Title

# Evaluate Zero-Emissions Vehicle Charging Stations at Caltrans Facilities - A Corridor DC Fast Charger Infrastructure Performance Study (Final Report for Agreement 65A0730)



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# Final Report for Agreement 65A0730:

# Evaluate Zero-Emissions Vehicle Charging Stations at Caltrans Facilities

A Corridor DC Fast Charger Infrastructure Performance Study

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California Department of Transportation

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# Abbreviations

Caltrans – California Department of Transportation

CEC – California Energy Commission

CPUC – California Public Utilities Commission

DCFC – Direct Current Fast Charger

EB and WB – Eastbound and Westbound

EVITP - Electric Vehicle Infrastructure Training Program

ITS – University of California Davis, Institute of Transportation Studies

NB & SB – Northbound and Southbound

NEC – National Electrical Code

NFPA 70 - National Fire Protection Association standards

PEV – Plug-in Electric Vehicle (usually refers to both battery electric vehicles and plug-in hybrid electric vehicles)

PSPS – Public safety power shutoff

PVC - Polyvinyl chloride

SRRA – Safety Roadside Rest Area

ZEV – Zero Emissions vehicle

## Executive Summary

The purpose of this report is to study the installation, maintenance, and utilization of fifty-four public DC Fast Chargers (DCFC) installed in thirty-seven public locations within the state highway right of way and other Caltrans owned locations in California. They were funded by the California Department of Transportation's 30-30 Zero-Emission Vehicle Implementation Plan, better known as the Caltrans "30-in-30" Project. The locations have been programmed into the State Highway Operation and Protection Plan (SHOPP). This project will help the California Department of Transportation in learning from the installation and utilization of the chargers to understand the impact of the current locations, study the cost and benefits of those locations and direct future growth of the charging infrastructure. Furthermore, this project aims to provide insights into the utilization of highway corridor charging infrastructure and understand charging infrastructure performance indicators such as energy usage, power performance and reliability and will help understand the need to invest in critical infrastructure along major transportation corridors in the future.

This report is organized into three parts that cover important aspects of the Caltrans 30-30 project. The first part, so named Task 1, covers the project launch and construction phase evaluation. The second chapter Task 2 covers the charger usage data analysis to understand the demand for the ZEV chargers. Task 3 covers the maintenance and operations phase to verify operation and maintenance issues to maintain chargers at best performance. The goals of the 30-30 project were to fill gaps in California's DCFC network service of 80 miles or greater in remote or underserved locations while collaborating with the California Energy Commission (CEC) and the Governor's office. The ultimate goal of the project was to install 54 ZEV charging stations in 37 Caltrans locations on high priority routes. The sites have been selected by Caltrans by evaluating previous studies and the best information available at the time [1].

There were obvious stresses that drove project costs higher for the Caltrans properties selected compared to other ZEV charger installations in urban areas. The total costs of construction for these grid-connected ZEV chargers under the Caltrans 30-30 project installations range anywhere between $122,000 – $440,000. We find that this is higher than the information shared by other sources. Given the remoteness of the sites, obtaining energy supply is usually a challenge that incurs high costs, based on three key factors. (1) Most ZEV fast charger construction in dense urban areas would benefit from existing utility infrastructure already invested by cities and utilities. Although we take this for granted, such shared infrastructure creates a complimentary ecosystem that drives prices down for individual customers. (2) Moreover, the remoteness of the sites drives cost stresses on mobilizing labor and materials necessary for the construction projects. The project construction crew had to take necessary safety measures in Caltrans locations that had high foot traffic. (3) Furthermore, the co-location of ZEV charging stations on twin rest areas on opposite sides of a freeway adds significant costs and challenges for construction. This is especially true if local electrical grid capacity is only accessible from one side of the highway. We find that it is cheaper for the utility to provide a new connection to each side of the freeway (before the electrical meter at a higher voltage than at a lower voltage for the construction crew). At low voltage, higher resistance in the conducting materials leading to additional conductors to support the same power output leading to more boring, trenching, and ultimately higher costs.

From the charging data we analyzed, we found that a driver who uses the BTC Power CCS connector would be connected on average 41.2 minutes and would charge 24.2 kWh on average, whereas drivers who use a CHAdeMO connector would be connected for 35.3 minutes and would consume 17.3 kWh on average. Drivers who would use the ChargePoint network would consume 23.2 kWh for CCS users and 17.1 kWh for CHAdeMO users. More information of data protocols and charging patterns can be found in Chapter 2.

Chapter 3 outlines the key challenges and recommendations for enhancing the reliability of Caltrans 30-30 ZEV chargers. We discovered maintenance and operational issues, particularly during the 2021-2022 reporting period. Notably, eight stations requiring repairs were left unattended for over a week as of the second quarter of 2022. Concerns raised by PEV drivers encompass equipment damages, charging capability issues, local power outages, and planned rest stop closures by Caltrans. Current charging reliability monitoring standards and protocols may be unable to effectively capture these consumer concerns. The key metric of Electric Vehicle Supply Equipment (EVSE) reliability right now is uptime, reflecting how long a charging station is operational. Regulatory standards, like the California Energy Commission's mandate for 97% uptime over five years and the Federal Highway Administration's proposed minimum annual charging port uptime of 97%, mainly focus on technical aspects. However, real reliability from an EV driver's perspective involves more factors. Challenges like electrical issues in EVSE components, vulnerability of external parts to environmental damage, communication network problems, and logistical hurdles like membership requirements and payment issues contribute to the overall reliability of charging ports. Existing uptime calculations might overlook these varied challenges, potentially leading to inaccurate assessments of reliability for both operators and drivers.

A Charge Point Operator (CPO) oversees the ongoing operations of EV charging infrastructure, ensuring chargers meet jurisdictional uptime requirements. Real-time monitoring using the Open Charge Point Protocol (OCPP) helps detect most electrical and software failures, but challenges arise with mechanical, communication, and logistical issues. This can result in certain failures going unnoticed by CPOs, impacting consumer experience, and contributing to overall reliability challenges. EV drivers are likely to charge their EVs in the same public charging locations along travel routes. Therefore, any sudden gaps within the usage pattern of a given EVSE location could reveal a technical or logistical failure that standard reliability monitoring protocols fail to capture. We can leverage the habitual usage patterns of EV chargers to effectively identify potential charger faults that may not be captured by traditional reliability measures. We introduce and demonstrate a probabilistic method that uses this behavioral intuition. The method identified over 100 gap hours for three chargers at a Caltrans charging facility. If these gap hours were indeed due to charging faults, they would result in uptime reductions ranging from 16% to 38%. Depending on the method's preferred confidence level, CPOs could've detected these charging usage gaps 1.5 to 3 times faster. Given the capacity of the method to significantly enhance Caltrans charger operation and maintenance by addressing hidden charge failures, we will further develop and calibrate this method in the next phase of this project.

**Project Title: Evaluate Zero-Emission Vehicle Charging Stations at Caltrans Facilities**

## Introduction

The State of California aims to support 5 million Zero emission vehicles (ZEVs) on the road by 2030[1]. A publicly accessible statewide network of Direct Current Fast Chargers (DCFC) is an important precursor to the mass adoption of electric vehicles in the state. Such a network of Zero-Emission Vehicle (ZEV) charging stations in major transportation corridors can facilitate connectivity and long-distance travel using plug-in electric vehicles (PEVs). As interest in long range electric vehicles grows along with new PEV models in the market that can support ranges of 300 miles and beyond, fast charging infrastructure around popular transportation corridors become even more necessary [2]. Pilot projects such as the U.S. Department of Energy's 'EV project' have identified that DCFCs are more effective when located close to major transportation corridors for long trips between metropolitan regions. Optimal locations of such facilities are locations where PEV drivers can have easy access to fast charging, where drivers will not have to make any deviation from their pre-planned trips, however small that deviation may be [3]. Such optimally located corridor DCFCs are usually in remote and underserved communities. They are located immediately next to a highway where they lack the advantages of shared utility infrastructure in an urban setting that creates a complimentary eco-system that brings down costs.

Further investments in DC Fast Charging infrastructure across California and the United States has public benefits and helps to achieve GHG goals in the State. The aim of the "30-in-30" project is to finance the construction and launch of 54 different ZEV fast charger stations in 37 different locations. These sites were selected under the "30-30" project along priority highways, such as Interstate 5, State Route 99, and U.S. Highway 101. The objective of the "30-30" project was to "fill the gaps within California's DC Fast Corridor Network along key routes of the State Highway System where sufficient commercial zero-emissions vehicle (ZEV) fueling opportunities do not currently exist" [4].

The project was originally proposed in 2016 by the ZEV 2016 Action Plan put forth by the Office of Governor Edmund G. Brown Jr. The proposed project timeline aimed for the ZEV 30-30 project to be completed in 2018. However, due to legal obstacles, the project only began implementation in the beginning of 2020. Uniquely, these sites are at remote or underserved locations that other commercial networks likely did not consider to be economically viable in

[1] California Public Utilities Commission (2021), Transportation Electrification https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/transportation-electrification

their business model but were found to be necessary to support long distance travel using PEVs. [4]. A map of the final 37 locations selected for the Caltrans ZEV 30-30 project is found in Figure 1 below market in red. The existing network of non- Caltrans public DCFCs at the time of writing this report is marked in green. Further details of the charging gap analysis can be found in Section 2 of this report.


*Figure 1: Caltrans ZEV public charging stations installed by the 30-30 program*

A team from the PHEV Center at the Institute of Transportation Studies (ITS) were tasked to evaluate and analyze the construction and launch of chargers, their utilization and maintenance and operation phase of the corridor chargers installed as part of the ZEV 30-30 project. The aim was to capture lessons learned from the project. The first phase incorporated understanding costs and design elements of the project to inform future Caltrans projects of this nature. The

California State Department of Transportation will be referred to as **Caltrans** from henceforth in this report. This report aims to capture the most up-to date information about financing corridor DC Fast Chargers in general and hopes to understand the cost differences between the 37 different locations than span across 20 counties and different utility service territories with different regulatory and technical compliance requirements.

While the design phase of the project may have started in 2019, project implementation of the 37 DC Fast Charging facilities began only in 2020. The project was then impacted by the Covid-19 pandemic. The California Governor's stay at home orders were issued on March 15, 2020, and had some impacts on the projects which we hope to capture in the document.

**History and Evolution of the Project**

The State of California has a long history of supporting the adoption of zero emissions vehicles by public investments in essential infrastructure and filling infrastructure gaps to support PEVs. The initial concept for this project emerged in 2012 with California Governor Edmund G. Brown's Executive Order B-16-2012 directing all State Entities under him shall "support and facilitate the rapid commercialization of zero-emission vehicles" [5]. However, the executive order did not have any milestones or project ideas. The first plan followed in 2013 with the ZEV Action Plan of 2013 that put into actionable goals the need for PEV infrastructure in public places. The iteration of the plan, the ZEV Action plan, which was released in 2016, further homed in on the ZEV 30-30 project that specifically directed the State to install public ZEV Fast Chargers at a minimum of 30 locations, including highway rest stops and other strategically located Caltrans properties [6].

The 2016 Governor's ZEV Action plan stated: "Install public DC fast chargers at a minimum of 30 locations, including highway rest stops and other strategically located Caltrans properties. Utilize the CEC DC fast charger corridor gaps analysis related to the West Coast Electric Highway to inform decisions." [6] However, the project met with legal obstacles from a federal law prohibiting commercial activities or sale of services or electricity at interstate rest areas. But November of 2019 only three charging stations have been built and the rest of the selected sites for the Caltrans ZEV charging stations began construction in early 2020. A brief timeline of the project inception to present is described in Figure 2.


*Figure 2: Timeline of events for the Caltrans 30-30 ZEV project*

**Goals of the 30-30 project**

The goals of the 30-30 project were to fill gaps in California's DCFC network service of 80 miles or greater in remote or underserved locations while collaborating with the California Energy Commission (CEC) and the Governor's office. The ultimate goal of the project was to install ZEV charging stations in 37 Caltrans locations on high priority routes. The sites have been selected by Caltrans by evaluating previous studies and the best information available at the time [1].

**Scoping and original budget**

In November 2017, the total cost estimate for the "30-30" project was $25.3 million. $16.2 million was allocated for construction and the remaining $9.1 million was allocated for support costs. An additional $1.72 million of grant funding was received from Local Air Districts to District 5 and District 6 to install additional chargers.

For administrative purposes Caltrans has divided their activities into 12 administrative districts as shown in Figure 3. The ZEV 30-30 chargers were distributed amongst 10 districts and the activities of charger construction and launch, and maintenance was administered by personnel in their respective districts. Figure 4 indicates the spatial distribution of the 30-30 ZEV chargers within Caltrans district and California's major highways.

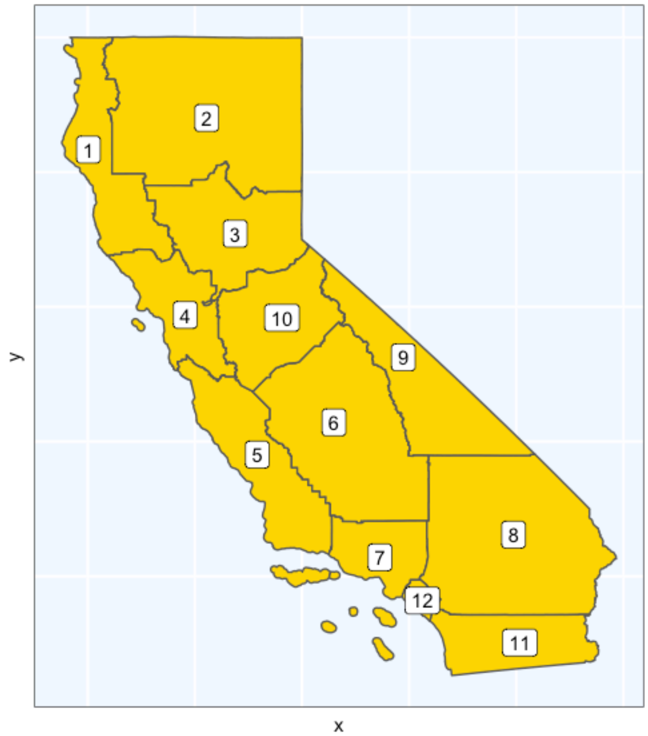



*Figure 3: Map of Caltrans administrative districts*

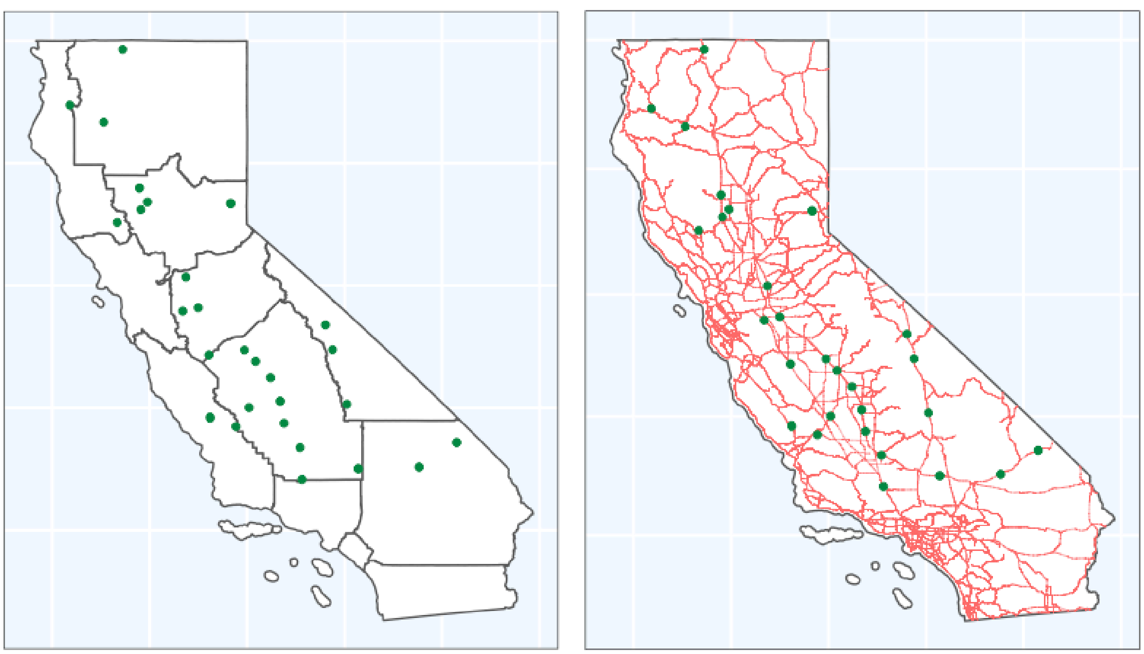


*Figure 4: Location of the ZEV 30-30 chargers within Caltrans districts (left) and along the major highways in California (right)*

Table 1 summarizes each individual Caltrans owned location selected for ZEV charger installation along with the major highway route they currently serve.

*Table 1: Distribution of the ZEV 30-30 chargers amongst Caltrans districts*

| Caltrans District | County | Route | Description | No. of ZEV Stations |
|---|---|---|---|---|
| 1 | Lake | 20 | Clear Lake Oaks Maintenance Station | 1 |
| | Humboldt | 96 | Willow Creek Maintenance Station | 1 |
| 2 | Siskiyou | 5 | Randolf Collier Safety Roadside Rest Area | 2 |
| | Trinity | 299 | Moon Lim Lee Safety Roadside Rest Area | 2 |
| 3 | Glenn | 5 | Willows Safety Roadside Rest Areas (Northbound & Southbound) | 2 |
| | Colusa | 5 | Maxwell Safety Roadside Rest Area | 2 |
| | Nevada | 80 | Donner Summit Safety Roadside Rest Areas | 2 |
| 5 | Monterey | 101 | Camp Roberts Safety Roadside Rest Areas | 2 |
| | San Luis Obispo | 46 | Shandon Safety Roadside Rest Areas | 1 |
| 6 | Madera | 99 | Madera Maintenance Station | 2 |
| | Fresno | 99 | Caltrans District 6 District Office | 4 |
| | Kings | 5 | Kettleman City Maintenance Station | 2 |
| | Tulare | 99 | C.H. Warlow Safety Roadside Rest Area | 2 |
| | Tulare | 99 | Philip S. Raine Safety Roadside Rest Areas | 4 |
| | Kern | 99 | Delano Maintenance Station | 2 |
| | Kern | 58 | Route 58/184 Park & Ride | 2 |
| | Kern | 5 | El Tejon Safety Roadside Rest Area | 4 |
| 8 | San Bernardino | 15 | Clyde V. Kane Safety Roadside Rest Areas | 2 |
| | San Bernardino | 15 | Valley Wells Safety Roadside Rest Areas | 2 |
| 9 | Kern | 58 | Boron Safety Roadside Rest Areas | 2 |
| | Inyo | 395 | Coso Junction Safety Roadside Rest Area | 1 |
| | Inyo | 395 | Division Creek Safety Roadside Rest Area | 1 |
| | Inyo | 395 | Caltrans District 9 District Office | 1 |
| 10 | Stanislaus | 5 | Westley Safety Roadside Rest Areas | 2 |
| | Merced | 5 | John "Chuck" Erreca Safety Roadside Rest Areas | 4 |
| | San Joaquin | 99 | Lodi Park & Ride | 2 |
| | | | Total | 54 |

# 1. Task 1: Project Launch and Construction Phase Evaluation

## 1.1. Introduction

This task will review the DC Fast charger costs of installation, challenges, and opportunities for process improvements in the future. The section will also include construction timelines, costs and analysis, and opportunities for future process improvements. The latter section will include factors and design elements that affect costs and best practices to bring down costs in the future.

Figure 5 is a summary of the administrative and planning process pertaining to the project launch and construction phase from early-stage planning and final launch of a ZEV charging station at a Caltrans facility.

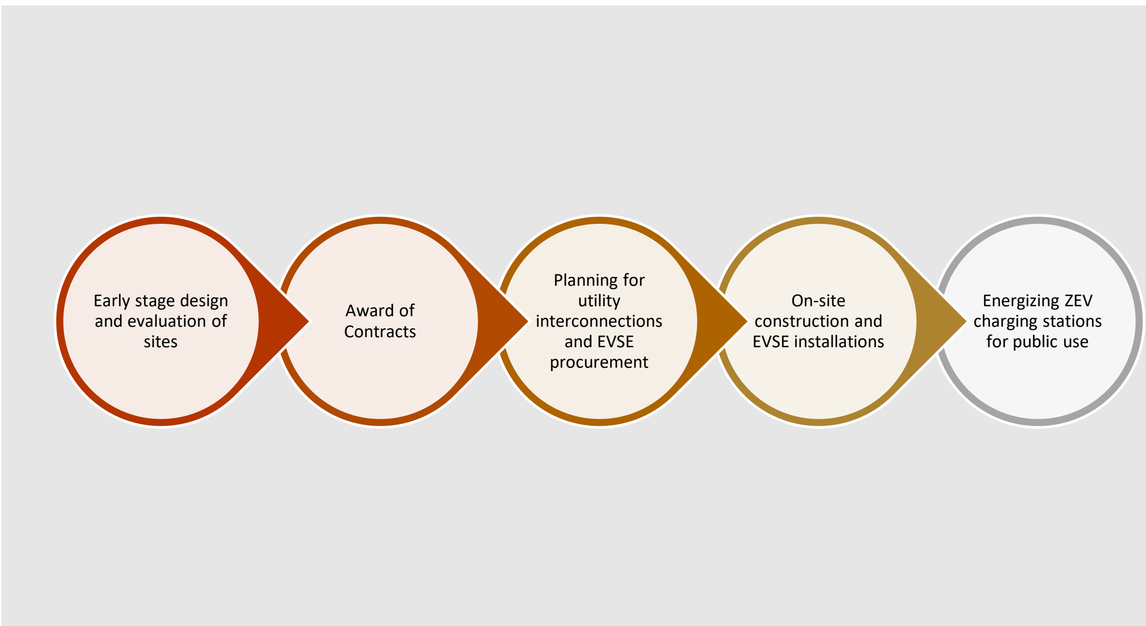



*Figure 5: Summary of activities in the construction and launch phase:*

## 1.2. Research Methodology

Since the kickoff meeting in February 2020, the UC Davis ITS team conducted literature review pertaining to other studies of DC Fast Charger construction costs and launch. Team also reviewed publicly available DCFC construction cost information/ studies conducted and published by State Agencies, U.S. Department of Energy, national labs, and independent research agencies. Existing studies show costs ranging from $20,000 - $150,000 per DC Fast Charger. However, we found out that this information is incomplete for a variety of reasons. Most studies did not include major cost components such as the cost of make-ready infrastructure that is necessary to the installation and operation of the chargers. Moreover, reports that published cost information were from private institutes and the information were either incomplete or was based on major assumptions that did not factor in the unique conditions of Caltrans facilities. There was a gap in reliable studies that used real world case studies that were published and peer reviewed. Major private charging network companies who have reliable information and experience were not willing to share such information publicly because of their competitive advantage in an industry that is relatively new. Therefore, the full costs of installation and project launch for the Caltrans sites were carefully collected and validated independently for this study as described below. Due to inconsistencies in definitions of charging infrastructure across reports and studies within the topic area, we provide a comprehensive set of definitions for terms used in this paper in Table 2

*Table 2: Some common charging infrastructure nomenclature used in this report*

| Word | Definition |
|---|---|
| **Charger** | The above-ground appliance or the EVSE[2] unit that delivers electricity to charge the PEV[3] |
| **Connector** | A charger may have one or more connectors. It is the physical socket that connects to the PEV |
| **Charging Station/ Electric Vehicle Charging Station** | Synonymous to "gas station", a charging station is a physical address where one or more chargers are available for use. They can be public, private, or shared private |
| **Make-ready infrastructure** | All necessary on-site electrical infrastructure in between the utility connection and chargers, including all conduit, electrical service panels and concrete work |
| **EV ARC** | Photovoltaic (PV) power supply on a motorized sun tracking, structure. Includes PV panels, batteries, wireless communications, emergency panel, lighting, and transformers. |
| **EVSE** | Electric Vehicle Supply Equipment (EVSE) is the above-ground electric Vehicle charging station hardware, including, but not limited to, Level 1, Level 2, and DC Fast Charge. |

**Data collection and analysis**

The Institute of Transportation Studies (ITS) research team first interviewed Caltrans personnel such as design engineers, program managers, resident engineers, and landscape architects because they were involved in the construction and launch of the chargers. This is a form of

[2] Electric Vehicle Supply Equipment (EVSE) is the above ground electric Vehicle charging station hardware, including, but not limited to, Level 1, Level 2, and DC Fast Charge.

