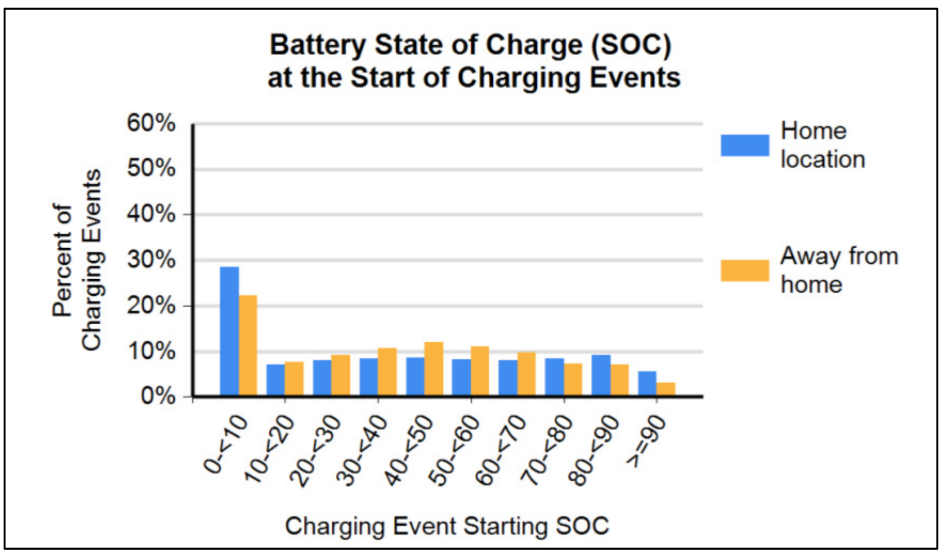


Figure 13-11. Battery SOC at start of Volt charge events.

As seen in Figure 13-12, Volt drivers have a fairly high SOC at the end of charging, with 85% of home charge events ending at 90% or greater SOC and 65% of away-from-home charge events ending at 90% SOC or higher.

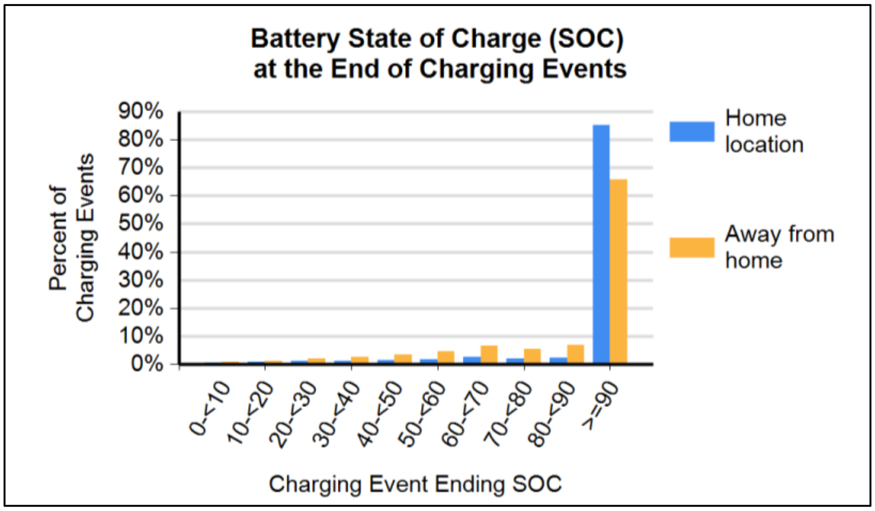


Figure 13-12. Battery SOC at the end of Volt charge events.

13.4 ChargePoint America Project and The EV Project Comparative Results

13.4.1 Introduction

The intent of this section is not to determine if one project or EVSE provider was "better" than another in terms of deployment numbers or usage rates. Both projects were distinct and differently designed and conducted in mostly different regions of the United States. The intent of this section is to examine if PEV drivers displayed significantly different charging behavior in different projects and different regions. The results for the second reporting quarter (i.e., April through June) of 2013 are used because this reporting quarter saw the highest number of EVSE from both The EV Project and the ChargePoint America Project providing data to INL. This reporting quarter also saw the most data generated from charge events, both independently and combined, with a combined 830,000 charge events reported.

As seen in Figures 13-13 and 13-14, the residential EVSE time connected and drawing power profiles are fairly similar. Looking at public EVSE in both projects (Figures 13-13 and 13-14), the ChargePoint public EVSE had a PEV connected more often (i.e., ChargePoint public AC Level 2 EVSE units had a vehicle connected 14% of the time compared to The EV Project's 8% of the time). For the percentage of time power was being transferred for AC Level 2 EVSE, it was 4% for ChargePoint and 2% for The EV Project. However, this ignores The EV Project's public DCFC connection time of 5% and power transfer time of 5%.

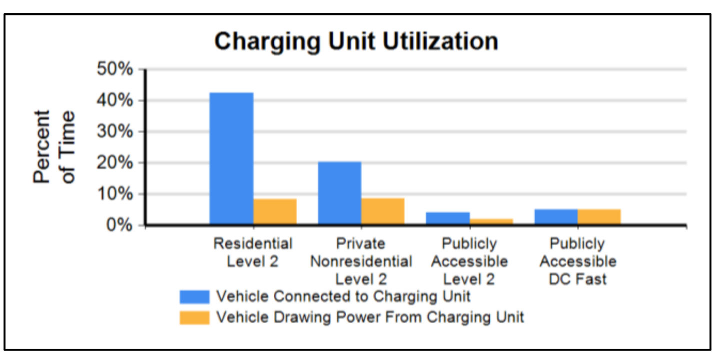


Figure 13-13. EV Project EVSE utilization.

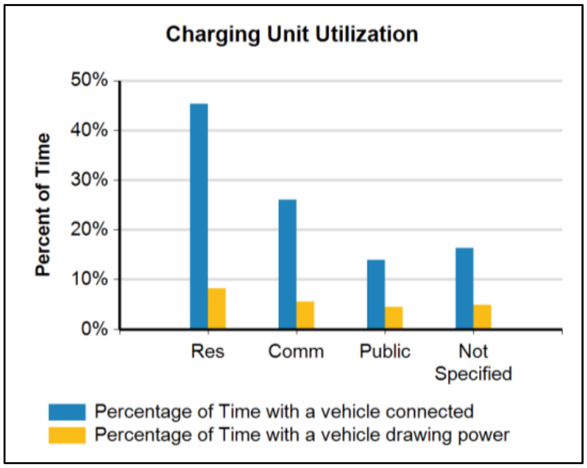


Figure 13-14. ChargePoint America EVSE utilization.

13.4.2 Residential EVSE

When looking at the weekday residential connection profiles in Figures 13-15 and 13-16, the median connection percentages (i.e., black line) are extremely similar.

