Baseline Multi-Unit Dwelling Charging Infrastructure Data Analysis

Vehicle Charging Innovations for Multi-Unit Dwellings (VCI-MUD)
Award Number: DE-EE0008473

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<u>*Prepared for*</u>
U.S. Department of Energy, Vehicle Technologies Office

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PROJECT OBJECTIVES

Vehicle Charging Innovations for Multi-Unit Dwellings (VCI-MUD) seeks to address the barriers to electric vehicle (EV)[1] charging at MUDs. The project developed a Multi-Unit Dwelling EV Charging Toolkit that includes all the information necessary (e.g., technical considerations, business case, sample agreements, and sample policies) to evaluate and implement innovative, cost-effective, and flexibly-expandable charging solutions to build and grow EV charging systems to serve MUD residents. The project results, findings, information, and the Multi-Unit Dwelling EV Charging Toolkit will be broadly disseminated to ensure the project has a meaningful impact on the market.

OVERVIEW

This document describes:

1) The Project Schedule
2) Data Diversity
3) Baseline Data Provider Recruiting
4) Data Provider Data Sharing Agreements
5) Data Parameters and Other Collected Information
6) EV Charging Session Summary Data Collection Period
7) EV Charging Session Summary Data Storage Methodology and Security
8) EV Charging Session Summary Data Analysis
9) Qualitative Baseline Data Aggregation and Analysis
10) Conclusions

A companion document (*Charging Infrastructure Technology Pilot Demonstration Plan*) describes: 1) the process to finalize the list of innovative technologies to be included in the demonstration phase, 2) the Innovative Technology Demonstration Planning process, and the 3) Pilot Demonstration Implementation.

Project data providers include data owning organizations that: 1) committed to provide owned EV charging station usage data during the project proposal to the U.S. Department of Energy (DOE) and 2) organizations who agreed post-proposal submission to provide data to the project. Organizations that committed to provide data during the proposal include: 1) the City of Los Angeles Bureau of Street Lighting, Electric Vehicle Institute, FreeWire Technologies, OpConnect, PowerFlex Systems, Rocky Mountain Power, St. John Properties, Liberty Plugins, and Cyber Switching Solutions.

The project is leveraging the established robust stakeholders' networks of the project partners (Center for Sustainable Energy (CSE), Energetics, and Forth), the partner Clean Cities Coalitions (Figure 1), and the Project Advisory Committee members to identify additional data providers during the project period.

Project data includes: 1) EV charging station, also referred to as electric vehicle supply equipment (EVSE), demonstration host site information, 2) EVSE specification information, 3) charge session summary data, and 4) 15-minute interval data (if available). These data categories are described in more detail in this

[1] In this report, the term EV includes both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs).

document. The collected data analysis were used to determine: 1) MUD resident charging infrastructure use patterns, 2) operating characteristics, 3) business case, and 4) potential areas for improvement.

The collected data is being managed pursuant to both the CSE-managed Data Management Plan guidelines and the Data Sharing Agreement between Energetics and each data provider organization.

Energetics is leading the project's EV charging station data collection, data analysis, and data results reporting. Idaho National Laboratory (INL) is providing Energetics and the project with technical direction and best practices for data collection, storage, cleaning, and analysis techniques.

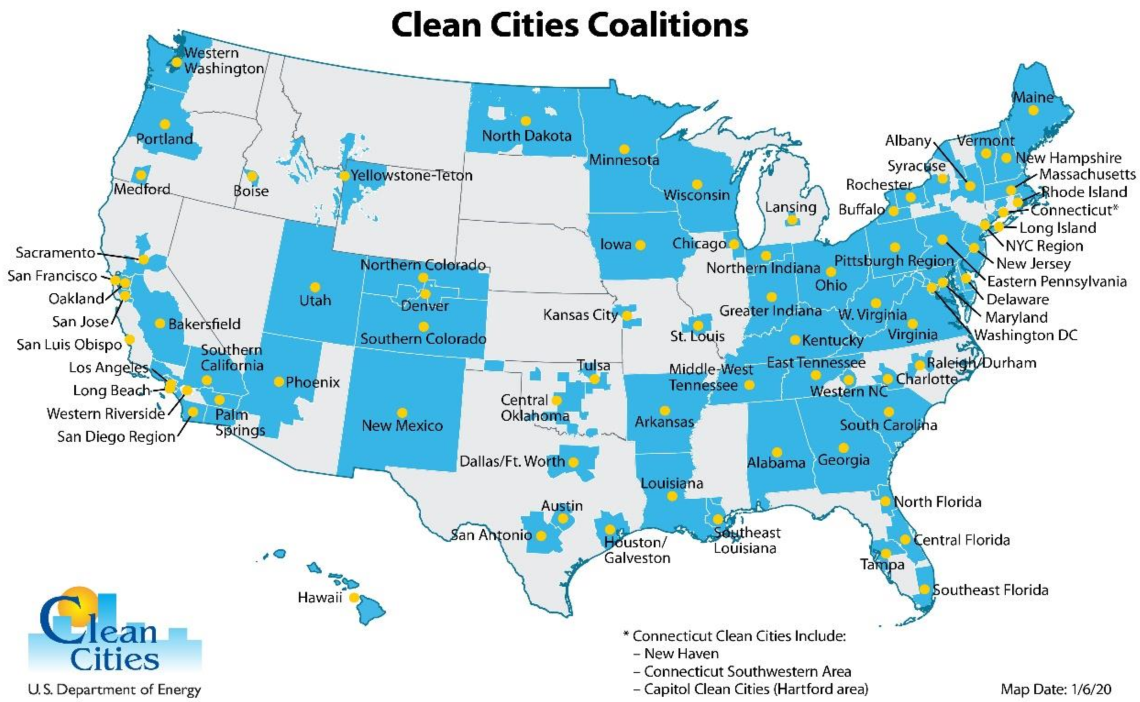

Figure 1. Clean Cities Coalitions participating in the VCI-MUD project

PROJECT SCHEDULE

The project schedule is shown in Figure 2.

- The baseline period data collection and analysis occurred in Budget Period 1, Task 1
- The charging infrastructure innovations demonstration planning occurred in Budget Period 1, Task 2
- The pilot charging infrastructure innovations demonstration deployment, field evaluations of the technologies, and data analysis evaluations occurred in Budget Period 2, Task 3
- The findings from the baseline data analysis were included in the Multi-Unit Dwelling EV Charging Toolkit in Budget Period 2 and 3

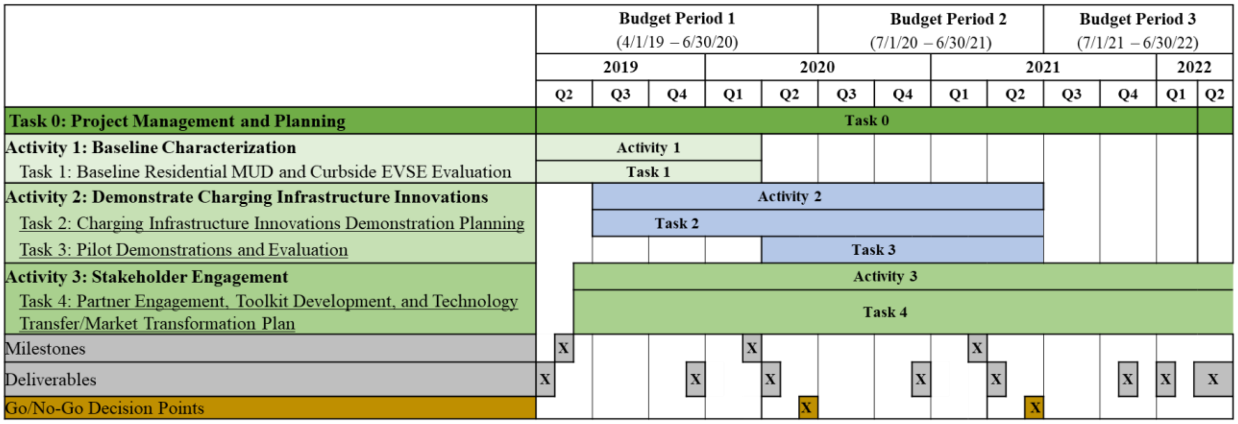

Figure 2. Project schedule

DATA DIVERSITY

The project sought to collect a representative dataset to characterize the baseline condition of non-single-family residential charging. The final dataset includes data from: 1) the committed data partners and 2) data partners recruited during the project using project team member and Clean Cities Coalition connections and outreach. The goal was to collect a diverse dataset that included different sizes of MUD properties (e.g., small to large) and different parking situations (e.g., open, restricted, and dedicated parking spaces, and curbside residential parking). The final collected data set characteristics depended on the identified data providers and where the EVSE are located.

The data collection targeted collecting data from a range of MUD property types (condominiums and apartments) across a spectrum of property sizes (such as “large”, “medium”, and “small”). The difficulty securing data led to a smaller amount of data than originally anticipated. The amount of data and information provided about the MUD properties were not detailed enough to determine trends by property type or size.

Input from data providers that are EV charging network providers (OpConnect and Electric Vehicle Institute) showed that EV charging stations installed off-property, but nearby MUD properties were also regularly being used by MUD residents. These “MUD-Supporting” EV charging stations were not installed to primarily serve MUD residential EV customers, however, the data providers indicated that their data analysis showed that some EV charging stations are regularly used by local residential customers. Location examples include, but are not limited to, EVSE located: 1) on public property such as libraries and parks, 2) at strip malls, and 3) at mixed-use building parking such as residential and commercial. These MUD-Supporting EV charging stations are an interesting approach to MUD resident parking since the installation and operations logistics are handled by a third-party. So, these stations were included in the analysis, separated from the MUD property located stations.

BASELINE DATA PROVIDER RECRUITING

Baseline data providers included data-owning organizations that: 1) committed to provide owned EV charging station usage data during the project proposal to the DOE and 2) organizations who agreed during the project to provide data.

Committed Data Providers – Organizations that committed to provide data during the proposal include: 1) the City of Los Angeles Bureau of Street Lighting, Electric Vehicle Institute, FreeWire Technologies, OpConnect, PowerFlex Systems, Rocky Mountain Power, St. John Properties, Liberty Plugins, and Cyber Switching. (Underlined text indicates pilot demonstration period only.)

Data Risk Management Approach – For any data provider that committed to provide data as cost share, but did not provide sufficient data, or was unable to continue participating in the project, CSE engaged with data provider(s) identified during the project (see the *Additional Data Provider Recruiting* subsection directly below) to discuss/negotiate their formal commitment to provide data to make up any lost data.

Additional In-Project Data Provider Recruiting – The project leveraged the established robust stakeholders' networks of the project partners (CSE, Energetics, and Forth, and Clean Cities Coalitions) and the Project Advisory Committee members to identify additional data providers during Budget Period 1 (*Baseline Characterization*) to increase the amount of charging session data and diversity of the dataset. The information below summarizes the major areas of data provider recruiting.

Discussed Data-Sharing with Replacement Organizations for Committed Project Advisors
(*Note:* underlined indicates data was shared)

- GIV Development (replaced a portion of the Rocky Mountain Power Data)
- Salt Lake City (replaced a portion of the Rocky Mountain Power Data)
- Bozzuto Management Company (replaced St. John's Properties Data)

Discussed Data-Sharing with Committed Project Advisors
(*Note:* underlined indicates data was shared)

- Baltimore Gas and Electric
- ComEd
- New York State Energy Research and Development Authority
- Ross Group
- Electrify America

Clean Cities Coalition and National Association of State Energy Officials (NASEO) Outreach
(*Note:* underlined indicates data was shared)

- Tasked with recruiting MUD and curbside residential EVSE data partners
- City of Chicago EVSE reimbursement program (55 MUD sites)
- King County Housing Authority (Washington state)
- Virginia Clean Cities – 20 MUD sites identified
- Sacramento Metropolitan Air Quality Management District (EV Car Share Program)
- NASEO sent multiple emails/mentioned the project's data needs to its stakeholders on web conference call meetings → The State of Hawaii followed up with interest in supporting the project. Follow-up calls were made to introduce the team to key relevant local stakeholder organizations.

Expanding Utility Engagement (seeking connection to the larger parent companies and data)

- Rocky Mountain Power → PacifiCorp
- Baltimore Gas and Electric → Exelon Corporation
- ComEd → Exelon Corporation

Additional Outreach

- EVSE manufacturers – Clipper Creek
- EV Charging Network Providers – SemaConnect
- Property Management Companies – Avalon Bay Communities, Friedkin Property Group, and AXA Realty
- Additional Innovative Technology Manufacturers – Liberty Plugins, PowerFlex Systems, Xeal Energy, ampUp, and EverCharge
- Property Management Industry Organizations – Building Operators and Managers Association (BOMA) (headquarters and chapters near project hubs), National Apartment Association (headquarters and chapters near project hubs), International Facilities Management Association (IFMA) (headquarters and chapters near project hubs)

Targeted sites that met the following criteria:

1. Site host/data provider that agreed to share EVSE charging session summary usage data with the project
2. EV charging station(s) located at a MUD as an ideal location → Considered EVSE within ½ mile of a MUD
3. Ideally a minimum of four charging ports at a location. However, the project was cognizant of the fact that four charging ports is not realistic for many sites. So, data providers with fewer were evaluated to determine if they should be included in the project.
4. EVs actively use the charging ports at least daily
5. EV charging stations collect session-level data including:
    - Charge session start/end time
    - Power flow start/end time
    - Energy dispensed
    - Maximum power level
    - Anonymous user identification (ID) number
6. EVSE Location (address & latitude/longitude), EVSE Site Name, and usage fees (if applicable and sharable)

DATA PROVIDER DATA SHARING AGREEMENTS

Formal data sharing agreements were executed with each data provider prior to each organization's sharing data with Energetics and the project. The agreements define: 1) what data was included, 2) if PII was shared, how PII would be handled and safeguarded, 3) how the data would be used, 4) who can access/use the data, 5) the data provider's responsibilities, and 6) Energetics' responsibilities. INL's experience collecting end-user EV charge session data showed that the agreement mechanism used should be flexible to meet the data provider's needs. A non-disclosure agreement that included the key data sharing agreement information was also developed, at INL's suggestion, and was used with some data providers.

