cool the earth

My name is Carleen Cullen, founder and Executive Director of Cool the Earth, a 2018 campaign policy advisor for Governor Newsom, and the ChargeX consortium. I urge CARB to reject Electrify America's plan due to widespread evidence of station failures and customer dissatisfaction, particularly impacting those in our equity communities, who rely most on public charging.

Recommendations that we believe fit within the consent decree's framework:

1. **Reject the Current Plan:** Encourage EA to reformulate its strategy in collaboration with CARB staff.
2. **Prioritize Station Replacement and Maintenance:** From the $80 million allocated for existing sites, $25 million is for station replacement, with the rest for operations, maintenance, and demand fees. CARB should work with EA to remove the $25 million cap, prioritizing the replacement of stations from all Cycles with GEN 4 models. Operations and maintenance come next -- even Gen 4 stations have reliability problems -- followed by new stations and demand fees, using any remaining funds.
3. **Develop Specific Metrics:** EA should submit detailed metrics in the selection methodology, with CARB staff ensuring these metrics identify all underperforming stations.
4. **Enforce Penalties:** Implement consent decree penalties from the time underperforming stations are decommissioned until new ones are operational.

The focus should be on reliability; the expected increase in stations, fueled by Tesla, state, and federal investments, will expand availability. Other issues that contribute to station congestion are EA's broken stations, slow power delivery, and possibly their business practice of offering free charging to drivers of select popular vehicles from Ford, Kia, Hyundai, and companies from the VW group including VW ID 4, Audi, Porsche, and others.

I urge the board to match investment in 'Clean Cars for All' with reliable charging stations.

From: **Carleen Cullen** ccullen@cooltheearth.org
Subject: Follow-up regarding Electrify America unreliability
Date: January 23, 2024 at 10:19 AM
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Chair Randolph,

Thank you for meeting with us yesterday. We share and support your concern about unreliable EV charging stations. EA's Cycle 4 ZEV Investment Plan presents a critical juncture to substantially improve the performance of EV charging stations in California.

Attached are our recommendations for enhancing the reliability of Electrify America's charging stations. Designed within the existing consent decree's framework, they aim to benefit all consumers, especially those in low-income and disadvantaged communities, and align with CARB's and the state's climate goals.

Electrify America's reports in their Cycle Three and Four ZEV investment plans acknowledge significant reliability issues. Their Cycle Four Plan points to an industry-wide failure rate of one in five charging attempts, adversely affecting EV adoption rates. Given Electrify America's status as the largest public EV charging network, their impact on these statistics is considerable. This failure rate is contrary to the objectives of the Consent Decree.

We urge CARB to reject the parts of the ZEV Investment Plan that pertain to reliability upgrades and replacements. We recommend directing staff to meet and confer with Electrify America to create a more robust plan. In this process, we would be happy to engage with staff to provide expert recommendations informed by my involvement in the ChargeX consortium, ensuring the metrics for station replacement are thorough and effective.

We have also attached a PDF of the Berkeley study.

Your leadership in addressing these issues is greatly valued.

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2023 Rempel EV
HF.pdf
612 KB

Research Article

Human Factors
2023, Vol. 0(0) 1–11

DOI: 10.1177/00187208231215242
journals.sagepub.com/home/hfs
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Reliability of Open Public Electric Vehicle Direct Current Fast Chargers

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Abstract

Objective: The aim was to systematically evaluate the usability of all public electric vehicles (EV) direct current fast chargers (DCFC) in the San Francisco region.

Background: To achieve a rapid transition to EVs, a highly reliable and easy to use charging infrastructure is critical to building confidence among consumers.

Methods: The functionality and usability of all 182 open, public DCFC charging stations with CCS connectors (combined charging system) in the 9 counties of the Bay Area were tested (655 electric vehicle service equipment (EVSE) ports). An EVSE was classified as functional if it charged an EV for 2 minutes.

Results: Overall, 73.3% of the 655 EVSEs were functional. The causes of the nonfunctioning EVSEs (23.5%) were blank or unresponsive screens or error messages; payment system failures; charge initiation failures; network failures; or broken connectors. In addition, the cable was too short to reach the EV inlet for 3.2% of the EVSEs. A random sampling of 10% of the EVSEs, approximately 8 days after the first evaluation, found no overall change in functionality.

