ELECTRIC POWER RESEARCH INSTITUTE

A Review of Initial Analysis and Early Market Data on DC Fast Charging

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Technical Update, December 2013

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This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

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ABSTRACT

At present, battery electric vehicles (BEVs) have limited on-board energy storage, and their limited range is a concern for potential customers. Direct current (DC) Fast Charging offers a way to mitigate this concern, but there is considerable uncertainty about how DC Fast Chargers will integrate with the existing electricity system and what the business case will be for installing and operating these chargers. This technical update provides a preliminary analysis of several of the issues raised by fast charging, including estimates of the potential market size for fast charging and the willingness of customers to pay a premium for the service. DC Fast Chargers are expected to be installed in commercial locations and are therefore likely to use commercial electricity rates, which often include both energy-based costs and power-based demand charges. Understanding how existing rates affect DC Fast Chargers is challenging and will change over time as the DC Fast Charging market develops.

The report summarizes currently available data on DC Fast Charger utilization. These data indicate that an average utilization of about 200 charge sessions per charger per month is plausible today, equivalent to 75-100 full charges. However, the data are too limited to make conclusions about the performance of individual chargers or the future direction of the DC Fast Charging market. The update concludes with an illustrative case study from Northeast Utilities concerning their effort to create a rate for DC Fast Charging.

Keywords
Battery electric vehicles (BEHs)
Fast charging
DC Fast Charging
Demand charges

EXECUTIVE SUMMARY

Plug-in Electric Vehicles (PEVs) are being adopted at an impressive rate, far surpassing the historical adoption rate of Hybrid Electric Vehicles (HEVs). One of the more interesting aspects of PEV adoption has been that of Battery Electric Vehicles (BEVs). In contrast to other types of PEVs, BEVs utilize a single fuel source: electricity. Because current BEV designs incorporate relatively limited amounts of on-board energy storage, these vehicles in general have less range than other types of vehicles. Furthermore, since electricity is their only fuel source, they require charging in order to 'fill-up.' While vehicles spend most of their time parked and generally don't drive very far between potential charging events, the limited range of a BEV can be constraining and range limitations are often cited as a concern for potential customers.[i] Direct Current (DC) Fast Charging offers one opportunity to mitigate this concern, since the power delivered by these chargers can quickly fill the battery and allow the range of the vehicle to be extended. However, despite this potential benefit to BEV drivers, there is still considerable uncertainty about how DC Fast Chargers will integrate with the existing electricity system and what the business case will be for installing and operating these chargers. This Technical Update presents initial work on understanding these issues.

Background on DC Fast Charging

In the U.S. there are three types of DC Fast Charger connectors, shown in Figure 1.[ii]

Figure 1
DC Fast Charger connectors

There are currently around 350 DC Fast Chargers in the US, of which roughly 40 are Tesla Superchargers,[iii] 1 is a dual CHAdeMO/Combo charger, and the balance are CHAdeMO only[iv].

Most of these chargers are shown in Figure 2.[v] (There currently is not a publically available database which includes all fast chargers; this map does not include the Tesla Superchargers and many recent CHAdeMO chargers).

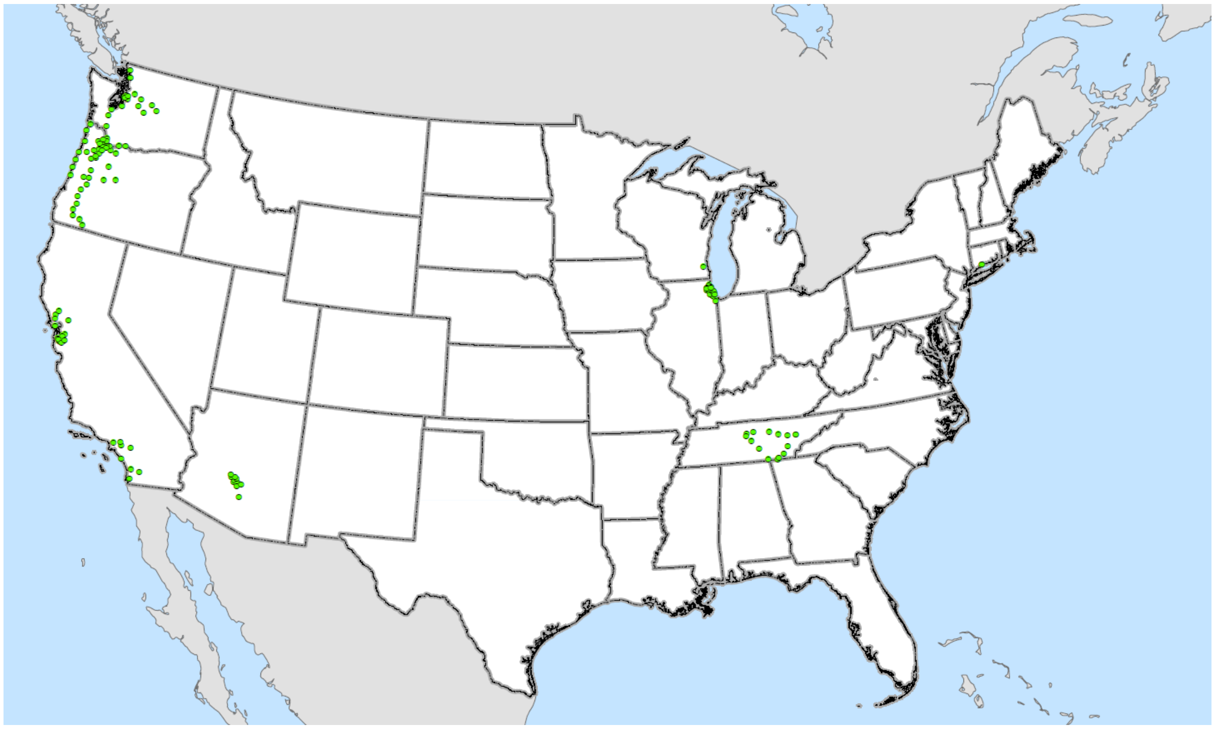

Figure 2
Locations of CHAdeMO DC Fast Chargers

Results

This Technical Update provides an initial look at EPRI's ongoing research into the issues surrounding DC Fast Charging. Each of these analyses is preliminary, and should be thought of more as indicators of where more research is needed rather than definitive answers. The following is a brief summary of each topic covered in the upcoming sections of this report:

- **Estimation of the potential market size for DC Fast Charging:** It is difficult to estimate the potential market size for DC Fast Charging from data on electric vehicles since the vehicle and charging market sizes are both small enough that they are not likely to be representative of the usage patterns for a mature market. EPRI is evaluating techniques that use data on the driving patterns of conventional vehicles to provide an alternate estimate for this market size. This estimate indicates that less than 5 percent of vehicles will need to charge on an average day, once the average BEV range reaches 100 miles, and that this level of usage will require less than 5 chargers per 1000 vehicles.

- **Estimated willingness to pay:** A key question concerning the economics of DC Fast Charging is how much drivers would be willing to pay for fast charging, since slower charging is often available at low cost and gasoline vehicles are a commonly-available alternative. This section of the report describes an initial analysis indicating that a price of $10-20 per session would be economically desirable relative to the alternatives for current shorter-range BEVs, and that significantly higher prices could be economic as vehicle range increases.

- **The effects of sampling period on demand level:** Electricity demand charges are a significant fraction of operating costs for DC Fast Chargers, especially at low utilization. This section describes an analysis of an esoteric technical issue concerning demand charge calculation. It seemed possible that given the precise power profile of DC Fast Chargers that current rates would automatically cause demand charges to scale with utilization given relatively minor adjustments to the rates. Unfortunately, the analysis indicates that this is not the case for utilization levels that have already been reached in many areas and are likely to be common in the future.

- **Levelized electricity cost at different usage levels:** In some service territories commercial rates without demand charges are available for loads with moderate power levels. Some DC Fast Charging service providers have reportedly derated the power of their chargers in order to conform to these rates to avoid demand charges. This section presents the results of an analysis of commercial rates with demand charges compared to energy-only rates for DC Fast Charging. The analysis indicates that if utilization is low, energy-only rates can provide a significantly lower cost to the service provider, particularly on a per-charge-session basis. However, as utilization increases this advantage goes away and at utilization levels that have already been reached in some locations the rate with demand charges would be preferred for the rate structures analyzed. (Note that this analysis does not include an accounting of utility cost-of-service and is not a rate recommendation, but instead shows that assumptions about usage have to be carefully considered as the market evolves.)

- **Utilization data from the EV Project:** At the present time, data about the actual usage of current DC Fast Chargers is very limited. One potential source of data is the EV Project, a federally-funded project intended to collect and report data on early-market plug-in electric vehicle and infrastructure usage. Unfortunately, the data released from this effort has been relatively limited. This section shows an analysis of this data, which indicates that the assumptions concerning usage levels in the above sections are plausible, but unfortunately the data is too limited to make any analytic conclusions.

The Update concludes with an illustrative case study from Northeast Utilities concerning their effort to create a rate for DC Fast Charging. Each of these issues proved to be important, but it was found that current data was too limited to establish final rates so a rate was proposed that allows further study of costs and market size.

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ESTIMATION OF THE POTENTIAL MARKET SIZE FOR DC FAST CHARGING

As the PEV and charging markets develop, both utilities and private parties are trying to understand the potential market for DC Fast Chargers. They serve a similar function as gas stations, but the majority of refueling for BEVs will likely still occur at home.[vi] This means that the potential 'gas station' refueling market for BEVs is significantly more limited than for other fuels. This section presents an initial analysis on the number of DC Fast Chargers that will be required for a given number of BEVs.

Figure 1-1 shows results from an EPRI analysis of the fraction of vehicles that need to DC Fast Charge on an average day. In this analysis, it is assumed that DC Fast Charging will be used for trips between 80% and 160% of the range of a BEV. Trips of shorter duration will not require DC Fast Charging, and trips longer than 1.6 times the range of the vehicle would require multiple fast charges, which is assumed to push most drivers to use a different vehicle or create an alternate plan for the trip.

