Evolution of Plug-In Electric Vehicle Charging Infrastructure in the United States

Preprint

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Evolution of Plug-In Electric Vehicle Charging Infrastructure in the United States

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Summary

The U.S. Department of Energy's Alternative Fuels Data Center (AFDC) has tracked alternative fueling and electric vehicle charging infrastructure in the United States since 1991. This paper explores the history of the AFDC Station Locator, which was launched in 1999, and discusses the growth of electric vehicle supply equipment. It also looks at how electric vehicle drivers access public charging, and evaluates challenges, gaps, and opportunities facing both electric vehicle drivers and the industry as a whole.

Keywords: alternative fuel, electric vehicle supply equipment (EVSE), data acquisition, deployment, infrastructure

1 History of the Station Locator

The U.S. Department of Energy's (DOE's) Alternative Fuels Data Center [1] (AFDC) was launched in 1991 in response to the Alternative Motor Fuels Act of 1988 and the Clean Air Act Amendments of 1990. Originally, it served as a hard copy resource for alternative fuel performance data, and eventually became an internet resource in 1995. Since then, the AFDC has evolved dramatically into a robust online resource that provides a broad range of information on alternative fuels and advanced transportation technologies, including fueling and charging station data.

The Station Locator database includes information on public and private non-residential alternative fueling stations in the United States and Canada. The Station Locator began by tracking ethanol (E85), biodiesel, compressed natural gas (CNG), electric vehicle supply equipment (EVSE), hydrogen, liquefied natural gas (LNG), and propane stations in the United States. In 2017, NREL partnered with National Resources Canada (NRCan) to expand the dataset to include the location of those same alternative fuel stations across Canada as the Electric Charging and Alternative Fuelling Stations Locator or Localisateur de stations de recharge et de stations de ravitaillement en carburants de remplacement [2]. The National Renewable Energy Laboratory (NREL) is responsible for maintaining and enhancing the Station Locator, which serves as a primary resource for fleets, fuel providers, policymakers, Clean Cities coalitions, and others working to improve efficiency, cut costs, and reduce emissions in transportation. ICF, NREL's subcontractor, leads data collection efforts in the United States and Canada, engages with stakeholders, and works closely with NREL to ensure that the data and user interface meet the needs of the industry.

The Station Locator has evolved since its launch as an online, interactive tool in 1999. In particular, the way EVSE is represented in the Station Locator has changed to reflect the needs of a fast-moving industry. Prior to 2011, all EVSE in the Station Locator were legacy chargers designed to serve the first-generation all-electric vehicles (EVs), such as the EV-1 from General Motors. In 2010, the Station Locator included 541 legacy chargers. As of January 2020, less than 75 of those chargers are still in service across the country.

The installation of modern EVSE started in 2011, in preparation for a surge in original equipment manufacturer (OEM) plug-in electric vehicle (PEV) offerings (e.g., Chevrolet Volt, Nissan Leaf). Many of the new EVSE had multiple connectors. As such, NREL updated the Station Locator to display EVSE counts by the number of connectors, rather than the number of stations. In response to feedback from the industry, in 2014, NREL began displaying both the number of charging outlets and the number of station locations.

As of 2019, the Station Locator team is transitioning its counting logic to align with the hierarchy defined in the Open Charge Point Interface [3] (OCPI) protocol: locations, EVSE, and connectors (more information on OCPI is provided in Section 1.1.2 below). With this transition, the number of charging outlets in the Stations Locator is being updated to represent the number of EVSE (or number of vehicles that can charge simultaneously) at a station location, rather than the number of connectors previously counted. The Station Locator still identifies the available connector types. See Section 1.1.1 for more information on EVSE in the Station Locator.

1.1 EVSE Data Sources

NREL and ICF use a variety of methods to gather and verify EVSE data in the Station Locator. Electric Vehicle Service Providers (EVSPs) who are responsible for managing a network of EVSE share data directly with the Station Locator team and are the largest data source for EVSE on the Station Locator. For non-networked stations (i.e., not connected to the internet), data sources include trade media, Clean Cities coordinators, a Submit New Station form on the Station Locator website, EVSE manufacturers, electric utilities, OEMs, state and municipal governments, private companies, and others. NREL and ICF regularly monitor news outlets for press releases on new EVSE openings and seek out more information as appropriate to confirm and add the EVSE to the Station Locator.