DATA PARAMETERS AND OTHER COLLECTED INFORMATION

The EV charging station usage data collected included operational data (charge session summary data) and business case related data (where available) to characterize the current state of practice, the operating characteristics, business case, and to identify areas of improvement.

EVSE Host Site and EVSE Location Data

Since some data providers operate EVSE in different venues (e.g., MUD, workplace, and retail), data providers were requested to only share data for EVSE that are regularly used by MUD residents. Each data provider was asked to provide the following information (in an Energetics-provided spreadsheet file) for each EVSE for which data were shared. The EV charging station identification information parameters are shown in Table 1. Each line describes an individual EVSE. This data allowed the team to understand the location and usage characteristics of each EV charging station.

Table 1. Requested EVSE location information

Specific EVSE Identifier*	EVSE Location Name	Primary Use Type	Secondary Use Type (if relevant)	Parking Type	Additional Location Information**	Address	City	State	ZIP

* The "Specific EVSE Identifier" MUST match the EVSE identifier in the provided session data

** The "Additional Location Information" column allows for more description from the data provider

The Primary Use Type, Secondary Use Type (if relevant), Parking Type, and State fields were provided as dropdown menus to maximize the data consistency. The selections for each field are shown below:

- Primary Use Type – 1) Multi-Unit Dwelling (the desired use type), 2) Commercial, 3) Workplace, 4) Public (general public access including mixed use locations), and 5) Other**
- Secondary Use Type – 1) Multi-Unit Dwelling (the desired use type), 2) Commercial, 3) Workplace, 4) Public, 5) None, and 6) Other**
- Parking Type – 1) Street – Assigned, 2) Street – Unassigned, 3) Lot/Garage – Assigned, 4) Lot/Garage – Unassigned, 5) Lot/Garage – Valet, 6) Other**
- State – All 50 states, Puerto Rico and the District of Columbia

EV Charging Session Summary Data

Charge Session Summary Data consists of one line of summary data per charging event. The requested EV charging session summary data parameters are listed below.

Mandatory Charging Session Summary Data Parameters

The data parameters shown in Table 2 were identified as "mandatory" to ensure the project collected the base level of information that was needed to compare EVSE usage across data providers. The data parameters were selected based on the project team's experience collecting this information from leading EV charging station network providers. These base level parameters were selected because they: 1) should be available from all data providers, and 2) allow for a consistent dataset that is comparable across data providers. The exact data parameter names and formats differ by EV charging station network provider/data provider. The parameter names and format were adjusted for consistency in the data cleaning and aggregation process.

Table 2. Required minimum data parameters

Specific EVSE Identifier (*MUST match EVSE identifier in the provided Location Data)	
EVSE Location (address and latitude/longitude)	Session Start/End Time/Date
EVSE Location Name	Session Duration

EVSE Type (AC Level 1, AC Level 2, DCFC)	Charging Duration
EVSE Max Rated Power (kW)	Peak Power (kW)
Use fees (e.g., $/hour, $/session)	Total Energy Supplied (kWh)

Additional Charging Session Summary Data Parameters

The charge session parameters shown in Table 3. Additional requested data parameters were also requested if data providers had the data and were willing to share it.

Table 3. Additional requested data parameters

EV User ID#	Start State of Charge (SOC) and End SOC (if available) – or- Charge Type (Partial or Full)
User EV Make/Model	Session End Reason (Driver Removed Plug, Session Timeout, Network Issues, etc.)

15-minute interval data was also requested to better understand the temporal power consumption, but no data providers were able to share it with the project.

EV CHARGING SESSION SUMMARY DATA COLLECTION PERIOD

To maximize the amount of charging session data collected, the project collected both data generated during the project period and, where relevant, historical data.

EV CHARGING SESSION SUMMARY DATA STORAGE METHODOLOGY AND SECURITY

Energetics created a database (housed in a secure, access-controlled cloud-storage environment) to store the collected charging event and other program data. None of the data provided to the project included "personally-identifiable information" (PII).[2] No personal information was shared with Energetics. The data included an anonymous charging network User ID number. Energetics' results summaries do not include the anonymous User ID, or EVSE station ID number to maintain users' anonymity.

The raw data from each data provider are stored in this secure cloud storage environment. Access to the raw dataset is limited to 1-2 key Energetics transportation data analyst staff members. The data were manipulated using an "ETL" (extract, load, and transform) tool (e.g., Python programming language, including Jupyter, numpy, pandas, matplotlib, and seaborn). Energetics staff work on the user access-controlled dataset locally via a secure web interface.

[2] As defined in 2 CFR § 200.79 - Personally Identifiable Information (PII); https://www.govinfo.gov/app/details/CFR-2014-title2-vol1/CFR-2014-title2-vol1-sec200-79/summary and https://www.govinfo.gov/content/pkg/CFR-2014-title2-vol1/pdf/CFR-2014-title2-vol1-sec200-79.pdf.

EV CHARGING SESSION SUMMARY DATA ANALYSIS

Data Source Description

Several key data providers committed to provide MUD charging data to the project. Additional project outreach was performed to identify and secure additional data to augment the dataset. This effort has been challenging because MUD EV charging stations are not always publicly known by stakeholders or included in accessible databases. Some MUDs were located with non-networked EV charging stations. These EV charging stations do not collect the usage data, so these locations could not be used in the project for the baseline phase. EVSE data included a row summarizing each station and its attributes. Each row included a unique EVSE identifier, location name (a descriptive name that may be repeated among several stations that are side-by-side or at the same address), charging level (e.g., L2 or DCFC), max rated power in kilowatt (kW), street address, city, state, and ZIP code. A category for the station's primary use type (e.g., MUD) was also requested from data providers. However, many data providers did not provide this primary use type information due to lack of availability. Summary session data included a row summarizing each plug-in session. Each row included charging start and end times and plug-in start and end times from which charging duration and plug-in duration were derived. The amount of energy supplied during a session was provided in kilowatt-hours (kWhs). Lastly, each charging session also included an EVSE ID to link the charge session to its respective station and an anonymized User ID to link the charging session to an individual user. As of this writing, the project has obtained summary data for a total of 512,175 charge sessions from six data providers that include: 1) 1,474 EV charging stations (mostly AC Level 2), 2) 11 states and the District of Columbia, and 3) six (6) charging networks. The charging session data spans a period of approximately six years (2014 - early 2020). Data providers include EVSE charging network management companies, property owner/management companies, and state/local governments.

Analysis Methodology

The master dataset was manipulated using Python. The implemented data cleaning process ensures alignment of the individual data parameters is consistent with the combined dataset structure. Standard classifications for each data category were cross-referenced to produce an anonymized consistent dataset without PII, but with the appropriate characteristics to facilitate the data analysis. As part of the quality control procedures, Energetics used common accepted thresholds for EV and EVSE performance to identify and remove erroneous data points and to identify and correct inconsistencies. INL was consulted on the approach and thresholds. In some cases, data providers were contacted to answer questions about the data. Additional random data checks and quality assurance methods were used to ensure the data set is valid. Detailed quality control of each parameter of every charging event, however, is not cost-effective within the scope and budget for this project. The quantity, quality, and diversity of available data impact the analysis results. To the extent possible, Energetics quantified and reported on the level of data quality and diversity.

Removal of Outliers

Energetics received charging data from six data providers that included 1,474 EV charging station charge ports and included 512,175 charging sessions.

The first data analysis step was to remove outlier data. The data filters were selected based on Energetics' EVSE charging session data analysis project experience to exclude charging sessions with abnormal energy output and/or duration. The proposed data filters were discussed with project partner INL who agreed they were appropriate. The data filters applied to the data included: 1) maximum average charging session power, 2) maximum share of charging time, 3) minimum plug-in duration, and 4) minimum energy provided per charging session. Table 4 presents the outlier data filters that were used. The result rescreened a total of 79,312 plug-in events (15.5% of the total) by the outlier filters. After applying the data filters, the database contained 432,863 charging sessions.

Table 4. Charging session data excluded by data filters

Data Filter Description	Number of Charging Sessions Excluded	% of Total Charging Sessions Excluded
Average power > 500 kW	1,538	0.3%
Energy < 0.02 kWh	45,006	8.8%
Charging duration > Plug-in duration	34,772	6.8%
Plug-in duration < 3 minutes	42,961	8.4%
Charging duration < 0 seconds	67,012	13.1%
Combined rows removed by filter**	**79,312**	**15.5%**

*** Note: Some charging sessions were filtered out by multiple filters. The result*

MUD EV Charging Station and Charging Session Classification

As mentioned earlier, even though data providers were requested to only share data for EVSE that are regularly used by MUD residents, not all of the raw data provided was from MUD residents use at home. Complicating this situation, three data providers did not provide a venue/location type category associated with the EV charging stations. Attempts were made to collect this information from these three data providers, but the location/venue data was still not provided. This made it difficult to determine which EV charging stations were at/nearby MUD properties and, for the case of mixed-use EV charging stations, MUD resident EV charging sessions.

Charging sessions from the clean MUD stations charging session summary dataset were classified based on if they were known/believed to be MUD resident charging sessions. The EV charging stations in the dataset were analyzed and categorized into three groups: 1) MUD-Located EVSE – EV charging stations indicated as MUD stations by the data provider, 2) MUD-Supporting EVSE – EV charging stations located within 300 feet of a MUD property, and 3) all other Non-MUD Supporting EV charging stations. (The MUD-Supporting EV charging stations, described earlier, were not installed to primarily serve MUD residential EV customers. However, the data providers indicated that their data analysis indicated that some EV charging stations are regularly used by local residential customers. Only the MUD-Located EVSE and MUD-Supporting EVSE groups were considered for further analysis.

MUD-Located EVSE – Three data providers included an EV charging station location/venue category in their data. This data subset included 223 EV charging station charging ports that were located on a MUD property. A total of 23,925 charging sessions occurred at these 223 EV charging station ports located on MUD properties.

A conservative approach was taken to estimate which EV charging stations should be included in the MUD-Supporting EVSE group.

To inform this process, a literature review was performed to identify if information was available regarding acceptable distances that MUD residents are willing to regularly walk to use an off-property located MUD-Supporting EVSE. The research identified that there is no industry standard/typical for defining the accepted service radius from an EVSE. Of the 41 publications reviewed, only three references addressed this issue, with only one reference specifically considering potential MUD applications.

Several factors influence an EV owner's ability, or willingness, to walk to an EV charging station. These factors include, but are not limited to 1) age, 2) EVSE distance from home, 3) the terrain, 4) the time to walk, and 5) the weather conditions. The concept of an acceptable service radius around an EVSE is subjective, so is not consistent among all EV drivers.

A study conducted in in Vasteras, Sweden stated that the maximum distance an EV driver was willing to walk was 500 meters (~1,640 ft; 0.31 mi).[3] This statement is not supported by any EV owner input, and no information was provided to describe how this number was determined.

Data from a cohort survey of EV owners in California was gathered and studied to determine charging patterns and behaviors.[2] The survey had a response rate of 15% and asked EV drivers about their travel behavior, driving behavior, vehicle performance, vehicle characteristics, response to EV-related incentives, and charging behavior. Over 80% of the respondents had household incomes higher than the median income in California and owned a single-family home. This study considered two MUD residents related scenarios:

1) PHEV owners that lived in apartments within 300 meters (~985 ft.; 0.19 mi) of an AC Level 2 public EV charging station.
2) BEV owners that live within 300 meters (~985 ft.; 0.19 mi) of AC Level 2 or DC fast charging (DCFC) public station. The paper did not state why the study used a threshold of 300 meters (~985 ft.; 0.19 mi).

There was a significant effect on the choice of charging location for BEV owners living in apartments. This group of survey respondents charged their vehicles at their workplace and at public stations, likely due to a low availability of MUD-located EV charging stations.[4]

Another study that focused on EVSE in Lisbon, Portugal considered the coverage area radius of an EV charging station to be 400-600 meters (1,300-1,970 ft; 0.25-0.37 mi).[5] The maximum *desirable* walking distance was stated to be 400 meters (~1,300 ft.; 0.25 mi.), while the maximum *acceptable* walking distance was 600 meters (~1,970 ft.; 0.37 mi.). There was no derivation or description provided for either distance threshold.

