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

September 2014

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 DC Fast Charger (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 Level 1 or Level 2 charges.
- Overall, usage of DCFC by drivers of vehicles in this study, all having access to a 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 electric vehicles without access to home charging.

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. Appendix A shows how these vehicles were distributed across the 17 regions. 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.

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 Society of Automotive Engineers J1772-compliant connector. Each EV Project participant had such a 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 Level 1/Level 2 or DCFC. The data collected from The EV Project's Leafs were such that it is not possible to accurately distinguish between Level 1 and 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 1.

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.

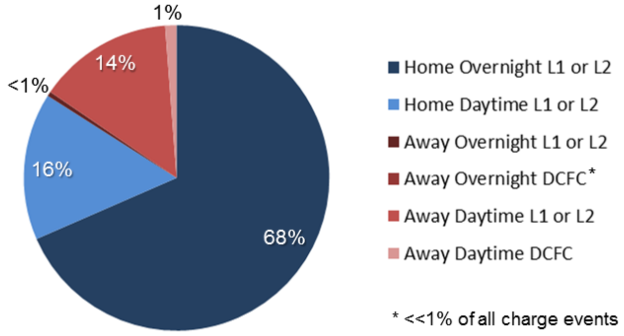

Figure 1. Percent of charging events performed by location, power level, and time of day.

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 Level 1/Level 2 charges. DC fast charges (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 Level 1/Level 2 charges. There were only seven overnight DCFC events.

Figure 2 shows the amount of charging energy consumed by vehicles during the charging events described in Figure 1.

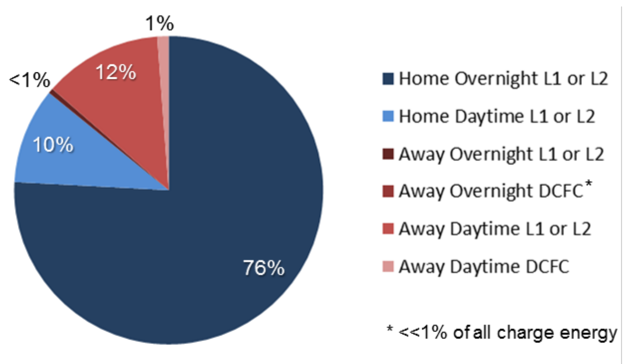

Figure 2. Percent of energy charged by location, power level, and time of day.

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 2) was nearly 0. Although daytime charging frequency was split almost evenly between home and away (as shown in Figure 1), 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 [1].

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.

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 3.

Figure 3 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 Level 1/Level 2 or DCFC; therefore, breaking down away-from-home charges by power level is important to further understand drivers' charging habits. Figure 4 shows the percent of charges at each power level performed by the vehicles in the groups defined in Figure 3.

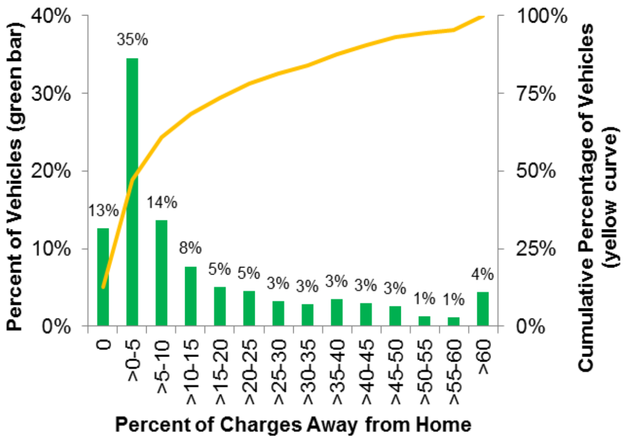

Figure 3. Distribution of the percent of charges performed away from home by each vehicle.

It is apparent that most away-from-home charging occurred at Level 1 or 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.

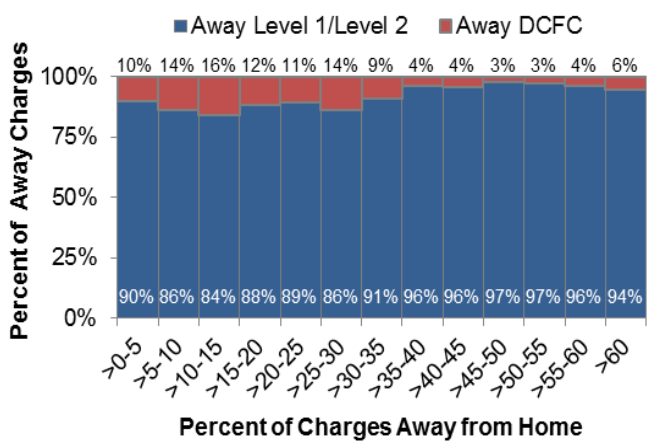

Figure 4. Occurrence of Level 1/Level 2 and DCFC charging for groups of vehicles with different amounts of away-from-home charging.

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 1.

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 state of charge (SOC) due to charging each day. These vehicles were driven 25 miles per day on average.

Table 1. 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 electric vehicles without access to home charging.

About The EV Project

The EV Project was the largest plug-in electric vehicle 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 DCFCs, 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 The 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.

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.

References

1. See "Where do Nissan Leaf drivers in The EV Project charge when they have the opportunity to charge at work?" at avt.inl.gov/pdf/EVProj/ChargingLocation-WorkplaceLeafsMar2014.pdf.

Appendix A

Figure A1 shows the number of vehicles included in this study in each of the 17 regions where Nissan Leafs 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.

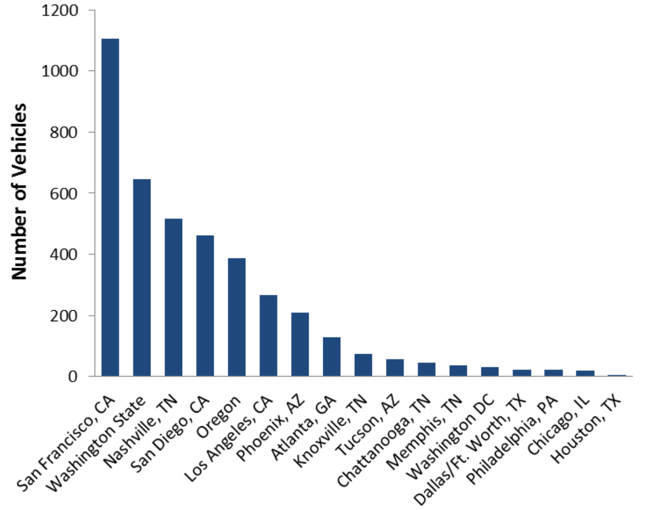

Figure A1. Number of The EV Project Nissan Leafs by region.