In addition, Clean Cities coalitions proactively provide information on station updates and additions throughout the year. Coalitions also serve as an on-the-ground resource for stations that ICF is not able to confirm through normal station confirmation processes [4]. Unconfirmed stations are sent to coalitions throughout the year for confirmation; if the coalition is not able to provide any additional information, the station is subsequently removed from the Station Locator.

1.1.1 EVSE in the Station Locator

Current charging infrastructure in the Station Locator generally falls into the following categories:

- **Public:** A broad category that includes EVSE located in publicly accessible areas or along highway corridors
- **Workplace:** EVSE intended to provide charging to employees during the workday
- **Commercial/Fleet:** EVSE intended to provide charging for electric fleet vehicles, including municipal/private fleets, car sharing, and transportation network companies.

The Station Locator does not maintain data on single-family charging and has minimal, yet expanding, data on charging at multifamily buildings.

The following fuel-specific fields are tracked in the Station Locator for EVSE [5]:

- EVSE Information:
  - Outlet Count (i.e., EVSE or port—represents the number of vehicles that can simultaneously charge)
  - Charger Type (e.g., Level 2, DC fast)
  - Connectors (number and type)
  - Network
  - Manufacturer
  - Power Output
- Open Date
- Workplace (yes/no)
- Pricing
- On-site Renewable Source.

1.1.2 Application Programming Interfaces

Prior to 2014, NREL manually collected all EVSE data, including EVSE managed by EVSPs. To keep up with the rapid growth of charging infrastructure while maintaining the efficiency, accuracy, and completeness of the Station Locator data, in 2014 NREL began incorporating daily updates on networked (i.e., connected to the internet) charging station data directly from EVSPs when available. NREL does this by gaining access to the network's application program interface (API) and developing custom software to import each network's API data into the Station Locator database. Fig. 1 shows a timeline of the integration of the network APIs into the Station Locator data management process.

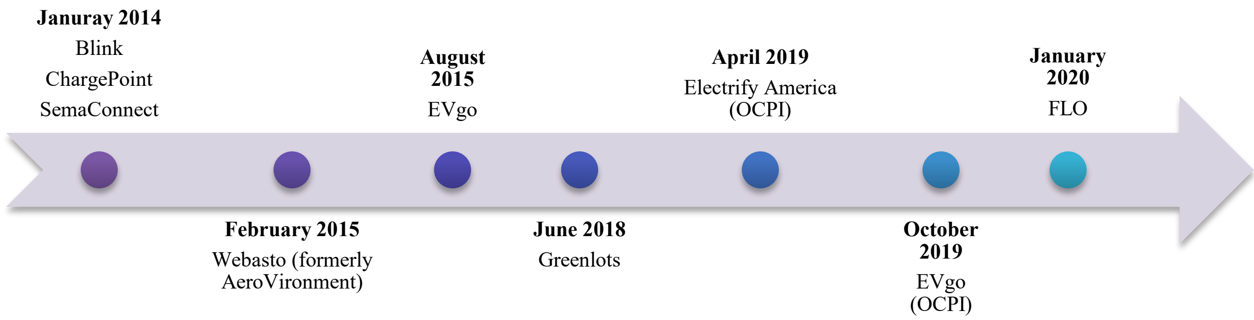

Figure 1: Timeline of API Integrations in the Station Locator

As of February 2020, there were 27,820 U.S. public and private charging stations in the Station Locator database [6], which are viewable on the Station Locator or accessible via API or data download. Of those, approximately 55% are automatically updated daily via EVSP-provided APIs (also see Fig. 7 below), while the rest are managed and updated manually. NREL and ICF are working with additional EVSPs to gain access to and integrate existing APIs or provide them with best practices on developing an API if they have not yet automated their data sharing. This will help ensure that station data are as current and accurate as possible, while also increasing the efficiency of the EVSE data update process.

Early APIs made available by EVSPs did not have a common data format. More recently, many EVSPs have adopted OCPI-based APIs. NREL is incorporating these as EVSPs make them available and, as of February 2020, has incorporated OCPI-based APIs from Electrify America and EVgo, and is in the process of integrating Greenlots' and ChargePoint's OCPI-based APIs.