A conservative radius of 300 feet from a MUD property to an EVSE was selected to use for the MUD-Supporting EVSE classification effort for this project. This low radius may screen out some EV charging stations and charging sessions, but Energetics felt that the error induced by increasing the radius, the

[3] Bian, C., Li, H., Wallin, F., Avelin, A., Lin, L., Yu, Z. (Aug 2018). *Finding the optimal location for public charging stations – a GIS-based MILP approach* (6586).
[4] Lee, Hyun L., Chakraborty, D., Hardman, Scott J., Tal, G. (Jan 2020) *Exploring electric vehicle charging patterns: Mixed usage of charging infrastructure*. (3, 11).
[5] Frade, I., Ribeiro, A., Goncalves, G., Antunes, Antonio P. (2011) *Optimal Location of Charging Stations for Electric Vehicles in a Neighborhood in Lisbon*, Portugal (95).

uncertainty of using mixed-use EV charging stations, and the lack of certainty about the actual EV charging station and customer information details was high so warranted this conservative approach.

MUD-Supporting EVSE Classification Approach

The GPS/street address location is known for each EV charging station. The locations of MUD properties are needed to determine the shortest distance between the pairs. In many cases, the MUD property location information is available in publicly available datasets that indicates the property address and use type (e.g., apartment, condominium, commercial, or retail); such as residential permit location data. Some data providers (e.g., City of Los Angeles Bureau of Street Lighting[6], Salt Lake City, and the Electric Vehicle Institute) had numerous EV charging stations in a single geography (e.g., a single city or state), so using this approach was feasible. Other data providers (e.g., OpConnect) operate nationally, so it was not feasible to locate residential permit location data (or similar) datasets for every EVSE location.

Using this approach, the dataset for each geography was filtered to identify MUD property addresses. The latitude and longitude coordinates for both the EV charging stations and MUD properties were imported into Python to analyze the data to determine the distance between each EV charging station and the nearest MUD property. The Python package *Scipy.Spatial* provides efficient computing when considering multiple sets of location coordinates. The built-in K-dimensional tree function was used to identify the nearest neighbor in a collection of points. This functionality was useful for this effort for identifying EVSE/MUD property pairs. K-dimensional trees evaluate a set of points and split the dataset in half at the median into two separate sets of points. The function continues this splitting process until the number of splits is equal to $\log_2(n)$; where n is the total number of points in the dataset. The following describes how this approach was applied to the Los Angeles dataset:

- The dataset included 2,628 apartment permits (n = 2,628).
- $\text{Log}_2(2{,}628) = 11.36$, so the K-dimensional tree function performed 11 splits of the dataset.
- Each EVSE will be in one sub-section of the K-dimensional tree.
- The Python algorithm calculated the distance between a given EV charging station and all the MUD properties within its sub-section.
- The shortest distance between each EV charging station and the nearest MUD property was determined and recorded.
- Distances were expressed in degrees of separation, which were converted to feet. Lines of longitude are widest at the equator and converge at the poles. So, the distance between degrees of longitude lines varies by latitude. The distance between degrees of longitude in Los Angles is approximately 92 kilometers (or 57.2 miles; 301,800 feet).

<u>Approach limitations/assumptions</u>

- The results provide the straight-line distance between an EV charging station and the nearest MUD property (i.e., rather than a walking route distance). It is unlikely that an EV driver will be able to walk in a straight line from their building to the EV charging station. So, the real-world walking distance may be 3-4 times further than the L-dimensional tree results because of the

[6] Building and Safety Certificate of Occupancy. https://catalog.data.gov/dataset/building-and-safety-certificate-of-occupancy (data.lacity.org).

layout of buildings, roads, sidewalks, etc. in that area. (Equating to 900-1,200 feet; 0.17-0.23 mi.) The conservative distance threshold was used because of this.

- The approach assumes that the publicly available datasets are accurate and include every MUD property in the coverage area.

Figure 3 summarizes all of the Station-to-MUD property distance for this example for a total of 285 EV charging stations. Figure 4 summarizes the Station-to-MUD property distance data but shows only up to 2,000 feet. For this example, the distance from MUD property to EV charging station ranged between 39 - 11,589 feet (2.19 miles). The mean distance was 1,510 feet (0.29 miles). Twenty-five percent (25%) of the EV charging stations were within 600 feet (0.11 miles) of a MUD property. Seventy-five percent (75%) of the EV charging stations were within 2,000 feet (0.38 miles) of a MUD property.

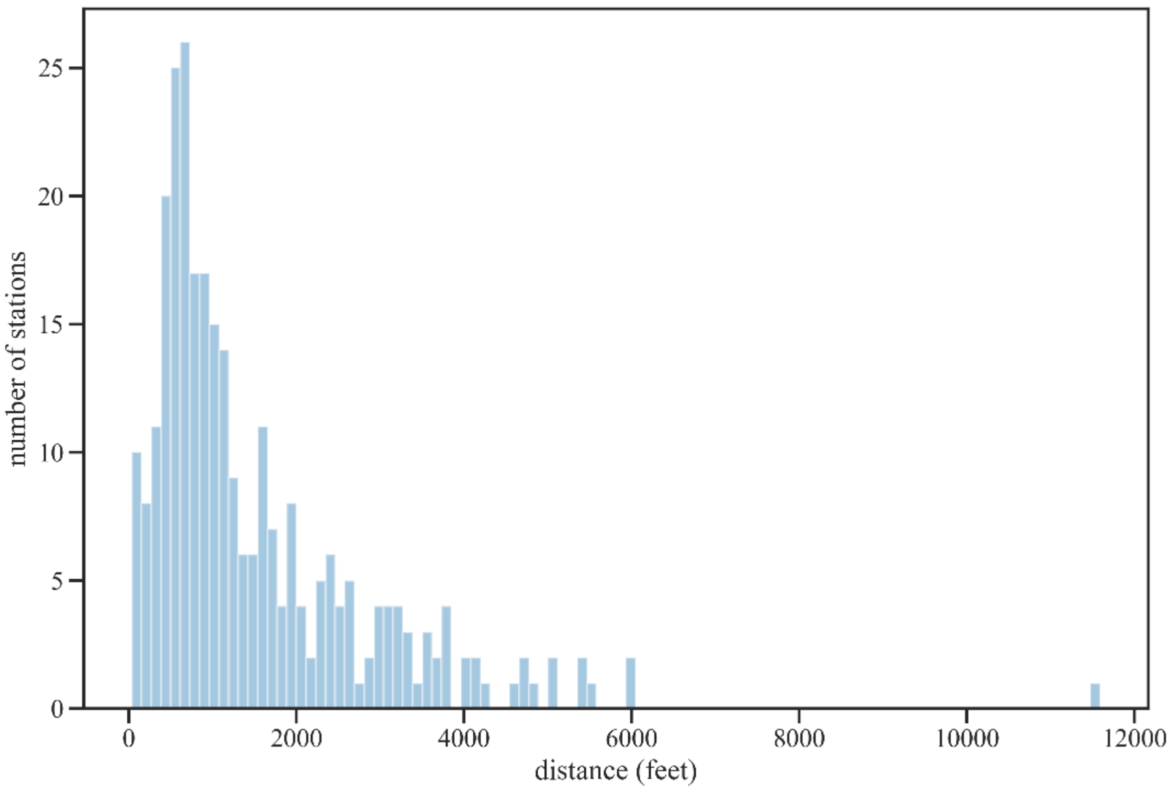

Figure 3. Distribution of EV charging station-to-MUD property distance

In total, this process was used to evaluate 347 EV charging stations (303 AC Level 2 and 44 DCFC) were evaluated. Only 33 EV charging stations (comprising 18,519 sessions) were determined to be within 300 ft of a MUD property. These following results show only the EV charging stations that fit this distance from a MUD property criteria. Since the EV charging station users are mixed-use (e.g., retail and MUD residential), additional filters were applied to the data to attempt to identify MUD resident charging sessions. A session start time filter window was also applied. Start times between of 6 PM and 12 AM (midnight) were selected. The earliest time of 6PM was selected to coincide with a typical/common time when people would start to return home after work. The latest session start time of midnight was selected. Since MUD residents are expected to frequently charge their vehicles at home, a repeat user filter was applied. It is unlikely that users with only two (2) or three (3) sessions are MUD residents. So, a more conservative (for the provided data) filter of at least 10 charging sessions was used.

- Total starting potential MUD-Supporting data – 110,545 sessions at 303 AC Level 2 EV charging stations.
- Remaining data after 300’ from MUD criteria – 18,519 sessions at 33 AC Level 2 EV charging stations.
- Remaining data after the time of day (6 PM – 12 AM) filter - 4,423 charging sessions at six (6) AC Level 2 EV charging stations.
- Remaining data after users with 10+ sessions filter – 262 users that produced 2,699 sessions at six (6) AC Level 2 EV charging stations.

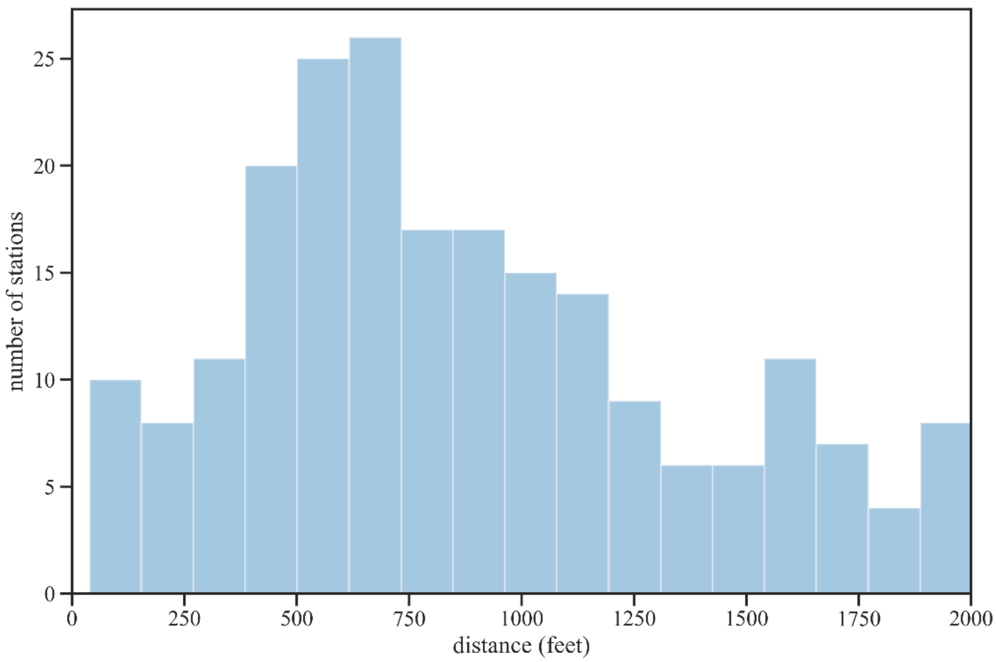

Figure 4. Distribution of charging station-to-MUD property distance (<2,000 ft)

These MUD-Supporting EVSE charging sessions were analyzed separately from the MUD-Located EVSE sessions. The purpose is to supplement the MUD-Located EVSE charging sessions. MUD sessions were analyzed separately from MUD-Supporting sessions.

DCFC Sessions

One data provider (Electric Vehicle Institute) provided charging session data for DCFC that were not installed on a MUD property. Many of these DCFC are located in urban areas. The company stated that internal data analysis that also used the user ID and home address seemed to indicate that the DCFC were being used by MUD-residents. So, a similar filtering approach to what was done for the AC Level 2 stations was used to identify what DCFC charging sessions could be classified as MUD-Supporting DCFC. The same 300’ from a MUD property filter was applied, however the distance from home may not be as relevant for DCFC charging since the charge sessions are short (~20 minutes). The same charge session start time of day filter was also applied; however, the start time may not be as relevant for DCFC charging since the charge sessions are short (~20 minutes) and users can quickly charge during their normal daily business. The data provided to Energetics did not include the user ID, so the repeat user filter could not be applied.

- Total starting potential DCFC MUD-Supporting data – 60,237 sessions at 44 DCFC EV charging stations.

- After 300' from MUD criteria – 9,626 sessions at 8 DCFC EV charging stations.
- After time-of-day filter - 2,022 charging sessions that began after 6 PM at 8 DCFC EV charging stations.

Final Dataset

MUD-Located AC Level 2 EVSE Data

As mentioned above, the MUD-Located AC Level 2 EVSE data subset included 223 EV charging station ports and included 23,925 charging sessions. Figure 5 summarizes the collected MUD-Located AC Level 2 charging *sessions*. MUD sessions were collected from eight states and Washington, DC, three data providers, and two charging networks over a period of approximately five years, with the bulk of the data in 2018-2020. A small percentage of the MUD charging sessions were not classified by charging type (denoted as "Unknown"). These charging sessions were not included in the charging type-specific visuals. These "Unknown" stations are believed to be AC Level 2 EV charging stations based on the products and services the data provider offers, however confirmation was not received to validate this.

