# Customer-Focused Key Performance Indicators for Electric Vehicle Charging

Working Group 1: Defining the Charging Experience

CHARGEX consortium

JUNE 2024

INL/RPT-24-77388

Argonne NATIONAL LABORATORY

INL Idaho National Laboratory

NREL Transforming ENERGY

# Disclaimer

# Authors

Casey Quinn[1,2], Sarah Cardinali[3], Jason Clifford[2], Kaleb Houck[2], Kristi Moriarty[3], Mayuresh Savargaonkar[2], John Smart[2], David Smith[2], and Benny Varghese[2]

# Contributors

The authors gratefully acknowledge the invaluable contribution of industry participants in the ChargeX Consortium, including representatives from ABB E-mobility (Cuong Nguyen), AMPECO (Petar Georgiev), Atlas Public Policy (Nick Nigro), ChargeHub (Simon Ouellette), ChargePoint (Tiffany Bley, Mal Skowron), Cool the Earth (Carleen Cullen), Electrify America (Jeffrey Samalot), Enel X Way (Hope Bovenzi), EVBox (Becky Knox), EVgo (Alex Beaton, Jeffrey Dunn, Ivo Steklac), EVSession (Bill Ferro), FLO (Matthieu Loos), Ford Motor Company (Nick Herhusky, Dale Jordan, Kai Wu), FreeWire Technologies (Nate Rosenbloom), General Motors (Frank Marotta), Hubject (Nate Steele), JD Power (Brent Gruber), KIGT (Paul Francis), Lucid Motors (Jasmeen Bal), New York Power Authority (Neal Addison, Philip Saglimbene), NovaCharge (Mark Gross), Plug In America (Ingrid Malmgren), Qualcomm, Inc. (Drew Van Duren), Red Inc. Communications (Jeremy Webster), Rove (Michael Lumbley), SAE International (Frank Menchaca), Siemens (Noam Bilt, Sesha Yeruva, Sudeep Vakiti), Tesla (Noelani Derrickson, Francesca Wahl), UC Davis (Tisura Gamage, Alan Jenn, Vaishnavi Karanam, Ken Kurani, Kai Lim, Gil Tal), University of Washington (Daniel Malarkey, Don MacKenzie, Rubina Singh), VinFast US (Michael Colpitts, Sean Ackley), Xeal (Michael Smith)

# Acknowledgments

The National Charging Experience Consortium (ChargeX Consortium) is a collaborative effort between Argonne National Laboratory, Idaho National Laboratory, National Renewable Energy Laboratory, electric vehicle charging industry experts, consumer advocates, and other stakeholders. This document was produced by the ChargeX Consortium's Working Group 1: Defining the Charging Experience.

The authors gratefully acknowledge the Joint Office of Energy and Transportation (Joint Office) for supporting this work. The Joint Office and national laboratory staff would like to recognize the invaluable contribution of industry partners in providing the input summarized in this report.

[1] casey.quinn@inl.gov
[2] Idaho National Laboratory
[3] National Renewable Energy Laboratory

# List of Acronyms

| | |
|---|---|
| CCS | **Combined charging system** |
| CPP | Customer pain point |
| CSO | Charging station operator, also referred to as a charge point operator |
| EMSP | e-mobility service provider |
| EV | Electric vehicle |
| EVSE | Electric-vehicle supply equipment |
| KPI | Key performance indicator |
| OCPI | Open Charge Point Interface |
| OCPP | Open Charge Point Protocol |
| SOC | State of Charge |
| WG | Working group |

# Revision Log

| Version Date | Description | Author |
|---|---|---|
| **06.18.2024** | 0 | All authors and contributors |
| **01.16.2025** | 1 | Casey Quinn |
| **04.25.2025** | 2 | Casey Quinn |

# Definitions

*Charger.* A device with one or more charging ports and connectors for charging electric vehicles (EVs). Also referred to as electric-vehicle supply equipment (EVSE).

*Charging network.* A collection of chargers located on one or more properties that are connected via digital communications to manage the facilitation of payment and of electrical charging together with related data requests.

*Charging port.* The system within a charger that charges one EV. A charging port may have multiple connectors, but it can provide power to charge only one EV through one connector at a time.

*Charging station.* The area in the immediate vicinity of a group of chargers that includes the chargers, supporting equipment, parking areas adjacent to the chargers, and lanes for vehicle ingress and egress. A charging station could enclose only part of the property on which it is located.

*Charging-station operator.* The entity that owns the chargers and supporting equipment and facilities at one or more charging stations. Although this entity may delegate responsibility for certain aspects of charging-station operation and maintenance to subcontractors, it retains responsibility for operation and maintenance of chargers, supporting equipment, and facilities. In some cases, the charging-station operator and the charging-network provider are the same entity.

*Connector.* The device that attaches an EV to a charging port in order to transfer electricity.

# Table of Contents

# List of Figures



# List of Tables

# 1. Introduction

Electric vehicle (EV) sales account for a rapidly growing portion of the light-duty vehicle market. However, the growth of EV adoption is inherently tied to the reliability and usability of public EV charging. Today, customers of public charging stations, EV drivers, frequently encounter problems, such as lengthy wait times, trouble starting charging sessions, and slow charging speed. It is crucial for the EV charging industry to understand and address these issues to improve the customer experience and ensure a continuing upward trend in EV adoption.

## 1.1. Measurement Is Required for Improvement

To systematically improve the public charging experience, EV-charging-industry stakeholders need to define and measure it precisely. Many stakeholders currently measure aspects of the charging experience, but they typically employ metrics that are either operational in nature, such as charger uptime and mean time between failures, or composite customer-satisfaction indices. To improve the customer experience most effectively, the industry needs metrics that define the charging experience from the perspective of the customer, not business operations. Furthermore, industry practitioners need granular metrics to know what specific aspects of the charging experience need improvement and what data are needed to evaluate those metrics. This report defines such customer-focused metrics, called key performance indicators (KPIs).

## 1.2. Shared Responsibility

Although charging station operators (CSOs) are often perceived as bearing the responsibility for the charging experience, many other stakeholders share this responsibility, including EV manufacturers, charger manufacturers, and electric-mobility service providers (EMSPs, i.e., third-party map and payment app developers). To effectively improve the charging experience, this ecosystem of interdependent companies must uniformly adopt common, customer-focused KPIs and measurement methods to ensure common understanding. Additionally, no single stakeholder currently generates or has access to all data necessary to provide full visibility of the charging experience. Cross-industry coordination and innovation are required to achieve this.

For these reasons, the ChargeX Consortium established Working Group 1 (WG1): Defining the Charging Experience. This group includes representatives from CSOs, charger manufacturers, EV manufacturers, EMSPs, field service providers, national laboratories, consumer-advocacy and non-profit organizations, and academia who specialize in EV charging customer research.

## 1.3. Benefits of Customer-Focused Key Performance Indicators

Developing and implementing customer-focused KPIs will:

- Provide industry a uniform set of metrics to quantitively assess the charging experience
- Segment the charging experience and identify areas of strength and areas to prioritize for improvement
- Validate claims about the charging experience
- Provide a method for gauging the effectiveness of new protocols, EVSE or EV modifications, etc., in improving the charging experience

# 2. Purpose of this Report

This report provides the EV charging industry with two sets of clearly defined KPIs that measure key aspects of the charging experience.