Conclusions: The level of functionality found with field testing conflicts with the 95–98% uptime reported by the EV service providers (EVSPs) who operate the EV charging stations. There is a need for precise and verifiable definitions of *uptime*, *downtime*, and *excluded time*, as applied to public EV chargers.

Application: The level of failure of the existing public EV DCFC charge infrastructure highlights the importance of improving the system design and maintenance to improve adoption of EVs.

Keywords

electric vehicle charging infrastructure, renewable energy, zero emission vehicles

Background

Reliable, functional, open, public Direct Current Fast Charge (DCFC) electric vehicle (EV) charging stations are critical as countries rapidly transition to EVs. A recent survey of EV drivers in California ($N = 1290$) reported mixed experience with existing EV chargers (CARB, 2022a). They reported experiencing broken plugs (9%), unexpected shut off

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Received: April 11, 2023; accepted: October 30, 2023

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during charging (6%), charging station not functioning (22%), payment problems (18%), and the need to contact customer service via cell phone (53%). This experience appears to contradict a simultaneous survey of some of the EV service providers (EVSPs) who reported 95 to 98% uptime of their public chargers. An accurate assessment of the reliability, functionality, and uptime of the existing public EV chargers is needed to provide guidance for the successful buildout of the EV charging infrastructure.

Open EV charging stations are those open to all EVs (NREL, 2022). Closed systems, such as Tesla Superchargers, will not accommodate all EVs. Public charging stations are those that are open to the public 24 hours per day 7 days per week (AAI, 2022; NESCAUM, 2019). Examples of nonpublic charging stations are those in paid parking lots or those limited to customer and employee use. Open, public DCFC charging stations are designed to charge different models of EVs and, therefore, have multiple connector types, such as CCS (Combined Charging System; SAE, 2022), CHAdeMO, and Tesla connectors. Charging stations have one or more kiosks (also called posts), with each kiosk situated adjacent to one or two parking spaces. A kiosk may have one or more EVSEs (Electric Vehicle Supply Equipment) or ports (OCPI, 2019). An EVSE or port provides power to charge only one vehicle at a time even though it may have multiple cables with the same or different connector type (Figure 1). The EVSE provides information on charging and controls the delivery of electricity to the cable (DOE AFDC, 2022). Each kiosk typically includes a payment system that collects payment information from credit cards, debit cards, membership cards or smartphone applications; the transaction may be by tap, insert, swipe, or near field detection depending on the payment method. Another method of payment is *Plug and Charge* where the only action required is to plug in the EV and the EV is automatically identified and linked to a previously established payment method.

The US Department of Energy maintains a national database/map of public EVSEs (Alternative Fuels Data Center, Electric Vehicle Charging Station Locations). The database includes charging station location and number of EVSEs (ports) and connection types at each station (NREL AFDC, 2022). The data is updated on a periodic basis by EV service providers (EVSPs); some states, for example, California, require updates at least monthly (CARB, 2022b). In addition, commercial smartphone, tablet, and desktop apps, such as PlugShare, provide EV users with information on the location of EV charging stations, the name of the EVSP, the number and types of connectors, the maximum power delivered, and other information.

There are different methods of measuring reliability of an electrical system, but essentially, it is the degree to which the performance of the system results in electricity being delivered to the customer in the amount desired (ORNL, 2004). The reliability of an EVSE, that is, the functional state, can be considered from the perspective of the EVSP or the EV driver. The EVSP may detect the

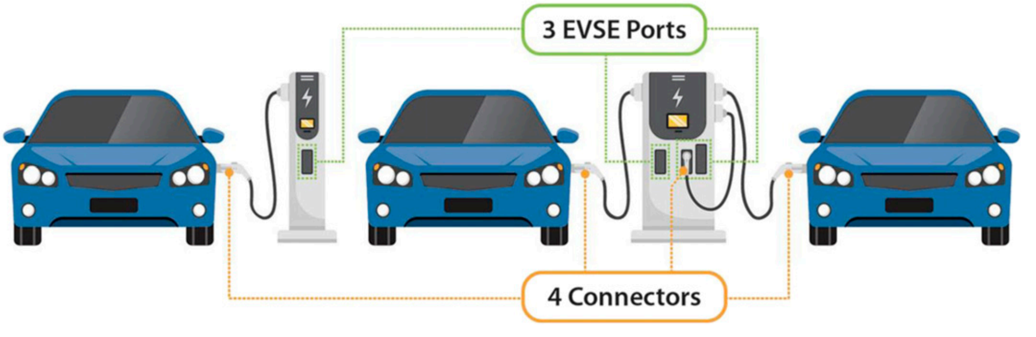

Figure 1. A model of an EV DCFC charging station with 2 kiosks or posts, 3 EVSE charge ports, and 4 connectors. Kiosks may have multiple connectors of the same or different types (e.g., CCS and CHAdeMO).
Note. CCS: combined charging system; DCFC: direct current fast charger; EV: electric vehicle; EVSE: electric vehicle service equipment (from DOE AFDC, 2022).

