Forecasting Demand for Electric Vehicle Charging Infrastructure: Definitions, Assumptions and Conceptual Models

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May 12, 2021

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INTRODUCTION

As the U.S. begins a transition away from fossil fuels and toward electric vehicles (EVs), a key question emerges: How are we going to charge all of these new EVs? Forecasting the number of EV charging stations required to meet the needs of EV drivers is complicated due to three sets of issues: 1) A wide range of definitions and equipment, 2) the many assumptions used in forecasts and 3) some fundamental differences in our conceptual models of EV charging. This brief will explore these three areas in more detail and surface areas of uncertainty that require more research and analysis.

1. Definitions and Equipment

Let's start with the easiest of the three areas to clarify: definitions. First off, engineers will tell you that almost all EVs have a "charger" on board. When charging with AC equipment, the charger converts AC power into DC power of appropriate voltage. With DC charging, the charging station provides power directly to the vehicle's battery pack as controlled by the battery management system. So, to make the engineers happy, when referring to the equipment used to charge EVs, talk about charging stations. EV wonks call charging stations electric vehicle infrastructure (EVI) or electric vehicle supply equipment (EVSE).

Another definition that's important once we start trying to quantify things: Charging stations, depending on their type and model, can have anywhere from one to four outlets – also known as plugs, ports or connectors. Think of these like nozzles on a pump at a gas station. The U.S. Department of Energy (DOE) Alternative Fuels Data Center reports there are 42,221 public EV charging stations in the U.S. that host 103,040 Level 1, Level 2 and direct current fast charging (DCFC) outlets (U.S. DOE, 2021). Thus, the average charging station in the U.S. has 2.4 plugs.

Confusingly, an individual charging station – a single piece of equipment with one or more plugs – is often grouped with additional units into a broader charging station location. So, just like an individual gas station can have many pumps, each with several nozzles, an EV charging station location can have many individual Level 2 or DCFC units, each of which may have multiple plugs.

Another important issue to consider: At least three major kinds of charging stations are currently available—Level 1, Level 2 and DCFC. Level 1 stations are the slowest and lowest power; they operate on 110-volt power (a typical electrical outlet) and are typically found in homes and at some workplaces or other long dwell locations. Level 2 stations are faster; they operate on 220-volt power (which requires an upgraded outlet, like a clothes dryer outlet) and are increasingly being installed in homes and public settings.

DCFC are a world unto themselves; they provide the highest output and the fastest charge times. Most battery electric vehicles (BEVs) can accept at least 50 kilowatts (kW) of charge while newer vehicles may have higher capacities. A potential limitation of high-power DCFC is that their frequent use may degrade certain EV batteries. Table 1 compares the power levels of typical EV charging equipment.

Table 1: EV Charging Station Types

Charger Type	Input Voltage and Output Power Level	Range Per Hour
Level 1	120 volts and 1.3 kW to 2.4 kW of power	3-5 miles
Level 2	220 volts and 3 kW to 19 kW of power	18-28 miles
DCFC	480 volts and typically 50 kW to 150 kW of power, but new equipment can provide up to 350 kW to those vehicles able to accept it	100-300 miles