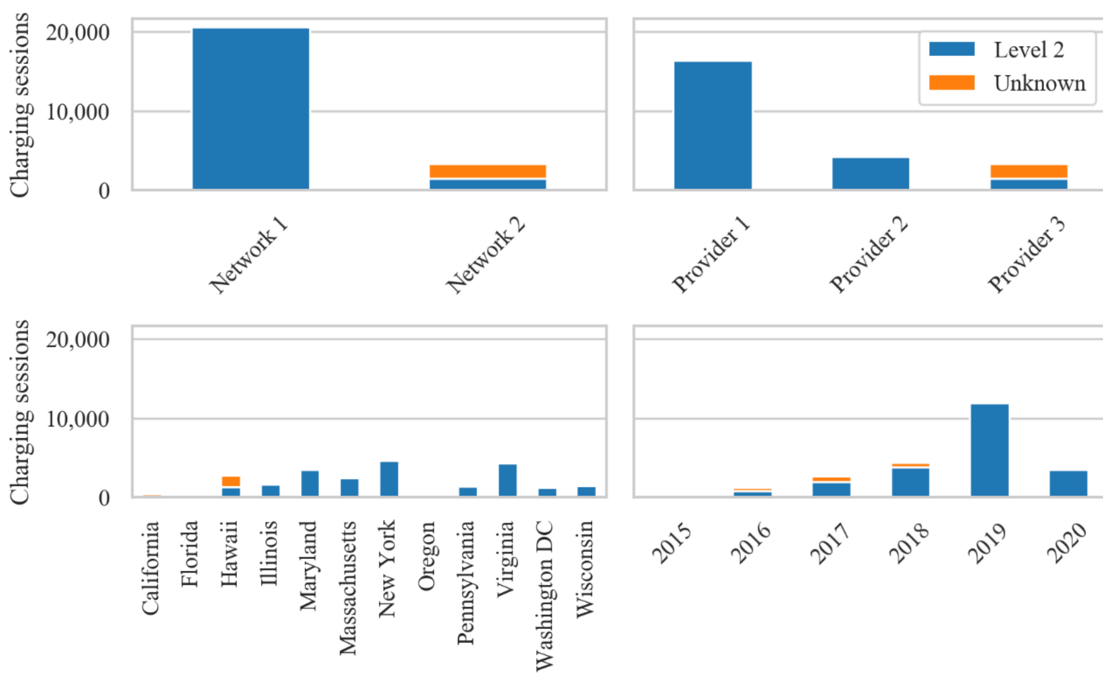

Figure 5. Total MUD-Located charging sessions by anonymized network, anonymized data provider, state, and year

Figure 6 summarizes the total MUD EV charging *stations* (versus sessions presented above) in the collected dataset, displayed by anonymized data provider, anonymized charging network, state, and year. The majority of the L2 charging sessions in the dataset are associated with Network 1.

A representative sample of EV charging sessions was sought, but the analysis was limited by the amount of actual MUD-Located charging stations and charging session data.

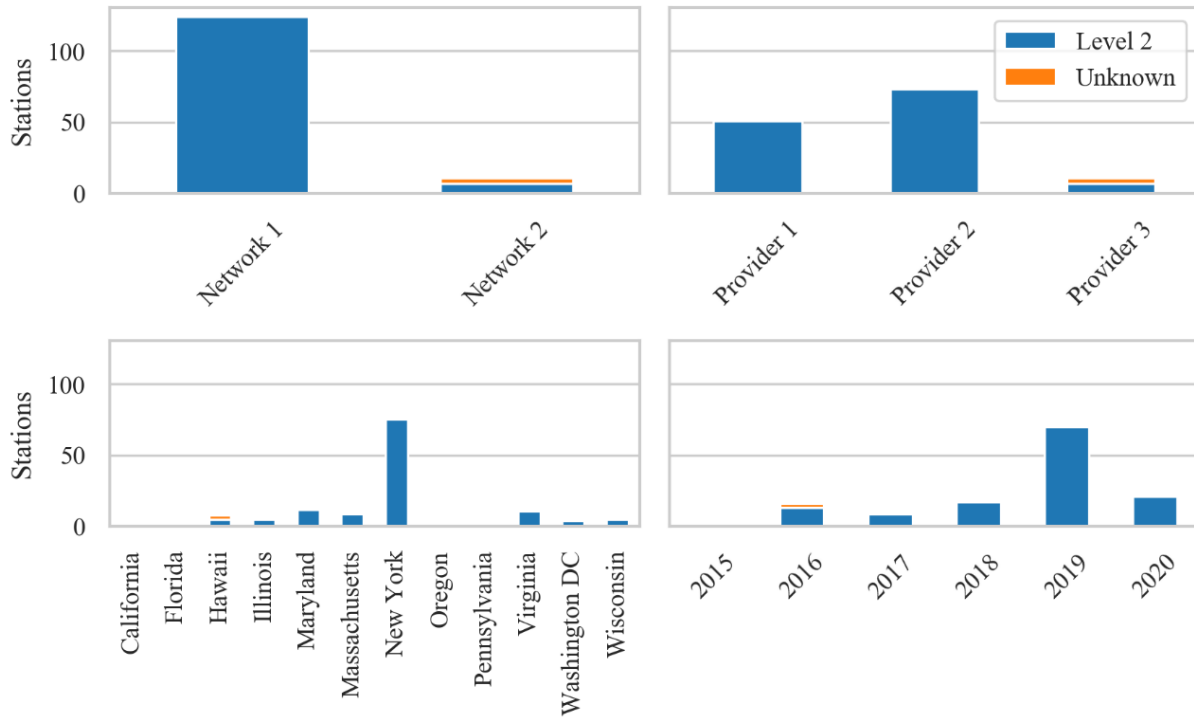

Figure 6. Unique MUD-Located EV charging stations by anonymized network, anonymized data provider, state, and year

The collected MUD resident EV charging sessions ware relatively evenly distributed across data provider and state, though Network 1 was a clear leader in the number of MUD charging sessions that were shared with the project. One point to note is that a number of the L2 stations were installed in 2020, so have not yet provided many charge sessions. Comparing Figure 5 and Figure 6 highlights several interesting differences between the total number of sessions per category and the number of unique stations per category. The relative even distribution of charging sessions across the states and most MUD-classified stations in New York seems to indicate low EV charging station utilization in New York. Similarly, most MUD charging sessions were provided by Network 1; however, the majority of MUD-classified stations were included in the Network 4 dataset. This can potentially be explained by the large number of Network 4 charge stations with low utilization rates. Further analysis of utilization by EV charging station is needed to better understand this.

MUD-Supporting AC Level 2 EVSE Data

MUD-Supporting AC Level 2 EV charging station session data were collected from only two states (as described earlier), two data providers, and one charging network over a period of approximately six years, with an increasing amount of data each year since 2015. The data summaries are shown in Figure 7 and Figure 8.

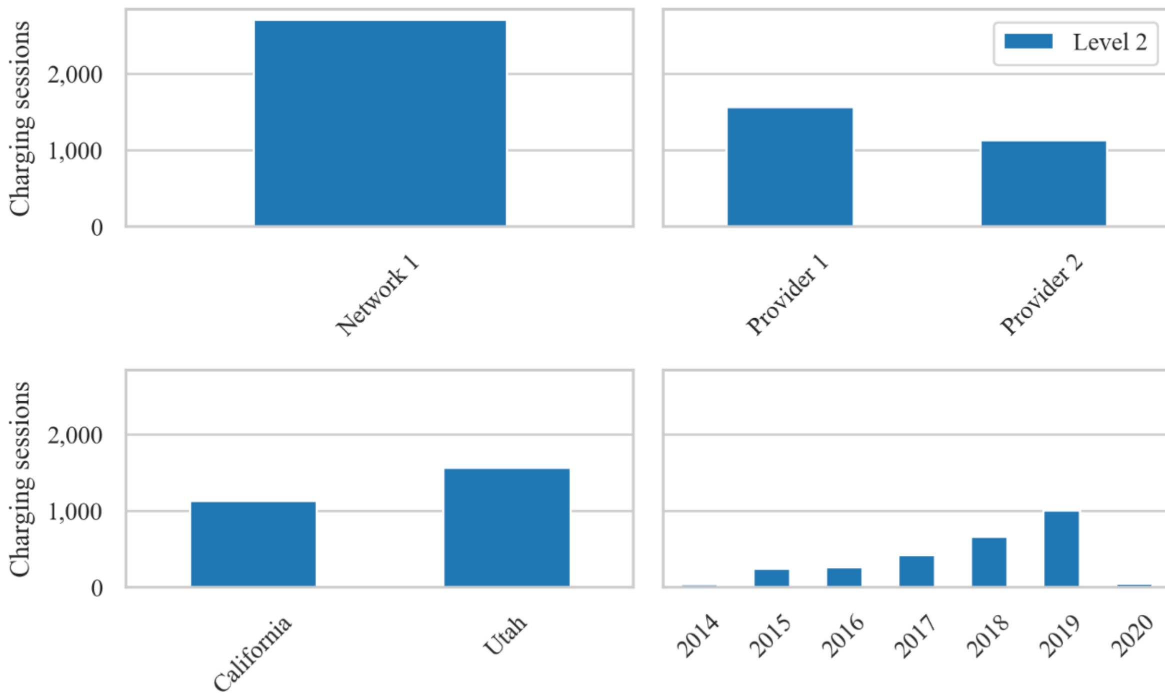

Figure 8. Total MUD-Supporting charging sessions by anonymized network, anonymized data provider, state, and year

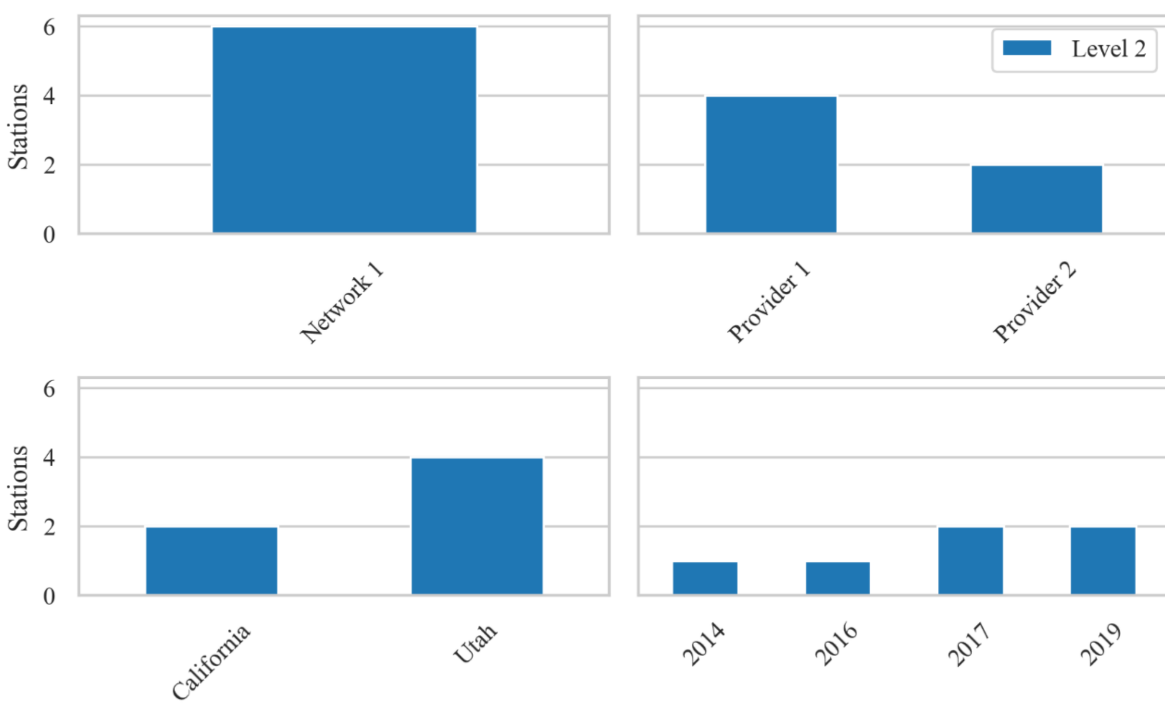

Figure 7. Unique MUD-Supporting EV charging stations by anonymized network, anonymized data provider, state, and year

DCFC MUD-Supporting EVSE Data

All DCFC MUD sessions are associated with a single data provider, network, and state. As expected with increasing number of EV charging stations and EVs, the amount of annual charging sessions increased by year.

EV Charging Station Usage Data Analysis

The anonymized and cleaned data sets described above were analyzed to characterize the baseline installations current state of practice and operating characteristics. Although the analysis used data from various locations across the country, the dataset is not comprehensive enough to develop comprehensive statistically-valid national conclusions.

MUD-Located AC Level 2 EVSE Analysis Results

The 23,925 charging sessions MUD-Located AC Level 2 EVSE charging sessions collected by the project were analyzed to determine usage patterns to characterize how MUD residents are using these EV charging stations. Figure 9 shows trends in total charge sessions and total energy usage over time at MUD-Located EV charging stations. There is an increase in both the number of charging sessions and the amount of total electricity provided by MUD EV charging stations every year. The increased growth rate starting in 2017 matches expectations from increased EV model availability and adoption. There is a positive correlation between the energy provided and the number of charging sessions over time (as time passed, more annual charging sessions provided more total energy). There is a clear and consistent relationship between the number of charging sessions and the amount of energy provided, with an average of approximately 18.4 kWh provided per charge. The hypothesis at the project outset was that MUD-Located AC Level 2 EV charging station session would frequently/typically last for many hours, likely overnight, to fully charge vehicles, so this is an interesting finding. This level of average MUD resident session charge is consistent with statements made by some of the project's innovative technology provider partners.