state of an EVSE through its communication network, or as calls to a service number by EV drivers, as a measure of reliability. From the EV driver perspective, a reliable EVSE is one that charges the EV, for the expected duration, after using an appropriate payment method, at the expected charge rate (i.e., kW). The upper bound on charge rate is influenced by many factors including the EV's state of charge, the maximum rate allowed by the EV, and the charging station nominal rate. The Alliance for Automotive Innovation (2022) defines a reliability standard as one specifying a minimum uptime requirement. States have different minimum uptime requirements for EVSEs that are paid for with public funds. For the Northeast States (NESCAUM, 2019) "Each connector on each public DC fast charging station pedestal shall be operational at least 99% of the time based on a 24 hour 7-day week (i.e., no more than 1.7 hours of cumulative downtime in a 7-day period)." For California, "The equipment must be operational at least 97% of the standard operating hours of the charging facility for a period of 5 years" (CEC, 2021).

However, the use of *uptime* as the reliability metric is controversial since there is no standard definition nor is there a standard calculation methodology. Given the complexity of the EVSE ecosystem and technology stack, from hardware to software, ensuring a high uptime and assigning "uptime ownership" of each EVSE may be difficult and may require standardization across different jurisdictions.

The EVSE ecosystem is composed of different stakeholders. For example, when an EVSE is installed, it is connected to the local utility electrical infrastructure that delivers power to EVSE. The EVSE is installed by a certified installer, operated by the charge station operator (CSO) and located at a site where it may be owned and managed by a site host or the EVSP. The EVSE is connected to an internet service provider (ISP) network and a payment system. Finally, the EVSEs may be serviced by the EVSE or by an independent EV charger servicing company.

Depending on the jurisdiction, the overall responsibility for keeping the EVSE functioning, can be either with the local electric utility, the installer, the site host, the CSO, or the servicing company. These stakeholders may be independent or may be integrated, that is, installer can also be the CSO, etc. These stakeholders will likely have different levels of visibility over the status of the system. For example, the site host might have information about the electrical infrastructure and outages and physical damage to kiosks but not information about the functional status of each kiosk, whereas the CSO may have continuous EVSE status information. This partial visibility of the EVSE operation poses a challenge in maintaining a high uptime from the EV driver perspective. Moreover, since these stations are in public locations, events such as road blockage due to construction, theft, or vandalism can occur, which are beyond the immediate control of the CSO. Therefore, the complex nature of the ecosystem and the lack of a clear definition and metrics describing EVSE uptime may interfere with stakeholders' accountability.

The usability of the public EV charging system can be assessed at many levels. At the micro level, some important considerations are the screen interface design, ease of connecting the charging cable to the EV, payment methods, charging rate, lighting, safety, and protection from weather. No usability studies of EVSE interfaces designs were found; however, guidelines can be extracted from usability studies of self-service technologies (Henderson et al., 2023). At the macro level, important considerations are density and distribution of charging stations, reliability, and functionality. While there are studies on range anxiety and charging efficiency, behavior, and scheduling (Alinia et al., 2019; Jonas et al., 2023; Pevic et al., 2020; Shahriar et al., 2021; Thorgeirsson et al., 2020; Vaidya & Mouftah, 2020), there are few systematic studies on other micro and macro usability issues (Yim et al., 2023). A pilot study of 20 EV drivers in Germany found that the most important criteria for evaluating EVSEs were availability and functionality (Fabianek & Madlener, 2023).

