CRC Report No. SM-E-16

CRC SM-E-16 - Charging Plaza Load Analysis and Forecast

Final Report

May 2023

COORDINATING RESEARCH COUNCIL, INC.
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Exploring DC Fast Charging Load Profiles and Implications for Operators

Final Report - Project No. SM-E-16

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Prepared by Smart Electric Power Alliance

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Glossary

Term & Acronym	Definition
Direct current fast charging (DCFC)	Also commonly known as Level 3 charging, DCFC uses 3-phase AC electric circuits and delivers direct current (DC) to the vehicle. Typically power output ranges between 50-350 kW per dispenser.
Electric vehicle service providers (EVSPs)	EVSPs deliver end-to-end EV charging services for chargepoint operators and EV drivers. They are entities responsible for operating one or more networked or non-networked EVSE.
Electric vehicle supply equipment (EVSE)	The EV charging equipment, including cables, cords, conductors, connectors, couplers, enclosures, attachment plugs, power outlets, power electronics, transformer, switchgear, switches and controls, network interfaces, etc.
Level 1 Charging (L1)	The slowest EVSE unit, which uses common 120-volt AC outlets. Typical power output is 1kW-2kW.
Level 2 Charging (L2)	EVSE unit that uses 240-volt or 280-volt AC outlets and are common for home, workplace, and public charging. Typical power output is 7kW-19kW.
Load factor (LF)	A measurement charger usage. Load factor is the ratio of average load to the maximum load. It is calculated by taking the total electricity (kWh) used over a period of time, divided by the peak demand (kW) multiplied by the number of hours in the same period of time. $$\frac{Actual\ Electricity\ Usage\ (kWh)}{(Peak\ Demand\ (kW)\ x\ Hours\ in\ Period\ (h))}$$
Nameplate Capacity	The maximum rated output of an EVSE, usually expressed in kW. A station’s nameplate capacity is the summation of all the rated capacities of the individual chargers in the station.
Nameplate Load Factor (NLF)	A measurement of actual charger usage compared to the charger’s nameplate capacity. Nameplate load factor is the ratio of the average load to the maximum potential load at nameplate capacity. It is calculated by taking the total electricity (kWh) used over a period of time, divided by the rated power output of the charger unit (kW) multiplied by the number of hours in the same period of time. $$\frac{Actual\ Electricity\ Usage\ (kWh)}{(Rated\ Power\ Output\ of\ Unit\ (kW)\ x\ Hours\ in\ Period(h))}$$

National Electric Vehicle Infrastructure (NEVI)	Federal funding from the Bipartisan Infrastructure Law that provides funding to states to strategically deploy EV charging infrastructure and to establish an interconnected network to facilitate data collection, access, and reliability.
Original equipment manufacturers (OEMs)	Companies that manufacture a wide variety of components and hardware that are used in automotive vehicles. OEM is sometimes used interchangeably with automotive companies.
State of charge (SOC)	The level of charge of an electric battery relative to its capacity, often expressed as a percentage.
Time-of-use (ToU)	A method of structuring electricity rates based on the time of day in which the electricity is delivered to the customer. ToU rates vary among utility territories.

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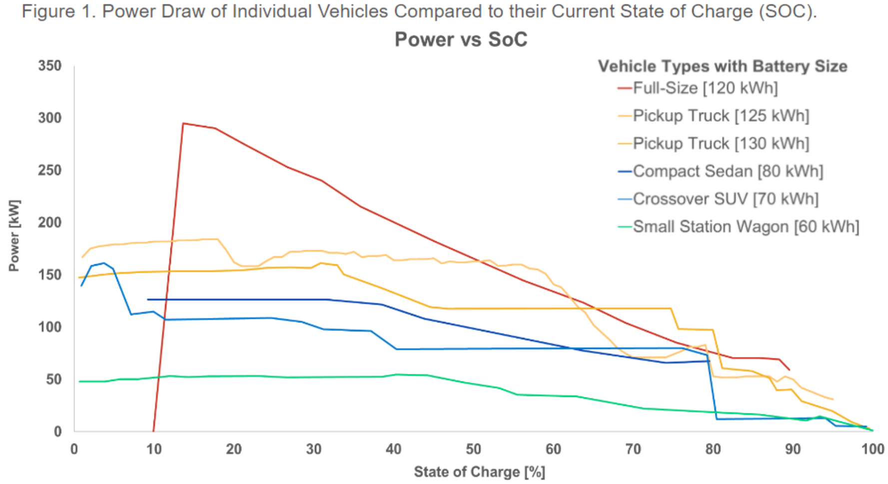
Executive Summary

To meet the energy needs of over 26 million electric vehicles (EVs) by 2030, U.S. utilities need to plan for hundreds of thousands DC fast charging (DCFC) ports. Many of these DCFC ports will be distributed among publicly available, retail charging stations, and utilities and site owners alike will benefit from modeling the utilization of these sites. However, predicting the load shape and peak demand at these multi-port charging stations is complicated, in large part due to the current, and predicted, diversity in charging characteristics among EVs. EV charging characteristics include differences for charge tapering, maximum kW limitations, bi-directional charging capabilities, and temperature dependency. Notably, nearly all of the currently available EV models use a tapered charging curve, which has significant implications for site planning, including estimating peak demand and meeting a site's capacity limits (Figure 1). With tapered charging curves, simply multiplying the max capacity of each port by the total number of ports will drastically overestimate the actual peak demand realized at retail charging depots.

Figure 1. Power Draw of Individual Vehicles Compared to their Current State of Charge (SOC).



In practice, charging station utilization and peak demand will be dictated by customer charging behaviors, site locations, seasonal changes in demand, and outlier events such as emergency evacuations. This report uses scenarios to illustrate how these variables influence peak demand, load profiles, and overall utility bills (Table 1). The authors recognize the limitation of using modeled scenarios rather than real-world data and suggest that future research be conducted to expand, test, and refine the observations presented in this work.

Table 1. Charging Scenario Descriptions.

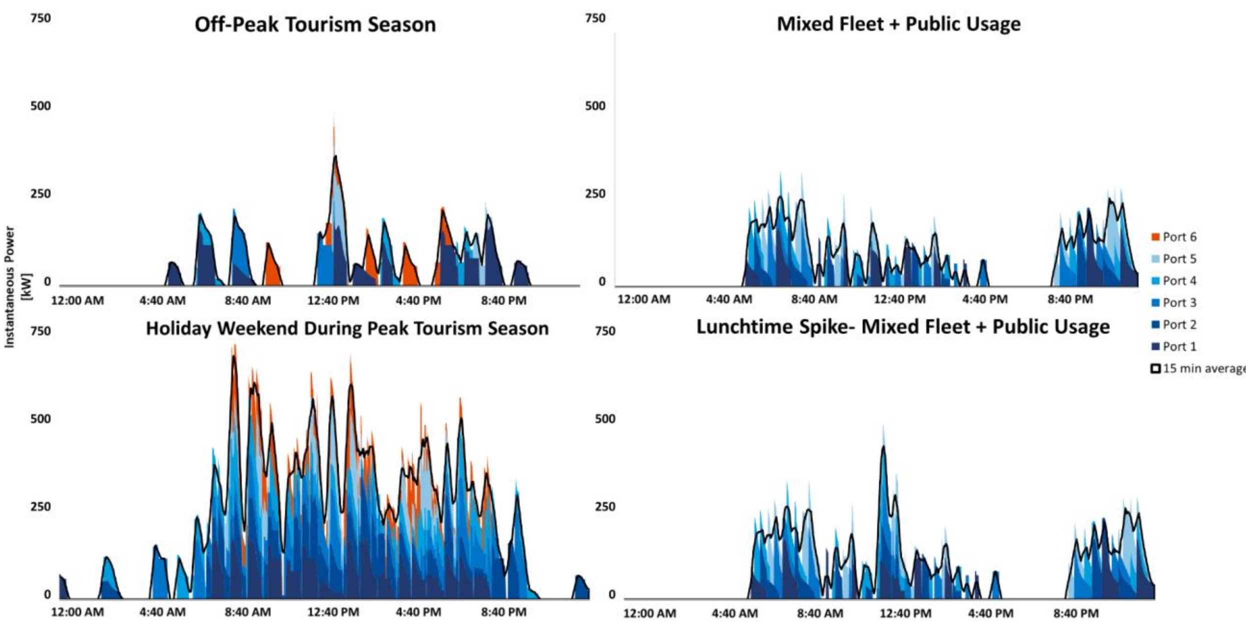
Scenario	Scenario Description	Sub Scenarios	Utilization Level
Residential Charging	Examines increased EV adoption and growing interest in equitable distribution of public charging. Sub scenarios explore how different locations (i.e. single-family vs multi-family) and different charging times impact site utilization and peak demand.	• Single-family Residential • Multi-family Residential Weekday Charging • Multi-family Residential Dedicated Weekend Charging Day	Medium

Mixed Usage with Fleet & Public Charging	Examines an emerging deployment model where fleet operators open their charging site to public usage during the day. Examines the impacts of co-locating use cases.	• Fleet Usage • Public Usage • Mixed Fleet + Public Usage	Low to Medium
Rural Highway Charging	Examines a use case with a growing focus with challenging underlying economics due to predicted low utilization. Sub scenarios explore how utilization changes throughout the year due to seasonal demand changes.	• Off-Peak Tourism Season • High Tourism Season • Holiday Weekend during Tourism Season	Low to Medium
Emergency Pre-evacuation	Examines the utilization of a shopping mall's DCFC chargers as a site for emergency pre-evacuation charging. Sub scenarios examine how limiting charge times can impact the peak demand.	• Retail Shopping Plaza • 15-Minute Limited Charging • 20-Minute Limited Charging • No Charging Time Limit	Very High

Key Takeaways

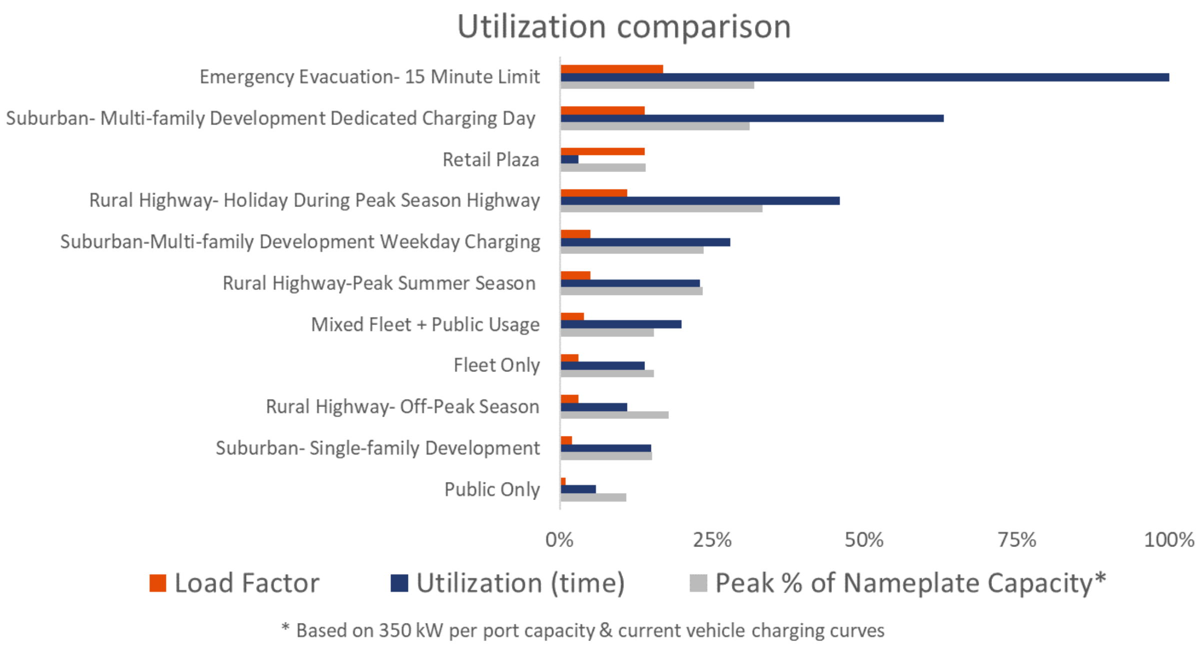
1) **Site utilization can vary widely** depending on the time of year, changes in customer charging behaviors, and if there are surges in site traffic due to nearby events. Figure 2 depicts how simple changes, such as moving from an off-peak tourism season to a high traffic tourism season and introducing a lunchtime spike in customer demand, could greatly influence a site's utilization and load profile.

Figure 2. Results from the Rural and Mixed Fleet + Public Usage Scenarios.



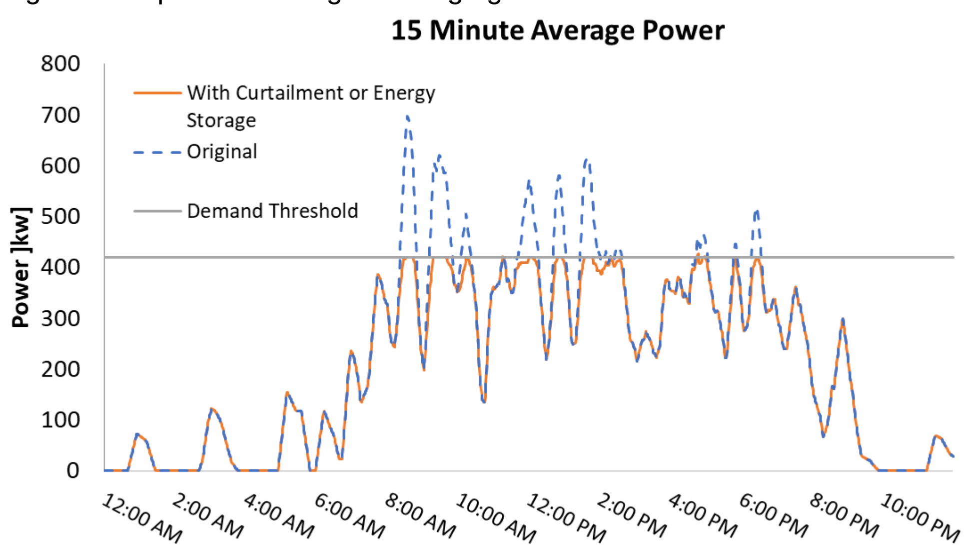
2) **Station level nameplate load factors and ratio of peak demand to nameplate capacity are low and are expected to remain low** due to the tapered charge curve of nearly all currently available EV models (Figure 3). Even as vehicle charging curves improve and are able to accept higher peak powers, as long as power remains a function of state of charge, we can expect charging stations to experience peak loads lower than the nameplate capacity rating.

Figure 3. Summarized Scenario Results



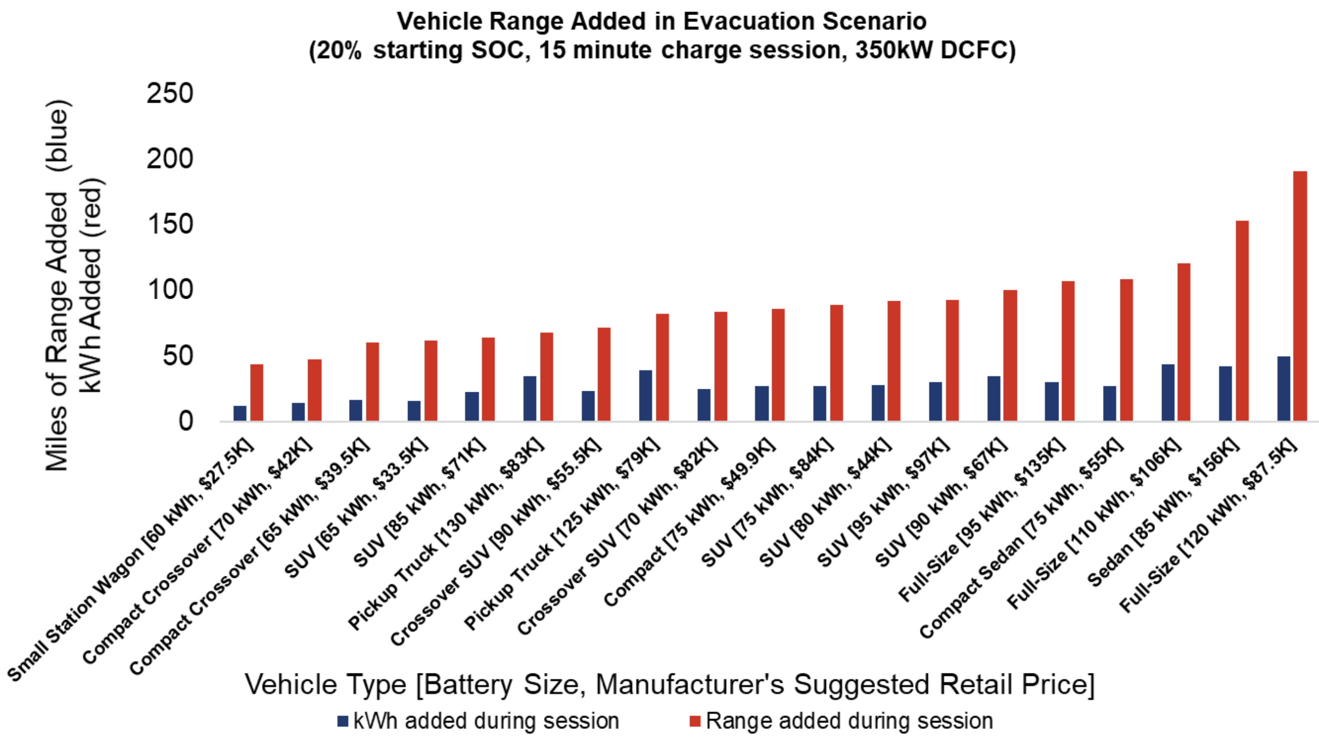
3) **Managed charging strategies, including curtailment, staggered charging, and use of energy storage, can be beneficial** to site owners and DCFC operators seeking to lower peak demand (Figure 4). Site owners in territories with high demand charges can especially benefit from managed charging strategies.

Figure 4. Impact of Managed Charging Scenarios.



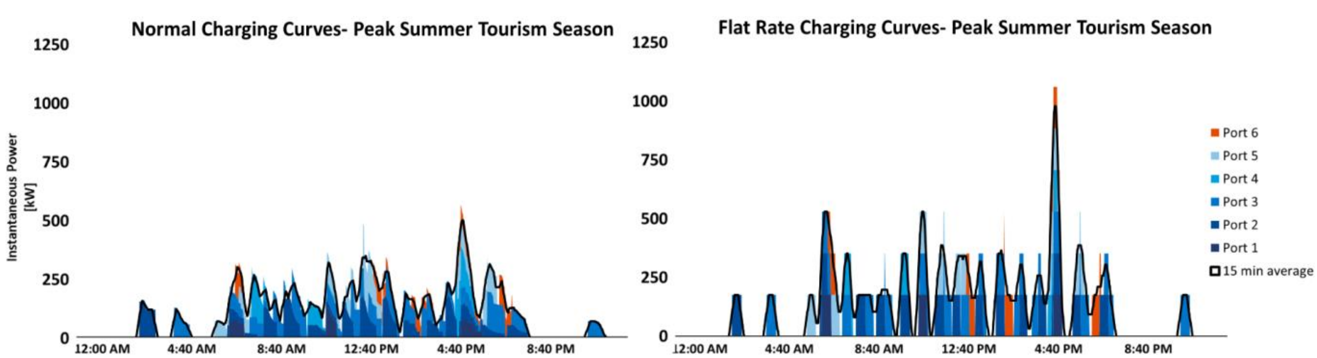
4) **Site utilization planning can extend beyond utilities and site owners to regulators, government agencies, and emergency services**. Public charging stations will replace traditional petroleum services and emergency services will need to incorporate EV charging into their plans. Modeling can help regulators and government agencies test the efficacy of their programs and theorize on secondary effects of their policies.

Figure 5. Impact of 15-minute Charging Sessions on Vehicle Range.



5) **More collaboration needs to occur among industry partners, utilities, and DCFC site owners**. Access to real-world data on load shapes, nameplate load factors, and utilization data will be extremely valuable to utilities and site owners alike. Utilities and site owners can currently utilize the charge curves they have today, and if original equipment manufacturers (OEMs) can predict the future of charging, e.g. expanding beyond 150-200 kW charge limits or using flat rate charging curves, they should inform utilities as early as possible. Changes to existing charging capabilities will have significant impacts for utility planning (Figure 6).

Figure 6. Effects of Different Charging Curves on Load Profiles.