[3] Plug-in Electric Vehicles: Includes Battery Electric vehicles and Plug-in Hybrid Vehicles

expert solicitation to gather input. Initially the ITS team had a targeted interview questionnaire matrix from input from the literature reviews. However, our conversations with Caltrans personnel proved that information gathering will not easily fit into our interview matrix and questionnaire format. Each Caltrans site had unique construction and planning challenges to understand. Feedback from Caltrans personnel helped understand the management structure and the division of labor/ responsibilities within the DCFC projects design, scoping, and execution.

Then we collected best available cost information from winning project bids and any further cost changes during the project execution. Other project costs such as utility interconnection fees and cost of purchasing EVSE equipment were also collected via utility bills and purchase documents. The cost information was categorized into relevant project sites where possible. Then cost information was further categorized by item description and amounts to better understand the cost elements and their contribution to final costs.

Then we analyzed detailed architectural plans as well as detailed civil and electrical construction plans to understand the cost elements for most sites and how early-stage planning and design decisions have impacted final costs. Then we compared costs between different design choices in make-ready infrastructure, and between grid connected and off-grid solar DCFC station designs to better understand the holistic costs and implications of different design choices.

**Interviews**

The responsibility for the 37 sites were shared between 8 teams from 8 Caltrans districts. Some teams were responsible for one site, whereas other teams were responsible for as many as 10 sites. The interviews were conducted either with the entire team present with the project manager, resident engineers, design engineers and architects together. We conducted individual interviews with design engineers to better understand the early-stage planning and design decision they had to make with the best available information during the planning stages.

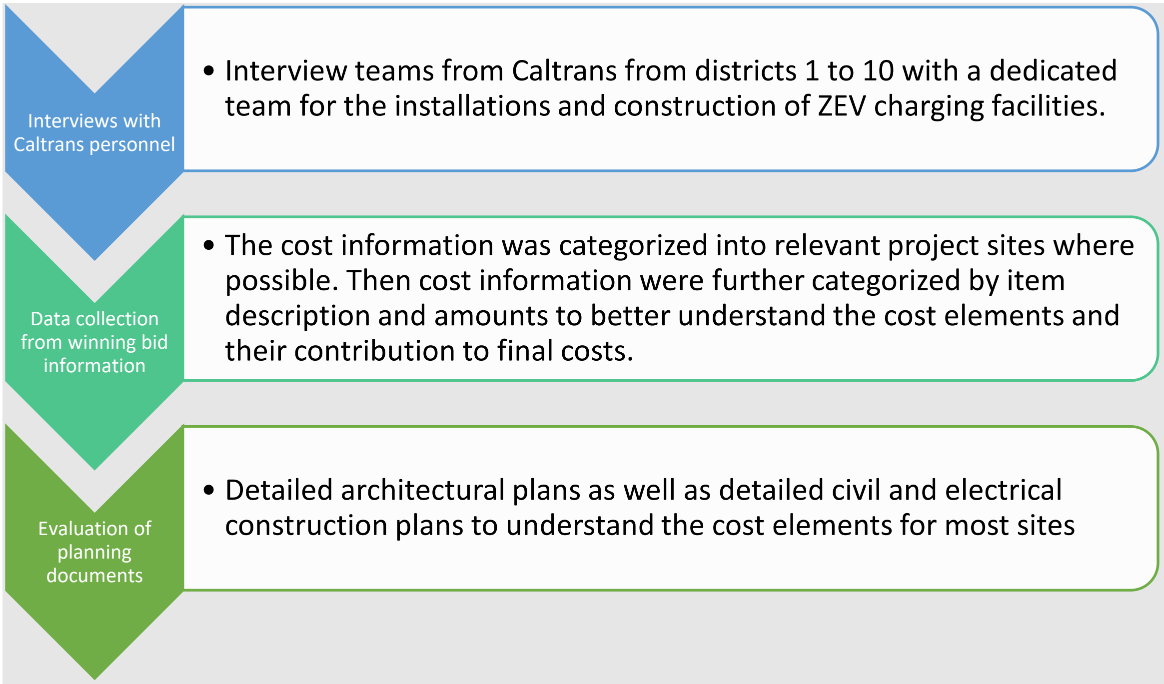



*Figure 6: Summary of data collection and evaluation*

**Site Visits**

Due to the covid-19 pandemic and the California Governor's stay at home orders for the first phase of the pandemic, the research team were not able to do site visits during the construction phase as planned.

### 1.3. Design Elements

All the sites had planned for DC Fast charging output up to 50 kW at 480 Volts. The aim was to provide 200 Miles of Range Per Hour (RPH) of charging. On the user side, Caltrans ZEV charging stations were expected to be compatible with CHAdeMO ports and & SAE J1772 Combo. Therefore, design engineers planned each charger to have two connectors, a CHAdeMO connector and a CCS combo connector for vehicles that relied on either socket for charging.

The design engineers planned the make-ready infrastructure with extra capacity to install extra chargers (or above ground EVSE units) in each location if usage data suggests the need. A detailed image of the above ground EVSE unit is found in Figure 7.

**Connectors and Parking spots**

Each charger was required to have two connectors, with the ability to install extra chargers in each location if usage data suggests the need. Each location was designed to use three existing parking spaces in Caltrans facilities to create two dedicated PEV parking spaces with enough space for the above ground EVSE unit. Each location was also planned to ADA compliant according to the Americans with Disabilities Act (ADA) of 1990. An example plan is available in Figure 8 [7].

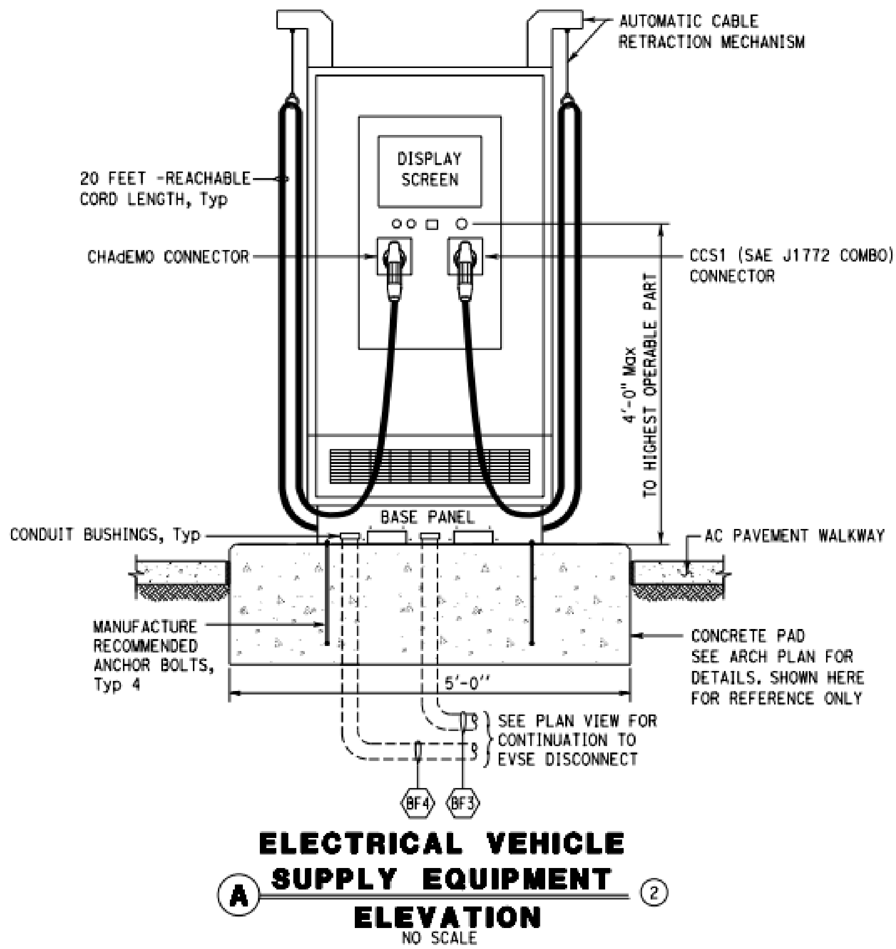
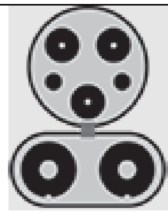
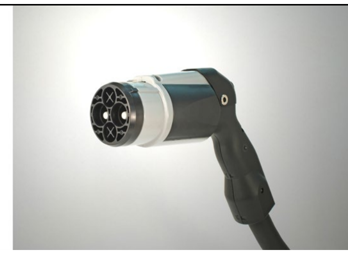



*Figure 7: Front end view of above ground EVSE units (from Caltrans)*

A detailed cross-section and images of the CCS combo connector (SAE J1772 Combo) and CHAdeMO connector is included in Table 3 below.

*Table 3: CCS vs CHAdeMO connectors [8] [9]*

| CCS Combo Connector | CHAdeMO Connector |
|---|---|
|  |  |
|  |  |

## Parking spots

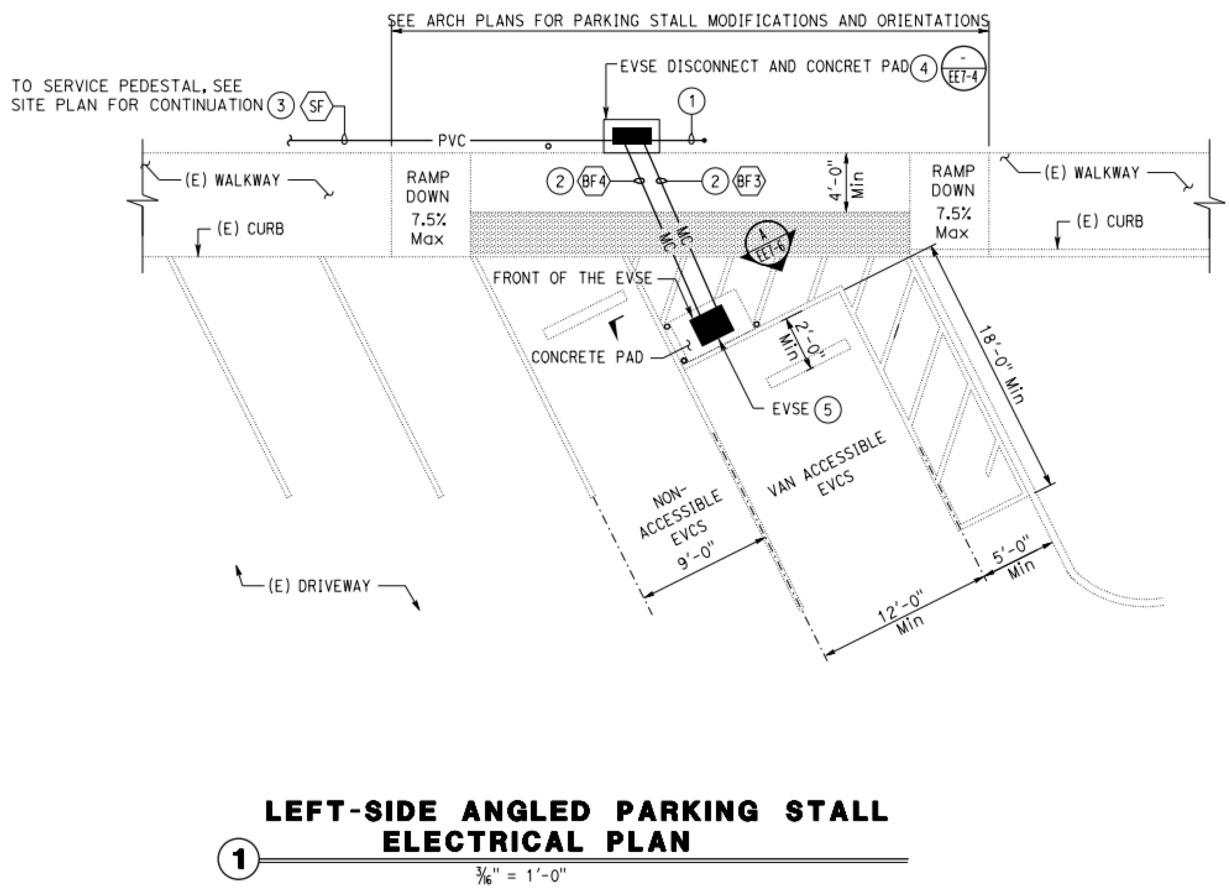



*Figure 8: Example of an ADA compliant PEV parking spot (from Caltrans designs)*

**Energy supply and make ready infrastructure.**

In terms of energy sources and energy supply infrastructure, 34 out of the 37 sites had opted to receive energy drawn from the electricity grid. Three sites in Caltrans District 5 had opted to try a different off-grid design with solar arrays and onsite storage. In the conventional design of grid connected charging system, there were two elements of the energy supply infrastructure, (1) getting the utility grid connection to the site and (2) getting power from the utility drop site to the designated PEV parking spot. Local electric utilities were only responsible for getting adequate power for your work site. Afterwards it was the responsibility of Caltrans to install the necessary on-site electrical conductors connecting the EVSE unit in the PEV parking spot to the utility drop site.

Caltrans engineers decided to request new utility connections in almost every location as the project engineers estimated that available feeder capacity was not enough for the high-power requirements of the charging stations. Existing electrical loads in Caltrans properties were very small (i.e., lighting, and other needs in rest areas). This decision makes a significant cost difference for remote sites. In most locations, utilities needed to upgrade their infrastructure with new electrical cabinets and panels. If there is a considerable distance between the utility service drop site to the PEV parking spot, they need to be connected by PVC (Polyvinyl chloride) insulated copper conduit wire that is buried under 30’’ inches. The conduit sizes, insulation requirements and undergrounding and safety requirements are guided by the National Fire Protection Association standards or NFPA 70, National Electrical Code (NEC) and Caltrans safety requirements. This is called “make-ready infrastructure” by industry stakeholders.

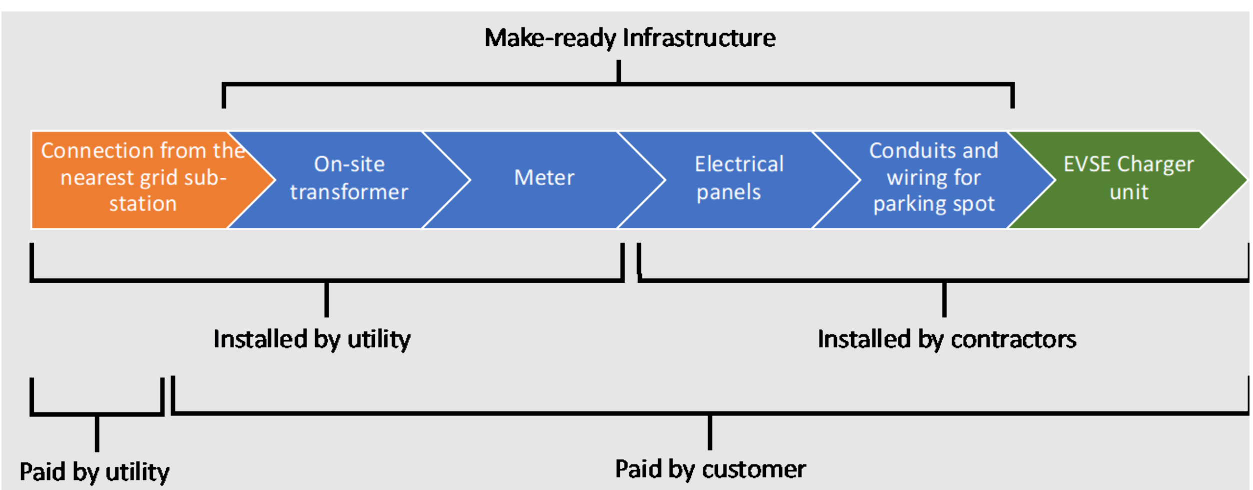



*Figure 9: Summary of infrastructure required for a working DCFC and who is involved with what. The blue indicates the make-ready infrastructure, the green indicates the above ground EVSE unit and orange indicates all utility infrastructure leading to the work site*

Figure 10 is taken from the modified electrical design plan for Willows Northbound safety rest area. See the utility drop site towards the left end of the diagram and the EVSE unit and parking spot towards the mid-right end of the diagram. The buried copper conduit connecting the utility drop site and EVSE unit is trenched through pavement and sidewalks and any other concrete layer that was present in the rest area before the construction. After the trenching, this area needs to be backfilled with concrete and restored to previous conditions before the trenching. All this civil and electrical construction work is called make ready infrastructure in this report.

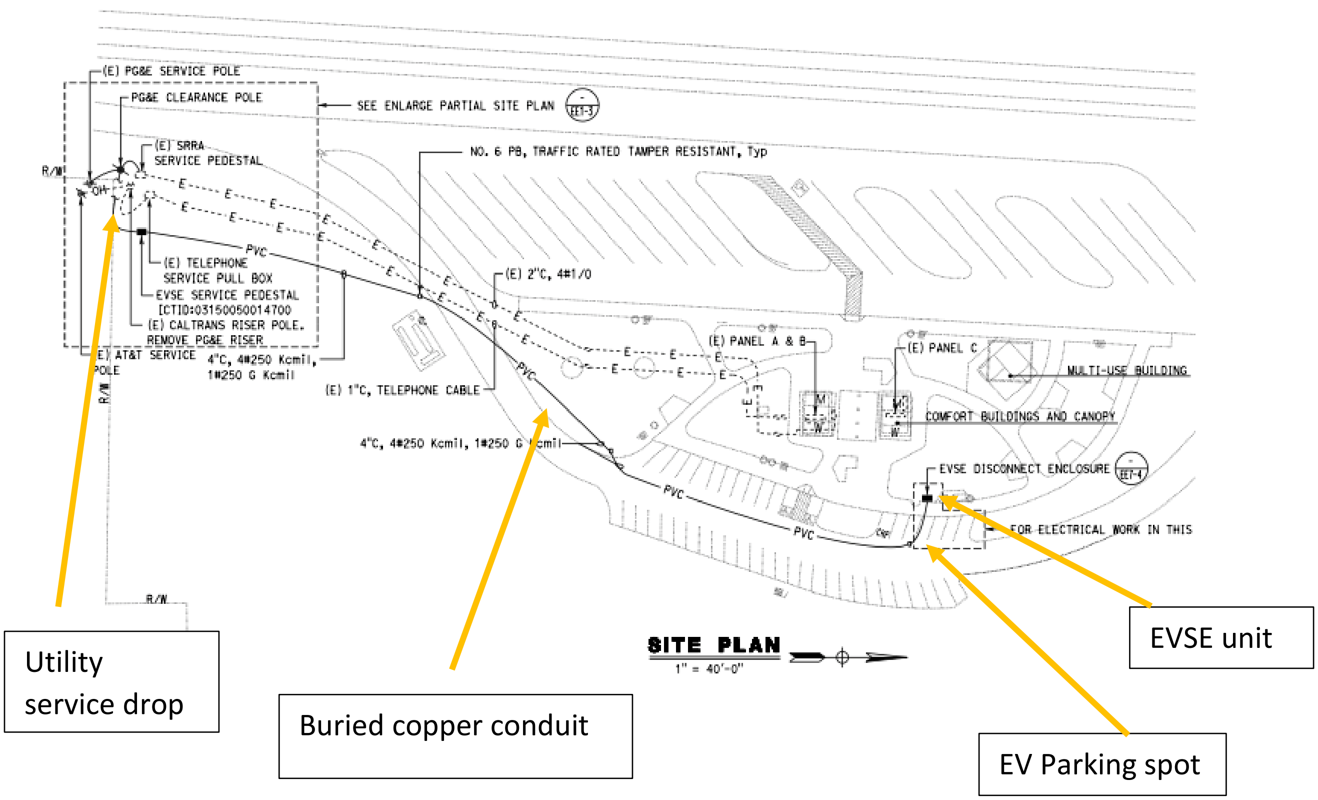



*Figure 10: Brief overview of the on-site make-ready infrastructure in a rest area (from Caltrans)*

**Off-grid design**

Caltrans team in district 5 overseeing Camp Roberts safety roadside rest areas (northbound and southbound) and Shandon safety roadside rest areas decided to try an off grid solar connected charging stations design with adequate on-site storage attached to the sun tracking solar-ARC solar panels. Here the EVSE charger directly connects to four solar tracking stations with attached storage. The solar photovoltaics (PVs) are called solar EV ARC (trademark) in the Caltrans bid documents because they have some sun tracking features.

As seen in the engineering drawing *Figure* the EVSE unit is connected by underground conduits to the four solar ARC units. A more detailed cost and benefit analysis is discussed later in this report.