OCPI is an open-source protocol meant to provide a standard interface and data structure for data exchange between charge point operators, EVSPs, and PEV infrastructure data hubs. OCPI development is led by the Netherlands Knowledge Platform for Charging Infrastructure. OCPI categorizes charging infrastructure as seen in Figure 2, with the primary components being *locations*, *EVSEs*, and *connectors* [7]. *Locations* have one or many *EVSEs* which are related geospatially. A *location* might be something like a parking garage or a business. *EVSE* is the part that controls the power supply to a single PEV in a single session. *EVSEs* may have multiple *connectors* and connector types, such as CHAdeMO and Combined Charging System (CCS), but only one may be used to charge a vehicle at a time. OCPI also defines a specification for pricing information which can be assigned at both the EVSE and connector level [7].

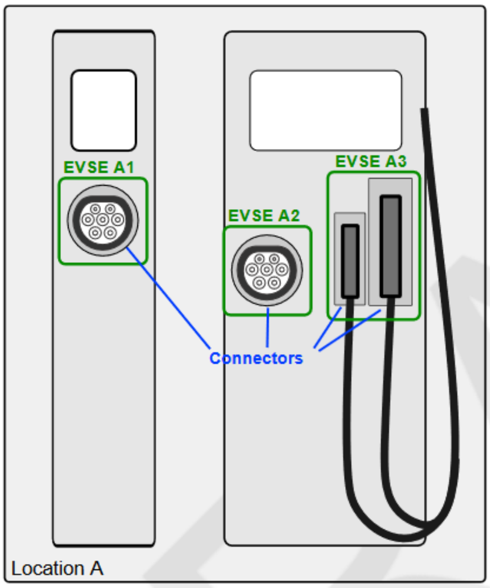

Figure 2: OCPI Charging Infrastructure Hierarchy [7]

1.2 EVSE Technology and Charging Standard Development

EVSE technology continues to progress, with the 2018 introduction of extreme fast charging (XFC) infrastructure and the addition of a medium- and heavy-duty charging standard (SAE J3068). SAE J3068 is under development and aims to provide higher rates of AC charging using three-phase power, which is common at commercial and industrial locations. While standard direct current (DC) fast charging infrastructure currently offers a maximum output power of 50 kilowatts (kW), XFC equipment offers output powers of up to 350 kW and higher. While XFC technology is commercially available, most light-duty PEVs on the market today are not capable of accepting XFC power outputs [8].

As a result of the wide range in DC fast charging infrastructure power outputs offered, in 2018 the Station Locator began tracking EVSE power output levels when the information is available. The Station Locator continues to evolve in order to provide optimal data to a wide group of users. For example, with the onset of medium- and heavy-duty PEV applications, the Station Locator will adapt to effectively track associated charging infrastructure, discussed further in Section 4.2.2.

2 Electric Vehicle Charging Infrastructure Trends

The number of charging outlets in the Station Locator has been growing consistently since 2011, and the number of charging stations has also increased since NREL started tracking the two figures separately in 2014 (Fig. 3) [6]. In fact, between December 2015 and December 2019, the number of charging station records in the Station Locator doubled. In 2019 alone, the number of charging station records in the database grew by 28%.

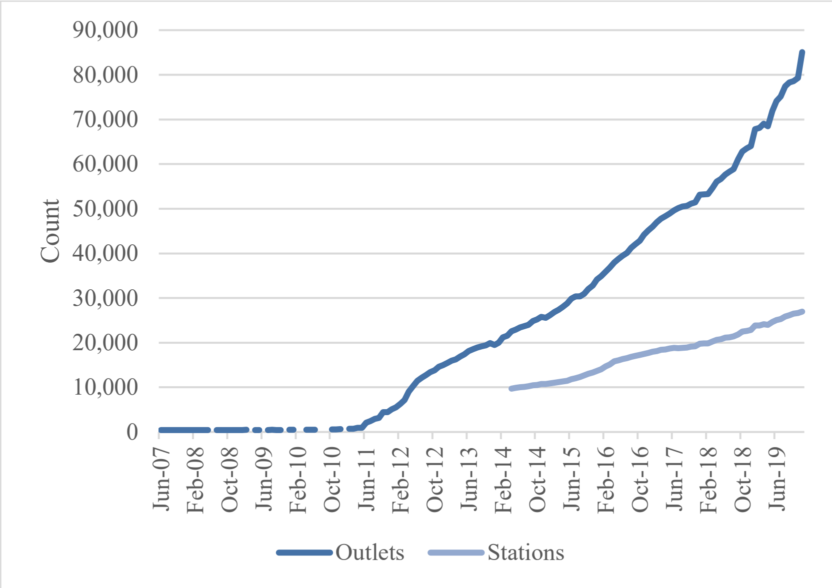

Figure 3: Charging Outlet and Station Records by Month (2009–2019)

Note: Breaks in the graph represent months where data are not available, and outlet data prior to 2019 may reflect connector numbers rather than outlet numbers.