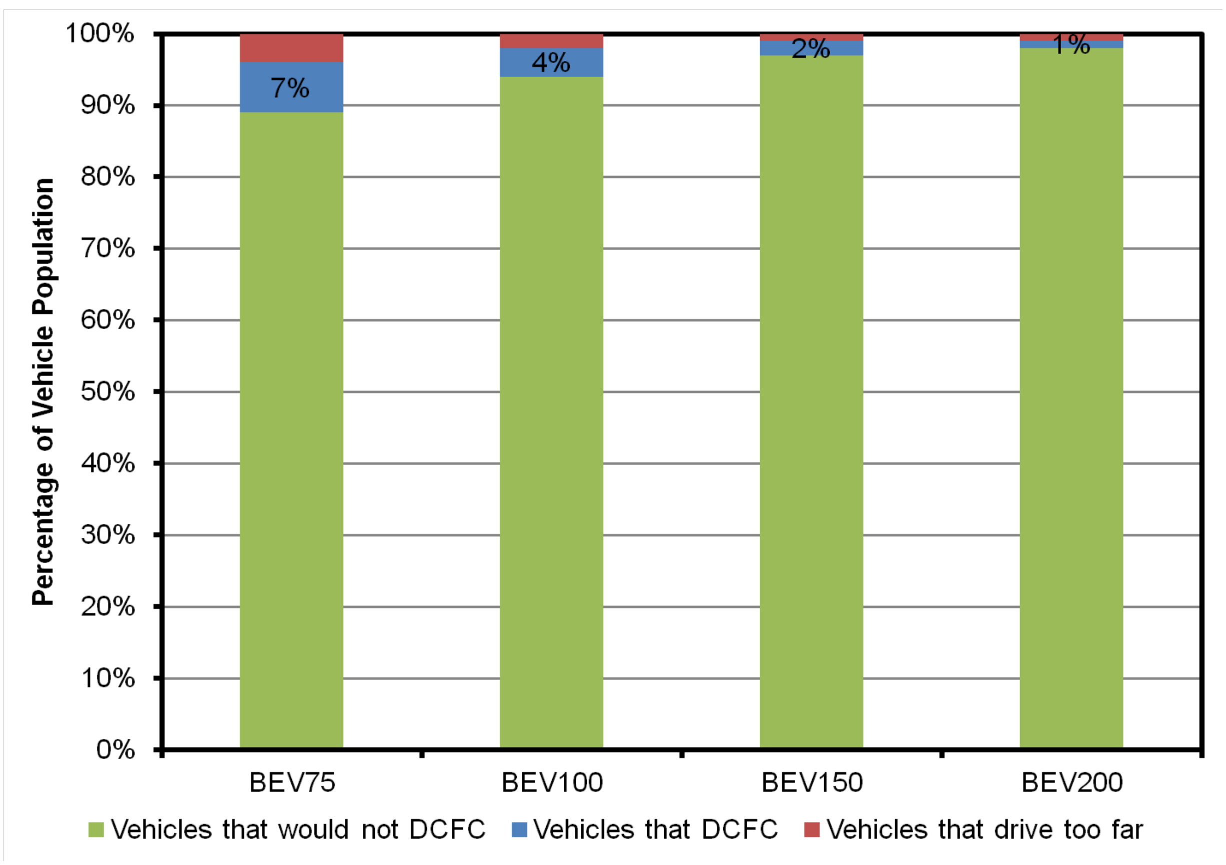


Figure 1-1
Estimated demand for DC Fast Charging on an average day

The chart is broken down into three segments for four ranges of vehicles:

- **Vehicles that would not fast charge**: these vehicles do not drive far enough in their sample day to require fast charging. This analysis, along with other EPRI analysis, assumes that most charging will occur at the home and that other charging methods would only be used if necessary. As range increases, the portion of vehicle days which can be covered without fast charging increases, but there are diminishing returns after about 100 miles.
- **Vehicles that fast charge**: The market for DC Fast Charging is different for BEVs with different amounts of driving range. For the lower range BEVs, such as the Nissan LEAF, the market for DC Fast Charging is about 7% of vehicle days. As the range increases, this numbers steadily declines. For example, the Tesla Model S may only need to fast charge on 1-2% of vehicle days, and if a greater range is achieved, this number would decrease further.
- **Vehicles that drive too far:** This analysis assumes that on days where the total trip distance exceeds 160% of the range of the vehicle, a different vehicle would have to be used. As vehicle range increases, the number of long trips that are possible will increase, but the small number of very long trips means that this does not represent a significant number of vehicle days once the BEV range exceeds about 150 miles, at least for the light-duty vehicles analyzed here.

Figure 1-1 seems to indicate that a relatively large number of fast chargers will be required for a given vehicle fleet. However, the chart is illustrating the demand over the entire day. The number of chargers in use at any one time during the day, as seen in Figure 1-2 for a BEV100, indicates that only about 5 DC Fast Chargers per 1000 cars are in use during the peak hour. This peak usage decreases and broadens across a wider time period as vehicle range increases.

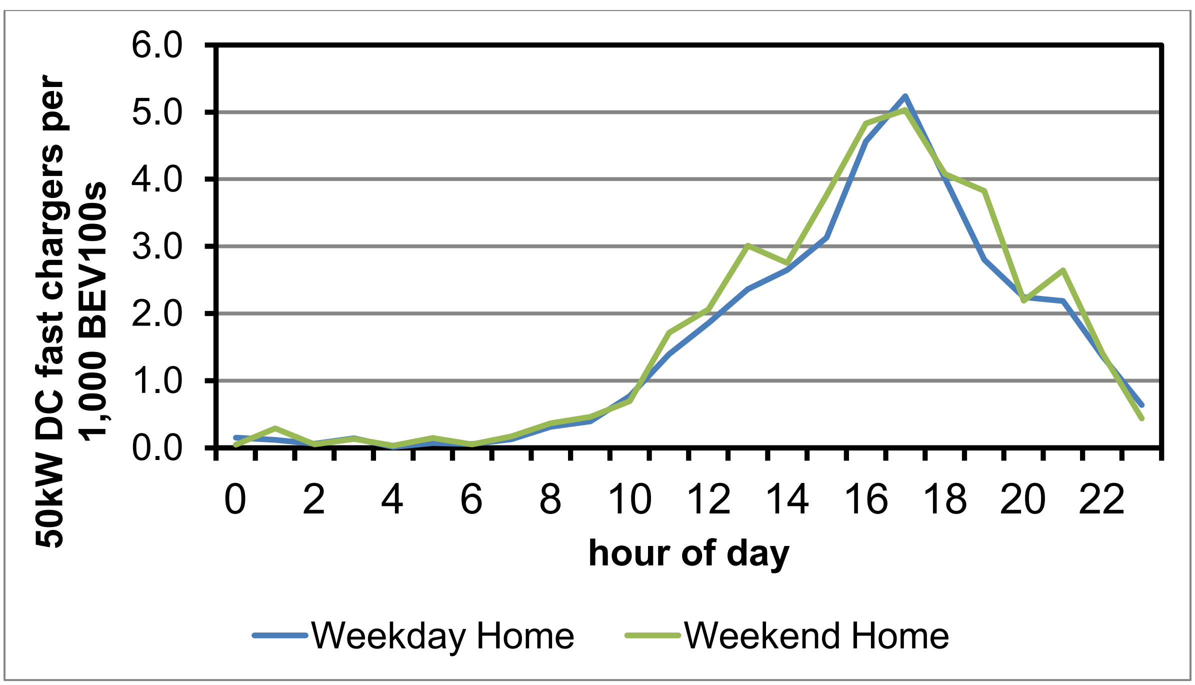


Figure 1-2
DC Fast Chargers in use throughout an average day

This analysis provides only a rough estimate of the DC Fast Charging market size, and there are many factors that will push it to be smaller and many factors that will push it to be larger. Two main factors will decrease fast charging demand. The first factor is that there are numerous alternatives to fast charging, including waiting for a slower charge, driving a different vehicle, or choosing a different method to complete a given journey. If fast charging is too expensive or too inconvenient, drivers will likely choose to forgo fast charging entirely. This tradeoff is discussed in more detail in the next section. A second important factor which will decrease the size of the fast charging market is that drivers who have intensive driving needs and are likely to regularly need fast charging are also likely to instead purchase a different vehicle, such as a plug-in hybrid or longer range BEV. There is very limited data at this time to understand how this type of choice would be made in practice, but anecdotal discussions indicate that BEV drivers do not like to be dependent on regular fast charger use.

Two main factors could increase the number of DC Fast Chargers required. First, this analysis assumes relatively ideal matching between the location of vehicles and the placement of chargers. In reality, only a fraction of chargers will be well-located enough to achieve this level of optimization in the near term, so there will likely be a large number of low-utilization chargers in locations that are less favorable. A second factor that will increase the number of DC Fast Chargers is that there are likely to be days like national holidays on which more fast chargers are required than average, so extra capacity will have to be required to insure that sufficient chargers will be available when needed. This is a common problem for many industries, but it is too early to determine how it will affect the requirements for DC Fast Charging.

2
ESTIMATED WILLINGNESS TO PAY

Understanding how to set pricing for DC Fast Charging is a pivotal question in both ensuring the success of the technology and perhaps making a business case for installing chargers. This section describes the results of using a model developed by EPRI to estimate customer willingness to pay for DC Fast Charging. It is important to remember that these results are based on modeling efforts, and do not necessarily reflect true consumer behavior, so they are indicative at best.

Methods and Assumptions

One of the main assumptions made in the development of the model was to assume that **DC Fast Charging is selling both energy and convenience**. This means that a trade-off occurs when a driver decides to use DC Fast Charging as opposed to using a different vehicle or charging at Level 2, so a fast charging session is priced relative to both gasoline and the value of time.[1] To model this, we assign a $/hour value for an individual's time, but assume that the overall price of electricity is otherwise the same for Level 2 and for DC Fast charging.

In addition to the value of a driver's time, we also consider whether or not a car needs to be rented in order to replace the BEV on a long-distance driving day. Sixty-five percent of households have more than one vehicle, so they have an in-house replacement vehicle available at approximately zero cost. The second part of this analysis investigates the cost of a rental vehicle for those households without a second vehicle or for days when the other cars in the household are not available.

Table 2-1 lists the assumptions used in this analysis.

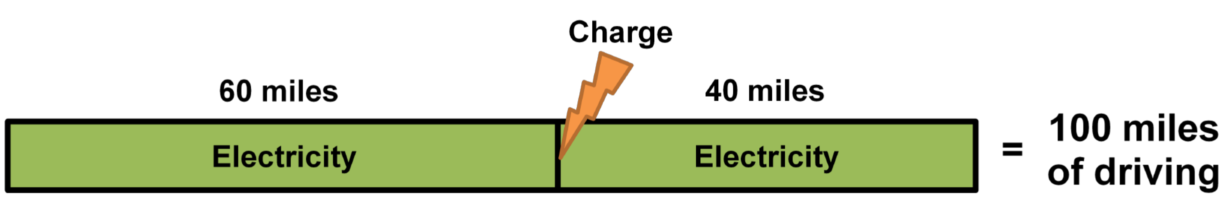
[1] We do not cover other vehicle costs such as maintenance and depreciation, or that an individual could utilize the time charging at Level 2 to do something else such as dining or shopping.

Table 2-1
Assumptions for willingness to pay analysis

Variable	Value
Level 2 Charging Rate	6.6 kW
DC Fast Charging Rate	50 kW, continuous
Electricity Fuel Consumption Rate	360 Wh/mile
Gasoline Fuel Consumption Rate	25 MPG
Gasoline Costs	$4/gallon
BEV Range Utilization	80-160% of electric range
Charger efficiency	90%
Value of time	$10/hour
Rental Car prices	Two scenarios: $10 or $30 per day

The willingness to pay model assumes there are three options when choosing whether and how to use a BEV on a journey that is beyond the range of the vehicle but within the range of DC Fast Charger. Consider a BEV75 traveling on a 100 mile trip. The driver of the BEV75 should have little to no range anxiety driving the first 60 miles of a trip. This is considered 'comfortable'. If the vehicle were to drive past the 60 miles, it could drive an additional 15 miles but this would likely induce range anxiety as the driver became concerned about the limited range remaining We will depict this as such below: green is comfortable, and red is uncomfortable.