## 2.1. Interim Set of KPIs to Provide Near-Term Benefits

The first set is composed of KPIs that can be calculated by individual companies using data currently generated and communicated via Open Charge Point Protocol (OCPP). These KPIs provide a limited view of the charging experience, but they are implementable in the near term, allowing them to provide benefits to address challenges faced today. Instructions for calculating these KPIs using specific OCPP messages are provided in a supplemental report entitled "Implementation Guide for Customer-Focused Key Performance Indicators for Electric Vehicle Charging."[4]

## 2.2. Ideal Set of KPIs Requires Significant Development

The second set of KPIs recommended in this report are considered ideal, in that they provide a more complete view of key aspects of the charging experience. However, calculating most of these KPIs is not possible today. Significant effort is required to develop and implement new business practices (e.g., cross-industry data sharing), new technology (e.g., senor suites), or updates to standards, to calculate this ideal set of KPIs in its entirety. This report provides some recommendations for future work to advance toward this goal.

## 2.3. Intended Audience

The intended audience for this report is industry practitioners. It does not provide policy recommendations. The intent of the report is to mature both individual industry stakeholders' capabilities and the industry's collective capability to improve the public charging experience by establishing uniform methods for measuring it.

# 3. Customer Pain Points as the Basis for Key Performance Indicators

To structure KPI development, the ChargeX Consortium first identified six key components of the charging experience that represent major steps EV drivers take or experience to charge their vehicles at public stations. These components are shown in Figure 1.

[4]To be published in Fall 2024

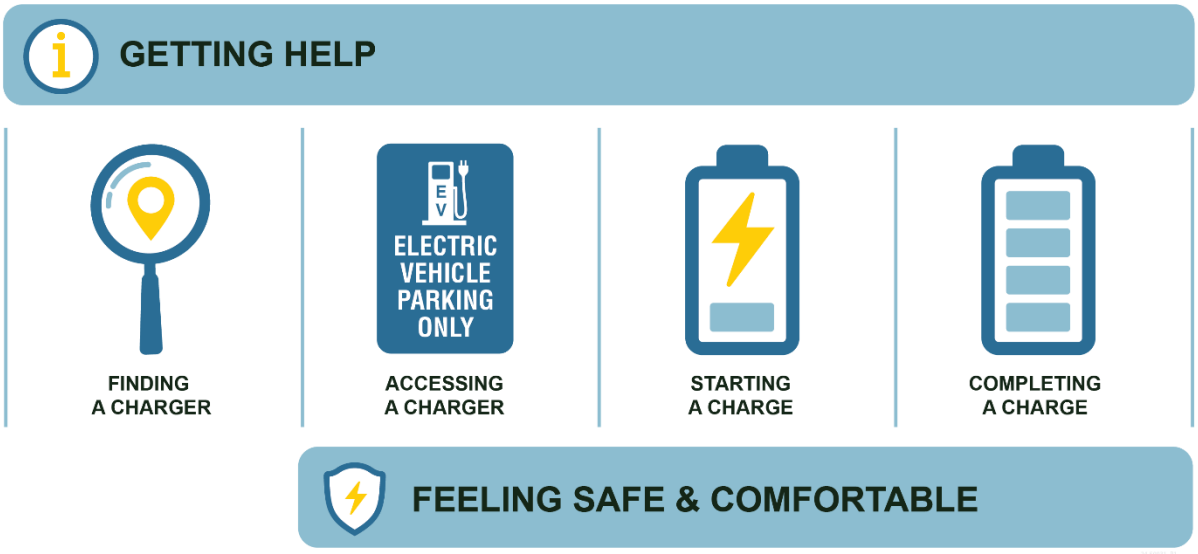


**Figure 1. Key components of the charging experience.**

These components are defined as follows:

1. **Finding a charger.** Identifying, navigating to, and locating a public charging station with confidence that it will meet the customer's needs (i.e., accurate and clear information is available that describes the station location, port count and availability, pricing; and other information, such as payment methods accepted, site access restrictions, and amenities).
2. **Accessing a charger.** The customer's EV gaining physical access to a functional charger.
3. **Starting a charge.** The process the customer follows to start the flow of power to their EV, including authorizing payment and plugging in the vehicle.
4. **Completing a charge.** Events from the time power starts flowing to an EV until the EV's battery reaches the customer's desired state of charge. This includes the rate of charging, any intervention the customer must make to ensure continuation of the charging session, automated or manual actions to stop charging and unlock the connector from the EV, and unplugging. This also includes communication of information about the charging session, such as the amount of energy delivered and total cost paid by the customer.
5. **Getting help.** The process of seeking and receiving assistance if a problem occurs while trying to access a charger, start a charging session, or complete a charging session.
6. **Feeling safe and comfortable.** Factors such as charging-station location, layout, lighting, level of upkeep and repair, and amenities that affect the customer's perceived and actual safety and comfort while at the station.

Each step also includes the process by which customers receive information to help them set accurate expectations for and maintain awareness of the charging process. This includes information about charging station attributes, price of charging, instructions for starting and ending a session and getting help, and status of a charging session.

For each step of the charging experience, the Consortium identified common pain points that customers have experienced and ranked them according to significance. Consortium members based these decisions on professional experience, literature review, and review of customer comments online. Ranked customer pain points are provided in Appendix A, Customer Pain Points for Public EV Charging.

# 4. Key Performance Indicators

This report recommends KPIs for four of the six components of the charging experience: finding a charger, accessing a charger, starting a charge, and completing a charge. The remaining two components, feeling safe and comfortable and getting help, are better served by best-practice recommendations, which are beyond the scope of this report. KPIs were chosen that address the highest-ranked customer pain points, with an emphasis on charging reliability. Further work is needed to develop additional KPIs that measure other important aspects of the charging experience, such as the adequacy of information provided to customers about the charging stations and the user-friendliness of chargers and related apps.

As previously described, two sets of KPIs were developed to address the customer pain points; an interim set for near-term assessments and an ideal set to provide a full view of key aspects of the charging experience. An overview of how these two sets of KPIs were identified is provided in Appendix B, Additional Rationale for Selection of Key Performance Indicators.

The interim set of KPIs consists of the following:

1. Charge start success (%)
2. Charge start time (seconds)
3. Charge end success (%)
4. Session success (%)

Figure 2 shows the relationship of the interim set of KPIs to the charging experience.

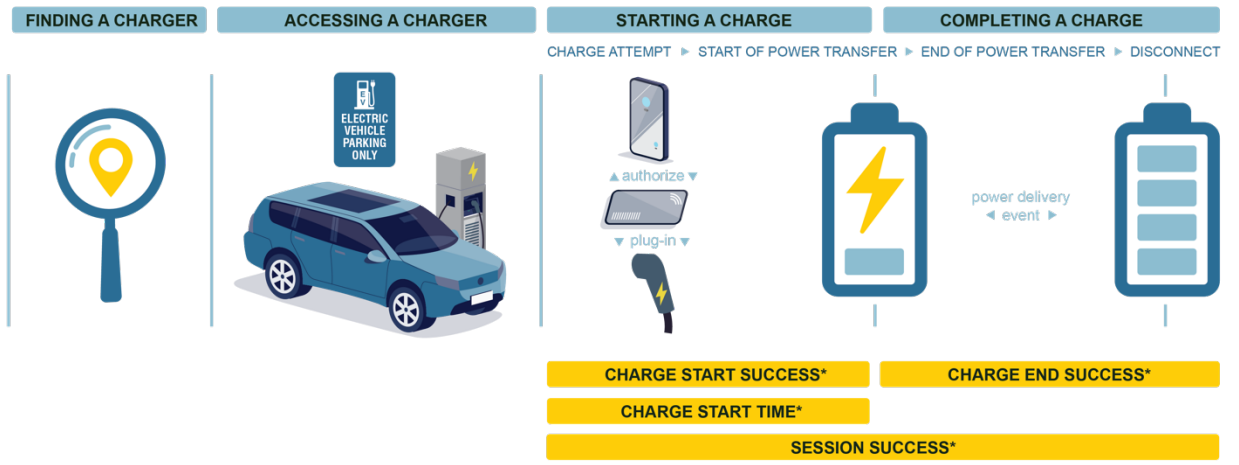


**Figure 2. Interim set of KPIs.**

The ideal set of KPIs consists of the following:

1. Location accuracy (meters)
2. Wait time (minutes, seconds)
3. Charge start success (%)
4. Charge start time (seconds)
5. Charge end success (%)
6. Extended charge time (minutes, seconds)
7. Session success (%)
8. First-time session success (%)
9. Visit success (%)

Figure 3 shows the relationship of the ideal set of KPIs to the charging experience.

