Workplace Charging Case Study: Charging Station Utilization at a Work Site with AC Level 1, AC Level 2, and DC Fast Charging Units

June 2014

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 current (AC) Level 1- and AC Level 2-capable units and a direct current (DC) fast charger. 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 DC fast charger. 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 Level 2 cords for around 4 hours or for around 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 Level 1 and Level 2 options were available, they chose to use the Level 2 cord 98% of time. With only a few exceptions, the Level 1 outlet was only used if the Level 2 cord was already connected to another vehicle.
- Facebook followed a few simple guidelines to encourage employees to self-manage electric vehicle supply equipment (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 DC fast charger 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 DC fast charge event ended and another event began on the same work day, a vehicle had been connected to the second DC fast charger cord prior to the end of the first vehicle's charging event.

Introduction

An increasing number of organizations are installing plug-in electric vehicle (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 utilization of EVSE units at a large work site where multiple types of EVSE were installed and where a variety of PEVs charged.

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 DC fast charger that were part of The EV Project and ChargePoint America. 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 DC fast charger. The ChargePoint units were equipped with a 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 DC fast charger was a dual-cord unit. Both cords were equipped with a CHAdeMO-compliant connector. The fast charger 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 Level 2 units were also free to use and required a Blink membership card. The Blink DC fast charger also required a Blink membership card to access. It was free for a majority of the study period. During July 2013, a flat fee of $5.00 per charge session was instituted for all Blink 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.

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 Level 2 EVSE cords. Drivers performed 11% of the events and consumed 9% of the energy using the DC fast charger. Six percent of the events were conducted using the Level 1 outlets on the ChargePoint EVSE. Level 1 charging accounted for 4% of the total energy consumed. Table 1 gives a summary of the EVSE usage during the study period. Overall, charging with the AC Level 2 cords and DC fast charger was vastly more popular than using the AC Level 1 outlets in the ChargePoint EVSE.

Table 1. Summary of EVSE usage by EVSE power level.

	AC Level 1	AC Level 2	DC Fast Charger
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%)

EVSE Utilization

The DC fast charger'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 DC fast charger 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 Level 1 or Level 2 EVSE. The data show that there were also some users of the DC fast charger who only parked at the work site when they used the DC fast charger. These are believed to be the general public.

The 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 Level 2 charge cords for an average of 8.7 hours per cord, which represents high utilization with respect to connection time. However, Level 2 cords averaged 4.4 hours of transferring power to a vehicle per cord, indicating that often vehicles remained connected to Level 2 cords for several hours longer than was needed to completely charge their batteries.

The 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 Level 1 ports the longest, averaging 8.9 hours connected per charging event. Level 1 ports provided power to vehicles for 4.6 hours per charging event, on average.

Table 2 provides several metrics to summarize the average utilization of Level 1 outlets, Level 2 cords, and the DC fast charger at this work site.

Table 2. Summary of EVSE average usage by charge power level.

	AC Level 1	AC Level 2	DC Fast Charger
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 (hr)	8.9	5.6	0.36
Average time transferring power to a vehicle per charging event (hr)	4.6	2.9	0.36
Average time connected to a vehicle per cord per work day (hr)	1.9	8.7	1.6
Average time transferring power to a vehicle per cord per work day (hr)	1.0	4.5	1.6

The distributions of the number of charging events per cord or outlet per work day for the Level 1 (L1), Level 2 (L2), and DC fast charger (DCFC) charge power levels are shown in Figure 1. Level 1 outlets were not used at all on 79% of the outlet-work days. 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 4 times. Level 2 cords experienced one or two charging events on 84% of the cord-work days. At most, a Level 2 cord was used five times in one work day. DC fast charger usage frequency varied between 0 and 12 charging events in one day, with 49% of the days having 4 to 6 charging events.