The purpose of this study was to assess a key issue that impacts EV owners, the functional state of the public EV charging system. In this study, a *functional* (or available) EVSE is one that can charge a compatible EV for a minimum of 2 minutes, using an appropriate payment method, without the need to make a service call. In pilot studies, we found that charging may start, however, for no apparent reason, will stop charging within the first minute. The 2-min threshold was selected to confirm that charging was initiated and initially stable. An EVSE includes all the system components within a kiosk that are necessary for a successful charge, including the port, screen, network communication, payment system, power source, software, cable, and connector. If a kiosk has more than one cable with a CCS connector, the functionality of each connector is evaluated and reported as a separate EVSE.

The purpose of this study was to systematically evaluate whether open, public DCFC EV chargers with CCS connectors were functional in the 9 counties of the Greater San Francisco Bay Area and collect information on usability of these chargers. California has the greatest density of public open DCFC chargers in the US (NREL, 2022) and within California the density is high in the Greater Bay Area.

Methods

All open, public DCFC EV charging stations with EVSEs with CCS connectors in the 9 counties of the Greater Bay Area were identified using the AFDC database and the PlugShare.com Web site. Stations with CCS connectors with a charge rate >= 50 kW were identified. The 9 counties were Alameda, Contra Costa, Marin, Napa, San Mateo, Santa Clara, San Francisco, Solano, and Sonoma. Nonopen EV charging stations, for example, Tesla, as well as nonpublic EV charging stations, for example, stations in paid parking lots, private workplaces, or business sites with restricted access hours, were excluded.

The identified EV charging stations were visited by a driver with an EV with a CCS charge inlet. Each EVSE at the station was tested by plugging the CCS connector into the EV and attempting to initiate and sustain a charge for 2 minutes. If the charge was successful, the EVSE was classified as functional. The unique kiosk and CCS connector number or name were recorded. If the parking space was occupied by another EV and the EV was charging, the EVSE was classified as functional. If the parking space was occupied by a non-EV or by an EV and not charging, it was classified as not tested. If none of payment methods tested worked, or the EVSE was not functioning, or did not initiate or sustain a charge, the EVSE was classified as nonfunctional. If the cable was too short to reach the EV charge inlet, the EVSE was classified as a design failure.

The payment methods tested included 2 different functioning credit cards and the vendor mobile app or membership card. Payment methods were tested in the following order, credit card 1 insert, credit card 1 swipe, credit card 2 insert, credit card 2 swipe, and then mobile app or membership card, until one of the payment methods was accepted. Each method, that is, a swipe, was attempted twice before moving to the next payment method. The credit cards used for testing were Mastercard, Visa, and Amex. If any of the payment methods worked and led to a 2-minute charge, the EVSE was classified as functional.

The EV drivers were instructed not to call the service number if the EVSE did not work; a functioning EVSE should not require a call to a service number. In addition, requiring a call could have significantly prolonged the testing process. In a pilot study in Marin County, where the service number was called for nonfunctioning EVSEs, 17 calls were made and in only 2 instances was charging ultimately successful. The average call duration was 16 minutes.

Twenty volunteer EV drivers assisted in the testing of the EV charging stations. Only EVs with CCS charge inlets were used. The vehicles used for testing were the Chevy Bolt, Kia Niro, Hyundai Kona, Ford Mustang Mach E, and Porsche Taycan. The EV battery charge level was less than half-full at the time of testing. The volunteers were trained on the study methods and assigned EV charge stations to test. The survey was completed using a Qualtrics survey on a mobile device while the driver was at the charging station.

A random sample of 10% of the stations was tested approximately 1 week after the first round of testing to determine whether the functional state of the EVSEs changed over time.

Results

A total of 182 open public DCFC EV charging stations and 678 EVSEs with CCS connectors were identified in the 9 counties of the Greater Bay Area and visited between February 12, 2022, and March 7, 2022. Of these 675 EVSEs, in 20 instances, the adjacent parking space was occupied by a non-EV (6) or an EV that was not charging (14); therefore, these 20 EVSEs were excluded from the evaluation. The remaining 655 EVSEs that were evaluated are listed by EVSP in Table 1.

Reliability of EVSEs

The functional states of the 655 EVSEs are summarized in Table 2. 72.5% of the EVSEs were functioning at the time of testing; 57.2% were tested and charged for 2 minutes; and 15.2% were occupied by an EV that was charging. 22.8% of the EVSEs were not functioning. System electrical failures, for example, screen blank or nonresponsive, text on screen of “charger unavailable” or “connection error”; payment system failure; or charge initiation failure, were the most common causes of failure. A charge initiation failure occurred if the charge did not start after the payment was accepted or the charge started but was interrupted before 2 minutes of charging was completed. A payment system failure was recorded only after all payment methods failed. A broken connector, for example, cracked or with bent pins, was recorded for 0.6% of EVSEs.