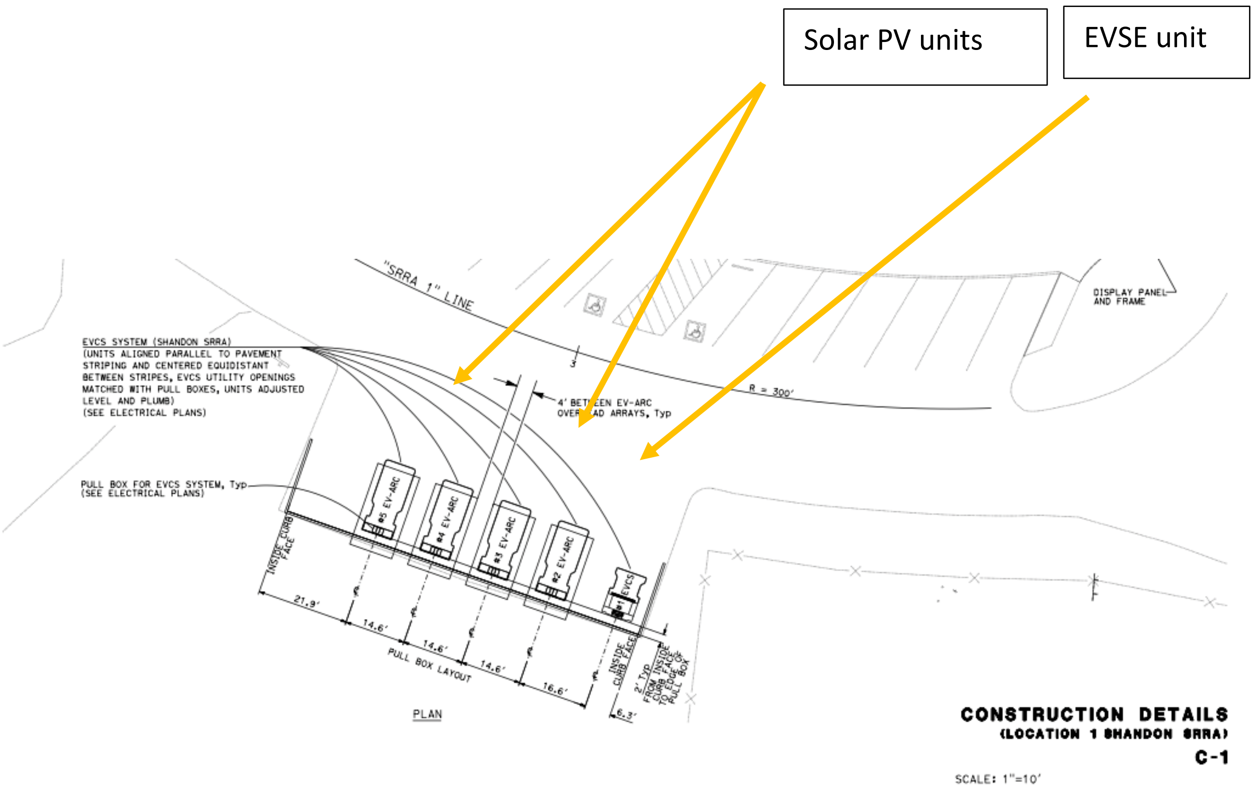



*Figure 11: Site design for on-site solar EV ARC + attached storage design of DCFC (from Caltrans)*

### 1.4. Projects Execution

#### Management of Projects

After policy direction is set, and budget is made available, then Caltrans begins the implementation stage comes after all legal considers are met. Caltrans would initially create a working unit with a project manager and a project engineer (also referred as the design engineer) for a given Caltrans district. The project manager is responsible for scoping, scheduling, and costing for the project and the project engineer is responsible for the design and technical guidance of the project.

We spoke to project managers and design engineers to understand the early stages of the project implementation process. At this point, they considered 3 main issues. (1) purchasing EVSE unit(s),

(2) getting adequate power supply for the PEV parking spot (EVSE unit) and (3) designing and construction of necessary on-site make-ready infrastructure. This early design and planning stage is important for understanding cost variables in the project.

Purchase of the EVSE unit was done through the Department of General Services (DGS) which administers all California State contracts with suppliers. Two EVSE manufacturers were selected, BTCPower and ChargePoint. (Both followed the Caltrans design requirements. Because the BTCPower were purchased in bulk, they received a discounted rate.) Then design engineers survey the proposed construction site to understand initial conditions. From our interviews, we identified that design engineers must finalize the engineering design for the site, which has a detailed project plan for building civil/ electrical construction for all sites. This plan includes a detailed site plan, with detailed parking spots, their layout, and existing and modified electrical works plan. They also included other plans such as tamper protection designs for EVSE.

The design engineers are the first personnel on the ground who understand the realities on the site and assesses the available energy supply infrastructure and needed upgrades. They will usually estimate the total costs of the project beforehand and call for bids from contractors. The PM (Project Manager) will oversee the administration and evaluation of projects. All this ends up in the hands of the Resident Engineer who must effectively oversee contractors and launch the projects under their supervision. The maintenance manager is responsible for maintenance of the system once turned over to maintenance.

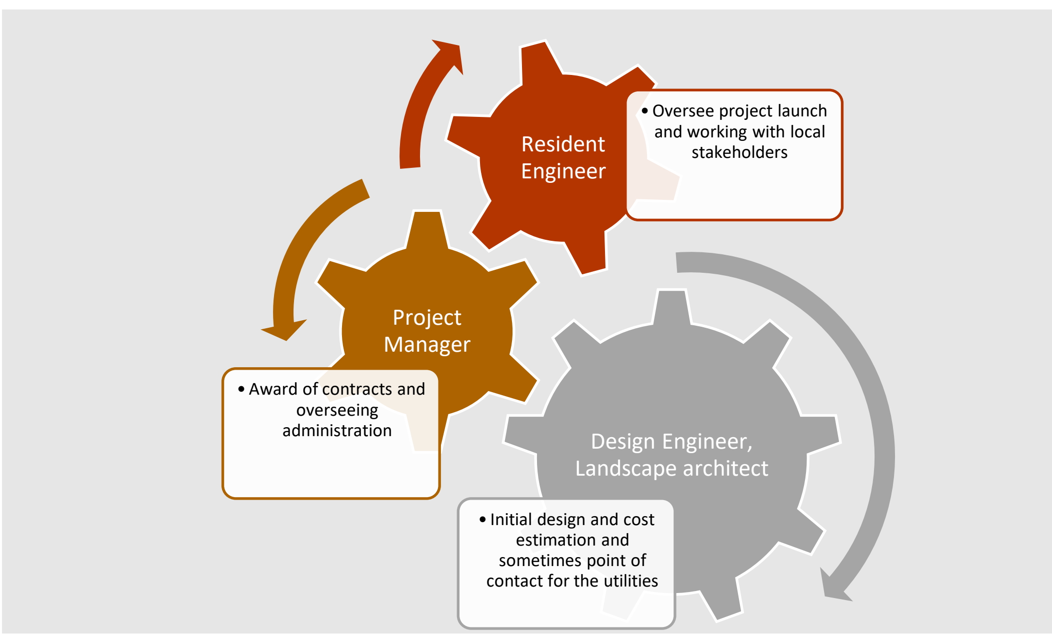



*Figure 12: Management structure of projects*

## 1.5. Construction timelines and costs

### Construction timelines

*Table 4* summarizes the construction timelines from beginning of construction to launch.

*Table 4: Construction timelines*

| Location | Caltrans District | County | Route | Description | No. of DCFC Stations | 2020 | | | | 2021 | | | | 2022 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 |
| 1 | 1 | Lake | 20 | Clear Lake Oaks Maintenance Station | 1 | | | | | | | | | | |
| 2 | | Humboldt | 96 | Willow Creek Maintenance Station | 1 | | | | | | | | | | |
| 3 | 2 | Siskiyou | 5 | Randolf Collier Safety Roadside Rest Area | 2 | | | | | | | | | | |
| 4 | | Trinity | 299 | Moon Lim Lee Safety Roadside Rest Area | 2 | | | | | | | | | | |
| 5 | 3 | Glenn | 5 | Willows Safety Roadside Rest Area (Northbound) | 1 | | | | | | | | | | |
| 6 | | Glenn | 5 | Willows Safety Roadside Rest Area (Southbound) | 1 | | | | | | | | | | |
| 7 | | Colusa | 5 | Maxwell Safety Roadside Rest Area (Northbound) | 1 | | | | | | | | | | |
| 8 | | Colusa | 5 | Maxwell Safety Roadside Rest Area (Southbound) | 1 | | | | | | | | | | |
| 9 | | Nevada | 80 | Donner Summit Safety Roadside Rest Area (Eastbound) | 1 | | | | | | | | | | |
| 10 | | Nevada | 80 | Donner Summit Safety Roadside Rest Area (Westbound) | 1 | | | | | | | | | | |
| 11 | 5 | Monterey | 101 | Camp Roberts Safety Roadside Rest Area (Northbound)* | 1 | | | | | | | | | | |
| 12 | | Monterey | 101 | Camp Roberts Safety Roadside Rest Area (Southbound)* | 1 | | | | | | | | | | |
| 13 | | San Luis Obispo | 46 | Shandon Safety Roadside Rest Area* | 1 | | | | | | | | | | |
| 14 | 6 | Madera | 99 | Madera Maintenance Station | 2 | | | | | | | | | | |
| 15 | 6 | Fresno | 99 | Caltrans District 6 District Office | 4 | | | | | | | | | | |
| 16 | 6 | Kings | 5 | Kettleman City Maintenance Station | 2 | | | | | | | | | | |
| 17 | 6 | Tulare | 99 | C.H. Warlow Safety Roadside Rest Area | 2 | | | | | | | | | | |
| 18 | 6 | Tulare | 99 | Philip S. Raine Safety Roadside Rest Area (Northbound) | 2 | | | | | | | | | | |
| 19 | 6 | Tulare | 99 | Philip S. Raine Safety Roadside Rest Area (Southbound) | 2 | | | | | | | | | | |
| 20 | 6 | Kern | 99 | Delano Maintenance Station | 2 | | | | | | | | | | |
| 21 | 6 | Kern | 58 | Route 58/184 Park & Ride | 2 | | | | | | | | | | |
| 22 | 6 | Kern | 5 | El Tejon Safety Roadside Rest Area (Southbound) | 2 | | | | | | | | | | |
| 23 | 6 | Kern | 5 | El Tejon Safety Roadside Rest Area (Southbound) | 2 | | | | | | | | | | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 8 | San Bernardino | 15 | Clyde V. Kane Safety Roadside Rest Area (Eastbound) | 1 | | | | | | | | | | |
| 25 | | San Bernardino | 15 | Clyde V. Kane Safety Roadside Rest Area (Westbound) | 1 | | | | | | | | | | |
| 26 | | San Bernardino | 15 | Valley Wells Safety Roadside Rest Area (Eastbound) | 1 | | | | | | | | | | |
| 27 | | San Bernardino | 15 | Valley Wells Safety Roadside Rest Area (Westbound) | 1 | | | | | | | | | | |
| 28 | 9 | Kern | 58 | Boron Safety Roadside Rest Area (Eastbound) | 1 | | | | | | | | | | |
| 29 | | Kern | 58 | Boron Safety Roadside Rest Area (Westbound) | 1 | | | | | | | | | | |
| 30 | | Inyo | 395 | Coso Junction Safety Roadside Rest Area | 1 | | | | | | | | | | |
| 31 | | Inyo | 395 | Division Creek Safety Roadside Rest Area | 1 | | | | | | | | | | |
| 32 | | Inyo | 395 | Caltrans District 9 District Office | 1 | | | | | | | | | | |
| 33 | 10 | Stanislaus | 5 | Westley Safety Roadside Rest Area (Northbound) | 1 | | | | | | | | | | |
| 34 | | Stanislaus | 5 | Westley Safety Roadside Rest Area (Southbound) | 1 | | | | | | | | | | |
| 35 | | Merced | 5 | John "Chuck" Erreca Safety Roadside Rest Area (Northbound) | 2 | | | | | | | | | | |
| 36 | | Merced | 5 | John "Chuck" Erreca Safety Roadside Rest Area (Southbound) | 2 | | | | | | | | | | |
| 37 | | San Joaquin | 99 | Lodi Park & Ride | 2 | | | | | | | | | | |
| | | | | Total (Construction and launch Phase) | 54 | | | | | | | | | | |

* The off-grid solar ARC charging stations in District 5 had a different construction timeline.

## Installation Costs

*Table 5: Detailed cost breakdown of the sites*

| Location | Caltrans District | County | Route | Description | No. of DCFC Stations | EV vendor | Utility fee ($) | Contractor's cost ($) | EVSE unit cost ($) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Lake | 20 | Clear Lake Oaks Maintenance Station | 1 | BTCPower | no data | 437,990 | 26,000.00 |
| 2 | | Humboldt | 96 | Willow Creek Maintenance Station | 1 | ChargePoint | 11,960.22 | 205,220 | 51,150.00 |
| 3 | 2 | Siskiyou | 5 | Randolf Collier Safety Roadside Rest Area | 2 | ChargePoint | no data | 475,000 | 51,150.00 |
| 4 | | Trinity | 299 | Moon Lim Lee Safety Roadside Rest Area | 2 | ChargePoint | 11,760.74 | 289,600 | 51,150.00 |
| 5 | 3 | Glenn | 5 | Willows Safety Roadside Rest Area (Northbound) | 1 | BTCPower | 14,918.30 | 321,300* | 26,000.00 |
| 6 | | Glenn | 5 | Willows Safety Roadside Rest Area (Southbound) | 1 | BTCPower | 22,673.09 | | 26,000.00 |
| 7 | | Colusa | 5 | Maxwell Safety Roadside Rest Area (Northbound) | 1 | BTCPower | 24,211.72 | 878,900* | 26,000.00 |
| 8 | | Colusa | 5 | Maxwell Safety Roadside Rest Area (Southbound) | 1 | BTCPower | | | 26,000.00 |
| 9 | | Nevada | 80 | Donner Summit Safety Roadside Rest Area (Eastbound) | 1 | BTCPower | no data | 102,300* | 26,000.00 |
| 10 | | Nevada | 80 | Donner Summit Safety Roadside Rest Area (Westbound) | 1 | BTCPower | no data | | 26,000.00 |
| 11 | 5 | Monterey | 101 | Camp Roberts Safety Roadside Rest Area (Northbound) | 1 | ChargePoint | N/A | 1,557,513 | 51,150.00 |
| 12 | | Monterey | 101 | Camp Roberts Safety Roadside Rest Area (Southbound) | 1 | ChargePoint | N/A | | 51,150.00 |
| 13 | | San Luis Obispo | 46 | Shandon Safety Roadside Rest Area | 1 | ChargePoint | N/A | | 51,150.00 |
| 14 | 6 | Madera | 99 | Madera Maintenance Station | 2 | BTCPower | 2,359.21 | 3,999,402 | 26,000.00 |
| 15 | 6 | Fresno | 99 | Caltrans District 6 District Office | 4 | BTCPower | 170,264.68 | | 26,000.00 |
| 16 | 6 | Kings | 5 | Kettleman City Maintenance Station | 2 | BTCPower | 115,036.70 | | 26,000.00 |
| 17 | 6 | Tulare | 99 | C.H. Warlow Safety Roadside Rest Area | 2 | BTCPower | 45,814.30 | | 26,000.00 |
| 18 | 6 | Tulare | 99 | Philip S. Raine Safety Roadside Rest Area (Northbound) | 2 | BTCPower | 5,312.27 | | 26,000.00 |
| 19 | 6 | Tulare | 99 | Philip S. Raine Safety Roadside Rest Area (Southbound) | 2 | BTCPower | 3,639.40 | | 26,000.00 |
| 20 | 6 | Kern | 99 | Delano Maintenance Station | 2 | BTCPower | 8,793.89 | | 26,000.00 |
| 21 | 6 | Kern | 58 | Route 58/184 Park & Ride | 2 | BTCPower | 2,760.52 | | 26,000.00 |
| 22 | 6 | Kern | 5 | El Tejon Safety Roadside Rest Area (Southbound) | 2 | BTCPower | 2,256.22 | | 26,000.00 |
| 23 | 6 | Kern | 5 | El Tejon Safety Roadside Rest Area (Southbound) | 2 | BTCPower | | | 26,000.00 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 24 | 8 | San Bernardino | 15 | Clyde V. Kane Safety Roadside Rest Area (Eastbound) | 1 | BTCPower | 1,337.39 | 882,803 | 26,000.00 |
| 25 | | San Bernardino | 15 | Clyde V. Kane Safety Roadside Rest Area (Westbound) | 1 | BTCPower | | | 26,000.00 |
| 26 | | San Bernardino | 15 | Valley Wells Safety Roadside Rest Area (Eastbound) | 1 | BTCPower | 308.33 | | 26,00.00 |
| 27 | | San Bernardino | 15 | Valley Wells Safety Roadside Rest Area (Westbound) | 1 | BTCPower | | | 26,000.00 |
| 28 | 9 | Kern | 58 | Boron Safety Roadside Rest Area (Eastbound) | 1 | BTCPower | 4,271.80 | 594,954 | 26,000.00 |
| 29 | | Kern | 58 | Boron Safety Roadside Rest Area (Westbound) | 1 | BTCPower | 4,359.11 | | 26,000.00 |
| 30 | | Inyo | 395 | Coso Junction Safety Roadside Rest Area | 1 | BTCPower | 2,791.96 | | 26,000.00 |
| 31 | | Inyo | 395 | Division Creek Safety Roadside Rest Area | 1 | BTCPower | 30,540.00 | | 26,000.00 |
| 32 | | Inyo | 395 | Caltrans District 9 District Office | 1 | BTCPower | 16,793.78 | | 26,000.00 |
| 33 | 10 | Stanislaus | 5 | Westley Safety Roadside Rest Area (Northbound) | 1 | BTCPower | 143,548.81 | 996,563 | 26,000.00 |
| 34 | | Stanislaus | 5 | Westley Safety Roadside Rest Area (Southbound) | 1 | BTCPower | | | 26,000.00 |
| 35 | | Merced | 5 | John "Chuck" Erreca Safety Roadside Rest Area (Northbound) | 2 | BTCPower | 3,088.07 | 849,128 | 26,000.00 |
| 36 | | Merced | 5 | John "Chuck" Erreca Safety Roadside Rest Area (Southbound) | 2 | BTCPower | | | 26,000.00 |
| 37 | | San Joaquin | 99 | Lodi Park & Ride | 2 | BTCPower | 27,497.80 | | 26,000.00 |

**Experience with utilities during construction**

A major learning experience we heard from almost all our interviewees were how the project engineers have underestimated timelines and costs of working with major utilities and regulatory compliance. That applies to the longer time for working with electric utilities, cost overruns and requirements of planning, communication, documentation, and other compliance requirements that were unforeseen. Given the remoteness of most of the sites, power utilities need to expand the energy supply capacity and other electrical equipment such as transformers. Almost all interviews described that they had misjudged the time and resources needed to work with electric utilities. Many suggested a 4–6-month precautionary time to begin working with electric utilities to get the necessary cost estimated for a new connection, lead times for supply infrastructure, and a down payments for the necessary upgrades.

One or more of the DC Fast Charger Stations draws significant power from the energy grid and in-order to serve that anticipated new energy demand utilities will almost all the time plan and install additional capacity upgrades, Electric Distribution Line Extensions and Service Line Extensions to the energy grid to service one or more 50 kW DC Fast Charging Stations.

**Understanding utility costs and timelines**

Utilities have a complex web of regulatory rules to determine how much of the cost of upgrades are passed onto Caltrans. It cost Caltrans between $100 to $71,700 per site to bring adequate power to the charging stations from the local grid. We do not have enough information to calculate how utilities determine the cost of utility fees for a new connection and upgrades. But regulatory rules pertaining to ZEV chargers are constantly evolving. A new resolution issued by the California Public Utilities Commission (CPUC) in October 2021 is an attempt at clarifying such rules on how utility side make ready costs for PEV chargers are rate based and how much costs are passed onto the customer (i.e., Caltrans). These rules will come into force in California from 2022.

### 1.6. Impact of the covid-19 pandemic on the construction phase

The ITS team began conducting interviews in the month of May 2020 well into the stay-at-home orders issued by the Governor of California in March 2020. The team was able to capture some of the impacts and disruptions of covid-19 on phase 1: The Project Launch and Construction Phase. The most obvious impacts were disruptions in the construction work of the sites. We identified that in May of 2020, sites in Stanislaus, Merced and San Joaquin counties were briefly halted due to the stay-at-home orders and the confusion in the early days of the pandemic. Also, these sites had disruptions in the supply of electrical equipment and delays in delivering the DC Fast Charger units to be mounted on the sites where the ground preparation work was completed.

We identified another disruption to the sites in Kern and Inyo counties in Southern California as the contractor's crew had tested positive for covid-19. According to the resident engineer, although the contractor's crew were asymptomatic, with little to no symptoms showing from coronavirus, the crew were not able to return to work until they tested negative because of strict quarantine measures. In the same counties, we identified other potential cost increases on the construction of the sites as the price of basic construction materials such as concrete. Such material cost increases were potentially due to the uncertainty in the material supply chains and increased demand from uncertainty. US Concrete reports that their sales revenue in the first quarter of 2020 increased by 1.6 percent and aggregate product sale volumes 5.4 percent compared to the first quarter of 2019 [10]. The Resident Engineer overseeing the sites expected extended price overlays from the contractors as building materials directly impacts the final costs. However, such price increases are not significant compared to total project costs.

### 1.7. Unique construction conditions in Caltrans Properties

There were obvious stresses that drove project costs higher for the Caltrans properties selected compared to other ZEV charger installations in urban areas. The total costs of construction for these ZEV chargers under the Caltrans 30-30 project installations range anywhere between $122,000 – $440,000. We find that this is higher than the information shared by other sources. Here are some factors that are responsible for higher costs in these remote sites.

Given the remoteness of the sites, obtaining energy supply is usually a challenge that incurs high costs. (1) Most ZEV fast charger construction in dense urban areas would benefit from existing utility infrastructure already invested by cities and utilities. Although we take this for granted, such shared infrastructure creates a complimentary ecosystem that drives prices down for individual customers. (2) Moreover, the remoteness of the sites drives cost stresses on mobilizing labor and materials necessary for the construction projects. The project construction crew had to take necessary safety measures in Caltrans location that have high foot traffic. (3) Furthermore, the co-location of ZEV charging stations on twin rest areas on opposite sides of a freeway adds significant costs and challenges for construction. This is especially true if local electrical grid capacity is only accessible from one side of the highway.

*Table 6* is a summary of the costs of construction for Maxwell Northbound (NB) and Southbound (SB) SRRAs and Willows NB and SB SRRAs. These “twin” rest areas are located only 25 miles apart along the same highway 5 and have the same contractor for the project. But they have very different construction cost, almost $540,000 in difference because of different design decisions.

Table 6: Project costs of Willows Safety Roadside Rest Area (SRRA) vs. Maxwell SRRA. The conduit and conductor costs are a sub-cost of the make ready infrastructure costs. They are indicated in parathesis not to be confused as a new cost element.

| Description | Utility fee ($) | Make-ready infra. Cost | Conduit & Conductor (Sitework) costs | EVSE |
|---|---|---|---|---|
| Willows Safety Roadside Rest Area (Northbound) | $14,918.30 | $321,300 | ($123,951) | $26,000.00 |
| Willows Safety Roadside Rest Area (Southbound) | $22,673.09 | | | $26,000.00 |
| Maxwell Safety Roadside Rest Area (Northbound) | $24,211.72 | $878,900 | ($516,983) | $26,000.00 |
| Maxwell Safety Roadside Rest Area (Southbound) | | | | $26,000.00 |

Willows SRRAs were able to save significant resources because that site was able to obtain two different utility connections for NB and SB rest areas, whereas at Maxwell, only the SRRA servicing Southbound traffic was able to obtain a connection. The construction crew must get power from Maxwell SB to the Maxwell SRRA (Northbound) under the freeway by using a construction technique known as boring and supporting conducting materials. Boring is a construction technique that uses directional drilling (as opposed to trenching), that creates a horizontal tunnel underground without harming the surface [11]. The higher costs for Maxwell SRRAs are attributed to this process and as seen in column "Conduit and Conductor costs" in *Table 6*, higher conduit costs and labor costs lead to much higher costs. During the design phase, it may be difficult to have foreseen such high costs and location specific geography and distribution of the utility grid are important factors for this decision.