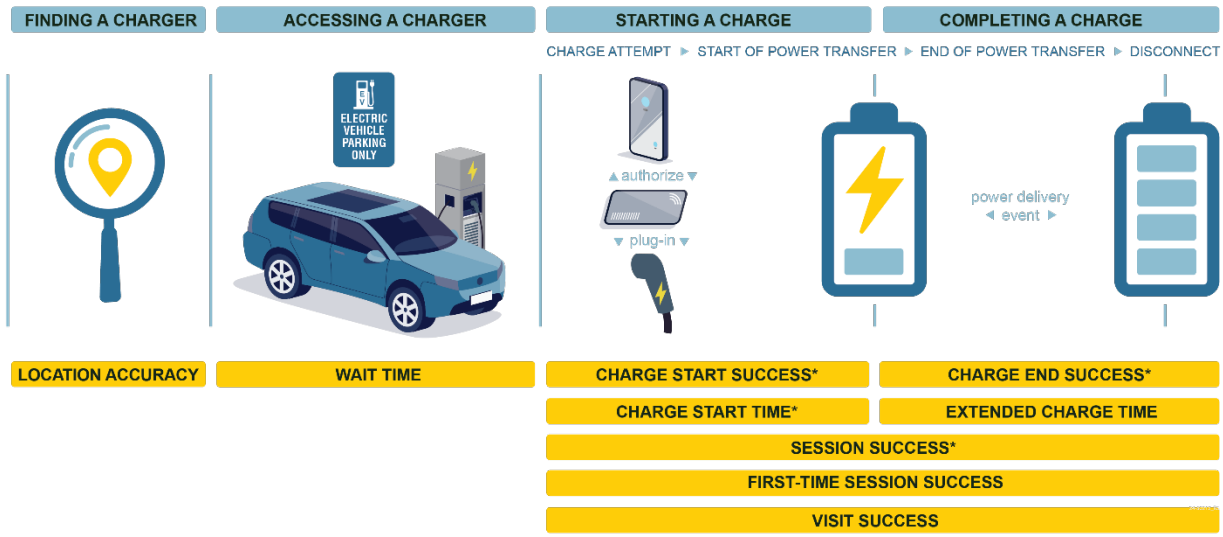


**Figure 3. Ideal set of KPIs.**

The remainder of this report provides detailed definitions for these KPIs.

## 4.1. Interim Set of KPIs

### *4.1.1. Charge Start Success*

**Background:** This KPI addresses the effort required to start a charging session. This KPI is also included in the ideal set of KPIs shown in Figure 3.

**Definition:** Percent of charge attempts that result in an EVSE starting to deliver power to an EV.

This KPI measures the fraction of all charge attempts made by all customers over a period of time that were successful, meaning all the steps required to start the delivery of power to the EV occurred without requiring the customer to repeat actions or otherwise intervene (including obtaining payment authorization, authenticating the EV or EV driver, establishing communication between the EV to the EVSE).

Charge Start Success is measured as a percentage and applies to one or more charging ports at one or more charging stations, as follows:

$$\left(\frac{\sum EVSE\ port\ charge\ attempts\ that\ successfully\ start\ power\ delivery}{\sum EVSE\ port\ charge\ attempts}\right) \times 100 \qquad (1)$$

*where*

Charge attempt = a customer's attempt to start a charging session by either (a) plugging the EVSE connector into the EV or (b) presenting valid credentials and/or payment or taking another appropriate action to authorize a charging session

Start of power delivery = the instant when electricity starts being transferred from EVSE to EV

This KPI should be calculated twice; once for all sessions when plug-in occurred first, and separately for all sessions when authorization occurred first. Thus, two sets of KPIs would be reported for EVSE that permit both charge attempt methods. This is necessary to avoid obscuring potentially skewed results: CSOs can confidently detect when chargers are plugged into vehicles, but they do not always have visibility to failed authorization attempts.[5]

**Implementation:** For detailed instructions on how to populate this equation with data from OCPP, see INL/RPT-24-77389.

### 4.1.2. Charge Start Time

**Background:** This KPI addresses the time required to start a charging session. This KPI is also included in the ideal set of KPIs shown in Figure 3.

**Definition:** Time required for an EVSE to begin delivering power after a charge attempt is initiated.

This KPI measures how long it took to start delivering power to the EV from the time the customer initiates a charge attempt. This KPI includes customer dwell time—e.g., time the customer takes to find a credit card or radiofrequency identification (RFID) card, open the charge door on the EV and plug in (for chargers that require authorization first), etc.

Charge start time is measured in seconds and applies to one or more charging ports at one or more charging stations for each unique session ($i$), as follows:

$$\left(t_{power,i} - t_{attempt,i}\right) \quad (2)$$

*where*

$t_{power}$ = timestamp when power delivery begins

$t_{attempt}$ = timestamp when a charge attempt begins

A charge attempt = a customer's attempt to start a charging session by either (a) plugging the EVSE connector into the EV or (b) presenting valid credentials and/or payment or taking another appropriate action to authorize a charging session

Start of power delivery = the instant when electricity starts being transferred from EVSE to EV

Only times associated with sessions that successfully start delivering power are included in this KPI.

[5] See the ChargeX Consortium report, "Best Practices for Payment Systems at Public Electric Vehicle Charging Stations," for more information on payment issues and proposed solutions. Further collaboration between charging and payment industry stakeholders is needed to ensure that all parties, including the driver, are aware of unsuccessful authorization attempts.

This KPI should be calculated twice: once for all sessions when plug-in occurred first, and separately for all sessions when authorization occurred first. Thus, two sets of KPIs would be reported for EVSE that permit both charge-attempt methods. This is necessary to avoid obscuring potentially skewed results: CSOs can confidently detect when chargers are plugged into vehicles, but they do not always have visibility to failed authorization attempts.[6] The median (50th percentile), 10th, 25th, 75th, and 90th percentiles should be calculated for each reporting period.

**Implementation:** For detailed instructions on how to populate this equation with data from OCPP, see INL/RPT-24-77389.

### 4.1.3. Charge End Success

**Background:** This KPI addresses the effort required to receive a complete charge. This KPI is also included in the ideal set of KPIs shown in Figure 3.

**Definition:** Percent of charging sessions that successfully complete.

This KPI measures the fraction of successful charge attempts made by all customers over a period of time that also resulted in (a) a charging session that has a termination due to customer intervention as defined in OCPP (e.g. Local or Remote) or reaches an energy[7] or state of charge (SOC)[8] limit, and (b) the customer is able to unplug without manual intervention to unlock the connector from the vehicle.