The cord was too short to reach the EV inlet for 3.2% ($N = 21$) of EVSEs tested. This design failure was recorded at a ChargePoint station (1), EVgo stations (4), and Electrify America stations (16). The EVs tested were driven into the parking space either forward or backward during testing to position the EV inlet as close as possible to the charging kiosk. The EVs used, when it was recorded that the cord was too short, were all Chevy Bolts.

Reliability by EV Service Provider

Three EVSPs, ChargePoint, Electrify America, and EVgo accounted for 97.3% (637 of 655) of the EVSEs evaluated. The functional states of the EVSEs for the 3 EVSPs are summarized in Table 3. It should be noted that most of the Electrify America kiosks each had 2 CCS connectors that were each tested and reported as independent EVSEs. However, the 2 CCS connectors cannot be used simultaneously. If each kiosk ($N = 217$), rather than a connector, was considered a single EVSE, and it was functional if either connector provided a successful charge, then the percent of functional EVSEs for Electrify America would increase to 79.3%. On the other

Table 1. Evaluated Open Public DCFC EV Charging Stations and EVSEs by EV Service Provider.

	Stations		EVSE[a]	
EVSP	N	%	N	%
ChargePoint	23	12.7	44	6.7
Delta	2	1.1	3	.5
Electrify America	54	29.8	378	57.7
EV Connect	2	1.1	3	.5
EVgo	91	49.7	215	32.9
Freewire	2	1.1	2	.3
Greenlots	1	.6	2	.3
Powerflex	3	1.7	4	.6
Volta	4	2.2	4	.6
Total	182	100.0	655	100.0

Note. DCFC: direct current fast charger; EV: electric vehicle; EVSE: electric vehicle service equipment.
[a]An EVSE includes all the system components in a kiosk necessary to deliver a charge to a single connector.

Table 2. Functional States of 655 CCS DCFC EVSEs.

	N	%
Functioning		
Charged for 2 minutes	376	57.4
Occupied by EV and charging	104	15.9
Total	480	73.3
Not functioning		
Connector broken	4	0.6
Blank or nonresponsive screen	24	3.7
Error message on screen[a]	30	4.6
Connection error[b]	6	0.9
Payment system failure[c]	50	7.6
Charge initiation failure[d]	40	6.1
Total	154	23.5
Station design failure		
Cable would not reach[e]	21	3.2
Total	655	100

Note. DCFC: direct current fast charger; EV: electric vehicle; EVSE: electric vehicle service equipment.
[a]Charger error, unavailable, under maintenance, etc.
[b]Connection, network, communication error, etc.
[c]Twelve of these were evaluated with 2 credit cards but not an app or membership card.
[d]Short session failure.
[e]At some EVSEs the space was too small to safely back into.

Table 3. Functional State of EVSEs by the Top 3 EV Service Providers.

	ChargePoint		Electrify America		EVgo	
	N	%	N	%	N	%
Functioning						
Charged for 2 minutes	21	47.7	228	60.3	121	56.3
Occupied by EV and charging	6	13.6	56	14.8	36	16.7
Total	27	61.4	284	75.1	157	73.0
Not functioning						
Connector broken	0	.0	2	.5	2	.9
Blank or nonresponsive screen	4	9.1	14	3.7	5	2.3
Error message on screen	6	13.6	19	5.0	4	1.9
Connection error	1	2.3	0	.0	5	2.3
Payment system failure	3	6.8	28	7.4	16	7.4
Charge initiation failure	2	4.5	15	4.0	22	10.2
Total	16	36.4	78	20.6	54	25.1
Station design failure						
Cable would not reach	1	2.3	16	4.2	4	1.9
TOTAL	44	100	378	100	215	100

Note. EV: electric vehicle; EVSE: electric vehicle service equipment.

hand, if it was functional if both connectors were required to work (excluding a short cable problem) then the percent functional would decrease to 72.4%.