Background

In recent years, electric vehicles have gained popularity, support, and interest. As of September 2022, the total number of electric vehicles (EVs) in the U.S. surpassed a previous record of over 3 million on the road.[1] This growth in the EV stock has been supported by increasing EV sales, which reached 6% market share in Q3 2022.[2] Manufacturers are working to meet this increased demand by introducing a suite of new plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs). By the end of 2024, original equipment manufacturers (OEMs) are expected to introduce dozens of new vehicles,[3] adding to the over 65 PHEVs[4] and BEVs[5] currently available in the United States. As more OEMs offer a variety of EV options, more customers are expected to transition over to EVs over the next decade. Projections from the Edison Electric Institute (EEI) indicate that by 2030, there will be over 26 million EVs on the road.[6]

To meet the energy needs of 26 million EVs, utilities need to plan for hundreds of thousands of DC fast charging (DCFC) ports.[7] DCFC charging has more variable power demands and has a greater potential impact on the utility system than Level 2 (L2) charging. DCFC units can deliver between 25-350+ kW depending on the EV's ability to accept the energy, with many EVs accepting a maximum rate of 50 kW to 300 kW.[8] These charging speeds vary greatly depending on the vehicle make and model due to each OEM taking a different approach on their vehicle's charging capabilities. Defining characteristics of charge curves can include charge tapering, maximum kW charge limits, bi-directional charging capabilities, temperature dependency, and

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[1] Veloz. (2022, October 28). *EV Market Report.* Retrieved January 3, 2023, from https://www.veloz.org/ev-market-report/

[2] Johnson, P. (2022, November 14). *Here's how US electric vehicle sales by maker and EV model through Q3 2022 compare*. Electrek. Retrieved January 3, 2023, from https://electrek.co/2022/10/18/us-electric-vehicle-sales-by-maker-and-ev-model-through-q3-2022/

[3] Bartlett, J. S., & Preston, B. (2022, September 9). *Automakers are adding electric vehicles to lineups*. Consumer Reports. Retrieved January 3, 2023, from https://www.consumerreports.org/hybrids-evs/why-electric-cars-may-soon-flood-the-us-market-a9006292675/

[4] EVAdoption. (2022, September 4). *PHEV models currently available in the US.* Retrieved January 3, 2023, from https://evadoption.com/ev-models/available-phevs/

[5] EVAdoption. (2022, September 4). *Bev models currently available in the US.* Retrieved January 3, 2023, from https://evadoption.com/ev-models/bev-models-currently-available-in-the-us/

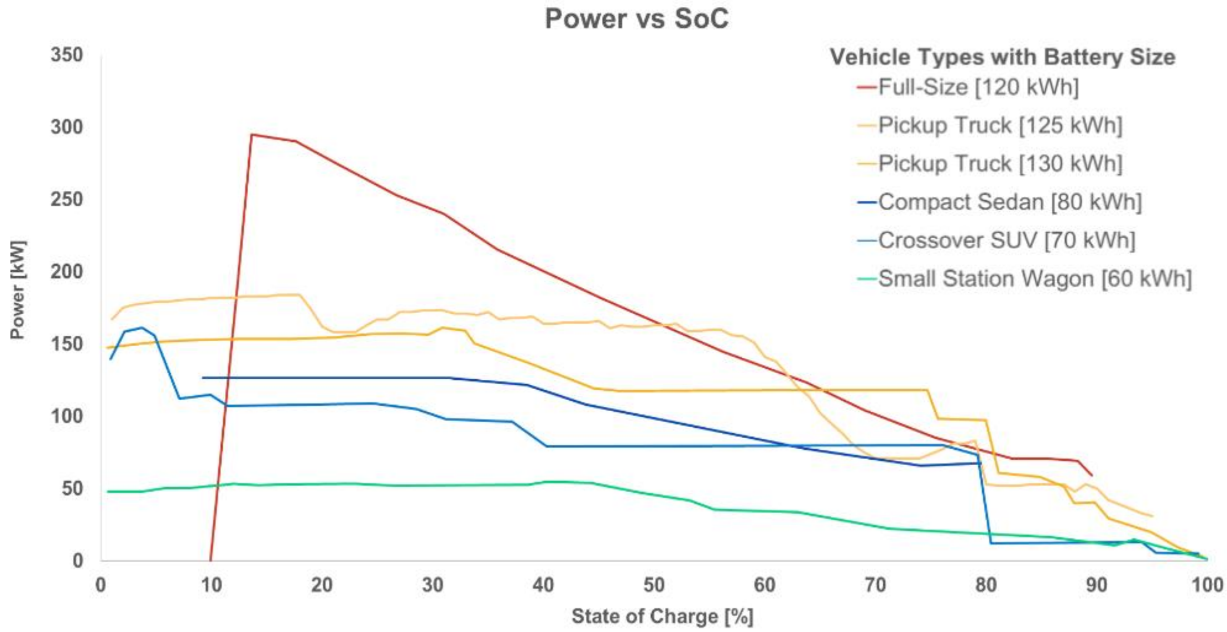
[6] Satterfield, C., Schefter, K., & Edison Electric Intitute. (2022). *Electric Vehicle Sales and the Charging Infrastructure Required Through 2030*. EEI. Retrieved January 3, 2023, from https://www.eei.org/-/media/Project/EEI/Documents/Issues-and-Policy/Electric-Transportation/EV-Forecast--Infrastructure-Report.pdf

[7] EEI. (2022, June 20). *EEI Projects 26.4 Million Electric Vehicles Will Be on U.S. Roads in 2030*. Retrieved January 3, 2023, from https://www.eei.org/News/news/All/eei-projects-26-million-electric-vehicles-will-be-on-us-roads-in-2030#:~:text=The%20number%20of%20EVs%20on,on%20U.S.%20roads%20in%202030.

[8] FreeWireTech. (2020, July 1). *What's the Difference Between EV Charging Levels?* Retrieved January 13, 2023, from https://freewiretech.com/difference-between-ev-charging-levels/#:~:text=DCFCs%20are%20designed%20to%20fill,by%20the%20EV%20acceptance%20rate.

the overall charge profile as a function of battery state of charge. Figure 1 illustrates examples of charging curves from six manufacturers.

Figure 1. Power Draw of Individual Vehicles Compared to Their State of Charge.



If the diversity of charging characteristics continues to expand to accommodate different price points and customer preferences, predicting the load shape and peak demand at multi-port charging stations becomes more complicated. Simply multiplying the max capacity of each port by the total number of ports will drastically overestimate the actual peak demand realized at charging depots because it does not take into account the vehicle side of the equation (vehicle model, starting SOC, etc.). Setting a site's demand based on the max capacity of the ports will cause many sites to be rated in the 1-10 MW category,[9] when in actuality their peak demand may remain in the 700-800 kW range for the next several years. Traditionally utilities have planned sites based on the customer's rated nameplate capacity. However, some question if this approach will cause near-term overbuilding of utility generation assets to meet peaks that would rarely, if ever, occur. Rating sites based on nameplate capacity causes issues when distribution systems have limited capacity to allow for future EV sites and causes utilities to have to build new capacity that may be unneeded in the near-term timeframe. In the near-term, with the current charging capabilities of EVs, some stations will have a peak demand far lower than their nameplate capacity.

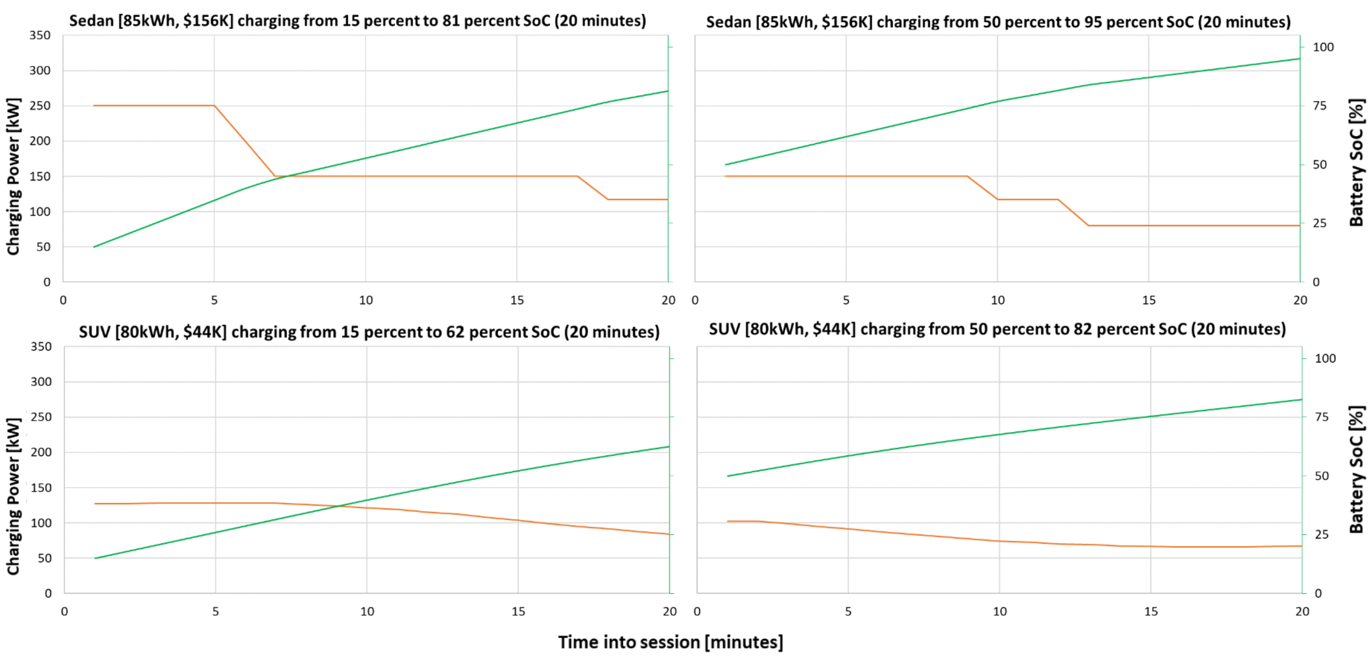
To better understand a site's actual utilization and load factor, planners can study how customers would potentially use their site (or utilize existing site data from electric vehicle service providers (EVSPs) and OEMs) and model the impacts of those charging sessions. EVSPs and OEMs can give utilities information on DCFC load shapes, load factors, site utilization patterns, and customer charging habits. This information can help facilitate

[9] Assuming a 10-port site with 350 kW DCFC, this site would be rated for a peak demand of 3.5 MW.

interconnection requests and help utilities plan for more realistic site peaks, load profiles, and energy demand.

Customer charging behaviors, customer charging preferences, and individual vehicle charging characteristics all greatly impact the load shape of charging plazas. For example, some EV owners use public DC fast charging as their primary means of charging and charge from a low starting state of charge (SOC) of 20% to a high ending SOC of 95%, while others use DCFC opportunistically to ‘top up’ and thus charge only the upper capacity of their batteries. These two scenarios greatly impact the charging rates. Charging at low SOC uses more power than charging at a high SOC, a characteristic common to luxury and economic EVs alike (Figure 2). Understanding how these variables impact overall load shape and coincident peak demand will inform electricity costs and retail pricing strategies.

Figure 2. Charging Power as Directed by Starting State of Charge for a High-end Sedan & Mid-market SUV. *Note. Orange represents power as a function of time. Green represents Battery SOC as a function of time.*



From a modeling perspective, there is uncertainty around charging locations and behaviors. Until more sites are installed and more data is collected on customer charging habits and behaviors, modelers have to make many assumptions on when, where, and how often customers will be using DCFC ports. In this report, we have created four scenarios to illustrate how differences in charging behaviors and site locations influence peak demand, load profiles, and overall utility bills.[10] These scenarios utilize a simplified version of load profiling that is not indicative of actual load profiles, but rather illustrate the site’s potential time based utilization over a 24-hour period and the resulting nameplate load factor. This report analyzes the different

[10] See Appendix A for the full list of assumptions and data used for scenarios.

scenarios using nameplate load factor,[11] a variation of load factor, to better understand the relationship between a DCFC's rated capacity and its expected usage.

Approach to Modeling DCFC Site Utilization

Through four scenarios, this report explores how the growing diversity of vehicle charging capabilities and customer charging behaviors impact load shape, peak demand, and ultimately the site host utility bill. The scenarios are used to explore how different approaches to optimizing operational costs through on-site storage, curtailment, and throttling will influence peak demand and host costs. The scenarios utilize an excel model to explore site level utilization and estimate the frequency and duration of the charging station reaching its nameplate capacity. The results show the feasibility and estimated cost-effectiveness of optimization approaches and give insight into how modeling efforts can inform next steps in system design and pricing strategies.

Each scenario generates results that can be used to characterize the relative operational costs of different charging stations based on the defined scenarios. Results from the scenario analysis provide guidance on how a retail charging plaza can evolve to meet increased utilization or continue to see low utilization and load. These models show the relative viability of rural and remote DCFC stations and provide information on the potential need for supportive subsidies or other state, local, or federal incentives.

Scenario modeling involves analyzing the aggregated patterns of a charging station over a 24-hour period. Several steps are taken to create a station's 24-hour load profile.

1. Create a charging scenario that could occur at this charging station. Charging scenarios include those that are common today (urban/metro charging depots and supercharger stations), those that are heavily influenced by geography (rural vs urban and workplace vs near residential), and those that may become more common in the future (shared public-private charging lots, highway charging corridors, pre-evacuation charging events, etc.). Charging scenarios will influence:
    a. *Customer charging behaviors*: Charging behaviors include how often customers use a charging station within a set time, the times of day they are most likely to use the charging station, and the duration of charger use. Customer charging behaviors will influence how closely in time charging sessions will occur on each port, the rate of utilization of the charging station, and the overall peak demand of the station.

    b. *Customer access to the charging station:* Depending on the access limits to the charging station, some customer classes may have limits on when they can charge. For instance, a private charging station may only allow the public to charge in the

[11] Time based utilization [min/min] = Time in use for a given 24 hours / 24 hours
Nameplate load factor [kWh/kWh] = Energy Delivered in 24-hour period / (Station nameplate capacity * 24 hours). Time based utilization and nameplate load factor are equal when all vehicle charging happens at the charging station nameplate capacity.

middle of the day or a national park may only allow overnight charging for people with camping permits.

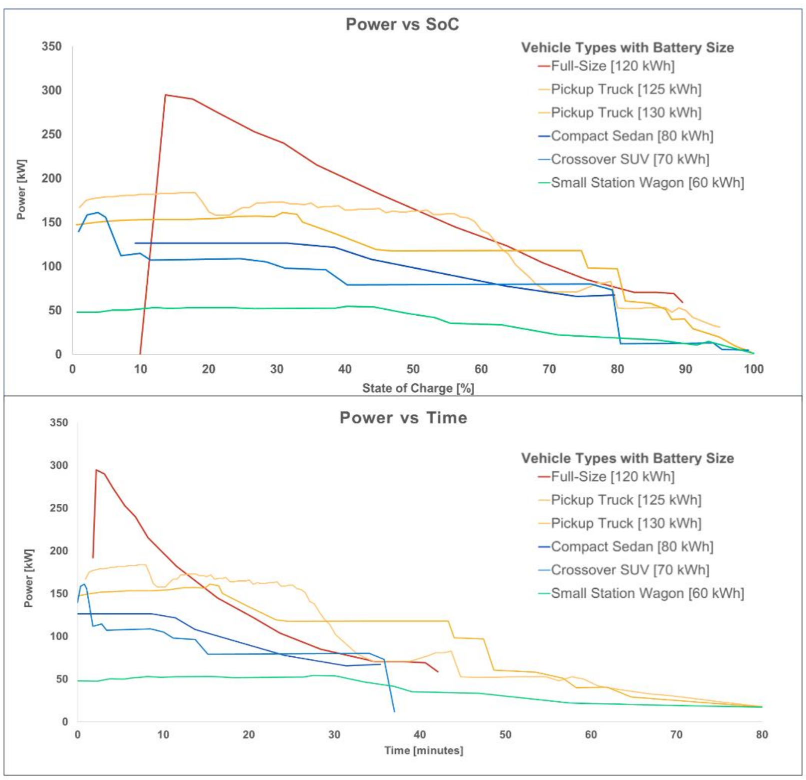
c. *Customer vehicle type:* Depending on the location of the charging station and the primary customer class using the station, different scenarios will analyze a different range of vehicles. For instance, urban populations may favor lighter sedans while more rural populations may favor larger SUVs and trucks.

2. Create a series of individual charging sessions. Individual charging sessions consist of several assumptions:
   a. *Time of day [hr: min]:* Based on a customer's behavior patterns and/or charging habits, select a time of day for the charging session to occur.

   b. *Starting SOC [%]:* Based on a customer's behavior patterns and/or charging habits, the starting SOC is randomized within a set range. E.g. 15-35% for low starting SOC compared to 35-60% for high starting SOC.

   c. *Amount of time for the charging session* ***or*** *a set ending SOC [minutes]:* Charging sessions are influenced by either the amount of charging time allocated to the session or by a desired ending SOC. Most publicly available data represents charging through power vs. state of charge. However, utilities and customers view charging in terms of time. Thus, to calculate utility bills, the model uses a power vs. time analysis (Figure 3).

Figure 3. Graphical Representation of Power vs. SOC Compared to Power vs Time for Six Representative Vehicles.



d. *Vehicle Model:* Charging sessions are heavily influenced by the specific model of the car charging (Figure 1/ Figure 36). Individual charging sessions will require the vehicle's model in order to utilize the correct charging curve to produce the charging load profile.

3. Aggregate the series of individual charging sessions to create a 24-hour load profile for the charging station. Individual charging sessions are aggregated both at the charging port level (to analyze how many charge sessions a day a single port handles) and aggregated across ports (to analyze how many charge sessions overlap throughout the day). The aggregated series of charging sessions produce the site's overall load profile that can then be used to produce a site host's monthly utility bill, site utilization, and nameplate load factor. See the Results section for examples of scenario load profiles.

4. Once a 24-hour load profile has been assembled, further analysis is conducted on the monthly utility bill & peak demand reduction strategies. Select utility tariffs to evaluate the site's utilization and monthly utility bill under different pricing mechanisms. Utility EV charging tariffs can differ widely among different jurisdictions. Different pricing mechanisms include pricing variations for demand, volumetric, and fixed charges. Table 1 includes examples of existing utility tariffs and their different rate structures.

Table 1. Existing Utility Tariffs for Public EV Charging.

Tariff	Demand Pricing Mechanism	Volumetric Pricing	Fixed Charges
EV Tariff 1	None	ToU Delivery ToU Generation	Medium
EV Tariff 2	Subscription Blocks	ToU Delivery ToU Generation	None
EV Tariff 3	None	ToU Bundled	Low
EV Tariff 4	Demand based tiered kWh pricing	ToU Generation	High
General Commercial Tariff 1	Demand Charge	ToU Delivery Flat Generation	High
General Commercial Tariff 2	Demand based tiered kWh pricing + Demand charge	Tiered volumetric	Low

5. Further site analysis can be done by examining different peak demand reduction and other optimization strategies including: temporary curtailing EV charging, using storage to reduce peak demand, throttling down charging speeds, evaluating different DCFC output capacities, and modeling constant power vehicle charging curves.

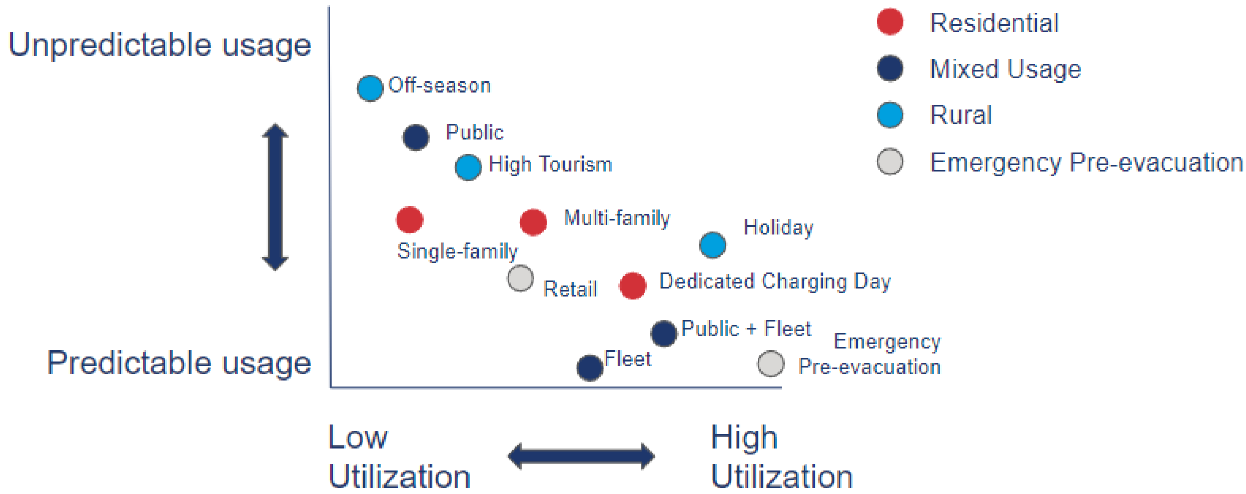
Results

While there are an infinite number of potential charging scenarios, this report covers four scenarios that analyze different archetypes in charging behaviors. Each scenario varies in terms of site location, utilization, and customer access. Each scenario examines a 24-hour charging period and how that utilization can predict a site's monthly usage.

Table 2. Charging Scenario Descriptions.

Scenario	Scenario Description	Sub Scenarios	Utilization Level
Residential Charging	Examines increased EV adoption and growing interest in equitable distribution of public charging. Sub scenarios explore how different locations (i.e. single-family vs multi-family) and different charging times impact site utilization and peak demand.	• Single-family Residential • Multi-family Residential Weekday Charging • Multi-family Residential Dedicated Weekend Charging Day	Medium
Mixed Usage with Fleet & Public Charging	Examines an emerging deployment model where fleet operators open their charging site to public usage during the day. Examines the impacts of co-locating use cases.	• Fleet Usage • Public Usage • Mixed Fleet + Public Usage	Low to Medium
Rural Highway Charging	Examines a use case with a growing focus with challenging underlying economics due to predicted low utilization. Sub scenarios explore how utilization changes throughout the year due to seasonal demand changes.	• Off-Peak Tourism Season • High Tourism Season • Holiday Weekend during Tourism Season	Low to Medium
Emergency Pre-evacuation	Examines the utilization of a shopping mall's DCFC chargers as a site for emergency pre-evacuation charging. Sub scenarios examine how limiting charge times can impact the peak demand.	• Retail Shopping Plaza • 15-Minute Limited Charging • 20-Minute Limited Charging • No Charging Limit	Very High

Figure 4. Sub Scenario Utilization Parameters [Illustrative].



Beyond the four scenarios, there are additional sections on peak demand reduction and the effects of utilizing flat vehicle agnostic charging curves instead of existing vehicle specific charging curves (e.g. all vehicles charge from 0%-100% SOC at constant power). These additional scenarios examine how optimization strategies and future battery technology improvements impact peak load and ultimately a site owner's monthly bill.

Residential Charging

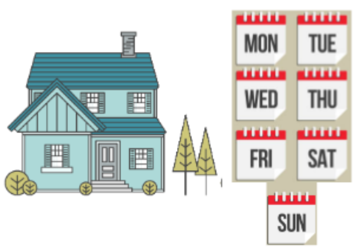
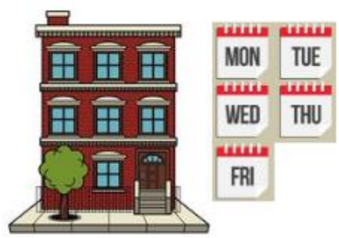
Public charging near residential zones is assumed to be primarily used by residents without access to at-home charging. The rates of usage vary depending on whether the zone contains single-family or multi-family homes. Single family homes have easier access to L2 charging while multi-family homes have limited or no access to L2 charging. The three residential charging sub scenarios examine variations in charging patterns between single-family and multi-family sites and variations between weekday and weekend charging for multi-family sites.

The residential charging scenarios assume that in the near term, residents who do not currently utilize home charging will charge around the times when they used to use gasoline stations (See Appendix A for further details). This assumption means that the majority of residents charge between 10 am to 7 pm. In actuality, EV charging is predicted to be different from traditional gasoline fueling behaviors; however, gasoline fueling behavior is a starting point to examine customer habits and a possible future for DCFC usage. As more consumers switch over to EVs, further differences in EV charging and gasoline fueling will arise. Differences in the two habits may include shifting charging times to account for longer charging times compared to fueling times and include reducing the frequency of public charging due to customers using at home and workplace charging as their primary means of charging.