In hindsight we can advise that when it is necessary to lay conduit under the freeway, it is cheaper for the utility to do it before the meter at a higher voltage than at a lower voltage for the construction crew. At low voltage, higher resistance in the conducting materials leading to additional conductors to support the same power output leading to more boring, trenching, and ultimately higher costs

Another unique cost driver was California's seismic anchoring requirement. Contractors were required to build the DC Fast chargers to adhere to special seismic anchoring requirements pertaining to the California Building Code and the Essential Building Seismic Safety Act, Senate Bill 230, Title 24. This may increase the costs compared to other DC Fast charger investments in other States.

**Alternative Solar Off-grid design**

We include a cost analysis of the alternative solar-ARC off grid design at the Caltrans properties in District 5. Table 7 is a summary of the cost components of this unique design in SRRA is located alongside route 46 in Shandon Safety Roadside Rest Area. The engineers chose the unique solar powered DC Fast charger design for this location. Below is a breakdown of all the costs incurred for the 50kW DC Fast Charger installed.


Figure 13: Shandon Rest Area (Images from Google under fair use)

The solar units are called Solar ARC because of the motorized sun tracking feature. This unit includes Photovoltaic (PV) panels and attached batteries. A schematic diagram can be found in Figure 11.

*Table 7: Cost breakdown of the Shandon safety roadside rest area charging system with necessary components that enable the operation of the off-grid ZEV DC fast charging station.*

| Item | Unit Price |
|---|---|
| 4 EV ARC (Sun-tracking PV array with battery storage) | ($420,545) |
| DC Fast Charging Station | ($51,150) |
| Additional Battery Storage | ($60,132) |
| 5-year monitoring and maintenance plan | ($31,221) |
| Taxes, training, and testing | ($51,150) |
| Other | ($13,588) |
| Total of EVSE system | $627,786 |
| Electrical Trenching and Backfill | $24,000 |
| Site Specific other costs | $66,873 |
| Contractor’s other costs averaged for this site | $138,900 |
| Total | $857,559 |

This unique design of ZEV Chargers supported by the mobile solar-ARC does not require a new utility service connection. Therefore, this design does not incur very high make-ready costs and can be installed and launched within a shorter timeline.

The shaded items contain the costs of the Solar EV ARC system. The other costs are related to the site preparation, compliance costs and other costs relating to the installation of the ZEV charger system. The total cost for this project is indicated above as $857,560 per ZEV Charging unit with solar and storage capabilities.

**New developments since the scoping and planning stages of the ZEV 30-30 project in 2017**

From the time the project scoping and planning was done in 2017, there were some changes to ZEV charger technology and speeds that could have been incorporated into the final scoping plan in 2020. For example, speed and capacities of DCFC charging stations have improved since 2017 when 50 kW was considered high charging speeds. By 2020 many charging station manufacturers and EVSE units were able to attain higher speeds of 150 kW and more and some experimental designs had theoretical speeds up to 350 kW. Moreover, more DCFC stations are now available in locations that were previously isolated.

This project is even more relevant for now as range of PEVs have improved significantly as many PEV now allow for a range of 200-300 miles per charge. As of august 2022, the EPA has certified at least 14 light duty electric vehicles models to have a range of 300 miles or more [2].

### 1.8. Learning Experiences

From our interviews, we understood that only a handful of Caltrans personnel had direct experience or technical background pertaining to ZEV charger construction. Although this is like a civil construction project, installation of these ZEV chargers required significant planning for electrical make ready infrastructure and compliance with electrical codes and fire safety measures. We think having electricians and engineers trained in Electric Vehicle Infrastructure Training Program (EVITP) certification on site for DCFC installations[4] or similar certification programs who are familiar with National Electric Code (NEC) and National Fire Prevention Association (NFPA) code requirements for EVSE installations can bring down costs and reduce missteps in the future. We think investing in Caltrans workforce training in such programs can be a step in the right direction.

---

[4] CALeVIP (2021), "How do I comply with the Electric Vehicle Infrastructure Training Program (EVITP) certified electrician requirement?"
https://calevip.org/faq/how-do-i-comply-electric-vehicle-infrastructure-training-program-evitp-certified-electrician-0

Working closely with local utilities and communicating with them 4-6 months in advance can save time and resources. We recommend reaching out to local utility during the site selection process and during the design phase once sites are selected. Some make-ready costs could have been saved by locating the EVSE installations and EV parking spot closer to the utility drop site. We think planning and design should be an ongoing process during the construction phase and some design flexibility where applicable can save resources.

### 1.9. Strategies for bringing down costs:

A summary of strategies for bringing down construction costs is listed below:

During planning and purchase phase:

- Bulk purchase of EVSE items together to receive possible discounts.
- Reaching out to local electric utility personnel early in the design process. If possible, include them in decisions such as site selection and location of PEV parking spots.
- Communicate intent to local utility stakeholders to receive new connection to locations 4-6 months in advance.
- Plan to receive separate connections for each Caltrans property where possible.
- Recommend mandatory training programs such as EVITP and other training before the start of the construction process.

**Prefabricated charging stations for isolated sites:**

There is some evidence to suggest that a certain EVSE manufacturer is using a technique of pre-casting and prefabricating EVSE foundations and make-ready infrastructure before they are installed in the final location of interest. The aim is to achieve lower construction costs and timelines. This can be a strategy for project sites that are remote and difficult to construct. However, the ITS team is unable to verify construction budgets or timelines from this manufacturer.

*Figure 14: prefabricated charging station modules*[5]

## 2. Task 2: Charger Operation Data and Analysis

### 2.1. Introduction

The purpose of this section is to study infrastructure performance and the impact of the Caltrans ZEV Fast Chargers installed by the 30-30 project. This chapter will study charger performance metrics such as downtime, power performance, energy dispensed, charging profiles through the usage data collected from the ZEV chargers. This will also include an analysis of the charging gap analysis with changes to the State's network of ZEV fast chargers in Caltrans and non-Caltrans infrastructure from the inception of project to now.

**Charger gap analysis**

Figure 15 is a summary of a plot of the available ZEV public DC Fast chargers accessible to PEV drivers. The data is from the U.S. Department of Energy Alternative fuel data center. The map includes the distribution of 1,445 DC Fast publicly accessible charging station locations across the State of California. Chargers with CCS combo and CHAdeMO connectors were filtered in as most PEVs use this type of connector to charge their vehicles. Tesla Supercharger stations were not included in this analysis because they are not publicly accessible at the time of writing this report. The map on the right displays the Caltrans ZEV 30-30 stations with red color, and the non-Caltrans stations are indicated in green.

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[5] Teslarati (2021), Tesla rolls out clever prefab Supercharger model for faster installations: Accessed on 2022 September at https://www.teslarati.com/tesla-prefab-supercharger-images/

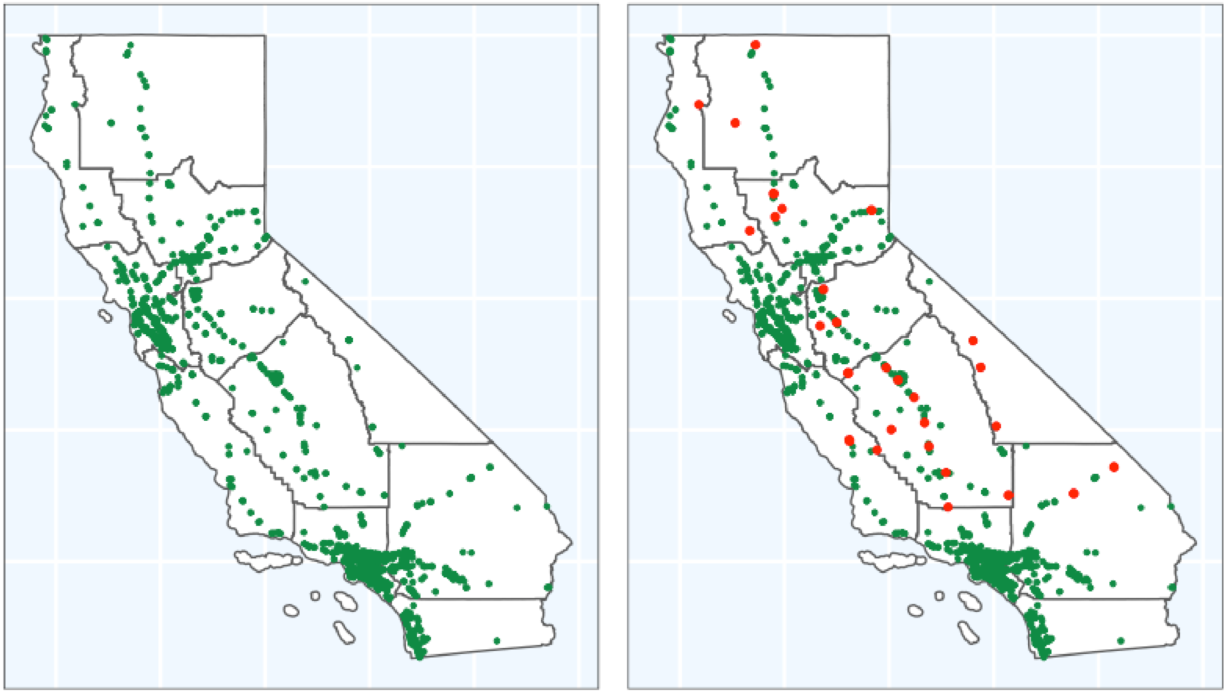


*Figure 15: Caltrans chargers (right) indicated in red with non-Caltrans chargers (left) as of September 2022*

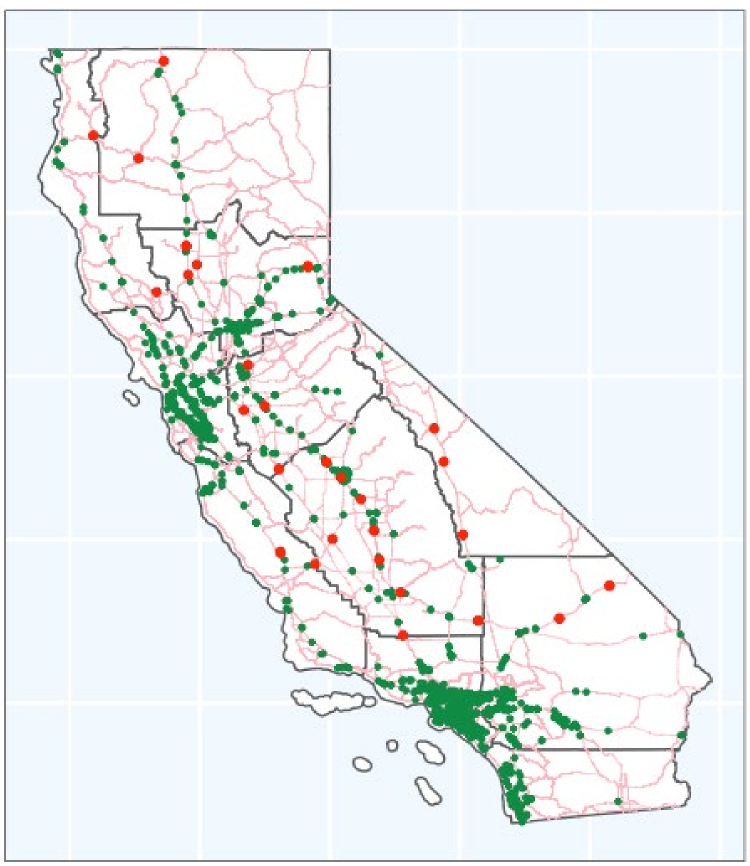


*Figure 16: Caltrans ZEV stations with California major roadways*

Figure 16 and Figure 19 show the Caltrans ZEV chargers with California’s major highways in the background as a layer. By the time of writing this report many more ZEV DCDC stations have come online for public use. But the Caltrans 30-30 ZEV stations are still relevant in most regions where they are the only ZEV stations as indicated in Figure 19. Our analysis shows that ZEV stations in Moon Lim mee SRRAs and Willow Creek SRRAs are the only fast DCFC ZEV stations accessible to PEVs using route 299. Furthermore, the ZEV stations in Division Creek SRRA, Coso Junction SRRA and ZEV stations in Caltrans District 9 office are amongst the only ZEV stations servicing traffic along route 395. This is the same for ZEV stations in CV Kane SRRA and Valley Wells SRRAs servicing traffic along highway 15. ZEV stations along Boron SRRAs are also the only ZEV stations along route 58 in the vicinity.

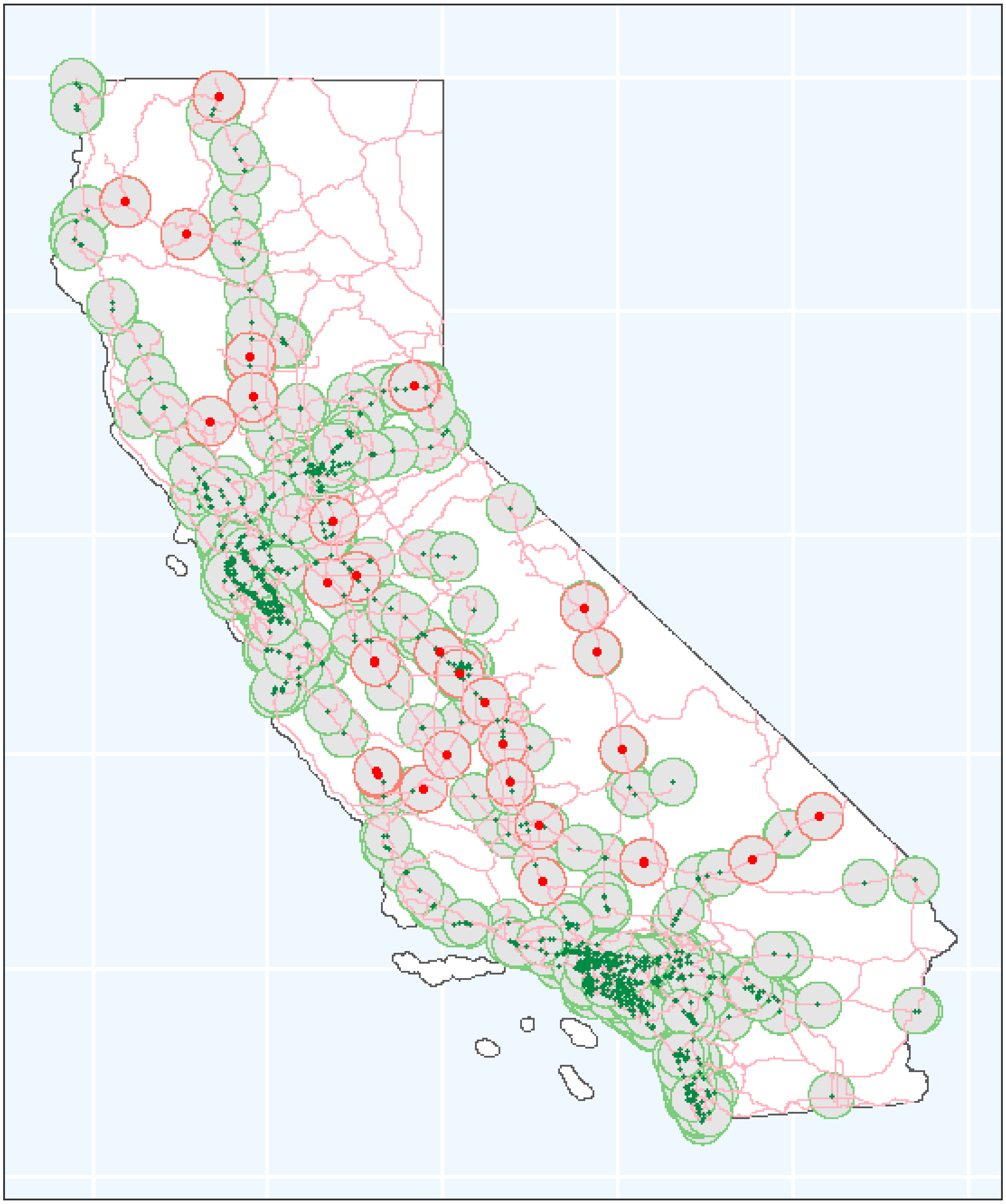


*Figure 17: Caltrans ZEV sites with a 15-mile radius (in color red) and non-Caltrans public ZEV stations with a 15-mile radius (in Green)*

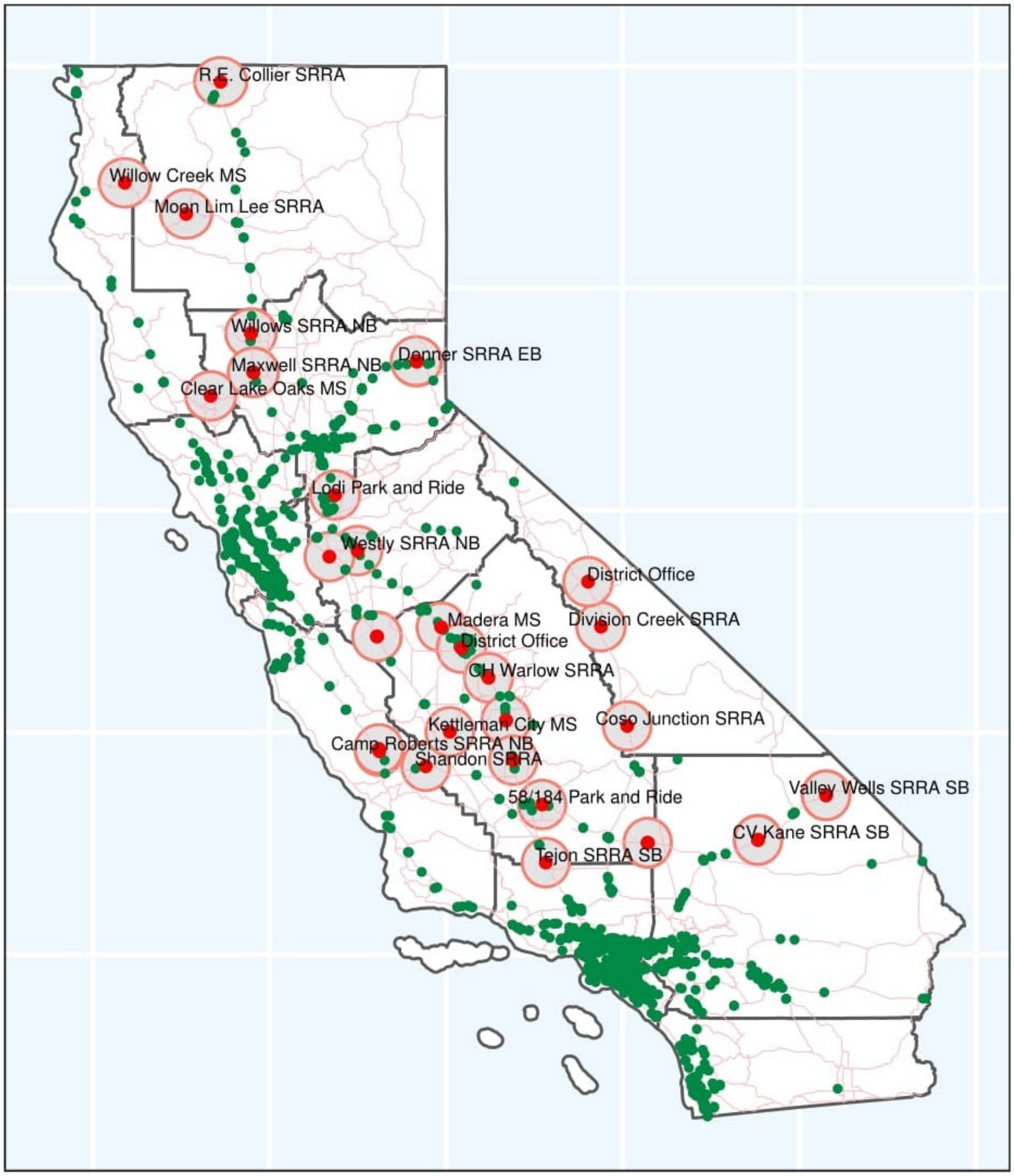



*Figure 18: Public fast ZEV stations in California with respect to Caltrans district boundaries*


Figure 19: Charger gap analysis

## 2.2. Data cleaning and validation

This section aims to understand the nature of charging demand and use of the Caltrans ZEV 30-30 charging stations. It is assumed that demand for charging along highway corridors represent largely inflexible charging demand that need fast charging as PEV drivers in mid journeys between metro regions prioritize low wait times and fast charging.

Shortcomings in readily available data is a barrier in understanding demand for corridor charging. This is partly because of shortcomings in the supply side of corridor charging infrastructure. The Caltrans 30-30 project aimed to fulfill that gap in California's transportation corridors by "filling the gaps within California's DC Fast Corridor Network along key routes of the State Highway System where sufficient commercial zero-emissions vehicle (ZEV) fueling opportunities do not currently exist" [4]. Here we analyze charging data from the 54 DCFCs from the Caltrans "30-30" project to study this further and inform the optimal buildup of corridor charging infrastructure along major transportation corridors in the future.

### Charging data protocols

The ZEV charging station funded by the Caltrans 30-30 project began operationalizing from January of 2021 starting from sites that were energized earlier such as Clear Lake Oaks maintenance station and followed by ZEV stations in Caltrans District 6. (More information is available in *Table 4*). As mentioned before, the ZEV stations selected for the sites were from two different EVSE suppliers, ChargePoint and BTCPower. ITS team received data from both platforms. The attributes are mostly similar across the platforms. The data includes observations from the Caltrans ZEV infrastructure. Every observation is an attempted charging session. Every row is an observation, and every column is a variable that describes some attributes about that unique charging session. More details of the data are included in Table 8.

*Table 8: Attributes of data charging data and charger data protocols*

| **Attribute** | **Description** |
|---|---|
| **EVSE ID** | Unique identifier for each ZEV station |
| **Connector Type** | Indicates which connector was used for the charging session (CCS or CHAdeMO) |
| **Energy delivered in kWh** | How much every was delivered from the charger to the vehicles in each charging session in (kWh) |
| **Start Date Time** | Start time of charging event in yyyy-mm-dd hh:mm:ss format in local time zone |
| **End Data Time** | End time of charging in event yyyy-mm-dd hh:mm:ss format in local time zone |
| **Plug-Out-Time** | Date and time of plug out by the customer |
| **Max Power in kW** | Max power output during charging session in kW |
| **OCPP Session ID** | A unique identifying number for each individual charging session. |
| **Session End type** | A description of how charging session was ended |
| **Start SOC in %** | Vehicle state of charging at the beginning of the charging session |
| **END SOC in %** | Vehicle state of charging at the end of charging session |
| **Ending Voltage** | Ending voltage of the vehicle battery |

| | |
|---|---|
| **User ID (ChargePoint)** | Some anonymized unique used identification information |
| **Gasoline Savings (ChargePoint)** | A calculated value of equivalent gasoline amount in gallons |

Table 8 summarized the main attributes of the data collected from the ZEV charging infrastructure. Out of the 37 charging stations, 5 sites had opted to install ChargePoint stations, and the rest had decided to install BTC Power. Majority of the charging data were from the BTCPower platform. Table 9 includes further information of the manufacturer and unique identification information of each EVSE usage information for each Caltrans site and charger ID.