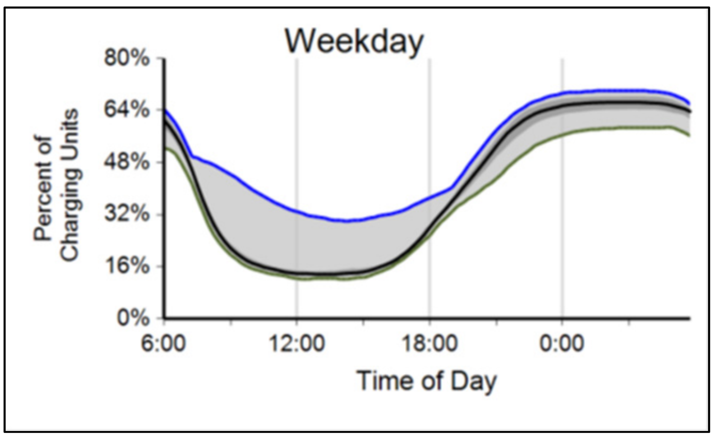


Figure 13-15. The EV Project charging weekday residential EVSE connection profile.

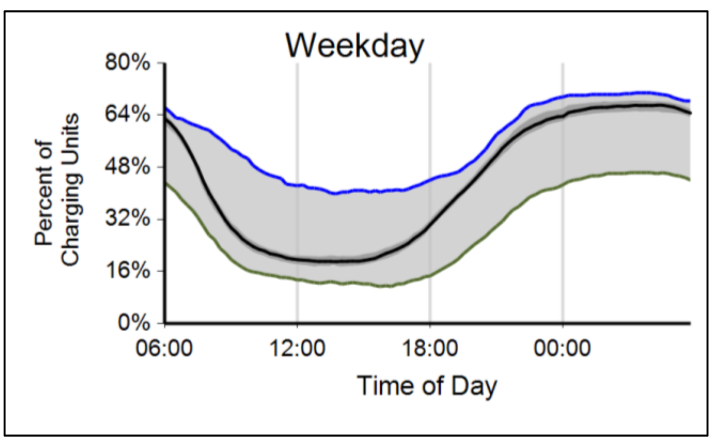


Figure 13-16. ChargePoint America charging weekday residential EVSE connection profile.

Ignoring the difference in the scales in Figures 13-17 and 13-18 due to the different number of residential EVSE, the weekday profiles are fairly similar and both display similar power transfer characteristics at midnight (0:00), when TOU rates influence drivers to set midnight as the time to start charging.

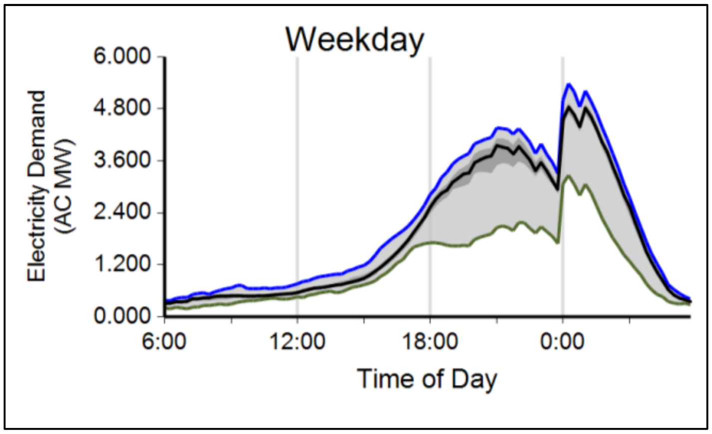


Figure 13-17. EV Project power transfer weekday residential EVSE profile.

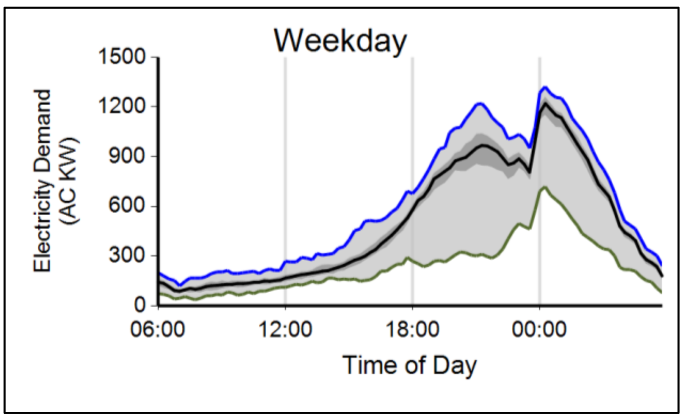


Figure 13-18. ChargePoint America power transfer weekday residential EVSE profile.

Table 13-4 shows that the average length of time with a vehicle connected per charging event at residential EVSE in The EV Project was about 30 minutes less than residential EVSE in the ChargePoint America Project, and they also drew power for a slightly shorter period of time. However, The EV Project residential EVSE transferred slightly more energy per charge event. This result is driven by the weekday average of 8.1 kWh transferred in The EV Project, while weekend charge events saw a 6.89 kWh average energy transfer. The energy transfer amounts for the ChargePoint America residential EVSE were 7.34 kWh on weekdays and 6.17 on weekends.

Table 13-4. Overall length of time with a vehicle connected, energy being drawn, and total energy transferred at residential AC Level 2 EVSE. This includes summary weekday and weekend data for The EV Project and ChargePoint America project.

	EV Project	ChargePoint
Average length of time with vehicle connected per charging event (hour)	11.5	12.2
Average length of time with vehicle drawing power per charging event (hour)	2.2	2.3
Average electricity consumed per charging event (AC kWh)	7.8	7.03

While there were some differences in the length of time with a vehicle connected, both The EV Project (Figure 13-19) and ChargePoint America Project (Figure 13-20) residential connection times are similar.

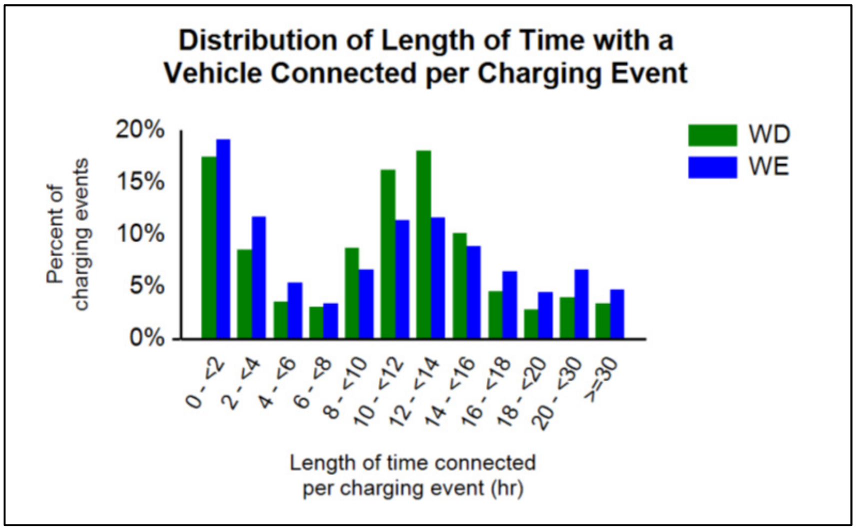


Figure 13-19. EV Project distribution of length of time with a vehicle connected at residential EVSE.