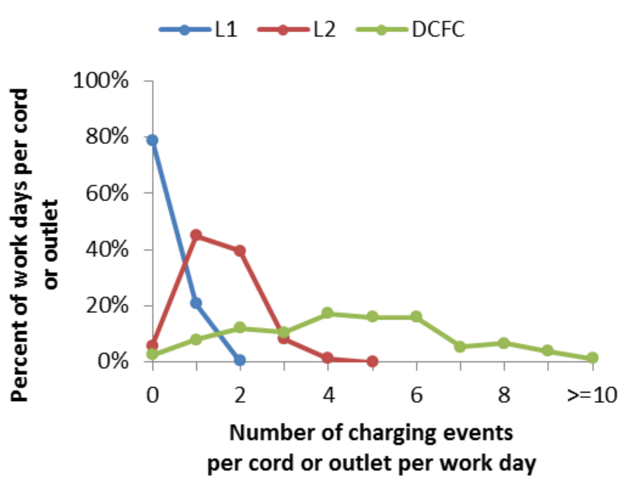

Figure 1. Frequency distributions of number of charging events per cord or outlet per work day for different charge power levels.

The DC fast charger 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 Level 2 cords and Level 1 outlets, there was significant variation in time spent connected to a vehicle per charging event. Figure 2 shows the distributions of connection time per charging event for Level 1 and Level 2 events.

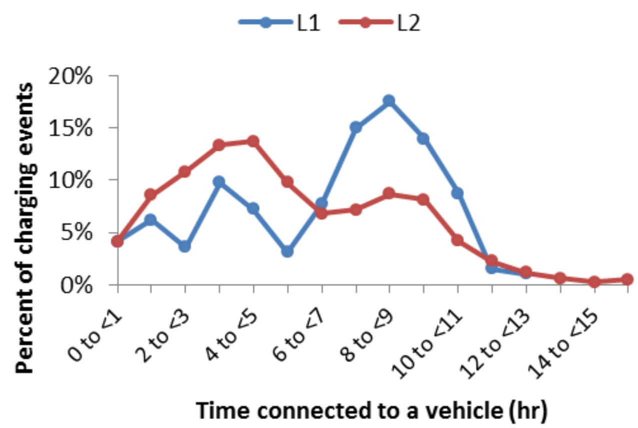

Figure 2. Frequency distributions of time Level 1 outlets and Level 2 cords were connected to a vehicle per charging event.

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 Level 1 outlets for a full work day, whereas they more often used 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 DC fast charger while it was still drawing power from the charger or within minutes after the end of power flow. By contrast, Table 2 shows vehicles connected to Level 1 outlets and 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 3 presents the distributions of time EVSE spent transferring power to a vehicle during Level 1 and Level 2 charging events.

During most 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.

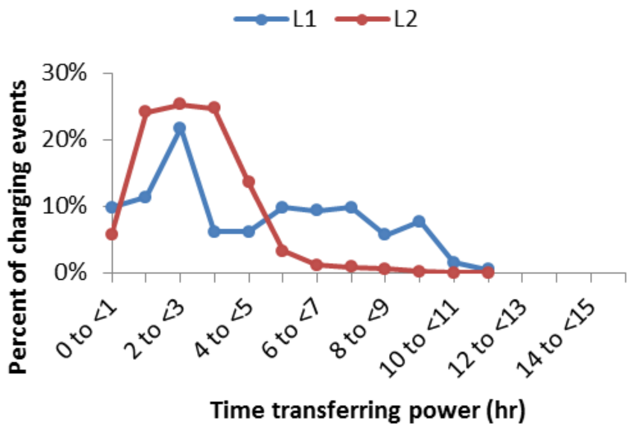

Figure 3. Frequency distributions of time Level 1 outlets and Level 2 cords transferred power to a vehicle per charging event.

For 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 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 Appendix A.

Comparison of the blue lines in Figures 2 and 3 shows that the Level 1 cords were more efficiently utilized than the averages in Table 2 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, the EVSE was left connected to the vehicle long after the vehicle was fully charged.

Comparison of the red lines in Figures 2 and 3 shows that the Level 2 cords were also more efficiently utilized than the averages in Table 2 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 4 provides the percent of charging events that ended with a full battery for charging events with a varied connection time.