Charge end success is measured as a percentage and applies to one or more charging ports at one or more charging stations, as follows:

$$\left(\frac{\sum EVSE\ port\ charge\ attempts\ that\ result\ in\ a\ charging\ session\ ending\ successfully}{\sum EVSE\ port\ charge\ attempts\ that\ start\ power\ delivery}\right) \times 100 \qquad (3)$$

*where*

Charge attempt = a customer's attempt to start a charging session by either (a) plugging the EVSE connector into the EV or (b) presenting valid credentials and/or payment or taking another appropriate action to authorize a charging session

Start of power delivery = the instant when electricity starts being transferred from EVSE to EV

A session ending successfully = a charging session that has a termination due to customer intervention as defined in OCPP or by reaching an energy or SOC limit and the EV can be disconnected from the EVSE

[6] See the ChargeX Consortium report, "Best Practices for Payment Systems at Public Electric Vehicle Charging Stations," for more information on payment issues and proposed solutions. Further collaboration between charging and payment industry stakeholders is needed to ensure that all parties, including the driver, are aware of unsuccessful authorization attempts.

[7] Only defined in OCPP 2.0.1.

Only sessions that successfully started power delivery are included in this KPI.

**Implementation:** For detailed instructions on how to populate this equation with data from OCPP, see INL/RPT-24-77389.

### 4.1.4. Session Success

**Background:** This KPI encompasses both charge start success and charge end success; thus, it provides an assessment of the overall effort required to complete a charging session. This KPI is also included in the ideal set of KPIs shown in Figure 3.

**Definition:** Percent of charge attempts that successfully start a charging session (i.e., that result in an EVSE starting to deliver power to an EV) and the charging session goes on to successfully complete.

This KPI measures the fraction of all charge attempts made by all customers over a period of time that also resulted in (a) a charging session that has a termination due to customer intervention as defined in OCPP (e.g., Local or Remote) or reaches an energy[8] or state of charge (SOC)[9] limit and (b) the customer can unplug without manual intervention to unlock the connector from the vehicle.

Session success is measured as a percentage and applies to one or more charging ports at one or more charging stations, as follows:

$$\left(\frac{\sum EVSE\ port\ charge\ attempts\ that\ result\ in\ a\ charging\ session\ ending\ successfully}{\sum EVSE\ port\ charge\ attempts}\right) \times 100 \qquad (4)$$

*where*

Charge attempt = a customer's attempt to start a charging session by either (a) plugging the EVSE connector into the EV or (b) presenting valid credentials and/or payment or taking another appropriate action to authorize a charging session

A session ending successfully = a charging session that has a termination due to customer intervention as defined in OCPP or by reaching an energy or SOC limit and the EV can be disconnected from the EVSE

When calculating this KPI, the data should be separated into two groups based on how the charging attempt is initiated (items a and b under charge attempt definition, above) for each individual session. Thus, two sets of KPIs would be reported for EVSE that permit both charge attempt methods. This is necessary to avoid obscuring potentially skewed results: CSOs can confidently detect when chargers are plugged into vehicles, but they do not always have visibility to failed authorization attempts.[9]

[8] Only defined in OCPP 2.0.1.

[9] See the ChargeX Consortium report, "Best Practices for Payment Systems at Public Electric Vehicle Charging Stations," for more information on payment issues and proposed solutions. Further collaboration between charging and payment industry stakeholders is needed to ensure that all parties, including the driver, are aware of unsuccessful authorization attempts.

**Implementation:** For detailed instructions on how to populate this equation with data from OCPP, see INL/RPT-24-77389.

## 4.2. Ideal Set of KPIs

### 4.2.1. Location Accuracy

**Background:** This KPI addresses the effort to locate an EVSE. There is no interim proxy measure for this KPI.

**Definition:** Difference between the geolocation of EVs charging at the EVSE or charging station and the EVSE or charging station geolocation published by the CSO.

This KPI measures distance between the actual EVSE-port or charging-station location and the location published by the CSO on its map or communicated to others' maps. Note that some CSOs publish geolocations of each EVSE port at a charging station whereas others report only a single location for all EVSE ports at a charging station, such as the centroid. Latitudes and longitudes must be converted to radians; if they are provided in decimal degrees, this can be accomplished by dividing by 57.29578.

Location accuracy is measured in meters and is applied to one or more charging stations (or one or more EVSE port), as follows:

$$6378137 \times arcos[(\sin(EVSE\ lat) \times \sin(EV\ lat)) + \cos(EVSE\ lat) \times \cos(EV\ lat) \times \cos(EV\ long - EVSE\ long)] \quad (5)$$

*where*

EVSE lat = EVSE port or charging station latitude (radians) provided by the CSO

EV lat = Latitude (radians) of an EV when connected to the EVSE port, or any EVSE port at the charging station

EVSE long = EVSE port or charging station longitude (radians) provided by the CSO

EV long = Longitude (radians) of the EV when connected to the EVSE port, or any EVSE port at the charging station

**Implementation:** This KPI is dependent on the availability and provision of precise GPS data (i.e., latitude, longitude) both from the CSO for the published EVSE location and from some other device that measures actual location.

In theory, actual-location measurement could come from EVs when they charge at the EVSE or station. Implementation of this KPI as defined would require EV telematics data to be shared with CSOs. This could be incorporated into the data-sharing specification, called minimum required-diagnostic information (MRDI), being developed by the ChargeX Consortium's Diagnostics Task Force.

An alternative to using EV location data could be to use a CSO or EMSP smartphone application to capture the GPS location of the phone of customers while charging and compare it to reported EVSE or station location. Another potential alternative for this KPI could involve the use of the integrated-navigation user interface in the EV, combined with EV GPS location data, to assess the location accuracy of an EVSE or charging station.

To further enhance the customer experience while finding a charging station, additional work is recommended to develop best practices to improve last-mile directions provided to EV drivers and implement these last-mile directions in a standardized way within Open Charge Point Interface (OCPI).

### 4.2.2. Wait Time

**Background:** This KPI addresses the time required to access an available, functional charger.

**Definition**: Time to access a functional charging port at a site.

Wait time measures how long drivers wait on average to access a charging port. Because demand for charging varies by time of day, this KPI should be calculated in hourly blocks. Also, because charging stations offer connector types that are not compatible with all vehicles, this KPI should be calculated separately for the following three grouping of connector types: (1) CCS and J3400 connectors, (2) CHAdeMO connectors, and (3) J1772 AC and Tesla destination charger connectors.

Wait time is measured in seconds for each unique charging session ($i$) and is applied at the charging station level, as follows:

$$\left(t_{attempt,i} - t_{arrival,i}\right) \tag{6}$$

*where*

$t_{arrival}$ = timestamp when a vehicle arrives at a charging station

$t_{attempt}$ = timestamp when a charge attempt is made

The median (50th percentile), 10th, 25th, 75th, and 90th percentiles should be calculated for each reporting period.

**Implementation:** One option for implementation of this metric is dependent on the availability and provision of precise GPS data (latitude, longitude) from EVs to determine how long each EV was at the charging station prior to initiating a charge attempt. This method would require EV telematics data to be shared with CSOs and/or OCPP charging session level data shared with the EV. This could be incorporated into data-sharing specification, MRDI, being developed by the ChargeX Consortium's Diagnostics Task Force.

Other potential long-term solutions could include the development of a virtual queuing system or CSOs developing the capability of detecting EVs arriving on site using various methods.

### 4.2.3. Extended Charge Time

**Background:** This KPI addresses the time required to complete a charging session. There is no interim proxy measure for this KPI.

**Definition:** The time a charging session is extended due to power limitations of the EVSE.

This KPI represents the extra time required to complete a charge session (i.e., reach the customer's desired SOC) because the power provided by the EVSE was less than the power that the EV would have requested had the EV's request not been limited by the EVSE.

Extended charge time is based upon error in charge power requested versus delivered over a single charging session. From the EVSE's perspective, providing the charge power requested by the EV would lead to the shortest charging session.