Payment Methods

For the 376 EVSEs that charged for 2 minutes, the payment methods that worked are summarized in Table 4. The payment methods were tested, in a waterfall approach, in the order presented in Table 4. For example, 50.5% of successful charges occurred with payment when the first credit card was inserted; and 49.5% of the first credit card insertion payment failed. However, 24.7% of the successful charges required an app or membership card for payment, that is, attempts to pay with 2 credit cards were not successful. If any payment method worked, and led to a 2-min charge, the test was rated as functional.

Table 4. Payment Method That Worked, in the Order Tested, for the 376 EVSEs That Charged for 2 Minutes.

	N	%
Credit card 1 insert	189	50.3
Credit card 1 swipe	33	8.8
Credit card 2 insert	45	12.0
Credit card 2 swipe	8	2.1
App or membership card	94	25.0
Free	7	1.9
Total	376	100.0

Note. EVSE: electric vehicle service equipment.

Testing EV Charging Stations at Two Points in Time

Nineteen (19) randomly selected stations (88 EVSEs) were tested by 2 different EV drivers to determine if their functional state changed over time. The mean time between samplings was 8.0 days ($SD = 4.9$). Eight of the EVSEs could not be compared between the time points because during one of the sampling times the EVSE was occupied by a non-EV, an EV that was not charging, or the cord was too short. Of the remaining 80 EVSEs, 48 remained in a functional state, 14 remained in a nonfunctional state, and 18 (22.5%) changed state from functional to nonfunctional or a nonfunctional to functional (5 of these occurred with the same EV model). For 13 of the 14 EVSEs that remained in a nonfunctional state, the cause of failure was the same at both sampling times. The overall functional status changed little between the sampling times, that is, 72.5% were functional at time 1 and 70.0% were functional at time 2.

Discussion

Of the 655 open public DCFC CCS EVSEs evaluated in this study, 73.3% were functional at the time of testing while 26.7% were either not functional or the cable was too short to reach the EV inlet. The most common cause of a nonfunctional EVSE was an electrical systems failure which included an unresponsive or unavailable screen, a payment system failure, a charge initiation failure, a connection failure, or a broken connector. An interoperability problem, that is, an incompatibility between the EV and the EVSE, does not explain the nonfunctional findings. When an EV failed to charge on an EVSE, it was also able to charge on an adjacent EVSE at the same charging station. It should also be noted that no cables were observed to be severed.

This is the first study we are aware of that systematically evaluated the functional state of open public EV chargers. The findings corroborate recent nonsystematic surveys of EV owners. In a survey of 1290 EV owners, 34% reported that charging station operability issues were a barrier to using public charging stations (CARB, 2022a). In survey of 5500 EV owners, 25% of those who use public DCFCs reported a major difficulty with chargers being nonfunctional or broken (Plug In America, 2022). In the same survey, only 4% of Tesla owners reported a major difficulty with the Tesla closed DCFC system.

In the Greater Bay Area, three EVSPs, ChargePoint, Electrify America, and EVgo accounted for 97.3% of the open public DCFC EVSEs evaluated. The comparison of failures between the three largest EVSPs indicates that the functionality problem was not unique to one EVSP. There were important functional and design differences between the three largest EVSPs. ChargePoint had the highest percent of nonfunctional EVSEs at 36.4% followed by EVgo (25.1%) and Electrify America (20.6%). The most critical design flaw was that 4.2% of the Electrify America cables were too short to reach the Chevy Bolt charger inlet, a problem that may be experienced by other EVs with the power inlet on the driver's side of the vehicle. The cable length problem could be addressed with an industry standard on minimal cord length based on the kiosk location relative to the parking space.

The term reliability, when referencing an electrical system, typically refers to the percent of time, over a given time period, that the system is fully operational and available to deliver power at the intended level. This percent is also referred to as *uptime*. For public EV charging stations, the definition from the Northeast States, is "the percent of time that a charging station must be functioning properly and available for use by EV drivers" and "Each connector on each public DC fast charging station pedestal shall be operational at least 99% of the time based on a 24 hour 7-day week (i.e., no more than 1.7 hours of cumulative downtime in a 7-day period)" (NESCAUM, 2019). New York, California, and the Federal Highways Administration require a minimum uptime of 97% (CEC, 2021, FHWA, 2022, NYSERDA, 2021).