This first scenario examines how residents may use public fast charging to either supplement their at-home level 2 charging or to act in place of home charging. In this exercise residential charging is divided into two main categories: single-family residential and multi-family residential. To better examine different charging habits of multi-family residents, the multi-family category is further divided into weekday charging and a dedicated charging day. Single-family residents are not expected to have a dedicated charging day given that many of them have at-home charging access and primarily use public chargers to top-off their vehicles as needed.

For residents with a weekday charging habit, they may more often top-off their vehicle than residents who choose to only charge once a week on a dedicated charging day. For residents with a dedicated charging day, they will typically pick their off-times from work and the majority of residents are expected to select a weekend day to be a dedicated charging day. If many residents dedicate their charging to a certain day a week, DCFC site owners should expect to see a higher number of residents charging on those days and anticipate that these will likely influence the site's peak demand. To gain a fuller understanding of multi-family charging, site planners should combine both the weekday charging and dedicated charging day patterns to see how a variety of charging habits influence the site.

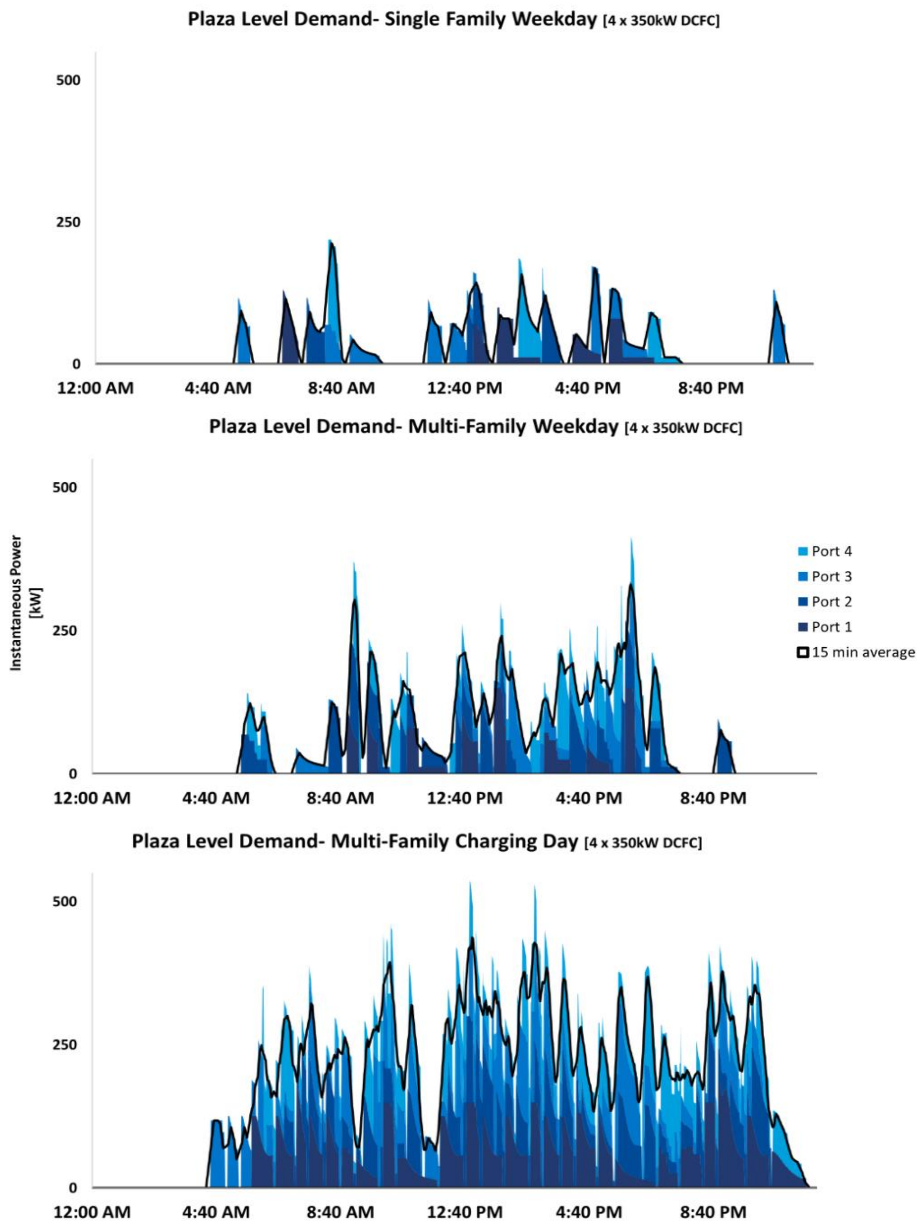
Table 3. Residential Sub Scenario Descriptions.

Residential Charging		
Single Family Residential-Weekday & Weekend Charging	**Multi-Family Residential-Weekday Charging**	**Multi-Family Residential-Dedicated Charging Day**
Scenario Description: A sprawling **single-family residential** neighborhood in California has installed four DCFC at its community center to benefit residents with EVs, about **half of which do not have a charger at home**. Residents are allowed to charge any day of the week.	**Scenario Description:** A sprawling **multi-family residential** neighborhood in California has installed four DCFC at its community center to benefit residents with EVs, **none of whom have dedicated L2 chargers where they park.** Residents are allowed to charge any day of the week.	**Scenario Description:** A subset of the multi-family residents prefers charging solely on Sunday. None of these residents have dedicated L2 charging where they park and primarily use the 4 DCFC at the local community center.
Site Location & Access: 	**Site Location & Access:** 	**Site Location & Access:** 
Utilization: Low utilization; daytime charging	**Utilization:** Medium utilization; daytime charging	**Utilization:** Medium utilization; weekend charging
Defining Characteristics: • Low utilization due to half the residents having at home charging	**Defining Characteristics:** • Greater utilization than a single-family neighborhood due to the lack of access to home charging • Potentially large variability in utilization based on residents driving habits	**Defining Characteristics:** • Potentially large variability in load shape on weekends vs. weekdays • Potential for site owners to restrict the site access so that it is open to the public and residents during the week and only to residents during the weekends.

All of the residential scenarios are modeled using the same base assumptions: the mix of vehicles are the same for single-family and multi-family residents, the same number of vehicles in the area, a baseline of charging based on traditional fueling habits, and the same starting and ending ranges for the batteries' SOCs. The main difference between the single-family and multi-family scenarios is that 54% of single-family residents use the DCFC as their primary charger and 100% of the multi-family residents do so.

Peak demand is heavily dependent on customer habits, and small behavioral changes can impact the size and time of day of peak demand. By doubling the number of people using the DCFC the peak shifts from the morning to the evening for single-family and multi-family charging respectively, due in part to the increased randomness of people using the site (Figure 5). While the multi-family weekday scenario has more than double the number of residents using the site compared to the single-family scenario, the peak demand and monthly consumption habits are not doubled. Rather, the peak only increases 1.5 times from 213 kW to 331 kW (Figure 5, Table 4).

Figure 5. Load Profile for Residential Charging. [Station Nameplate Capacity of 1,400 kW].



The multi-family scenario is more complex than the single-family scenario given that it accounts for nearly double the population of residents using the chargers and includes residents who do not have any option to charge at home. The charging behavior of some of the residents will change because of increased demand. Many may find that having a dedicated charging day is more convenient than waiting for a charger during the week when they have less time to wait for a charger to become available. The dedicated charging scenario models some of the potential impacts of residents opting for a dedicated charging day. These vehicles are typically more drained than their weekday counterparts and will start at lower SOCs. The vehicles will charge to nearly full SOCs to account for their lower charging frequency, and the site will be serving more vehicles back-to-back rather than sporadically as in the case of the weekday charging.

In contrast to the weekday multi-family charging, the dedicated charging day utilizes all four DCFC for a significant part of the day (Table 4). By using all four DCFC at once, the site's peak increased by approximately 110 kW compared to the multi-family weekday (Table 4). The two multi-family scenarios highlight the need for fleet operators to plan for different charging behaviors that may occur at their site and subsequently influence the site's peak demand and monthly energy consumption.

Table 4. Utilization for Residential Charging.

	Single Family	Multi-family Weekday (22 days per month)	Multi-family Dedicated Day (8 days per month)	Unit
Peak Demand	210	330	440	kW
Monthly Energy Consumption	24,000	34,600	36,400	kWh/month
Utilization in a 24-hour time period	15%	28%	63%	min/ min
Nameplate load factor	2%	5%	14%	kW-min/ kW-min
Peak 15-minute demand / Nameplate capacity	15%	24%	31%	kW/kW

Due to higher consumption, the average cost of charging for multi-family residents is lower compared to that of single-family residents (Figure 6). The difference in the average cost of charging between the two residential types varies depending on the service territory and rate structure. Utility rates with high demand charges, such as the General Commercial Tariffs 1 and 2, are especially impacted by changes in customer behaviors that ultimately change the peak demand (Figure 7). Between the single-family and multi-family scenarios, the demand charge increases from $4,000 for single-family to over $8,100 for multi-family. However, General Commercial Tariff 1's cost per mile drastically decreases for multi-family because the multi-family scenario has a monthly consumption of over 70,000 kWh compared to the single-family scenario of 24,000 kWh. This tripling of energy consumption spreads the demand rate among more transactions and helps reduce General Commercial Tariff 1's cost per mile from 10 cents to 7 cents. If a single day of atypical energy demand sets the system peak for a site with generally low energy consumption, the demand charges can significantly impact the cost per mile of charging and adversely affect the site's economics.

Notably, the multi-family dedicated charging day, which sets the peak demand, utilizes only 31% of the nameplate capacity of the site (Table 4). This indicates that utilizing 350 kW chargers may be overbuilding the capacity needs of the site. It also shows that for site owners in territories with high demand charges it will be difficult for the site to utilize its peak capacity unless the site owner can ensure high monthly energy consumption.

Figure 6. Cost per mile Non-Home Residential Charging.

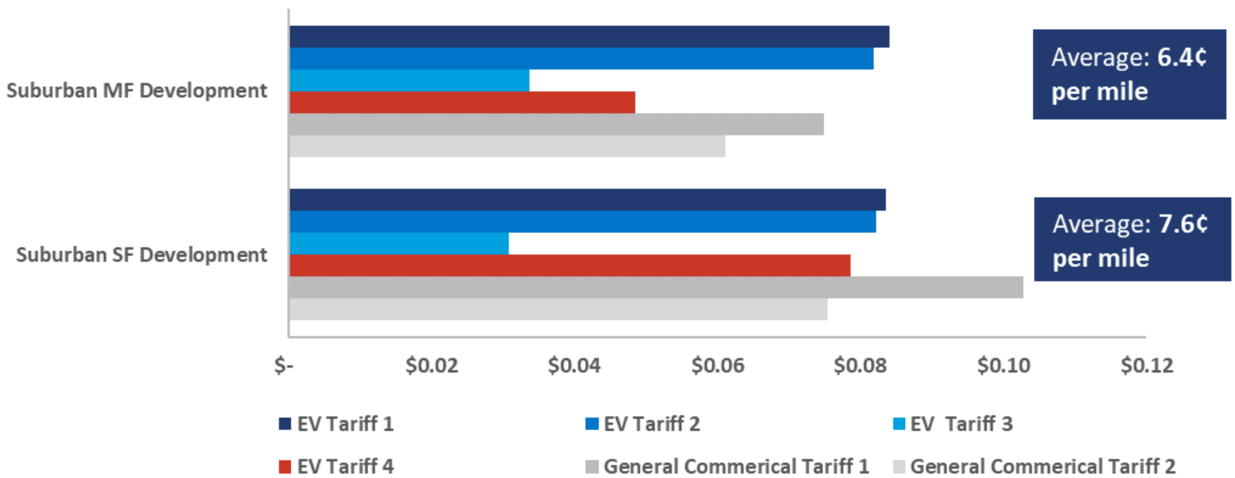
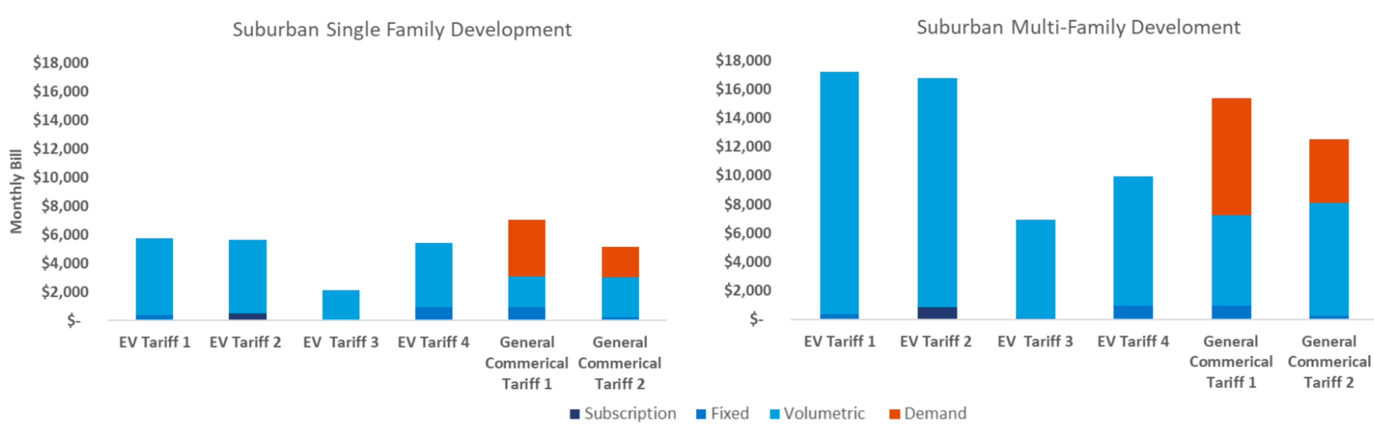


Figure 7. Site Host Bill Comparison Based on Location near a Single Family or Multi-family Development.



Mixed Usage Fleet & Public Charging

Fleets are expected to be an early driver in the transition of vehicles from ICE to EV and significant charging infrastructure will be needed to meet demand. In contrast to residential customers who are not expected to own any DCFC infrastructure, many fleet operators are expected to own DCFC. Having DCFC on-site allows fleet operators to quickly charge fleet vehicles in-between runs, to have fewer chargers to vehicles (e.g. 4 chargers for 20+ vehicles), and to allow fleet operators more flexibility in how they plan vehicle charging. While some larger fleets are expected to keep their chargers entirely private, some smaller fleets[12] have begun opening their chargers up to the public to increase the utilization of their chargers and to help reduce operational costs and increase public access to charging.

Mixed usage for fleet DCFC can appear in several different configurations: 24/7 public access, restricted public access to select customers such as employees or local residents, or limited time access such as weekdays between 9 am to 5 pm. For smaller fleets that may not hire a dedicated employee to manage the charging site, it is easier to limit public access to daytime hours (e.g. 8 am to 5 pm) and to charge their fleets overnight and during the early morning hours. For fleets that do not have a one-to-one ratio of chargers to vehicles, an important component of fleet management and operation will be having an employee(s) move vehicles on and off chargers after each charging session. While fleets can use optimization softwares to improve their charger usage, operators will still need to plan for moving vehicles on and off chargers at the optimum times and to not allow vehicles to monopolize the charger.

Fleet charging optimization will also include utilizing managed charging strategies, including charging during favorable time-of-use (ToU) times, designing charging schedules to harmonize with a vehicle's delivery schedule, and using optimization software that can dynamically adjust charging speeds, charging schedules, and set charging caps to prevent exceeding the site's designated demand limit. Managed charging strategies are important for charging costs associated with demand charges and peak-ToU pricing rates. Many fleet operators are expected to use a combination of several strategies to avoid unwanted charges.

In this scenario, a small fleet manager has opened up its 5 DCFC ports to the public between 9 am and 5 pm and charges its fleet between 8 pm and 9 am to avoid charging during peak hours. The fleet operator is on a commercial EV rate and employs several strategies to reduce its monthly bill. The fleet returns for the day around 5 pm and five of the returning vehicles immediately plug into the DCFC. The fleet operator uses optimization software to ensure that the vehicles will not start charging until after 8 pm and are set to begin charging on a staggered schedule. This is a small fleet business, and there are limited staff to switch out the cars. The fleet operator plans to charge two vehicles per port between 8 pm and midnight and two per port between 6 am and 9 am. During the day, fleet vehicles will occasionally top-off as needed when they return to the warehouse between shifts. This schedule allows the operator to reduce the employee burden for managing the vehicles, to effectively charge the vehicles outside of their working schedules, and to avoid charging during the system's peak from 5 pm to 8 pm. To

[12] Revel. Interview by SEPA. Q3 2022.

reduce operating costs and increase the utilization of the chargers, the fleet operator also opens the chargers to the public during its normal business hours, from 9 am to 5 pm and does not manage who uses the chargers during those hours.

Table 5. Mixed Usage Fleet & Public Charging Sub Scenario Descriptions.

Mixed Usage Fleet & Public Charging		
Light-duty Fleet Usage Only	**Public Access Only**	**Combined Light-duty & Public Usage**
Scenario Description: A private 20-vehicle delivery fleet has installed 5 DCFC at its parking lot in a light-industrial zoning area near a suburban zone. The private fleet company primarily charges its fleet overnight and has decided to open the lot to the public for daytime access.	**Scenario Description:** The private fleet has registered its chargers on a charger map platform, such as PlugShare or Google Maps, so that the public is aware of the chargers. An industrial center located 5 miles from a residential zone that contains both single-family and multi-family homes is expected to serve their daytime charging needs.	**Scenario Description:** The private fleet has registered its chargers on a charger map platform, such as PlugShare or Google Maps, so that the public is aware of the chargers and will use them between 8 am & 5 pm. The fleet schedules the majority of its own charging for between 9 pm and 8 am.
Site Location & Access: 	**Site Location & Access:** 	**Site Location & Access:** 
Utilization: Medium utilization; overnight charging	**Utilization:** Low utilization; daytime charging	**Utilization:** Medium utilization; daytime & overnight usage
Defining Characteristics: • Good use case for managed charging due to charging predictability • Will naturally have periods of low and high utilization that map to business needs • Public charging can fill in the 'gaps'	**Defining Characteristics:** • Typically have low utilization today and uncertain utilization in the future • Not typically responsive to price signals for curtailment	**Defining Characteristics:** • Fleet and Public are complimentary load shapes that can increase overall asset utilization

Due to the fleet operators' management of the chargers, the public and fleet usage complement each other and increase the site's overall utilization (Figure 8, Table 6). Fleet charging occurs during the nighttime and early morning hours with small demands during the middle of the day when the vehicles return to the warehouse and top-off. During the fleet's primary charging hours, the fleet manager maintains a lower peak by allowing one to two vehicles to charge at a time and overlaps the starting period of one vehicle to correspond with the ending period of another to decrease the total power draw (Figure 9). Figure 9 shows the benefits of staggering the charging to help reduce site peaks. For three charge sessions during the evening charging period, the site operator is able to maintain the site peak at approximately 220 kW compared to an unmanaged peak of 390 kW.

Figure 8. Load Profile for Mixed Usage Sub Scenarios. [Station Nameplate Capacity of 1,750 kW]

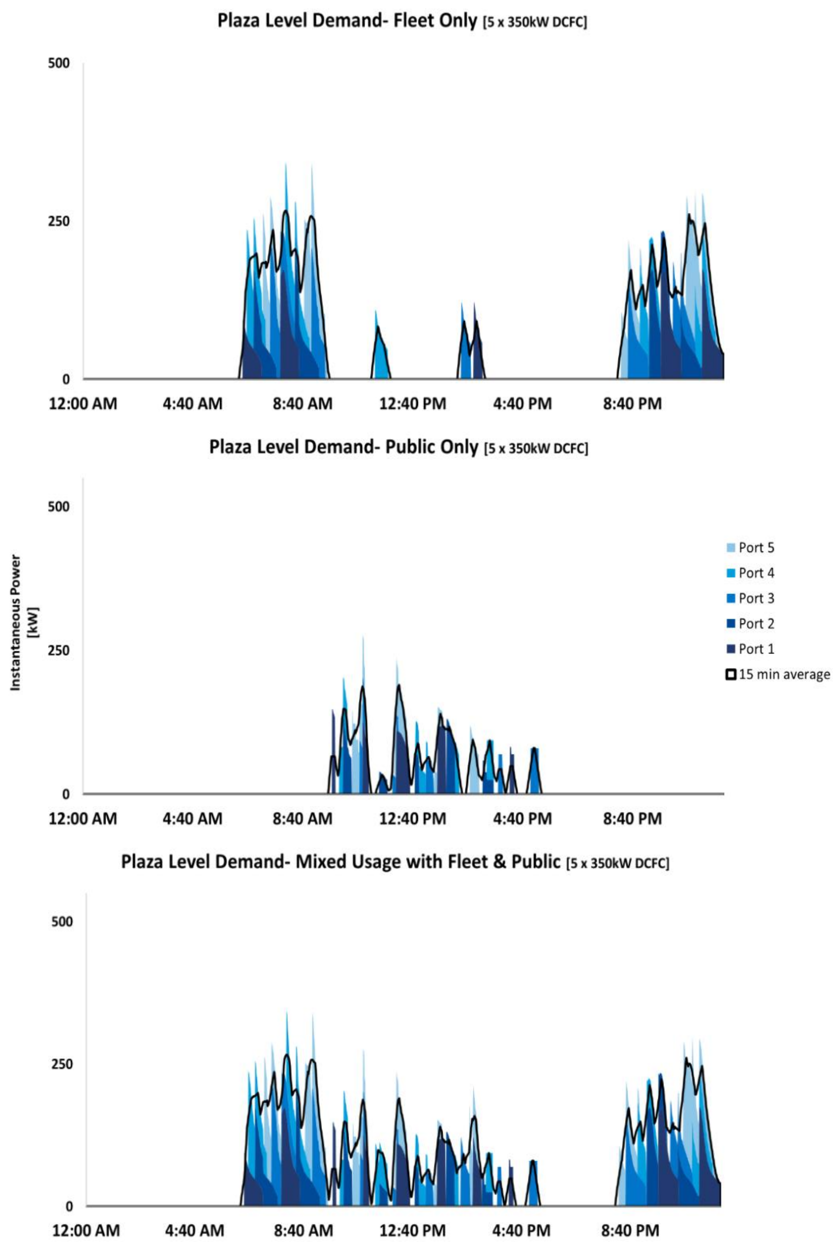


Figure 9. Effects of Staggering Charging Times on Site Load Profile.