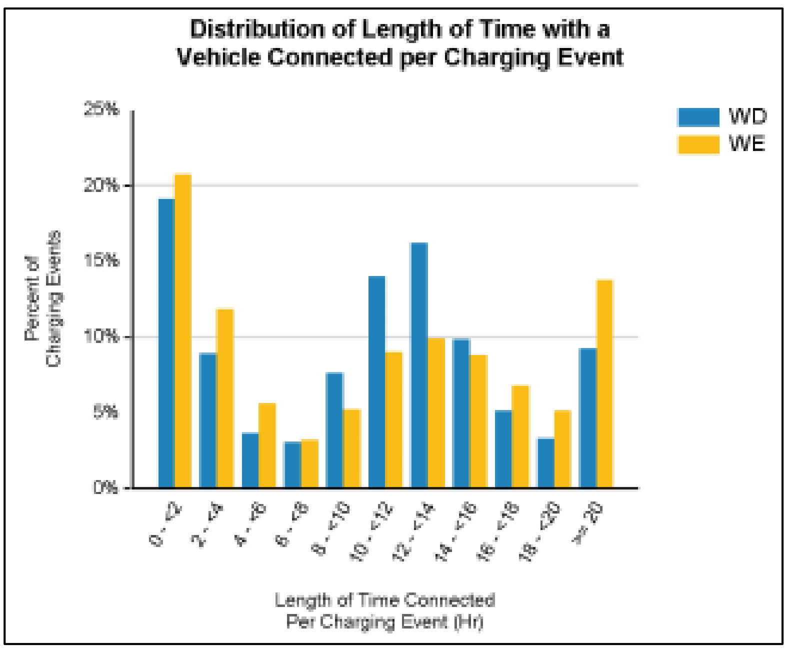


Figure 13-20. ChargePoint America distribution of length of time with a vehicle connected at residential EVSE.

At first glance, distribution of length of time with a vehicle drawing power per charge event for The EV Project residential EVSE (Figure 13-21) seems to be longer than charge times for ChargePoint America (Figure 13-22). However, they are actually fairly similar when one considers that The EV Project's x axis is in 1-hour increments and the ChargePoint America's x axis is in 2-hour increments.

Unfortunately, the scales used for binning residential kWh used per charge event for The EV Project EVSE were in 3-hour increments (Figure 13-23) and 2-hour increments for the ChargePoint America Project (Figure 13-24); therefore, direct comparisons are difficult. The spike in the 10 to <12 kWh bin in the ChargePoint data is interesting, and it is believed to have been mostly the result of Volts recharging from low SOCs.

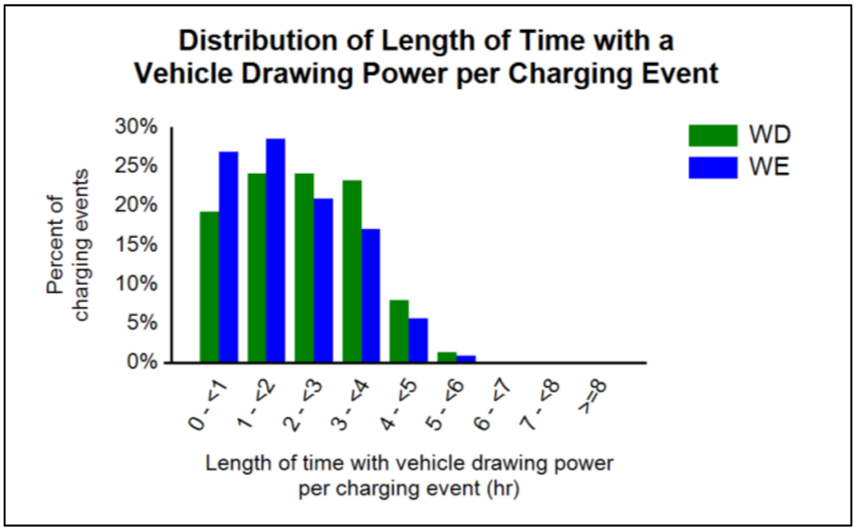


Figure 13-21. EV Project residential EVSE distribution of length of time with a vehicle drawing power per charge event.

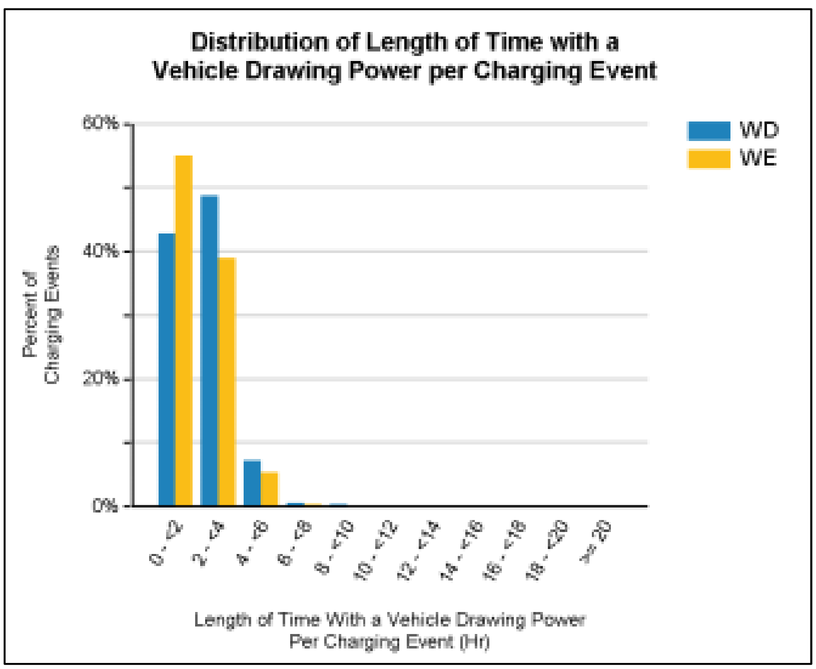


Figure 13-22. ChargePoint America residential EVSE distribution of length of time with a vehicle drawing power per charge event.