2. Model Assumptions

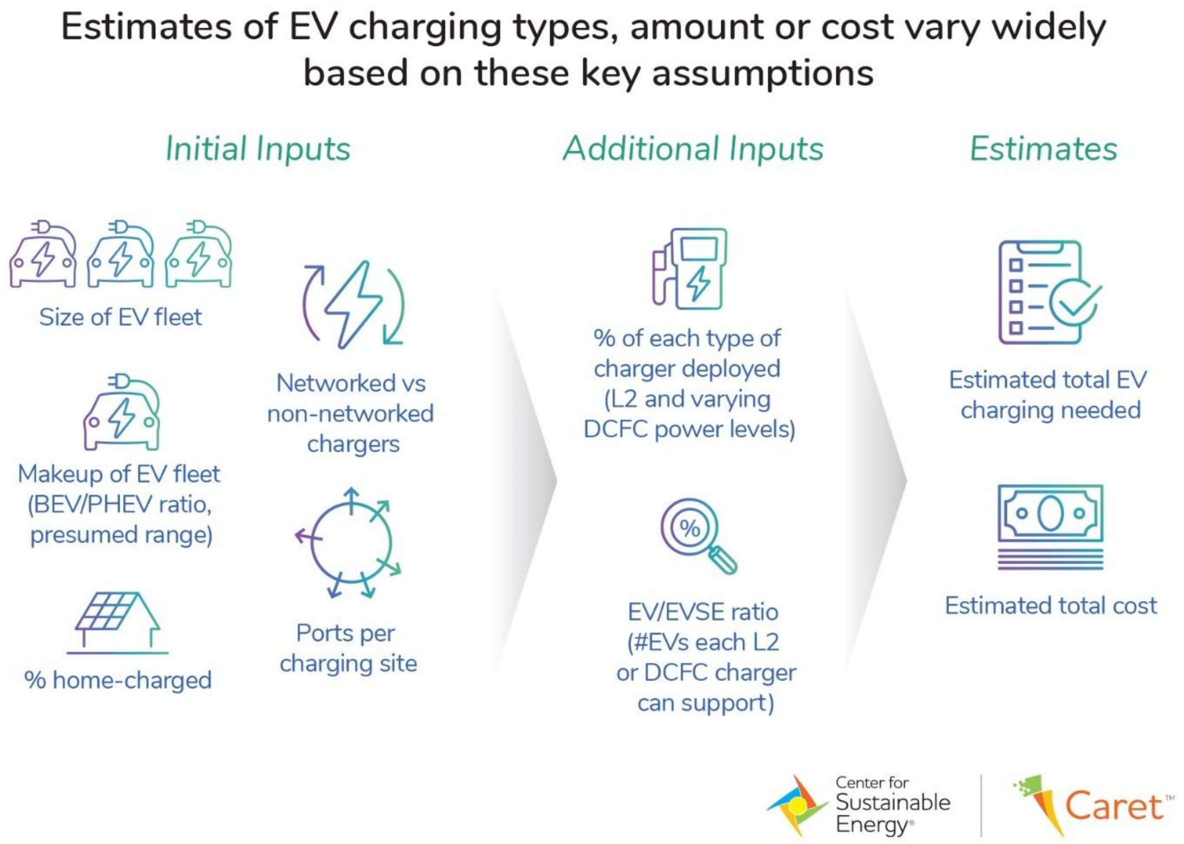
Returning to our original question: How many EV charging stations do we need to support an EV fleet? A wide range of assumptions go into forecasting the number and types of charging stations that can support broad electrification of the transportation sector.

There are two key considerations, each with a variety of inputs and assumptions:

1) How big will the EV fleet be and what kinds of vehicles will it be composed of?
2) How many EVs can be supported by a single charging outlet?

The Center for Sustainable Energy's (CSE) Caret™ modeling platform can forecast the size of the light-duty EV fleet up to 40 years into the future. Caret leverages technology diffusion prediction algorithms and relevant data sets from around the world to calculate, among other things, EV market penetration over time based on selected incentive types, amounts and durations (CSE, 2021). We won't delve into the assumptions that go into that model. For this brief, we will focus on the second question. Figure 1 below shows how various assumptions affect estimates of needed EV charging infrastructure and cost.

Figure 1: Inputs for Forecasting Required Electric Vehicle Infrastructure



EVI-Pro Assumptions

Many EVI policy studies in the U.S. use a tool developed by the National Renewable Energy Laboratory (NREL) called EVI-Pro. EVI-Pro and its simpler, publicly available cousin, EVI-Pro Lite, forecast the number of charging outlets required to support a given number of EVs. EVI-Pro and EVI-Pro Lite use spatial data on driving behavior and combine that with models of charging behavior and network design (all of which have their own assumptions) to estimate the number of EVs that can be supported by one charging outlet (see Wood, et al 2018 and other publications on the NREL site).