If the car needs to be taken on a 100 mile trip, we can assume that the driver would likely stop around the 60 or 50 mile mark and recharge, depending on charger location:



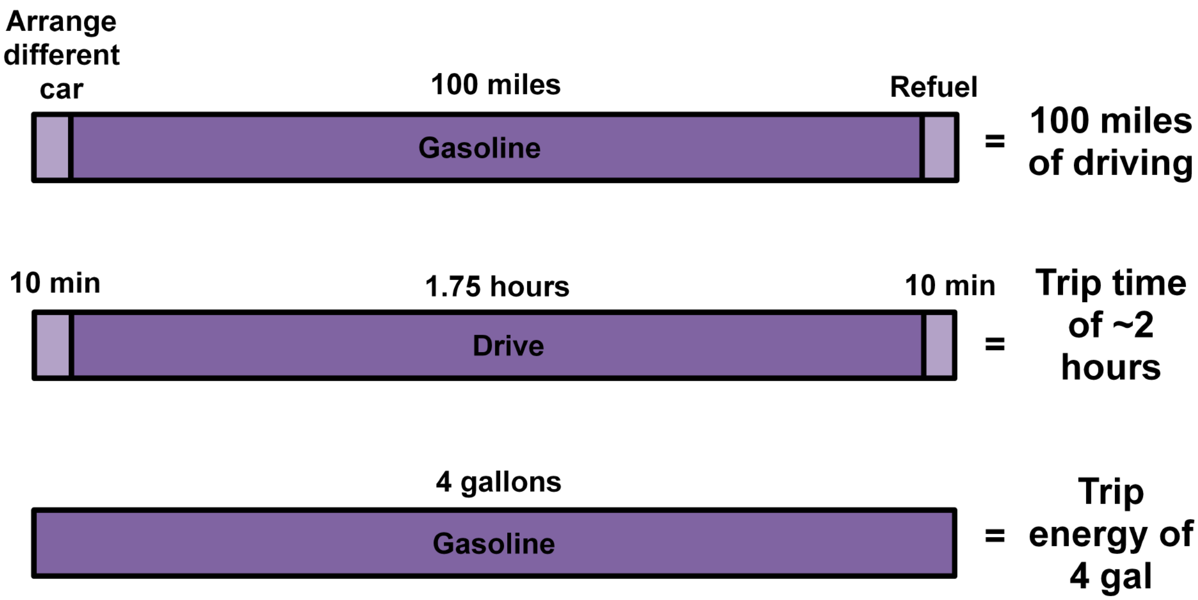
The driver has two options to charge the BEV:

- **Option 1: Level 2 Charging**: The vehicle would stop after about an hour of driving so that it could recharge for about two hours. After charging, the vehicle would drive for another hour to complete its 100 mile trip. This results in a trip time of four hours, with a total energy consumption of 32 kWh.

- **Option 2: DC Fast Charging:** If we assume that the same 100 mile trip is taken, but that DC Fast Charging is available, we still have two hours of driving but now only about 20 minutes of charging would be required in the middle of the trip to recharge the battery instead of the two hours required for Level 2 charging. The trip still consumes 32 kWh of electricity.

The previous two options assume that the BEV is still driven on the 100 mile trip. The third option assumes that the BEV is replaced with a different vehicle:

- **Option 3: Replace the electric vehicle with a gasoline vehicle:** This choice results in a new scenario taking about 2 hours and using 4 gallons of gas:



Comparing Option 2 and Option 3, the cost savings from fuel switching from electricity to gasoline would need to outweigh the cost of additional time to charge. Furthermore, if the vehicle is in a single vehicle household, there may be additional time requirements to arrange a different car. The value of time, cost of gasoline, and availability of a different car all change the consumer's willingness to pay for DC Fast Charging.

Results

The willingness to pay for fast charging was estimated for four ranges of BEV: 75, 100, 150, and 200 miles. As mentioned previously, there are two sub-categories to this analysis, single-car households and multi-car households. For drivers within a multi-car household, we assume that there is a 'free' in house BEV replacement.

Willingness to pay for DC Fast Charging for multi-car households

The results are presented for the multi-car household first, in Figure 2-1. The results are presented as quintiles; each blue box represents 20% of the population. Some of the boxes are quite close because more than 20% of the vehicles fell within that spectrum. For this analysis, only vehicles with daily trips of 80-160% of vehicle range were analyzed for each BEV. The result shown in the first column of each graph is Level 2 (L2) versus DC Fast Charging at a time valuation of $0/hour. Since electricity costs are the same in all cases analyzed here, if an individual places no value on his or her time, there is no cost advantage of using DC Fast Charging over L2. The second column shows the comparison of L2 vs DC Fast Charging at a value of time of $10/hour, which results in a cost savings for consumers who use DC Fast Charging instead of L2. For drivers who need very little energy there is a relatively small cost savings (these drivers are clustered at the zero axis). The number of low-willingness-to-pay customers decreases as the BEV's electric range increases—a larger battery means a longer time spent charging. The third case considers an available in-house vehicle replacement with the consumer still valuing his or her time at $10/hour. For this scenario, the value of the driver's time spent charging has to be less than the total cost of gasoline, since otherwise there is no real incentive to using the DC Fast Charger. Note that since the entire drive has to be driven on gasoline in order to use an alternate vehicle there is a minimum lump-sum that must be paid in order to cover the distance which the BEV would normally drive on electricity with no incremental cost or inconvenience. This minimum amount scales with the range of the BEV.

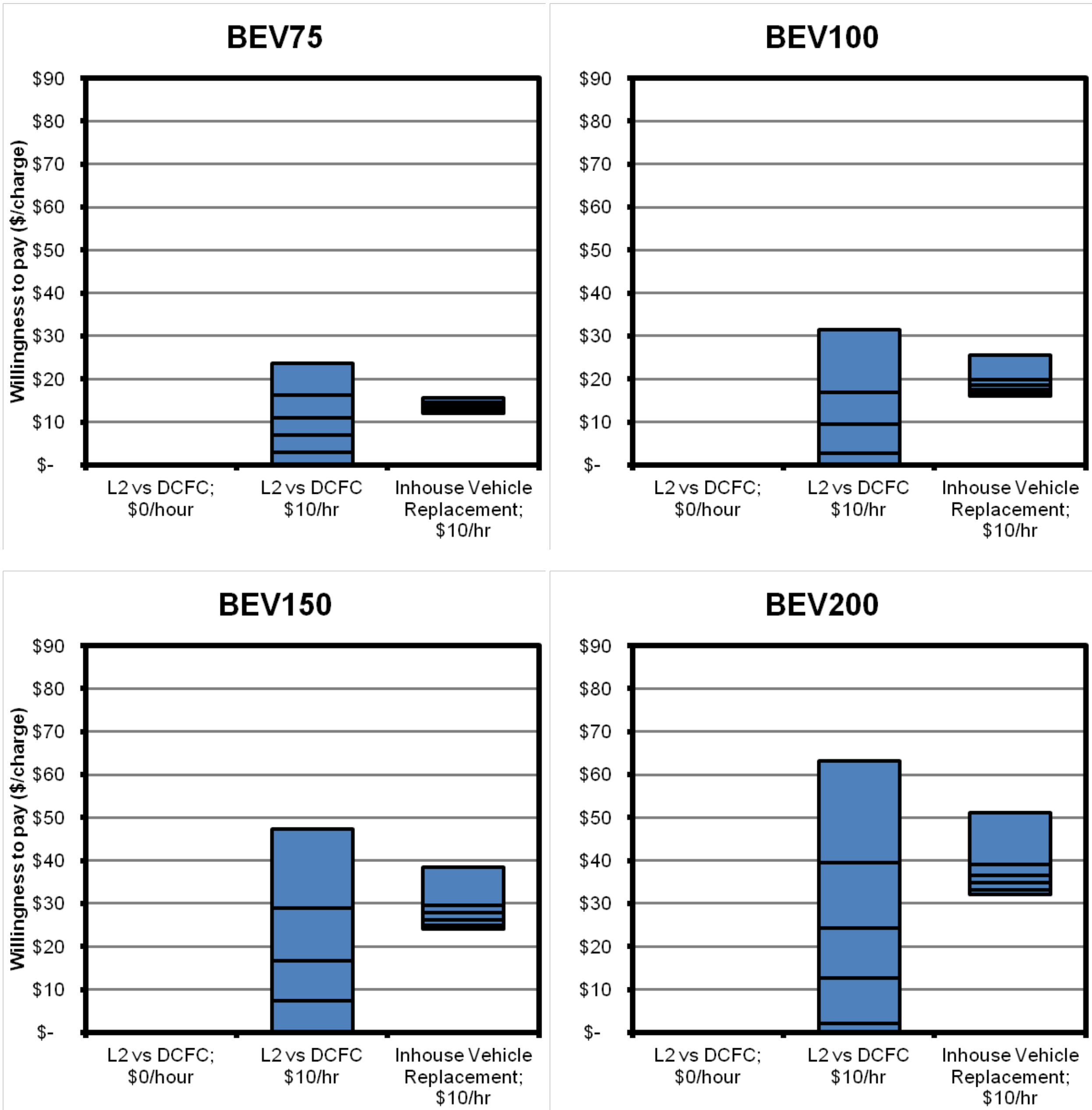


Figure 2-1
Willingness to pay for multi-car households

The results for the multi-car household indicate that the willingness to pay for DC Fast Charging for current low-range vehicles like the BEV75 is somewhere between $10-20/session for a large number of customers. This is significantly higher than the amount currently charged by Blink Networks for a fast charge session, which is currently $5.[vii] Increasing range will lead to the potential for higher fees, potentially up to a cost comparable to a current tank of gasoline. Tesla is currently the only manufacturer that provides a long-range vehicle (greater than 100 miles range), but they do not charge a per-charge fee for their Supercharger network. Instead, Tesla either includes the service as part of the vehicle purchase or charges a one-time fee,[viii] so it is unclear how the market value of the Supercharger service compares to our willingness-to-pay results.

Willingness to pay for DC Fast Charging for single car households

Next, we examine the effects of having to rent an alternate car. The values chosen for this segment assume there is a vehicle replacement cost of $10 or $30. Ten dollars is a relatively low price for a rental car, but it is possible that the customer could use a car sharing service or could use a friend's or family member's car at a low 'cost' equivalent.

Similar to the multi-vehicle household, we present the results for all four vehicle ranges in Figure 2-2. Starting with the leftmost column, the first result is the same as the in-house replacement: there is $0 replacement cost but there is a 'lump-sum' cost for gasoline use. Similar to the previous case, it is assumed that no incremental time is spent getting or returning the vehicle. The next two columns show an assigned replacement cost of $10 and $30, respectively. Perhaps unsurprisingly, as the replacement cost increases, the value of DC Fast Charging increases: renting a car can be expensive.