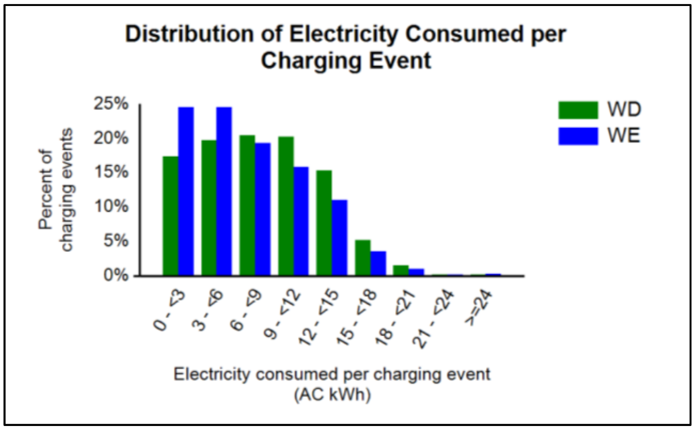


Figure 13-23. EV Project distribution of AC energy (kWh) consumed per charging event at residences.

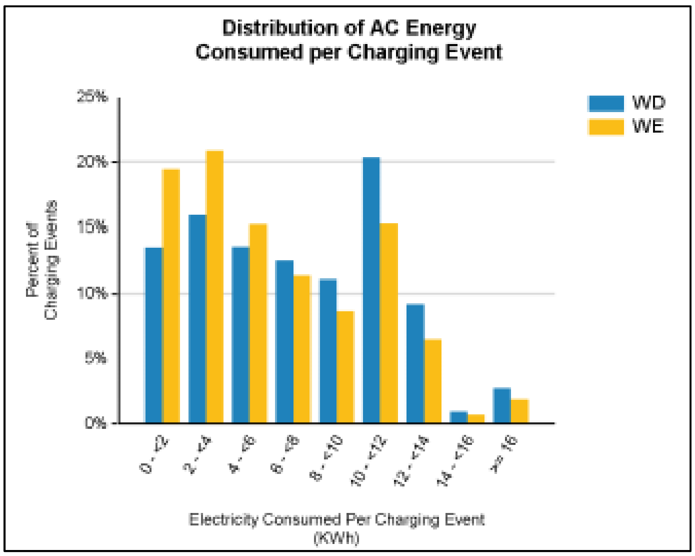


Figure 13-24. ChargePoint America distribution of AC energy (kWh) consumed per charging event at residences.

13.4.3 Public Alternating Current Level 2 Electric Vehicle Supply Equipment

Based on the percentage of public EVSE with a vehicle connnected in The EV Project (Figure 13-25) and in the ChargePoint America Project (Figure 13-26), it appears that the ChargePoint public EVSE consistently had a higher percentage of time with a vehicle connected on weekdays. Weekend connection time percentages were much flatter, but again, the ChargePoint public EVSE had more vehicles connected as measured by a percentage of EVSE in each project. By this time, The EV Project was requiring a fee at nearly all public EVSE, while ChargPoint public EVSE use was believed to be 70% free.

The public demand profiles for both of the EVSE projects (Figures 13-27 and 13-28) are fairly similar, with power transfer peaking before noon on weekdays. However, the ChargePoint America peak demand was about twice as high as The EV Project peak demand, even though The EV Project had about 25% more public EVSE reporting use data during the April through June 2013 reporting quarter. Again, the fees charged for public charging in The EV Project versus ChargePoint America's mostly free charging were likely the greatest influence.

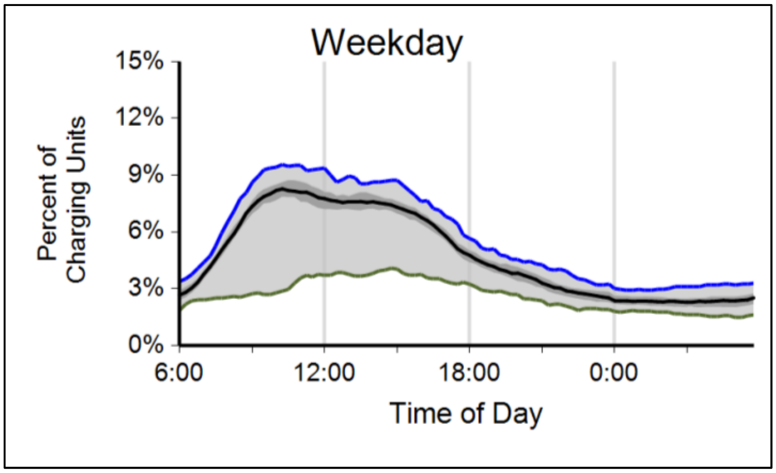


Figure 13-25. EV Project weekday public EVSE percent of charging units with a vehicle connected.

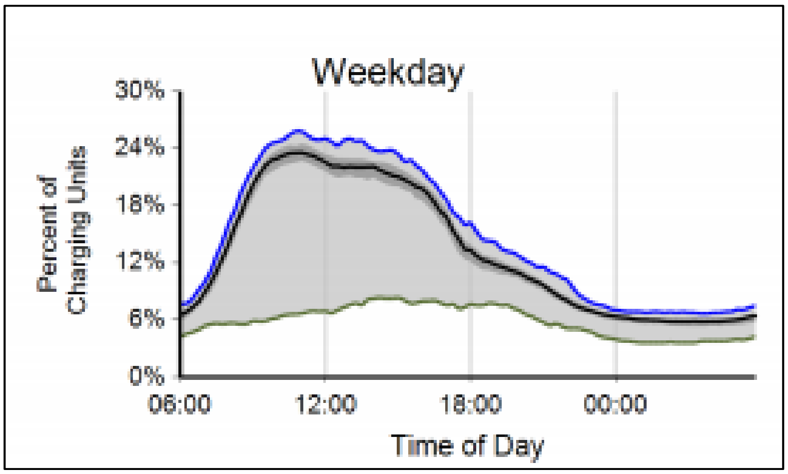


Figure 13-26. ChargePoint America weekday public EVSE percent of charging units with a vehicle connected.

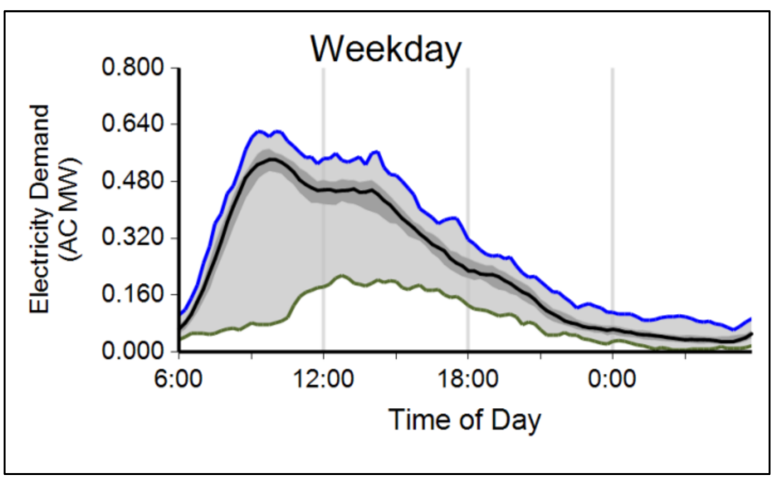


Figure 13-27. EV Project weekday public EVSE aggregate demand.