When we began modeling EVI needs, we started with the California Energy Commission (CEC) implementation of EVI-Pro because this model is the most detailed currently available and is grounded in real-world data for California, which has the largest percentage of EVs on the road and the most mature EV market in the U.S. (Bedir, et al, 2018). However, as we have begun to look further into the future and create national-level models, we have also started thinking about additional models and assumptions.

The key assumptions required to generate outputs from EVI-Pro Lite are:

- The number of EVs to support
- Whether plug-in hybrid electric vehicles (PHEVs) require full or partial support
- The makeup of the fleet by vehicle type (short-range PHEVs, long-range PHEVs, short-range BEVs, long-range BEVs)
- The percentage of drivers with access to charging at home

For U.S. light-duty fleet makeup, EVI-Pro Lite's default assumptions are that the current fleet is composed of 15% short-range PHEVs, 35% long-range PHEVs, 15% short-range BEVs and 35% long-range BEVs. At a high level these are not unreasonable assumptions, but given that PHEVs make up just under 38% of the current fleet (Alliance for Automobile Innovation, 2021) and that most PHEVs have pretty short ranges, EVI-Pro Lite biases towards long-range PHEVs. Looking at BEVs, the current average range of BEVs on the road is already about 250 miles (EV Adoption 2019) so these built-in assumptions are relatively conservative for the current fleet and become even more so when looking to the future. Using internal projections created by our modeling team, we estimate that sales of new PHEVs will drop to zero within five years.

Looking at the support for PHEVs input, we note that many PHEVs are driven like gas-powered vehicles (Plötz et al, 2020) thus, we typically assume only partial support for PHEVs. In other words, we assume that the typical PHEV driver will use a 50-50 ratio of gas and electricity to power their vehicle.

Turning to the proportion of drivers with home charging, we typically assume this number is 80%, since this figure is reported by the DOE (No date) and echoed by other surveys (Voelcker, 2021). However, as the EV market moves from early adopters to early majority adopters, our research shows that this number will decline to 60%. This is because 32% of U.S. residents live in multi-unit dwellings and about 36% are renters (Mateyka & Mazur, 2021)—and it's usually more difficult to install a charging station if you rent a home or live in a multifamily building.

Benchmarking and Model Averages

Given the many assumptions that feed into EVI forecasts, we have researched other modeling efforts and benchmarked our work against their approaches and assumptions. Our research shows there is quite a range depending on the assumptions used in EVI-Pro Lite and for the other key parameters. Table 2 compares our use of EVI-Pro Lite against assumptions in the CEC implementation of EVI-Pro Lite and against assumptions used in recent work by the Edison Electric Institute, The Brattle Group and Atlas Public Policy.

As can be seen below, there is a broad range of outputs and assumptions across these models. Given this, we use a model-averaging approach, which offers a "convenient approximation to full blown Bayesian analysis" (Bartels, 1997). The averages for the models and scenarios in Table 2 are that 34 EVs can be supported by one Level 2 port and 152 EVs can be supported by a single DCFC port.