The breakdown of infrastructure installed by charging level has evolved in recent years, as shown in Fig. 4. Most notably, the percentage of DC fast charger (480 Volt (V)+) outlet installations has increased, as compared to Level 1 (120 V) and Level 2 (240 V) charging infrastructure.

As previously mentioned, the Station Locator does not include residential charging, which contributes to the low number of Level 1 outlet installations reflected here. Also note that outlet opening dates are estimated based on assumptions, particularly for older stations and stations that are provided to NREL directly from charging networks through an API. In addition, for each year, note that the graph does not include stations on a charging network that had previously opened and closed.

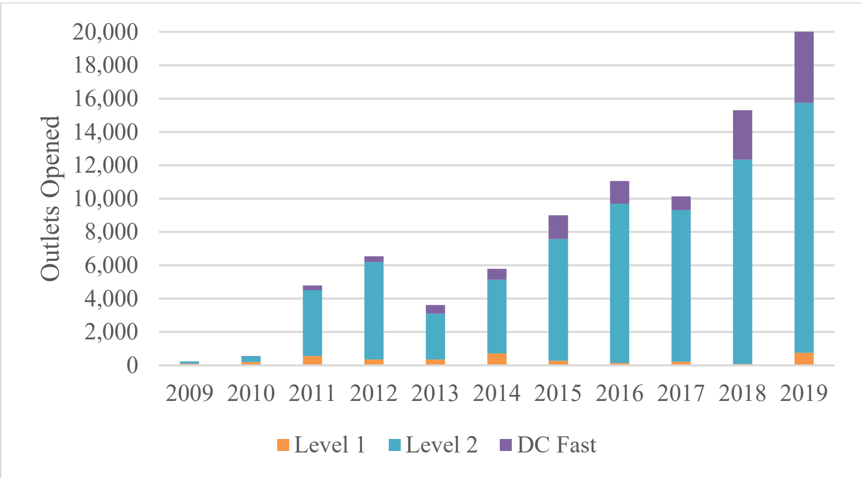

Figure 4: EV Charging Outlet Openings in the Station Locator by Charging Level (2009–2019)

Charging outlet growth has generally tracked with other industry growth indicators, including PEV model availability [9,10] (Fig. 5) and light-duty PEV registrations [11,12] (Fig. 6). In the last two years, both PEV model availability and PEV registrations have begun to outpace EVSE installations.

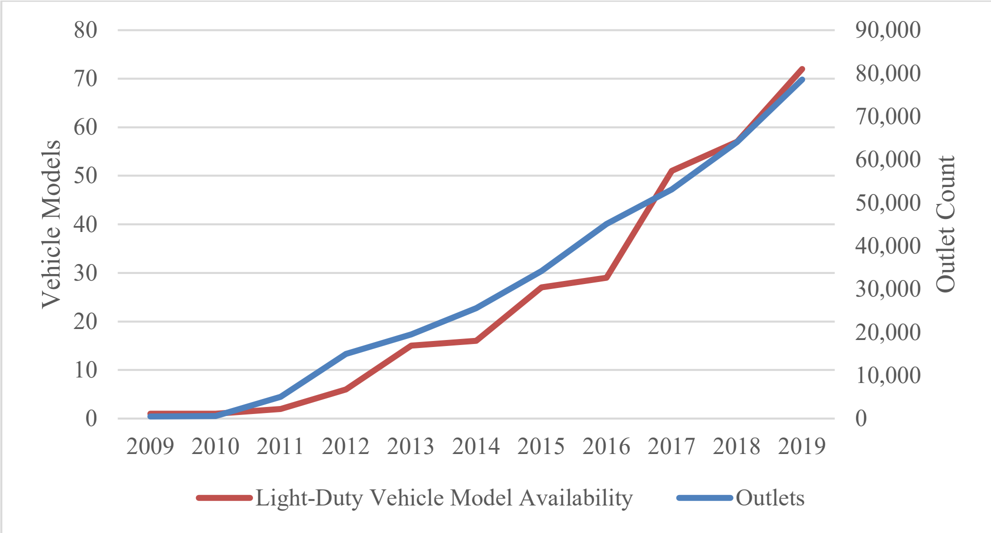

Figure 5. Charging Outlets and Light-Duty PEV Models (2009–2019)