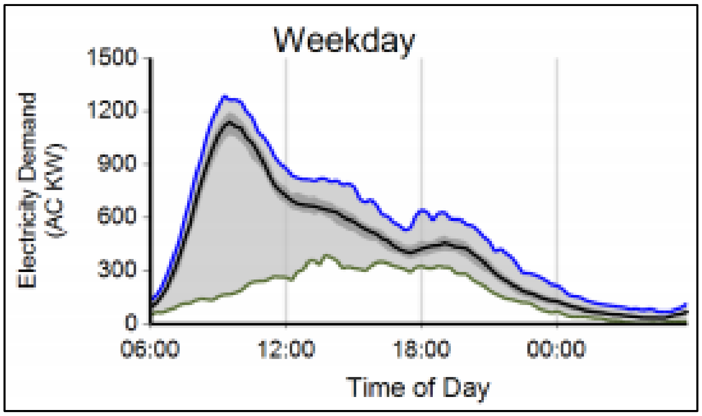


Figure 13-28. ChargePoint America weekday public EVSE aggregate demand.

Table 13-5 shows that even though drivers charging at public EVSE in The EV Project are connected for about 30 minutes less than public EVSE in the ChargePoint America Project, they actually transferred power for a slightly longer period of time. The longer power draw times resulted in slightly more energy used during the average public charging event.

The EV Project's public EVSE saw an average of 8.7 kWh used on weekdays and 8.4 kWh on the weekends. The energy transfer amounts for ChargePoint America's public EVSE were 7.86 kWh on weekdays and 7.56 on weekends.

Table 13-5. Overall length of time with a vehicle connected, energy being transferred, and total energy transferred at public AC Level 2 EVSE. This includes weekday and weekend data for The EV Project and the ChargePoint America Project.

	EV Project	ChargePoint
Average length of time with vehicle connected per charging event (hour)	4.5	5.1
Average length of time with vehicle drawing power per charging event (hour)	2.3	2.2
Average electricity consumed per charging event (AC kWh)	8.6	7.9

While there were some differences in the length of time with a vehicle connected, both The EV Project (Figure 13-29) and ChargePoint America Project's (Figure 13-30) public connection times are similar.

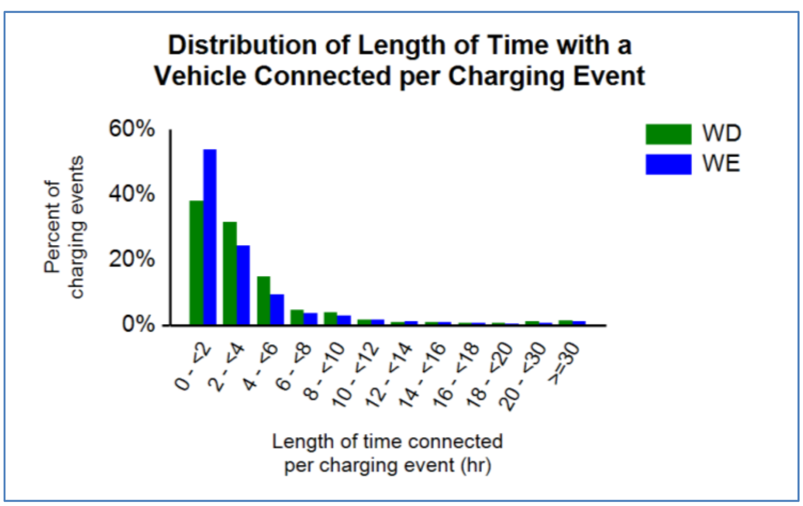


Figure 13-29. EV Project distribution of length of time with a vehicle connected at public EVSE.

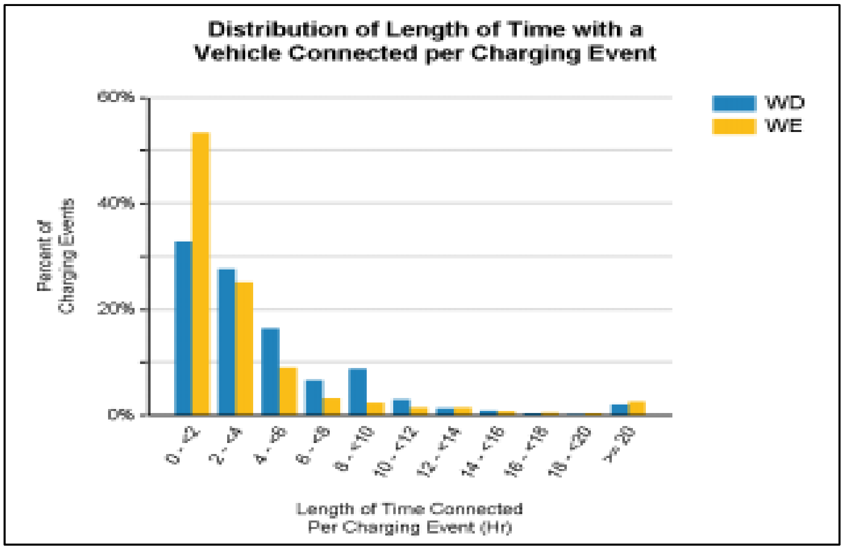


Figure 13-30. ChargePoint America distribution of length of time with a vehicle connected at public EVSE.

At first glance, public EVSE distribution of length of time with a vehicle drawing power per charge event for The EV Project (Figure 3-31) seems to be longer than the charge times for the ChargePoint America Project (Figure 3-32); however, they are actually fairly similar when one considers that The EV Project's x axis is in 1-hour increments and the ChargePoint America's x-axis is in 2-hour increments.

Unfortunately, the scales used for binning the residential kWh used per charge event for The EV Project were in 3-hour increments (Figure 3-33) and 2-hour increments for the ChargePoint Project (Figure 13-34); therefore, direct comparisons are difficult. Having said this, there does appear to be fairly similar amounts of energy being used for charging in both projects.

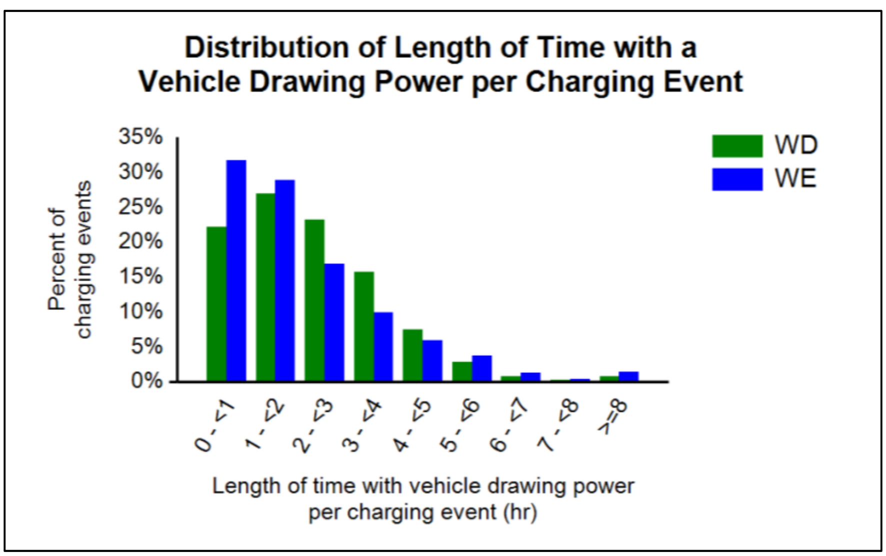


Figure 13-31. EV Project public EVSE distribution of length of time with a vehicle drawing power per charge event.