Extended charge time is measured in seconds and is applied to one or more charging ports at one or more charging stations, as follows:

$$\left(T - \left(\frac{E}{\left(\frac{E}{T}+SPE\right)}\right)\right) \times 3600 \quad (7)$$

*where*

SPE = session power error = error between power delivered by EVSE port and power an EV can accept throughout the session (kW)

E = charging energy delivered to EV (kWh)

T = total time during a session when electricity is transferred from EVSE to EV (hours)

The median (50th percentile), 10th, 25th, 75th, and 90th percentiles should be calculated for each reporting period.

**Implementation:** To calculate this KPI, standards governing the communication between EVs and EVSE (e.g., DIN 70121 and ISO 15118) must be updated to enable messages with sufficient content and frequency to be generated and recorded. The ChargeX Consortium Communications Task Force is investigating changes necessary to track requested versus provided power throughout the charging session.

### 4.2.4. First-Time Session Success

**Background:** This KPI encompasses both charge start success and charge end success; thus, it provides an assessment of the overall effort required to complete a charging session. Session success (see Section 4.1.4) is the interim proxy measure for this KPI.

**Definition:** Percent of ***first*** charge attempts that successfully start a charging session (i.e., that result in an EVSE starting to deliver power to an EV) and the charging session goes on to successfully complete the ***first*** charge attempt by a customer at a charging port for each EV visit to a charging station.

This KPI measures the fraction of ***first*** charge attempts made by a customer for each visit to a charging station over a period of time that also resulted in (a) a charging session that has a termination due to customer intervention as defined in OCPP (e.g. Local or Remote) or reaches an energy[10] or SOC[11] limit, and (b) after which the customer was able to unplug without manual intervention to unlock the connector from the vehicle.

First-time session success is measured a percentage and applies to one or more charging ports at one or more charging stations, as follows:

$$\left(\frac{\sum FirstTime\ EVSE\ port\ charge\ attempts\ that\ result\ in\ charging\ session\ ending\ successfully}{\sum EVSE\ port\ charge\ attempts}\right) X100 \quad (8)$$

*where*

Charge attempt = a customer's attempt to start a charging session by either (a) plugging the EVSE connector into the EV or (b) presenting valid credentials and/or payment or taking another appropriate action to authorize a charging session

A session ending successfully = a charging session that has a termination due to customer intervention as defined in OCPP or by reaching an energy or SOC limit and the EV can be disconnected from the EVSE

**Implementation:** One option for implementation of this metric is dependent on the availability and provision of precise GPS data (latitude, longitude) from the EV to determine when the EV arrives at and leaves the EVSE, relative to when the charging attempt is made. Implementation of this KPI using this method would require EV telematics data to be shared with CSOs and/or OCPP charging-session-level data shared with the EV. A data-sharing framework could be developed as part of ChargeX WG3 MRDI.

### 4.2.5. Visit Success

**Background:** This KPI encompasses both charge start success and charge end success; thus, it provides an assessment of the overall effort required to complete a charging session. Session success (see Section 4.1.5) is the interim proxy measure for this KPI.

**Definition:** Percent of visits to a charging station where at least one charge attempt successfully starts a charging session (i.e., result in an EVSE starting to deliver power to an EV) and where the charging session goes on to successfully complete.

[10] Only defined in OCPP 2.0.1.

This KPI measures the fraction of charging station visits that have at least one charge attempt made by a customer for each visit to a charging station over a period of time that also resulted in (a) a charging session that has a termination due to customer intervention as defined in OCPP (e.g., Local or Remote) or reaches an energy[11] or SOC[12] limit, and (b) after which the customer was able to unplug without manual intervention to unlock the connector from the vehicle. This KPI allows for failed charge attempts using the same or other hardware at a charging site but does not require the EV driver to move to another charging site.

Visit success is measured as a percentage. It applies to one or more charging stations, as follows:

$$\left(\frac{\sum EV\ visits\ to\ a\ charging\ station\ that\ result\ in\ charging\ session\ ending\ successfully}{\sum EV\ station\ visits}\right) \times 100 \qquad (9)$$

*where*

EV station visit = a distinct visit to a charging station (i.e., period of time the customer's EVs spends at the station between arrival and departure), during which the customer makes at least one charge attempt

Charge attempt = a customer's attempt to start a charging session by either (a) plugging the EVSE connector into the EV or (b) presenting valid credentials and/or payment or taking another appropriate action to authorize a charging session

A session ending successfully = a charging session that has a termination due to customer intervention as defined in OCPP or by reaching an energy or SOC limit and the EV can be disconnected from the EVSE

**Implementation:** One option for implementation of this metric is dependent on the availability and provision of precise GPS data (latitude, longitude) from the EV to determine when the EV arrives at and leaves a charging station, relative to when any charging attempts are made. Implementation of this KPI using this method would require EV telematics data to be shared with CSOs and/or OCPP charging-session-level data shared with the EV. A data-sharing framework could be developed as part of ChargeX WG3 MRDI.

[11] Only defined in OCPP 2.0.1.

# 5. Next Steps

This document details the two sets of KPIs and how they address the main aspects of the charging experience. The next logical steps for establishing these KPIs are these:

- Validate and publish the "Implementation Guide of Customer-Focused Key Performance Indicators for Electric Vehicle Charging (INL/RPT-24-77389)," a guide with detailed instructions on how to implement the interim set of KPIs
- Seek commitments from industry partners to implement the interim set of KPIs
- Implement interim set of KPIs into the EVerest Project[12]
- Work with industry partners to identify the necessary data to calculate the ideal set of KPI and develop detailed instructions on how to implement the ideal set of KPIs
- Seek commitments from industry partners to implement the ideal set of KPIs
- Work with a standards development organization to codify the KPIs in a formal standard.

[12] https://lfenergy.org/projects/everest/

# Appendix A

## Customer Pain Points for Public EV Charging

Customer pain points (CPPs) were identified by reviewing existing reports, peer-reviewed documents, industry surveys, social media, customer reviews from various EV charging websites and tools, press releases, new articles, and input from ChargeX Consortium WG1 members. However, the diversity and lack of structured data around EV charging issues makes categorizing and understanding the problems that EV drivers face a daunting task. Publicly available reviews from EV drivers were leveraged to provide additional insight and guidance in the identification and prioritization of the CPPs, because they contain rich information about the charging experience and its challenges. Once CPPs were identified and agreed upon by the members of WG1, CPPs were grouped into six categories, and the members were asked to vote on the CPPs they thought should be within the scope of the ChargeX WG1. The results from the CPP survey provide a prioritized list of categorized CPPs that was used to guide the development of quantitative KPIs that can track EV-charging-infrastructure performance over time.

The members of ChargeX WG1 identified 52 CPPs and placed them into the six components of the charging experience shown in Figure 1.

After identifying and categorizing the CPPs, a survey was distributed to gather input from the 40 ChargeX WG1 member organizations. Note that this count does not include input from the members from the DOE national laboratories. We received survey input from 24 of the 40 (60%) organizations, and that input was used to prioritize the CPPs as high, medium, or low priority. The priority levels identified as high were used by the ChargeX WG1 to guide the development of the KPIs described in this document. The summary results from the survey are shown in Figure A-1. Members of the ChargeX WG1 identified most CPPs in the starting-a-charge category: a total of 18 CPPs identified. Each category had at least two CPPs identified as high priority by the WG. A comprehensive list of all the CPPs grouped by priority and CPP categories are listed in the following sections.