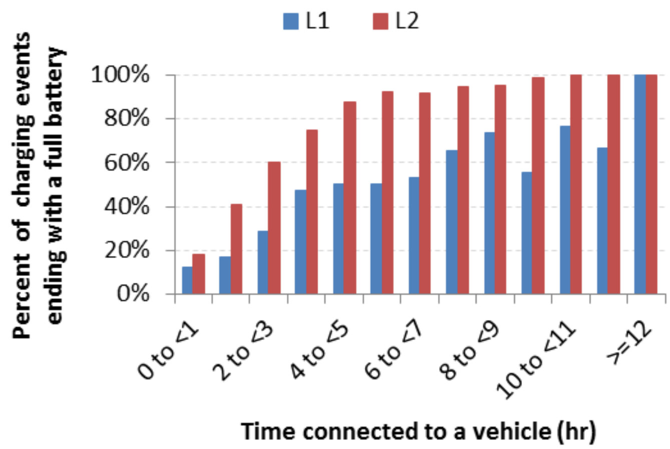

Figure 4. Percentage of charging events ending with a full battery for charging events of varying length.

Figure 4 shows that most Level 2 charging events lasting longer than about half a work day resulted in a full battery; 75% of Level 2 events between 3 and 4 hours and 87% of Level 2 events lasting between 4 and 5 hours ended with a full battery. For Level 1 charging, a full work day was required to completely charge vehicles for the majority of charging events; 66% of Level 1 events lasting between 6 and 7 hours and 74% of 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 Level 1 charging and less than 1 hour for Level 2 charging) that ended with a full battery. These are consistent with the charging behavior of vehicles with small battery packs 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 it is 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 the 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 – 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 which allowed them to communicate with each other to coordinate EVSE usage. This message board included license plate and contact information so 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, or change-overs, 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 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 Level 2 cords experienced high overall utilization.

The DC fast charger 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 DC fast charger'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 DC fast charger was installed next to a group of Level 2 EVSE. The host company reported that sometimes drivers parked in front of the DC fast charger but connected to the Level 2 EVSE, thereby blocking others from using one of the DC fast charger ports.

Charging Energy Consumption

The amount of energy consumed by vehicles per charging event at this work site varied greatly. Level 2 cords provided an average of 12 kWh per charging event. The DC fast charger delivered an average of 9.3 kWh per charging event. Level 1 charging events averaged 6.6 kWh per event. Figure 5 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 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.

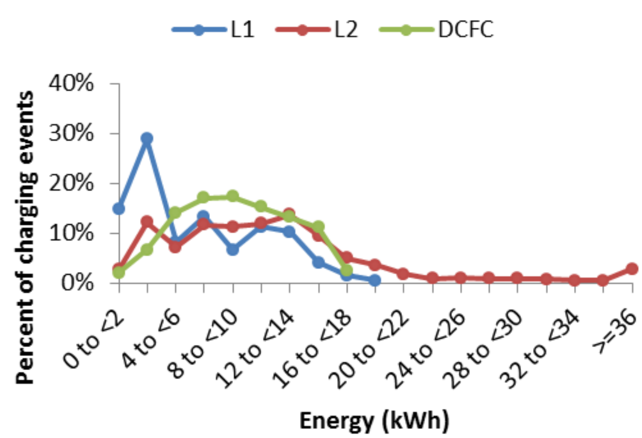

Figure 5. Distribution of energy consumed per charging event by charge power level.

Most of the vehicles using the DC fast charger were Nissan Leafs, which is a battery electric vehicle with a 24-kWh battery; therefore, it is no surprise that DC fast charging events consumed less than 20 kWh. (See Appendix A for more discussion on differences in charging behavior among vehicle makes and models.)

Driver Preference for Level 1 versus Level 2 Charging

Because the ChargePoint EVSE offered both Level 1 and 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 Level 2 cord 98% of time. The Level 1 outlet was only selected first for 2% of the charging events. This means that nearly every time a driver chose to use a Level 1 outlet, it was because the 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 Level 2 cord was available on the EVSE, whereas a driver would need to retrieve their own Level 1 cord to plug into the Level 1 outlet on the EVSE.