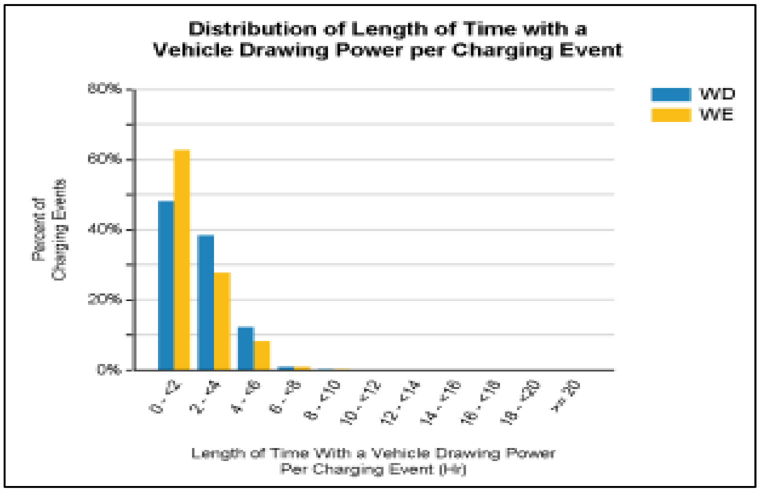


Figure 13-32. ChargePoint America public EVSE distribution of length of time with a vehicle drawing power per charge event.

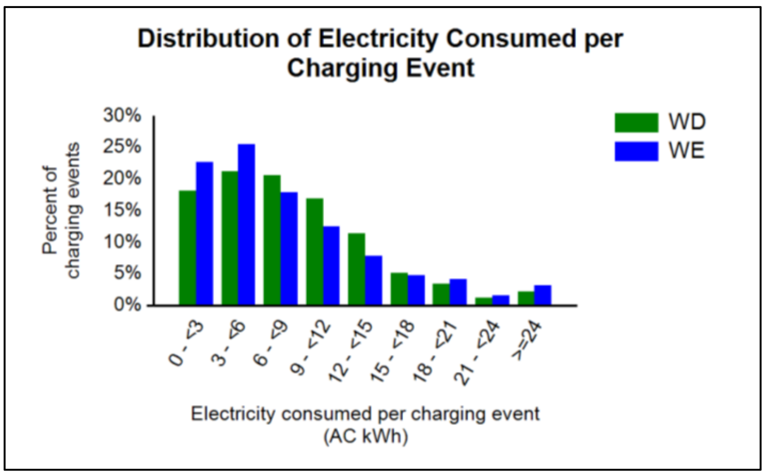


Figure 13-33. EV Project distribution of AC energy (kWh) consumed per charging event at public EVSE.

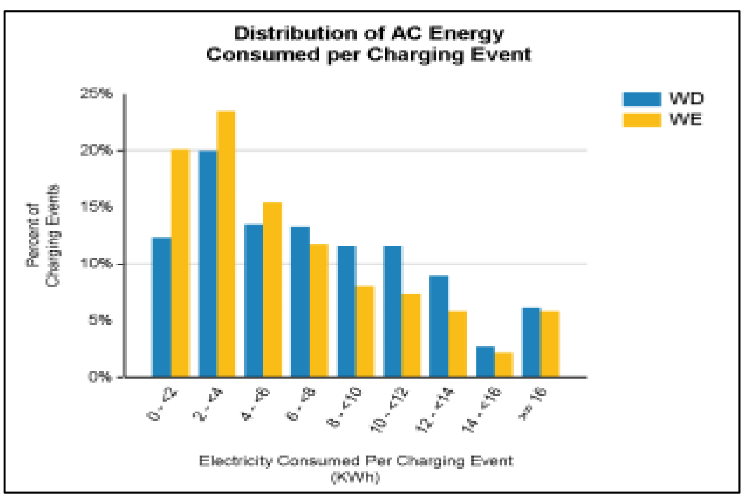


Figure 13-34. ChargePoint America project distribution of AC energy (kWh) consumed per charging event at public EVSE.

13.4.4 Summary

While some slight differences in use patterns exist, public and residential AC Level 2 EVSE were used in similar ways, with similar amounts of energy being transferred per charge event. However, the ChargePoint America Project's public EVSE were used more frequently than The EV Project's public EVSE, but again, free charging does have higher use rates than fee-based charging. Private commercial/non-residential EVSE were not compared because the specific types of EVSE sites included in these categories varied between the two projects.

13.5 Who Has Used This Information and How Have These Results Helped Progress the Plug-In Electric Vehicle Market?

INL reports on PEV performance and petroleum reduction capabilities and drivers' use of PEVs and charging infrastructure in national and regional PEV and charging infrastructure demonstrations have been used by automakers to inform decisions in the following areas:

- Vehicle powertrain architecture design, electric range selection, and battery sizing
- Onboard charger power level
- Battery life and warranty cost prediction models.

Representatives from Ford, GM, Chrysler, Honda, Nissan, Toyota, BMW, and Mitsubishi have expressed appreciation for information published by INL. Independent and unbiased data gathering and analysis from real-world demonstrations provides them with valuable feedback on how customers are using their products. Ford, GM, Honda, and Toyota have asked for additional special analysis and reporting.

eVMT and other behavioral statistics have been published for the SAE committees and for state and federal regulators to validate assumptions used in development of testing standards and regulatory policy.

Charging behavior and subsequent demand on the electric grid continue to be requested by electric utilities in the United States and abroad to inform their assessments on the following:

- The impact of EV charging on the electric grid
- Pricing elasticity and efficacy of TOU electricity rates for EV owners.

Reports and presentations on PEV charging station usage have been used by auto companies, PEV charging equipment manufacturers, facilities management companies, PEV advocacy groups, and federal and state government agencies to inform EV charging infrastructure deployment decisions with respect to location, equipment charge power level, and pricing models.

PEV infrastructure installation cost data have been requested by PEV charging equipment service providers, automakers, and researchers to help them understand how equipment installation decisions and subsequent costs can be a barrier to EV adoption.