*Table 9: Unique charger identification information*

| Location No. | Supplier | Charger ID | Physical Location |
|---|---|---|---|
| **1** | BTCP | CALT0041 | Clear Lake Oaks MS |
| **2** | BTCP | CALT0026 | Willow Creek MS |
| **3** | ChargePoint | CT D2 / COLLIER ST 1 | R.E. Collier SRRA |
| | ChargePoint | CT D2 / COLLIER ST 2 | R.E. Collier SRRA |
| **4** | ChargePoint | CT D2 / RESTAREA 1 | Moon Lim Lee SRRA |
| | ChargePoint | CT D2 / RESTAREA 2 | Moon Lim Lee SRRA |
| **5** | BTCP | CALT0024 | Willows SRRA NB |
| **6** | BTCP | CALT0025 | Willows SRRA SB |
| **7** | BTCP | CALT0023 | Maxwell SRRA NB |
| **8** | BTCP | CALT0022 | Maxwell SRRA SB |
| **9** | BTCP | CALT0020 | Donner SRRA EB |
| **10** | BTCP | CALT0021 | Donner SRRA WB |
| **11** | ChargePoint | EV ARC / CAMP ROBERTS NB | Camp Roberts SRRA NB |
| **12** | ChargePoint | EV ARC / CAMP ROBERTS SB | Camp Roberts SRRA SB |
| **13** | ChargePoint | EV ARC / SHANDON | Shandon SRRA |
| **14** | BTCP | CALT0042 | Madera MS |
| | BTCP | CALT0046 | Madera MS |
| **15** | BTCP | CALT0043 | District Office (Fresno) |
| | BTCP | CALT0044 | District Office (Fresno) |
| | BTCP | CALT0045 | District Office (Fresno) |
| | BTCP | CALT0047 | District Office (Fresno) |
| **16** | BTCP | CALT0039 | Kettleman City MS |

| | | | |
|---|---|---|---|
| | BTCP | CALT0051 | Kettleman City MS |
| **17** | BTCP | CALT0027 | CH Warlow SRRA |
| | BTCP | CALT0030 | CH Warlow SRRA |
| **18** | BTCP | CALT0029 | Phillip Raine SRRA NB |
| | BTCP | CALT0031 | Phillip Raine SRRA NB |
| **19** | BTCP | CALT0033 | Phillip Raine SRRA SB |
| | BTCP | CALT0048 | Phillip Raine SRRA SB |
| **20** | BTCP | CALT0034 | Delano MS |
| | BTCP | CALT0036 | Delano MS |
| **21** | BTCP | CALT0032 | 58/184 Park and Ride |
| | BTCP | CALT0037 | 58/184 Park and Ride |
| **22** | BTCP | CALT0028 | Tejon SRRA SB |
| | BTCP | CALT0035 | Tejon SRRA SB |
| **23** | BTCP | CALT0038 | Tejon SRRA SB |
| | BTCP | CALT0040 | Tejon SRRA SB |
| **24** | BTCP | CALT0011 | CV Kane SRRA SB |
| **25** | BTCP | CALT0010 | CV Kane SRRA NB |
| **26** | BTCP | CALT0013 | Valley Wells SRRA SB |
| **27** | BTCP | CALT0012 | Valley Wells SRRA NB |
| **28** | BTCP | CALT0004 | Boron SRRA EB |
| **29** | BTCP | CALT0003 | Boron SRRA WB |
| **30** | BTCP | CALT0005 | Coso Junction SRRA |
| **31** | BTCP | CALT0002 | Division Creek SRRA |
| **32** | BTCP | CALT0001 | District Office (Bishop) |
| **33** | BTCP | CALT0049 | Westly SRRA NB |
| **34** | BTCP | CALT0050 | Westly SRRA SB |
| **35** | BTCP | CALT0017 | John "Chuck" Erreca SRRA NB |
| | BTCP | CALT0018 | John "Chuck" Erreca SRRA NB |
| **36** | BTCP | CALT0016 | John "Chuck" Erreca SRRA SB |
| | BTCP | CALT0019 | John "Chuck" Erreca SRRA SB |
| **37** | BTCP | CALT0014 | Lodi Park and Ride |
| | BTCP | CALT0015 | Lodi Park and Ride |

**Data Cleaning:**

Here will include a summary of infrastructure performance from a systemic level in data aggregation. Figure 20 is an analysis framework for data cleaning and further analysis of charging data. Only charging events recorded from 06/15/2021 were considered for this analysis.

We observe 47,7800 observations from BTC Power stations. We observe data entries where energy dispense was recorded as very low close to ~0 kWh dispensed or where the connector was plugged into the vehicles for less than a minute. We removed all this observation from the analysis as they cannot be considered successful charging events. Only events that are equal or higher than 0.1 kWh and events where the connected was plugged in at least 1 minute were considered.

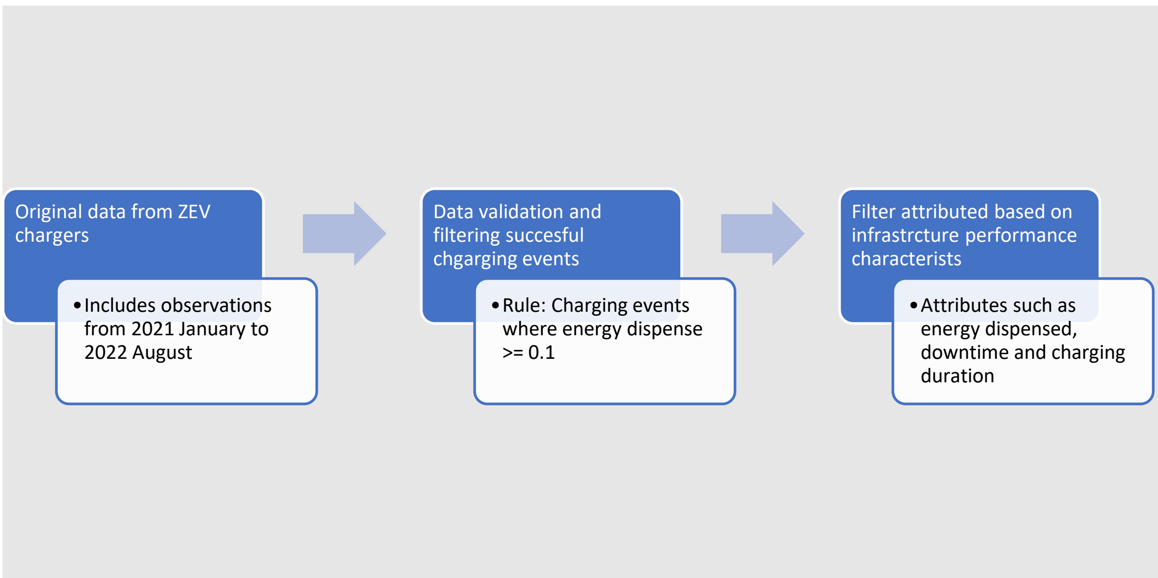



*Figure 20: Matrix for data cleaning and validation*

### 2.3. Charging data analysis:

The data in *Figure 21* includes all successful charging events from January 2021 to July 2022 in BTCPower (BTCP) station that contains 24,700 observations. We observed that PEV drivers who use CCS combo and CHAdeMO connector use the charging stations differently. On average, a PEV driver with a CCS connector uses the BTCP ZEV charges for an average of 41.2 minutes as opposed to drivers who use CHAdeMO connectors that have an average charge time of 35.3 minutes. We believe this is because newer models of PEVs that are capable of higher range have CCS combo connectors whereas older PEV models have CHAdeMO connectors. This is further observed in the distribution of energy dispensed by CCS combo chargers as indicated in *Figure 22*.

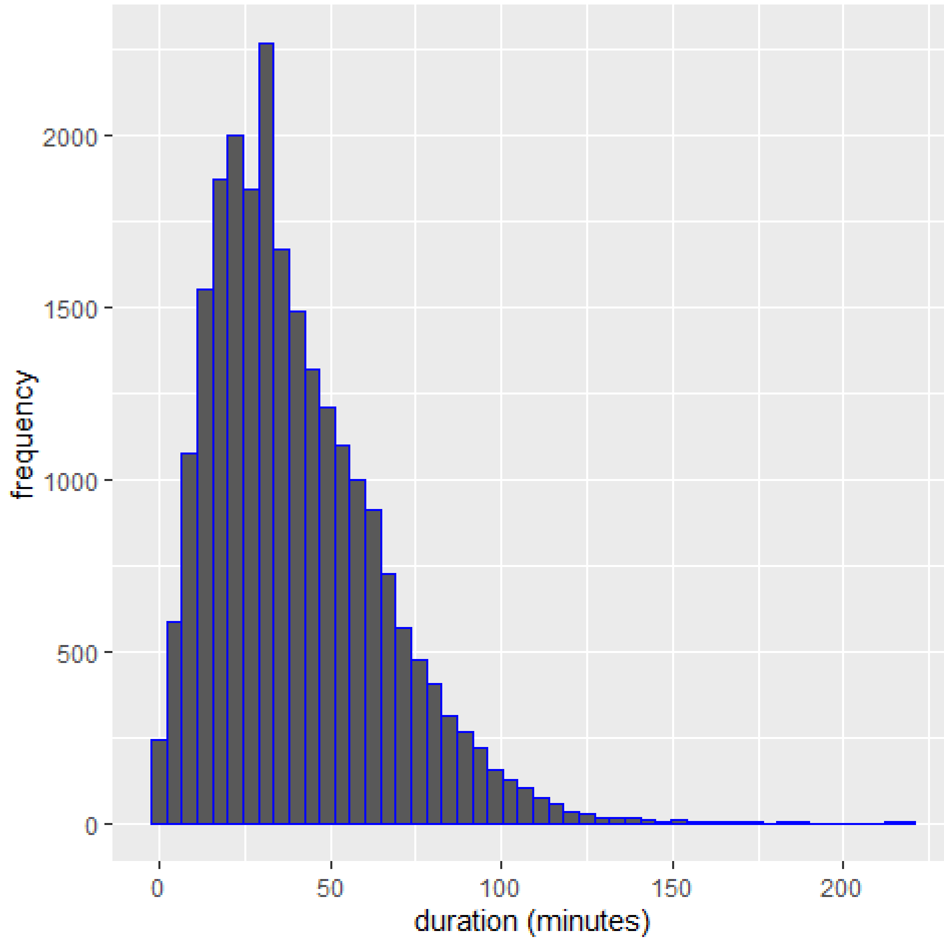



*Figure 21: Distribution of charging time at BTCPower locations*

| Connector Type | Infrastructure Utilization |
|---|---|
| | Average use per charging event |
| **CHAdeMO** | 35.3 minutes |
| **CCS** | 41.2 minutes |

Figure 22 indicated the distribution of energy usage at BTCPower charging stations. This indicates higher than the average energy consumed by ordinary electric vehicles per charge in California and in Europe as observed by other studies [12] [13]. This is because of (1) steadily improving range and battery capacities of newer PEV models and (2) en-route use case of these chargers for longer distance travel.

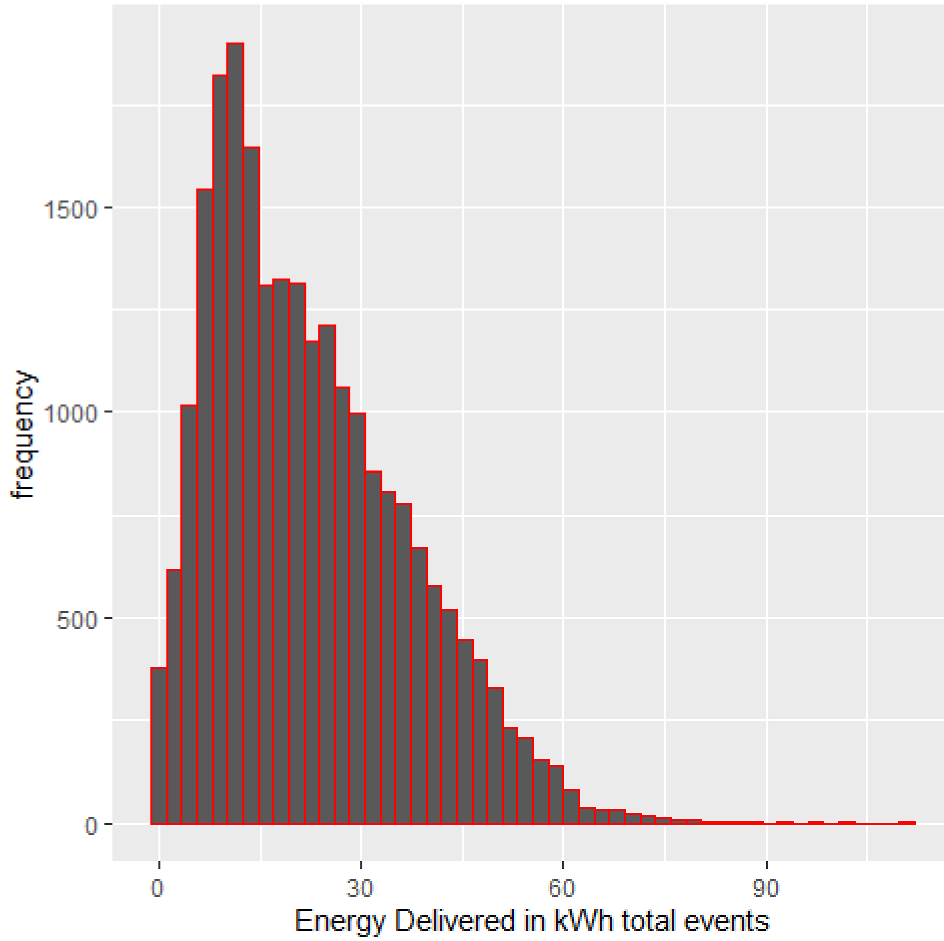



*Figure 22: Distribution of energy usage per successful charging event*

| Connector Type | Infrastructure Utilization |
|---|---|
| | kWh per average charging event |
| **CHAdeMO** | 17.3 kWh |
| **CCS** | 24.2 kWh |

If we assume electric vehicles have an efficiency of 28 kWh per 100 miles [12] then drivers added about 86.4 miles worth of range per average charge with CCS combo connectors and about 61.8 miles worth of range with CHAdeMO connectors.

**Power Performance**

Figure 23 is the distribution of the power performance of the ZEV chargers across the observations. The y-axis indicates the maximum power delivered in kW in every successful charging event. The graph is as expected for a 50-kW rated ZEV charger. Most charging events will achieve a maximum energy delivery speed between 40-50 kW.

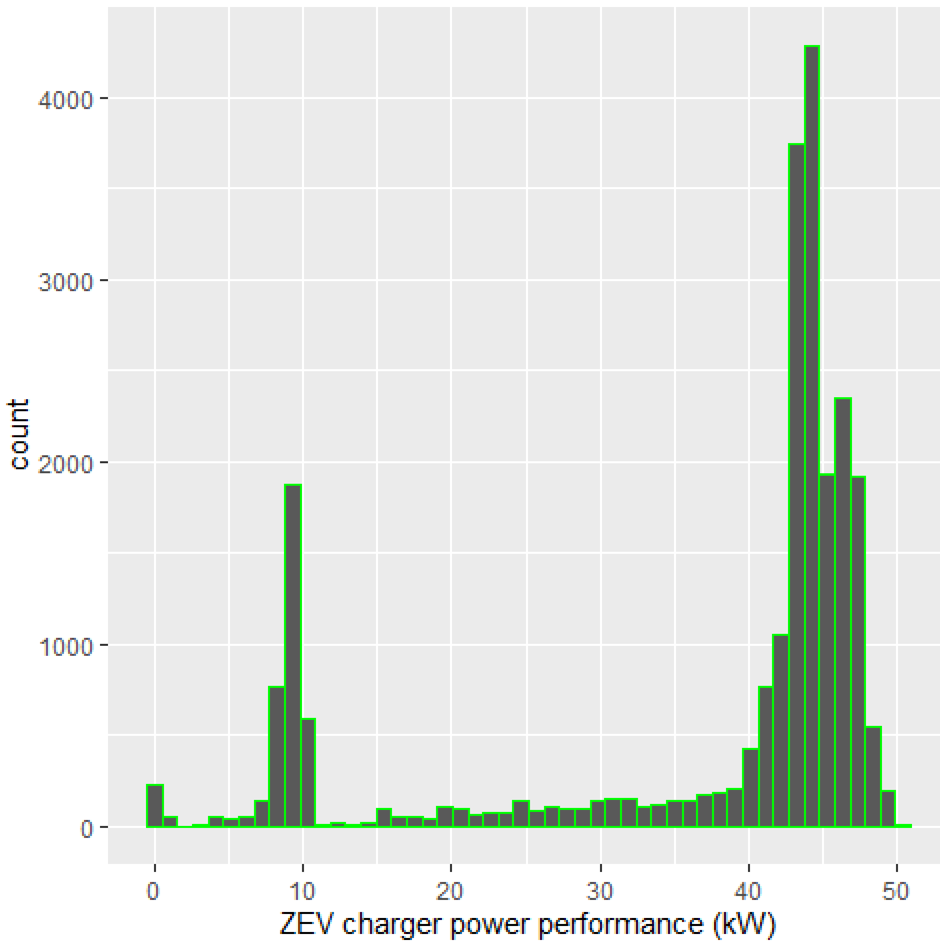



*Figure 23: Power performance of chargers*

**Charging Profiles**

Figure 24 is a summary of how drivers use the chargers in different hours of the day. We identify that more drivers will use the BTCPower chargers between 10 am and 7 pm on average. Further analysis is necessary to capture the emission benefits from this data.

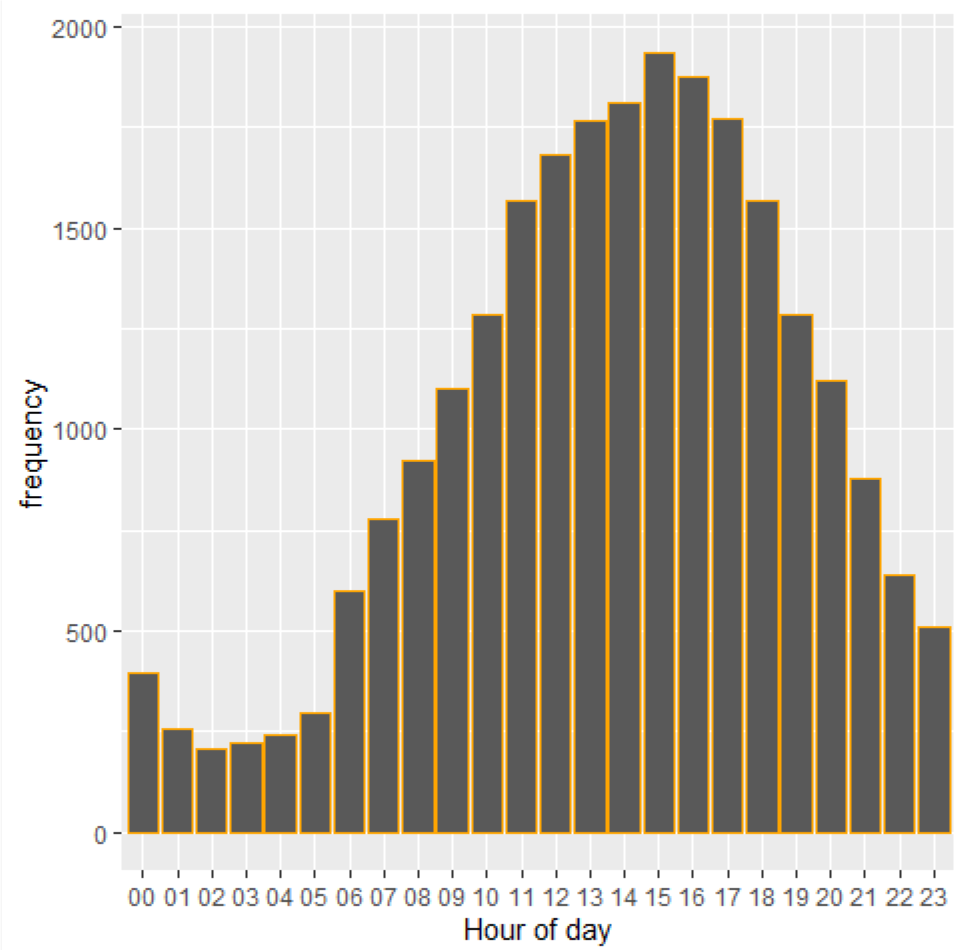



*Figure 24: Charging distribution during the day.*

**Data from ChargePoint**

Figure 25 is a summary of the charging data from ChargePoint. It employs data from 4000 successful charging events. The average energy dispensed is 19.4 kWh per charge at ChargePoint stations.

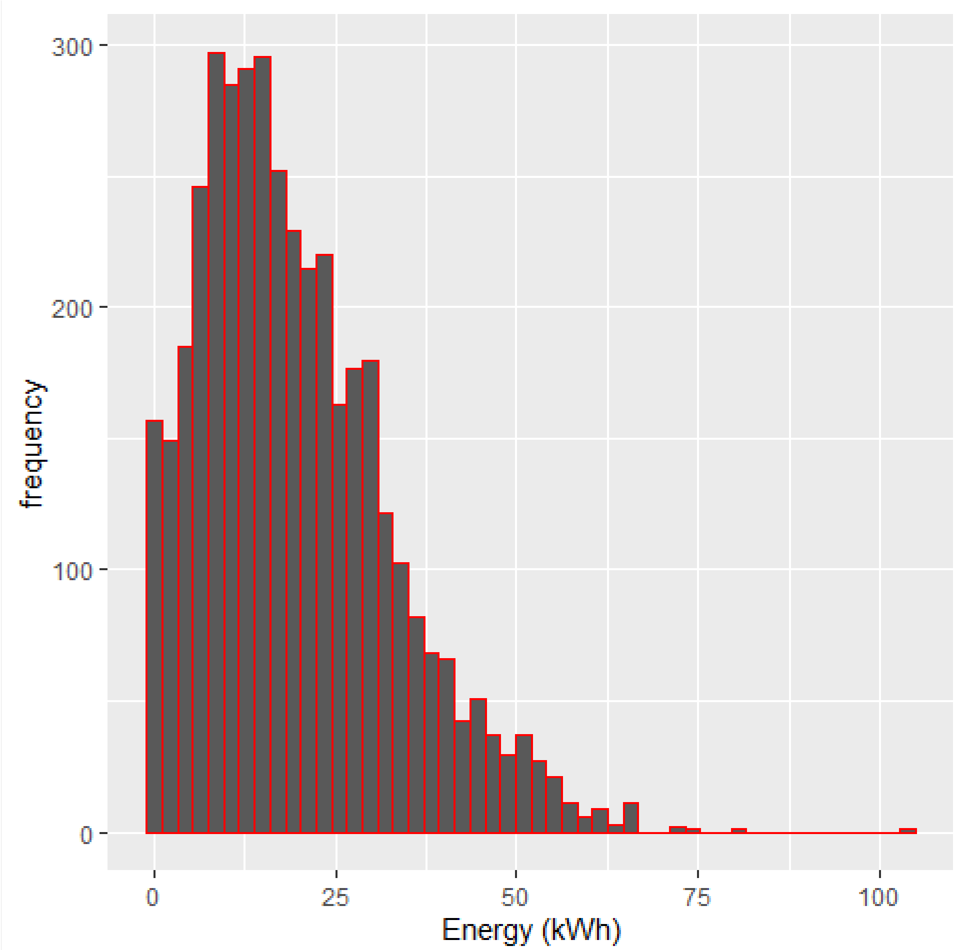



*Figure 25: Distribution of ChargePoint charging events.*

**Charger Utilization**

| Connector Type | Infrastructure Utilization |
| --- | --- |
| | kWh per event |
| **CHAdeMO** | 17.1 |
| **CCS** | 23.2 |

**Usage Data at select charging stations:**

**Division Creek Safety Roadside Rest Area**

Division creek rest area is located alongside route 395 in Caltrans district 9. The ZEV charger in division creek SRRA is identified as a critical charger for PEV driver using that route. The route begins in Southern California Mojave Desert community in San Bernadino County in California.