Table 2: Comparison of EV-to-EVI Ratios for Select Models

Source for EV:EVI ratios	Scenario Description	EV:L2 Ratio	EV:DCFC Ratio	PHEV / BEV Model Assumptions
CSE Assumptions	Caret Model Assumptions	21	78	CSE adjusted CEC EVI-Pro ratios
CEC EVI-Pro (2018)				Starts at PHEVs (short-range) 23%, PHEVs (long-range) 21%, BEVs (short-range) 40%, BEVs (long-range) 16%; 2025 fleet additions are 61% long-range BEVs
	Public L2 Lower Estimate	28	80	Lower estimate "represents the minimum quantity of chargers that must be available to meet drivers' simultaneous need to charge" (p. 4)
	Public L2 Average Estimate	21	43	Average of Lower and Upper
	Public L2 Upper Estimate	17	29	Upper estimate is the "quantity of total sessions", "divided by two to reflect that a public charger is shard with at least one other vehicles"; a "very conservative proxy" (p. 4)
EVI-Pro Lite (2021)	Public L2 Scenario 1	29	291	PHEVs (short-range) are 32%, BEVs (long-range) are 68%, partial support for PHEVs (e.g., 50% of miles driven are battery), 80% home charging
	Public L2 Scenario 2	57	143	PHEVs (short-range) are 10%, BEVs (long-range) are 90%, partial support for PHEVs (e.g., 50% of miles driven are battery), 60% home charging
	Public L2 Scenario 3	102	138	PHEVs (short-range) are 5%, BEVs (long-range) are 95%, partial support for PHEVs (e.g., 50% of miles driven are battery), 60% home charging
The Brattle Group (2020)	Public L2 & DCFC	17	333	PHEVs are 40% to 20% (no range info); BEVs are 60% to 80% (no range info); PHEVs use battery power for 33% to 50% of driving
Edison Electric Institute (2018)	Public L2 & DCFC	23	187	PHEVs (short-range) 15%, PHEVs (long-range) 25%, BEVs (short-range) 15%; BEVs (long-range) 45%
Atlas Public Policy (2021)	Public L2 & DCFC (2021-2031)	25	201	BEVs (long-range) are 100% of the fleet; assumes all DCFC chargers are 350 kW
	AVERAGES	34	152	

3. Conceptual Models of EV Charging

As we move from technical modeling issues to policy-relevant scenarios, a final set of issues is worth considering: The future of EV charging may not look like the gas-station-powered present. Seminal work by Denzau and North (1994) argues that the “mental models” that we hold in our head guide the economic choices we make. Today’s cutting-edge technology involves the “gas station model”—you drive until your tank is nearly empty and then you pull into a gas station and fill up in less than 10 minutes. This gas-station model has been driving the installation of bigger and more powerful DCFC charging stations. Although manufacturers are pushing the technology up to 350 kW, in most places the electrical grid limits how many of these high-power chargers can be installed (Siuru, 2019). In addition, high-power DCFC may also have negative impacts on EV batteries (Argue, 2020).

Thus, some observers are asking: Is the gas-station model the right model to follow? Unlike drivers of gas-powered cars, many EV drivers can charge at home and some can charge at work. Although we will clearly need large numbers of public EV charging stations, we are already seeing signs that the behavior of EV drivers is likely to deviate from the gas-station model. For many EV drivers, destination charging may become the most popular approach to charging an EV for the vast majority of trips. If this is the case, “fairly fast charging” will be adequate for most EV drivers most of the time (Templeton, 2020). So, although high-power DCFC may become more popular as EV batteries improve, it’s also possible that lower-power DCFC will be adequate for most drivers not taking long-distance trips.

Another conceptual issue to consider is that battery technology may change. Major automakers, including Ford, Toyota and BMW, are investing in solid state batteries (Hoffman, 2021). Solid state batteries, which are still in the research and development phase, may offer greater energy density and faster charging times.

Conclusion

In summary, we need to invest in public EV charging infrastructure to accelerate the adoption of EVs and to ensure that lower- and moderate-income Americans have equitable access to charging—even if they can’t charge at home. We also need public charging to increase drivers’ confidence that EVs are viable and to meet the diverse range of trips drivers may take—from running errands near home to driving across the country.

As we discuss in this brief, there are a range of assumptions that go into forecasting how much EVI will be needed to support the future EV fleet. As the industry evolves and as policy research efforts continue, we need to work toward greater clarity in definitions and assumptions, continue to update our models with real-world data and keep an open mind regarding the conceptual models we apply.

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