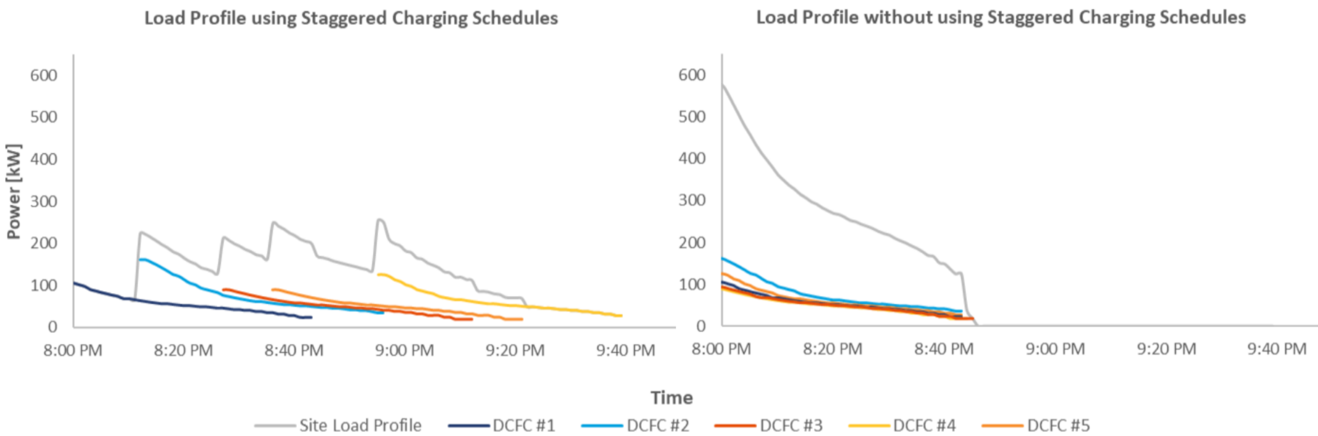
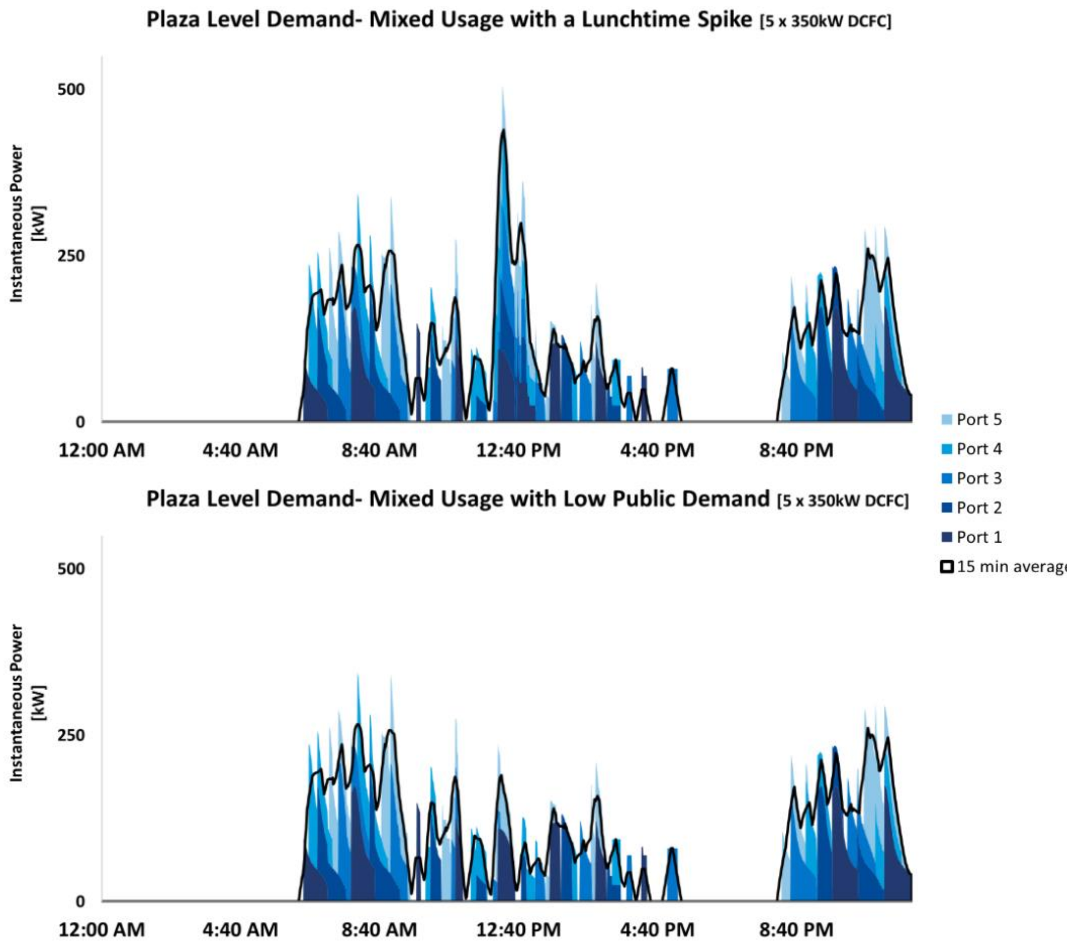


Table 6. Utilization for Mixed Fleet + Public Usage.

	Fleet Only	Public Only	Mixed Fleet + Public	Mixed Fleet + Public - High Public Usage	Unit
Peak Demand	270	190	270	440	kW
Monthly Energy Consumption	38,000	15,000	53,000	59,000	kWh / month
Utilization in a 24-hour time period	14%	6%	20%	22%	Min / min
Nameplate load factor	3%	1%	4%	5%	kW-min / kW-min
Peak 15-minute demand / Nameplate capacity	15%	11%	15%	25%	kW / kW

While fleet operators have control over their own contribution to peak demand, opening their DCFC to the public can have implications for creating a new peak demand. Figure 10 illustrates how a simple change in charging behaviors from the public can shift the peak demand. In this case, a new lunch-time restaurant opened up next door to the fleet's warehouse and now draws a larger crowd of customers to the area between 11:30 to 1:30 pm. These customers typically stay for approximately 30-45 minutes to eat lunch. There is enough customer demand for the DCFC that often all five ports are utilized at nearly the same time. The influx of public customers at this time now changes the site's peak from being fleet-driven to public-driven and increases the peak to 440 kW compared to the previous 270 kW. Depending on the service territory of the fleet, peak changes have implications for fleet operators that are subject to demand charges and, as seen with the residential scenario, greatly influence the monthly utility bill and ultimately the cost per mile of charging.

Figure 10. Effects of Changing Public Charging Habits. [Station Nameplate Capacity of 1,750 kW]



Done correctly, combined fleet and public usage of the DCFC benefits both the public and fleet operators. Public usage of the DCFC has the highest cost per mile across the six different utility tariffs, with an average cost of 8.1 cents per mile (Figure 11). Fleet usage is much lower with an average of 6.1 cents per mile. However, sharing the DCFC between both the public and the fleet vehicles helps to drive down the cost per mile to 5.6 cents (Figure 12). The decrease in the average cost per mile is a function of utility rate structures. Each of the six utility rates use a variety of subscription, volumetric, fixed, and demand charges. Utility rates that are largely volumetric, such as EV Tariff 1 (Figure 12), are inelastic to energy consumption changes and have little fluctuation in terms of the cost per mile (Figure 11). Utility rates that have higher fixed and/or demand charges, such as General Commercial Tariff 1 rate, benefit from higher energy consumption that allows the fleet operator to spread the fixed charges among more charge sessions and off-load some of that cost to the public consumers.

Figure 11. Cost per mile Mixed Use Fleet + Private.

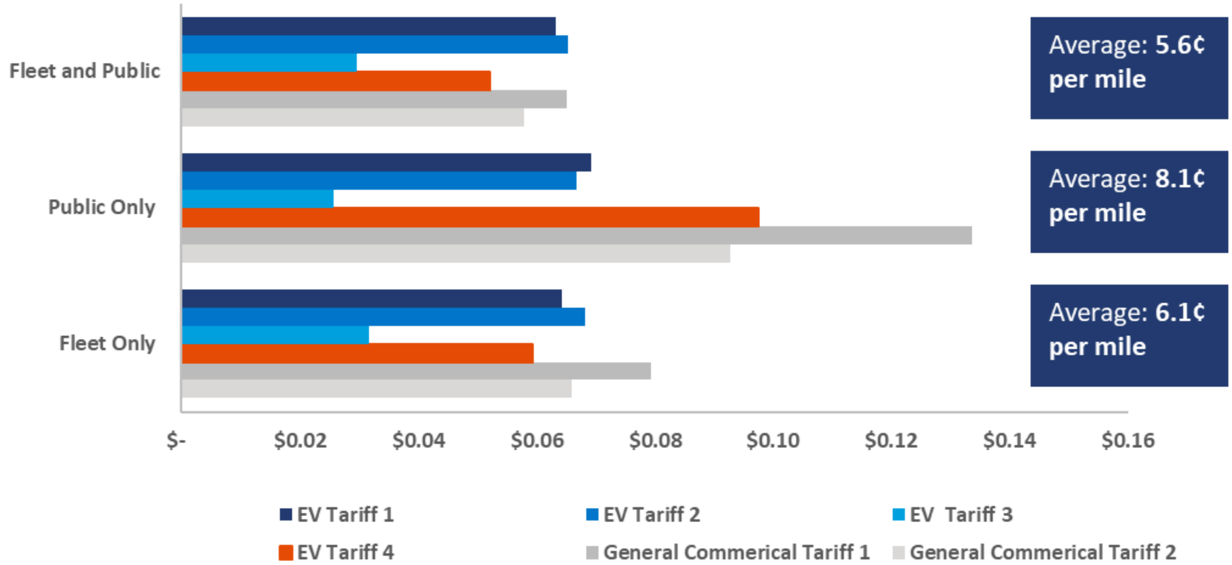
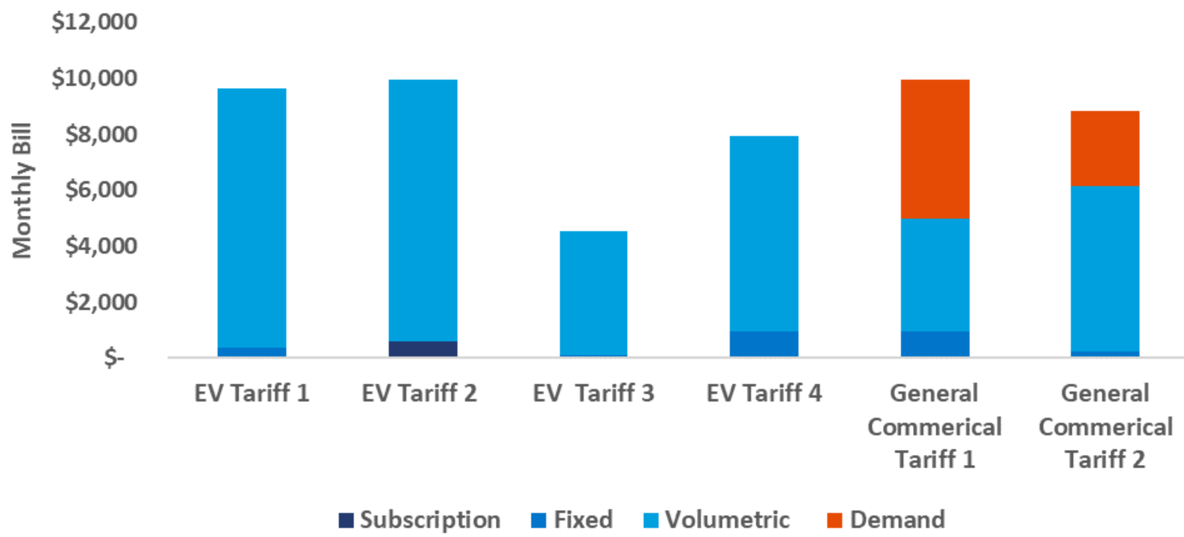
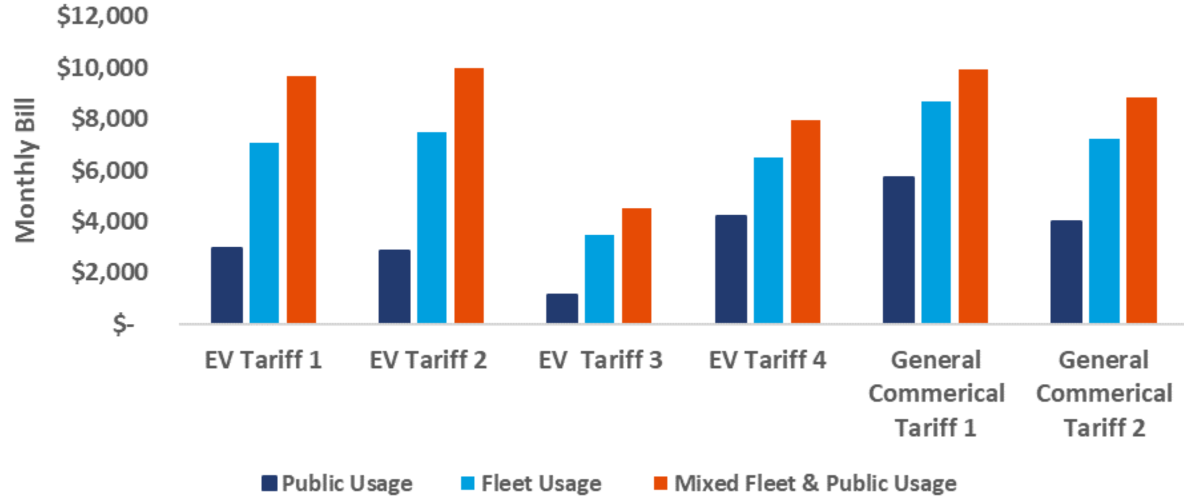


Figure 12. Site Host Monthly Utility Bill with Breakdowns for Subscription, Fixed, Volumetric, and Demand Charges for the Mixed Fleet & Public Usage Scenario.



Whether fleet operators open their DCFC to the public will in large part depend on their service territories and whether there are any substantial monthly bill savings. Service territories with highly volumetric rates (Figure 12) offer less bill savings than those with higher fixed and/or demand charges (Figure 13). General Commercial Tariff 1 shows the significant impact of combining public and fleet charging; the mixed usage scenario has a monthly bill of $9,900, which is much less than having a site serving the public that has a bill of $5,700 and another site serving the fleet that has a bill of $8,700. In contrast, EV Tariff 3 provides less benefit to the mixed usage scenario; the mixed usage has a monthly bill of $4,500 and the summation of having a public site and a fleet site would only be $4,600.

Figure 13. Monthly Utility Bill for Fleet, Public, and Combined Usage Scenarios.



Rural Highway

Increased rural charging is necessary to increase EV adoption. Many state National Electric Vehicle Infrastructure (NEVI) plans include provisions for increasing the distribution of EV charging stations across rural areas and the federal highway system.[13] Compared to urban charging, rural public charging patterns introduce levels of seasonality and unpredictability that make planning for demand peaks and usage far more difficult than sites in more urban, high-use areas.

Many rural charging sites will be placed along high-volume highway routes that run through rural towns. These highway stations are expected to serve different mixes of local EV owners, regional commuters, and long-haul interstate travelers, all of whom are influenced by different seasonal charging behaviors. Rural stations are expected to have sporadic usage, due in part to limited rural EV traffic during most of the year with interspersed peaks due to peak tourism seasons, weekend vacation traveling, and holidays. In this scenario, a rural highway station is located in a region that is popular with tourists, both on holiday weekends and during the summer months. The rural station will meet the needs of local residents as well as tourists and other highway users. The three sub-scenarios are designed to examine how charging patterns may change due to these seasonal fluctuations and provide some insight into how demand peaks may be set by holidays and tourism seasons.

Similar to the residential charging scenarios, the rural highway charging scenarios assume that the daily charging patterns of local residents and travelers will generally align with existing fueling patterns observed at gasoline stations (See Appendix A for further details). The scenario assumes that consumers will primarily use the charging ports during the daytime with the majority of the charging occurring between 7 am and 8 pm. Known gasoline fueling behaviors provide a useful starting point to modeling how often travelers stop at highway charging stations and which periods of the day see the most traffic.

The first sub-scenario models rural highway stations during non-tourism days. In this scenario, the station serves primarily local, rural residents and regional commuters who may use public charging to replace at-work or at-home charging, or for at least half of the local EV population for topping-off their vehicles. The second and third scenarios examine how peak season and holiday weekend traffic can create traffic multipliers that would significantly increase the charging volume and peak demand at the station. The scenario models that the majority of the EV traffic during peak seasons and holidays are expected to have traveled long distances and come into the station with low SOCs. The peak season and holiday scenarios differ in that the peak season has less of a daily spike in traffic and that the increase in tourism spreads the charging demand over the entire season rather than a shorter holiday period. Holiday upticks in

[13] U.S. Department of Transportation Federal Highway Administration. (2022, September 14). *Biden-Harris Administration Announces Approval of First 35 State Plans to Build Out EV Charging Infrastructure Across 53,000 Miles of Highways*. Highways.dot.gov. Retrieved January 13, 2023, from https://highways.dot.gov/newsroom/biden-harris-administration-announces-approval-first-35-state-plans-build-out-ev-charging

charging demand are assumed to be less sporadic than off-season and peak-season usage and should be easier to predict and model.

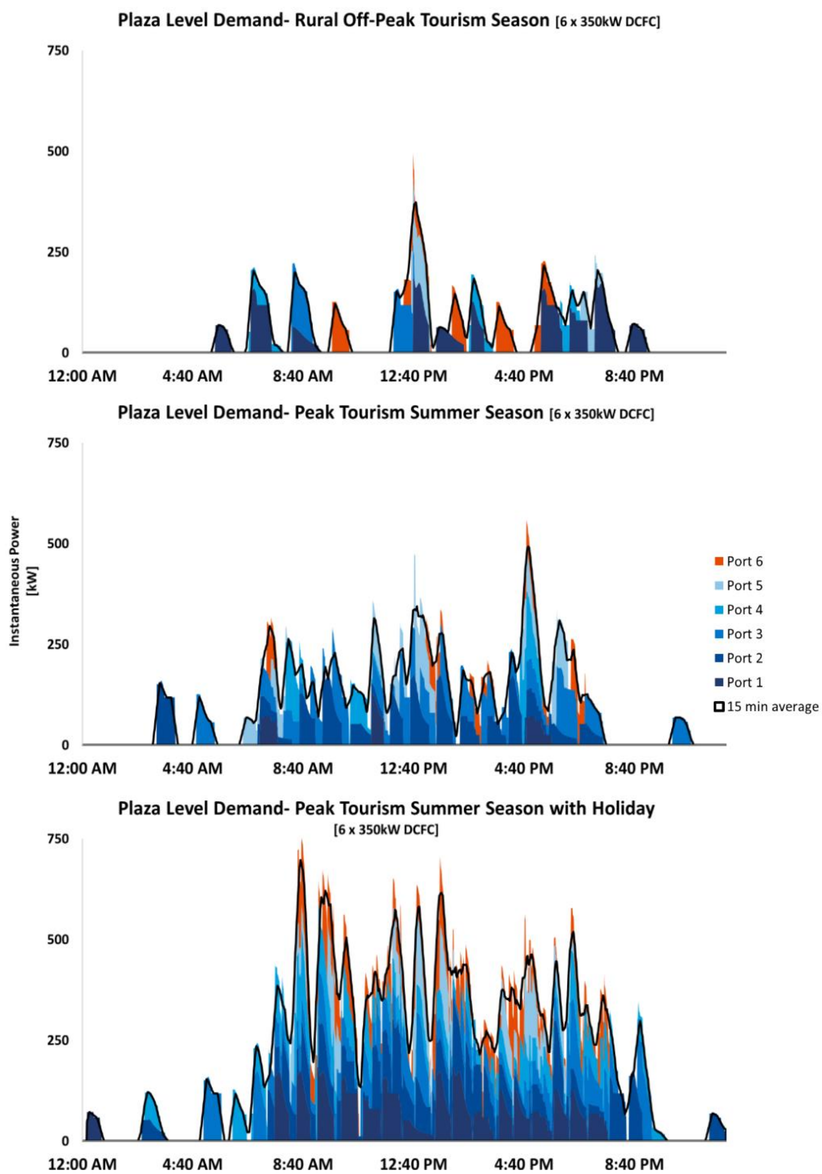
The rural highway scenarios are modeled using many of the same base assumptions. Namely that the mix of vehicles using the station represent the average mix of EVs in the ten most rural states and that the peak season and holiday weekend scenarios use double and quadruple the number of vehicles compared to the off-peak season to account for the higher interstate traffic during those periods. Additionally, the peak season and holiday weekend scenarios assume that customers had been traveling long distances between EV charging ports due to the currently low distribution of EV chargers throughout the rural highway system.

Table 7. Rural Highway Sub Scenario Descriptions.

Rural Highway		
Off-Season Tourism	**High Tourism Season**	**Holiday Weekend**
Scenario Description: An interstate highway gas station operator in a rural area has installed 6 DC fast charges in order to capitalize on the charging demand alongside ICE vehicle fueling. During the off-season, few people are passing through, and the station largely serves locals without home chargers and/or a few non-local owners traveling along the interstate.	**Scenario Description:** An interstate highway gas station operator in a rural area has installed 6 DC fast charges in order to capitalize on the charging demand alongside ICE vehicle fueling. During the site's peak tourism season, customers are expected to come in with drained batteries and very few local EV owners top-off.	**Scenario Description:** An interstate highway gas station operator in a rural area has installed 6 DC fast charges in order to capitalize on the charging demand alongside ICE vehicle fueling. During a holiday weekend, the volume of vehicles using the station is double that of the high tourism season scenario due to a higher-volume holiday tariff multiplier.
Site Location & Access: 	**Site Location & Access:** 	**Site Location & Access:** 
Utilization: Low utilization; early morning to evening charging	**Utilization:** Low-to-medium utilization; early morning to evening charging	**Utilization:** Low-to-medium utilization; early morning to overnight charging
Defining Characteristics: • Highly variable depending on regional EV penetration • Low usage suggests that demand peaks are likely to occur as a result of randomness rather than predictable charging habits	**Defining Characteristics:** • Likely will experience large seasonal variability • Summer electricity usage is typically higher than winter	**Defining Characteristics:** • Outlier days such as a three-day weekend may cause significant increase in peak demand • Building for the peak surge days is required, but will result in the majority of days being low levels of utilization

As in the other scenarios, the peak demand in these rural highway scenarios is heavily dependent on circumstantial surges in traffic and customers' charging habits. Small changes in customer behaviors can have large impacts on the magnitude, duration, and time of peak demand. For example, heavy traffic during the middle of the day causes a temporary charging bottleneck that subsequently causes a significant, short-term spike in demand around the middle of the day for the off-peak season's load profile (Figure 14). In scenarios where traffic increases drastically, as in the peak season and holiday scenarios, the increased traffic volume can cause multiple charging peaks throughout the day, which makes it more difficult for site managers to use curtailment schemes and battery storage to reduce the peak demand (Figure 14). The peak season and holiday weekend scenarios highlight the need for charging station operators to plan for short-term periods of greatly increased charging volume that can impact the site's peak demand and energy consumption.