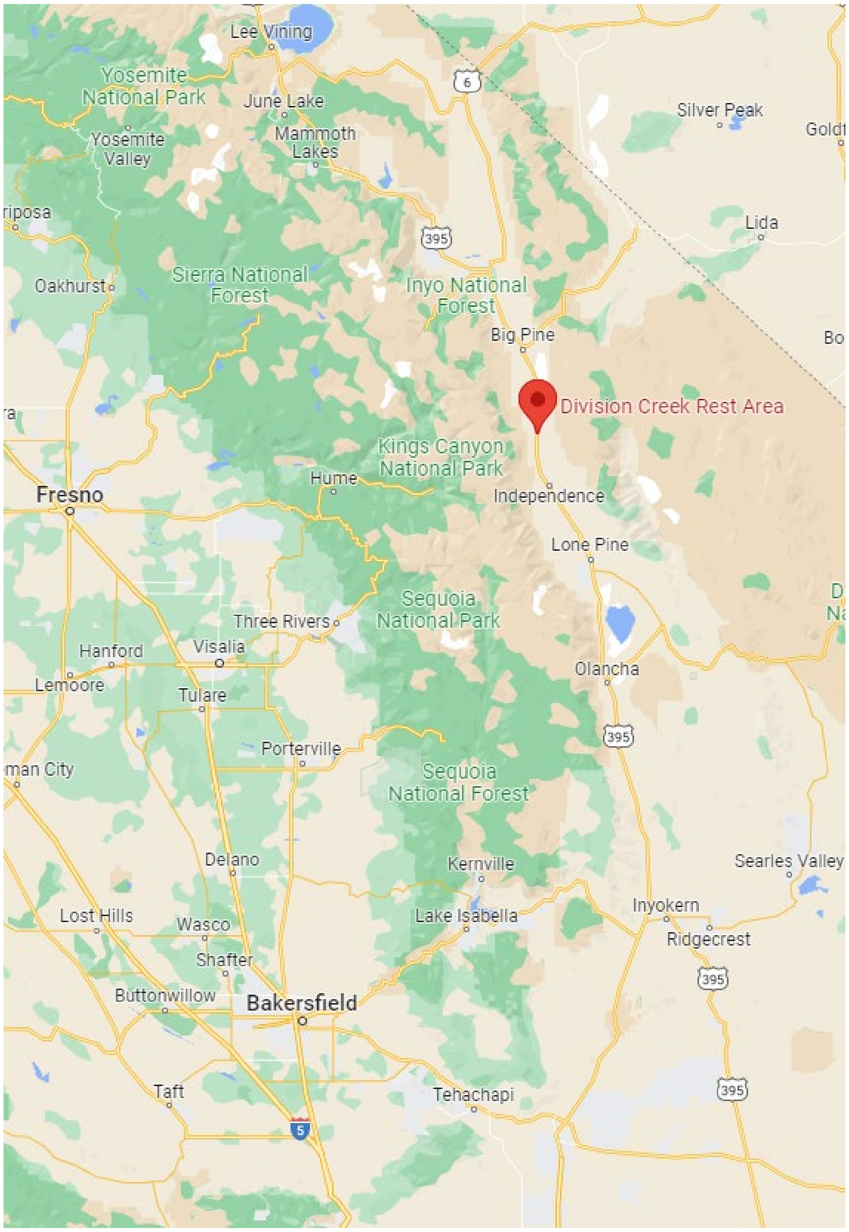



*Figure 26: Location of division creek rest area (from Google maps under fair use)*

The data indicates that the ZEV station in this rest area is frequently used and is the only fast public ZEV in the vicinity for 30 miles north and 67 miles south.

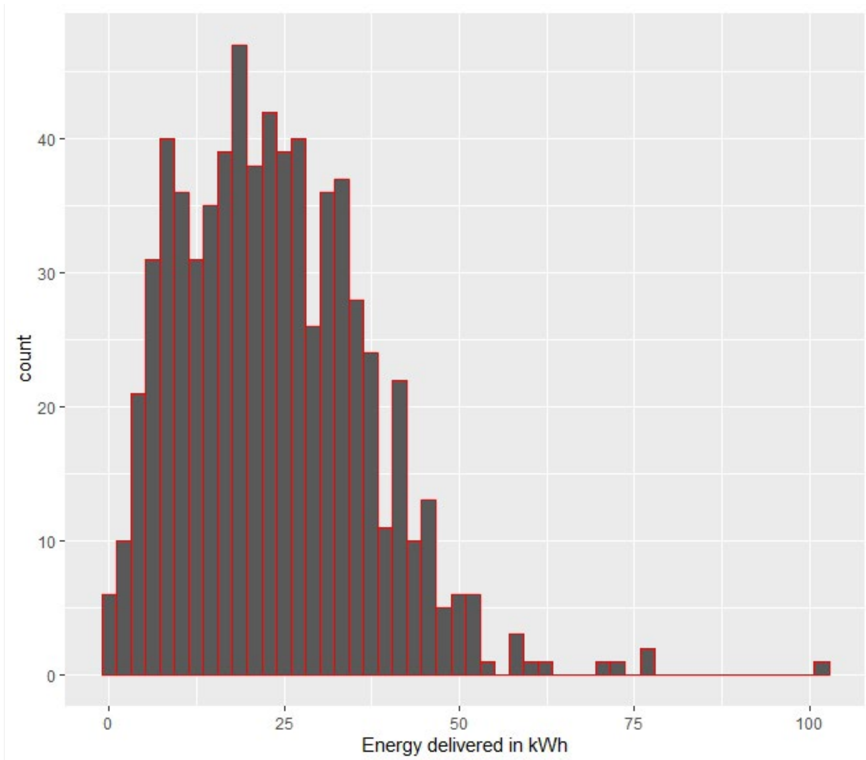



*Figure 27: Distribution of energy dispensed per charging event at Division Creek SRRA*

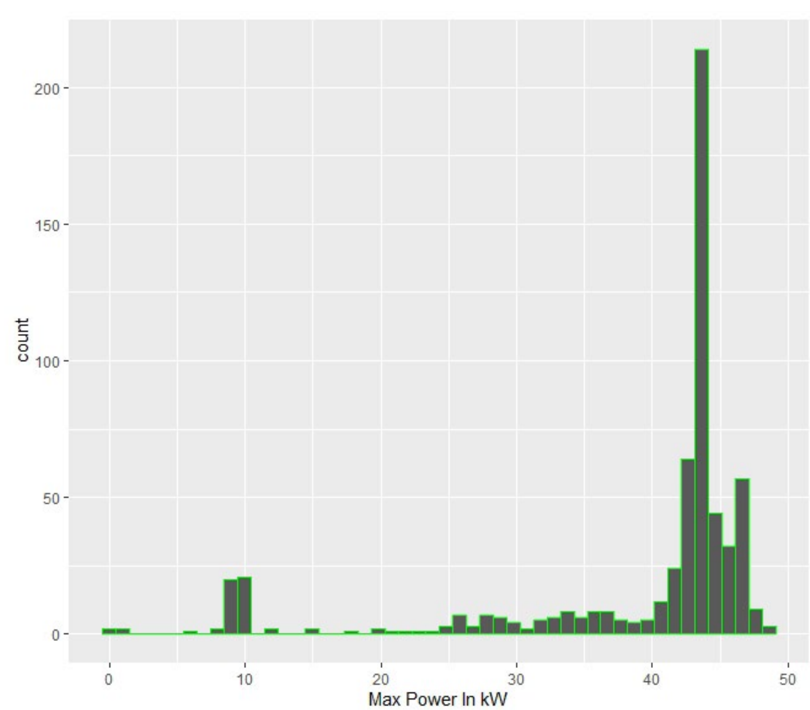



*Figure 28: Power performance of Division Creek SRRA ZEV station*

**Coso Junction Rest Area**

This rest area ZEV stations is the closest available fast charger after Division Creek ZEV station for drivers driving south in route 365. We have identified that EV drivers using route 365 have no other non-Caltrans charging alternative.

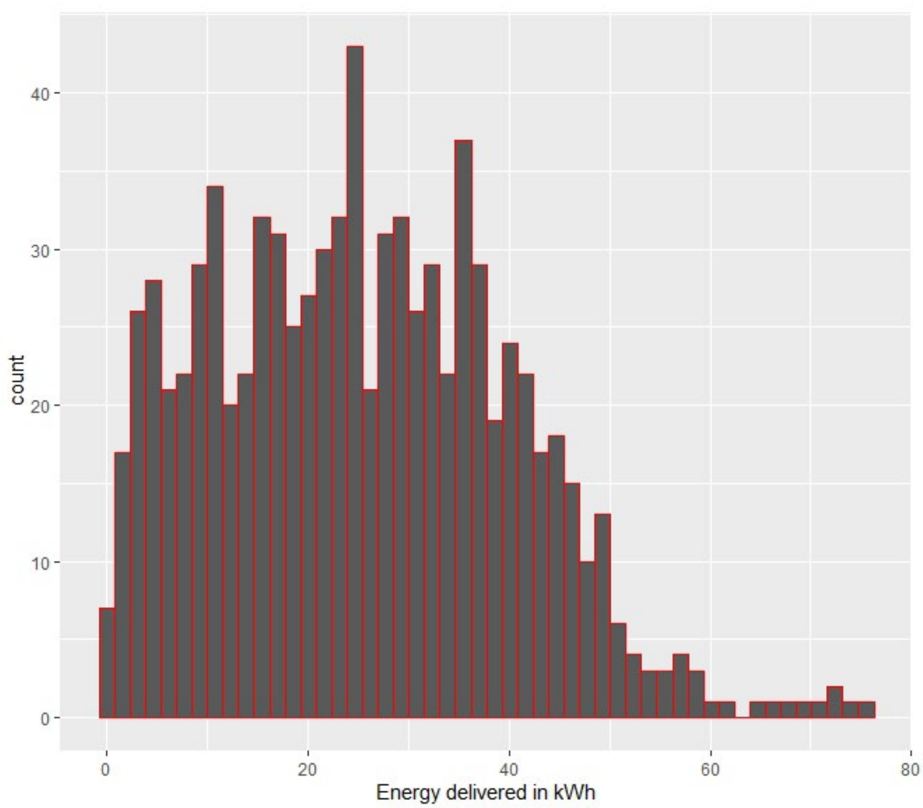



*Figure 29: Distribution of energy dispensed per charging event at Coso Junction SRRA*

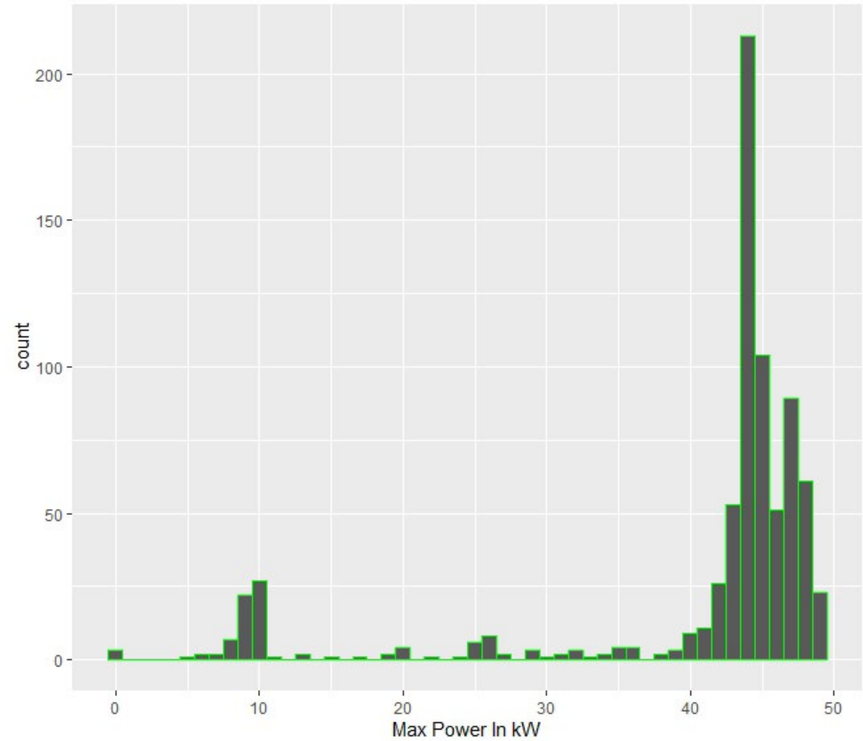



*Figure 30: Power performance of Coso Junction SRRA ZEV station*

## C. H. Warlow Safety Roadside Rest Area

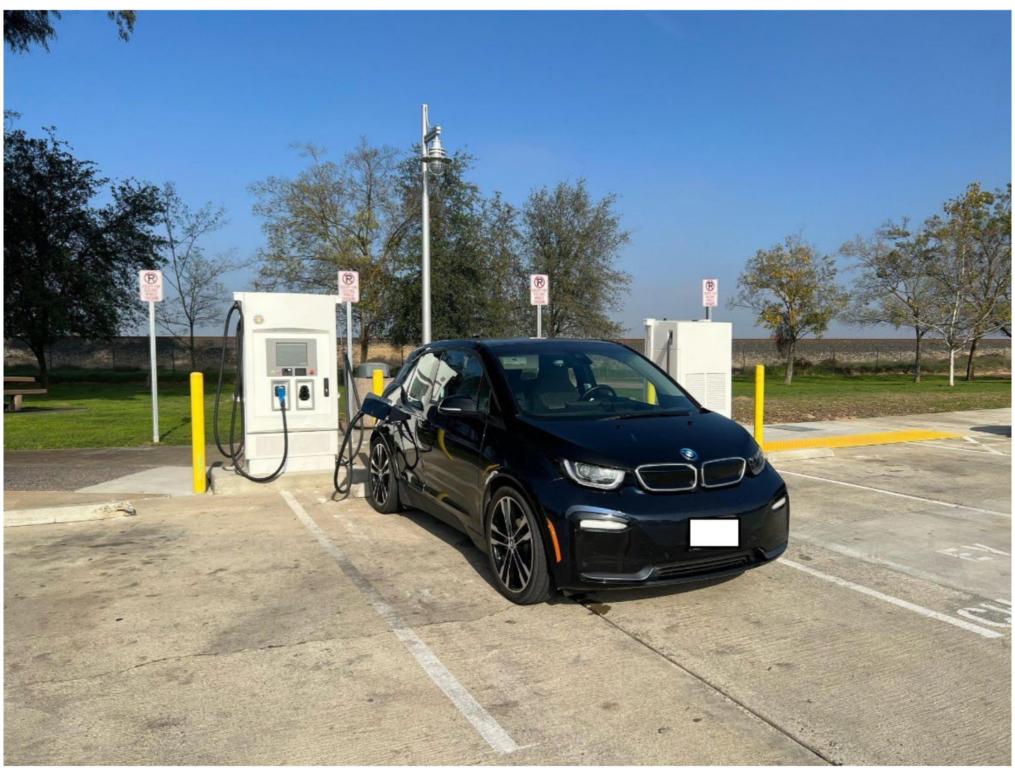


*Figure 31: ZEV stations in C.H. Warlow SRRA (from Plugshare under fair use)*

This rest area is located to the South of Fresno along route 99. This ZEV station has higher utilization than average. From the power performance data from C.H. Warlow charger, we identify an ongoing issue with the ZEV chargers. More specifically we think charger 'CALT0030' located in this rest area might not be operating optimally.

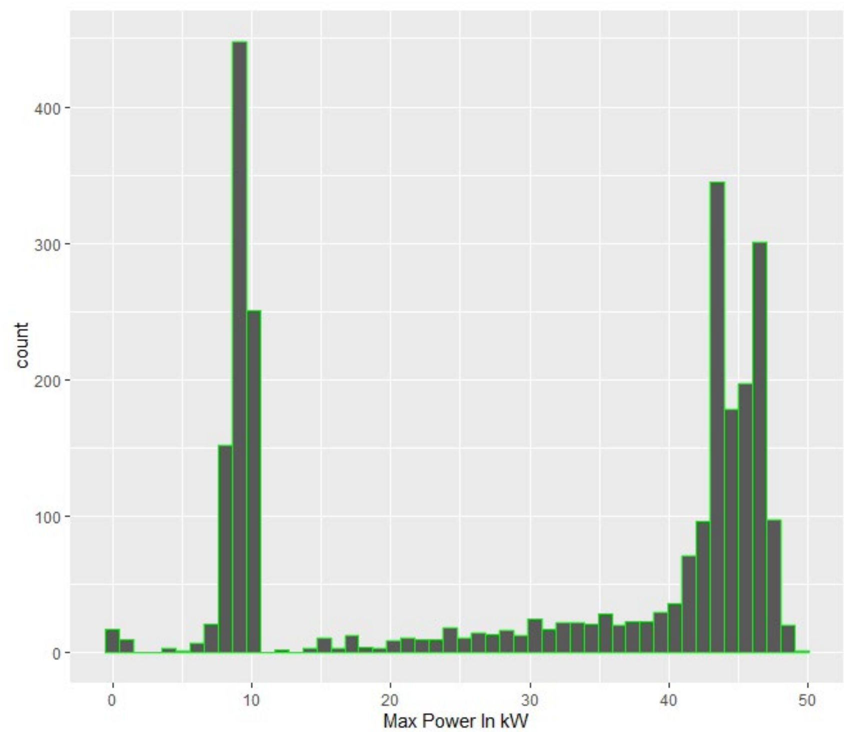



*Figure 32: Power performance of ZEV chargers in C.H. Warlow SRR*

**District 1 - Clear Lake Oaks Maintenance Station – Serving Route 20**

The charging station at Clear Lake Oaks maintenance station has been in operation since October 2020.

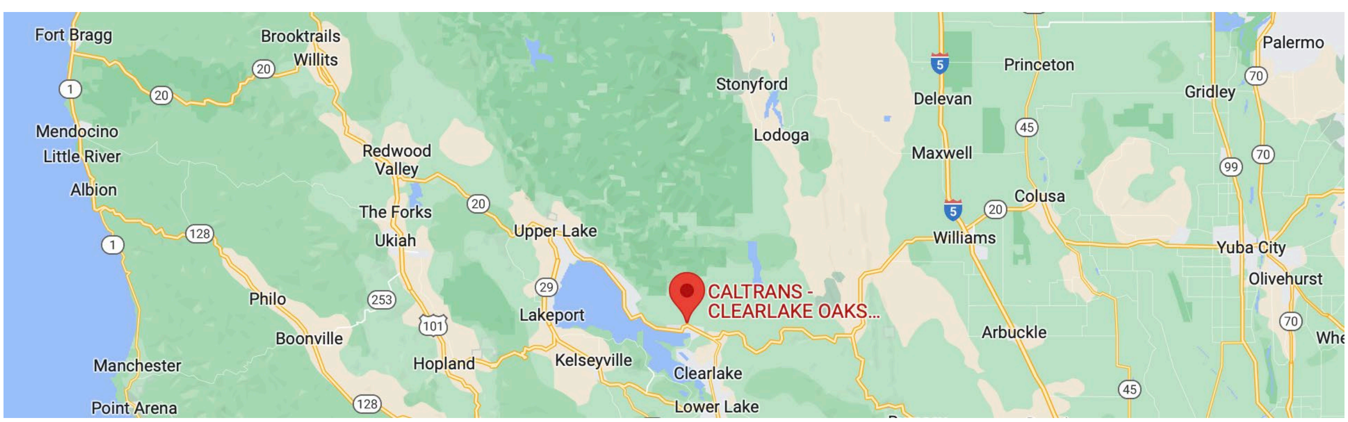


*Figure 33: Location of Clear Lake Oats maintenance station (Image from Google under fair use)*

This ZEV station is strategically location in route 20 between major routes 101 and interstate 5. This station is the only open fast charging options available to drivers for the nearest 15-mile radius.

From the Figure , the power performance data indicates too many charging events where was very low. Observing such a spike in near ~0 kW power performance was unexpected after data cleaning to filter out errors and unsuccessful charging attempts. This suggests that despite attempts from drivers to use the chargers, the ZEV hardware did not reach an acceptable level of charging speeds for about 30 charging attempts. Majority of those events have been recorded in the months of March and April on 2022 and two events were recorded in July 2022.