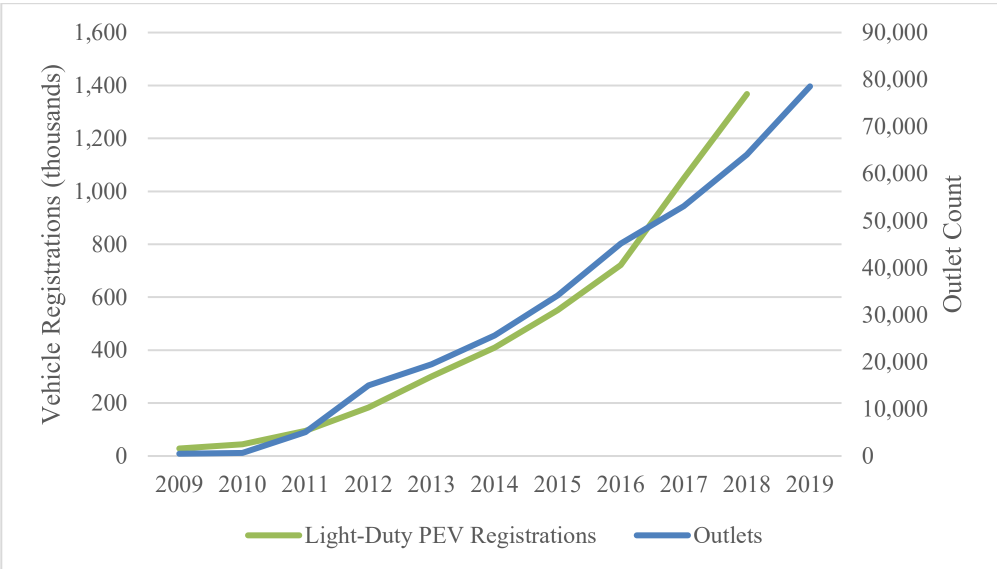

Figure 6. Charging Outlets and Light-Duty PEV Registrations (2010–2019)

Fig. 7 shows the split of outlets added to the database that are on a charging network, versus non-networked (see Sections 1.1.2 and 3 for a discussion of charging networks). Since 2013, the number of networked outlets added to the database each year has increased steadily, save for a dip in 2017, while the number of non-networked outlets added per year has remained relatively steady.

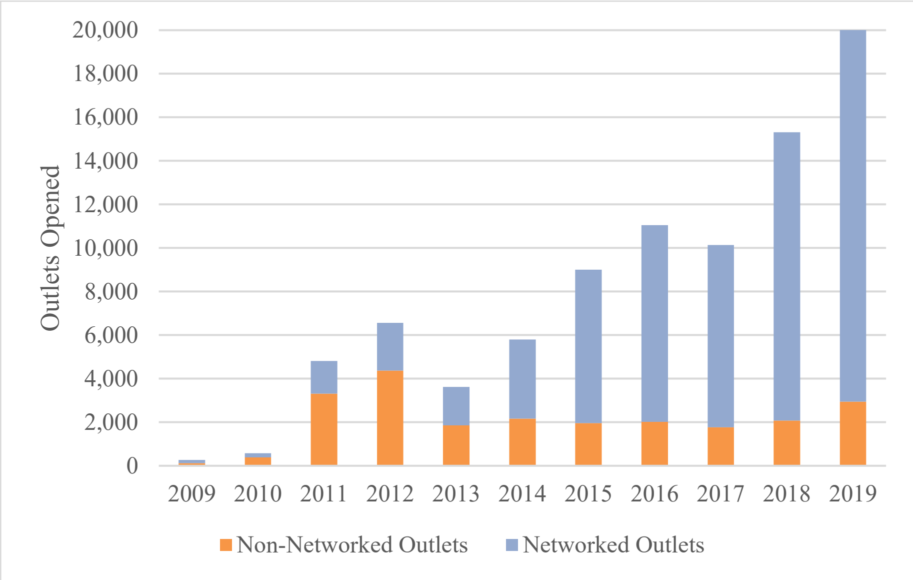

Figure 7. Charging Outlet Openings by Year (2009–2019)

As discussed above, NREL incorporates daily updates on station data directly from charging networks. As outlined in Fig. 1, NREL has integrated these charging network APIs over time. Fig. 8 breaks out the outlet openings, showing those that were incorporated into the database via API when they opened (blue bar) versus those that were manually added to the database. Since 2014, the percentage of outlet openings from API data has increased—both due to new APIs being integrated into the database (see Section 1.1.2) and increasing numbers of networked stations being installed.