Figure 14. Load Profile for a Rural Highway Station. [Station Nameplate Capacity of 2,100 kW].



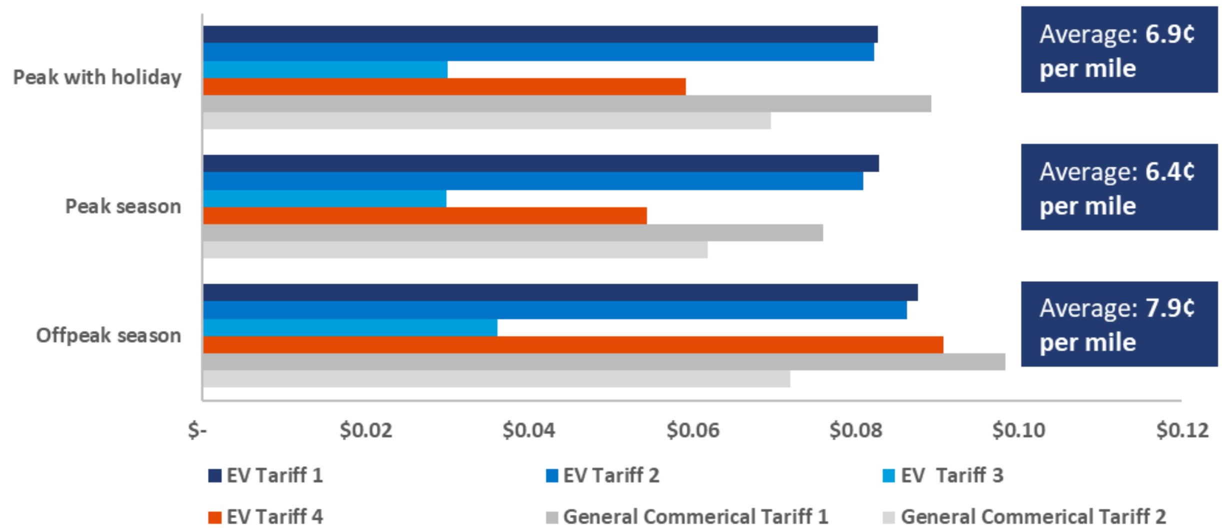
Increased traffic seems to impact the frequency, rather than the magnitude, of demand peaks, with the number of significant demand peaks increasing from one to eight between the off-peak and holiday weekend scenarios. While the holiday weekend scenario has quadruple the traffic, the peak demand only increases to 700 kW, less than double that of the off-peak season (Table 8). For the peak season and holiday weekend scenarios, the increase in traffic causes more frequent, concurrent use of the charging ports which increases the peak demand by 31% and 87% respectively compared to the off-season scenario (Table 8). While the nameplate load factor greatly increases for these scenarios, they still remain relatively low at 5% and 11% respectively. These findings are congruent with the other scenarios. Peak demand is greatly limited by the site's number of ports and is far more restricted by the charging capacity of individual vehicles than the capacity of the chargers themselves (See the Constant Power Charging section for more details).

Table 8. Utilization for Rural Highway Station.

	Off-Season Tourism	High Tourism Season	Holiday Weekend	Unit
Peak Demand	375	490	700	kW
Daily Energy Consumption	1,300	2,500	5,300	kWh / month
Monthly Energy Consumption	39,300	76,300	N/A	kWh / month
Utilization in a 24-hour time period	11%	23%	46%	Min / min
Nameplate load factor	3%	5%	11%	kW-min / kW-min
Peak 15-minute demand / Nameplate capacity	11%	23%	33%	kW / kW

As a result of the increase in interstate traffic, the average cost per mile of charging tends to be lower during the peak season and holidays than during off-peak times (Figure 15). This decrease in cost is likely due to an increase in charging volume that allows monthly demand charges to be distributed amongst a greater number of customers. Similar to the other scenarios, the difference in charging costs varies depending on the EV charging rate structure and the stations' service territory.

Figure 15. Cost per mile for a Rural Station.



Compared to urban site monthly bills, the monthly bills for rural highway sites will fluctuate more throughout the year and with more drastic changes in the cost per mile depending on the service territory. For site owners in service territories that are more heavily influenced by volumetric pricing, monthly bills will fluctuate based on changes to energy consumption. This is largely a pass-through charge and will have a smaller effect on the cost per mile of charging throughout the year (Figures 15 & 16). EV Tariff 3 is a good example of how a volumetric based rate will reduce fluctuation in cost per mile charging (Figure 16). Other rates that are highly volumetric, but have high fixed and/or subscription costs, will have larger fluctuations in the cost of charging. EV Tariff 4 benefits from large increases in energy consumption because it has higher fixed costs that can be spread among more charge sessions.

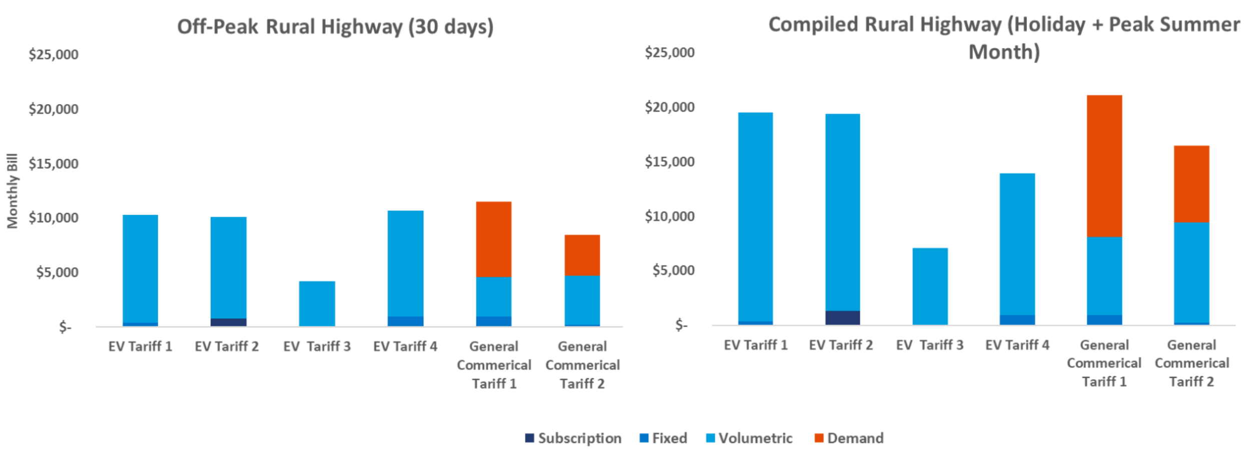
Demand and subscription dependent rates are most heavily impacted by the change in peak demand during peak tourism times rather than by energy consumption fluctuations. The final cost per mile of charging for these types of rates will be dependent on the adequacy of energy consumption volume to spread the demand and subscription costs across more charge sessions. EV Tariff 4, General Commercial Tariff 1, and General Commercial Tariff 2 show that as energy consumption increases between off-peak and peak tourism season, the overall cost per mile will decrease, so long as there is only a small increase or lack of change in peak demand (Figure 15). Between the off-peak and peak tourism scenarios, the peak only increases by 115 kW, while the energy consumption increases nearly 37,000 kWh/month. This allows the incurred demand charges to be spread across nearly twice the amount of energy consumption.

In contrast to the peak season scenario, when there is a holiday weekend the cost per mile increases due to the higher peak demand and relatively low addition of energy consumption. The holiday weekend causes the peak demand to increase to 700 kW, compared to the tourism season peak of 490 kW, but only adds an additional energy consumption of 5,300 kWh/day. In a peak season month with no holiday weekends, the energy consumption is 76,300 kWh/month, while a peak season month with one holiday has an energy consumption of 81,600 kWh/month.

Peak tourism months with this type of holiday weekend will incur more demand charges without sufficient energy consumption to mitigate the resulting price increase (Figure 16).

Off-peak charging has the highest cost of all the utility rates, and due to the rural location of the site, there are fewer opportunities to increase the demand and spread costs among more charge sessions. In the future, as EV adoption increases, demand will increase and improve the utilization of these sites. However, in the near-term, rural site owners may look into deploying several different strategies to decrease their site peak and reduce their overall costs. Rural owners can use staggering techniques, such as that discussed in the fleet scenario, to ensure that even if the site's ports are being used, there isn't an aggregated peak from all the charge sessions starting at the same time. Additionally, rural owners could choose to close off some of the ports during the off-season so that only 2-3 are available at a time. In this scenario, the peak was set when four ports were being used at the same time. Rural owners can also take this time to do routine maintenance on the chargers. As the site becomes more active and more EV drivers use the site, site managers may look to curtailment and energy storage as potential solutions to reduce their peak demand (see the Peak Demand Reduction Strategies section for more details).

Figure 16. Site Host Bill Comparison Based on Seasonal Variations.



Emergency Pre-evacuation

Local governments will need to incorporate EV charging into their resilience and climate planning processes as EV adoption continues. Evacuations are becoming more common with the increased frequency and severity of extreme weather events and will have implications for designing DCFC charging plazas. EV charging differs from traditional fueling in that more time is needed per charging session, and abnormally high demand can potentially cause long queuing. Local governments will need to design evacuation routes that include adequate charging, design and/or utilize EV charging stations that can accommodate long queues of vehicles, and create evacuation protocols, such as limiting the time per charge, that can help more vehicles gain sufficient charge to leave affected areas.

In this scenario, the local government is planning for next year's hurricane season. During the planning meeting, they agree that they do not have enough time to design a pre-evacuation hub to meet residents' charging needs for evacuation. The local government has identified one of their shopping plazas as a potential solution. This shopping plaza has 10 DCFC charging ports, is located along one of the pre-evacuation routes, and has sufficient space to accommodate long queues of vehicles needing to use the charger. The pre-evacuation planning team is concerned that without limits on charging session times they will not be able to accommodate many of their evacuating residents. To examine how different evacuation protocols influence the charging site, three pre-evacuation sub scenarios will utilize either a 15-minute charging limit, a 20-minute charging limit, or no time limit. The no time limit scenario also examines how extreme charging behaviors, in this case all customers charging to 75-80% SOC, affect the site's utilization and load profile.

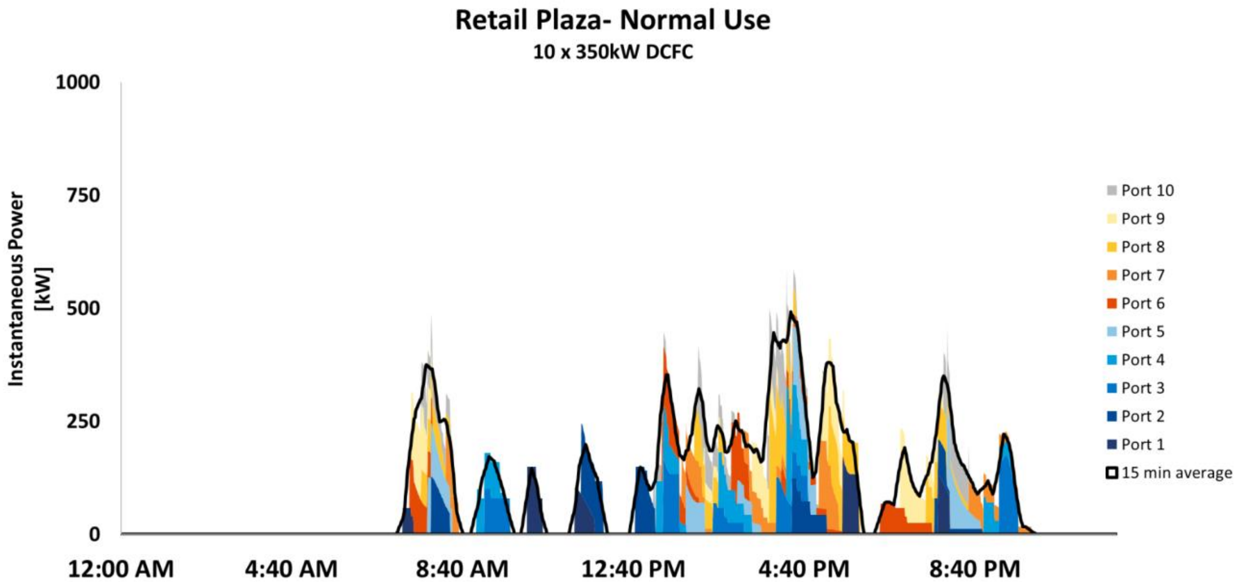
Pre-evacuation events are rare and will not account for the majority of a site's usage, so this scenario also models how the plaza would function during its daily operations. This scenario models a retail plaza with a grocery store, shops, a movie theater, and restaurants. While the previous scenarios used fueling habits as the basis for customer behaviors, a retail plaza's charging station is more heavily influenced by the customers' shopping habits. Customers' shopping habits determine both the time of day that the customer will use the DCFC and for how long the customer will leave their vehicle to charge. Shopping centers that serve a variety of businesses will be subject to a wider range of charging times. Retail customers may charge for approximately 30 minutes, or the amount of time it takes them to shop at a single store. Other customers such as those eating at one of the mall's restaurants may leave their vehicle to charge for anywhere between 45 minutes and 2 hours, and customers that are movie-goers will charge their vehicles for over 1.5 hours. In comparison to those using a public station purely for refueling and only stopping for the shortest time possible, customers at a retail plaza will charge their vehicle in accordance with how long they stay at the shopping mall. Those eating at a restaurant or watching a movie may not move their vehicle after it is done charging. These charging behaviors have implications; people overstaying their charging session reduce the utilization of that charging port.

Table 9. Emergency Pre-evacuation Sub Scenario Descriptions.

Emergency Pre-evacuation			
Normal Plaza Usage	**Mandated Limit of 15 Minute Charging Sessions**	**Mandated Limit of 20 Minute Charging Sessions**	**No Time Limit for Charging**
Scenario Description: A local city of 300,000 people has implemented an evacuation plan and has identified a shopping plaza's 10 DCFC charging ports as an ideal pre-evacuation charging location during hurricane season. During non-emergency times, the plaza serves customers with shops, a grocery store, a movie theater, and restaurants.	**Scenario Description:** A local city of 300,000 people has implemented an evacuation plan and has identified a shopping plaza's 10 DCFC charging ports as an ideal pre-evacuation charging location during hurricane season. During evacuation events, the city has limited charging to **15 minutes per charging session.**	**Scenario Description:** A local city of 300,000 people has implemented an evacuation plan and has identified a shopping plaza's 10 DCFC charging ports as an ideal pre-evacuation charging location during hurricane season. During evacuation events, the city has limited charging to **20 minutes per charging session.**	**Scenario Description:** A local city of 300,000 people has implemented an evacuation plan and has identified a shopping plaza's 10 DCFC charging ports as an ideal pre-evacuation charging location during hurricane season. During evacuation events, customers will charge their EVs to **75-80% SOC.**
Site Location & Access: 	**Site Location & Access:** 	**Site Location & Access:** 	**Site Location & Access:** 
Utilization: Low-to-medium utilization; daytime & evening charging	**Utilization:** High utilization; daytime & overnight charging	**Utilization:** High utilization; daytime & overnight charging	**Utilization:** High utilization; daytime & overnight charging
Defining Characteristics: • Represents a normal retail plaza with periods of high utilization and low utilization • Very low nameplate load factor today • Sustained afternoon usage makes a more challenging case for energy storage	**Defining Characteristics:** • Very high utilization (100% between 8am – 8pm) • Relatively low nameplate load factor (17%)	**Defining Characteristics:** • Very high utilization (100% between 8am – 11pm) • Relatively low nameplate load factor (21%)	**Defining Characteristics:** • Very high utilization (100% between 8am – 4am the next day) • Relatively low nameplate load factor (22%)

While some of the day-time shopping is similar to people's fueling habits, the retail plaza experiences a higher influx of customers during the evening and has more customers that use the chargers for an extended period of time (Figure 17). Due to the number of customers using the plaza at the same time, the system peak is 490 kW, which, while high for this charging plaza, represents only 14% of the nameplate capacity. As discussed below, the evacuation scenarios only reach 32% of the nameplate capacity despite all 10 ports being utilized at once.

Figure 17. Load Profile for Normal Retail Plaza Usage. [Station Nameplate Capacity of 3,500 kW].



The three emergency pre-evacuation scenarios also do not follow typical charging habits. All three scenarios assume that customers are willing to wait a long time to charge their vehicle, that customers will charge as much as possible given the limits of the individual scenarios, that customers are beginning with the same range of starting SOCs, that the site is serving the same distribution of vehicle types, and that each scenario is serving the same number of customers. Each scenario models 40 vehicles per port per day, for a total of 400 vehicles using the site in a 24-hour time period.[14] Each emergency pre-evacuation scenario begins around 8 am, assuming that an emergency pre-evacuation order had gone out the hour prior and people began using the site to prepare for evacuation. The first two scenarios examine how designated limits on the charging sessions influence the site's peak and how an additional 5-minute allowance influences both the charging sessions and the site's utilization.

All three of the emergency pre-evacuation scenarios experience similar peak demands of 1,120 kW, 1,110 kW, and 1,100 kW respectively (Table 10). This result indicates that due to the high demand of this scenario, the peak is relatively inflexible. Despite the inflexibility in the peak demand, the site's peak demand does not exceed even 33% of the nameplate capacity, even when all 10 ports are utilized at the same time (Table 10). This result aligns with industry

[14] Modeling 400 vehicles per scenario is a factor of the limitations of the model rather than a deliberate assumption of the scenario.

concerns that the planning for nameplate capacity, rather than actual peak usage, does not accurately reflect the reality of charging sites' power and energy needs given current vehicle charging capabilities. In the future, different charging strategies may increase a site's ability to reach its nameplate capacity. In such a case, planning for nameplate capacity would benefit utilities and site planners alike. See the Constant Power Charging section detail for one alternative charging strategy and its implications on a site's peak demand.

Figure 18. Load Profile for Pre-Evacuation Sub Scenarios. [Station Nameplate Capacity of 3,500 kW].

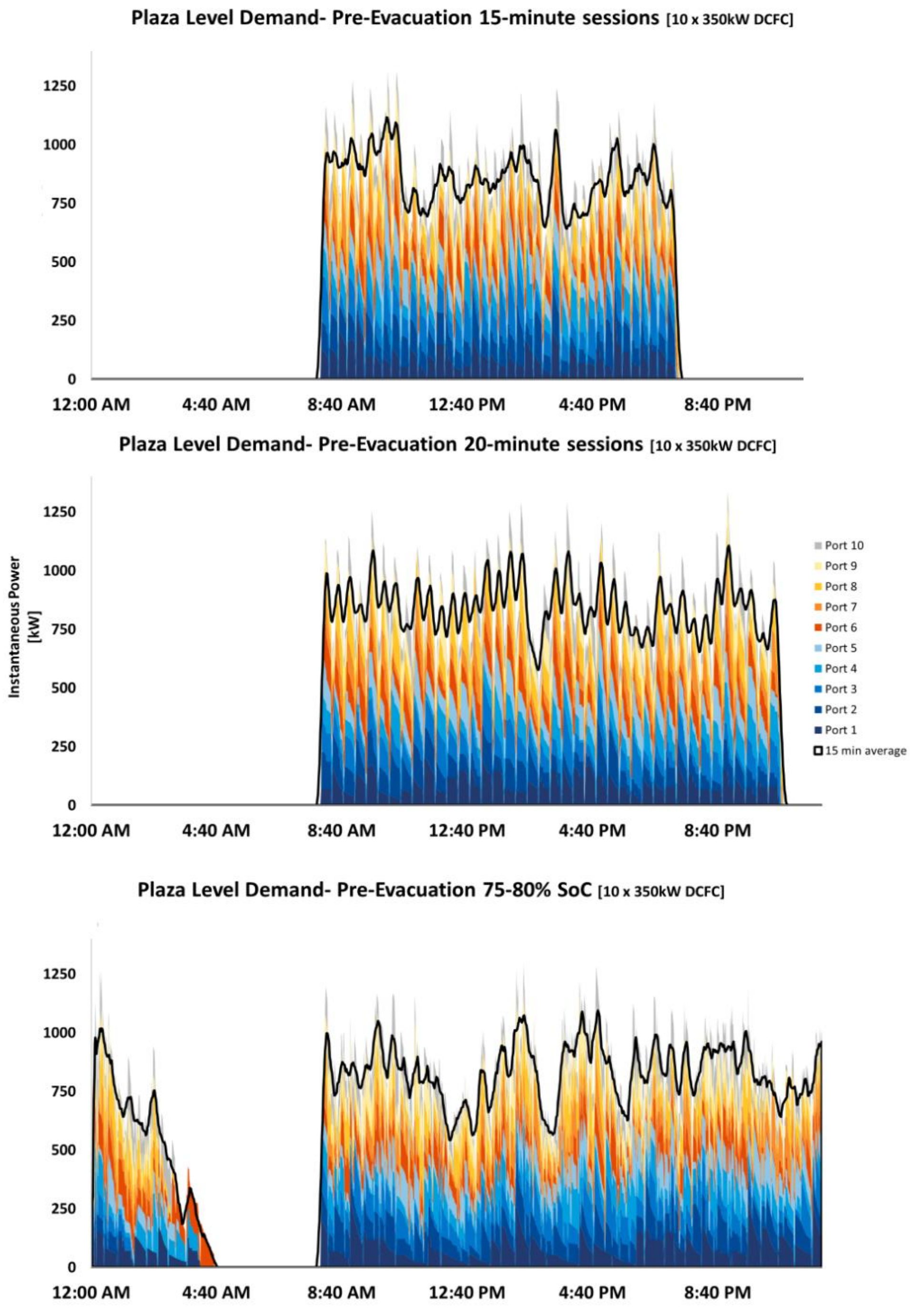


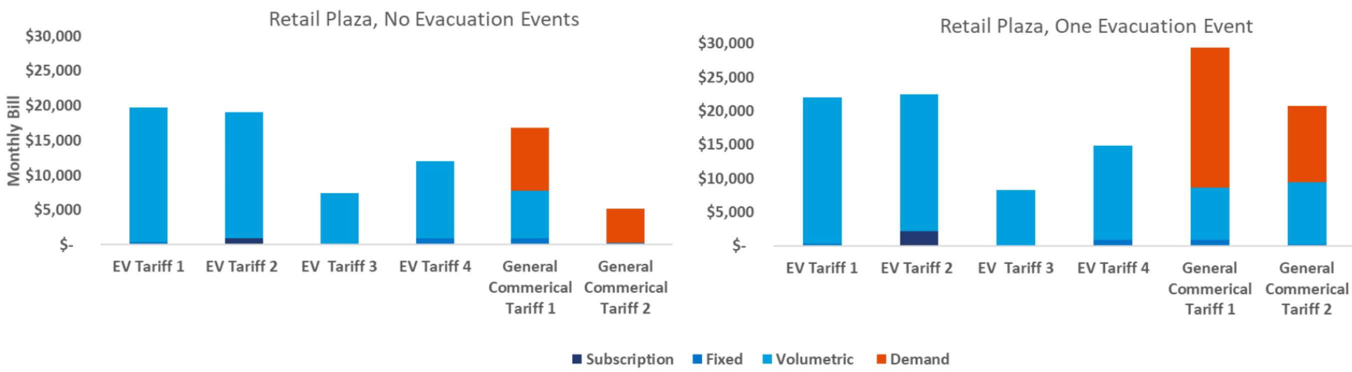
Table 10. Utilization for Emergency Pre-evacuation.