Figure 6 depicts how much time the ChargePoint EVSE had only its Level 2 cord connected to vehicles, only its Level 1 outlet in use, and both the Level 2 cord and Level 1 outlet in use. This figure further supports the finding that drivers preferred to use the ChargePoint Level 2 cord over the Level 1 outlet. In fact, the time vehicles spent connected to Level 1 outlets would have been even lower, were it not for a single Level 1 charging event that lasted 3 weeks.

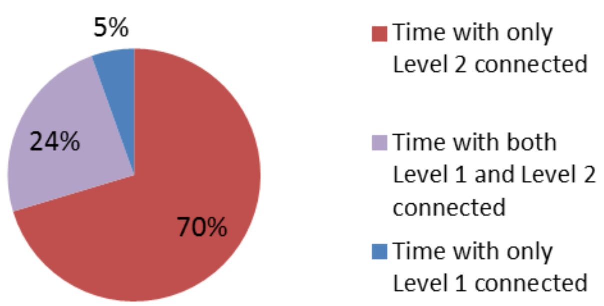

Figure 6. Percent of time ChargePoint EVSE had their Level 1 outlet, Level 2 cord, or both in use.

About The EV Project

The EV Project was the largest PEV infrastructure demonstration project in the world, equally funded by the United States Department of Energy (DOE) through the American Recovery and Reinvestment Act and private sector partners. The EV Project deployed over 12,000 AC Level 2 charging stations for residential and commercial use, as well as over 100 dual-port DC fast chargers, in 17 U.S. regions. Approximately 8,300 Nissan LEAFs™, Chevrolet Volts, and Smart ForTwo Electric Drive vehicles were enrolled in the project.

Project participants gave written consent for EV Project researchers to collect and analyze data from their vehicles and/or charging units. Data collected from the vehicles and charging infrastructure represented almost 125 million miles of driving and 4 million charging events. The data collection phase of The EV Project ran from January 1, 2011, through December 31, 2013. Idaho National Laboratory is responsible for analyzing the data and publishing summary reports, technical papers, and lessons learned on vehicle and charging unit use.

For more information about The EV Project, visit avt.inl.gov/evproject.shtml.

About ChargePoint America

ChargePoint America was a large PEV infrastructure demonstration project, deploying over 4,600 AC Level 2 charging ports for residential and commercial use in ten regions across the U.S. The project was equally funded by the U.S. Department of Energy (DOE) through the American Recovery and Reinvestment Act and private sector partners. Project participants gave written consent for researchers to collect and analyze data from their charging units. Over 1.8 million charging events were logged by charging infrastructure in this project. The data collection phase ran from May 1, 2011, through December 31, 2013. Idaho National Laboratory is responsible for analyzing the data and publishing summary reports, technical papers, and lessons learned on vehicle and charging unit use.

For more information about ChargePoint America, visit avt.inl.gov/chargepoint.shtml.

Company Profile

Idaho National Laboratory is one of DOE's 10 multi-program national laboratories. The laboratory performs work in each of DOE's strategic goal areas: energy, national security, science, and the environment. Idaho National Laboratory is the nation's leading center for nuclear energy research and development. Day-to-day management and operation of the laboratory is the responsibility of Battelle Energy Alliance.

For more information about INL, visit www.inl.gov.

Appendix A: Discussion on Variation in Charging Behavior for Different Vehicle Makes and Models

Figures A1 shows the distributions of average power per charging event for Level 1 and Level 2 charging at the work site studied.

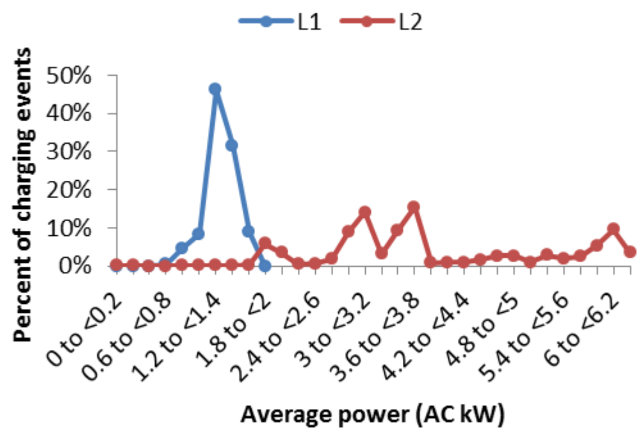

Figure A1. Distributions of average power per charging event for Level 1 and Level 2 charging.