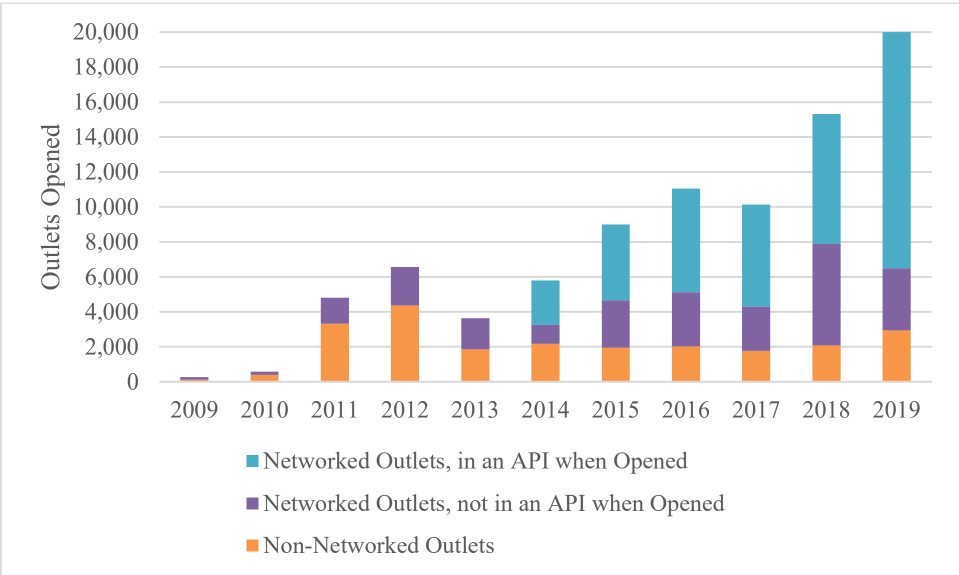

Figure 8. Charging Outlet Openings per Year (2009–2019)

3 Accessing Public EVSE

Because public charging is open to all PEV drivers, station owners and site hosts generally employ technologies and policies to control access and process payment. The methods for controlling access and processing payment are largely dependent on whether the charging is non-networked or networked.

Non-networked EVSE is not connected to the internet and provides basic charging functionality without advanced communications capabilities. Because of this, non-networked charging is generally free or offered as an amenity for those who pay for parking or access a business.

Networked EVSE is connected to the internet via a cable or wireless technology and can communicate with the backend computer system of an EVSP. Being connected to a network lets station owners or site hosts manage who can access stations and control how much it costs drivers to charge their vehicle. An EVSP typically manages a group of networked EVSE and may use its communication capabilities to communicate directly with drivers, other EVSPs, or utilities; monitor and share real-time station status; broadcast location information; collect and store usage data; or control access and facilitate payment. A summary of networked vs. non-networked EVSE characteristics is included in Fig. 9:

Non-Networked

- Not connected to internet
- Free, or nominal payment through other methods (e.g., keypad)
- Troubleshooting by site host
- Maintenance by site host

Networked

- Connected to internet
- Payment capabilities and processing
- Communication funcationality
- Utilization data and reports
- Troubleshooting
- Maintenance plan (with an extra fee)

Figure 9. Non-Networked vs. Networked EVSE

Common pricing structures include by kWh, by session, by length of time, or through a subscription. Session- and time-based structures are common in states where non-utilities are prohibited from selling electricity. While charging for the use of EVSE is common, more than 50% of public charging is free to use. There are different pricing models across the different charging network providers, including pricing for members versus nonmembers, user-specific pricing (i.e., free charging for certain vehicle owners), site host-specific pricing, and pricing based on rate of charge. Fig. 10 below provides a summary of the various pricing schemes employed by several EVSPs.