	Normal Plaza	15-Minute Limit	20-Minute Limit	75-80% SOC	Unit
Peak Demand	490	1,120	1,110	1,100	kW
Daily Energy Consumption	2,400	9,800	12,400	15,800	kWh / day
Monthly Energy Consumption	52,700	N/A	N/A	N/A	kWh / month
Nameplate load factor	3%	17%	21%	22%	kW-min / kW-min
Peak 15 minute demand / Nameplate capacity	14%	**32%**	**32%**	**31%**	kW / kW

While the three pre-evacuation scenarios model the same number of vehicles, the difference in time allowances cause significant variation in daily energy consumption. The five-minute time allowance difference between the first and second scenario increases the site's daily energy consumption by 2,600 kWh, and removing all time allowances between the first and third scenario increases the site's daily energy consumption by 6,000 kWh (Table 10). These changes in energy consumption determine how much energy the utility may need to plan to provide during evacuation events. Under time restrictions, the utility does not have to supply as much energy, while still allowing the same number of vehicles to access the charging site and gain some vehicle range to leave the evacuation zone. If there are no time restrictions, utilities will have to anticipate a large increase in energy demand within a short time period. For evacuations, the additional energy consumption represents 18%, 23%, and 30% respectively of the normal monthly energy demand.

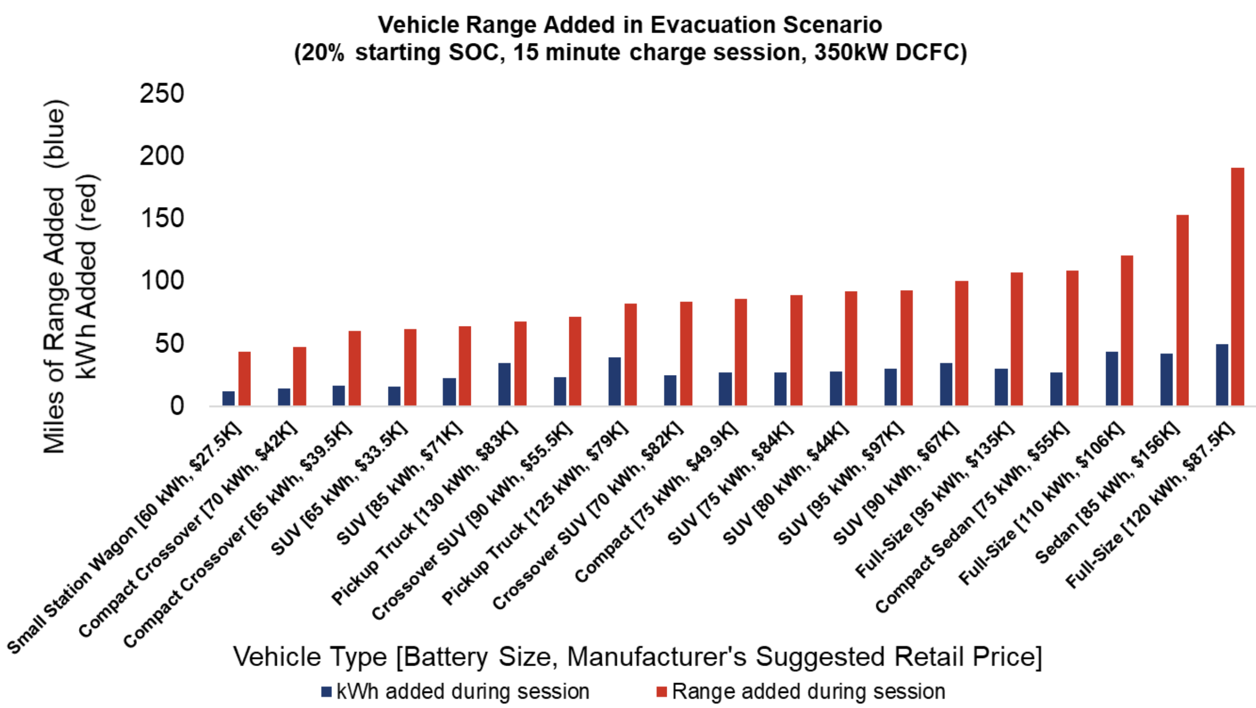
Additionally, the pre-evacuation event has significant implications for setting demand charges. If utilities do not have provisions to prevent the evacuation event from setting the site's demand and/or subscription charges, then the site owner's monthly utility bills will drastically increase. By having only one day of pre-evacuation charging sessions, the General Commercial Tariff 1's monthly demand rate increases from $9,160 to $20,720, and General Commercial Tariff 2's demand rate increases from $4,970 to $9,260 (Figure 19). EV Tariff 2 also has changes to its subscription charge, which increases from $960 to $2,200 (Figure 19). These changes in demand and subscription rates can cause the cost per mile charged to effectively double for the plaza and cause more economic pressure on the site.

Figure 19. Monthly Site Host Bill after 1 Evacuation Event.



During their pre-evacuation planning process, government officials should consider their emergency response measures and analyze how potential policy measures may affect their residents. Charging time limitations can potentially place burdens on customers that have vehicles with charging curves with low power draws (Figure 1, Figure 36). To illustrate the effects of limiting charge sessions during a pre-evacuation event, Figure 20 compares how much range is added per vehicle type. Higher end, luxury vehicles benefit more from a 15-minute charge session compared to more affordable, and often more commonplace, vehicles (Figure 20).

Figure 20. Vehicle Range added in 15-minute Charging Sessions.



These differences in miles of added range have a variety of implications for evacuation planners. Each individual vehicle will have to stop more often to recharge, which adds to more queuing at stations and prevents that individual or family from quickly leaving the area under evacuation. In service territories with large percentages of the EV population using lower-cost vehicles people will need to recharge their vehicles, thereby increasing demand for charging stations, and creating further need for time limits to accommodate the maximum number of evacuating vehicles. Evacuation planners will have to model many different evacuation scenarios to understand the scope of their policy impacts and prevent unintended consequences.

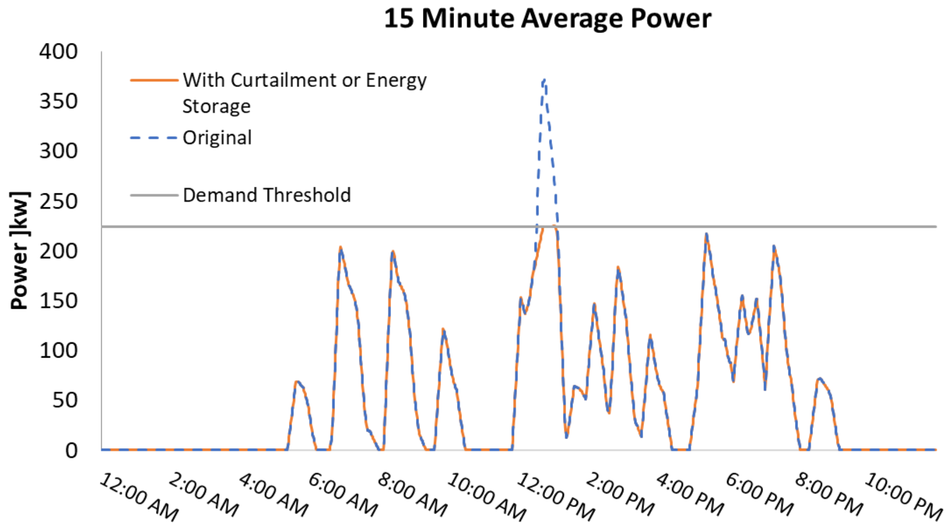
Peak Demand Reduction Strategies

Electric utility bills can comprise a significant portion of operating costs for DCFC sites. Due to the complex and varied nature of utility tariff structures, the electricity cost for a particular load profile can vary significantly depending on the service territory. DCFC stations are particularly sensitive to price differences due to their unique load shape characteristics as compared to other commercial and industrial customers. Specifically, operations with high peak power demand and low nameplate load factor can result in the demand component - the cost per kW of peak power demand - of the DCFC plaza utility bill comprising a significant fraction of the total monthly cost. This is particularly relevant when the peak demand of a station is significantly higher than the average demand - a common characteristic of DCFC plazas with low utilization.

In addition to the operational cost considerations of high-power, low load factor use-cases, the distribution infrastructure required to serve these customers can be costly and may require long lead times (due both to supply chain issues and normal utility interconnect timelines). Onsite energy storage and temporary throttling or 'managing' of DCFC output are two options that station operators consider as a means to mitigate some of the capital and operational cost challenges associated with DCFC operations. However, not all use cases or scenarios are ideal candidates for those demand reduction strategies. The economic viability of energy storage is largely dependent on the load prolife shape and the utility tariff. The practical viability of throttling is dependent on the customer's responsiveness to price signals or willingness to pay for uninterrupted charging. For example, load profiles with short intermittent periods of high demand are better candidates for batteries than stations with long periods with demand close to monthly peaks. Alternatively, customers using stations in metro areas for opportunity or 'Top Up' charging may be better candidates for throttling than rural corridor charging being used for full charges during road trips.

Figure 21 shows an hourly profile for an off-peak day on a rural corridor. In this example, the demand threshold is set to reduce peak demand by 40% from 400 kW to 224 kW. Due to the high singular peak in the middle of the day, a large battery would be required and would be used for only one hour on this particular day. If the battery needed to manage the instantaneous peak demand, 280 kW of battery capacity would be required. If the battery is sized to limit the 15 minute peak demand a battery power of 176 kW would be required.

Figure 21. Off-season Rural Corridor; 40% Demand Reduction.

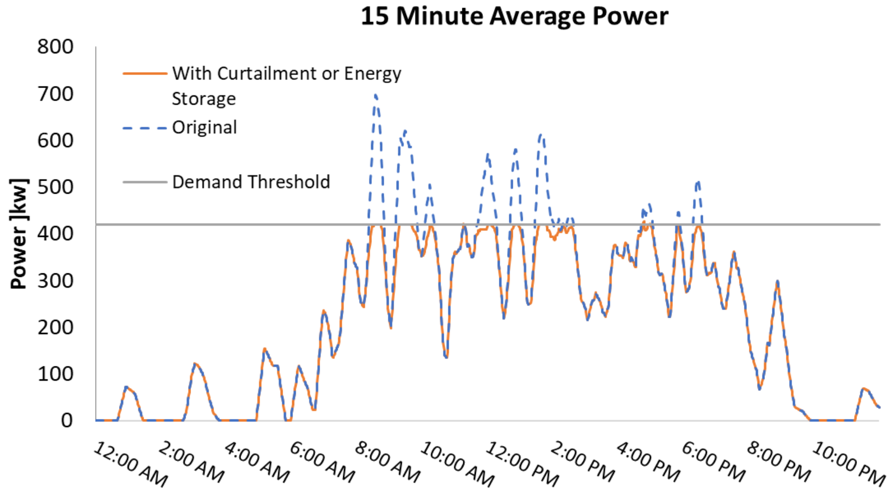


Alternatively, the same level of demand reduction could be achieved by throttling charging for 36 minutes and shifting 56kWh. In the throttling scenario, three customers would be impacted with their individual sessions being increased in length by roughly 30% or about 15 minutes. Simply extrapolating this scenario across the month would result in about 90 customers being curtailed in a given month. These approaches would result in monthly savings ranging from $800 to $3,700 per month, depending on the tariff structure. A station operator must assess if passing some of these savings on to the customer is worth the level of disruption or customer dissatisfaction.

It is important to note that demand charges are set by the monthly peak demand and any demand reduction approach needs to be capable of achieving the desired demand threshold for all hours of the month. Consider the scenario in which a system is sized for an average summer day on a rural highway (Figure 21 above) but on a handful of holidays each summer the charging station receives significantly more utilization than average (Figure 22 below). In this case, a normal day's demand reduction is irrelevant because of the new peak set on a holiday (e.g. a utility bill is set by the single highest 15-minute peak demand in a given billing period). An operator may consider sizing the storage to mitigate only holiday peak demands and set the demand threshold at the typical normal day peak demand (e.g. 400 kW in this case). In this scenario, the battery would likely only be used for demand reduction on holidays and could potentially serve other purposes throughout the rest of the year.

Similarly, if curtailment or throttling is used, it is important to anticipate (as much as possible) the outlier peak days that may occur and make any previous curtailment efforts within the billing period ineffective at achieving demand reduction. In a scenario where curtailment deployed in a billing period prior to an outlier day (that sets the new peak demand) ends up not resulting in demand reduction, it still creates a negative customer experience (and potentially impacts customer compensation) and must be balanced with the cost saving potential of demand reduction.

Figure 22. Holiday Rural Corridor; 40% Demand Reduction.



When the peak demand is short lived, relatively infrequent, and semi-predictable, an operator may consider energy storage and station curtailment to reduce demand related utility bill costs. However, due to differences in utility tariffs and the high sensitivity to load profiles, it is not practical to make generic recommendations on when one demand approach may be more or less effective than another. The model developed as part of this project allows the interested reader to explore various demand reduction strategies across scenarios and utility tariff structures. System operators must consider storage system costs, utility bill savings, customer preferences, and the level of load predictability in order to begin to assess the economic and practical viability of each demand reduction approach.

Comparison of Storage and Throttling - A Simplified Example

Figure 23 summarizes the monthly utility bill savings that could be achieved with different demand thresholds, demonstrating the economic sensitivity to utility tariffs and the level of demand reduction.

Figure 23. Summary of Monthly Utility Bill for Different Utility Tariffs and Demand Thresholds.

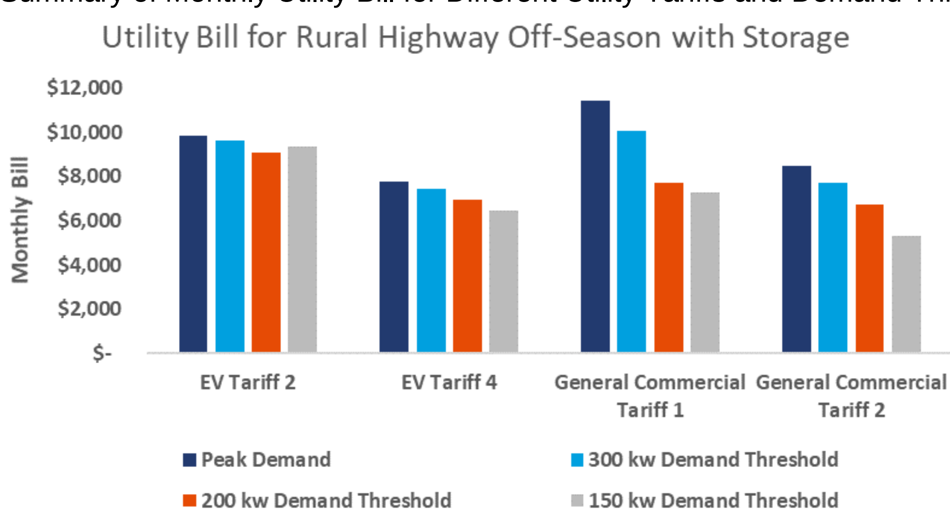


Table 11 summarizes the simplified customer implications from using throttling as a demand reduction approach for an off-peak day and for a peak holiday. Notably, the level of demand reduction achieved is not proportional to the customer impact across both scenarios. On busy holidays, the duration of curtailment and kWh of energy curtailed are an order of magnitude larger than an off-season day, while the range of utility bill reduction achieved is between 8-30% of the unmanaged scenario, depending on the utility tariff.

Table 11. Summary of Effects of Throttling.

	Off-peak day	Holiday
Level of Curtailment	40%	40%
New Peak demand	224	419
Minutes of curtailment per day	**36**	**251**
kWh Curtailed	**56**	**439**
% of Energy Curtailed	4.31%	8.22%

Constant Power Charging: A Potential Future

To explore how constant power vehicle charging curves could change the results presented in this report, we simulate daily load curves where all vehicle models can accept a constant power that is equal to the DCFC output. We simulate DCFC output powers of 50 kW, 100 kW, 175 kW, and 350 kW. In the constant power charging scenarios, the DCFC is the limiting factor, as opposed to the vehicle charge curve which is the limiting factor in all scenarios presented previously.

The figures below show load profiles when vehicles charge at constant power independent of the battery SOC. Figure 24 shows the load profile for a peak summer rural highway scenario with actual (SOC dependent) vehicle charge curves charging on 350 kW DCFC ports. The subsequent figures show the load profile of the same charge sessions (starting SOC, time available) charging a constant power of 350 kW, 175 kW, 100 kW, and 50 kW respectively. In these alternative constant power scenarios, the vehicles charge until the desired SOC is reached or the time available is exceeded.

Figure 24. High Season Rural Highway Load Profile; 350 kW DCFC output, normal vehicle charging curves.

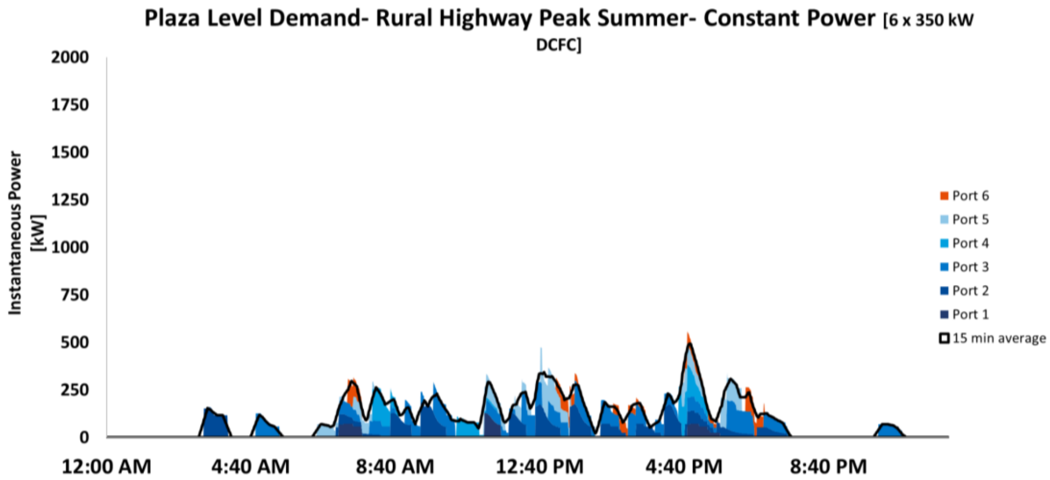


Figure 25. High Season Rural Highway Load Profile; 350 kW DCFC output, constant 350 kW vehicle charging.

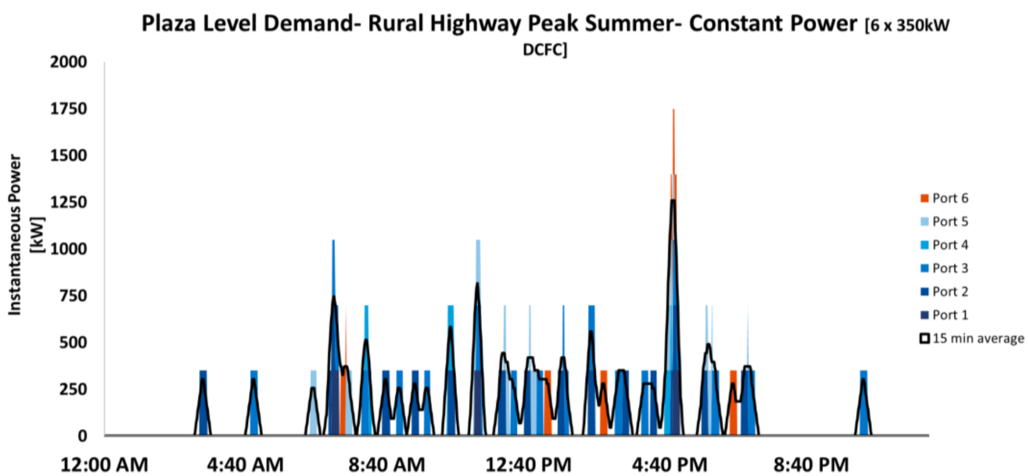


Figure 26. High Season Rural Highway Load Profile; 175 kW DCFC output, constant 175 kW vehicle charging.

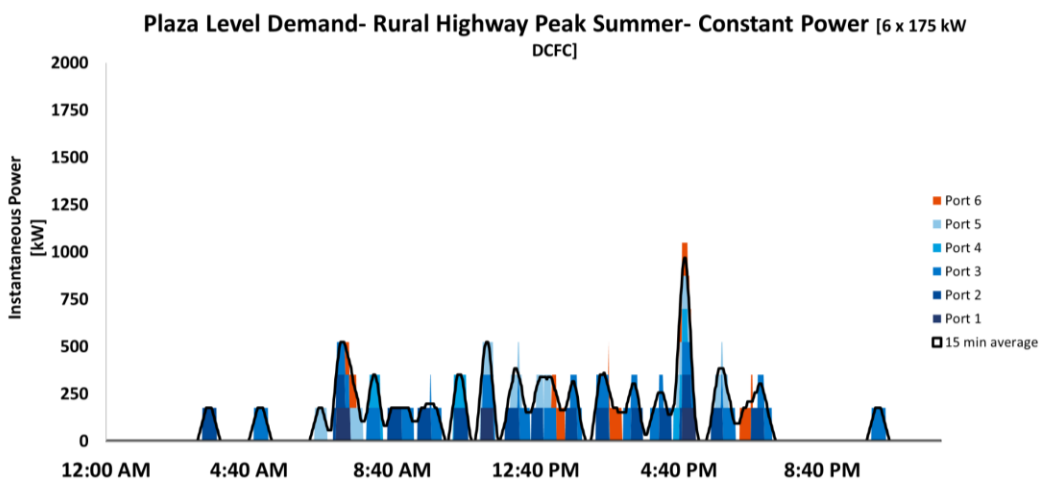


Figure 27. High Season Rural Highway Load Profile; 100 kW DCFC output, constant 100 kW vehicle charging.