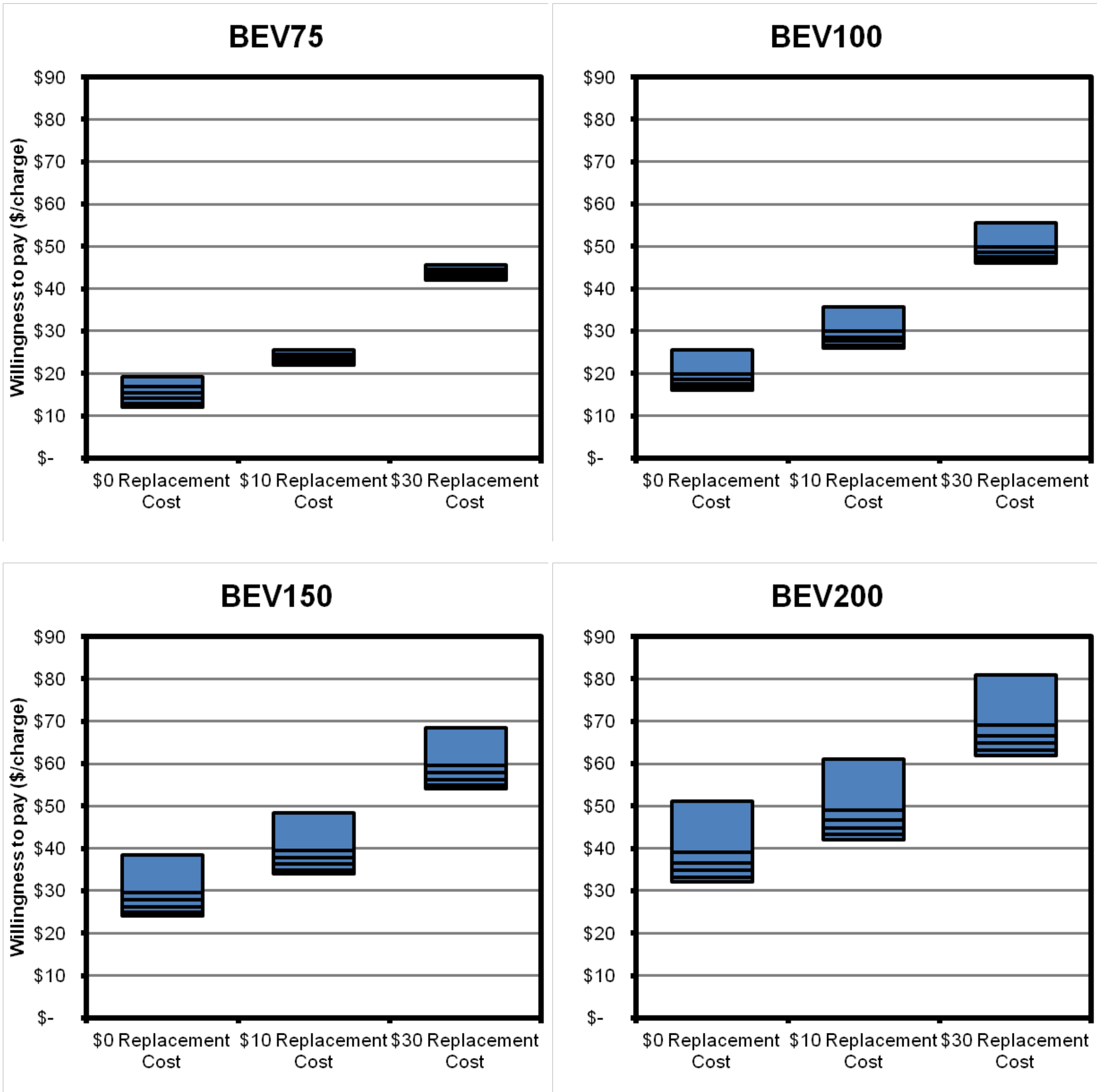


Figure 2-2
Willingness to pay for single car households

The results still show a general trend of a large market for DC Fast Charging at $10 and $20 per session for the BEV75s which are common today, although the customer base in this price range and above is larger. For longer range vehicles or high rental prices the willingness to pay can be quite a bit higher.

The results of the willingness to pay model show one input for estimating the potential pricing for DC Fast Charging. Of course, as an individual begins to value his or her time more, the willingness to pay may be more. Similarly, if gasoline prices increase, or the driver's trip plan already includes stops at restaurants or other locations, the value of fast charging may increase.

3
THE EFFECTS OF SAMPLING ON DEMAND LEVEL

One important aspect of the economics of operating DC Fast Chargers is the purchase of upstream electricity to supply to customers. DC Fast Chargers are expected to be installed in commercial locations and are therefore likely to use commercial electricity rates, which often include both energy-based costs and power-based demand charges. The separation between these two charges in utility rate structures is intended to align impacts from loads with costs of service. However, these rates have some embedded assumptions concerning use that may not be representative of DC Fast Charging loads. Typical commercial loads like a grocery store or office building run at a relatively constant level which will vary throughout the day and between seasons but do not typically change dramatically within short time periods. Additionally, the peaks of commercial loads are typically coincident with system peaks, so there is little benefit from diversification at the transmission and generation level. In contrast, the load from DC Fast Charging is entirely dependent on the presence of customers, and utilization levels can be very low, especially in the early market. Understanding how existing rates affect DC Fast Chargers is challenging, and will change over time as the DC Fast Charging market develops.

The following Sections present three different initial investigations of this problem. This section describes the investigation of a technical detail of demand charges, which is the effect of sampling period on actual demand charges incurred by a DC Fast Charger. The next section investigates the levelized cost of electricity for a DC Fast Charger given current utility rates and varying assumptions about the number of fast charging customers per month. The third section presents data from the EV Project to look at the current level of utilization for real-world chargers.

The analysis in this section is intended to answer a key question: How does the actual demand level of a DC Fast Charger compare to the peak power of the charger? There are some technical details of demand charge calculation which could mean that low utilization of DC Fast Chargers would automatically cause the demand charge to be low, so service costs would be well-matched to revenue. The results of the analysis indicate that this is not the case except for very low utilizations and long sampling periods. Utilization levels that have already been reached in many locations would cause the demand level to closely approximate the peak power level of the DC Fast Charger, so demand charges will not adjust 'automatically.'

Background on demand charges and DC Fast Charging demand

The concept of imposing charges on the level of demand for commercial customers is widespread within the utility industry, but the actual implementation of these charges varies widely. Different utilities have different demand charge costs, different thresholds at which demand charges begin, different sampling times, and variations in how demand levels carry over between months. Most utilities seem to use similar methods for measuring demand levels, though, as described below.

There is a common misconception that demand charges are incurred based on the highest instantaneous power level, but actually demand charges are calculated based on summing the amount of energy consumed within a sample period – and the sample period for assessing the demand level is relatively long. A survey of these periods was not performed for this analysis but consultation with rate experts indicated that periods of 15, 30, and 60 minutes are common. The highest demand period during a month then becomes the demand level for the month, and this sets the demand charge. This can have a significant impact on the demand level of a DC Fast Charger due to the specifics of the fast charging power profile.

For a '50 kW' DC Fast Charger, the peak power draw is a bit over 50 kW due to conversion losses. However, the average power draw over a full charge can be quite a bit different since current vehicles on the market do not draw constant power from the charger over the entire time spent charging, as shown in Figure 3-1.

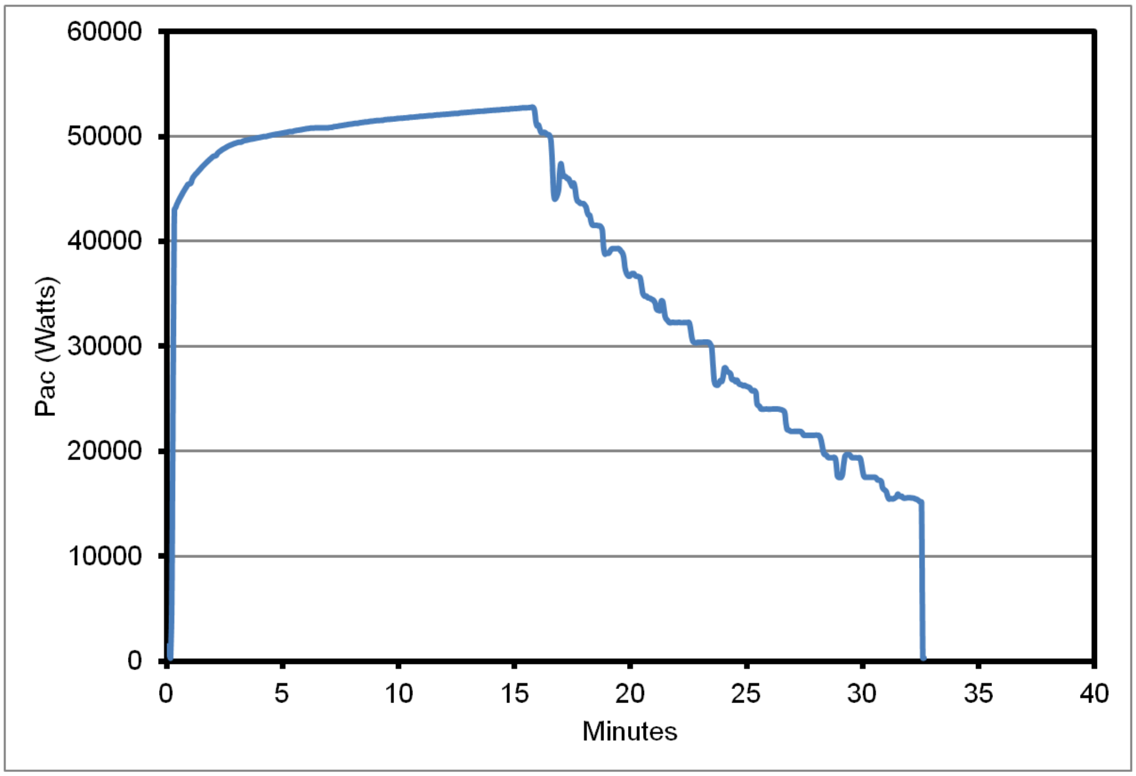


Figure 3-1
Power profile for a full charge on an existing battery electric vehicle

The specifics of this power profile mean that the demand level may be quite a bit lower than the instantaneous peak power if the demand is summed up over a long enough time period. If the profile shown in Figure 3-1 were averaged over 60 minutes the demand level would be about 20kW. However, it is also possible that drivers will only stop long enough to get a partial charge and will stop charging while the power is relatively high. If another customer starts charging immediately, high power could be sustained. This means that the demand level will increase with utilization, but in a complex way. The analysis in this section attempts to create an initial estimate of the demand charge at different levels of utilization and for different measurement intervals.

Methods and Assumptions

Since the power draw for DC Fast Charging is not constant, it is important to understand what the actual draw is for an individual user and how these profiles combine for multiple users per day. For simplicity the EPRI model assumes that vehicles that need to charge stop halfway through their journey and charge based on the profile in Figure 3-1 until the car is fully charged. This is a relatively pessimistic scenario at low utilization since it is likely that customers that need very little energy will not wait for a full charge and would cause a lower average demand charge. However, at high utilization levels the power level would actually be higher if vehicles only charge for the minimum amount of time, since other customers could be waiting and begin charging immediately at high power levels. Fully accounting for charging behavior would require complex customer model for which there is very limited data. Additionally, the results already indicate that if more than a few customers per day use the fast charger there would be little difference between the worst-case scenario and the near-worst-case scenario presented here.

This analysis investigates the effects of utilization level by assuming that between 1 and 10 vehicles use the fast charger in one day. The demand is then calculated based on intervals of 15, 30, and 60 minutes, providing a distribution of demand for different 'charger days.' In order to estimate the demand charge for a given charger, 30 of these days would have to be selected and then the highest demand would set the rate. This means that in order to ensure that the demand level does not exceed a specific threshold, about 95% of samples would have to be below this level. The results indicate that this will not be the case even for relatively few vehicles charging at a particular site per day.

Results

Since the model assigns vehicles randomly to a particular charger, the output is a statistical distribution of demand levels for the model day. The results will be presented as quintiles, with each box representing 20% of the population of DC Fast Chargers. For this analysis there is a significant amount of clustering of behavior, so the boxes are often close together and small. This makes it difficult to determine specific values, but the overall trends in the data are more important than the exact numerical result.

The results for the 15 minute summing interval are shown in Figure 3-2.