	Member Pricing?	*Member vs. Non-Member Difference*
Blink	Y	**kWh States**: Members pay $0.10/kWh less than nonmembers (L2, DC Fast) **Per-minute states**: Members pay $0.01/30 second less than non-members (L2); Members pay $3/session less than nonmembers (DC fast)
ChargePoint	N	N/A
Electrify America	Y	Members do not pay the $1 session fee, in addition members pay an average 20% less per minute of charger than nonmembers
EV Connect		
EVgo	Y	Member rates at least 10% lower than non-member
FLO	N	N/A
Greenlots	N	N/A
SemaConnect	N	N/A
Tesla	N	N/A

Figure 10. EVSP Pricing Structures

3.1 Transaction Methods

Networked EVSE can generally be categorized as member-only access or open access. The former requires a network membership to use and pay for charging and gain full access to all the features and services of a given network. On the other hand, open access EVSE offers a way for nonmembers to access charging by calling a customer service center or paying onsite with a credit card. However, these solutions limit the functionality available to the driver (e.g., notifications about charging status).

Current transaction methods used by EVSPs to allow charging by their members include radio-frequency identification cards or key fobs, near-field communication, mobile applications, and vehicle telematics. EVSPs allow members to find and access network-specific charging stations that can provide convenient charging services in a city, along a corridor, or nationally through mobile applications, proprietary websites, and third-party data providers, like the AFDC Station Locator.

3.2 Data Sharing and Roaming

Interoperability among EVSPs allows a member of one network to conveniently access charging on all other interoperable networks with a common credential and membership account. This requires EVSPs to adopt common data sharing protocols, agree to use universal credentials, and agree to share data via peer-to-peer exchange or a central clearinghouse. EVSPs are currently pursuing network interoperability through peer-to-peer agreements or a clearinghouse, and the advancement of common data sharing protocols, such as the OCPI protocol and the Open InterCharge Protocol (OICP).

Peer-to-peer roaming agreements are one EVSP interoperability solution. These allow an EVSP member to use charging stations operated by another EVSP while being billed to their member account. Roaming provides benefits to drivers because it enables them to access charging on multiple networks while only having to subscribe to and receive bills from a single network. Use of an out-of-network charging station through a roaming agreement could result in a higher price for a non-network member.

To facilitate roaming, some EVSPs in the United States have negotiated bilateral agreements to share account and billing information for each charging session. To effectively share information between networks, they have agreed to use the OCPI communications protocol, as discussed in Section 1.1.2. A drawback to peer-to-peer agreements is that it presents a fragmented approach that may not be able to scale with the growth of the EVSE market.

A clearinghouse is another network interoperability solution. It utilizes a third-party entity that maintains account and billing information to facilitate charging by PEV drivers across networks. Similar to EVSE network roaming, a clearinghouse provides benefits to PEV drivers because it enables them to access charging on multiple networks. Because a clearinghouse is a third-party entity, PEV drivers may be billed by the clearinghouse operator or by the network. In the United States, Hubject serves as a clearinghouse among EVSPs and uses the OICP communications protocol. Fig. 11 below provides a summary of current bilateral roaming agreements between networks and clearinghouse compatibility.

	Blink	*Electrify America*	*ChargePoint*	*EVConnect*	*EVgo*	*FLO*	*Greenlots*	*SemaConnect*	*Tesla*	*Hubject*
Blink										X
ChargePoint		X		X	X	X	X			X
Electrify America			X	X			X	X		
EV Connect		X	X		X		X	X		
EVgo			X	X						
FLO			X							
Greenlots		X	X	X				X		
SemaConnect		X		X			X			
Tesla										

Figure 11. Network Roaming Agreements

4 Gaps and Opportunities

As shown in Fig. 3, charging infrastructure has been implemented across the country in a relatively short period of time and continues to grow, with over 24,000 public station locations in the United States today. However, there are still areas across the country that may not be connected via a charging corridor with nearby regions, as well as areas that may not have much public charging available, such as in rural parts of the country. The Station Locator serves as a tool for the industry to determine where infrastructure is sufficient, and where there may be gaps or opportunities for expansion.

There are factors that can be considered when evaluating the robustness of PEV charging infrastructure, such as the diversity in public charging levels, DC fast connector types, and charging network availability. Where chargers are located is also a factor (e.g., metropolitan or rural areas, along major highway corridors, destination locations).

The U.S. Department of Transportation's Federal Highway Administration's (FHWA) alternative fuel corridors effort [13] aims to help address these issues using Station Locator data, by establishing a network of alternative fueling and charging infrastructure along national highway system corridors. From 2016 to 2018, corridor designations have included portions of 100 interstates and 76 U.S. highways and state roads in 46 states and the District of Columbia, covering over 135,000 miles. States must nominate corridors, but FHWA brings together a variety of stakeholders to promote and advance corridor designations. FHWA is continuing to nominate corridors through 2021. The Station Locator Corridor Measurement [14] tool launched in late 2019 and is used to measure the driving distance along Interstate Highways between stations that meet the criteria for the FHWA corridor effort. The tool is a helpful resource for nominating corridors.