Level 1 charging was limited by the power limit of the EVSE or, in rare cases, the vehicle's onboard charger. Figure A1 indicates that most 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.

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 Level 2 charging event provided some insights into the makes and models of PEVs being charged. 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 A2 presents the distribution of average power per charging event for DC fast charging (DC kW) at the work site studied. DC fast charger power also varied significantly, but for a different reason than Level 2 charging. DC fast charge power level is controlled by the vehicle and is a function of a number of factors, including vehicle state of charge. The Nissan Leaf, the only vehicle known to have used the DC fast charger 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 state of charge increases. Therefore, the average power per charging event for the Leaf was always less than 50 kW.

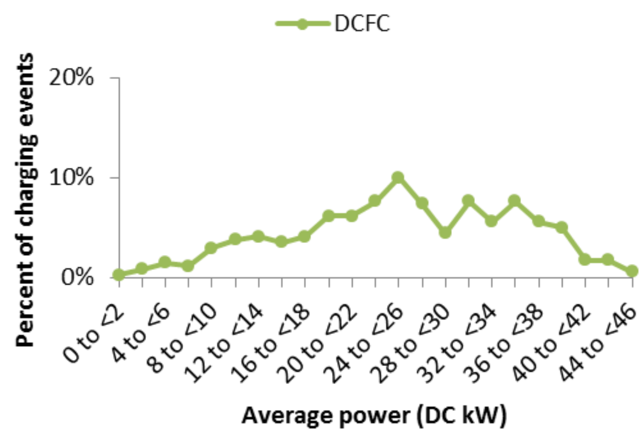

Figure A2. Distribution of average power per charging event for the DC fast charger.

Level 2 charging events were grouped by average charge power in order to look for trends in charging behavior by different types of PEVs.

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 Level 2 charging events in this study. Vehicles whose onboard chargers operate in this power range include the Toyota Prius Plug-in. Figure A3 shows the distribution of energy consumed by charging events in this average power group.

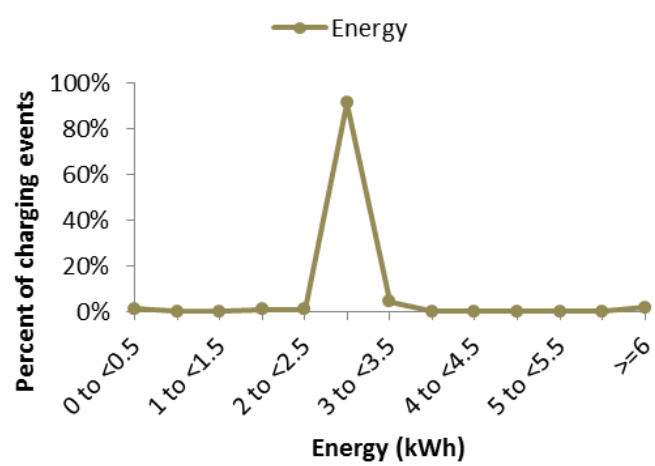

Figure A3. Distribution of energy consumed per charging event for Level 2 charging events with average power between 1.8 and 2.2 kW.

Figure A3 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 from 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 plug-in hybrid electric vehicles with a 3-kWh battery (e.g., the Prius Plug-in). The Prius Plug-in has a charge-depleting range of about 10 miles, after which it can continue to drive using an internal combustion engine. 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 A4 shows the time connected and time transferring power for 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.