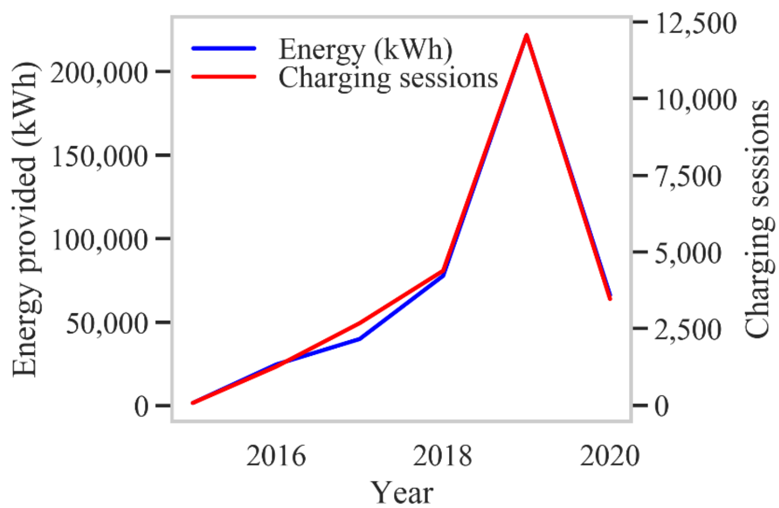

Figure 9. Historical trend of number of sessions and energy provided at MUD-Located AC Level 2 EV charging stations

The average weekly charging sessions per MUD-Located AC Level 2 EV charging station is shown in Figure 10. The apparent 2020 decrease is due to data reporting in early 2020. The increasing usage would seem to imply higher MUD resident EV adoption (assuming average energy requirements remained similar). The changes in the number of weekly charging sessions are likely highly-dependent on the locations (and their respective populations). An evaluation of the average charging sessions by state and year may shed some insight on these trends, however more data is needed.

The violin plots in Figure 11 show probability density functions for: 1) plug-in duration and 2) charging duration. The typical MUD-Located AC Level 2 charging session lasted an average of 12.2 hours and had an average charge duration of 3.6 hours, shorter than expected. The longer plug-in durations meet expectation for overnight charging sessions. The difference also highlights that energy is not being provided to the EVs for those entire plug-in sessions. The long period of time when charge is not being provided to the vehicle highlights the opportunity to increase EV charging station, or electric infrastructure utilization with software and hardware smart EV charging station technologies.

There were some outlier data in this data subset including five charging sessions that lasted longer than a week, one lasted one month. An AC Level 2 EV charging session chosen at random from the MUD-Located dataset would have a high probability of having a charging duration of less than 2.5 hours.

The violin plots in Figure 12 provide a similar view on the charging sessions but focus on the energy provided. The plots illustrate the variation between the energy provided per charging session and the charging session length. The plots show two probability density functions: 1) one for charging sessions where the plug-in duration/connection time equaled the charging time (orange), and 2) one for charge sessions where the plug-in duration/connection times were longer than the charging time (blue). The data profiles, averages, and interquartile range (i.e., 25%-75%), for both subsets are similar. The fact that the plots have similar profiles and summary parameters confirms the conclusion that energy is not being provided for the entire plug-in sessions.

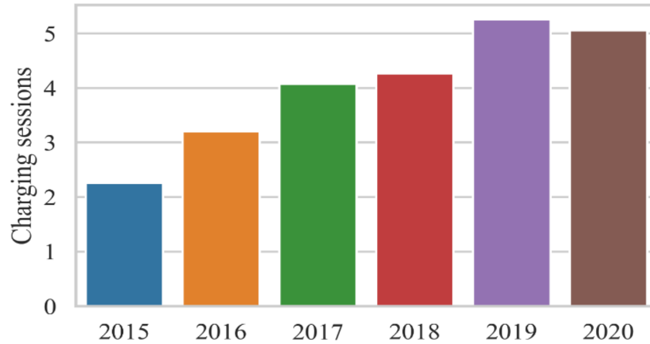

Figure 11. Average weekly charging sessions for MUD-Located AC Level 2 EV charging stations

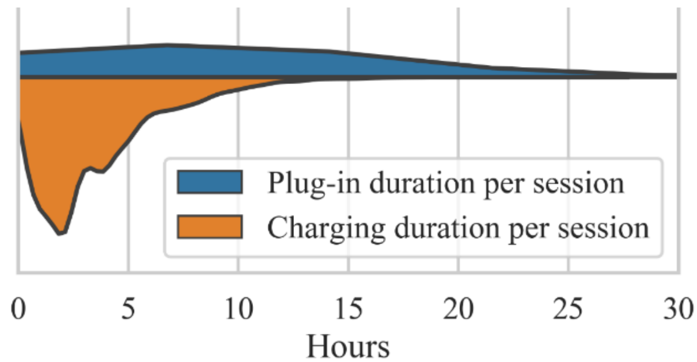

Figure 10. Distribution and comparison of charge session time for charge sessions equal to (orange) and longer than (blue) the plug-in time for MUD-Located AC Level 2 EV charging stations

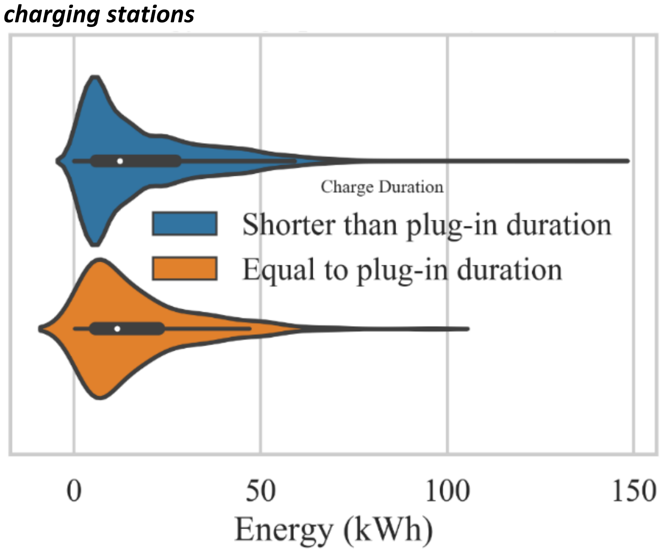

Figure 12. Distribution and comparison of charging energy provided per session for charge sessions equal to (orange) and longer than (blue) the plug-in time for MUD-Located AC Level 2 EV charging stations

Figure 13 provides a different visualization of the same MUD-Located L2 EVSE charge session data.

Seventy-five percent of the MUD-Located AC Level 2 charging sessions were between 0-13 hours, with 50% of the sessions were 0-8 hours (session length, not charging time). The short time spent charging suggests these sessions were partial BEV recharging and/or PHEV charging sessions. (The data provided did not state the vehicle make/model that was being charged.)

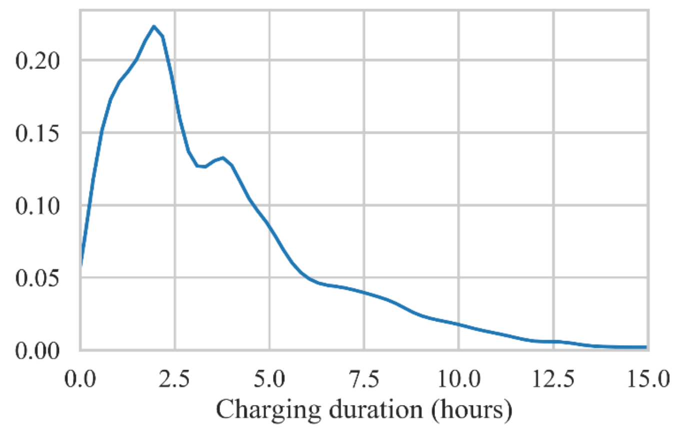

Figure 13. MUD-Located AC Level 2 EVSE charging event duration distribution

Figure 14 shows the combined *weekday* connection time data for all MUD Located charging ports with low, average, and high bands shown. As expected for residential charging, the average usage is low during the day and starts to increase as early as 3 PM an continuing through 11 PM. Usage remains high and nearly constant as expected overnight. The largest connections decrease occurs from 6 AM – 9AM as residents leave for the morning commute to work.

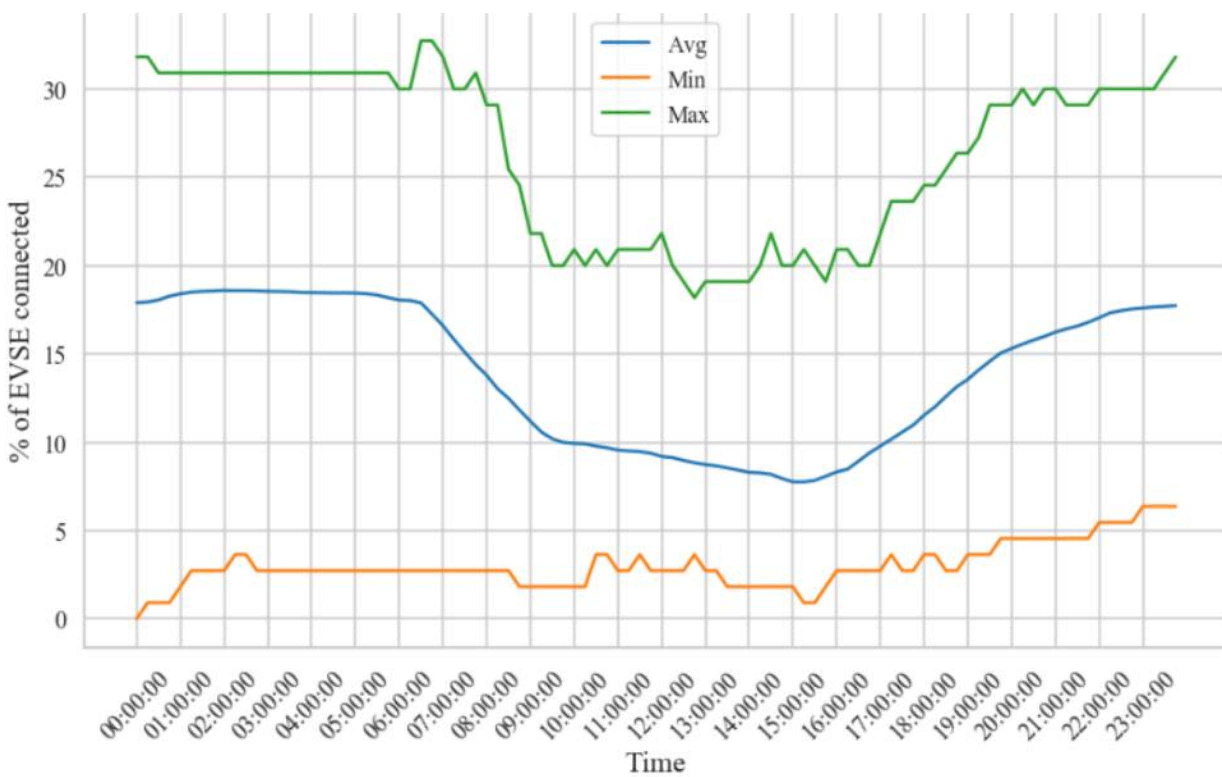

Figure 14. MUD-Located weekday charging port utilization (2019)

Figure 15 shows the combined *weekend* connection time data for all MUD Located charging ports with low, average, and high bands shown. As expected for residential charging, the usage is low during the day and starts to increase as early as 3 PM an continuing through 11PM. Usage remains high and nearly constant as expected overnight. The average *weekend* trends are similar to the *weekday* trends but are more muted and gradual. This is logical because it captures people's personal trips that happen on their schedule and not a set workday schedule. The somewhat lower number of connections on the weekend could be from a variety of factors including: less driving than workday commuting, charging at other locations, or weekend trips.