The findings of this study suggest that currently installed DCFC stations do not meet the 97–99% minimum uptime required by public funding agencies. The findings also appear to contradict the 95–98% national uptime levels reported by EVSPs (CARB, 2022a, p. 11). EVSPs do not report the details of how they define and calculate uptime. The EV charging infrastructure would greatly benefit from more data transparency and transparency on methodologies used by each EVSP in calculating uptime. For example, EVSPs could share data on the different subcomponent failure rates and whether the failure was localized, that is, only affecting one EVSE due to a component failure, or systemic, that is, affecting multiple EVSEs due to a communication or software problem. Such a reporting mechanism would benefit the entire industry by establishing an ongoing mechanism to identify the weak links in the system and developing a coordinated approach to addressing them.

While there are state reporting requirements for uptime, federal definitions of uptime are just emerging (FHWA, 2023). A definition of uptime also requires a definition of the opposite, or *downtime*. Downtime is the total time that the EVSE is not operational. The clock on downtime should start when the EVSP has evidence that the system is unable to sustain a charge at the expected level. For example, recording downtime could start when there is (1) a system fault detected through the EVSP network where the fault results in the inability to charge, (2) a call to the service center by an EV driver to report nonfunctioning kiosk, (3) evidence of damage to physical components observed either in person or remotely, or (4) a nonfunctioning EVSE reported during a third-party field evaluation of the station. If a failure is due to conditions outside of the control of the EVSP, for example, upstream loss of power or failure of the cellular system, it may be considered *excluded time*. If excluded time is used in calculating uptime, it should be subtracted from the reporting period time.

To improve the accuracy of reliability reporting, a third-party field audit of an EV charging station could be performed at the startup of the charging station and at periodic intervals thereafter. An audit of each EVSE should involve a standard methodology which could include an assessment of the allotted parking space, a measurement of the cable length, a test of payment methods and screen function, and a confirmation that power is delivered to the EV for a minimum period of time at the intended power level. A second type of third-party audit, following an Evaluation, Measurement and Verification (EM&V) process (CPUC, 2006; DOE, 2022), may also be useful to evaluate the EVSP system and data on uptime, downtime, and excluded time. Such audit findings should be made public.

To improve EV driver expectations and experience, accurate, real-time data on EVSE status should be made public. As mentioned before, the definition of reliability can be viewed from the perspective of the EV owner or the EVSE owner, and they are not necessarily the same. Acknowledging this difference, as the technology and regulatory framework matures and is better defined, is important to establish the correct expectations and prevent EV owners from giving up their EVs and returning to gas vehicles (Hardman & Tal, 2021). Real-time data would allow EV owners to better understand the actual reliability of the EV infrastructure and adjust their expectations accordingly (Savari et al., 2023). Real-time data could be reported by EVSPs and published on the National AFDC map and database. The data could also be made available for commercial applications that provide locations of EV charging stations and information on EVSE status to EV drivers.

Uptime may also be improved with standard maintenance and servicing agreements of EV charging stations. The Northeast State guidelines call for a 24-h window for servicing an EVSE when the EVSE owner or operator is aware that an EVSE is not functioning (NESCAUM, 2019). General maintenance may include the periodic checking of EVSE parts for damage; cleaning the EVSE kiosk, cables, and connectors; and removal of garbage and snow (NREL, 2022).

Several limitations of the study should be noted. First, the test of functionality required a 2-min successful charge of the EV. A charging process may be interrupted for no apparent reason at any time during charging, so the 2-min duration may be too brief a test period to fully evaluate functionality. Second, the EVSEs were evaluated at a single point in time, limiting conclusions about uptime. However, based on our reevaluation of 80 EVSEs, while the functional state of 22.5% the EVSEs changed, the overall percent of functional EVSEs did not change. Third, the test method used different payments methods, 2 credit cards and an app or membership card. A well-functioning system should work with just one payment method. However, if the test methodology had required successful charging with just one credit card, only half of the EVSEs would have been rated as functional. Fourth, the test methodology used did not include having the EV driver call a service number if they were unable to charge the EV. The need to call a service number for assistance might be considered by some a normally functioning system. Fifth, classifying “occupied by an EV and charging” as functional may overstate the overall percent functional since it is unknown whether the EV owner called the service number to initiate charging. Sixth, the test methodology did not determine whether the port was delivering power at the intended level; this should be included in future tests. Finally, the finding that the cable was too short to reach the EV was dependent on the EV model used for testing; testing with an EV that is not a Chevy Bolt may not identify this problem.