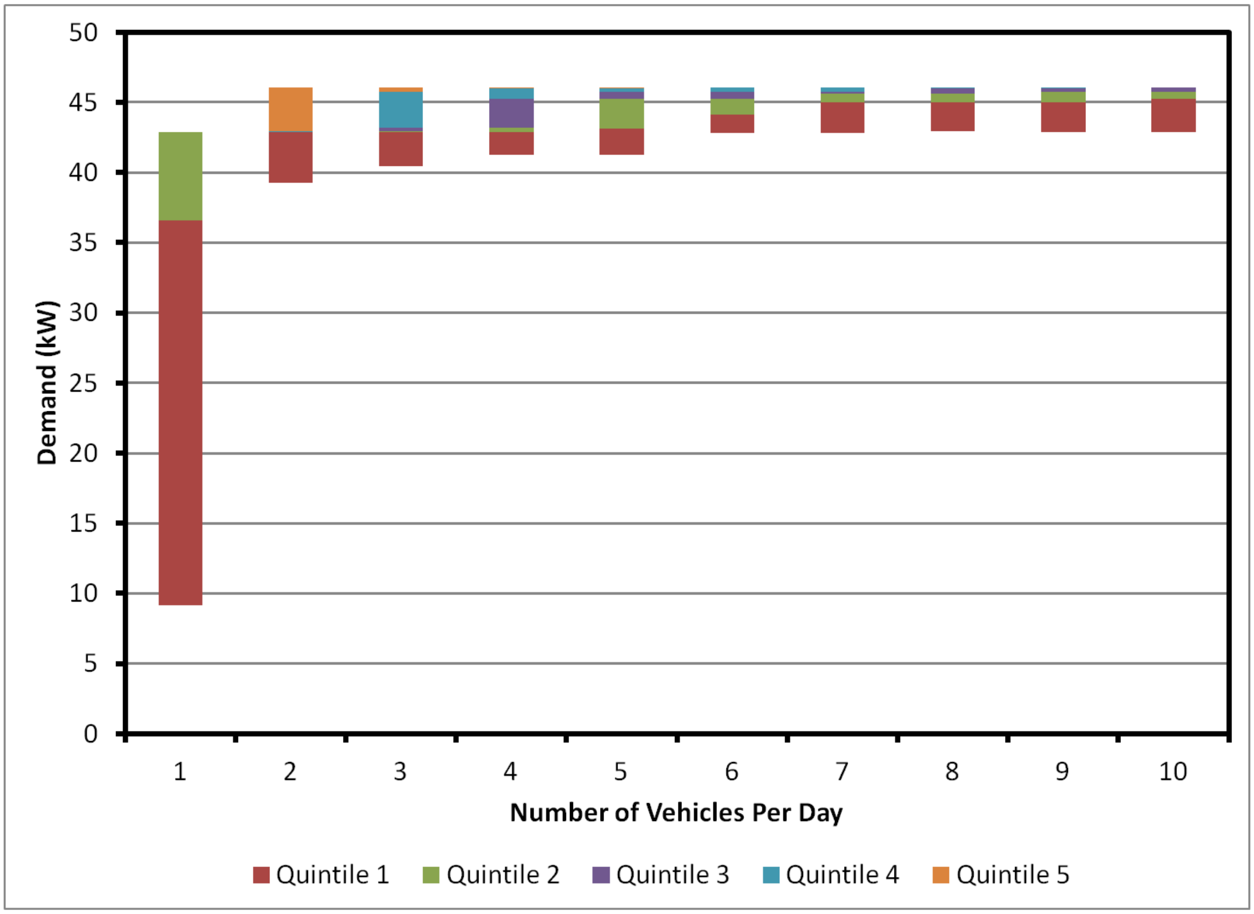


Figure 3-2
Average demand level for DC Fast Charging for a 15 minute summing interval

The 15 minute interval is approximately the same as the period of peak usage for a DC Fast Charger, so the demand is nearly equal to the peak power of the charger for almost all charge scenarios, even with a very low utilization level. Even if the charger only had one customer on a few days within the month it is likely that the demand level would exceed 40 kW, so it is almost the same as the demand level at very high utilization.

Next, we analyze the results for a 30 minute sampling period, shown in Figure 3-3.

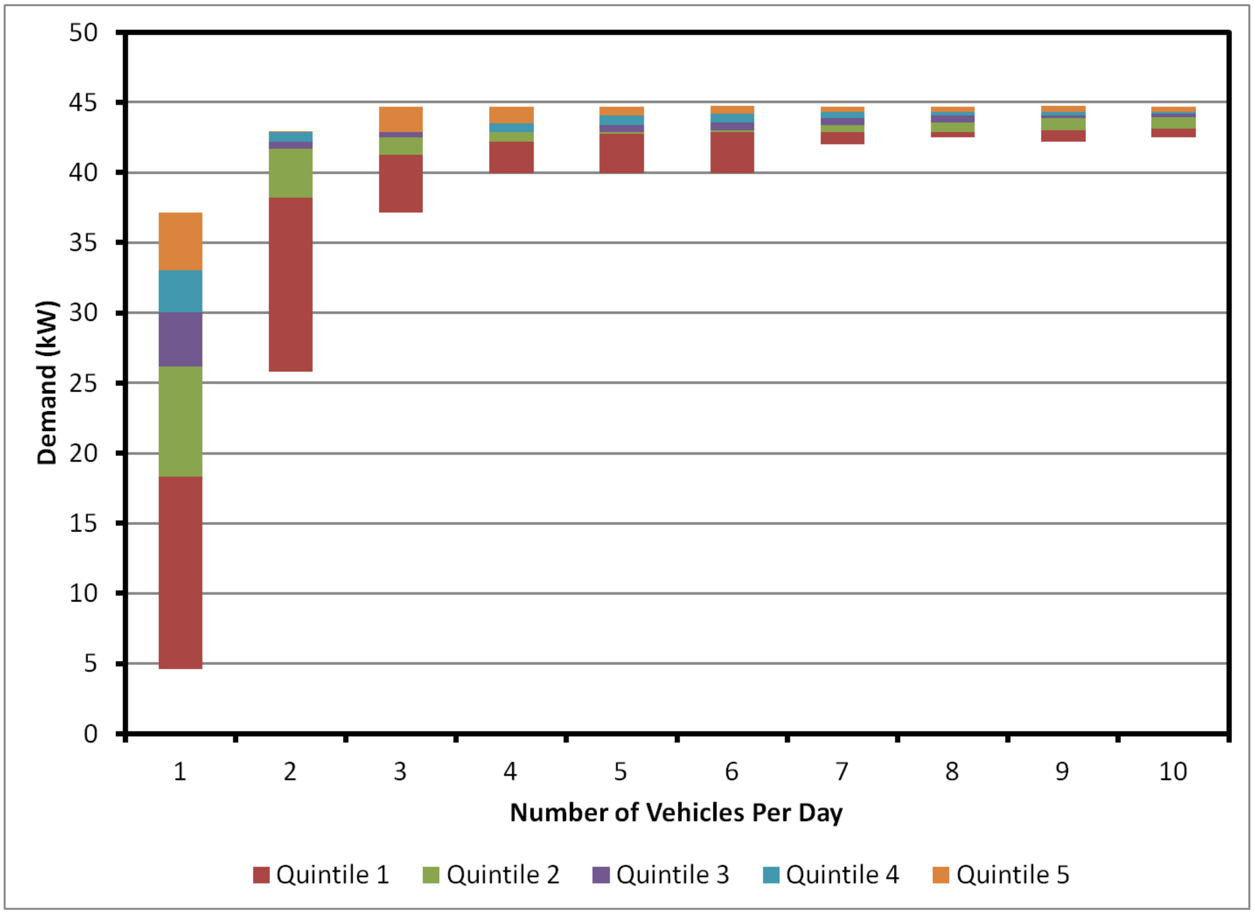


Figure 3-3
Average demand level for DC Fast Charging for a 30 minute summing interval

For a 30 minutes summing interval, the average demand is still consistently high even with modest charge utilization. Only for a utilization level of one vehicle per day will the demand level be lower than 75% of peak usage for a significant fraction of charger days. For the likely instance that two or more vehicles used the charger on a few days within the month the demand level would be over 40 kW.

Finally, we examine the scenario with a one hour sampling period, shown in Figure 3-4.

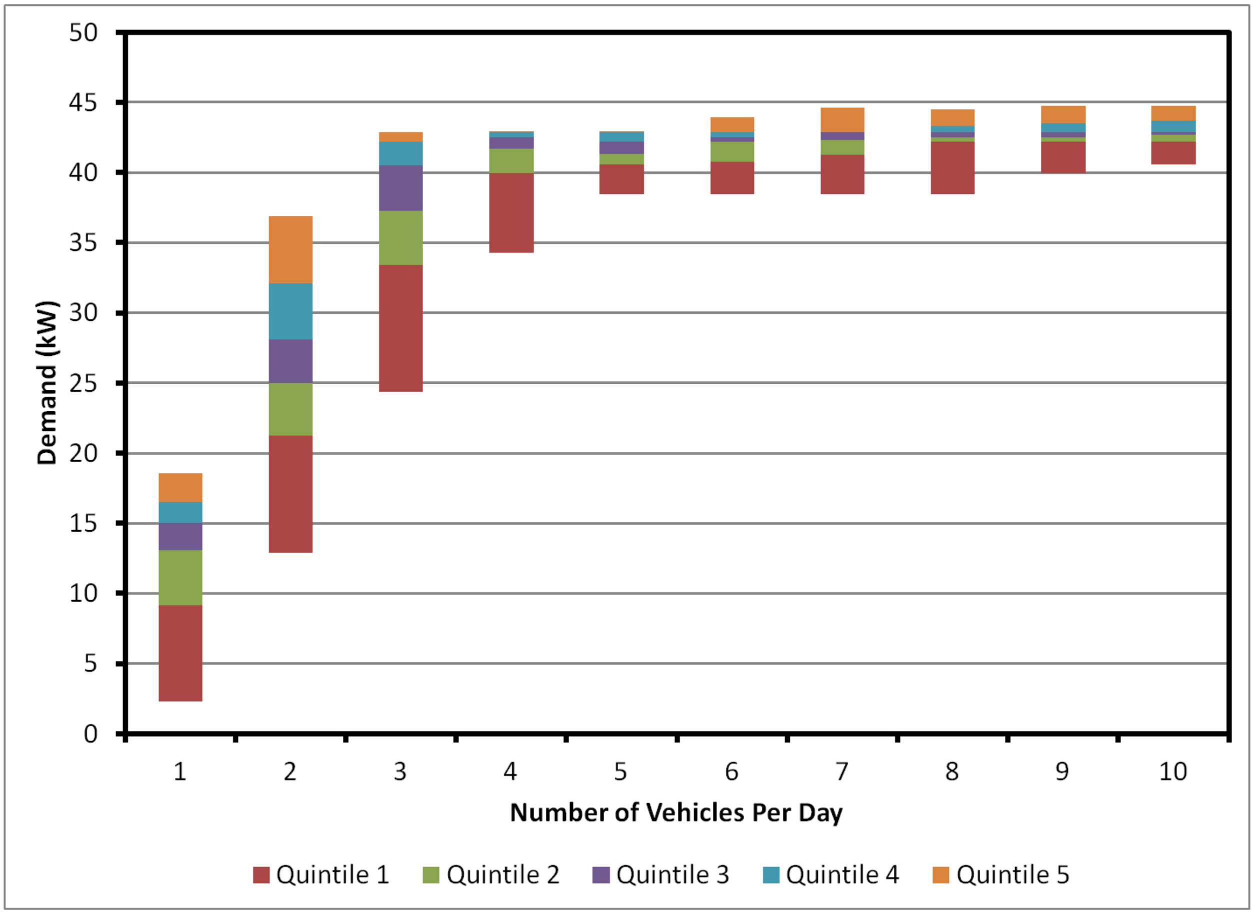


Figure 3-4
Average demand level for DC Fast Charging for a 60 minute summing interval

Finally, for a 60 minute sampling period there is some variation in average demand for lower utilization levels. For a utilization level of one user per day the demand level is less than half of the peak power output of the fast charger. However, even a modest usage level of 3-4 times per day causes the demand level to approach the peak power of the charger.