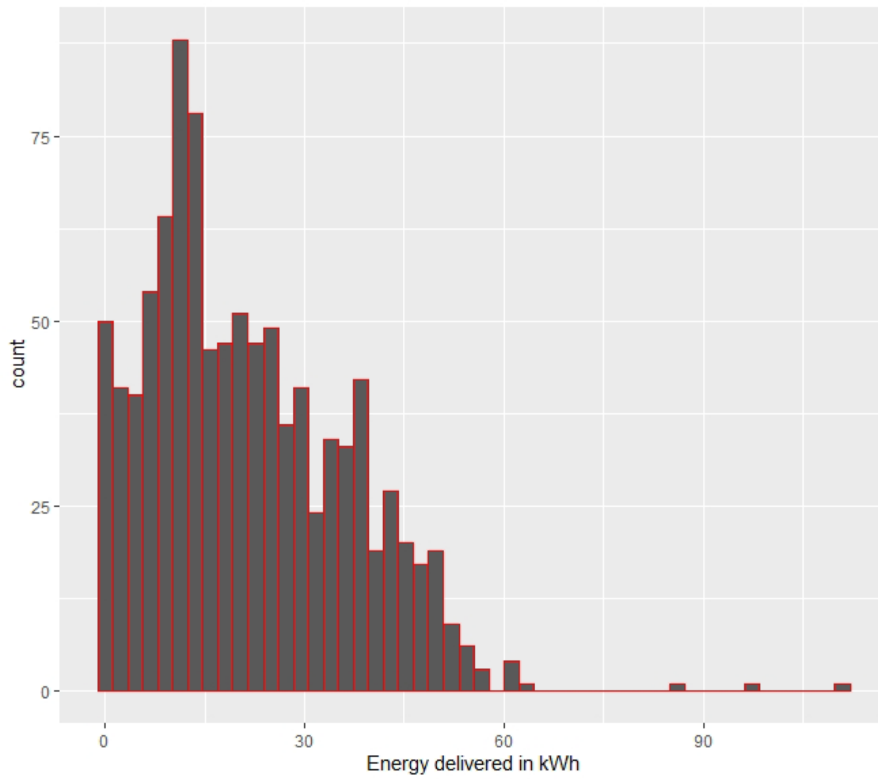



*Figure 34: Distribution of energy dispensed per charging event at Clear Lake Oaks maintenance station*

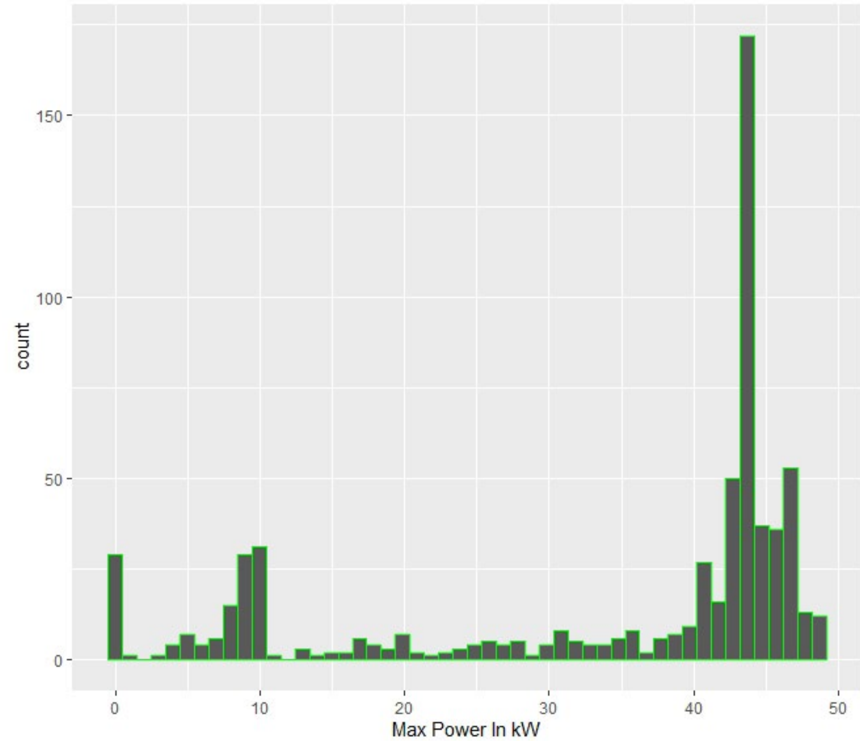



*Figure 35: Power performance of Clearlake Oaks ZEV station*

**Power performance for CCS and CHAdeMO users**

**Reliability concerns**

There is growing concerns and indication from the dataset about the reliability of the DC Fast EVSE stations. For example, a unique malfunction was identified in one station where the EVSE was operating at very low charging speeds. Charging events that may register 0.1 - 0.2 kWh of energy dispensed after keeping the charger plugged for a considerable time maybe included in unsuccessful charging attempts in the future. Other reliability concerns are damages to EVSE equipment and vandalism. We can corroborate such information from reviews in online user platforms such as Plugshare.

## 3. Task 3: Maintenance and Operation Phase

The Caltrans 30-30 project aimed to fill the gaps within California's corridor ZEV charging network along key routes of the State Highway System. Even though California's public fast charging network has expanded since the inception of this project, many Caltrans owned, and operated ZEV stations are still the only ZEV charging stations for the nearest 15-mile radius in some routes as of 2022. Therefore, many PEV drivers depend on this network for refueling and undisrupted travel across California. High reliability of the Caltrans ZEV charging stations is key to building driver confidence for long distance PEV trips.

This section will summarize suggestions and guidelines for ensuring high reliability for the Caltrans 30-30 ZEV chargers based on the information available to the ITS researcher. During the timeline of this study, we have identified several issues with maintenance and operations procedures in place for the Caltrans ZEV chargers, especially over the 2021-2022 reporting period. As of the second quarter of 2022 we identified that at least 8 Caltrans ZEV stations that needed repairs have gone without maintenance for over a week. Concerns from PEV drivers have been based on equipment damages and/or damage to the charging capable. Other complaints can come from local power outages and planned rest stop closures by Caltrans.

As the site-host, Caltrans has chosen a model of "owner operated system" where much of the obligation for maintenance and operations come under the purview of Caltrans. This model provides more autonomy to Caltrans allowing flexibility of operations in certain aspects such as deciding which rates are charged for users. The downside is having to undertake a higher maintenance burden to ensure that ZEV stations are operating within acceptable parameters without the advantage of a specialized team.

### 3.1. Why reliability is important.

The 37 locations of the Caltrans charging stations were situated in such optimal locations where PEV drivers have easy access to charging where drivers will not have to make any deviation from their pre-planned trips. And at the design stages of the project, these chargers were the only infrastructure available for PEV drivers for about 80 miles.

A recent study conducted by UC Berkeley found that public open access EVSE stations in the Greater Bay area are far less reliable than what charging station operating companies had reported. Out of a random survey of public and open EVSE units, they found that only 72.5% of the chargers were functional. They found issues that prevented successful charging such as unresponsive screens, payment system failures, charge initiation failure, network failures, or broken connectors as problems for not functioning [14]. This study identified immediate issues with charging station hardware and on the ground maintenance of EVSE that need attention. Other studies indicate that the possibility of being stranded without being able to charge is still a likely possibility in very isolated regions within California [15]. Ensuring charger reliability is key to fixing this. With long distance travel from PEVs, the possibility of potential disruption is much higher for drivers that will come to depend on highway charging facilities such as the Caltrans owned and operated charging stations.

Furthermore, as battery electric vehicles (BEVs) are increasingly replacing conventional fossil fuel vehicles, the State will have to plan for increased infrastructure stresses on public charging stations. This is more likely during extreme weather events such as flooding and short notice evacuation orders stemming from wild-fire events. Such extreme weather events should be considered in the planning process for EVSE reliability. Therefore, it is of the utmost importance that these Caltrans owned facilities are operated and maintained to be reliable, dependable, and functional when PEV drivers arrive at a facility for charging with depleted batteries. As PEVs are increasingly seen as long-distance vehicles with range improvements, their use for long distance trips beyond their battery range is invariably linked to charger reliability. Here we focus on open and public ZEV DCFC stations that are open to all PEV models that are open 24 hours a day 7 days per week [14].

**Stand-alone vs. Networked Chargers**

All the Caltrans owned ZEV stationed were networked chargers. Essentially, they are smart chargers connected to the internet and a cloud network that can remotely monitor and manage the charger hardware.  They provide higher visibility of usage information and control over the charging stations. Networked chargers also support online payment systems that can be used to charge a fee for charging services. These extra features come with increased electronic components that creates a higher likelihood of parts malfunctioning and overall system failure. This creates increased maintenance needs and specialized check facilities protocols for unique components.  The diagram in Figure 36 indicates the extra components necessary to function a networked charger.

Charging station owners must arrange a long-term service plan with the EVSE hardware manufacturers for the expected lifetime of the equipment.  Usually, the hardware manufacturer is the Charging Station Operator (CSO) that is responsible for remotely monitoring and ensuring smooth operations of the chargers. CSO’s usually use their own proprietary cloud network service platforms for this. BTC Power uses their own proprietary BTCP Network and ChargePoint uses their own ChargePoint Network. Such platforms usually include payment processing systems.

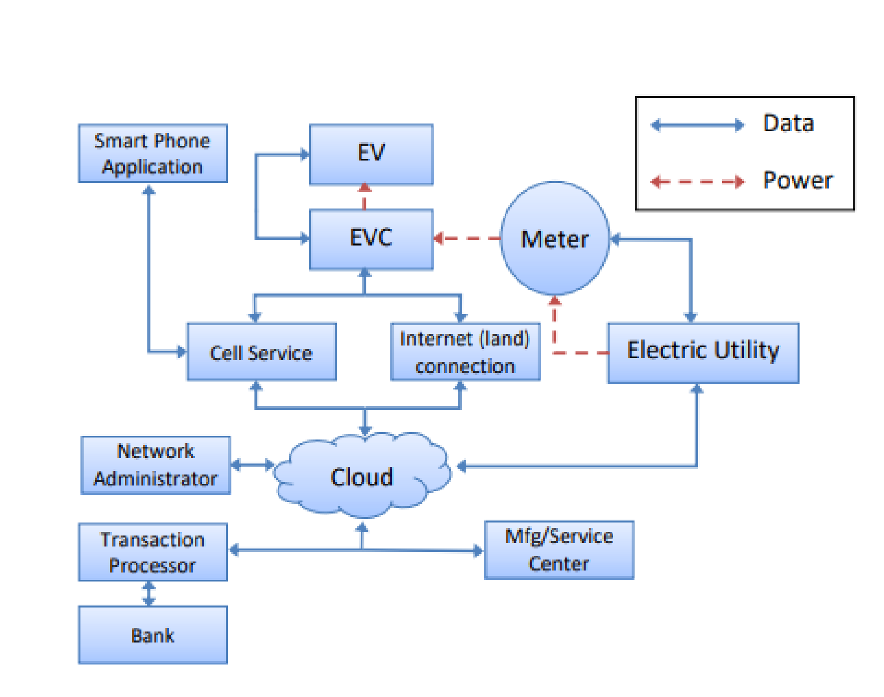



*Figure 36: EV charging system with network capability [16]*

Some issues in ZEV stations can be identified and resolved remotely without having a technician pay a visit to a facility. Other issues will require a service team to visit the sites and address them onsite. These issues are likely to be damages to physical connectors and cables, communication system failures, touch screen malfunction, issues with card readers etc. [17]. Most of the time, when a charger is in an unusable condition, it is indicated in the online platform provided by the CSOs. However, there can be many instances when CSOs are unable to identify charger breakdown remotely.

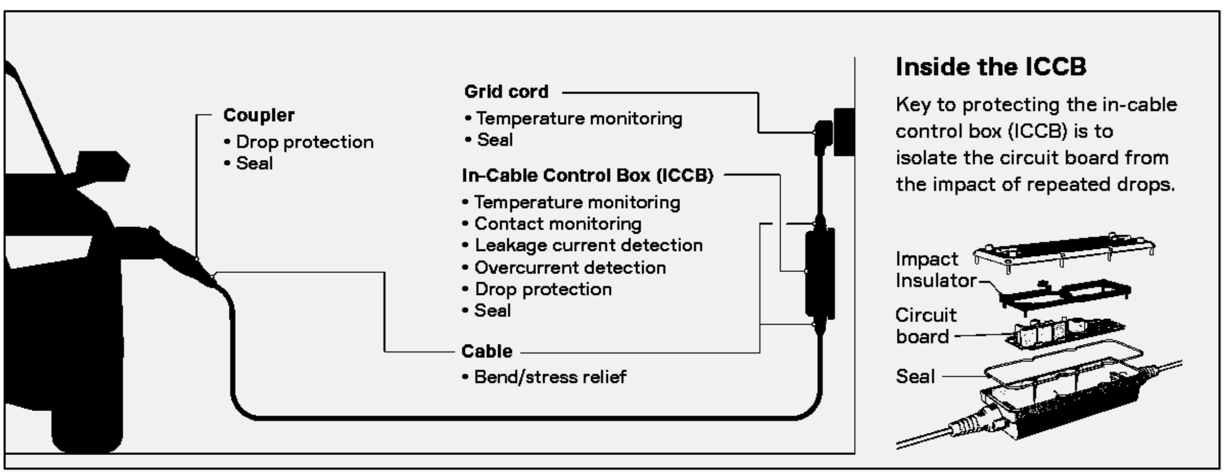



*Figure* 37 *Anatomy* of a EVSE connector and cable *[15]*

*Figure 37* indicates the many safeguards put in EVSE units to control the delivery of electricity to the cable and to communicate with the PEV users and PEV itself [15]. Any of these points can be a point of failure that prevents a ZEV charger from executing its charging function.

**Physical damage to hardware**

Physical damages to chords and connectors in a public and open station is the most common reason for charger malfunction. Figure 38 is an example where both connectors were found damaged. Unless otherwise stated in the maintenance contracts with the manufacturer, such damage adds extra costs to the station owner.

*Figure 38: Damaged ZEV station from a ZEV station in British Columbia [18]*

Station owners may have little incentive to correct such acts of vandalism or damage if station owners are not affected by loss of income or complaints of PEV drivers whose charging needs were not met.

### 3.2 Matrix of EVSE reliability

A broad understanding of possible points of charging failures is required to better understand the reliability problem and plan for maintenance protocols. Successful charging requires many elements in a broad eco-system of complex infrastructure systems to operate successfully. For example, we identified three main complex infrastructure systems essential for charger reliability. This is indicated in Figure 39. They are (1) the electricity grid, (2) greater transportation network and safety roadside rest areas that ensure physical access to the EVSE units and (3) EVSE hardware linked to the telecommunication network.

The reliability of the electricity grid directly impacts the reliability of chargers to successfully deliver energy to the chargers. Any point of failure from the electricity generation system to the transmission network and local distribution can impact the operation of the EVSE unit. Secondly, physical access to the charging station and the location of the charger is critical to a successful charging session. Roadblocks or rest stop closures can prevent drivers from physically accessing the EVSE units. Any kind of barrier between the EVSE unit can prevents access to the EVSE unit. This can even be in the form of a conventional vehicle not using the EVSE unit or a PEV which has finished charging and have not moved their vehicle. Then after physically reaching the dedicated EV parking spot, the EVSE unit hardware and network communication systems should function as expected. All the EVSE units selected by Caltrans are networked charging stations. If all the above-mentioned conditions are met, then we can assume a driver can make a successful charge from a EVSE unit.

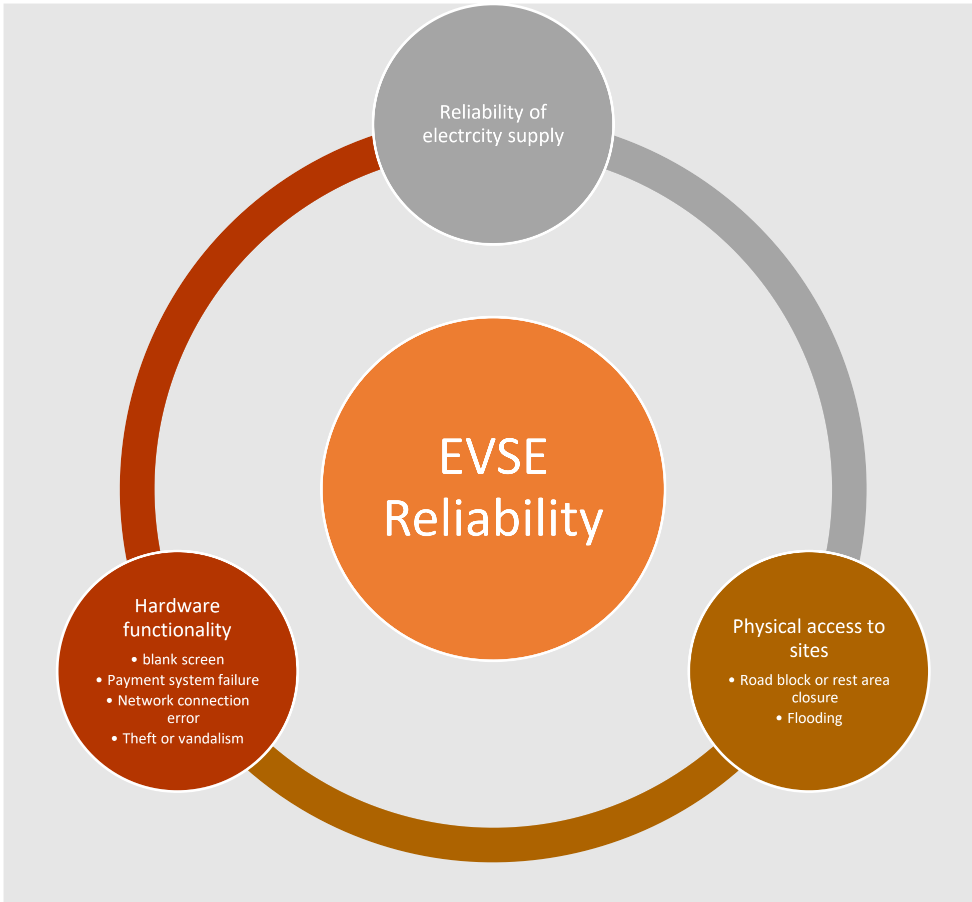



*Figure 39: Matrix of broad EVSE reliability*

This study will focus disproportionately on hardware functionality as that is the infrastructure system within Caltrans and site-owner's purview. Other infrastructure systems must be addressed at the level of policymakers.

### Charger reliability during extreme weather events

As battery electric vehicles (BEVs) are increasingly replacing conventional fossil fuel vehicles, the State will have to plan for increased infrastructure stresses on public charging stations. This is more likely during extreme weather events such as flooding and short notice evacuation orders stemming from wild-fire events. Such extreme weather events should be considered in planning process for EVSE reliability.

Extreme weather events such as inland flooding can hinder access to chargers for drivers within the affected regions as well as drivers coming from outside trying to access critical infrastructure. Flooding affects driving behavior for road network affected by flooding as well as highways network further away from the flooded regions.

During mass evacuation events such as wildfire, reports of long lines at gas stations are common. Overall emerging research suggests that existing charging infrastructure can be stressed during different extreme weather events whether EVSE stations are directly affected by such events or not.

*Table 10: How extreme weather events effect charging reliability*

| Level | Events | Description |
|---|---|---|
| **Climate Stressors** | Higher temperatures | • Planning for infrastructure that can withstand higher temperatures |
| **Hazards** | Extreme heat events | • Possible electricity curtailment due to major stresses on the electricity grid in extreme heat events |
| | Wildfires | • Demand spike for charging during wildfire evacuations<br>• charger outage during PSPS events |
| | Inland flooding, coastal flooding, and erosion | • Possible damage to EVSE stations by flooding<br>• Hindered access to stations in sites exposed to flooding<br>• Changes in traffic pattern in extreme weather events and Increased demand for charging for EVSE stations that are in the vicinity of flood affected regions |

**What can be done to improve reliability**

Improving overall reliability of public and open ZEV stations located in remote and underserved communities can be a challenging task. This is because (1) remote and unsupervised locations have a higher likelihood of EVSE hardware vandalism and theft. (2) Moreover, servicing hardware in rural locations includes higher costs (i.e., surcharge costs for maintenance crew). In combination of the factors above, (3) EVSE stations in remote locations can be left for neglect as station owners or CSOs have limited incentivizes to maintain ZEV stations.

*Table 11: Actions for higher reliability standards*

| Stakeholder | Actions |
|---|---|
| **For policymakers** | • Mandatory data sharing and transparency standards for public and open EVSE stations allowing independently to verify a higher rate of service uptime and customer service<br>• State mandated inspection teams around the clock to ensure higher reliability standards<br>• Sharing of best practices and guidelines |

| | |
|---|---|
| | • Mandated charging stations maintenance training programs, certification, and guidelines<br>• Enforcement of hardware maintenance and service contracts in a timely manner<br>• Explore possibilities of higher electricity grid reliability for remote chargers |
| **For station owners** | • Physically secure hardware to prevent tampering<br>• Adopting industry best practices for regular inspection |
| **For Charging Station Operator (CSO)** | • Enforcement of industry best practices across charging networks<br>• Install on-site advances sensors in remote locations to identify tampering and vandalism of equipment (i.e., inbuilt cameras) |

### 3.3 The Challenges of Measuring Reliability

**Current Charging Station Reliability Metrics**

The most common EVSE reliability measure is uptime i.e., the time during which a machine is in operation. CEC requires public ZEV stations to be operational at least 97% of the standard operating hours for a period of 5 years [14] . On June 2022, the Federal Highway Administration published a Notice of Rulemaking that defines regulations for projects funded under the National Electric Vehicle Infrastructure (NEVI). The NEVI regulations propose a minimum average annual charging port uptime requirement of 97%. The uptime percentage calculation for a given charging port captures the percentage of time that the port's hardware and software are both online and available to use. The calculation excludes the hours of outage caused by reasons outside the control of the charging station operator such as electric utility service interruptions and internet service provider interruptions.

From the perspective of an EV driver, a reliable charger successfully charges their EV, for the expected duration, at an expected rate, after accepting an appropriate payment method. Uptime, as it is currently defined, does not consider all the possible technological and logistical challenges within the charging ecosystem, illustrated in **Figure 39,** that ultimately determine the true reliability of charging ports experienced by consumers:

- On the electrical side, the components within an EVSE's ICCB are responsible for temperature monitoring, contact monitoring, leakage current detection, and overcurrent detection - all to ensure safe supply of power to the EV. A failure within even one of these components can make the EVSE unreliable and potentially unsafe.
- On the mechanical side, the external components of the EVSEs are prone to damage from various environmental factors. Consumers tend to drop EV chargers repeatedly, wrap and drive over cables, as well as leave them out in the rain. Animals may chew on the cables. EVSE design must account for these mechanical challenges.

- On the communication side, configuration errors, line damage, power loss or traffic spikes, and hardware failure anywhere along the communication network within the charging ecosystem may cause reliability issues as it can interrupt the flow of information between the various stakeholders in the EV charging ecosystem.
- On the logistical side, membership requirements, payment issues, complicated EVSE instructions/operations, difficulty locating EVSEs, lack of EVSE availability, and poor cell service/Wi-Fi availability make EV charging less reliable to current and prospective EV drivers.