4.1 Charging Infrastructure Needs

DOE's National Plug-In Electric Vehicle Infrastructure Analysis [15] addresses the fundamental question of how much charging infrastructure is needed in the United States to support PEVs in 2030. DOE estimates that 25,000 DC fast outlets and 600,000 Level 2 outlets will be needed to support 15 million PEVs in 2030. Similarly, the Institute for Electric Innovation and Edison Electric Institute [16] estimate that 9.6 million public and private charging ports will be needed to support 18.7 million PEVs in 2030.

In addition to the national projected infrastructure needs provided above, DOE's Electric Vehicle Infrastructure Projection Tool (EVI-Pro) Lite [17] tool provides a simple way to estimate how much PEV charging might be needed at city and state levels. EVI-Pro Lite is a free simplified version of the EVI-Pro tool. The tool uses detailed data on personal vehicle travel patterns, PEV attributes, and charging station characteristics in bottom-up simulations to estimate the quantity and type of charging infrastructure necessary to support regional adoption of PEVs. This tool has been used for detailed planning studies in many states across the country.

4.2 Station Locator Data

As previously discussed, the Station Locator currently has a robust dataset of public and private (workplace, light-duty fleet, non-residential) EVSE. That said, there are several opportunities for growth, including a more robust dataset of multifamily buildings and medium- and heavy-duty fleet charging.

4.2.1 Multifamily Building Charging

Historically, NREL has not collected information about EVSE at any residential locations, including multifamily buildings. While reliable estimates for the number of EVSE in multifamily buildings nationwide are not readily available, the California Air Resources Board [18] estimates that there were 5,888 to 9,561 Level 2 outlets in multifamily buildings in California in 2018. Using the total number of Level 2 EVSE in the Station Locator as of 2019 as a proxy, where roughly 25% were located in California, it can generally be estimated that there are 23,552—38,552 Level 2 outlets in multifamily buildings across the country.

Through conversations with government and industry representatives, NREL recognized multifamily building EVSE installations as a gap in data collection and began an effort to include these installations in the database in 2019. As this effort was underway, NREL and ICF experienced several barriers with data collection, including the inability or hesitancy to share data and lack of tracking for multifamily building

EVSE installations. However, when a multifamily building location was directly asked about charging infrastructure, they were willing and able to share detailed information.

In 2020, NREL will continue efforts to track multifamily building charging data. The multifamily building data collected through this effort is not included in the Station Locator. Multifamily building EVSE data are stored in the Station Locator database and only made available when requested. NREL will also use multifamily building data to understand trends in EVSE availability, such as geographic concentrations.

4.2.2 Fleet Charging

As mentioned in Section 1, medium- and heavy-duty PEVs are beginning to enter the market. While there are only about 50 OEM models available as of early 2020 [10], many more are expected to be available soon. There is an opportunity for the Station Locator to closely track associated charging infrastructure. To determine what information is important to the industry, NREL will conduct a variety of in-depth conversations with stakeholders, including OEMs, charging manufacturers, and fleet managers. NREL will also work closely with Clean Cities coordinators to identify fleet managers in their regions that are utilizing medium- and heavy-duty PEVs.

5 Conclusion

The Station Locator has provided alternative fuel station data to tens of millions of users and is the go-to resource for understanding the evolving PEV charging landscape. Through its strong partnerships with EVSPs, the Station Locator team has implemented technology solutions, such as APIs, to improve the accuracy and efficiency of collecting and displaying station data for networked EVSE on the Station Locator. It is critical for EVSPs to continue to share EVSE data via an API that follows a common data sharing protocol, such as OCPI. For non-networked EVSE, the Station Locator regularly engages its extensive network of stakeholders, including the Clean Cities Coalition Network, to provide and confirm data. Through its partnerships with the PEV industry and stakeholders, NREL will continue to collect and share valuable insights on trends, opportunities, and challenges associated with access to public, private, and fleet charging infrastructure. Furthermore, the Station Locator will expand data collection to accurately capture emerging alternative fueling opportunities, such as medium- and heavy-duty charging and XFC. With ongoing support from industry, academia, and government, the Station Locator will continue to evolve to support its stakeholders as a valuable resource for understanding how to meet the future needs of electrified transportation.

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