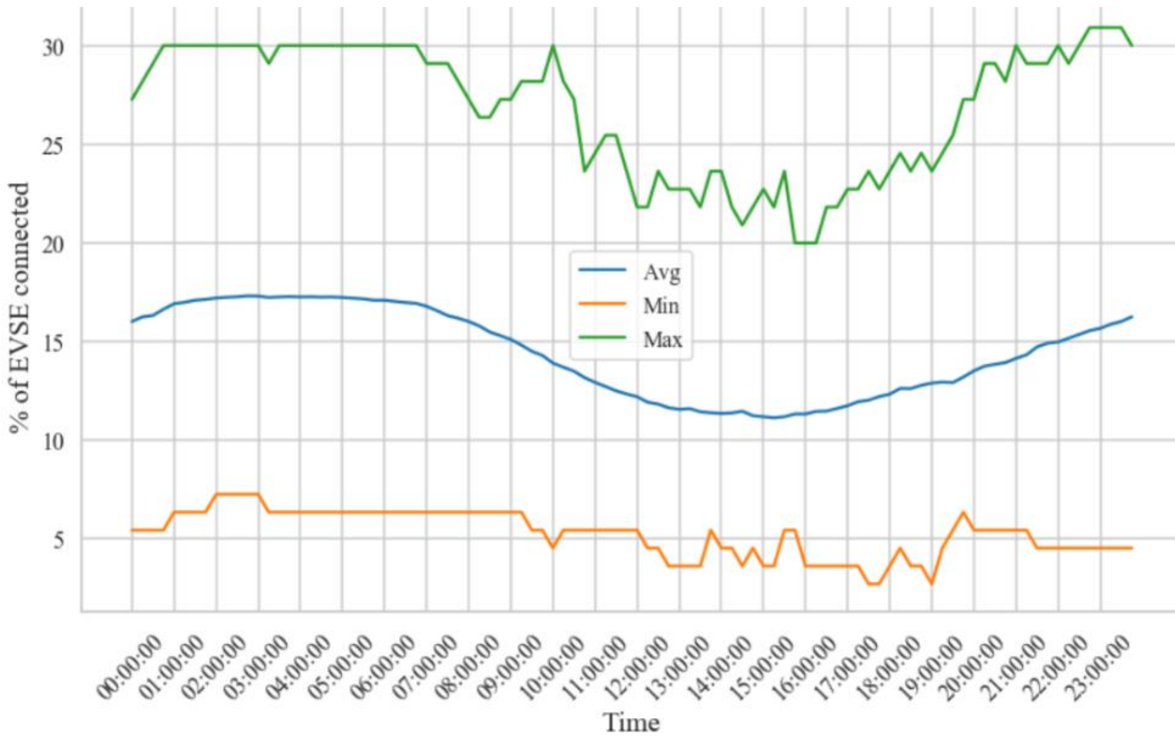

Figure 15. MUD-Located weekend charging port utilization (2019)

Figure 16 summarizes the EV charging station utilization and time the station was providing a charge to an EV (both as % of time). The colored boxes indicate the 25%-75% range. Because of the overall low usage, the visible line above the horizontal axis (0% utilization) indicates 50% of the data. The line at the top of the boxes indicates 75% of the data. The top horizontal lines (located above the colored boxes) indicate 100% of the data. The small number of outlier data points are shown as black diamonds. The main takeaways are: 1) overall EV charging station utilization is low, and 2) the time spent charging a vehicle is approximately 1/3 of that time. This reinforces the finding that the charging infrastructure and electrical capacity is underutilized. So, technologies, or operations practices that increase the EV charging station sharing, will be cost effective options to support much larger EV populations at these locations

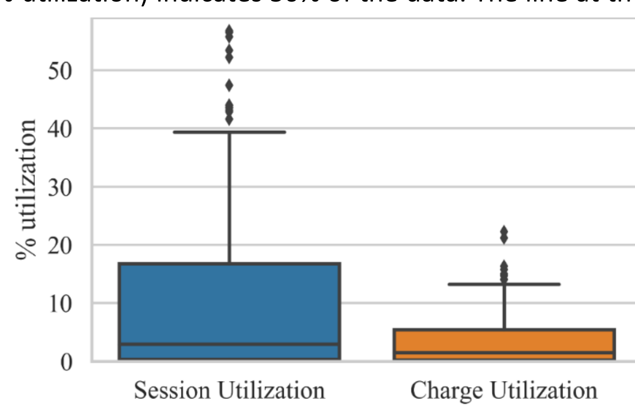

Figure 16. Boxplot of EV charging station usage (while connected [session] and while charging)

without installing additional infrastructure. For new installations, implementing technologies/systems to leverage charging infrastructure should be implemented to minimize capital costs while still serving the EV-owning MUD residents.

MUD-Supporting AC Level 2 EVSE Analysis Results

A total of 2,699 charging sessions (~11% the size of the MUD-Located charging session dataset) were classified to be included in the MUD-Supporting AC Level 2 EVSE charging session category. The MUD-Supporting classification approach (described earlier) introduced uncertainty regarding whether the charging sessions are indeed MUD resident charging sessions. Because of this uncertainty, the MUD-Supporting data were analyzed separately from the MUD-Located AC Level 2 charging sessions. The analysis targeted to determining the same usage patterns to characterize how MUD residents are using these EV charging stations as for the MUD-Located EV charging stations.

Figure 17 shows trends in total charge sessions and total energy usage over time at MUD-Supporting AC Level 2 EV charging stations. There is an increase in both the number of charging sessions and the amount of total electricity provided by MUD EV charging stations every year. The increased growth rate starting in 2017 matches expectations from increased EV model availability and adoption. There is a positive correlation between the energy provided and the number of charging sessions over time (as time passed, more annual charging sessions provided more total energy). There is a clear and consistent relationship between the number of charging sessions and the amount of energy provided, with an average of approximately 11.5 kWh provided per charge (38% less than the 18.4 kWh for MUD-Located). The hypothesis at the project outset was that MUD resident AC Level 2 EV charging station session would frequently/typically last for many hours, likely overnight, to fully charge vehicles, so this is an interesting finding. This level of average MUD resident session charge is consistent with statements made by some of the project's innovative technology provider partners.

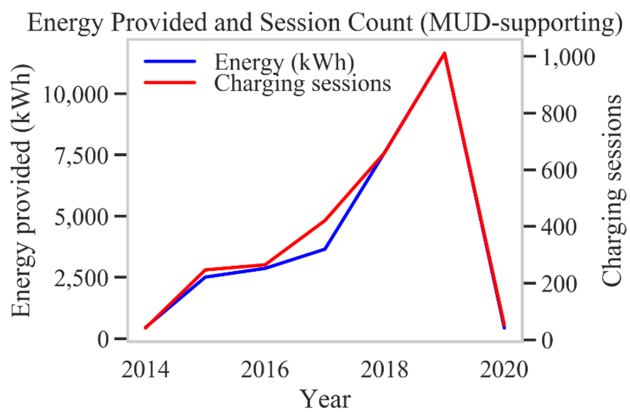

Figure 17. Historical trend of number of sessions and energy provided at MUD-Supporting AC Level 2 EV charging stations

The average weekly charging sessions per MUD-Supporting AC Level 2 EV charging station is shown in Figure 18. The apparent 2020 decrease is due to data reporting in early 2020. The varied, but generally increasing usage would seem to imply higher MUD resident EV adoption (assuming average energy requirements remained similar). However, as previously stated some data variations could be due to the MUD-Supporting session filtering process. The changes in the

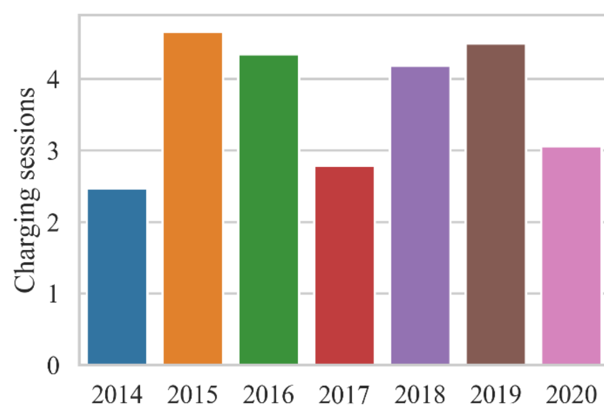

Figure 18. Average weekly charging sessions for MUD-Supporting AC Level 2 EV charging stations

number of weekly charging sessions are likely highly dependent on the locations (and their respective populations). An evaluation of the average charging sessions by state and year may shed some insight on these trends, however more data is needed.

The violin plots in Figure 19 show probability density functions for: 1) plug-in duration (blue) and 2) charging duration (orange). The typical MUD-Supporting AC Level 2 charging session lasted an average of 2.9 hours and had an average charge duration of 2.2 hours, shorter than expected and much shorter than an overnight session. The longer plug-in durations meet expectation for overnight charging sessions. The difference also highlights that energy is not being provided to the EVs for those entire plug-in sessions. The time when charge is not being provided to the vehicle highlights the opportunity to increase EV charging station, or electric infrastructure utilization with software and hardware smart EV charging station technologies.

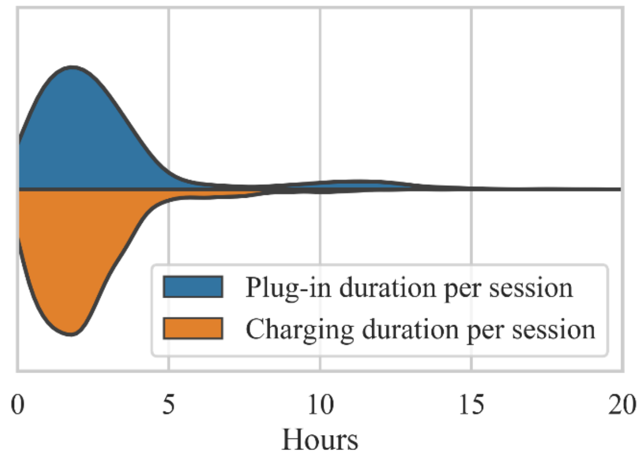

Figure 19. Distribution and comparison of charge session time for charge sessions equal to (orange) and longer than (blue) the plug-in time for MUD-Supporting AC Level 2 EV charging stations

The violin plots in Figure 20 provide a similar view on the charging sessions but focus on the energy provided. The plots illustrate the variation between the energy provided per charging session and the charging session length. The violin plots show two probability density functions: 1) one for charging sessions where the plug-in duration/connection time equaled the charging time (orange), and 2) one for charge sessions where the plug-in duration/connection times were longer than the charging time (blue). The data profiles, averages, and interquartile range (i.e., 25%-75%), for both subsets are similar. As with the MUD-Located sessions, the fact that the plots have similar profiles and summary parameters confirms the conclusion that energy is not being provided for the entire plug-in sessions.

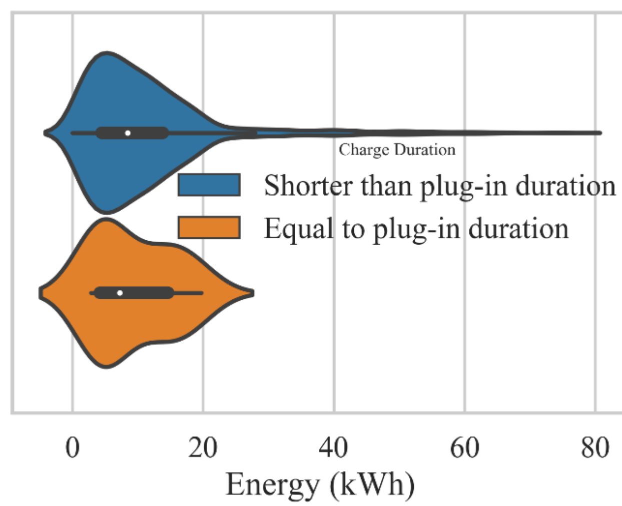

Figure 20. Distribution and comparison of charging energy provided per session for charge sessions equal to (orange) and longer than (blue) the plug-in time for MUD-Supporting AC Level 2 EV charging stations

Figure 21 provides a different visualization of the same L2 EVSE charge session data. Seventy-five percent of MUD-Supporting AC Level 2 charging sessions were between 0-3.3 hours, with 50% of the sessions were 0-2.0 hours (session length, not charging time). The short time spent charging suggests these sessions were partial BEV recharging and/or PHEV charging sessions. (The data provided did not state the vehicle make/model that was being charged.)

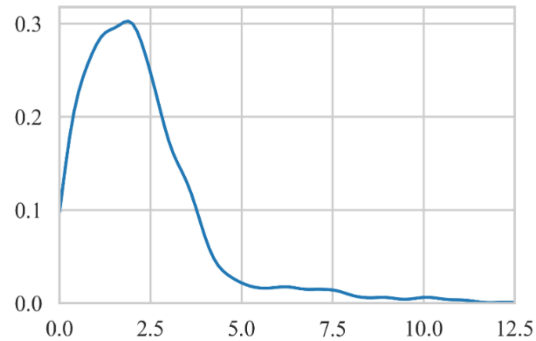

Figure 21. MUD-Supporting AC Level 2 EVSE charging event duration distribution

MUD-Supporting DCFC EVSE Analysis Results

As described earlier, the downselection approach identified 2,022 charging sessions at 8 DCFC EV charging stations that had a higher likelihood of being MUD resident sessions. The DCFC MUD-Supporting classification approach (described earlier) introduced uncertainty regarding whether the charging sessions are indeed MUD resident charging sessions. Additional uncertainty in the MUD resident selection process arose in the data because the DCFC use patterns are different than for AC Level 2 EVSE. For example, DCFC session time is ≤20 minutes, so MUD resident DCFC sessions could reasonably occur at any time during the day (on way to/from work, on lunchbreak, etc.). Because of this uncertainty, the MUD-Supporting DCFC data were analyzed separately from the other data. The analysis targeted to determining the same usage patterns to characterize how MUD residents are using these EV charging stations as for the MUD-Located EV charging stations.