This analysis indicates that increasing the averaging interval does not appear to be a viable method of matching demand level to utilization. Since most demand charges are set on a monthly basis, even moderate usage of a fast charger results in a monthly demand of about 90% of the total rating of the fast charger. This is due to the high likelihood that if multiple customers use the charger in a given day they will likely want to use it at about the same time and at least one of them will need a relatively full charge. The main caveat is that this analysis is based on a simple model of customer charging behavior. As more information becomes available, this model will be refined.

4

LEVELIZED ELECTRICITY COSTS AT DIFFERENT USAGE LEVELS

The analysis in this section continues the analysis of demand charges for DC Fast Charging from Section 3 by investigating the effects of utilization on the per-customer cost of electricity service. This analysis uses current rate structures from two utilities as typical examples. Other utilities will have different rates but the overall trend in the results will likely be similar. The results indicate that demand charges will lead to high per-customer electricity costs for low utilization levels, but that with plausible levels of utilization the total costs for rates with demand charges will be equivalent to total costs for energy-only rates. This implies that if specific rates are designed for DC Fast Charging, the likely evolution of utilization over time must be carefully analyzed to ensure that the rate does not quickly become obsolete.

Electricity cost impact from demand charges

Many utilities have multiple rates for the light-commercial segment, some of which include demand charges and some of which include just energy costs. We examined two utilities' retail rates, shown below in Table 4-1, to analyze the effect of demand charges on the average cost per DC Fast Charge. Rates A-1 and A-2 are the rate with demand charges and energy-only rate for an (anonymous) utility and Rates B-1 and B-2 are the rates for a second utility in the same region. The results were similar so only the results for Utility A will be presented here. (For Utility B the rate with demand charges was the lower cost option at slightly lower utilization levels).

Table 4-1
Sample commercial rate structures with and without demand charges

	$/kWh	Demand Charge	Meter Charge	Estimated Annual Fixed Cost
Rate A-1	Summer: $0.29/kWh Winter: $0.23/kWh	-	$0.40	$144 (20 kW system)
Rate A-2	Summer: $0.08/kWh Winter: $0.07/kWh	Summer: $33.43/kW Winter: $12.73/kW	$189.25/month	$16,120 (50 kW system) $7,810 (20 kW system)
Rate B-1	Summer: $0.14/kWh Winter: $0.09/kWh	Summer: $16.13/kW Winter: $11.79/kW	$145.30/month	$10,120 (50 kW)
Rate B-2	Summer: $0.21/kW Winter: $0.15/kW	-	$0.33/day	$120

The rates include some elements that scale with amount of energy (kWh) use and some elements that do not. The 'Estimated Annual Fixed Cost' shows the total cost of electricity service without any energy use. The variation in fixed cost is quite large – around two orders of magnitude – so the DC Fast Charger installer will have a large incentive to 'game' the rates. For example, there is an anecdotal report of an installer reducing the maximum power of the charger by about 10% in order to be under a threshold for demand charges. This 10% change significantly reduced their electricity cost but only marginally changed the cost to provide service, so the net effect on the utility was likely negative.

Total electricity costs per kWh

In order to understand the impacts of these fixed charges on total electricity costs, EPRI used these rates to calculate the average cost per charge and the resulting levelized price per kWh for each rate for different utilization levels. Utilization is represented as the number of full 20 kWh charges per month, so this number will have to be scaled to account for partial charges. The following charts show the total price per month on the left axis and the resulting average price per kWh is shown on the right. We calculate the average price per kWh based on the cumulative energy costs: including demand charges, meter charges, and energy costs.

Figure 4-1 shows the total electricity costs and per-kWh energy costs for the energy-only rate A-1, and Figure 4-2 shows the results for rate A-2. The comparison is somewhat complicated by the fact that there are separate summer and winter rates, but this is common in many regions so it is a necessary complication. The results indicate that during the summer the rates will be equivalent when the utilization level reaches approximately 200 full charges per month. In the winter, the crossover point will occur at approximately 150 full charges per month. At higher utilization levels, the DC Fast Charger operator will be better off using the rate with demand charges. As will be seen in Section 5 these utilization levels are plausible, even accounting for the effects of partial charges.

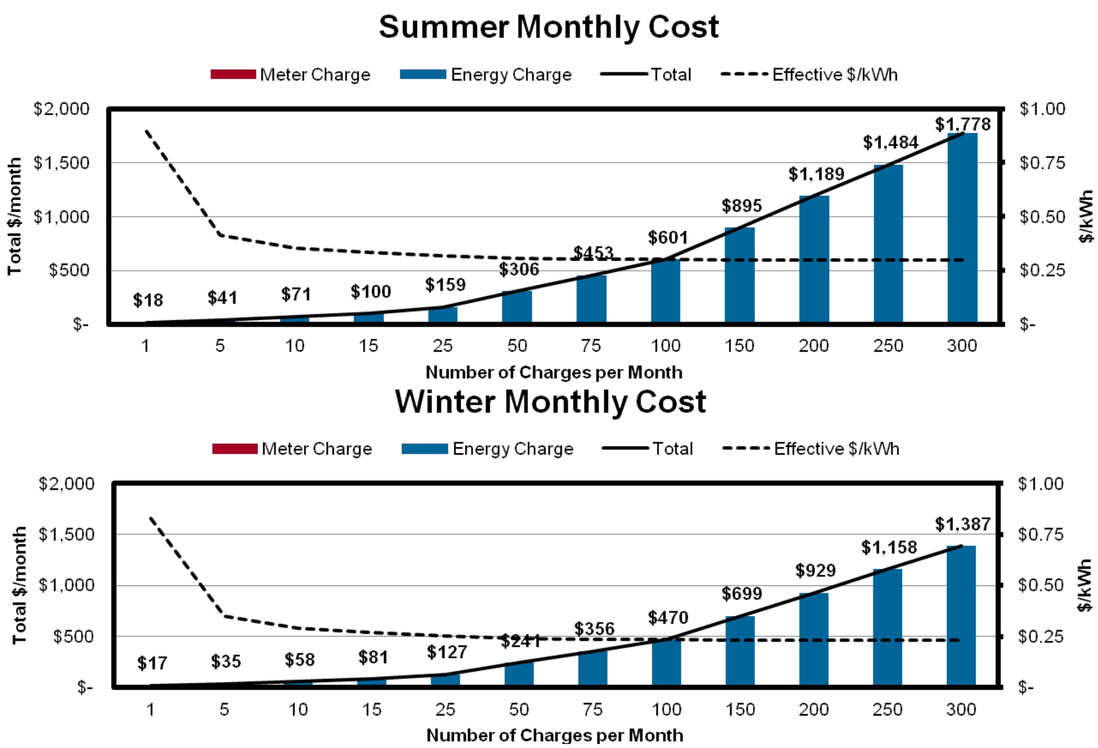


Figure 4-1
Total cost of service and cost per kWh for rate A-1

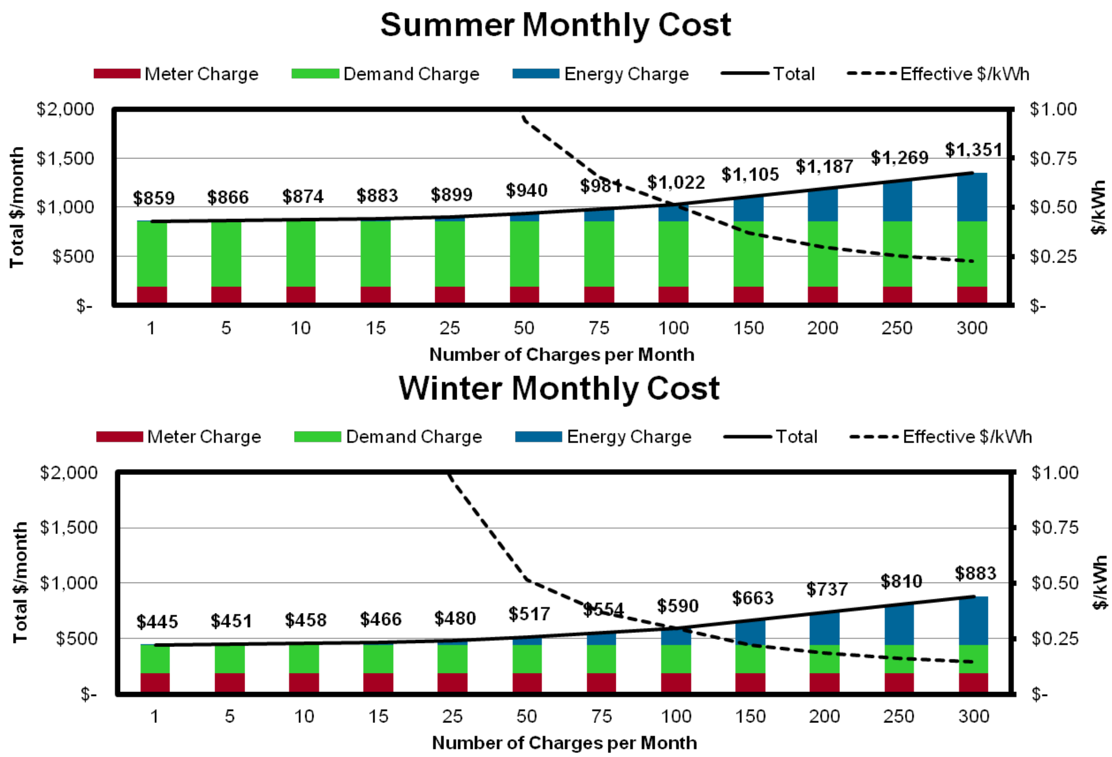


Figure 4-2
Total cost of service and cost per kWh for rate A-2

Total electricity costs per charge session

The previous section looks at the total cost per kWh, and finds that at reasonable utilization levels, rates with demand charges are comparable to rates without demand charges. However, much of the discussion around demand charges has focused on the per-charge cost, particularly at low utilization. Figure 4-3 shows the same costs, but scaled to the number of full charges per month for rate A-1 with no demand charges and rate A-2 with demand charges.

Rate A-1

Number of Charges	Winter	Summer
1	$ 16.40	$ 17.65
5	$ 6.80	$ 8.05
10	$ 5.60	$ 6.85
15	$ 5.20	$ 6.45
25	$ 4.88	$ 6.13
50	$ 4.64	$ 5.89
75	$ 4.56	$ 5.81
100	$ 4.52	$ 5.77
150	$ 4.48	$ 5.73
200	$ 4.46	$ 5.71
250	$ 4.45	$ 5.70
300	$ 4.44	$ 5.69

Rate A-2

Number of Charges	Winter	Summer
1	$ 445.26	$ 859.43
5	$ 90.18	$ 173.15
10	$ 45.79	$ 87.36
15	$ 31.00	$ 58.77
25	$ 19.16	$ 35.89
50	$ 10.28	$ 18.74
75	$ 7.32	$ 13.02
100	$ 5.84	$ 10.16
150	$ 4.36	$ 7.30
200	$ 3.62	$ 5.87
250	$ 3.18	$ 5.01
300	$ 2.88	$ 4.44

Figure 4-3
Cost of electricity per full charge at varying utilization levels

These results indicate that the costs at high utilization levels are significantly lower for the rate with demand charges. However, at low utilization levels the rate with demand charges will result in very high per-charge costs. Given that the market for DC Fast Charging is young and utilization levels are relatively low, these results make it clear why electric vehicle services providers have been so vocal about the costs of demand charges. However, these results also indicate that as utilization levels increase this problem will largely be resolved simply through economies of scale.