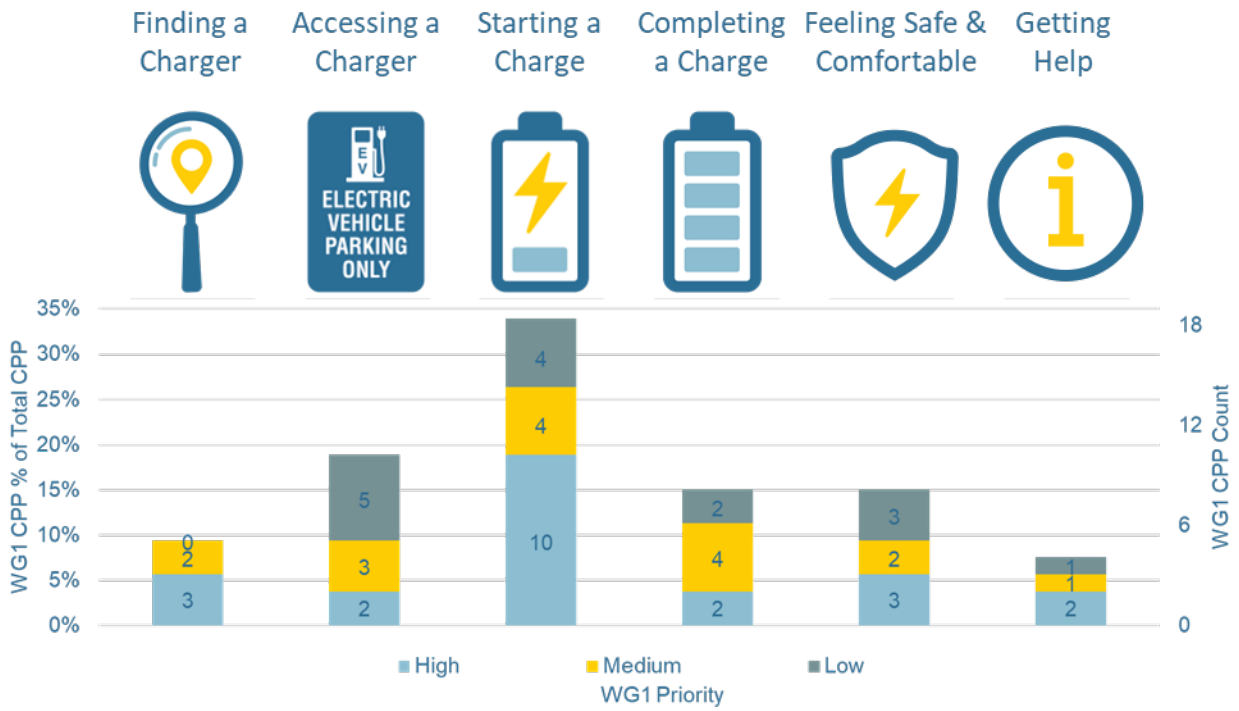


**Figure A-1. Number and fraction of the total CPPs identified and prioritized by the ChargeX WG1 based on a WG1 survey.**

## High-Priority Customer Pain Points

High-priority CPPs were selected as a result of receiving more than two-thirds majority vote (>66%) of the ChargeX WG1 members who voted in the survey. The ChargeX WG1 will work to build KPIs so that it can quantify these high-priority CPPs. All high-priority CPPs are listed below by CPP categories.

1. Finding a charger
    - Misleading availability for number of available or working chargers or plugs via in-app or in-vehicle EVSE mapping or inaccurate signage and lighting indicators
    - Charging station not at the communicated location
        - Location is incorrectly communicated
        - Charging station was removed
    - Charging station hard to locate when driver arrives on premise
2. Accessing a charger
    - Charger offline or out of service
    - Chargers in use or reserved by other EVs (i.e., waiting in queue) due to insufficient number of charging ports and/or excess demand (e.g., free charging programs that incentivize the use of public, rather than home chargers)

3. Starting a charge
    - Broken or missing components (screens, cables, plugs, front panels)
    - Cables too short
    - Cable management (cables on the ground, driven over, cumbersome to handle, etc.)
    - Charger powered off or no power available
    - App payment or authentication does not work
    - Failed to start charge (vehicle or EVSE)
    - Required multiple attempts to start successful charge
    - Unclear pricing—stations should clearly display pricing structure for customer to understand, and apps should match station-posted pricing policies)
    - Authenticating the correct station
    - No cell service or Wi-Fi limits charge initiation
4. Completing a charge
    - Incomplete charge—charging session stops early and cannot be restarted
    - Lower power than expected
5. Getting help
    - No option for getting help
    - No ability to report issue—i.e., broken charger at site did not disrupt a driver's charging because there was a plug that worked
    - No ability to see status of reported issue (drivers may benefit from the ability to see when a station is expected to become available again)
6. Feeling safe and comfortable
    - Lighting/security
    - Exposed electrical connections.

## Medium Priority Customer Pain Points

Medium-priority CPPs were selected as a result of their receiving less than two-thirds majority (<66%) vote, but more than a simple majority (i.e., >50%) of the ChargeX WG1 members who voted in the survey. The ChargeX WG1 will try to determine whether any of these CPPs can be integrated into the definition of high-priority KPIs. If not, KPIs will not be developed for these CPPs. All medium-priority CPPs are listed below by CPP categories.

1. Finding a charger
    - Confusion around EVSE-EV compatibility
    - Inadequate or unclear information about charging station and charger attributes:
        - Chargers accessible from Americans with Disabilities Act (ADA)-compliant parking stalls
        - Chargers accessible by vehicles pulling trailers—i.e., pull-through accommodation
        - Vehicle-size restrictions for the parking stall—e.g., compact vehicles only
        - Connector type
        - Power rating
    - Inadequate or unclear information about access restrictions:
        - Requirements to physically access parking area—e.g., cost/price, accepted payment method, membership, or affiliation requirements
        - Requirements to use the charger—e.g., cost/price, accepted payment method, membership, or affiliation requirements
        - Communication that charger has been reserved and is unavailable even though it is not currently in use
2. Accessing a charger
    - ADA accessibility issues
    - Inadequate or inappropriate space for EVs to stand or park while waiting in queue for chargers to become available
    - Chargers blocked
        - Occupied by non-charging vehicles (e.g., by vehicles with internal combustion engines [ICE'd])
        - Blocked by other objects (e.g., snow berm, construction materials, temporary fencing)
3. Starting a charge
    - EVSE lacks station ID, has incorrect ID that does not match app, or is placed in poor location
    - Could not pay with network of choice, lack of roaming ability

- Requires calling customer service to start charge session
- User interface or instructions too complicated or unclear

4. Completing a charge
    - Not able to track charging session live; no notification of when charging is complete
    - Charging session resets (once or repeatedly)
    - Plug physically stuck or frozen in vehicle
    - Unable to or hard to understand how to stop a charging session
5. Getting help
    - Requires calling someone
    - No one answers
6. Feeling safe and comfortable
    - Covered charging spaces.

## Low-Priority Customer Pain Points

Low-priority CPPs were selected as a result of receiving less than a simple majority (<50%) of the ChargeX WG1 members who voted in the survey. The ChargeX WG1 will try to determine whether any of these CPPs can be integrated into the definition of the high-priority KPIs. If not, while these CPPs are important, KPIs will not be developed for these CPPs. All of the low-priority CPPs are listed below by CPP categories.

1. Finding a charger
    - Insufficient charging-station density for long-distance travel
2. Accessing a charger
    - Longer wait time because EV using a charger with much-higher power capacity than the EV can accept
    - Charging stalls not large enough for newer EVs (e.g., full-size pickup truck)
    - Unreasonably high price in areas with few chargers (e.g., charging deserts) or in areas with or times of high demand
3. Starting a charge
    - Order of operations to start a charging session varies between charging stations
    - Lack of multilingual interface
    - No credit-card option
    - Prepay requirements or required deposit

4. Completing a charge
    - Inability to estimate charge time/charge rate. (time to reach 80% or 100%; mph or %state of charge/hr)
    - EVSE noise
5. Getting help
    - Lack of multilingual customer support
    - Time required to explain why something failed and how it will be improved or prevented in the future
    - Explore requiring an attendant during business hours for all new constructions accepting public funding
6. Feeling safe and comfortable
    - Lack of amenities at or near charging location.