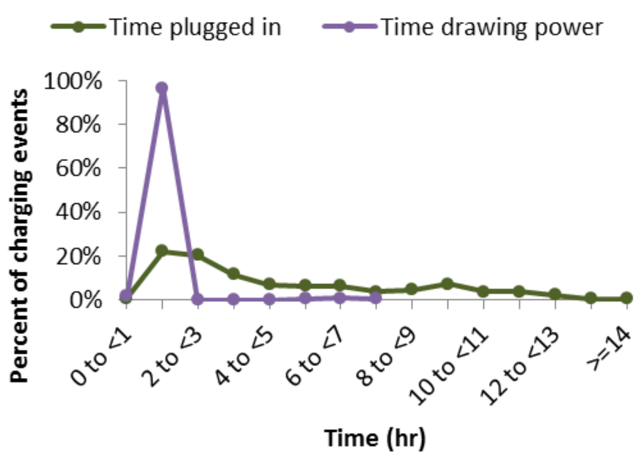

Figure A4. Distributions of time connected and time transferring power per charging event for Level 2 charging events with average power between 1.8 and 2.2 kW.

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 Level 1 outlets. Therefore, drivers performing these charging events could have used Level 1 outlets with similar results, leaving 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 Level 1 equipment.

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 Level 2 charging events in this study. The MY2011-2013 Chevrolet Volt is known to charge in this power range.

Figure A5 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 the 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 internal combustion engine.

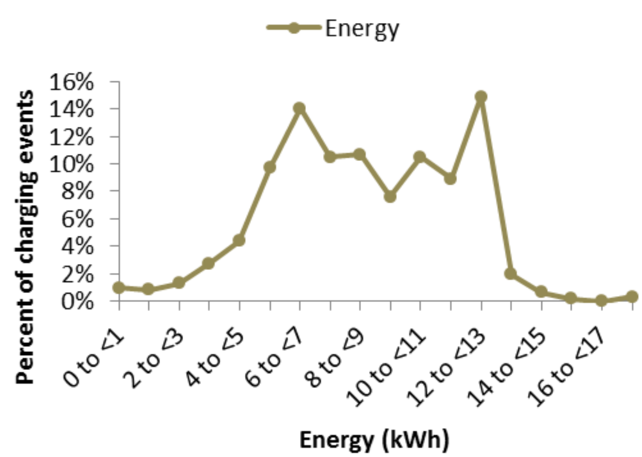

Figure A5. Distribution of energy consumed per charging event for Level 2 charging events with average power between 2.8 and 3.3 kW.

Figure A6 gives the distributions of time connected and time transferring power for 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. Naturally, 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 Level 2 cord available to other drivers, or because they unplugged their vehicle in order to drive it.

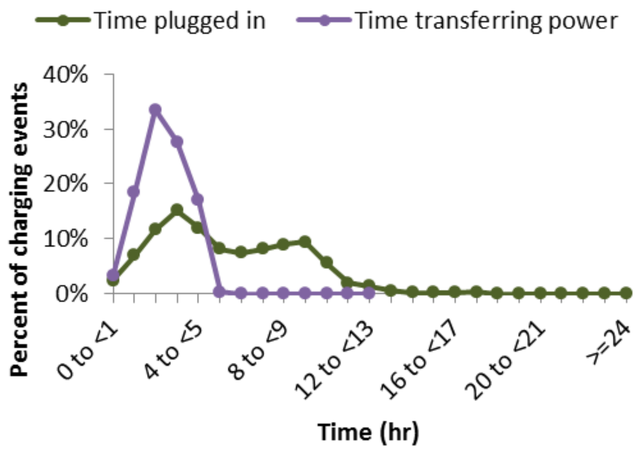

Figure A6. Distributions of time connected and time transferring power per charging event for Level 2 charging events with average power between 2.8 and 3.3 kW.

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 A7 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 battery electric vehicles (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 battery electric vehicles (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 battery electric vehicles 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 A7 shows that most charges were about half this capacity and batteries were never charged beyond 20 kWh.

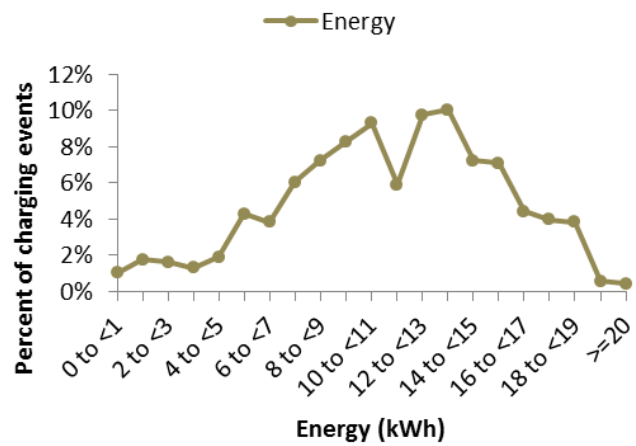

Figure A7. Distribution of energy consumed per charging event for Level 2 charging events with average power between 3.3 and 3.8 kW.