Numerous other organizations were provided with special reports or presentations to aid their research, planning, or policy decisions related to EVs design, promotion, and climate change. These groups include the following:

- Argonne National Laboratory
- APS
- CARB
- California Energy Commission
- Cardiff University, United Kingdom

- Center for Climate and Energy Solutions (formerly the Pew Center on Global Climate Change)
- City of Chattanooga, Tennessee
- City of Knoxville, Tennessee
- Clinton Foundation – Clinton Climate Initiative
- Colorado State University
- Colorado State Energy Office
- Columbia Hospitality
- Commonwealth Edison Company
- Delaware Valley Regional Planning Commission
- Electric Drive Transportation Association
- EPRI
- Energy and Environmental Resources Group, LLC
- Eugene Water and Electric Board
- Georgia Power
- Green Mountain College
- London Hydro, Inc.
- Los Angeles Department of Water and Power
- Massachusetts Institute of Technology
- Memphis Light Gas and Water
- Middle Tennessee Electric Membership Corporation
- Nashville Electric Service
- National Academy of Sciences Committee on Overcoming Barriers to Electric Vehicle Adoption
- National Renewable Energy Laboratory
- Oak Ridge National Laboratory
- Oncor Electric Delivery
- PG&E
- PacifiCorp
- PECO Energy Company
- PGE
- Public Utility District No. 1 of Snohomish County
- Puget Sound Energy
- Salem Electric
- Sacramento Municipal Utility District
- Salt River Project
- SDG&E

- Seattle City Light
- Seattle University
- State of Idaho
- State of Oregon
- State of Washington
- Tucson Electric Power
- Union of Concerned Scientists
- University of California – Davis Institute for Transportation Studies
- University of Georgia
- University of Texas Austin
- U.S. Department of Transportation
- Vermont Energy Investment Corporation
- Wall Street Journal
- Washington State Department of Transportation

14. IDAHO NATIONAL LABORATORY DATA SYTEMS USED FOR THE AMERICAN RECOVERY AND REINVESTMENT ACT OF 2009 BENCHMARKED PROJECTS

14.1 Introduction

Prior to its involvement with ARRA projects, INL had project experience with the processes involved in collecting data from vehicles and charging infrastructure in field applications. Current INL staff experience dates to the early 1990s, when data were collected via IBM-286 personal computers that were installed in each test vehicle. The computers collected data from custom-installed sensors. In order to transfer the data from the IBM-286 personal computers, floppy disks were manually removed and mailed to INL so data could be downloaded and checked for quality. Charging data were collected separately via ABB utility grade meters installed onboard the vehicles; the data were downloaded via optical sensors that were powered by early lithium batteries.

Eventually, as the above process matured, cellular communications and server-to-server data transfers were adopted that allowed data streams to be sent to INL from both vehicles and charging infrastructure. By the late 2000s, as data collection technology evolved, this had become standard INL practice. Many algorithms were developed for ensuring data quality and calculating the metrics and graphs that were used to populate the reports. By 2009, INL had databases that contained data collected from several thousand PEVs.

When the ARRA projects were initiated, based on extensive past experience, INL was tasked with using its mature vehicle and charging infrastructure data collection, analysis, reporting, and secure storage processes to benchmark the ARRA projects and various technologies' abilities to be successfully used by the consumers to reduce petroleum consumption. The integrated processes and systems used by INL are described in the following subsections.

14.2 Handling Data

In order to accomplish data transfers from various project partners and ensure raw data are handled securely, non-disclosure agreements were signed with each of the project partners.

This section of the report describes how INL handles data collection, quality analysis, storage, and other aspects of data management. This section contains the following subsections:

1. Data warehouse management
2. Work flow
3. Receiving files
4. File types
5. Servers
6. Processing files
7. Basic database practices
8. Quality assurance
9. Standard report calculations
10. Security.

14.2.1 Data Warehouse Management

Figure 14-1 shows the overall process used to transmit data from vehicles and charging infrastructure being benchmarked in field operations to INL and eventually produce external reports.

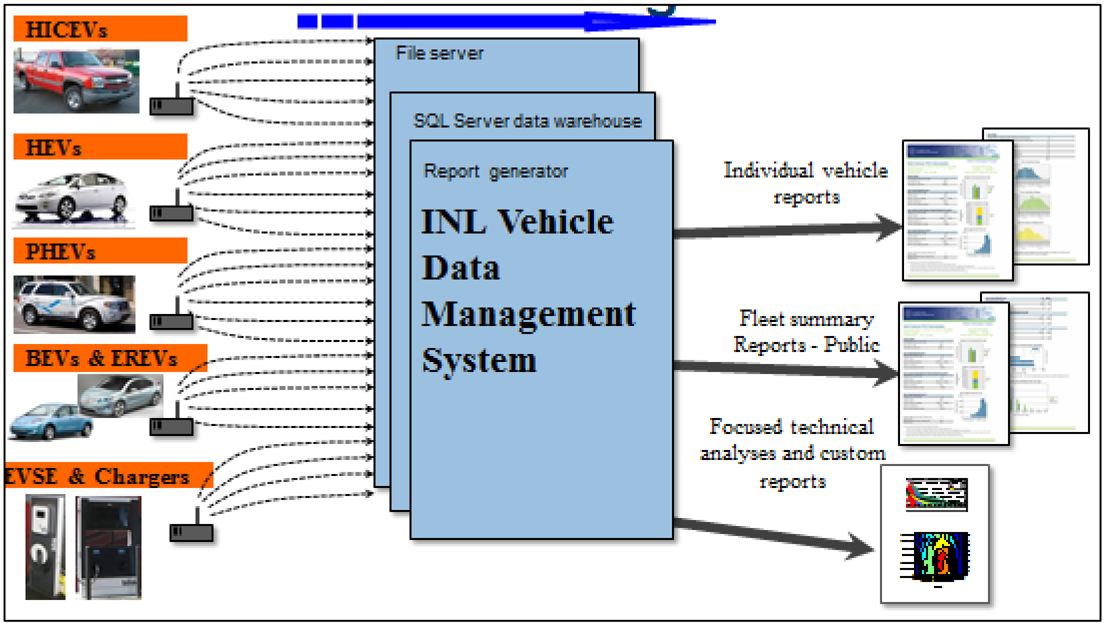


Figure 14-1. Overview of the vehicle and charging infrastructure data collection and report generation process used for ARRA projects.

14.2.2 Work Flow

The individual work flow steps for the ARRA projects can be seen graphically in Figure 14-2.