## Manual Assessment of CPPs in Public-Comment Data

EV-charger public user comments were manually accessed to aid in the identification of CPPs. Members of the ChargeX Consortium manually analyzed user comments to help them understand the top CPPs experienced by EV drivers and supplement the CPP list developed by the ChargeX WG1 members.

For this analysis, a total of 335 charge events were reviewed, based on their customer experience reviews of EV charge events. These data were taken from 30 different charging stations across the United States from a variety of geographic locations: 15 charging-station operators, 23 vehicle original equipment manufacturers, direct current fast charge (DCFC) stations (92% CCS; 7% CHADeMO; 1% unknown) and over a 12-month period between March 2022 and March 2023 (Figure A-2).

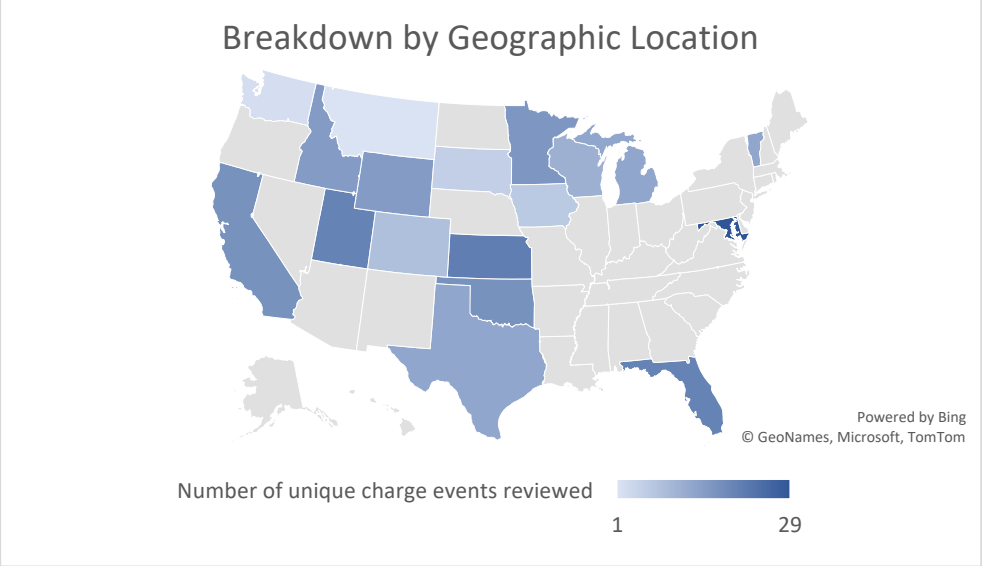


**Figure A-2. Location of the 30 charging stations selected to manually evaluate 300 negative reviews.**

Only reviews that had a negative charging experience were considered for this analysis. These negative reviews were used to generate a ranked list of the 14 CPPs identified during this preliminary manual assessment of the EV-charging customer reviews and are shown in Figure A-3. These CPPs identified in this preliminary manual assessment were the starting point for the CPP categories developed and described in Section 3 of this document. A detailed description of each of these CPPs is described below.

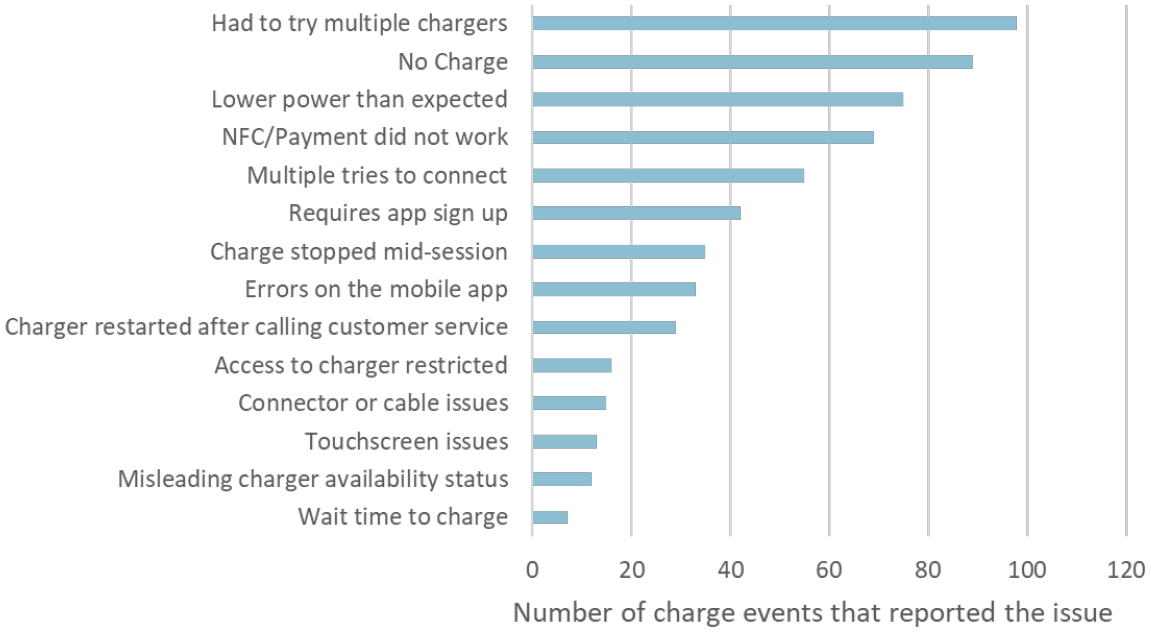


**Figure A-3. Ranked list of CPPs identified from 300 negative reviews left at 30 different charging stations across the United States.**

- **Had to try multiple chargers:** includes all reviews that mentioned having to move from one charger to another to start a charge event. Also includes reviews that mention one or more broken or inoperable chargers at the site.
- **No charge:** includes all reviews that mentioned not receiving a charge during their visit to the station. In most cases, no-charge reviews mentioned other issues that fell into one or more other problem categories.
- **Lower power than expected:** includes all reviews which mention receiving lower than expected charging power. This includes a mix of situations where the charger is limited by software, cable-temperature issues, and unrealistic customer expectation: vehicle not capable of expected power level, battery at high state of charge (SOC), ambient cold weather, battery not presoaked, etc. This problem category does not distinguish between the different reasons for lower-than-expected power.
- **Near Field Communications (NFC)/payment did not work:** includes all reviews which mention failed physical payment using one of the available payment methods on the charging dispenser. Also includes RFID membership card failure to scan or respond. Does not include any app or phone call related payment failures.
- **Multiple tries to connect:** includes all reviews which mention having to retry initializing a charge session that did not work on the first try. Only counts events where the EV customer did not report moving to a different charger.
- **Requires app sign up:** includes reviews which mention having to sign up in order to get a charger to work. Usually, a consequence of failed payment authorization or based on other reviews at the same site.
- **Charge stopped mid-session:** includes reviews which mention charge session stopping after successful initialization. Possible that a small percentage of customers might have settings on their EVs which end session after reaching a certain SOC during a charge session.
- **Errors on the mobile app:** includes all reviews that mention an issue with the mobile application they attempted to use at a charging station to start or monitor a session. Includes unresponsive app experience or failed payment when attempting to pay through the app. A small percentage of the issues were noted to be due to poor cellular coverage in the area where the chargers are located. Does not include reviews that mention misleading charger availability status shown on the app.
- **Charger restarted after calling customer service:** includes all reviews which mention having to call customer service to start or resume a charge session. Most of these calls seemed to result in the charger being restarted if customer service is unable to start a session remotely.