Conclusions and Recommendations

As more EVs are adopted nationally, the need for fully functional and reliable open public DCFCs will increase. Nonfunctional public chargers pose an important equity issue as residents in rented or multifamily dwellings usually need to charge at public charging stations. In addition, nonfunctional public chargers negatively impact drivers on long road trips. Furthermore, high rates of nonfunctional chargers may inhibit the adoption of EVs (Hardman & Tal, 2021). The planning for the location and quantity of needed DCFC charging stations, for the build out of a national EV charge infrastructure, should not have to assume that a quarter of the EVSEs will be nonfunctional.

Public EV chargers are complex systems with communications processes to confirm payments, software to interact with the EV, and hardware that delivers an appropriate charge based on signals from the EV. This study identified EV owner interactions with public chargers that can be frustrating. When someone purchases their first EV they should be warned that at public chargers it may be necessary to call an 800 number to initiate a charge. They should also be warned that sometimes charging may start but will be interrupted for no apparent reason before it is complete.

Some of the problems identified can be addressed through a systems analysis of predictable failure points. An example is the payment process. Having a single payment method, such as just plugging in the EV and having it charge using a preloaded payment method will reduce failures compared to chargers that have multiple payment methods, for example, card swipe, card insert, card tap, and app. Some states require the card swipe and insert payment methods; these payment methods increase failure due to the degradation of equipment from to exposure to dirt and rain and require additional hardware and software components that can fail. They are also susceptible to theft from card skimmers.

To decrease EV driver frustration when searching for a public charger, EV apps should provide accurate information on the status of chargers at a site. Charger status should include useful information, for example, the power level the charger can deliver and the last time it was successfully used. EV owners may be misled if only the number of chargers is displayed. It is more useful to present the number of chargers that are working and the number that are currently unoccupied.

EV drivers should be encouraged to report dysfunctional chargers on an EV app, to the 800 number, or to the relevant state agency. Chargers could be labeled with a scan code to make it easy for EV drivers to report a problem charger to a state agency. State agencies could improve EV driver experience by reporting station operational status on public websites (e.g., DOE Alternative Fuels Data Center). Moreover, EV manufacturers should provide educational material to new buyers explaining why it is important to report dysfunctional stations.

Owners of public EV charge stations should contract with a repair service that can maintain the system at a high level of uptime. Recent federal standards require government funded chargers to meet a minimum uptime of 97% (FHWA, 2023). Compliance measures require clear definitions of reliability, uptime, downtime, and excluded time. It may be useful to consider reliability metrics from other industries such as mean time to recovery or mean time between failures. In addition, effective compliance measures may require third-party field testing of chargers, similar to the methods used in this study.

Repairs can be triggered by failures reported on network monitoring, calls to the 800 number, or EV driver notification on apps. If the site has amenities and staff, similar to some gas station models, the staff can confirm a charger problem. Repairs should be made in a timely manner, preferably within a few days of notification. Certification of repair service providers may be necessary given the complexity of these systems. Repeated failures should trigger a reevaluation of components of the system, including communications, software, and hardware.

Other aspects of EV charger design, such as cord length and weight and payment methods, should be evaluated in future usability studies. The design of the human–machine interface on public chargers should consider design principles from other systems, such as bank cash machine interfaces (Rogers et al., 1996, Rogers & Fisk, 1997). These include the physical components such as protection from sun exposure to reduce glare and prevent screen degradation, text contrast and font size for readability, and button design. In addition, the instructions should be simple and understandable. It would be optimal if the interface designs of chargers from different manufacturers ultimately converged.

Beyond the complex hardware and software of these systems there are financial considerations that influence system functionality. The installation of public EV chargers is primarily funded through state agencies (even if funding comes from a federal source). The site owners and EVSEs make money on installation of the chargers; and unless the site is heavily used, it does not typically generate profit from EV charging. Therefore, state agencies should include language in contracts for installing new public EV chargers that requires timely maintenance of failed chargers.

Key Points

- 655 public Direct Current Fast Chargers with CCS connectors in the San Francisco Area were tested and 73.3% were found to be functional.
- The 26.7% failure rate was not due primarily to interoperability issues, but was due to failures of electrical components, network issues, short cables, and broken connectors.
- Precise definitions and systematic field testing are needed for establishing reliable measures of uptime, downtime, and excluded time.
- System design recommendations are made to address the observed failures.

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