Figure A8 shows the distributions of time when connected and time when transferring power for 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 the events in this group came from battery electric vehicles with larger batteries.

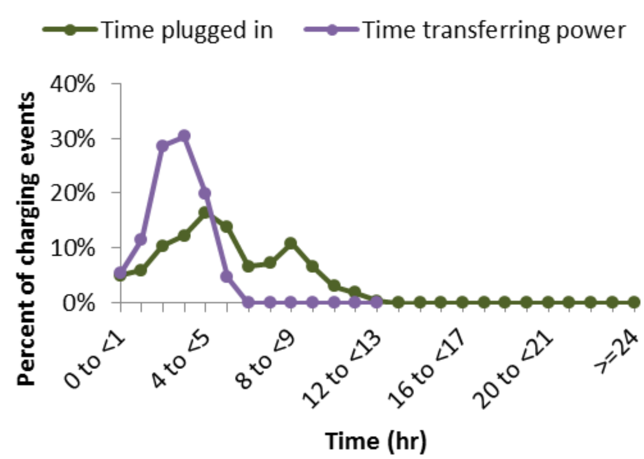

Figure A8. Distributions of time connected and time transferring power per charging event for Level 2 charging events with average power between 3.3 and 3.8 kW.

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 A9 shows the distribution of energy consumed by charging events in this average power group.

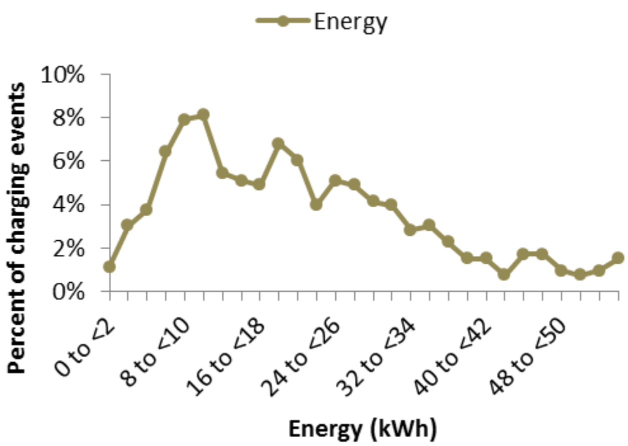

Figure A9. Distribution of energy consumed per charging event for Level 2 charging events with average power of 5.6 kW or greater.

The vehicles with onboard chargers capable of power in this range are mostly battery electric vehicles 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 A9 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 A10 shows the distributions of time connected and time transferring power for 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 battery electric vehicles with larger batteries.

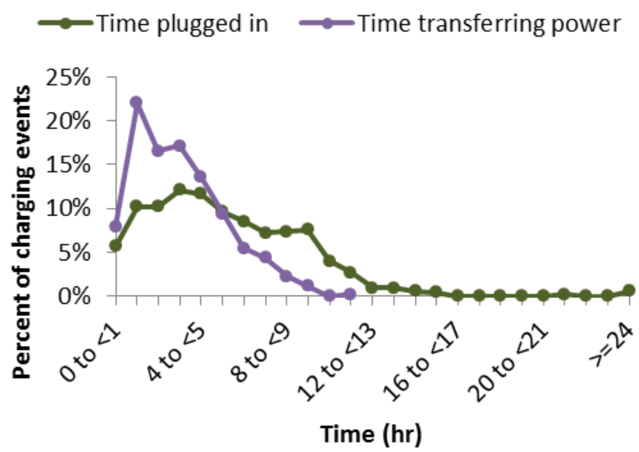

Figure A10. Distributions of time connected and time transferring power per charging event for Level 2 charging events with average power of 5.6 kW or greater.

References

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.