- **Access to charger restricted:** includes reviews which mention restricted access to the charger. Includes chargers blocked by debris, ICE vehicles, or EVs that are not plugged in. Also includes a small percentage of reviews that mention poor site layout, where customer can charge only when blocking other charging spots. This problem category does not include locations that are taped off or have a cone in front (presumed to be blocked off my station operator for maintenance).
- **Connector or cable issues:** includes reviews which mention cable or connector issues. Includes, cable-temperature warnings, broken connectors, connectors that do not lock or unlock, bulky cables, frozen, rigid cables, cable too short to reach vehicle, etc.
- **Touchscreen issues:** includes reviews that mention problems with the touchscreen, either blank, non-responsive, or stuck in a boot loop screen.
- **Misleading charger availability status:** includes reviews where the charger availability is not accurate on the application. Includes both charger working while shown as broken and charger broken while shown as available. While the total number of reviews explicitly mentioning this issue is low, it is likely that the real number is higher, based on the number of no charge events in the current data set.
- **Wait time to charge:** includes reviews that mention having to wait in line to charge. Potential causes include low number of chargers at the site, high demand, small number of functional chargers while app shows a larger number of available chargers. Also includes a small percentage of customers waiting for an EV/EVSE handshake longer than expected.

Other notable issues mentioned in the reviews:

- Pricing
  - Session-start fee—some reviews mentioned CSOs charging a session start fee, even when the session failed to start. This was charged multiple times as the customer tried to start a successful session on multiple chargers.
  - Being charged per minute instead of by kWh—some reviews mentioned that at sites charging per minute, the rate remains the same even when the charger is delivering lower-than-expected power (even when EV is compatible, and SOC is at a reasonable level).
  - Price too expensive.
- Location-specific complaints
  - Multiple reviews mentioned such location-specific complaints as accessibility, lighting, restrooms, sidewalks, pedestrian crossings, walking distance to amenities, and lack of visible markings showing which chargers provide 150 and which provide 350 kW.

# Appendix B

# Additional Rationale for Selection of Key Performance Indicators

## Two Key Dimensions: Effort and Time

KPIs were defined with respect to two key dimensions or factors. The first factor is the *effort* required of the customer, in the form of any of the following:

- Repeated actions due to a system error (e.g., multiple credit card taps)
- Intervention due to a system error (e.g., need to unplug and re-plug the connector)
- Unnecessary actions due to inaccurate or unclear information (e.g., extra driving to find the charging station because its location on the map is incorrect)

The second factor is the *time* required to complete steps in the charging experience, such as the time spent waiting to access a charger because it is in use by other EVs.

It is important to address both effort and time because improvement to one could lead to worsening of the other. For example, automating charge-attempt retry, to prevent the need for customers to unplug and re-plug, may lengthen the time it takes to start a charge.

## Staging KPIs in Time

Some of the ideal KPIs identified cannot easily be calculated today. KPIs that touch on accessing a charger, starting a charge, and completing a charge cannot be calculated today, but the authors identified a set of interim KPIs that could act as proxy measures in the near term. The authors compiled this full set of KPIs and had the members of ChargeX Consortium WG 1 vote on the level of importance of each KPI to improving the charging experience. In addition to ranking the KPIs in terms of importance for improving the charging experience, the authors mapped data sources to each of the KPIs to determine which of the KPIs could be calculated with data that CSOs currently generate (e.g., OCPP data fields, utilization rates, etc.). By combining these two assessments, the team was able to identify an interim set of KPIs that can be implemented in the near term using data currently available from the charging infrastructure. A breakdown of this process is visually shown in Table B-1.

**Table B-1. Categorization of KPIs by importance and implementation feasibility.[13,14,15]**

| | | Interim Set of KPIs<br>*CSO currently generating necessary data* | Ideal Set of KPIs<br>*CSO not currently generating necessary data; requires significant tech or process development* |
|---|---|---|---|
| **Importance for Improving the Charging Experience** | Higher Importance | • Charge Start Success[14]<br>• Charge End Success[14]<br>• *Session Success* (proxy for First-Time Session Success)[14] | • First-Time Session Success[15]<br>• Visit Success[15] |
| | Lower Importance | • Charge Start Time[14] | • Wait Time[15]<br>• Extended Charge Time[16]<br>• Location Accuracy[15] |

Note that some KPIs are in both sets. KPIs in the ideal set that are not in the interim set cannot be calculated today, given the state of the industry. The ideal set of KPIs is meant to be implemented in the long term. They are published here to guide the industry into maturity.

## Identifying Charge Attempts

As noted throughout this report, one of the challenges with comparing results from Charge Start Success, Session Success, First-time Session Success, and Visit Success is tied to how a charging session is initiated ([a] plugging the EVSE connector into the EV or [b] presenting valid credentials and/or payment or taking another appropriate action to authorize a charging session). The key reasons for this are: (1) plugging in first has fewer session attempt methods than those that do not start by plugging in first and (2) plugging in first can be more reliably tracked by key stakeholders as compared to charge attempts that are not initiated by plugging in first. In meetings with the members of ChargeX Consortium WG 1, Table B-2 was developed to identify how charging sessions can be initiated, what risk there is to missing a charge attempt, frequency that the attempt method is currently used in the North American market, and which stakeholder has the most information about that charge attempt method. The aim of this table is to help identify areas where the industry should prioritize improvements to help ensure all charge attempts are being observed and logged to better reflect the true customer experience with EV charging.

[13] Data sources have been identified in OCPP 1.6J and/or OCPP 2.0.1

[14] Likely requires data from EVs or other sources; to be investigated by ChargeX Consortium's Diagnostics Task Force.

[15] Likely requires modifications to ISO15118-2; to be investigated by ChargeX Consortium's WG2 Communication Task Force

**Table B-2. Charging session attempt methods with known risks and frequency of use.**

| Charging session attempt method | Risk an attempt is not logged (Low [1] - High [5]) | Frequency of use (Low [1] - High [5]) | Stakeholder with most information about attempts |
|---|---|---|---|
| Credit Card Swipe/Insert/Tap | 5 | 2 | Credit Card/Chip Reader |
| Phone Call | 5 | 1 | CSO |
| eMSP App - Roaming | 4 | 2 | eMSP |
| QR Code/Text | 4 | 2 | CSO |
| Vehicle User Interface | 3 | 2 | EV |
| eMSP App | 2 | 4 | eMSP |
| eMSP Card - Roaming (RFID/NFC) | 2 | 1 | CSO |
| Plug and Charge | 1 | 4 | EV |
| eMSP Card (RFID/NFC) | 1 | 3 | CSO |
| Credit Card RFID/NFC Digital Wallet | 1 | 3 | CSO |
| EVSE User Interface | 1 | 1 | CSO |

CHARGEX
consortium

# About the ChargeX Consortium

The National Charging Experience Consortium (ChargeX Consortium) is a collaborative effort between Argonne National Laboratory, Idaho National Laboratory, National Renewable Energy Laboratory, electric vehicle charging industry experts, consumer advocates, and other stakeholders. Funded by the Joint Office of Energy and Transportation, the ChargeX Consortium's mission is to work together to measure and significantly improve public charging reliability and usability by June 2025. For more information, visit **chargex.inl.gov**.

JUNE 2024

INL/RPT-24-77388

Argonne NATIONAL LABORATORY

INL Idaho National Laboratory

NREL Transforming ENERGY