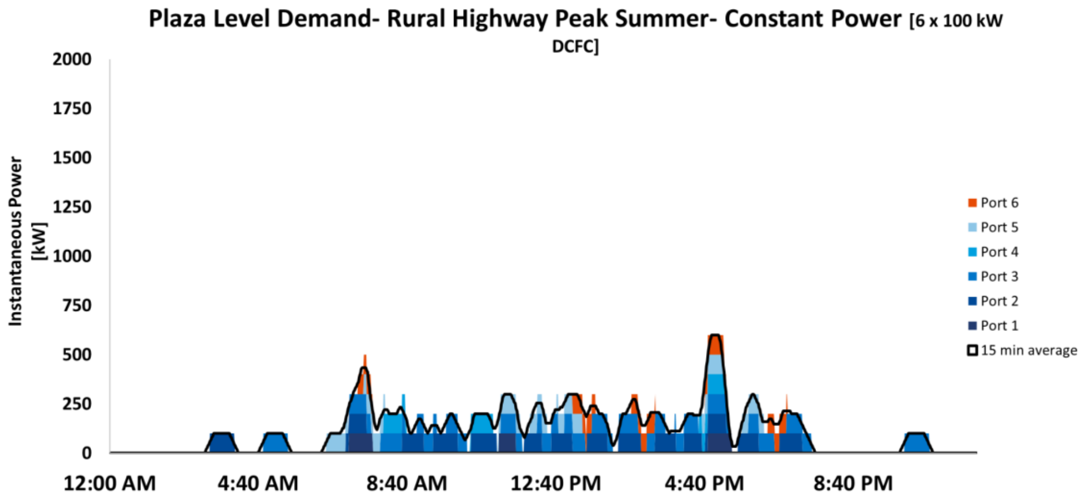
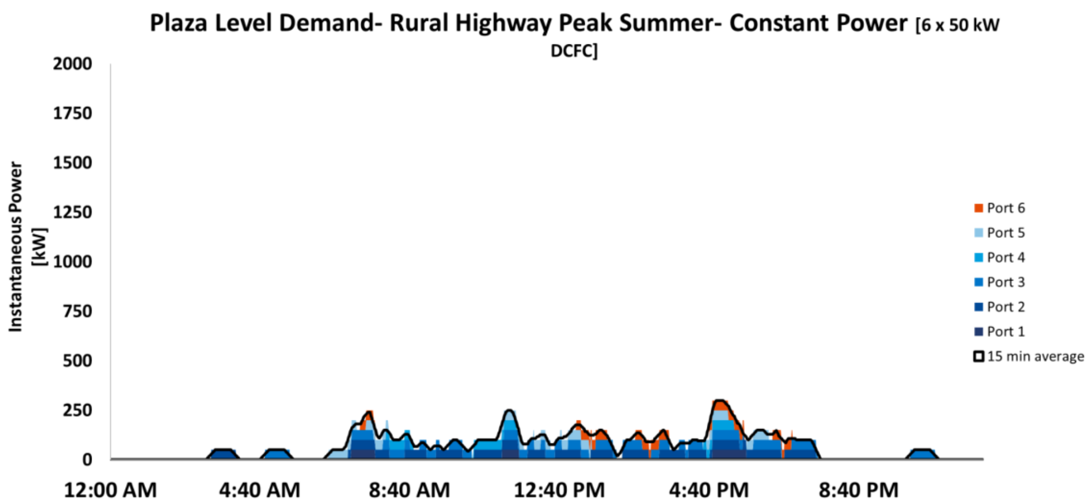
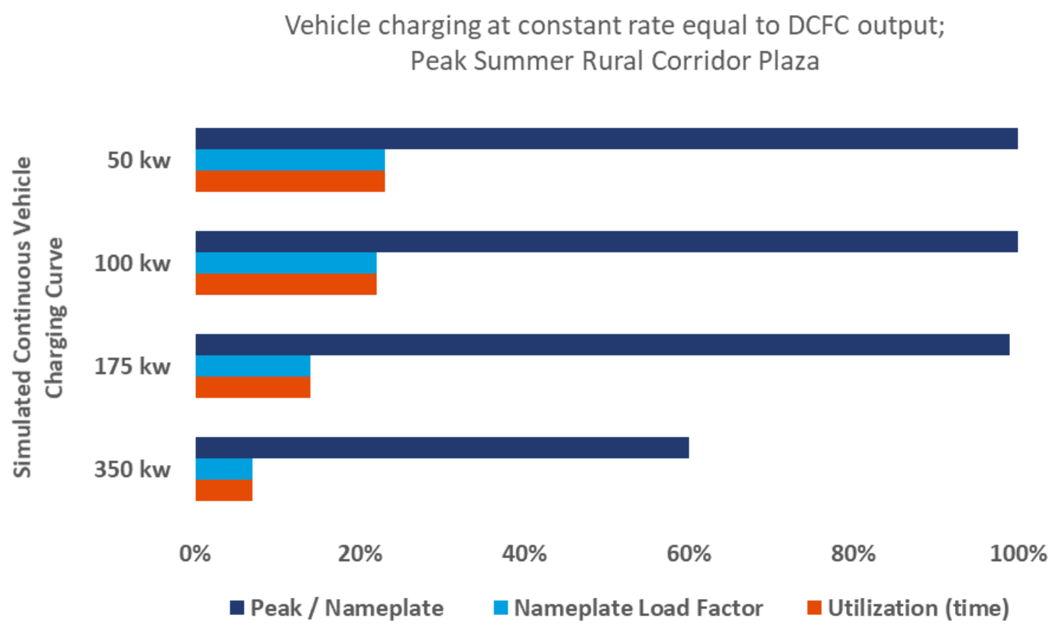


Figure 28. High Season Rural Highway Load Profile; 50 kW DCFC output, constant 50 kW vehicle charging.



The example scenarios shown above demonstrate that as vehicle charging power increases, the observed peak demand increases, although not directly proportionally. Additionally, the ratio of peak demand to nameplate capacity (e.g. observed peak demand / nameplate system capacity) still remains relatively low at 60% for the 350-kW output scenario, increases to 92% in the 175-kW scenario, and reaches 100% for both 100 kW and 50 kW constant power scenarios. This occurs because as the charging output power increases, the duration of each individual session decreases and the probability of overlapping sessions (coincident demand) decreases. Figure 29 shows how the fraction of peak nameplate capacity and nameplate load factor decrease as power output increases. Notably, when vehicles charge at constant power equal to the DCFC output capacity, the nameplate load factor and utilization converge to the same value.

Figure 29. Utilization summary for vehicles charging at constant power equal to the DCFC output capacity.



Vehicles Charging Limited by DCFC Output Power

To explore the impacts of increasing DCFC output capacity on load profiles (while keeping vehicle charging curves as a limiting factor) we evaluated charging scenarios with DCFC output capacity of 50 kW, 100 kW, 175 kW, and 350 kW. Modeling different DCFC output capacities allows one to explore at what level of DCFC output the charger output rating is significantly impacting vehicle charging needs. This exercise demonstrates that as DCFC output increases from 50 kW to 350 kW, vehicles transition from being DCFC limited to vehicle charge curve limited. This transition happens between the 50 kW to 100 kW scenarios while there is minimal variation in load profile comparing 100 kW, 175 kW, and 350 kW scenarios. We further evaluate the implications for nameplate load factor and utilization of installed peak nameplate capacity summarized in Figure 34.

The figures below provide a simulated example of how load profile is impacted by DCFC output capacity. Figure 30 shows the load profile for a busy retail plaza with 10 - 350 kW DCFC ports where the vehicle charge curve determines charging power. The subsequent figures 31, 32, and 33 show what the load profile would look like if the ports were limited to 175 kW, 100 kW, and 50 kW respectively. In all scenarios below, the vehicle charges at either the lower of the DCFC output capacity or the vehicle charge curve for that specific vehicle SOC. Note the almost imperceptible change between 350 kW and 175 kW, the minimal change between 175 kW and 100 kW, and significant change at a DCFC output capacity of 50 kW. The minimal changes between the DCFC output scenarios is due to the limited ability of the vehicles to pull large amounts of power; many of the current vehicle charging capabilities have maximum power draws below 150-200 kW and maintain the majority of their charge session below 150 kW.

Figure 30. Busy Retail Plaza Load Profile; 350 kW DCFC output, normal vehicle charging curves.

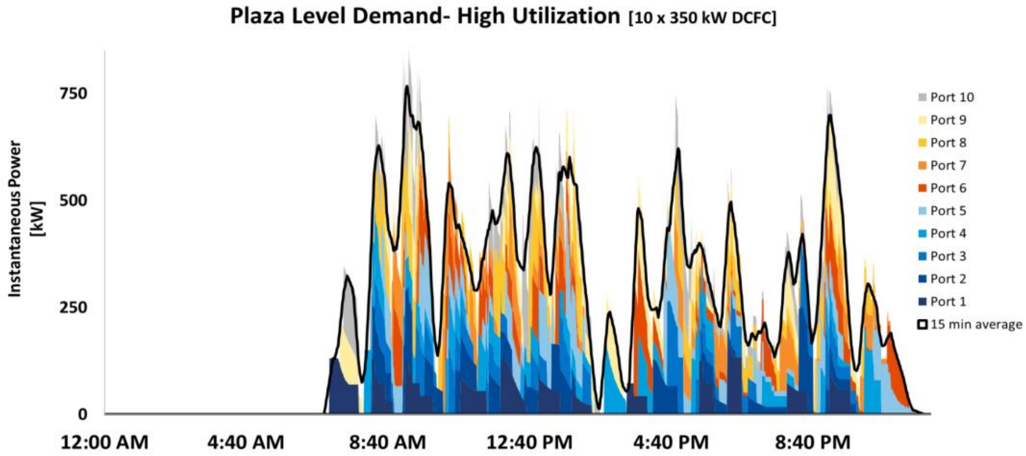


Figure 31. Busy Retail Plaza Load Profile; 175 kW DCFC output, normal vehicle charging curves.

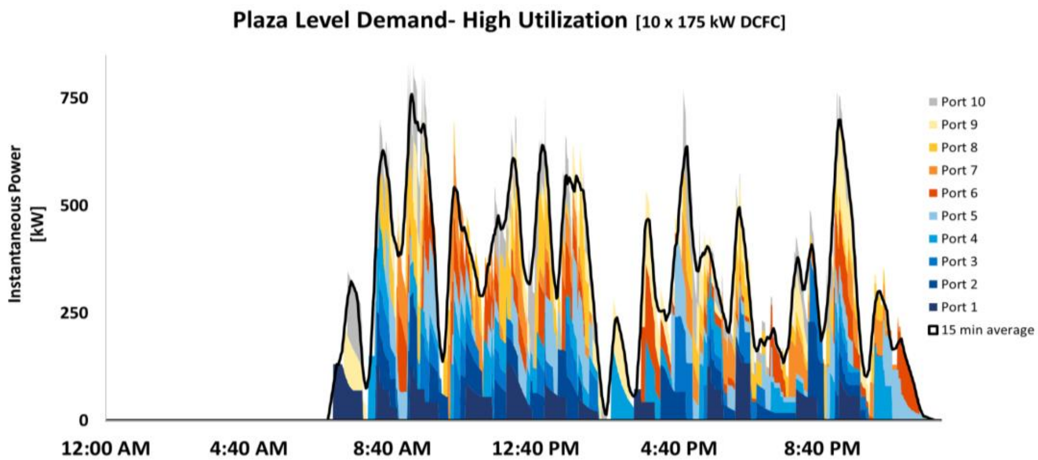


Figure 32. Busy Retail Plaza Load Profile; 100 kW DCFC output, normal vehicle charging curves.

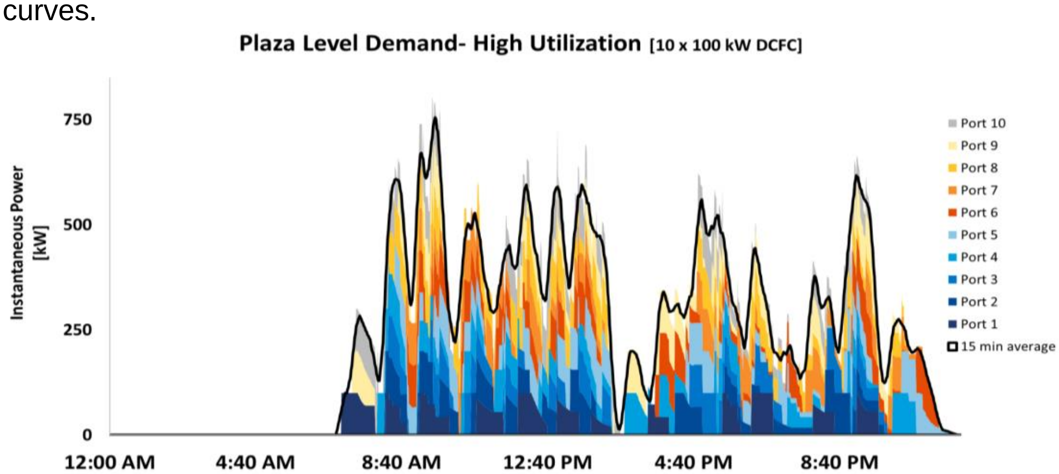


Figure 33. Busy Retail Plaza Load Profile; 50 kW DCFC output, normal vehicle charging curves.

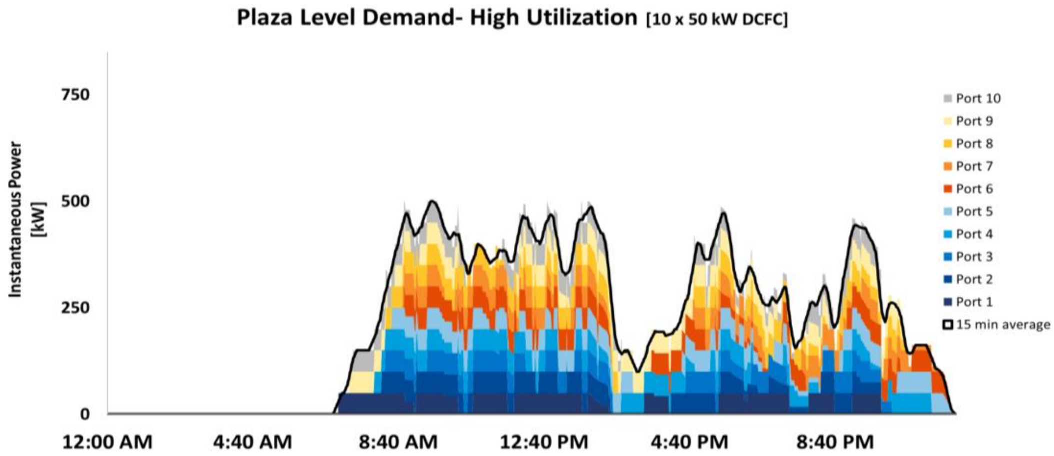
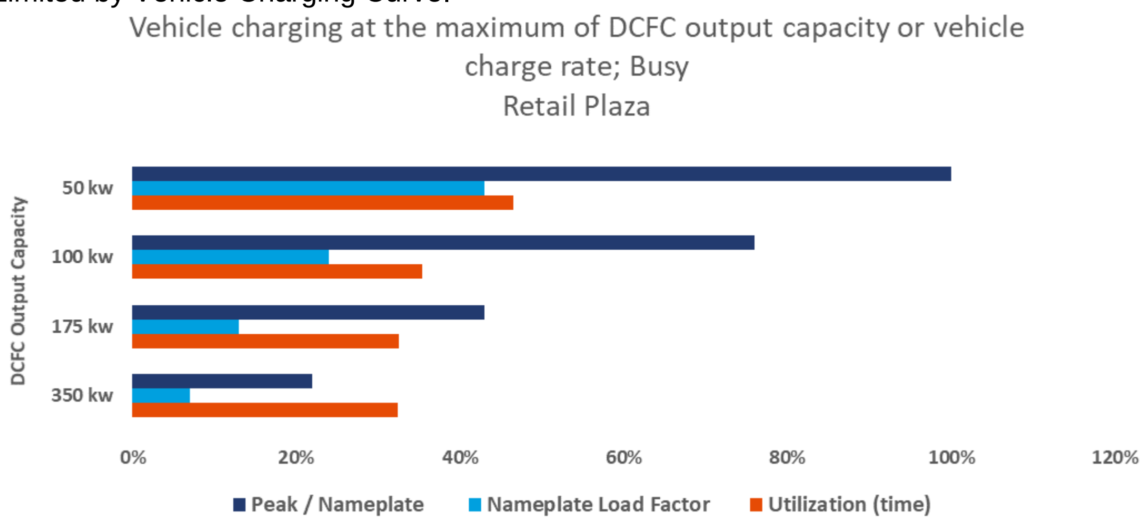


Figure 34. Utilization Summary for Vehicles Charging at Different DCFC Output Capacity Limited by Vehicle Charging Curve.



Modeling a future where cars are not the limiting factor and can accept the full charger output for the duration of the charging session helps us anticipate what may happen to nameplate load factor and utilization of peak nameplate capacity as battery technology improves. Figure 34 clearly demonstrates how nameplate load factor and utilization of peak nameplate capacity decrease significantly as DCFC output capacity increases, while the utilization (time based) is far less sensitive to DCFC output capacity. As DCFC output capacity increases, the time spent to achieve the customers desired range decreases and the likelihood of overlap of charging events is reduced.

These results demonstrate that modeling exercises that do not incorporate a SOC dependent charging curve (by assuming constant output vehicle charging) may have significant impacts on results and could lead to both overestimation or underestimation of aggregate station level demand depending on the utilization of chargers and the degree of coincident charging sessions.

Conclusion

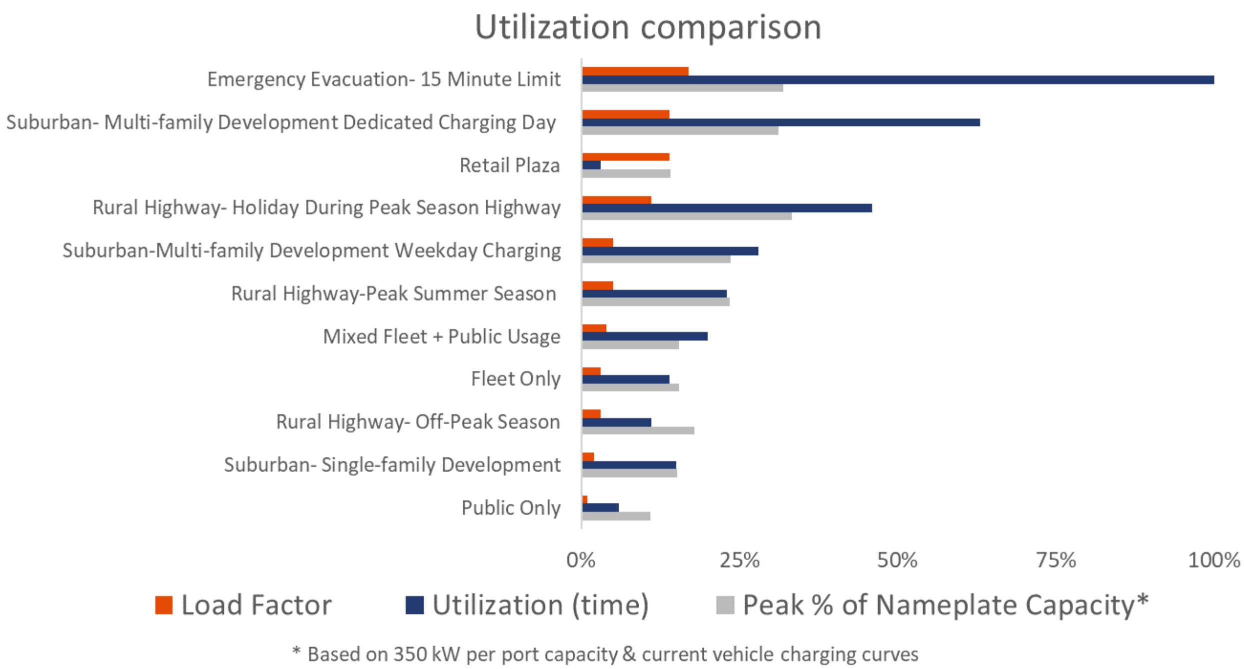
The growing diversity of vehicle charging capabilities and evolving customer charging behavior will continue to have meaningful implications for DCFC load profiles, asset utilization, and upstream utility infrastructure investment. Specifically, due to the tapered charge curve of nearly all currently available EV models, the station level nameplate load factors and ratio of peak demand to nameplate capacity are low and are expected to remain low for the foreseeable future. As Table 12 and Figure 35 show, the nameplate load factor is less than 14% in the typical charging scenarios evaluated in this report and only increases to 22% in the emergency scenarios where sites are used at full capacity (e.g. 100% utilization during time period of interest). The authors recognize the limitation of using modeled scenarios rather than real-world data and suggest that future research be conducted to expand and refine the observations presented in this work.

Table 12. Summarized Results.

Residential		Nameplate Capacity (kW)	Peak Demand (kW)	Peak % of Nameplate Capacity	Utilization (Time)	Load Factor (Capacity)
	Suburban SF	1400	210	15%	15%	2%
	Suburban MF (weekday)	1400	330	24%	28%	5%
	Suburban MF (weekend)	1400	440	31%	63%	14%
Fleet						
	Fleet Only	1750	270	15%	14%	3%
	Public Only	1750	190	11%	6%	1%
	Fleet + Public	1750	270	15%	20%	4%
Rural						
	Rural off-season	2100	375	18%	11%	3%
	Rural peak-season	2100	490	23%	23%	5%
	Rural holiday	2100	700	33%	46%	11%
Retail Plaza						
	Normal Retail Plaza	3500	490	14%	3%	14%
Evacuation						
	15 minute sessions	3500	1,120	32%	[redacted]	17%
	20 minute sessions	3500	1,110	32%	[redacted]	21%
	75% SOC	3500	1,100	31%	[redacted]	22%

Even as vehicle charging curves evolve and are able to accept higher peak powers, as long as power remains a function of state of charge, we can expect charging stations to experience peak loads that are lower than the nameplate capacity rating. This remains true as utilization increases due to the shorter duration of charging sessions and decreased likelihood of coincident peak charging events. The scenarios presented in this report are helpful to demonstrate the importance of differentiating utilization from nameplate load factor. **However, their usefulness is limited due to the assumption-based methodology used here and these load profiles and data should not be used for actual system planning.** It will become increasingly important for stakeholders to share load profiles, utilization, nameplate load factor, and other relevant metrics with utilities and regulators as they plan for growing demand for new or expanded electricity service.