5

UTILIZATION DATA FROM THE EV PROJECT

Data on DC Fast Charger utilization is unfortunately very limited, so it is difficult to test the assumptions used in the analyses in Sections 3 and 4 to ensure that they are plausible and representative. A limited amount of data is available from the reports from the EV Project, and this information is summarized below. This data indicates that the average utilization of about 200 charge sessions per charger per month is plausible today, equivalent to 75-100 full charges. However, the data are too limited to make conclusions about the performance of individual chargers or the future direction of the DC Fast Charging market.

Background

The EV Project was created through an award to ECOtality, Incorporated through the American Recovery and Reinvestment Act of 2009 to fund the installation of charging infrastructure and the study of plug-in electric vehicles operation and charging.[ix] The exact definition of the project scope and goals has changed throughout the project, but it led to the construction of over 3,000 publically accessible stations, around 100 of which are DC Fast Chargers.[x] Information on the use of these chargers is shared with Idaho National Laboratory (INL), which periodically publishes reports summarizing the data. Unfortunately, significant limitations have been placed on the sharing of the data, and only the heavily processed output is available. These results are detailed enough to be indicative of what is happening, but not sufficient for meaningful analysis.

Two reports were used in the writing of this section, the most recent Quarterly Report, which covers through the second quarter of 2013[xi] and Idaho National Laboratory's presentation at Plug-in 2013[xii]. Since numerical data was not made available this analysis is based on EPRI's interpretation of the data in the graphs from these reports, so they are not necessarily representative of the EV Project's actual results.

DC Fast Charging sessions per month

Figure 5-1 shows the number of DC Fast Charging sessions per charger during an average month for Q3 of 2012 though Q2 of 2013. The results show that usage of DC Fast Chargers is increasing, even though the number of chargers has also increased in each location (Figure 5-2). Importantly, they also show that during Q2 of 2013 the average usage in some locations was approaching 200 charge sessions per month, which is about 6 charge sessions per day. Relative to the analysis in Sections 3and 4, this indicates that these locations are moving from the 'low utilization' regime to a mid-utilization regime.

This data is interesting, but there are some important details that are not available. Within each of these regions there is likely to be variation in the quality of the charger locations, so there will be some chargers which are much more highly utilized than this average and some that are much less utilized. For example, an investigation of available charger maps indicates that there are chargers in each region which are well outside of the urban core and not near a transportation corridor. It is not possible to reach detailed conclusions without more information on individual charger utilization, but it is likely that there are some chargers that are mid- to high utilization and some that are low utilization. Since the analyses above contain some non-linear elements, they should be interpreted with the understanding that this average data can provide a directional indication of the results but that more data is required for a more representative analysis.

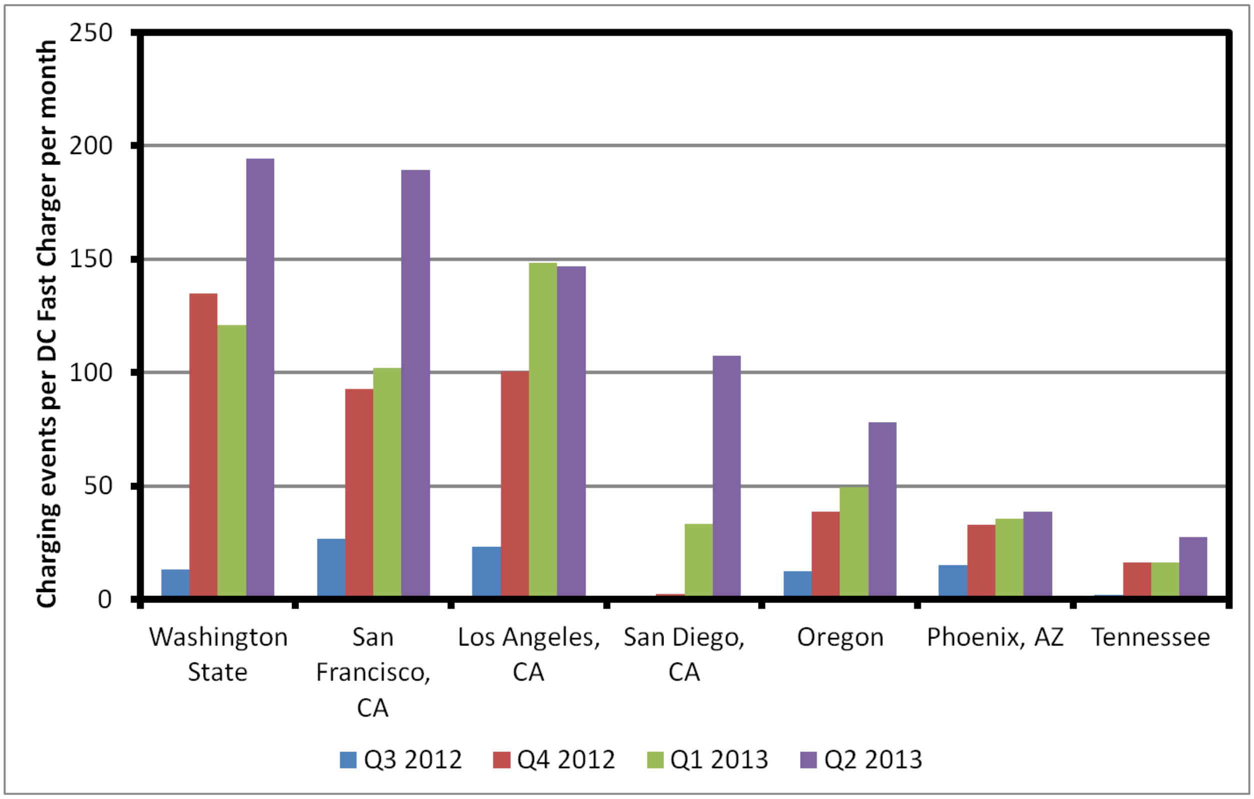


Figure 5-1
DC Fast charger utilization

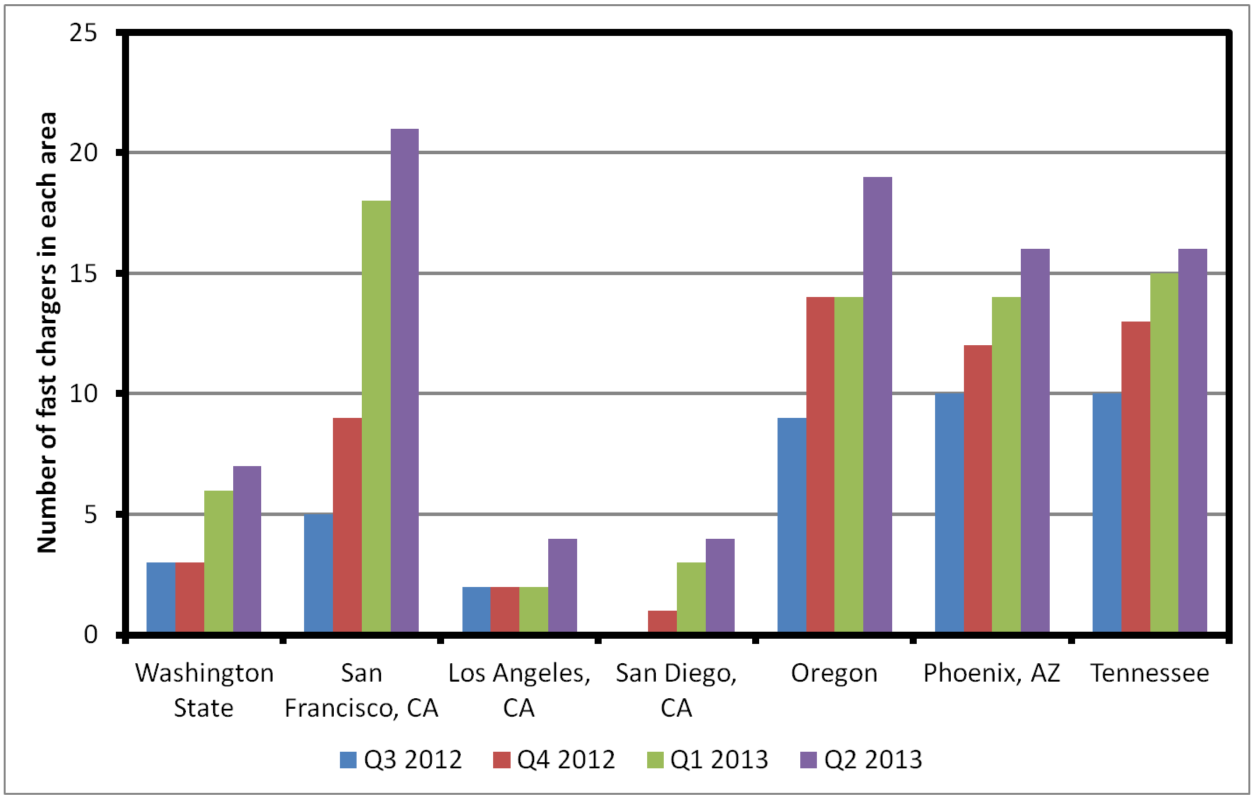


Figure 5-2
Number of DC Fast Chargers in each area

Energy delivered per charging session

It is also important to consider the amount of energy transferred per charge session. The EV Project provides data on this, but unfortunately the data sources available seem to indicate different results. Figure 5-3 shows the distribution of delivered energy per charge session from the INL Plug-in 2013 presentation, and Figure 5-4 shows the distribution from the EV Project Q2 2013 Quarterly Report. The energy bins differ between the two reports but it is clear that the distributions are quite different, with the report from Plug-in much more concentrated between 6-10 kWh than would be plausible with the data from the Quarterly Report. The average energy delivered is 7.7 kWh for the Plug-in result and about 8.4 kWh in the Quarterly Report result (assuming that each bin is represented by the energy use of the center of the bin). Given the energy requirements of the Nissan LEAF, the most common vehicle capable of using these chargers, the results indicate that it takes about 2-2.5 charging sessions from Figure 5-1 to equal a 'full charge' from Section 4. This indicates that even today an average utilization level of 75-100 full charges per month is plausible, with growth still increasing and the potential for wide variation within these averages.