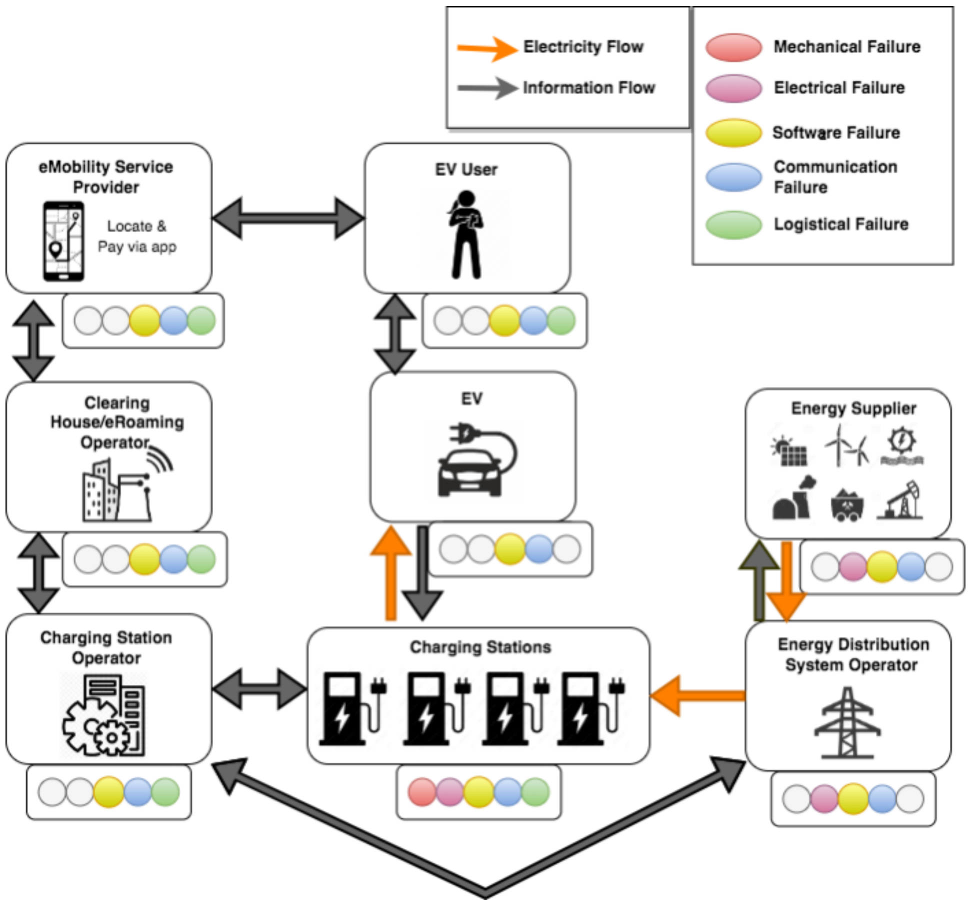



*Figure 39 Charging Reliability Points of Failure*

If charging station operators monitor their EVSEs using OCPP, they can effectively detect electrical and software failures given an operational communication network. However, they may be in the dark when it comes to failures caused by mechanical, communication and logistical factors. For instance, they may be unable to detect a physically damaged charging cable if the EVSE is otherwise operational and detected as so via their communication network. Or communication lags may cause charging station operators to be unaware of inoperable charging ports for substantial periods of time, resulting in inaccurate uptime calculations.

**Types of Charging Failures**

In their study on the reliability of open DCFC chargers in the California Bay Area, Rempel et al. uncovered six common charge failures: broken connectors, unresponsive screens, error messages on screens, connection errors, payment system failures, and charge initiation failures. Table X condenses these issues to offer a more complete understanding of the typical challenges encountered by consumers when charging their EVs [citation].

*Table X Common EV Charger Failures*

| | Failure | Description |
|---|---|---|
| *Remotely Observable* | Charger to Vehicle Communication Failure | Malfunction in the EV's charging port or the charging station's connector, issue with the communication protocol used by the EV and the charging station |
| | Connector/cable Issue | Charger cable improperly placed into vehicle charging port, poor conductivity due to corrosion |
| | Electrical Insulation / Safety Issue | Electrical system of charger may be overheating, insulation may need to be inspected |
| | Payment Errors | Technical issues with the payment system, compatibility issues with the payment method used, or user error during the payment process |
| | Vehicle Errors | Software or hardware malfunctions, charging port incompatibility, or battery issues. |
| | Charger Equipment Errors | Software or hardware malfunctions, power supply issues |
| | Power Outage | Power outage can cause EV charger to shup-down or interrupt an on-going charging process |
| *Remotely Unobservable* | Blocked Access to station | Access to chargers could be physically blocked by gas cars, other non-charging EVs, fences, snow, flood water, etc. |
| | Physically Damaged Equipment | External components of the EVSEs are prone to damage from various environmental factors. |
| | Logistical and interoperability Issues | Membership requirements, payment incompatibility, equipment incompatibility, complicated EVSE instructions/operations, difficulty locating EVSEs, lack of EVSE availability, and poor cell service/Wi-Fi |

| | | |
|---|---|---|
| | | availability make EV charging daunting to current and prospective EV drivers. |
| | Network Communication Failure | Configuration errors, line damage, power loss or traffic spikes, and hardware failure anywhere along the communication network |

*Figure X Consumer Uptime vs. CPO Uptime*

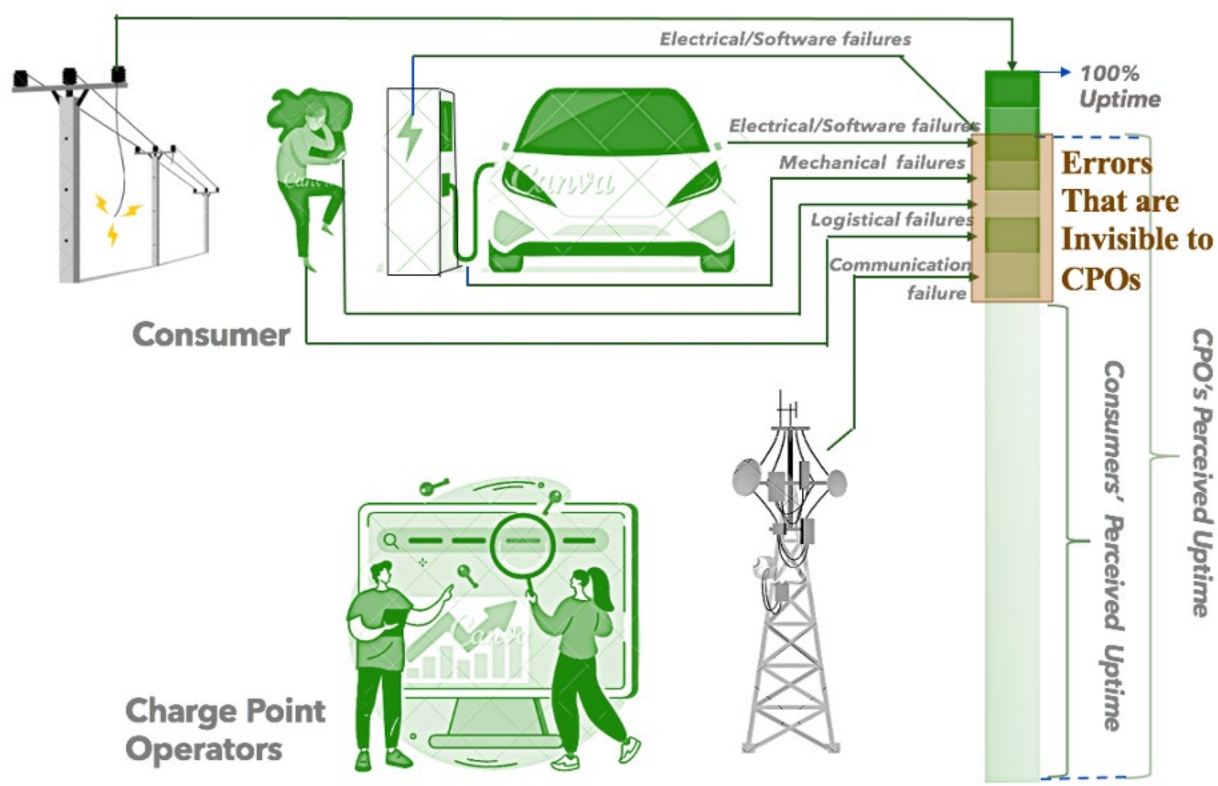



*Figure X Consumer Uptime vs. CPO Uptime*

A Charging Point Operator (CPO) typically ensures the smooth ongoing operations of EV charging infrastructure. This involves overseeing backend technologies and communication between the backend system and chargers. The CPO's responsibility is to guarantee that all chargers they manage meet the uptime requirements of their jurisdiction. To achieve this, they implement systems for timely notification of any charger issues. Ideally, real-time monitoring of charger statuses allows the CPO to proactively identify and address issues before customers become aware of them. Using the Open Charge Point Protocol (OCPP), CPOs can effectively detect most electrical and software failures within an operational communication network. However, challenges arise with failures caused by mechanical, communication, and logistical factors. For example, physical damage to a charging cable may go unnoticed if the EVSE is operational, creating potential blind spots in monitoring. Communication delays can also lead to charging station operators being unaware of inoperable charging ports for extended periods, affecting uptime calculations. **Figure X** illustrates the dichotomy between the uptime measured by CPOs and the uptime experienced by consumers due to the varying levels of visibility of certain charge failures. **Figure Y** enumerates the timeline of a charging attempt, accompanied by the possible charge failures that could occur at each stage of the attempt, separated by their level of visibility to CPOs. Failures invisible to CPOs may persist until an EV driver encounters an issue and reports it. Consequently, these unseen failures contribute to the overall reliability challenges faced by consumers.

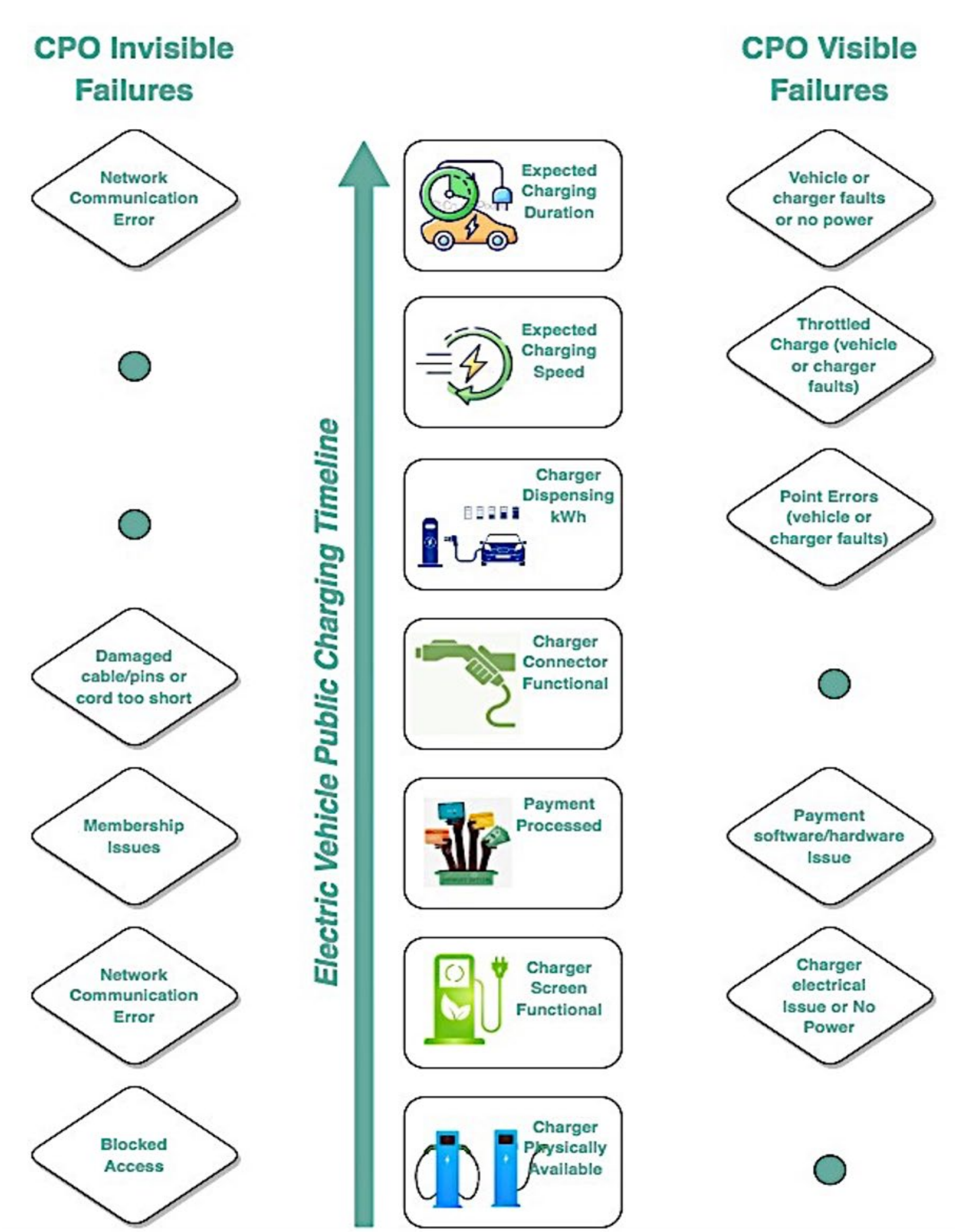
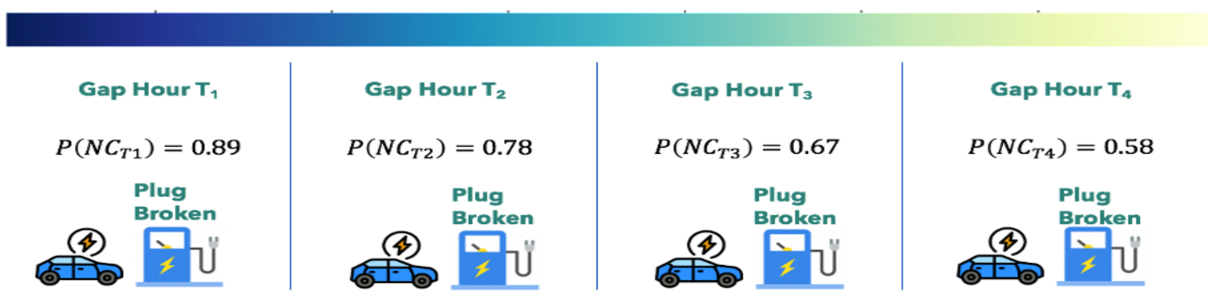



*Figure Y EV Charging Timeline and associated Failures*

**How to Effectively Detect Charge Failures**

EV drivers are likely to charge their EVs in the same public charging locations along travel routes. Therefore, any sudden gaps within the usage pattern of a given EVSE location could reveal a technical or logistical failure that standard reliability monitoring protocols fail to capture. **Figure Z** illustrates an intuitive demonstration of how our tool uncovers unexpected charging usage gaps that may indicate a reliability issue. Let's say we have a charger with a broken plug. This heatmap on the top defines the hourly probabilities of charging at this charger on a typical summer Saturday. At hour $T_0$, an EV that usually charges at the station around that time attempts to charge but fails to do so since it has a broken plug. The probability of no charge occurring in this hour is 89%, which is high. At hour $T_1$, another EV similarly attempts to charge but fails. No charge in this hour has a probability of 78%. Two more cars attempt to charge at hour $T_2$ and $T_3$ and fail with probabilities of 67% and 58%. So individually, the probability of not charging at those hours is high - all above 50%. But the probability of the entire 4-hour sequence of no charging sessions is low, 26%, potentially raising a red flag about the state of the charger.




$$P(NC_{T1}, NC_{T2}, NC_{T3}, NC_{T4},) = 0.89 * 0.78 * 0.67 * 0.58 = 0.26$$

*Figure Z Charging Anomaly Detection Intuition*

We can leverage the habitual usage patterns of EV chargers to effectively identify potential charger faults that may not be captured by traditional reliability measures. Using the aforementioned probabilistic technique, we identified over 100 gap hours for three chargers at a Caltrans charging facility. If these gap hours were indeed due to charging faults, they would result in uptime reductions ranging from 16% to 38%. **Figure A** presents the detected charging usage gaps or anomalous hours. The base time series represent the hourly energy usage of each charger. The coloured markers in the figures represent the charging usage gaps for the chargers. The colour of the markers indicates the probability that the detected usage gap is an actual usage gap. Gaps coloured in darker pink/red shades are more likely to be actual usage gaps, while gaps coloured in lighter yellow shades are less likely to be usage gaps. This color-coding provides a visual representation of the confidence level associated with each detected usage gap, aiding in the interpretation and understanding of the results.

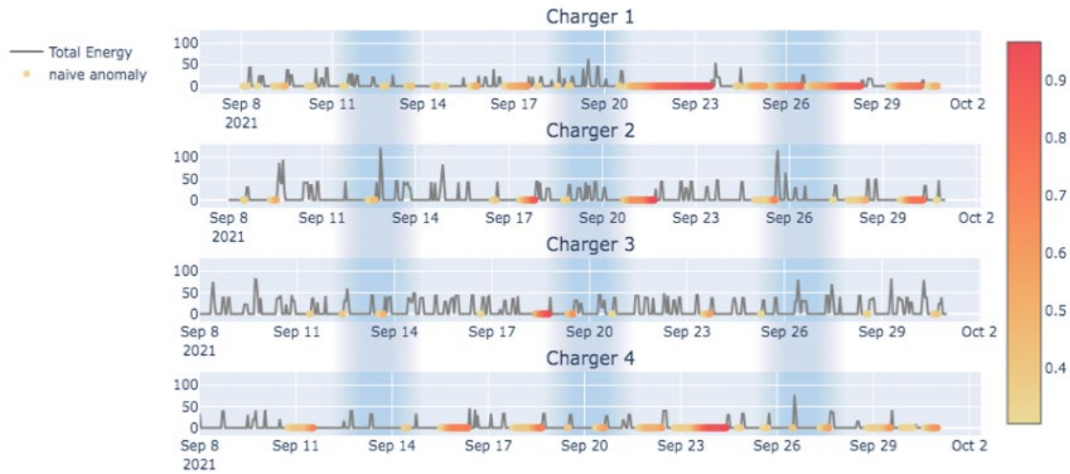



*Figure A Corridor DC Fast Charging Usage Gaps*

Detecting charging gaps in this manner can significantly reduce the repair time of inoperable chargers as CPOs would not have to solely rely on the unlucky EV driver who encounters the faulty charger and reports it to them. **Figure B** illustrates a detected charging gap for a charger in our study. The green line represents the hourly probability distribution of charging on a weekday for the charger, while the brown line represents the energy dispensed by the charger on a specific weekday. For this charger, a gap was detected between hours 5 PM and 11 PM. At 6:40 PM, the probability of an anomalous usage gap between 5 PM to 6:40 PM (for the past hour and 40 minutes) is over 0.5. So, if we translate the 0.5 gap probability to a 50% confidence level, we can estimate that the tool will notify the CPO of the gap within an hour and 40 minutes, potentially reducing the gap's length by 4 hours and 20 minutes or 72% with a 50% confidence level. Similarly, at 7:55 PM, the probability of an anomalous usage gap between 5 PM to 7:55 PM (for the past two hours and 55 minutes) is over 0.75. So, if we translate the 0.75 gap probability to a 75% confidence level, we can estimate that the tool will notify the CPO of the gap within two hours and 55 minutes, potentially reducing the gap's length by 3 hours and 5 minutes or 51%. the tool will notify the CPO of the gap within two hours and 55 minutes, potentially reducing the gap's length by 3 hours and 5 minutes or 51% with a 75% confidence level. And at 9:22 PM, , the probability of an anomalous usage gap between 5 PM to 9:22 PM (for the past four hours and 22 minutes) is over 0.90. So, if we translate the 0.90 gap probability to a 90% confidence level, we can estimate that the tool will notify the CPO of the gap within four hours and 22 minutes, potentially reducing the gap's length by 1 hour and 38 minutes or 27%.

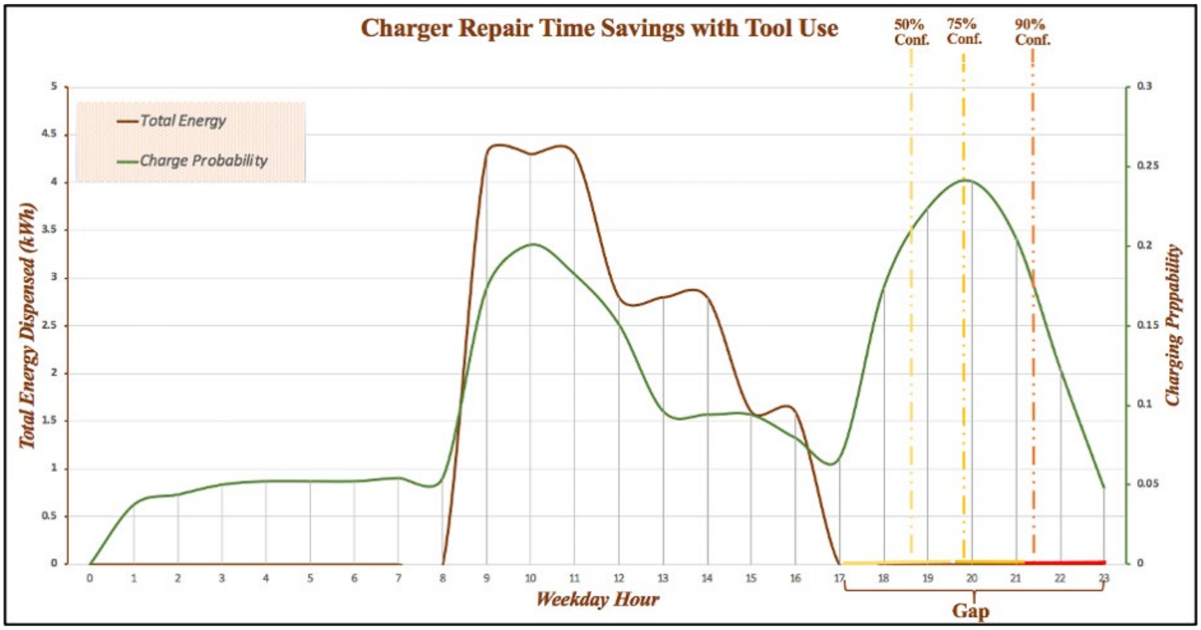



*Figure B Charger Repair Time Savings with Tool Use*

**Conclusion**

The Caltrans 30-30 project, focusing on the installation of ZEV chargers in remote locations, encountered notable challenges leading to higher construction costs ranging from $122,000 to $440,000 per charger. These challenges included difficulties in obtaining energy supply due to the remote nature of the sites, absence of shared utility infrastructure resulting in higher make-ready construction costs, and increased costs associated with labor and material mobilization, particularly in locations with high foot traffic. Co-locating charging stations on opposite sides of freeways also introduced complexities and potential costs linked to limited access to local electrical grid.

Since the project initiation in 2017, the range of many plug-in electric vehicle (PEVs) models have improved and PEV adoption rates have also increased in California. As this project aims to support drivers taking long distance trips using PEVs, the project is even more relevant now. Range of PEVs have improved significantly as many PEV now allow for a range of 200-300 miles per charge. As of august 2022, the EPA has certified at least 14 light duty electric vehicles models to have a range of 300 miles or more. In terms of charging data analysis, variations were observed among different connectors and networks. For instance, drivers using the BTC Power CCS connector experienced an average connection time of 41.2 minutes with a consumption of 24.2 kWh, while CHAdeMO users had a 35.3-minute connection time and consumed 17.3 kWh.

The report also delved into the reliability of Caltrans 30-30 ZEV chargers, uncovering maintenance and operational issues during the 2021-2022 period. Identified concerns included unattended repairs, equipment damages, charging capability issues, power outages, and planned rest stop closures. To address these challenges, the report proposed a novel probabilistic method leveraging usage patterns to identify hidden charge failures, showcasing its potential to significantly improve charger operation and maintenance in future project phases.

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