Figure 22 shows trends in total charge sessions and total energy usage over time at MUD-Supporting DCFC EV charging stations. There is an increase in both the number of charging sessions and the amount of total electricity provided by MUD EV charging stations every year. The increased growth rate starting in 2017 matches expectations from increased EV model availability and adoption. There is a positive correlation between the energy provided and the number of charging sessions over time (as time passed, more annual charging sessions provided more total energy). There is a clear and consistent relationship between the number of charging sessions and the amount of energy provided, with an average of approximately 13.7 kWh provided per charge.

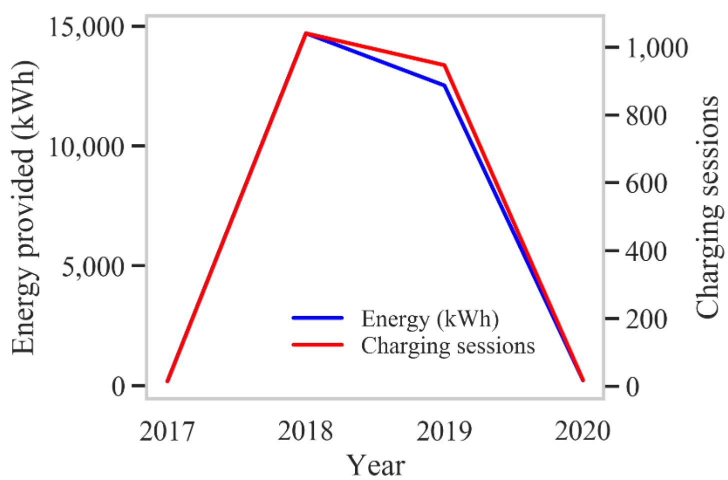

Figure 22. Historical trend of number of sessions and energy provided at MUD-Supporting DCFC EV charging stations

The violin plots in Figure 23 show probability density functions for: 1) plug-in duration (blue) and 2) charging duration (orange). As expected for DCFC sessions since the user is at/nearby the vehicle during charge, the charge session length is nominally the same as the plug-in duration.

Figure 24 provides a different visualization of the same DCFC EVSE charge session data. As expected, the charge sessions are typically a 30-minute session that are commonly used.

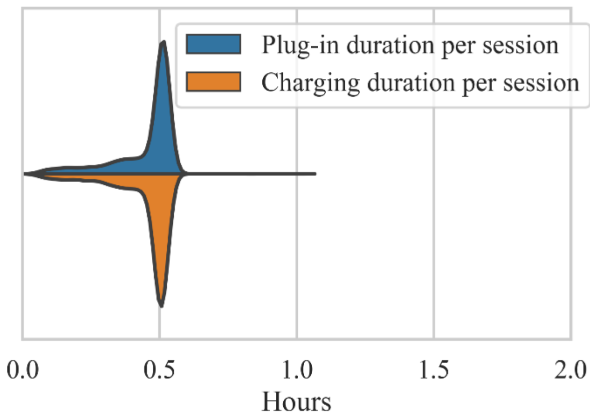

Figure 24. Distribution and comparison of charge session time for charge sessions equal to (orange) and longer than (blue) the plug-in time for MUD-Supporting DCFC charging stations

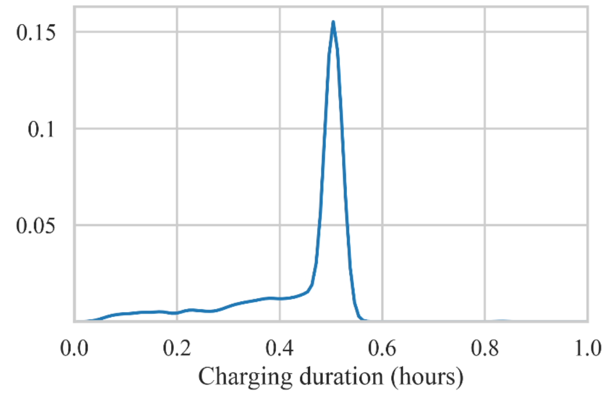

Figure 23. MUD-Supporting DCFC EVSE charging event duration distribution

EV Charging Station Business Case Analysis

The project targeted quantifying the business case, such as determining the annual cost to operate (per site, per EVSE), facilities' financial goals (e.g., revenue offsets annual usage costs, profit generation, or no requirement if EVSE are marketing tool to attract/retain MUD residents), cost-benefit, and return on investment for each of the data provider locations.

Energetics experience collecting the usage data alone proved to be a significant challenge. In many cases, data providers were willing to take the time to provide EV charging station utilization data but were not able to commit the time required to provide the required capital and operating cost data because of the much higher amount of time required. The data included a large number of sites, so locating and securing the capital and operating cost data for such a large cross-section of properties was not possible. Data provider and other MUD stakeholder feedback frequently cites the lack of data availability and business case as a barrier.

To ensure the required business case data was collected in the demonstration phase, the Demonstration Site Agreements included the requirement for the demonstration site owner/operator and the technology provider to provide the data required to quantitatively describe the business case for MUD charging for each of the demonstrated technologies. This, in addition to the much smaller number of properties, will make collecting the business case data a much easier process than in the baseline period.

EV Charging Station Data Analysis Conclusions

The increasing EV charging station usage trends would seem to imply higher MUD resident EV adoption (assuming average energy requirements remained similar). The data analysis results for the MUD-Located EV charging stations are the most accurate for developing conclusion from because of the data certainty. There is a clear and consistent relationship between the number of charging sessions and the amount of energy provided, with an average of approximately 18.4 kWh provided per charge. The hypothesis at the project outset was that MUD-Located AC Level 2 EV charging station sessions would frequently/typically last for many hours, likely overnight, to fully-charge vehicles, so this is an interesting finding. This level of average MUD resident session charge is consistent with statements made by some of the project's innovative technology provider partners.

Two key findings of the data collection effort were: 1) how difficult it was to locate the data sources and 2) how the collected EV charging station data represent a portion of a vehicle's charging behavior. A large source of uncertainty in the dataset is due to the lack of a comprehensive understanding the EV users' charging habits across venues and charging networks. For example, any EV owner may charge their vehicle at multiple venues (e.g., home, work, retail, and transit station) during the day, week, month, year, etc. Additionally, EV users may charge their vehicles on different charging networks (e.g., ChargePoint or Greenlots) or on non-networked unmanaged EV charging stations. The result is that there is no single off-board data source where a vehicle's complete charging profile can be determined. The result is that the charging session data collected in this project provides a view into what is likely a portion of the EV users' charging behavior but does not represent the whole picture.

QUALITATIVE BASELINE DATA AGGREGATION AND ANALYSIS

Decision-making for MUDs requires consensus, authorization, and action by numerous stakeholders (e.g., tenants, asset owners, property managers, homeowner association board members, and technology providers). The project's qualitative analysis includes identifying the decision-making process for MUDs, identifying the key barriers to charging, and an evaluation of tools/resources available to help MUD stakeholders select, install, and operate charging infrastructure.

MUD Decision-Making Process

MUD properties in the U.S. are a wide group consisting of multiple building types, including apartments, condominiums, duplex townhomes, and multilevel housing. Two key categories of MUD building types were created for the purpose of this project. Type 1 MUD buildings have a single owner and decision-maker. Type 2 MUD buildings have a collective decision-making process. Interviews revealed that the decision-making process at for Type 1 MUD buildings is straightforward. The process mostly involves the building owner or manager receiving requests from the residents to initiate the process, followed by a consultation with a vendor or installer and receiving one or more bids. Once the building owner accepts the installation cost bid, the installation can start. The decision-making process is much more complicated for Type 2 MUD buildings. For example, condominiums typically have a covenant or declaration that dictate the rules for the building, and bylaws that outline the management structure. For most circumstances, the bylaws prescribe that most of decisions be conducted through a group, like a board of directors, for a homeowner association (HOA). The board members are generally recommended by the homeowners and elected by a voting process that grants the elected delegates the power to decide on issues for the building on behalf of the homeowners. HOA boards do not have the power to make all decisions. For example, an amendment to declare common areas (e.g., parking) to install charging often requires a two-thirds majority vote to approve. The decision is made by a democratic voting process among all homeowners. In one example, a Seattle high-rise condo building resident with assigned parking took nearly 10 years to convince the HOA to provide a communal EV charging station, and later a program for limited common area charging.[7] The HOA members' education and engagement outlined the complicated processes to get charging through the HOA. While HOAs and buildings differ, the article captured the considerably more complicated stakeholder engagement and decision-making process for Type 2 MUDs.

Key Barriers Identification

To ensure that the project's final deliverable Multi-Unit Dwelling EV Charging Toolkit features resources that address the barriers faced by existing MUDs, this chapter focuses on identifying key barriers to providing EV charging stations in MUDs. The barriers are derived from a mixture of literature review and project outreach and engagement efforts, which include stakeholder survey responses and interviews.

Education and Awareness Barriers

There is a major knowledge gap between those working in the electric vehicle industry and the consumers and key players who make decisions for MUDs. Deficiencies in knowledge about both the vehicles and the charging infrastructure creates a significant barrier to the implementation of charging infrastructure. As one of the most documented and mentioned barriers in both the literature and the project outreach effort, the lack of EV education and awareness is one of the most important and easiest barriers to overcome.

Awareness Barriers among Building Owners, Managers, and HOAs

The lack of awareness among MUD building owners/managers was found to have a highly negative impact on the provision of charging infrastructure due to their position as key decision-makers. Their decision-making process is often dominated by common misconceptions and misinformation about charging such as limited demand, prohibitively high costs, and the lack of a business case. As pointed out by a 2015 study for Silicon Valley, property managers do not understand how to evaluate factors for deploying EVSE, and they lack business strategy and have limited authority.[8] Without proper education, the building owners/managers could oppose charging infrastructure out of unfamiliarity with the subject and a lack of awareness to residents' demands. HOAs for condominiums, under most circumstances, have the right to reject requests from the residents or homeowners for installing EV charging stations or electrical outlet for a resident-supplied EV charging station. The lack of awareness and understanding of EV and charging blocks homeowners from installing EV charging stations and may prompt HOA directors to dismiss the idea quickly without proper evaluation.

Awareness Barrier by Consumers and Residents

MUD residents' level of awareness about the available EV makes, models, and vehicle types that can meet their needs will dictate their demand for charging. Hence, educating consumers with proper EV knowledge is critical to improve EV adoption and encourage strong self-advocacy from the residents. As for EV charging, MUD residents most likely do not understand the complexities of installing an EV charging station in the building, and many non-EV drivers may reject the provision of charging infrastructure, due to extra costs. This may leave the EV advocate to either live somewhere else with charging or having to

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[7] Jeff Wilcox, My $6,000 Tesla Wall Connector. 2019. https://www.jeff.wilcox.name/2019/11/evcondo/#fees-for-ongoing-use.

[8] Kalb, Helmer, *Electric Vehicle Charging in Apartment-based Housing, Obstacles and Opportunities*, NOVA Workforce Development, 2015.

give up EV as a viable option entirely. MUD residents should be properly informed on the costs and benefits of EV charging stations and be equipped with basic information about charging infrastructure and installation. To advocate for such an amenity for the building calls for specific resources to educate all residents to gain support for installing EV charging stations at their buildings.

Financial Barriers

As an emerging technology, EVs and EVSE continue to undergo rapid changes. Figure 25 shows an estimate of costs for EVSE installation,[9] the potential costs related to EVSE installation at MUDs have multiple levels, and due to different building layout and structures, the total cost estimates vary greatly. The financial cost of EV charging stations is one of the most widely recognized and well-documented barriers that have been

Figure 25. Summary of component costs for EVSE installations

repeatedly brought up in the project's survey and outreach interview efforts. This section explores the range of costs associated with EV charging in MUDs, including those related to EVSE installation, operation and maintenance, and cost-sharing between parties.

Installation Costs

The capital to install EVSE and the ability to recover these investments are significant barriers for providing charging in MUDs. EVSE installation costs typically include permitting, inspections, engineering, electrical work, construction, and labor.[10] Unlike a single-family home with a more straightforward cost structure, installing EV charging stations at MUDs can vary greatly. The first installation cost category is connecting the parking spaces to the existing electrical distribution panel. This cost increases as the distance between the electrical panel and the parking space increases, resulting in one of the highest costs associated with EVSE installations. Excavation, trenching, or boring through parking garage walls and floors significantly increase the total installation cost.[11] Table 5 is from a report that assessed MUD barriers in Los Angeles County's South Bay region[12] shows the high cost of installation is mostly a factor of high labor costs related to construction activities. If the existing electrical distribution panel does not have sufficient available electrical capacity and/or breaker space to accommodate the needed EVSE, additional costs to upgrade

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[9] DeShazo, Wong, and Karpman, *Overcoming Barriers to Electric Vehicle Charging in Multi-unit Dwellings: A Westside Cities Case Study*, UCLA Luskin School of Public Affairs, 2017.

[10] DeYoung, McCauley, Eret, Williamson, and Rogers, *Zero Emission Vehicle Charging in Multi-Unit Residential Buildings and for Garage Orphans*, Pollution Probe, Delphi Group, 2019.

[11] Pike, Steuben, and Kamei, *Plug-In Electric Vehicle Infrastructure Cost-Effectiveness Report for San Francisco*, Energy Solutions, Pacific Gas and Electric Company, 2016.