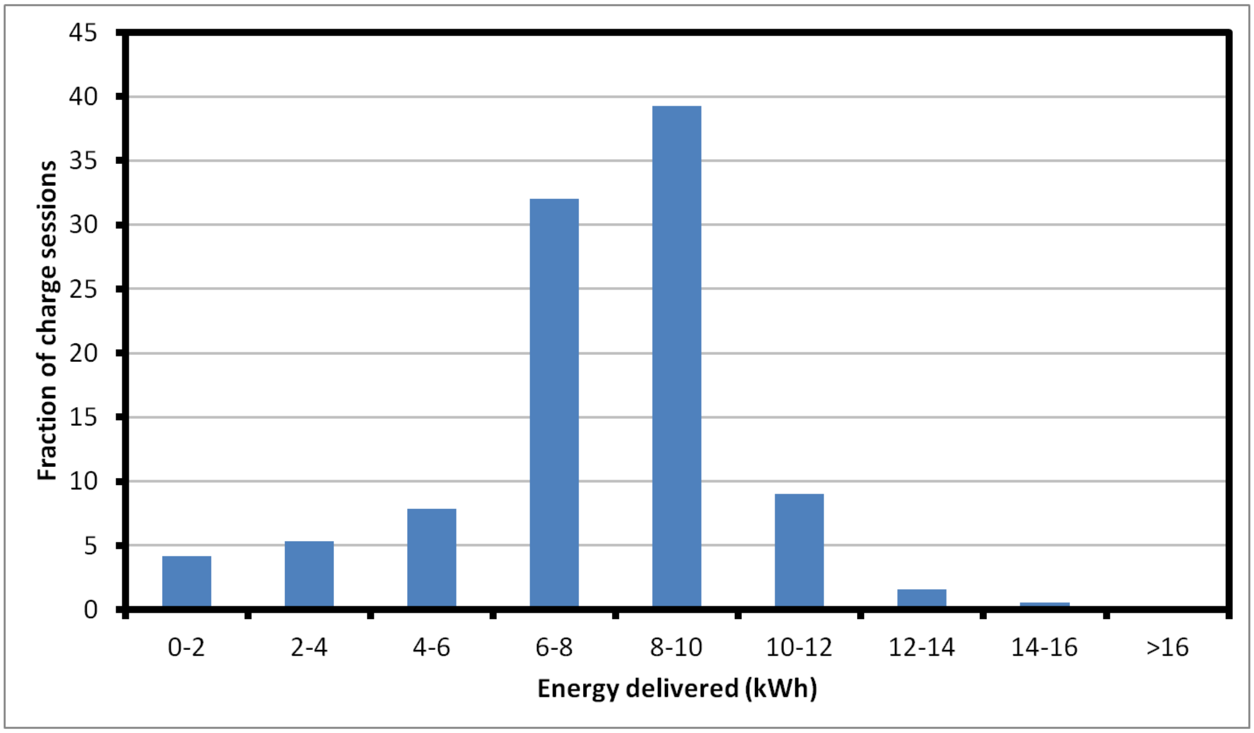


Figure 5-3
Energy delivered per charge session, Plug-in 2013

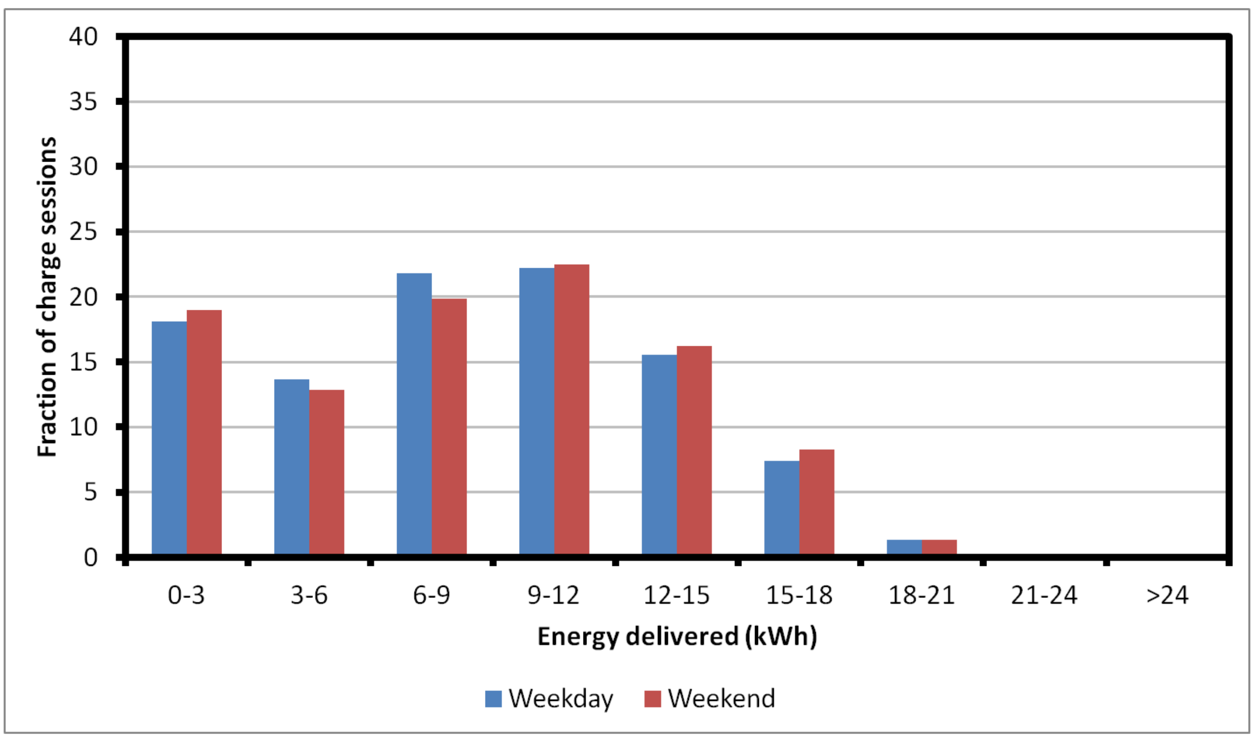


Figure 5-4
Energy delivered per charge session, Q2 2013 Quarterly Report

6 UTILITY CASE STUDY

Northeast Utilities – Written by Watson Collins

Northeast Utilities agreed to write a chapter on their experience installing, rate planning, and siting DC Fast Chargers in Connecticut. The following is a description of the work, the 'case' they made to regulators, and highlights their work with Tesla. The opinions presented here are not necessarily the opinions of EPRI.

Connecticut is home to a growing network of DC Fast Chargers. Northeast Utilities, through its Connecticut Light and Power subsidiary, is working with The State of Connecticut to develop a network of DC Fast Chargers. Construction is now complete on the first location and up to 15 additional locations are under consideration. In addition, Tesla has four Supercharger locations up and running with two more under construction. By the end of 2014, Connecticut could be home to more than 20 DC Fast Charger locations. Many of these locations will have multiple DC Fast Chargers. While this is a positive development for PEV drivers, these projects have surfaced a variety of issues for utilities. These issues include utility infrastructure upgrades, utility demand charges, equipment compatibility (CHAdeMO, SAE Combo, Tesla), DC Fast Charger ownership, billing users of the DC Fast Chargers, and DC Fast Charger installation issues.

The DC Fast Chargers require substantial utility service capacity. These first DC Fast Chargers were installed at the state's service plazas along the interstate highways. These service plazas were being modernized, undergoing a complete reconstruction. The State of Connecticut viewed this as a unique opportunity to include PEV charging into these new facilities. Construction included the installation of a new electric service along with separately metered electric accounts for the DC Fast Charging facilities. New utility transformers were installed at these sites which were sized large enough to also accommodate the DC Fast Chargers. The DC Fast Chargers could potentially add 340 kW of load at these locations (2 x 120kW for Tesla and 2 x 50 kW for the CHAdeMO / SAE Combo). The DC Fast Charging load is a substantial load and likely to impact transformer sizing and may necessitate other utility upgrades.

As these projects became operational the State of Connecticut started to ask questions about utility demand charges at these locations. Due to their load characteristics, DC Fast Charging stations are placed on commercial electric rates which are comprised of both energy and demand-based billing components. The demand charge component recovers the cost to utility of providing capacity to meet monthly peak demand. The electrical capacity (kW) of DC Fast Charging stations largely determines the demand level recorded by the utility meter which is ultimately used for billing purposes. Since these stations operate at their full capacity for only short periods of time, these stations need only be used by one EV customer to hit their peak demand. In other words, the demand component is expected to be largely independent the volume of kWh drawn by customers utilizing the charging stations. With low utilization rates in the early deployment stage, it is not inconceivable for the effective price per kWh (total electric bill divided by total kWh) to be well above $1/kWh. Therefore, an interim rate solution that is more closely correlated with the volume of customer usage is necessary to facilitate the operation of these stations in the early years when utilization is expected to be relatively low.

DC Fast Charging stations are being initially introduced into Connecticut in relatively small numbers. These stations are likely to experience utilization rates of only 2-5% during the initial months, and perhaps even years, of their deployment and operation. Recent data from the United States Department of Energy's EV Project confirmed this assumption and concluded that the DC Fast Chargers under study were only utilized at a rate of 5%. The average small commercial customer, on the other hand, which has a similar peak load, has an average utilization rate of 40%.

To address the State's policy objectives, Northeast Utilities has submitted a proposed interim approach to this issue while further investigation is underway. The proposed EV Rate Rider pilot is a critical bridge between this early stage momentum and long-term solutions to facilitate EV charging.

The EV Rate Rider pilot serves three inter-related goals: data collection, rate design research, and public policy support.

Data Collection

The nascent stage of any industry's evolution is characterized by uncertainty, particularly when it is sparked by new technology. DC Fast Charging stations are just beginning to emerge as a solution to serve the needs of the budding plug-in electric vehicle market. And as with any new technology, there will be a learning curve to figure out the optimal way to deploy the equipment, serve the market, manage the costs, and maximize the benefits. The Company's EV Rate Rider pilot program is a first step to learn what works best and what does not in order to facilitate DC Fast charging. The proposed pilot program will be used to collect data and help the Company better understand the usage and load profile of DC Fast Charging station locations. This information can then be used to assist the Connecticut Public Utilities Regulatory Authority (PURA) in this proceeding as it investigates new EV TOU rates and to help craft longer term rate strategies for electric vehicle charging.

Rate Design Research

As noted above, there is very little 'real-world' data or experience with the cost and usage characteristics of DC Fast Charging stations. The Company believes that by measuring and evaluating the demand and consumption of these stations on a time-of-day basis—while simultaneously offering per kWh rates in lieu of a demand rate—it can provide a meaningful support for PURA's evaluation of an electric vehicle time-of-day rate.

Public Policy Support

In February 2013, the Department of Energy and Environmental Protection (DEEP) issued the first-ever Comprehensive Energy Strategy for the State of Connecticut. This strategy included an assessment of the state's transportation sector and provided a spring-board for creating a cleaner and more efficient transportation system. More specifically, the strategy called for "[s]ufficient public electric vehicle charging stations (requiring an incremental 100 stations statewide) so that no one in the state need suffer from 'range anxiety'." Additionally, the strategy charged the state with developing recommendations for "rate design strategies [that] incentivize alternative fuel vehicles." As explained earlier, however, the technology characteristics and low utilization rates of DC Fast Charging stations will result in bills that are relatively high and could potentially dampen the market in the early stages of development. In order to mitigate this near term challenge and ensure that deployment of the technology is not stalled, the Company has designed the EV Rate Rider pilot proposed in this filing.

The Company's proposed EV Rate Rider is predicated on providing electric service to DC Fast Charging station customers under applicable, existing rate schedules, with modifications to demand charges for a limited term of service.

For a DC Fast Charging station that qualifies under the rider, electric service is provided in accordance with the rate schedule applicable to the entire load of that station as measured at the Company's electric service meter. The EV Rate Rider converts the demand charges of the applicable rate schedule to an equivalent per kWh charge for all kWh utilized by the customer during each billing period.

The Company believes that the proposed EV Rate Rider pilot will generate valuable research data, facilitate early deployment of DC Fast Charging technology, and provide a basis for evaluating a cost of service and time-of-day-rate for DC Fast Charging stations. We believe this pilot program will provide a foundation for long-term planning and rate design and proactively supports the state's policy goal of "developing an increasing network of alternative fuel infrastructure, [and] enabling a broader range of vehicle choice."

A
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