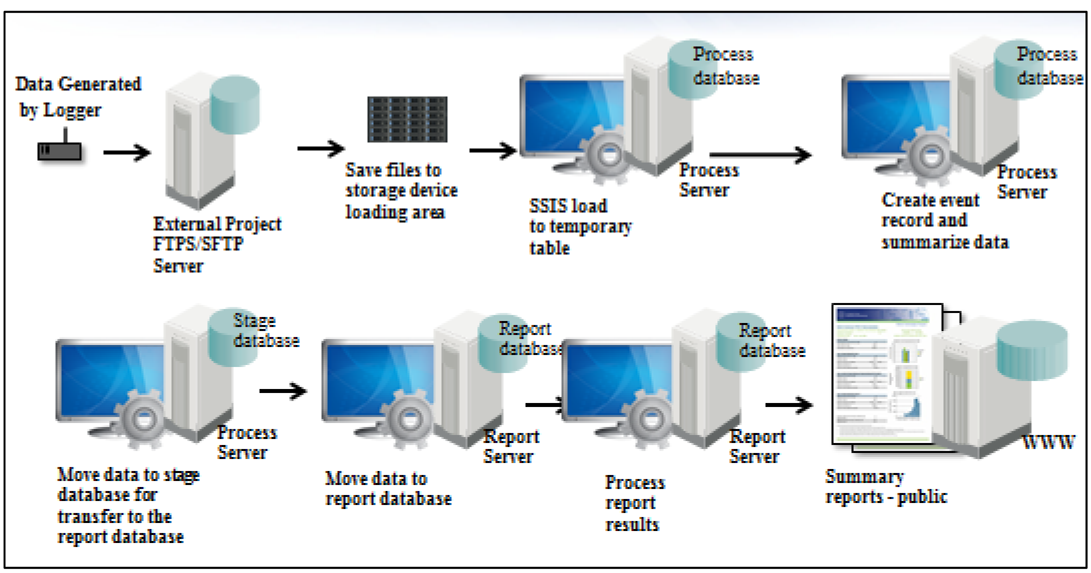


Figure 14-2. Work flow process for vehicles and charging infrastructure in the ARRA projects.

14.2.3 Receiving Files

Normally, data files were pushed to the INL secure file transfer protocol server by project partners. Sometimes data files were pulled by INL from the partners' data servers; rarely, data files were emailed for small projects; and, in some cases, the data files arrived on hard drives. The files were then moved to the INL file share server and all data files were archived. Note that there were not any direct links from INL databases to data providers per INL's and partners' security guidelines.

14.2.4 File Types

The files types included the following:

- Comma delimited files (i.e., CSVs) or column delimited files (i.e., txt) formats were used.
- The types of data collected in comma delimited files included the following:
  - Vehicle data (internal and external logging)
  - EVSE data
  - Maintenance data.
- No Excel files were allowed (Excel is not available on INL database servers).

14.2.5 Servers

INL employed numerous servers, including the following:

- Secure file transfer protocol server.
- Processing server, where a process database resided, into which data were loaded from raw files.
- Report server, which contained a stage database and report.
- Internet sever, which housed reports and other information made available to the general public.

14.2.6 Processing Files

Data were loaded using standard query language server integrated services and the following steps were required:

- Preprocessing was sometimes required, using Perl or server integrated services.
- Data were loaded into a process database in a temporary table.
- Raw data filenames were tracked with a load identifier.
- A unique numeric identifier was created for each record.
- Data were processed into standard data tables aggregating data on numerous levels to allow for reporting and analysis.

14.2.7 Basic Database Practices

A relational database and the following processes were used:

- Numeric keys in the database were always faster.
- Standard database, table and field names (process, stage, and report).
- Optimize indexing.
- Processing loads data into the temporary tables then does summations into the stage database. Stage is backed up and copied to the report server.
- Re-usable stored procedures for calculations.

- Finding the first and last value, maximum and minimum value, and average (mean and mode) value.

14.2.8 Quality Assurance

Based on experience with similar field-based data collection projects, the importance of proper quality assurance is a well-established INL requirement that included:

- Tables were used to store the database name, table name, field name, and low and upper bounds.
- Tables were used to store rules for a result.
- Data that was out of bounds was reported to the data reviewer.
- Data were marked as unusable in the reports base on the quality assurance check.

14.2.9 Calculation Standards

While data were received in several formats, the following processes ensure standard methods were used:

- Data were in standard units (miles per hour or kilowatts).
- Single stored procedure was used to make similar calculations.
- Tables were used to drive report results.
- Report results were prepared into a result table at report run time.
- Standard query language server reporting services were used.

14.2.10 Security

The security processes are intentionally not described in detail; however, an overall figure (Figure 14-3) is appropriate.

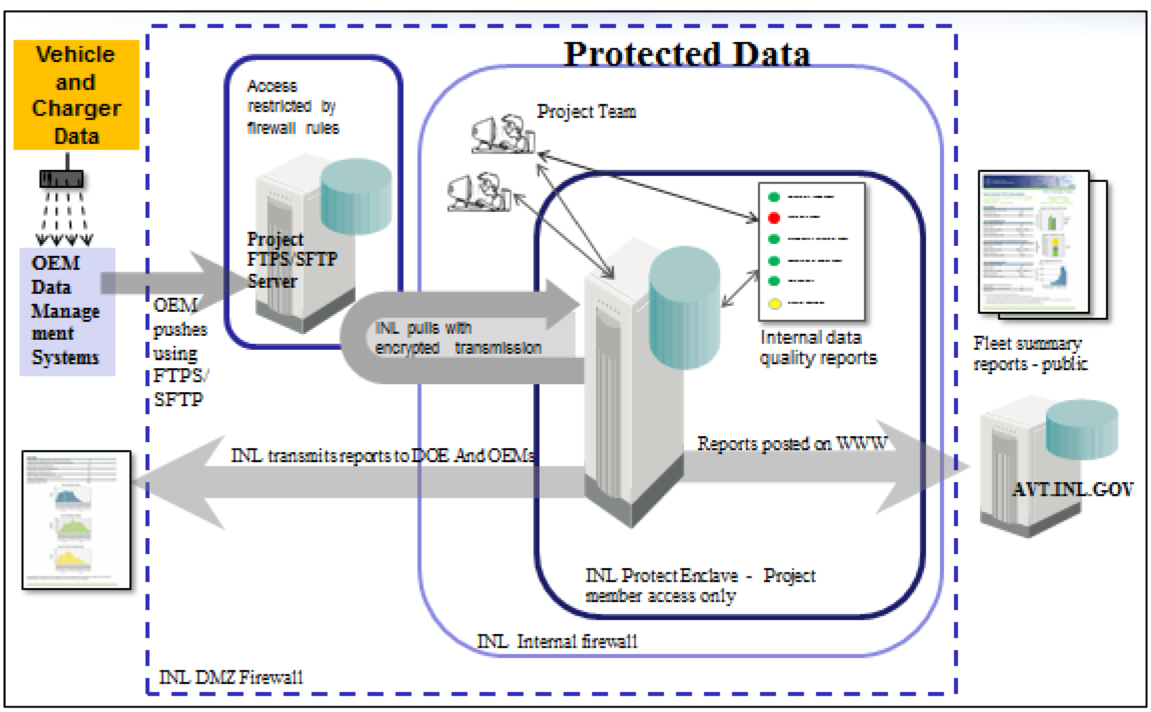


Figure 14-3. Overview of security used for ARRA data at INL.