Figure 35. Scenario Summary - Utilization, Nameplate Load Factor, Peak Demand.



Key Observations and Conclusions

For Modeling and Forecasting:

- Electric vehicles sales are gaining momentum and as more OEMs offer new makes and models, forecasting site utilization will become more complicated.
- Utilization is a helpful metric for customers and DCFC operators as it indicates the likelihood of queuing for the customer and the revenue for the DCFC operators. Nameplate load factor is far more important and relevant to utilities. Nameplate load factor and utilization are not and should not be interchangeable given current vehicle charging characteristics.
- As long as vehicle load curves remain a function of battery SOC and are not constant for the duration of charging, it is important to differentiate utilization from nameplate load factor. System planning should account for charging powers dependency on state of charge.
- Charging behavior (arriving with a low vs. medium SOC) has meaningful implications for nameplate load factor and peak demand.
- Nameplate load factors are likely to remain low even if utilization increases with growing EV adoption.

- If today's vehicles could charge at a constant high-power rating equivalent to the DCFC output (above 175 kW) the utilization and nameplate load factor would converge and decrease.

For Utility Planning:

- Access to real-world data on load shapes, nameplate load factors, and utilization will be extremely valuable to utilities as they plan to serve new EV charging loads.
- Even in the most extreme examples of ten hours of 100% utilization, the current fleet of vehicles did not exceed 1,100 kW for a 10-port system and nameplate load factors never exceeded 25%.
- With the current charging capabilities, charging site's will rarely, if ever, be able to reach their nameplate capacity. In the short-term utilities should consider planning infrastructure upgrades to accommodate actual peak demands. In the long-term, utilities will need to consider how changes to charging characteristics will affect site utilization and the ability to reach a site's nameplate capacity, and subsequently, the effects it will have on the broader grid.

For Solution Providers:

- Utilities can only go off the charge curves that they have today, and if OEMs can predict the state of charging in the future, e.g. 800 kW charging, they should inform utilities and charge point operators as early as possible.

For Site Owners:

- Customer charging habits can fluctuate throughout the year and cause spikes in a site's peak demand. Site owners should analyze how charging at their site will change throughout the year and prepare for the impact this may have on setting the site's monthly bill.
- The industry cannot only rely on expecting increased utilization to solve these business economic problems.[15]
- Energy consumption and peak demand will have different impacts on the site's monthly bill. Managed charging strategies such as using staggered charging, utilizing on-site battery storage, or throttling the charge sessions can decrease monthly bills. Managed charging strategies can be deployed both manually and through optimization software systems.

[15] Borlaug, B., Yang, F., Pritchard, E., Wood, E., & Gonder, J. (2023). *Public Electric Vehicle Charging Station Utilization in the United States.* Transportation Research Part D: Transport and Environment, 114. https://doi.org/10.1016/j.trd.2022.103564

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Appendix A: Scenario Design Assumptions

Limitations of a Scenario Based Approach

While a scenario-based approach to DCFC (Direct Current Fast Charging) load profiles provides valuable insights and allows modelers to test assumptions and sensitivity, it is not without limitations compared to real-world data. Given the limited availability of minute-by-minute public DCFC load profiles, the approach presented here is a practical and useful option for the industry better understand the nuances of DCFC load profiles until data is made available. Scenario-based approaches rely on predefined scenarios that may not capture the full range of real-world variability, potentially leading to biased or inaccurate results. The approaches used in this research effort are based on assumptions and simplifications that may not fully capture the complexity and dynamics of actual charging behavior. Therefore, future research is warranted to enhance findings by integrating more real-world data, which can provide a more comprehensive and accurate understanding of DCFC load profiles.

Residential Charging

SEPA designed the residential charging scenarios so that DCFC ports would be primarily deployed to support BEV charging within a single neighborhood, consisting of single-family or multi-family dwellings. As a reference, SEPA presumed the neighborhood in the residential charging scenarios to be in suburban California, a state which was chosen due to its high EV market share.[16] This choice allows the scenario to illustrate the impacts of residential charging in the near future as BEV market share increases across other states.

BEV Selection

To determine a load curve for the residential charging scenarios, SEPA considered what the breakdown of BEVs using a charging port might be on any given day. To determine this breakdown, SEPA referred to a recent analysis of used car sales from June 2021 through May 2022, which determined that in California, 36% were SUVs, 48.6% were cars, and 11.7% were trucks, and the remaining 2.3% were minivans.[17] SEPA developed a list of BEVs that matched this breakdown, and randomly selected vehicles from that list when developing the residential charging scenarios.

[16] EVAdoption. (2022, April 26). *EV Market Share by State.* Retrieved January 3, 2023, from https://evadoption.com/ev-market-share/ev-market-share-state/

[17] Blackley, J. (2022). *Which vehicle type is the most popular in each state? Which Vehicle Type is The Most Popular in Each State?* iSeeCars. Retrieved January 3, 2023, from https://www.iseecars.com/popular-vehicle-type-by-state-study

Charging Volume

To determine the volume of BEVs that would use the charging ports throughout the day, SEPA made a few assumptions based on existing fueling data for ICE vehicles. First, SEPA assumed that the average convenience store sells about 130,000 gallons of gas per month and that customers purchase an average of 8.8 gallons per fill-up.[18] Based on this, an average retail gas station would expect to serve ~492 vehicles per day. Next, SEPA found that California had 10,100 retail gas stations and 36,750 Electric Vehicle Supply Equipment (EVSE) ports.[19,20] SEPA assumed an average of six pumps per gas station to determine a ratio of gas pumps to retail EV chargers of ~1.65:1. Therefore, the analysis assumes that a similar retail charging station with six ports would be expected to serve 812 vehicles per day. The market share of BEVs in California is approximately 5.16%, and SEPA determined that a four-port residential EV charging station would be expected to serve 42 vehicles per day.[21] SEPA used this value as the base assumption for charging volume in multi-family residential charging scenarios.

For the single-family residential scenario, SEPA assumed that 46% of BEV owners would have the ability to charge an electric vehicle at work or home and would not need to rely on the commercial charging ports.[22] SEPA reduced the charging volume accordingly. For the charging day, SEPA assumed that double the charging occurred, back-to-back throughout the course of a day. This scenario was built to symbolize weekend charging when BEV owners can spend longer periods of time at charging ports in preparation for vehicle use throughout the week. SEPA assumed that BEV owners that charge during the charging day also have very drained batteries and start their charge sessions with low SOCs.

Load Shape

To demonstrate how a load curve might look for different residential charging scenarios (i.e. single-family residential, multi-family residential, or “charging day”), SEPA varied charging volume and temporal charging patterns. Across all scenarios, SEPA aligned temporal charging patterns to fuel purchasing data from the NACS February 2022 Consumer Fuels Survey:[23]

- 21% buy gas at 6:00-10:00 am
- 37% buy gas at 10:00-3:00 pm

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18 National Association of Convenience Stores. (2019, March). *Consumer Behavior at the Pump.* NACS. Retrieved January 3, 2023, from https://www.convenience.org/Topics/Fuels/Documents/How-Consumers-React-to-Gas-Prices.pdf

19 Public Retail Gasoline Stations by State and Year. (2014). [Dataset]. Alternative Fuels Data Center. https://afdc.energy.gov/files/u/data/data_source/10333/10333_gasoline_stations_year.xlsx

20 U.S. Department of Energy. (2023, January 4). *Alternative Fueling Station Counts by State*. Alternative Fuels Data Center. Retrieved January 3, 2023, from https://afdc.energy.gov/stations/states

21 EVAdoption. (2022, April 26). *EV Market Share by State*. Retrieved January 3, 2023, from https://evadoption.com/ev-market-share/ev-market-share-state/

22 National Association of Convenience Stores. (2022, May 19). *Convenience stores sell the most gas. convenience.org*. Retrieved January 3, 2023, from https://www.convenience.org/Topics/Fuels/Who-Sells-Americas-Fuel

23 Ibid.

- 33% buy gas at 3:00-7:00 pm
- 9% buy gas at all other times

For the residential scenarios, SEPA assumed that BEV owners would charge their vehicles in a similar manner, and ensured that charging was distributed as such.

Mixed Use Fleet + Public

SEPA designed the mixed-use fleet and public scenario to illustrate how public and fleet charging can be complementary to one another. SEPA designed the scenario to analyze how a fleet DCFC location would be utilized if it was located near a residential subdivision zone, where this specific fleet would be located within a few miles of a medium sized residential zone with approximately 35,000 residents and a mix of single-family and multi-family residential homes.

BEV Selection

To determine a load curve for both the public charging scenario, SEPA used a randomized mix of the vehicles used in the model. In a medium-sized city, SEPA expects there to be a wider range of EVs available to the public and wanted the model to reflect the randomness of vehicles that could visit this DCFC site.

For the fleet vehicles, SEPA picked a pick-up truck with a 125-kWh battery to see how a larger vehicle with a high-power charging curve would influence the fleet's charging sessions. The selected pick-up truck was the closest vehicle to a mid-sized fleet truck that had charging curves available to the public and ready to use in the excel model.

Charging Volume

Due to the location of the fleet warehouse, SEPA assumed that the scenario's public charging component would be comprised of residents from the area. SEPA designed this scenario to analyze a state with middle of the road EV adoption that was less than 1%.[24] Among these residents, SEPA assumed that those in single-family housing would only top-off once a week at the DCFC and those in multi-family housing would charge twice a week with 50% or lower starting SOC. Additionally, SEPA assumed that approximately half the EV residents had another public charger they preferred to use, which further decreased the public utilization of the site.[25]

The fleet charging volume should remain consistent and reflects daily usage of the EV batteries. SEPA assumed that each of the 20 fleet vehicles would need to charge at least once a day and would have fairly low starting SOCs after the vehicle had been used all day.

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[24] Doll, S. (2022, August 24). *Current EV registrations in the US: How does your state stack up and who grew the most YOY?* Electrek. Retrieved January 18, 2023 from https://electrek.co/2022/08/24/current-ev-registrations-in-the-us-how-does-your-state-stack-up/

[25] Fuels Institute. (2021, June). *EV Consumer Behavior*. Retrieved January 18, 2023 from https://www.fuelsinstitute.org/Research/Reports/EV-Consumer-Behavior/

Load Shape

For the public charging data, SEPA aligned temporal charging patterns to fuel purchasing data from the NACS February 2022 Consumer Fuels Survey:[26]

- 21% buy gas at 6:00-10:00 am
- 37% buy gas at 10:00-3:00 pm
- 33% buy gas at 3:00-7:00 pm
- 9% buy gas at all other times

SEPA assumed that BEV owners would charge their vehicles in a similar manner, and ensured that charging was distributed as such.

In contrast, SEPA designed the charging patterns for the fleet to reflect the needs of a small business. The business would charge during the night-time and early morning hours and would not charge during the peak hours of 5-8 pm. The fleet would randomly charge during the day so the small number of day-time charging sessions occur between 11-2 pm when the driver would come back for a break.

Rural Highway

The rural highway charging scenarios assume that DCFC ports would be deployed at an existing gas station to support BEV charging along a major interstate highway passing through a rural region. Throughout most of the year, these DCFC ports would see limited usage primarily from regional rural travelers. On weekends or during seasonal peaks, the ports would see increased volume from interstate travelers that would increase charging volume. As a reference, the location of the rural charging scenarios is based on the EV market shares of the ten states with the most rural residents, according to the US Census Bureau.[27] This choice may help users to consider the impacts of rural charging in other states or regions with significant rural populations, limited local EV market share, and short-term charging volume peaks resulting from through traffic.

BEV Selection

To determine a load curve for the rural charging scenarios, SEPA considered the potential breakdown of BEVs using a charging port on any given day. To determine this breakdown, SEPA referred to a recent analysis of used car sales from June 2021 through May 2022. The analysis determined that in the ten states used as a reference for the rural scenarios, roughly 46% were SUVs, 27% were cars, and 27% were trucks.[28] SEPA developed a list of BEVs that

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[26] Ibid.

[27] U.S. Census Bureau. (2021, October 28). *2010 census urban and Rural Classification and Urban Area Criteria*. Census.gov. Retrieved January 3, 2023, from https://www.census.gov/programs-surveys/geography/guidance/geo-areas/urban-rural/2010-urban-rural.html

[28] Blackley, J. (2022). *Which vehicle type is the most popular in each state? Which Vehicle Type is The Most Popular in Each State?* iSeeCars. Retrieved January 3, 2023, from https://www.iseecars.com/popular-vehicle-type-by-state-study

matched this breakdown and randomly selected vehicles from that list when developing the rural charging scenarios.

Charging Volume

To determine the volume of BEVs that would use the charging ports throughout the day, SEPA made a few assumptions based on existing fueling data for ICE vehicles. First, SEPA assumed that the average convenience store sells about 130,000 gallons of gas per month and that customers purchase an average of 8.8 gallons per fill-up.[29] Based on this, an average retail gas station would expect to serve ~492 vehicles per day. Next, SEPA found that the ten rural states had an average of 1,967 retail gas stations and 457 EVSE ports.[30,31] SEPA assumed an average of six pumps per gas station to determine a ratio of gas pumps to retail EV chargers of ~28.5:1. Therefore, the analysis assumes that a similar retail charging station with six ports could serve 14,012 vehicles per day. Based on the market share of BEVs in those rural states, about 0.49%, SEPA determined that a six-port residential EV charging station would be expected to serve 48 vehicles per day.[32] This value was used as the base assumption for charging volume in the high tourism season rural highway charging scenario.

For the off-season tourism rural highway scenario, SEPA assumed that traffic would be reduced by about 50% with fewer interstate travelers contributing to charging volume. SEPA reduced the charging volume accordingly. For the holiday weekend rural highway scenario, SEPA assumed that double the amount of charging would occur over the course of a day, as a significant increase in long-distance interstate travelers drives up charging volume. This scenario considers that BEV owners have been traveling longer distances and must recharge their vehicles from a heavily drained state in order to continue their trip.

Load Shape

To demonstrate how a load curve might look for different rural charging scenarios, SEPA varied charging volume and temporal charging patterns. Across all scenarios, SEPA aligned temporal charging patterns to fuel purchasing data from the NACS February 2022 Consumer Fuels Survey:[33]

- 21% buy gas at 6:00-10:00 am
- 37% buy gas at 10:00-3:00 pm
- 33% buy gas at 3:00-7:00 pm

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[29] National Association of Convenience Stores. (2019, March). *Consumer Behavior at the Pump.* NACS. Retrieved January 3, 2023, from https://www.convenience.org/Topics/Fuels/Documents/How-Consumers-React-to-Gas-Prices.pdf

[30] Public Retail Gasoline Stations by State and Year. (2014). [Dataset]. Alternative Fuels Data Center. https://afdc.energy.gov/files/u/data/data_source/10333/10333_gasoline_stations_year.xlsx

[31] U.S. Department of Energy. (2023, January 4). *Alternative Fueling Station Counts by State*. Alternative Fuels Data Center. Retrieved January 3, 2023, from https://afdc.energy.gov/stations/states

[32] EVAdoption. (2022, April 26). *EV Market Share by State*. Retrieved January 3, 2023, from https://evadoption.com/ev-market-share/ev-market-share-state/

[33] Ibid.

- 9% buy gas at all other times

For the scenarios, SEPA assumed that BEV owners would charge their vehicles in a similar manner, and ensured that charging was distributed as such.

Emergency Pre-evacuation

SEPA designed the emergency pre-evacuation to test how a DCFC site would support pre-evacuation, back-to-back charging. The scenario is designed to represent a medium-sized city in zones with high evacuation rates and high EV adoption. The emergency pre-evacuation scenarios use a retail plaza site, but their load patterns are unique to customer behaviors during an emergency pre-evacuation.

BEV Selection

To determine a load curve for both the retail plaza and emergency pre-evacuation scenarios, SEPA used a randomized mix of the vehicles used in the model. In a medium-sized city, SEPA expects there to be a wider range of EVs available to the public and wanted the model to reflect the randomness of vehicles that could visit this DCFC site.

Charging Volume

The emergency pre-evacuation scenario does not utilize normal customer behaviors and instead examines the impact that 400 vehicles charging back-to-back would have on the site. SEPA assumed that customers would be willing to wait for long periods of time to charge and that the chargers would quickly fill up once the evacuation order went out. Due to the design of the emergency pre-evacuation scenario, this scenario uses ten DCFC ports given that emergency planners would have identified larger DCFC sites as pre-evacuation charging sites.

SEPA designed the retail site to represent a mixed-use plaza with many amenities including a grocery store, many restaurants, a movie theater, and a variety of retail stores. Due to the varied amenities in the plaza, the DCFC would be used by a variety of customers. While other scenarios utilize customer fueling habits, SEPA assumed that the DCFC use would reflect customers' shopping habits.[34] A report from the Idaho National Laboratory indicated that popular public charging stations at retail stores and shopping malls could serve between 7 to 11 charges per day.[35] This retail scenario uses an average of 5 charges per port per day, for a total of 50 charge sessions, to examine how slightly lower usage would affect the site's utilization.

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[34] Union of Concerned Scientists. (2019, July). *Electric Vehicle Survey Findings and Methodology.* Retrieved January 3, 2023, from https://advocacy.consumerreports.org/wp-content/uploads/2019/07/ConsumerReports-UnionofConcernedScientists-2019-EV_Survey-7.17.19.pdf

[35] Idaho National Laboratory. (2015). *Plugged In: How Americans Charge Their Electric Vehicles*. Retrieved January 3, 2023, from https://inldigitallibrary.inl.gov/sites/sti/sti/7323604.pdf

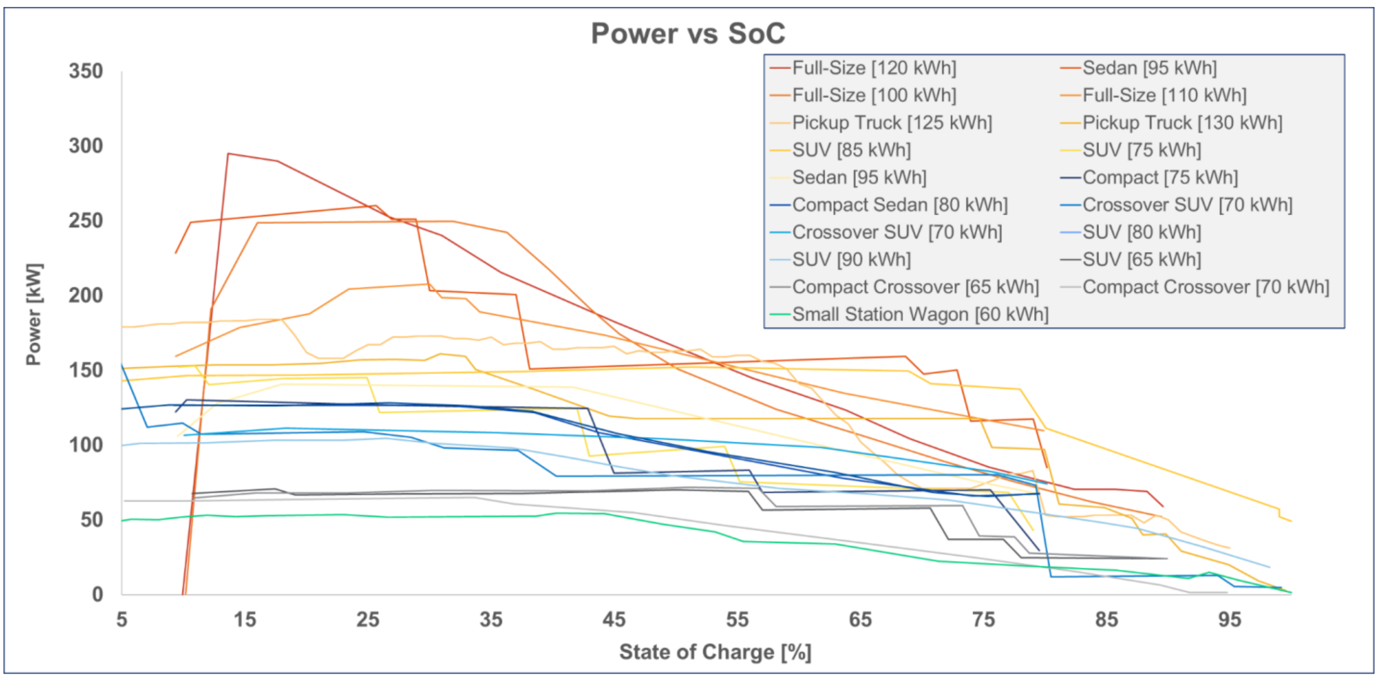
Load Shape

To demonstrate how a load curve might look for a retail plaza, SEPA based the charge session times on a mixture of shopping and movie going habits. In contrast to quick fueling sessions, shoppers average 135 minutes at the mall[36] and movie-goers spend an average of 2 hours and 15 minutes.[37] Additionally, people tend to shop around 12-3 pm[38] with a spike around 4-6 pm.[39] For movie-goers, SEPA assumes that the most popular times for movies are around 6:30-7:30 pm, when most people have had a chance to grab dinner before the movie. For this retail plaza, the load shape follows:

- 25% from 7:00-10:00 am
- 35% from 10:00-3:00 pm
- 24.75% from 3:00-6:00 pm
- 15.25% from 6 pm to 1 am

Appendix B: BEV Charging Curves

Figure 36. Power draw of individual vehicles compared to their current state of charge.



36 International Council of Shopping Centers Consumer Engagement Survey (2017). *Time Well Spent.* Wall Street Journal. Retrieved January 2, 2023, from https://partners.wsj.com/icsc/shopping-for-the-truth/time-well-spent/article

37 Statistica. (2021). *Average length of the top 10 highest-grossing movies in the United States and Canada from 1980 to 2021.* Retrieved January 13, 2023, from https://www.statista.com/statistics/1292523/lenght-top-movies-us/

38 Koenig, R. (2021, January 12). *The best times to go grocery shopping - and other ways to shop like a pro.* Today. Retrieved January 13, 2023, from https://www.today.com/food/best-time-go-grocery-store-worst-t205526

39 Fisher, L. (2022, July 22). *This is the best time of day to grocery shop*. Real Simple. Retrieved January 13, 2023, from https://www.realsimple.com/food-recipes/shopping-storing/food/best-time-to-grocery-shop