[12] Turek, DeShazo, Siembab, and Baum, *Assessing the Multi-Unit Dwelling Barrier to Plug-in Electric Vehicle Adoption in the South Bay*, UCLA Luskin School of Public Affairs, South Bay Cities Council of Governments, 2017.

the electrical distribution panel will be needed. The total implementation cost as a significant barrier has been well-documented in numerous reports and studies for cities ranging from EV-ready areas including Los Angeles, the San Francisco Bay Area, and in Midwest cities such as Columbus, Ohio.

Table 5. MUD EV charging infrastructure installation cost factors

Cost Category	Average % of Installation Costs	% Range
Materials	33%	28-40
Labor	46%	41-56
Tools, Permits, and Fees	7%	3-10
Others	13%	12-20

Operation and Maintenance Costs

In addition to the initial hefty cost of EVSE installation, the upkeep and operation of EVSE can constitute a set of cost barriers for MUD buildings. Operation and maintenance costs include but are not limited to electrical utility costs, including energy and demand charges, EVSE network subscription fees, management time, billing and transaction costs, and hardware maintenance and repairs.

Some MUD buildings may decide to install EV charging stations for communal use by all residents, which may also be used by the public in some cases. In these circumstances, it is typical for buildings to commit to a long-term contract with an EVSE service provider that handles all aspects related to EV charging station operation, maintenance, and customer billing with certain reoccurring costs.

Perceived Lack of Resident Demand and Business Case

Another significant financial barrier is that the business case for EV charging stations as an investment is deemed unknown. Many building owners/managers do not invest in EVSE due to unknown costs, lack of perceived demand, complex installation process, and unclear business model.[10] The typical “chicken-and-egg” problem for an emerging technology is in full play when buildings are deciding on such an investment. Are residents already driving EVs but utilizing charging elsewhere? Will additional residents purchase EVs if charging infrastructure exists in their building? Building owners/managers may not hear from residents interested in EV charging, or actively canvas residents’ interest levels regarding future EV charging needs. This situation leads to a vacuum of information, and an impression for the building management of a lack of demand for EV charging.

The project’s interviews revealed that building owners/managers are less willing to accept the risk of installing EV charging stations when little demand exists because there are other more urgent items of building maintenance and upkeep competing for the same resources For those building owners/managers looking at EVSE as a revenue source and a way to maintain competitiveness in the market, the return on investment is largely perceived as uncertain.

Electrical Preparedness Barriers

For existing MUDs, the building’s physical infrastructure, especially its electrical preparedness, can turn out to be a difficult to overcome or expensive cost barrier. Considering that most buildings today were built before EV charging infrastructure was future possibility that buildings should be prepared for, most are simply not designed to accommodate EV charging.

Electrical Capacity

In addition to the previously mentioned installation costs for bringing power from the electrical distribution panel to the parking spaces, there are potentially significant costs for additional transformer or service capacity upgrades. The total capacity and baseload of each building varies, so the ability of the building's electrical system to accommodate the additional load from EV charging also varies depending on the surplus capacity. Typically, utilities will work with building owners/managers to determine if electrical upgrades are required to support adding EV charging stations. The evaluation process includes a review of the facility's annual peak load or, alternatively, building owner can commission a qualified electrical engineer to perform a 30-day load study.

Interviews with stakeholders revealed that some building owners/managers found it difficult and expensive to determine available capacity without conducting a costly load study. One interviewee received an astonishing $100,000 quote for a load study to determine available electrical capacity. However, drawing from the project survey and comments of the Project Advisory Committee and key stakeholders, the barrier of existing electrical infrastructure requiring upgrades before EV charging stations can be installed is ranked on the lower end of the spectrum, indicating a lower level of concern.

Metering

Some older and smaller rental buildings are bulk metered, which means that the electric utility only has one master electric utility meter for the entire building, and the electricity costs are distributed among all residents based on the total electricity consumption. This configuration can create equity challenge when the building is paying for the energy of the stations while most stakeholders indicated that EV owners should pay for themselves.

MUD buildings that are direct metered by each unit still pose unique challenges. Even though each unit has its own meter and is charged for electricity based on the unit's consumption, the units' electric meter. According to project interviews, stakeholders noted that the situation could be even more expensive due to limited switchgear space, which requires upgrades, and the need for revenue-grade submeters to be compliant for direct meter regulations of local electric utilities.

Building Physical and Design Barriers

A facility's physical design can present both opportunities and barriers to EVSE installation as most existing buildings and parking areas were not designed with EVSE in mind.

Parking Arrangement and Operation

A building's parking type and operation situation is typically a major determining factor for where to locate EV charging stations. The interviewed stakeholders identified the supply of parking and different parking arrangements presented barriers to EVSE implementation.

For buildings with parking garages that are not assigned to a certain unit of the building, the limited parking spaces provided may result in a substantial barrier to station siting. Due to the lack of available parking spaces, it becomes a challenge to reassign parking spaces dedicated for EV charging. Even if the EV charging station will be for shared-use, it can be difficult to locate and may be an unpopular change to the residents.

For MUD buildings with deeded parking, the building's design could create prohibitive costs if the assigned stall of the EV driver is far from the electrical distribution panel. As mentioned, the necessary excavation, trenching, and/or boring through the parking garage structure to connect the EVSE to the electrical distribution panel could be cost prohibitive.

Stakeholders interviewed also noted that problems may arise from EVSE being utilized by outside visitors and unauthorized vehicles such as internal combustion-engine cars. This calls for educating the residents and operation personnel and creating a guideline of proper parking policy for EVSE operation and enforcement.

Internet Connectivity

For many MUD buildings looking to provide charging as an amenity for communal use, it is important to consider the EVSE's network capabilities. Networked EVSE enables access control and billing services for the site host, while also collecting data and providing analysis for station utilization.

In order to ensure data collection and EV charging station operation, it is important to provide stable internet connectivity. According to interviewed stakeholders, many have experienced the barrier of no connectivity in the parking area, especially in an underground garage that may not permit strong cellular signal essential for network functionality. This barrier results in the need to run ethernet wiring or install multiple Wi-Fi routers/repeaters that increase the overall EV charging station installation cost.

Other Barriers

Condo-Specific Barriers

In condos, the barrier to EVSE installation lies in common area management, which is dictated by the covenants of HOAs, including the processes required to amend anything. The need for amendment may be triggered when individual condominium owners desire to run electrical wiring from an electrical room to their parking space. The terms and conditions can impact a condo HOA's ability to implement modifications and make investments that would enable any or all owners to install EVSE.

HOA bylaws for an amendment typically require formal notice periods, approval votes of a two-thirds majority of unit owners, and legal amendments to covenants. These steps create delay, risk of non-approval, and add cost. This process requires a dedicated EV advocate(s) to educate the association members about the costs and benefits of charging infrastructure and to build a coalition of a two-thirds majority vote to approve any amendments. The EV advocate(s) could be an HOA member, a resident, local Clean Cities coalition staff, or others.

Rental Property-Specific Barriers

It is particularly challenging for renters to negotiate to get charging and to convince building owners/managers to install or pay for an EV charging station. Typically, other renters have low to no motivation to invest in EV charging, and the building owners/managers do not yet see charging as an amenity by which to increase property value and attract tenants. Furthermore, renters are unlikely to invest in immobile equipment in a building they may move away from in the future. The result is that no one has a strong enough motivation to invest in rental properties for EVSE.

Clean Cities Coalition Stakeholder Feedback

The Clean Cities Coalitions and other partners performed stakeholder engagement to understand the status of charging at curbside residential and MUD sites including existing installation, plans for future installations, motivations, and barriers. They engaged with housing authorities, charging equipment contractors, EVSE providers, MUD owners/managers, utilities, parking service companies and government agencies

The Coalitions and other partners used a discussion form created by the project team as guidance for their conversation with various stakeholders. There were forty-three individual responses to the discussion form. The outreach form is divided in two sections. The first section of questions focuses on learning about existing and planned EV charging stations. Of the forty-three responses, nine of stakeholders have 133 existing curbside residential or MUD EV charging stations and fourteen of the stakeholders have plans to install curbside residential or MUD EV charging stations in the next year. When asked who covers the fees, the most common answer was the HOA and then the residents. The charging manufacturers are BTC Power, Blink, ChargePoint, Clipper Creek, Webasto, Eaton, Signet, and Schneider. The network providers are Greenlots and Blink. Seven of the stakeholders have access to the information on utilization of the EV charging stations. The ownership of the chargers is spread out between the HOA's, apartment builders, residents, developers, and manufacturers. Although most charging infrastructure was owned outright by the charging host, some were leased, and the Virginia Clean Cities Coalition had helped execute a partnership with Nissan for charging.

The second part of the discussion form deals specifically with motivations, barriers, and innovation questions. The motivation respondents listed were: 1) demand from existing residents, 2) an extra amenity to attract new residents, and 3) points in certification programs like LEED. The barriers to installing and/or operating MUD EV charging stations list were lack of information on costs, HOA approval, limited parking, costs, vandalism, lack of education, lack of subsidies, and lack of funding. The barriers to installing and/or operating curbside residential EV charging stations that were given by stakeholders were liability, cost, having dedicated parking spaces, proper electrical infrastructure, parking enforcement, vandalism, coordination with municipality, lack of knowledge about curbside charging, distance from power source, people not moving their vehicle once they have charged, and low demand.

Table 6 summarizes the key identified MUD charging barriers that were identified through a survey of Project Advisory Committee members and other project participants, as well as the outreach performed by the Clean Cities Coalition partners. As indicated in interviews of key stakeholders, the **HOA-related barriers** category was ranked the highest, followed by **education barriers**, **parking limitation**, and **ongoing costs**. It is worth noting that the **installation costs** and **electrical-related barriers** also were in a significant position as a barrier. The identified barriers were derived from the open-ended question: "What are the most significant barriers to installing and/or operating MUD EV charging stations?"

Table 6. Summary of Identified Key Barriers

Barrier	Number of Responses	Descriptions and Examples
Information and education	**16**	- Chicken-and-egg problem for EV adoption and EVSE need - Need proper information for building owners/managers and HOA on features and benefits
HOA related	**18**	- Common area management

		- Association approval difficulties and homeowner buy-in - A few stalls located far from electrical distribution panel will be extremely costly
Parking limitation	**15**	- Deeded parking and limited parking spaces - Parking garage or spaces far from electrical panel, increasing costs
Parking operation	**9**	- Drivers do not unplug when done charging - Outside free-riders problem
Capital constraints	**10**	- Not enough funding and/or may need grants or incentives
Electrical related	**12**	- Older building may not have enough electrical capacity and require costly upgrades - Distance of electrical distribution panel from garage increases installation costs - Potential need to conduct expensive load study
Cost of installation	**16**	- Installation cost of running electrical circuit and conduit for EVSE - Installation cost for electrical distribution panel or service upgrade
O&M ongoing cost	**16**	- Power management and network subscription fees
Network signal	**4**	- Weak cellular signal in garages - Expensive to run internet cables and install a Wi-Fi router or cellular repeater(s)

Respondents had several ideas for tools or resources that could lead to more MUD EV charging stations. This feedback was used in the toolkit development process.

Overview of Existing Resources and Next Steps

The literature review conducted on the barriers also revealed many existing MUD charging resources. Hence, it is also important to take a holistic look at the existing resources available addressing these barriers. Existing resources for EV charging infrastructure facilitation have been developed by various parties around the nation, including the Department of Energy's Alternative Fuel Data Center, state agencies, nonprofit organizations and charging infrastructure and network providers. Many of the resources are already well developed to address the barriers identified by this report.

The VCI-MUD project-identified innovative MUD-focused/-relevant EV charging technologies pilot demonstrations that followed this baseline analysis demonstrated show how new technologies/operating practices can be used to overcome some of the/multiple identified barriers to EV charging across different building types. The fact sheets and demonstration case studies resulting from the technology demonstrations include both quantitative and qualitative data and provide clear guidance to property owners and managers interested in deploying EV charging at their properties.

The Multi-Unit Dwelling EV Charging Toolkit development will capture the high-quality resources identified during the research and provide a user-friendly platform to organize information and present it to stakeholders. toolkit the design was determined to be an interactive roadmap of charging installation in MUDs. This roadmap became the front-end for organizing the existing resources along with some new resources that will be finalized after the demonstration phase is completed.

CONCLUSIONS

The quantitative and qualitative data findings helped influence the next steps of: 1) Innovative Technologies Pilot Demonstrations Evaluation and 2) Multi-Unit Dwelling EV Charging Toolkit development.

Some key data collection effort findings were:

- How difficult it was to locate the charging data sources, and
- How the collected data represent a portion of a vehicle's charging behavior.
- The challenges of collecting installation and operations cost data.

Despite the challenges, the project assembled, collected, analyzed, and reported on a large and diverse data set, that deepened the understanding of MUD and curbside residential charging in the U.S. The qualitative data analysis confirmed that many of the previously perceived barriers for deploying charging at MUDs. The qualitative data analysis also reinforced that MUDs are not a monolithic sector, but rather have substantial differences in physical layout, ownership, and decision-making structures.